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HISTORY AND PROSPECTIVES OF GANIL

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Abstract

The first beam of the GANIL facility (Grand Accélérateur National d'Ions Lourds) at Caen was ejected from the second separated sector cyclotron forty years ago (November 19th, 1982). Since then, several evolutions occurred. In 2001, the first exotic beam, produced by the Isotope Separation On-Line method at the SPIRAL1 facility, was delivered to physics. The GANIL team realized an upgrade of this facility in order to extend the range of post-accelerated radioactive ions in years 2013-2017, with first radioactive beams delivered in 2018. In 2019, GANIL became also a LINAC facility, with the first beam accelerated in the SPIRAL2 facility. The DESIR facility is aimed at using beams from SPIRAL2 and from SPIRAL1 facility, motivating a major renovation plan of the cyclotron facility. Parts of ancient and recent history of GANIL will be presented as well as its future.

FROM THE BEGINNING FORTY YEARS AGO TO UPGRADE OF SPIRAL1

November 19th, 1982, 12h30 am, the first beam was seen on the profiler located at the output of the second separated sector cyclotron at GANIL (Fig. 1) 5 nA were ejected from 150 nA injected ($^{40}Ar^{16+}$), starting from 200 nA $^{40}Ar^{4+}$ ejected of SSC1.

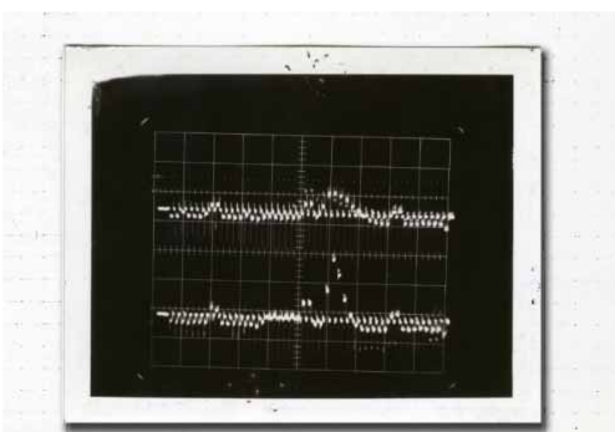

Figure 1: 1st beam profile, SSC2 ejection.

GANIL construction was decided in 1975. The design included two compact cyclotrons as injectors, one for SSC1 and for SSC2. In the final design, the two injectors may inject the beam into SSC1, and also SSC2 (the two SSCs were identical). There is one rebuncher between the injectors and SSC1, one stripper between SSC1 and SSC2, one low energy spectrometer and a high-energy one, called "Alpha" spectrometer due to its shape. The beam is distributed to experimental areas through a "fishbone" (Fig. 2).

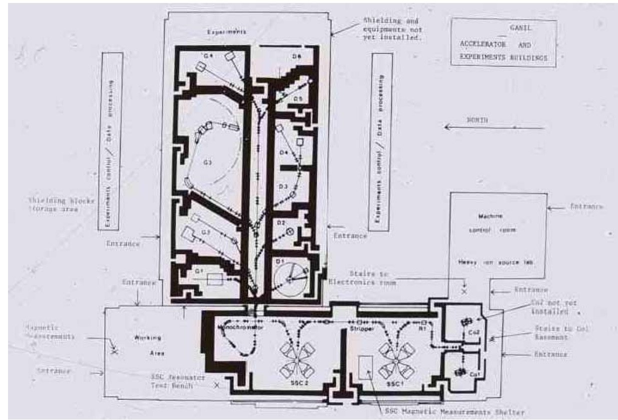

Figure 2: Design of GANIL.

The facility was built in the years 1978 – 1982. In 1983, the first experimental took place in January. That year, Ne, Ar, Kr, and O were accelerated. The O was accelerated at the maximal energy, 95 MeV/nucleon, but the energy was low for heavier beams (45 MeV/A for Kr beam).

Figure 3 shows an RF cavity ready for installation into the SSC.

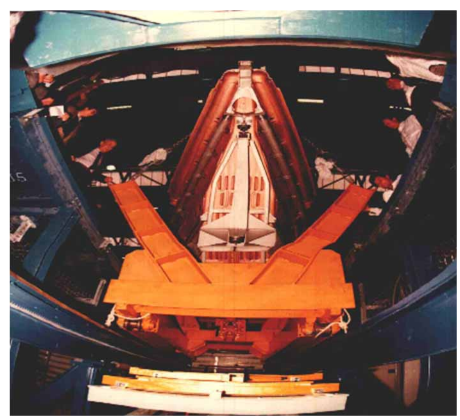

Figure 3: RF cavity installation.

In 1989, the OAE project was achieved [1], increasing the maximal energy for heavy beams. The key point was the stripping efficiency, increased with a higher SSC1 ejection energy (operation of SSC1 with harmonic 5 instead of 7, and new injection radius in SSC2 – 1,2 m instead of 0,825).

Increasing SSC1 energy was facilitated by the new sources, ECR technology replacing the PIG sources, inside the cyclotrons, in 1985. In 1992, the C01 ECR source was installed in a 100 kV platform and a new injection beam line was built, leading to better intensities and higher transmission (up to 65%). However, there were discharges in the accelerator tube and in 2004, we added a solenoid and a dipole inside the platform to have a pre-selection and limit the intensity in the tube.

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With high energies and intensity, we could get radioactive beams. The firsts were produced in flight in SISSI [2]. The target was cooled, rotated and designed for 1 KW deposited power (Fig. 4). A first superconducting solenoid gave a beam size of 0.2 mm radius, a second gave an angular acceptance of 80 mrad.

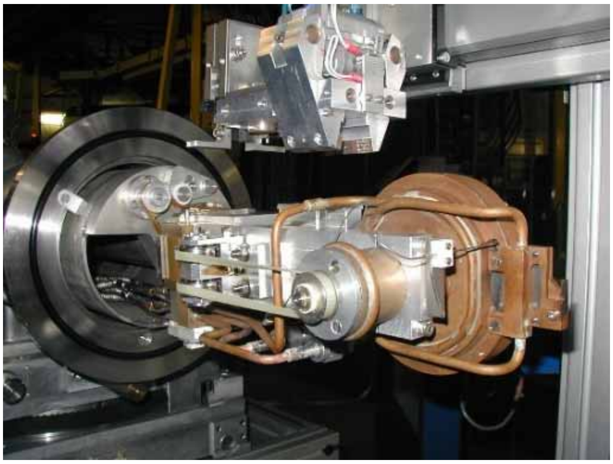

Figure 4 : SISSI target.

The THI project [3] increased the beam intensity in the years 95 – 2001, up to 5 kW. This was realized with beam loss monitors, a new rebuncher, a new septum for SSC2 deflector, and many hours of beam tests.

In parallel, it was the building and commissioning of SPIRAL1 [4], which consists in a **Isotope Separation On-Line method :** the beam is stopped in a carbon target, to produce secondary elements which diffuse in the target, are ionized in an ion source and transported to a new cyclotron to be post-accelerated. The cyclotron energy is 1.2 to 25 MeV/A using harmonics 2 to 6. In the original project there were two caves for the Target-Ion Sources (Fig. 5).

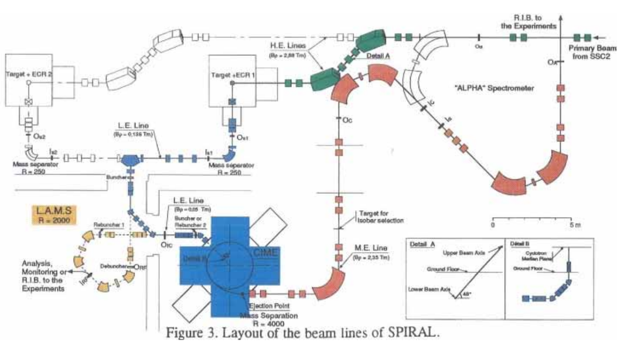

Figure 5: 1st design of SPIRAL1.

Three modifications were made to extend the use of GANIL beams: Medium Energy Exit (SME in French) in 1989, Low-energy irradiation south of injectors (IRRSUD) in 2002, and LIRAT which use the low energy beam of SPIRAL1 in 2005. LIRAT consists in a beam line, an RFQ-cooler and a trap in a platform to study the radioactive beam properties.

In recent years SPIRAL1 was upgraded. It is now possible to use different targets (and no more carbon only), different ion sources in particular FEBIAD source which is non selective and produces many elements, but is a 1+ source so that a Phoenix charge breeder is needed (Fig. 6). However, we use also N+ ECR sources, and in that case the beam must pass through the charge breeder.

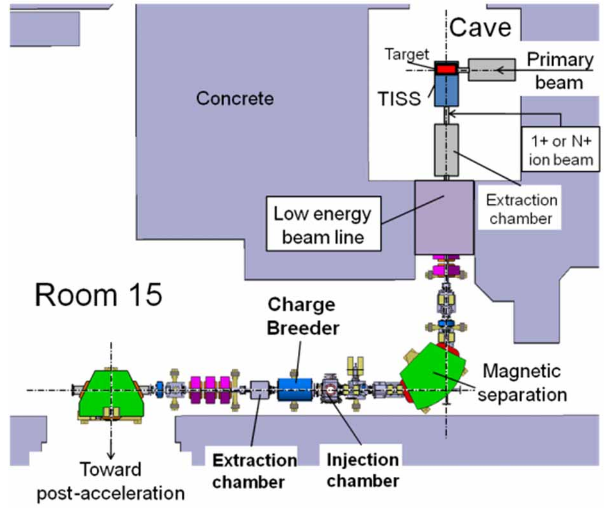

Figure 6: Schematic of the SPIRAL1 upgrade.

The integration of charge breeder and beam line modification was achieved between 2013 and 2016. In 2017, the charge breeder and beam line commissioning was started. The whole system was validated (performance, beam optics) by the end of 2017 [5]. First radioactive beams (^{17}F, ^{38}K) were delivered in 2018-2019. The mass resolution of CIME cyclotron allows us to purify the beam in many cases for light element (A<20). For heavier masses, stripping foils are generally used.

SPIRAL2 AND DESIR

From 2005 to 2019, GANIL was more concerned by the SPIRAL2 project than extending the cyclotron facility (Fig. 7). The original project included post-accelerations of fission products in CIME; only the LINAC part with 2 experimental rooms are built today. In 2019, GANIL became also a LINAC facility, with the first beam accelerated in the SPIRAL2 facility.

The DESIR (Decay, Excitation, Storage of Radioactive Ions) facility is aimed at using radioactive beams from SPIRAL2 and from SPIRAL1 facility (Fig. 8). The French Safety authority has now authorized its construction, which should begin in June 2023.

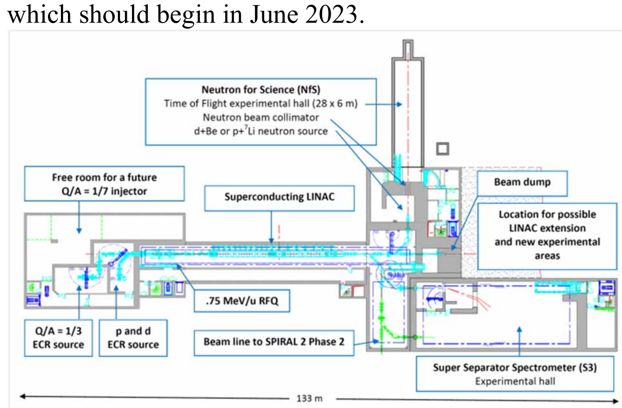

Figure 7: Layout of SPIRAL2.

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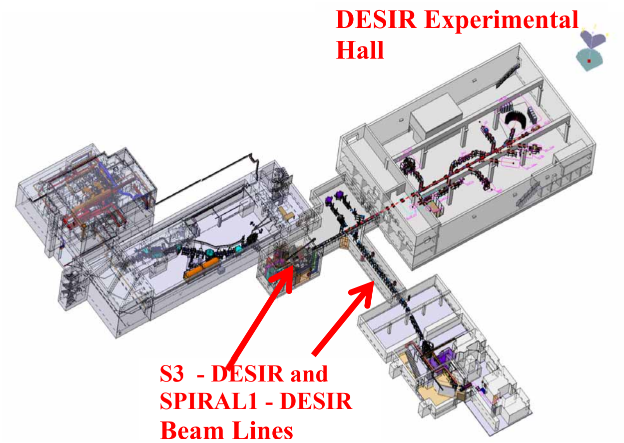

Figure 8: DESIR facility.

GANIL OPERATION STATUS

From the beginning, the time available for physics with cyclotrons was increasing until 2005, where we had a peak (more than 4000 hours physics time). Since then, the total operation time and the physics time are decreasing. Since 2019 yet, LINAC operation (2800 hours in 2021) is to be added to cyclotron operation (Fig. 9).

In the last 3 years we have an increase of the gap between the 2 curves. Indeed, we have a rise of the failure rate these last years, mainly due to water leak inside the machine, and particularly on the RF cooling circuits.

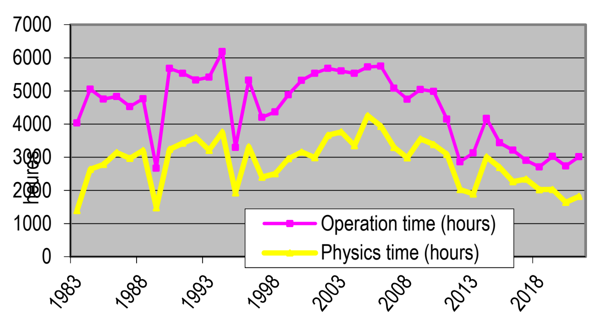

Figure 9: Beam time available for physics since 1983.

FUTURE OF THE CYCLOTRONS

There is still more demand at the PAC – Physics Advisory committee - than time available for cyclotrons. Demand include use of SSC2 beams in LISE spectrometer (fragmentation), fusion reactions with SSC1 beams, post-accelerated new SPIRAL1 beams, industrial beams, and, in next future, studies of SPIRAL1 beams in DESIR. Thus, we estimate that the cyclotrons will be used 20 years more. This motivates to continue developments for radioactive beams at SPIRAL1. The FEBIAD ion source, which at the beginning failed after a few days, has now been finalized. This source has first been used in alkali mode, with first post-accelerated beams K ones. The source team has now tested the FEBIAD with several primary beams, 80 different isotopes were produced [6]. The booster is to be upgraded to be used in double-frequency mode, one at 14 GHz with a klystron and one at 18 GHz with a travelling-wave tube amplifier. This mode will improve the charge states efficiency. There is also a motivation for a major renovation plan of the cyclotron facility. This is the CYREN (Cyclotron Renovation) project. The objective is to operate the facility 20 years more.

The main subject is the RF cavities with the water leaks concern. In the reference scenario a cavity will be constructed, will replace a SSC1 one, and the old one stored as a spare. The cost for a 1st cavity is estimated to 6 M€, and the delay 2 years plus the RF tests. There are difficulties with the storage and handling conditions (40 years ago, a storage area was present, now replaced by SPIRAL1 building extension. The girders were not present). In the "high scenario", the four RF cavities of the two SSCs will be replaced. Other major topics are power supplies, cooling systems and remote control.

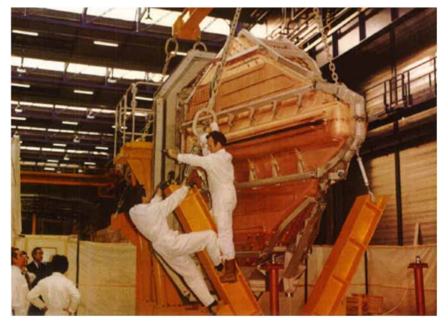

Figure 10: An RF cavity.

CONCLUSION

After forty years, GANIL cyclotrons are still demanded and it should be true for 20 years, including use of new SPIRAL1 beams in DESIR facility. SPIRAL1 development concerns Target Ion Source, charge breeder, and acceleration at low energy (1.2 MeV/A in harmonics 6). A large renovation plan of the cyclotrons is to be launched (5 to 8 years and 16 to 32 M€ depending on the scenario).

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