STATUS OF THE SPIRAL 2 PROJECT AT GANIL

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Abstract

Spiral 2 is a new European facility for Radioactive Ion Beams being constructed at the GANIL laboratory (Caen, France). Based in a High Intensity multi-ion Accelerator Driver (Superconducting Linac), delivering beams to a High Power Production system (converter, target, and ion source), producing and post-accelerating Radioactive Ion Beams with intensities never reached before. The preliminary safety report was released at the beginning of 2009, opening the official nuclear licensing procedures. Detailed studies of buildings, tunnels, and associated infrastructures were also finalized, allowing initiating ground works in 2010. The major components of the accelerator (injectors and Linac), have been presently ordered. The Superconducting Linac Accelerator incorporates many innovative developments around the Quarter-Wave Resonators and their associated cryogenic and RF systems. The first operation is scheduled for 2012 with an initial experimental program prepared within a large international collaboration with many institutions and laboratories around the world.

INTRODUCTION

The GANIL facility [1] (Caen, France) is one of the major Rare (or Radioactive) Ion Beam (RIB) and stable-ion beam facilities for nuclear physics, astrophysics and interdisciplinary research in Europe. Since the first beams delivered 25 years ago, the performances of the GANIL accelerator complex, was constantly improved with respect to the beam intensity, energy and available detection systems (the new Spiral facility is operated from 2000). In recent years, RIBs, have been recognized by the international scientific community as one of the most promising avenues for the development of fundamental nuclear physics and astrophysics, as well as in applications of nuclear science.

Between the existing and the next-generation facilities (FAIR project in GSI-Germany, and EURISOL), Spiral 2 is an intermediate-generation facility which meets the criteria of European dimension in terms of physics potential, site and size of the investment as it was recognised in the ESFRI (European Strategy Forum on Research Infrastructures) roadmap.

The French government approved the construction of SPIRAL 2 facility at GANIL, in 2005. Its construction cost (200 MEuros) is shared by the French funding agencies CNRS/IN2P3 and CEA/DSM, the regional council of Basse-Normandie and international partners. The construction of the SPIRAL 2 is supported by the EU FP7 through the Preparatory Phase contract since 2008.

SCIENTIFIC CASE OF SPIRAL 2

A complete presentation of the scientific case of the facility, going beyond the scope of this contribution, can be found in the White Book of SPIRAL 2, the Letters of Intent and the Technical Proposals for SPIRAL 2 (see ref. [2]). Hereafter a few examples of a rich and multipurpose scientific program [3]:

- Physics of Exotic Nuclei and Nuclear Astrophysics: basic nuclear science research, trying to establish a bridge between the nucleon-nucleon interaction inside a nucleus and the underlying quarks and gluons as well as understand the mechanism of interaction between nuclei. This research progresses, in particular, using nuclei with unusual neutron-to-proton ratios, artificially produced in laboratories.
- Neutrons for Science: One of the more interesting possibilities, with the SPIRAL2 facility is related to the production of a high neutron flux in the energy range from several hundreds of keV up to about 40 MeV. The facility will offer a unique opportunity for material irradiations and cross-section measurements, both for fission-related topics (notably Accelerator Driven Systems and Generation-IV fast reactors) and for nuclear fusion-related research.
- Research with high intensity stable beams delivered by the SC Linac: An experimental hall will be dedicated to the experiments with the Super Spectrometer Separator (S3) and in-flight production of exotic nuclei using LINAC heavy-ion beams. The most important physics topics to be addressed with this top-level equipment are nuclear haloes, N=Z nuclei, nuclear structure studied via deep-inelastic collisions as well as physics and chemistry of heavy and super heavy nuclei. The S3 will also provide access to many short-lived isotopes of refractory elements which are difficult to produce using ISOL technique.

LAYOUT AND PERFORMANCES OF THE SPIRAL 2 FACILITY

The SPIRAL 2 facility (Fig. 1) is based on a high-power, superconducting linac driver, which will deliver a high-intensity, 40 MeV deuteron beam as well as a variety of heavy-ion beams with mass-to-charge ratio of 3 and energy up to 14.5 MeV/nucleon. A possibility of construction of a second injector for heavy-ions with a mass-to-charge ratio 6-7 has been integrated in the base-line design of the facility.

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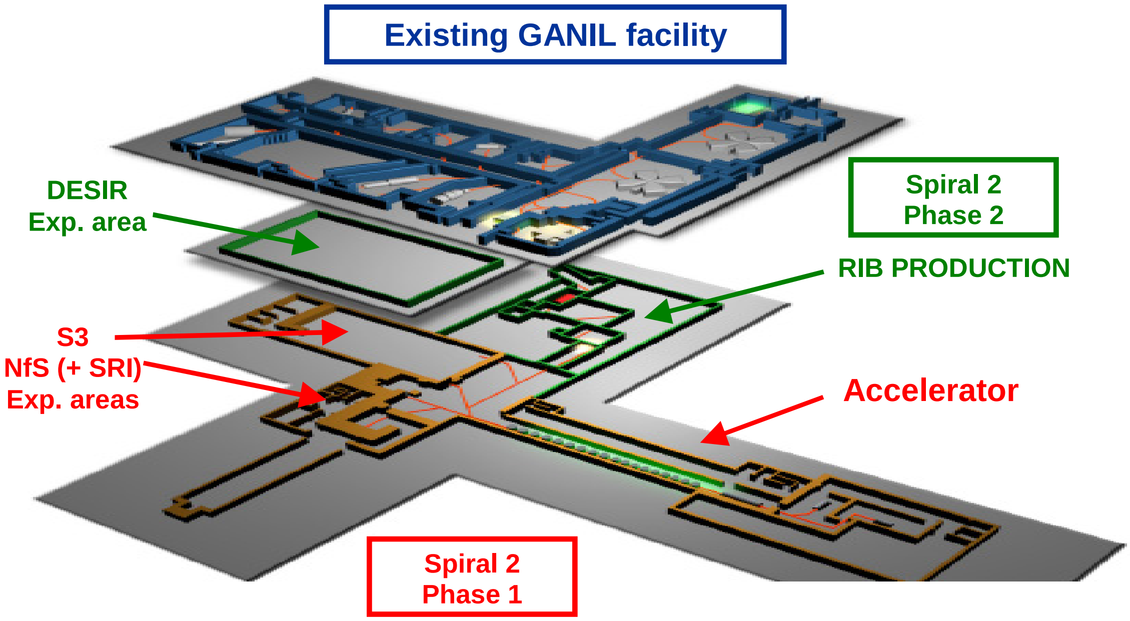

Figure 1: Layout of the GANIL/SPIRAL existing and future SPIRAL2 facilities.

The main RIB production scheme of SPIRAL2 is based on the fast-neutron induced fission of uranium target. Using a carbon converter, a 5 mA (CW) deuteron beam and a high-density (up to 11 g/cm3) 2.3 kg uranium carbide target, the fission is expected to reach a rate of up to 10^{14}/s. The intensities of the post-accelerated RIB in the mass range from A=60 to A=140 will be of the order of 10^6 to 10^{10} particles/s (pps) surpassing by one or two order of magnitude existing facilities. For example, the intensities should reach 10^9 pps for ^{132}Sn and 10^{10} pps for ^{92}Kr. A direct irradiation of the UC2 target with beams of protons or ^{3,4}He can be used if higher excitation energy leading to higher production rate for a specific nucleus of interest or if much smaller targets with fast release properties are required. The heavy and light-ion beams from LINAC can also be used directly on different production targets to produce high-intensity light RIB with the ISOL technique.

The extracted 1+ radioactive ions will be subsequently injected to the 1+ / n+ charge breeder (ECR ion source) and post-accelerated to energies of up to 20 MeV/nucleon (up to 7-8 MeV/nucleon for fission fragments) by the existing CIME cyclotron. Thus, using several different production mechanisms and techniques, SPIRAL 2 would allow users to perform experiments with a wide range of neutron- and proton-rich nuclei far from the line of stability. One of the important features of the future GANIL/SPIRAL1/SPIRAL2 facility will be the possibility to deliver up to five stable or radioactive beams to different users simultaneously in the energy range from keV to several tens of MeV/nucleon.

The civil construction of SPIRAL2 is divided into two phases (Fig 1). The first one (LINAC buildings and associated experimental areas) is going to begin in 2010 with a goal to provide first stable-ion beams in 2012. The second phase (RIB production building and DESIR facility) will start in 2011 aiming to begin the operation in 2013-2014. The construction of LINAC is already well advanced with, in particular, the serial production and tests of super-conducting cavities, ion sources and beam-line components.

The reference planning was adopted in September 2007 (Fig.2). The present situation is displayed in the same graph, showing how several major milestones (safety/licensing procedures and buildings contracts) were accomplished during the past months, and confirming the initial project schedule with only a few months of delay.

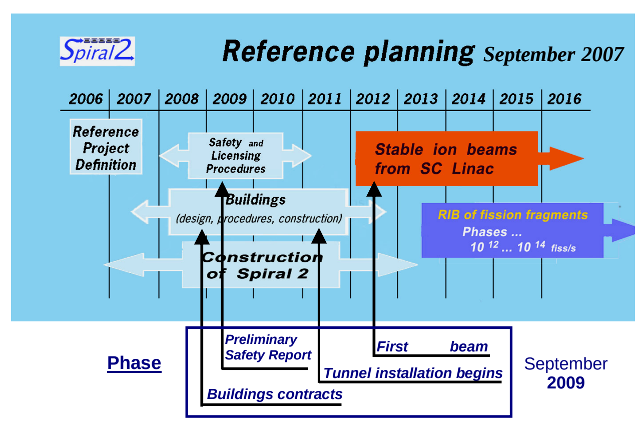

Figure 2: The Spiral 2 reference planning and present situation of the major project milestones.

CONSTRUCTION OF THE DRIVER ACCELERATOR

The baseline layout of the Driver Accelerator (Figure 3) was frozen in October 2006 [4]. At this date the design of the main components was launched and, today, only minor aspects have significantly changed.

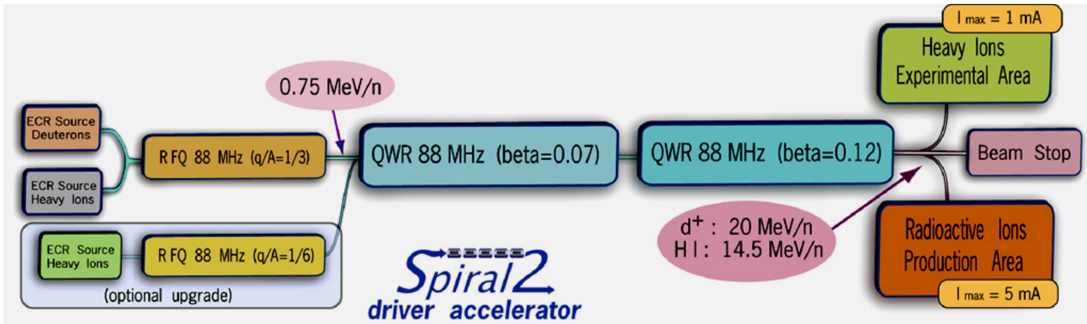

Figure 3: Spiral 2 Driver Accelerator.

In Table 1 are presented the accelerated ions with their intensities and energy ranges. In Table 2, a list of the main components.

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
CWmax 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
Frequency: 88 MHz
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)

Injector

Complete tests of the two ion sources are planned in parallel with the buildings construction, before their final installation in the Linac tunnels. The Heavy Ions source with its mass analyzer and beam diagnostics are presently being tested in the CNRS/LPSC laboratory in Grenoble. First beams were obtained at the beginning of this year, and a complete test program, including the test of a new ECR source with SC coils.

The light ion source (protons and deuterons) with its beam transfer line and diagnostics are tested in the CEA/Saclay laboratory. Different test phases, including beam characteristics measurements, beam diagnostics, and other beam handling equipments, are proposed for one complete year, starting in December 2009 and finishing beginning of 2011.

The construction of the RFQ cavity, under the responsibility of CEA Saclay laboratory, has started this year. A 4-vanes copper cavity composed of 5 sections, 1 meter long each, dissipating 240 KW, with an electrode voltage of 110 KV and output energy of 0.75 AMeV. The first section will be delivered and tested before the end of this year, with the goal to assembly and test the complete cavity in the tunnel mid-2011.

SC Linac

The SPIRAL2 SC Linac [5] [6], is composed of 2 families of 88 MHz SC QWR resonators (β=0.07, β=0.12), which permits the acceleration of all ions and energies mentioned in table 1. The basic principle of this design was to install the SC resonators in separate cryomodules (1 QWR per cryomodule in the β=0.07 section and 2 QWR per cryomodule in the β=0.12 section).

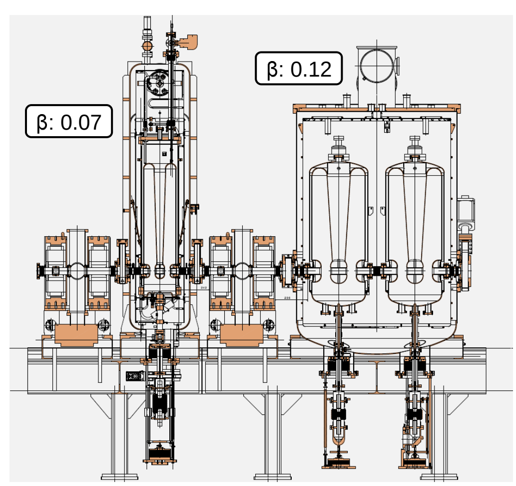

Figure 4: SC Linac Cryomodules.

Between each cryomodule (Fig. 4), beam focusing is performed by means of 2 warm quadrupoles with short vacuum/diagnostics boxes in between. Even if the cryogenic losses are higher, compared to other designs implementing 4, 5 or 6 resonators in a cryomodule, it offers several major advantages: flexible beam tuning system with RT Q-poles, space for beam diagnostics at room temperatures and optimized mechanical supports with precise alignment possibilities.

The two families of resonators have been developed in parallel by two partner laboratories (CEA Saclay for the β=0.07, and IPN Orsay for the β=0.12).

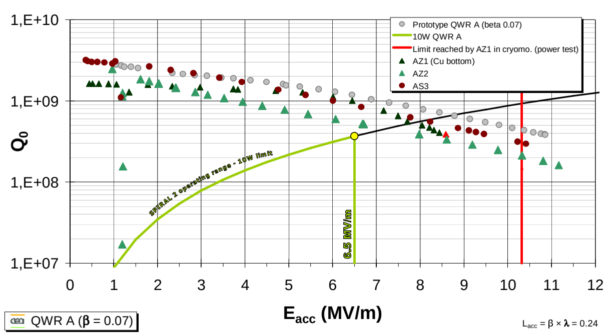

Figure 5: β=0.07 QWR tests at 4.2 K.

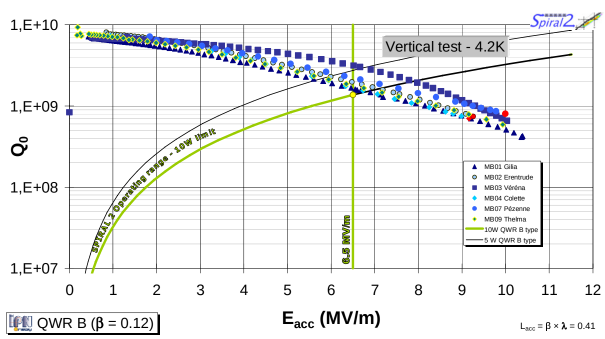

Figure 6: β=0.12 QWR tests at 4.2 K.

The results of all QWR tests are presented in Fig. 5 and 6. For the β=0.07 QWR it includes one prototype and the two pre-series resonators (fabricated by SDMS and Zannon companies). For the β=0.12 QWR only the first 6 series resonators (fabricated by RI company) are presented. All these results confirms the good quality The reproducibility is very good, nearly all the resonators have reached an accelerating gradient close to 10 MV/m (corresponding to Epk values of 50 MV/m), compared to the design goal of 6.5 MV/m. The Q_0 at this nominal value is higher than 10^9 at 4.2 K, which corresponds to a thermal load of 10 W per resonator.

A very challenging goal has been also reached during fabrication procedures: for nearly all resonators, controlled after manufacturing, the frequency was within the ± 20 KHz range, and the beam axis alignment (between inner electrode and beam ports) better than 0.4 mm.

The two first cryomodules have been tested during the last year (Fig. 7 and 8) in complete cryogenic and RF conditions. Many tests covering all the aspects have allowed the launch of the series fabrication of all components, including the cryogenic interface boxes integrating regulation and process valves.

Typical results obtained in these tests:

- Resonators dynamic losses: 10 W
- Static cryogenic losses: between 10 en 15 W, including cryomodule, valve box and transfer line.
- RF power levels between 5 and 10 KW were injected into the cavities.

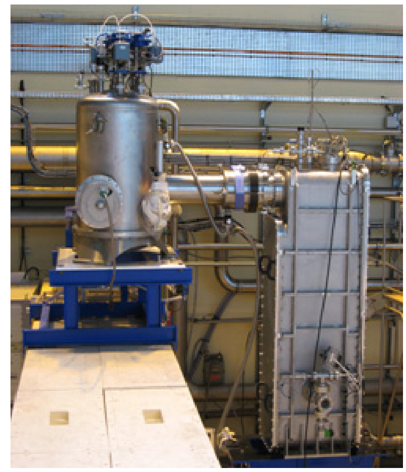

Figure 7: Cryomodule type A (β=0.07).

Figure 8: Cryomodule type B (β=0.12).

The frequency tuning system of the two types of resonators is different: mechanical deformation of the resonator external body for the β=0.07, and a new plunger system located on the high magnetic field side of the resonator for the β=0.12 (Fig. 9). This system can be implemented in two ways: fixed or adjustable plungers to compensate frequency shift and for fine on-line frequency control.

The RF power couplers, are developed by the CNRS/LPSC laboratory in Grenoble [8]. 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. During the initial prototyping phase several couplers

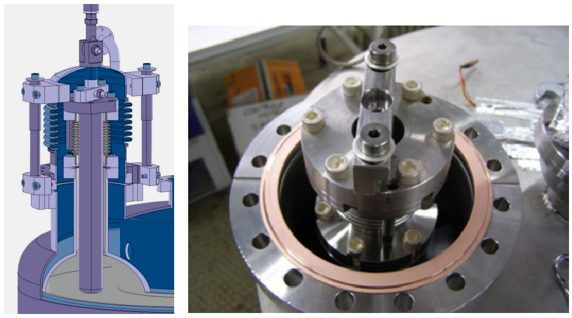

Figure 9: Resonators Frequency tuning with plungers.

were conditioned and tested at high power (40 KW), giving very useful information on multipacting and conditioning procedures. Some of these prototypes have been installed and tested at full power in the cryomodules (Fig. 10). The contracts for the series production (28 couplers) were finalised beginning of 2009, and the first couplers have been recently delivered.

Figure 10: RF power coupler.

RF Sytems

The RF system design proposed for Spiral 2 (Fig. 11) is based on two main components:

- Solid State amplifiers with external full power circulators (developed by GANIL laboratory)
- Digital Low Level RF system incorporating frequency tuning control (developed by CEA Saclay)

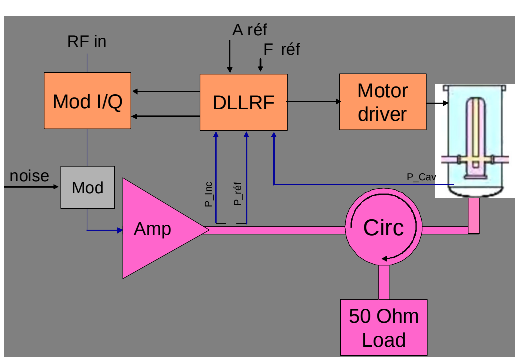

Figure 11: RF power and LLRF systems.

The basic unit amplifier is a commercial 10 KW model developed for FM broadcasting applications. It is composed by 4 modules of 3 KW and adapted for the accelerator specifications [9]. Two 10 KW amplifiers can be coupled to obtain 20 KW (Fig. 12).

Both models (10 and 20 KW) have been extensively tested in a special test-bench installed in the GANIL laboratory, and, later, powering the QWR during the cryomodule tests at the locations of Saclay and Orsay laboratories. Some improvements have been proposed and the series contract is in preparation for the end of this year.

Figure 12: (left) two 10 KW combined to deliver 20 KW, (right) 10 and 20 KW circulators.

The control of all RF cavities of the Driver Accelerator (SC resonators, RFQ cavity and re-bunchers resonators installed between the RFQ and the SC Linac), will be performed by a new Digital Low Level RF system which is presently under development. The first prototypes must be tested with SC resonators before the end of this year. These systems include VME interfaces, and perform independent amplitude and phase control of each cavity, as well as the accurate control of its QWR associated tuning system.

SPIRAL 2 SAFETY ASPECTS

Spiral 2 is the first major facility for nuclear research to be concerned by a recent new law (2007) regulating the nuclear related facilities in France. GANIL is already a nuclear facility and, for Spiral 2 authorizations, it is considered as an extension of the existing facility. During the last three years preliminary safety studies and initial talks with the National Nuclear Safety Agency have resulted in a final agreement for the licensing procedure: A global Safety Assessment report for Spiral 2 project will be presented, leading to a single Ministry Authorisation Decree with several steps.

This report must include: 1) Preliminary Safety reports of the two phases. 2) Operating ranges of the whole facility. 3) Study of the impact on the environment.

The preliminary report covering the Phase 1 (Accelerator and first experimental areas) was completed and presented to the authorities in April

2009. The complementary reports covering Phase 2 (RIB production and associated experimental areas) will be released at the end of this year.

Table 3 : Spiral 2 Operational Dose Rates

	Technical Staff	People and 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
• offices, labs and workshops limit: 7. 5 µSv/h • maintenance operations limit: 100 µSv/h		

The Radiation Dose Rates goals adopted by the Spiral 2 project (Table 3) have important consequences on the design of the Linac accelerator and associated buildings.

Concerning the beam losses in the SC Linac and High Energy lines, the main goal is to operate with a maximum level of 1 W/m. This is supported by extensive beam dynamics calculations [7], taking into account both the corrected and uncorrected errors. These errors were introduced in a statistical way for 1400 different Linac configurations and 1 million macro-particles trajectories were analyzed for each configuration resulting in a total integrated loss of 0.02 W for the whole linac), and maximum localised losses.peak of 0.64 W. The radioprotection calculations were performed with distributed losses of 0.6 W/m or the cryomodules and 0.2 W/m at the level of Q-poles. To operate within the dose rate limits adopted by the project, the following shielding characteristics are necessary: floor level of tunnels for Linac and High Energy lines at –9.5 m, concrete walls of thickness 80 cm around tunnels and 3 m of earth filling above the tunnels upper wall). This shielding allows operating with some margin on the distributed losses, and accepting localised undetected losses of 50 W for long time periods.

PHASE 1 BUILDINGS

During the last two years an intensive work has been developed for the definition of the buildings technical specifications, followed by a contract (November 2008) for detailed studies and construction works of the Phase 1 buildings (Accelerator, Experimental Areas, and Infrastructures). A detailed schedule was recently proposed: beginning of ground works in June 2010, with a progressive availability of different tunnels and buildings between May and October of 2011. A major decision on buildings constructing principles was to install all facilities underground. The level of Linac tunnel floor will be -9.5 m with a beam axis at -8 m and an available tunnel height of 6 m. Two major design guidelines oriented this choice: earthquake event and external aggression resistance, and radioprotection shielding. A technical tunnel running parallel to the Linac tunnel and other equipment rooms will allow to install all 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 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 13 shows a cut view of the underground tunnel, at the level of the cryogenic line connection. The access to the Linac tunnel for components installation is made through special pits and elevators.

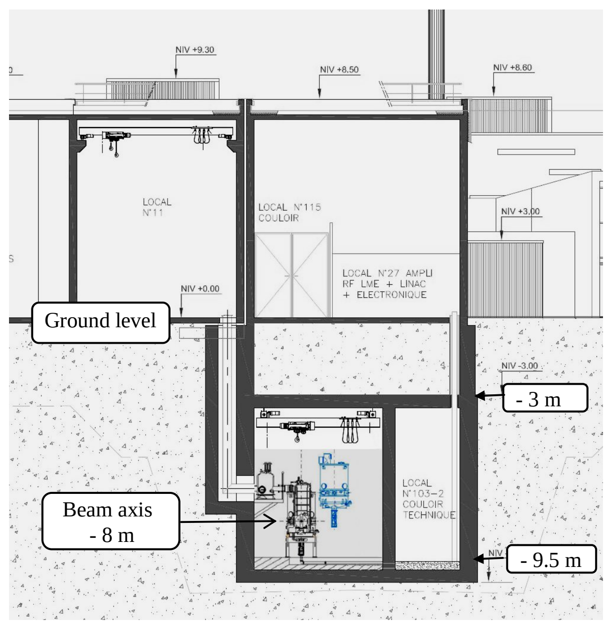

Figure 13: Underground Linac tunnel.

CONCLUSIONS

Many technical aspects and developments of the Spiral 2 project and proposed physics programs are not covered in this paper, particular emphasis is given to the topics of relevant importance for this high intensity accelerator, together with general information on the Linac design aspects, safety, and buildings. Other very challenging topics in this project are the Radioactive Ion Beams production, its licensing aspects and the associated buildings and infrastructures. These topics are far beyond the scope of this .conference, but interesting and useful information about the design and prototyping developments can be obtained in the project Web site [2]. More recently, the preparation of the first experiments with Spiral 2 have been discussed in a recent Scientific Advisory Committee, confirming the interest of the international community for the performances offered by this new facility.

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