

# THE SISSI FACILITY AT GANIL

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## Abstract

The GANIL cyclotrons at Caen provide ion beams from carbon to uranium, with maximum energies of, respectively, 95 and 20 MeV/nucleon. These primary beams may bombard a thick target located in the high energy beam line, in order to produce secondary radioactive beams. A device called SISSI (Superconducting Intense Source for Secondary Ions) has now been used since October 1994 to get a 0.4 mm diameter spot on the target, and to improve the downstream beam line angular acceptance, thus increasing the collection of the secondary ions.

This is realized with 2 superconducting solenoid coils, which provide a maximum field of 11 Teslas.

The cooling is provided by a closed circuit of liquid He at 4.6 K.

The target is a 3000 rpm rotating disk, so that the radiated heat is spread over a much larger area than that of the beam spot.

The whole system is described, in both the theoretical and technological aspects. The cryogenic and the target systems are more detailed. The tuning aspects and the results for the transmission of secondary ion beams are presented.

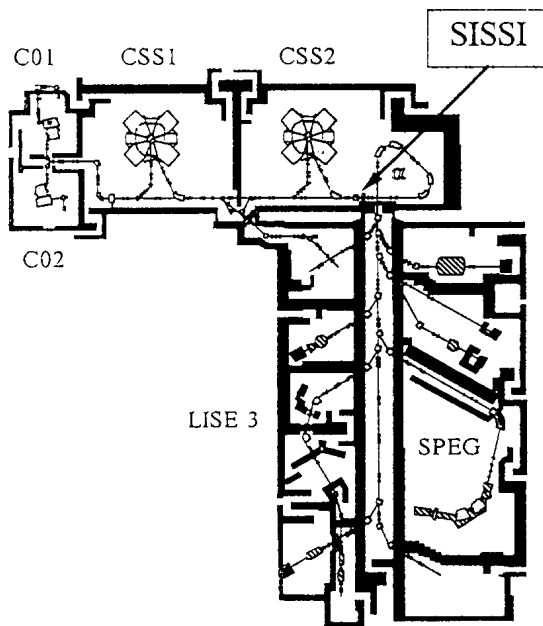


Figure 1: General layout of GANIL showing the location of SISSI

## 1 INTRODUCTION

The use of secondary beams in physics experiments becomes more and more usual. At GANIL, these secondary beams may be produced by projectile fragmentation in a thick target, located in the high energy beam line, between the second cyclotron (SSC2) and the alpha spectrometer « $\alpha$ » (see figure 1). Thus, any experimental area may receive the secondary beam.

SISSI (Superconducting Intense Source for Secondary Ions) enables to increase the transmission of the produced beams by a factor 10 or more, and to get better beam characteristics [1]. This system is described in both theoretical and technological aspects, and the results of its operation are reported.

## 2 THEORETICAL CONCEPTION

At GANIL, secondary radioactive beams have been produced for several years in the high energy beam line. However, their transmission was rather poor, due to their high energy and angular dispersions (the angular divergence may be larger than 100 mrad). The alpha spectrometer has a  $\pm 0.5\%$  momentum acceptance and the maximum angle must be about 10 mrad in the horizontal plane, and 5 mrad in the vertical one.

The role of SISSI is to increase the angular acceptance of the beam line, and, thus, the transmission of the secondary beams. SISSI is made of 2 superconducting solenoids, SOL1 and SOL2. SOL2 acts as a lens of short focal length to collect the ions produced within  $\pm 80$  mrad (fig.2).

Furthermore, in order to reduce the beam emittance, SOL1 is used to focus the beam on the target. A beam size of  $\pm 0.2$  mm is obtained, so that the beam emittance of the secondary beam is :

$$\varepsilon = \pi(0.2\text{mm})(80\text{mrad}) = 16\pi(\text{mm.mrad})$$

These beam characteristics (with  $\Delta p/p = \pm 0.5\%$ ) are estimated without aberrations. Taking into account the geometrical and chromatic aberrations, the transmission of a beam with these characteristics may be estimated to about 85%.

Solenoids have been preferred to quadrupoles as their effects are axially symmetric, and their focusing gradient more linear.

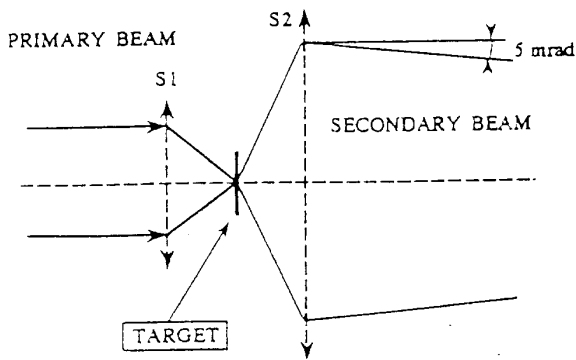


Figure 2 : Principle of the use of SISSI

### 3 TECHNOLOGICAL REALIZATION

The maximum magnetic field in the solenoids must be 11 Teslas at the maximum magnetic rigidity of 2.88 T.m. This is made possible by superconducting technology. The 2 solenoids, manufactured by Oxford Instruments, are located on both sides of a vertical tube in which the target is inserted (fig. 3). The solenoids are aligned within the cryostat, and the cryostat aligned with the beam line axis. Each solenoid has its own power supply, with an adjustable current. The currents are in opposite signs, so that the residual magnetic field at the target location is minimized. Each solenoid consists of two coaxial coils, the outer one being made of NbTi conductors, the inner one of Nb3Sn. Both coils operate at 4.6 K in a common vessel of liquid He.

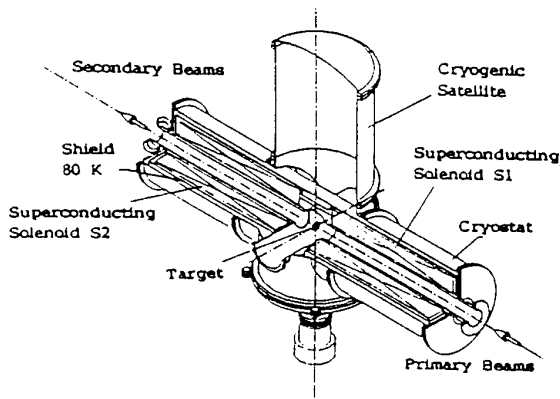


Figure 3: Schematic view of the cryostat of SISSI

#### 3.1 The cryogenic system [2]

The operation of SISSI needs an automatic cooling. This is made with a closed cycle refrigerator designed, and specially improved for the SISSI project, by the CEA. It consists of :

- a condenser where the gaseous Helium reliquefies
- a 3-stage refrigerator : the first one, at 80 K, is cooled by liquid nitrogen. The two others (42 K and 12 K) are the two stages of a Gifford-Mac-Mahon cold head.

- a Joule-Thomson expansion to get the 4.6 K temperature.

The cooling power of the module is only 4 W. This power must be larger than the thermal exchanges : the power deposited by neutrons issued from the target has to be taken into account.

#### 3.2 The target system [3]

The power of the primary beam is, up to now, limited to 400 W. This power is to be increased to several kW, with the THI [4] project. Nevertheless, due to the small diameter of the beam, and to the narrow Bragg peak, the power density is already too high : fusion or sublimation of the target may occur.

However, the target has, in fact, a diameter of 120 mm, and is rotating at 3000 rpm. Thus, the power is distributed over an area about 1000 times larger than the beam area.

Figure 4 shows the target system. The target is pinched between 2 pieces of graphite, and this set is enclosed in a water-cooled copper shell. This copper shell protects the cryogenic environment from the radiated heat.

However, the power loss in the target is limited by another aspect. The neutrons and gamma rays produced in the reactions could bring, in the cryogenic environment of the second solenoid, several tens of watts [5]. Several absorbing materials have been tested. A neutron-shield cone, made of a thin cadmium foil wrapped around a copper piece, has been set inside SOL2. The remaining power deposited in the cryostat must not exceed 2 watts : this limits the beam power deposited in the target to 1 kW.

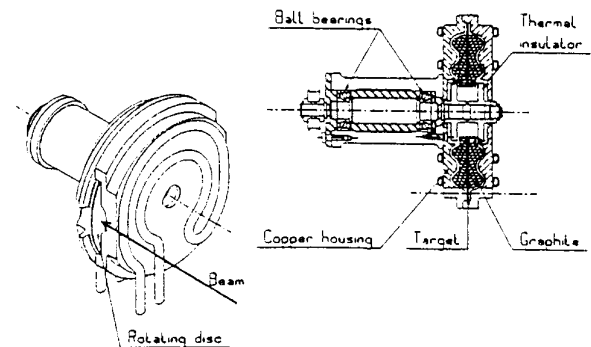


Figure 4: Schematic view of the target system

## 4 OPERATION

### 4.1 Tuning procedure

To align the secondary beam, we use a motionless target, which acts as an energy degrader, so that the magnetic rigidity of the degraded primary beam is equal to that of the secondary beam. This beam is guided toward the experimental areas.

Indeed, the radioactive beam is not visible on the ordinary wire profile monitors of GANIL. From SISSI to the experimental area, only two beam profile monitors, located at the exit of the alpha spectrometer and using the ionization of gas cells, enable to control the position and size of the secondary beam.

The exact setting of SISSI is depending on the characteristics of the beam emittance at its entrance. An optical method enables to check the beam size on the target, by measuring the size of the degraded beam on a wire monitor located after SISSI. Indeed, the beam size on this monitor is given by equation (1) :

$$\sigma_{x\text{mon}} = \sqrt{(T_{11}\sigma_x)^2 + (T_{12}\sigma_{x'})^2 + 2T_{11}T_{12} \langle xx' \rangle}$$

with  $\sigma_x$  and  $\sigma_{x'}$ , respectively the beam size and the beam angular divergence on the target, defined as the mean square root,  $\langle xx' \rangle$  the mean value of the product (position \* angle), and  $T_{11}$ ,  $T_{12}$ , the terms of the transfer matrix in the horizontal plane. The method consists in finding optical conditions for ( $T_{12}=0$ ), so that the two beam sizes are purely proportionnal.

To get a good transmission of the secondary beam, the tuning of the magnetic field of SOL1 must have an accuracy of less than 1%.

The tuning of SOL2 depends mainly on the energy of the secondary beam, which is measured in the alpha spectrometer and adjustable : indeed, the target thickness may be adjusted by tilting it by up to 45 degrees.

### 4.2 Transmission of the secondary beams

The transmission efficiency, from SISSI to the output of the alpha spectrometer, is given by simulations in table 1, as a function of the  $x'$  and  $\Delta p/p$  half widths.

An experiment has been made using an incident beam of  $^{12}\text{C}$  at 75 MeV/A, with a target of Tantalum used as an energy degrader. The thickness of the target was 2730mg/cm<sup>2</sup>. The expected angular scattering was 104 mrad, the estimated momentum dispersion  $\pm 2.25\%$ .

The expected transmission efficiency was about 17%. The measured one was about 11%. This may be explained by a target inhomogeneity, giving a  $\Delta p/p$  greater than expected.

$x'$ (mrad)	$\Delta p/p$ (%)	Transmission efficiency (%)
$\pm 70$	$\pm 0.4$	95.4
$\pm 70$	$\pm 0.5$	89.2
$\pm 80$	$\pm 0.5$	83.5
$\pm 70$	$\pm 2.25$	28.0
$\pm 80$	$\pm 2.25$	25.4
$\pm 100$	$\pm 2.25$	19
$\pm 110$	$\pm 2.25$	16.4
$\pm 120$	$\pm 2.25$	13.6
$\pm 80$	$\pm 3$	19.3
$\pm 100$	$\pm 3$	14.3
$\pm 110$	$\pm 3$	12.0

Table 1 : transmission efficiency as a function of the  $x'$  and  $\Delta p/p$  half widths.

The angular acceptance of the alpha spectrometer may be measured by an optical method. Using again equation (1), it can be seen that the maximum angle accepted by the beam line may be measured, if the  $T_{11}$  term is made zero from the target to a beam profile monitor located at the end of the alpha.

An angular acceptance of 70 mrad has been measured.

The  $\Delta p/p$  acceptance may be measured in the GANIL spectrometers LISE and SPEG. The results of the two experimental areas are sometimes different, but a momentum dispersion of  $\pm 0.5\%$  has been measured several times in LISE.

Therefore, the transmission of the secondary beams is close to the expected value, and ten times or more higher than the transmission of the same beams without SISSI.

## 5 CONCLUSION

Despite of the technological difficulties, SISSI has been used since October 1994 in physics experiments, and the interest of the physics community increases with time.

## 6 REFERENCES

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