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## Nuclear Safety at GANIL: Authorized Operation

### INTRODUCTION

GANIL is allowed by the French Nuclear Safety Authority (ASN) to use the facility (accelerator, experimental areas, ...) according to the Safety Report, Waste Management Report, General Operation Report. The majors' items are presented in this document.

#### 1. BEAMS AVAILABLE

##### 1.1 Accelerated beams

The ion sources produce ions which are accelerated successively by compact cyclotrons C01 or C02 and by the separated-sector cyclotrons CSS1 and/ or CSS2.

The ranges of available energy are as follows (where  $q/A$  is the ratio of charge- to-mass of the ion considered):

- very low energy (TBE)  $\leq 100 \times q/A$  keV/nucleon at the exit of the sources,
- low energy (BE)  $\leq 0.97$  MeV/nucleon after C01 or C02,
- intermediate energy (ME)  $\leq 13.5$  MeV/nucleon after CSS1,
- high energy (HE)  $\leq 95$  MeV/nucleon after CSS2 via CSS1.

The acceleration of the beams in the cyclotrons is subject to the following operating limits:

	C01 & C02	CSS1	CSS2	CIME	
Nature of accelerated ions	stable	stable	stable	stable	radioactive
A of primary accelerated ions	$\geq 12$	$\geq 12$	$\geq 12$	$\geq 12$	$\geq 12$
A of secondary accelerated ions	irrelevant				unlimited
Energy range of accelerated ions	$\leq 0.97$ MeV/u	$\leq 13.5$ MeV/u	$\leq 95$ MeV/u	$\leq 25$ MeV/u	
Range of intensities obtained	$\leq 5 \times 10^{14}$ pps	$\leq 3 \times 10^{13}$ pps	$\leq 2 \times 10^{13}$ pps	$\leq 5 \cdot 10^{11}$ pps	

#### Restrictions on cyclotron operating

The beams from the C0 (C01 and C02) can be sent to:

- the CSS1 cyclotron
- the very low-energy irradiation line IRRSUD.

Beams from CSS1 can be sent to:

- D1 experiment room via the SME line (intermediate-energy exit)
- all physics experimental areas accessible via the so-called "α" spectrometer
- the CSS2 cyclotron for further accelerated to achieve the highest energies.

The maximum energy of the primary beam from CSS2 is 95 MeV/u because of the accelerator operation diagram with a maximum intensity of  $2 \times 10^{13}$  pps and a power less than 6 kW, monitored by beam intensity measuring equipment.

##### 1.2-Spiral 1

Beams from CSS2 can be directed onto the carbon target for all the target/ion-source ensembles (ECS) of SPIRAL 1 to create secondary beams of radioactive and stable ions which are then accelerated in the cyclotron CIME.

The number of particles deposited on the same ECS of SPIRAL 1 is restricted to a value calculated according to a procedure with the agreement of the Safety Nuclear Authority (ASN), and in all cases remains below the limit of  $5.3 \times 10^{19}$  particles.

The number of particles deposited on the ECS is measured and controlled by the CICS equipment. The list of authorized primary beams for the irradiation of any ECS for SPIRAL 1 is presented below, for the isotopes and maximum energy most likely to be requested by users:

**List of allowed incident beams onto the target of SPIRAL 1**

ion	energy	ion	energy	ion	energy	ion	energy
<sup>12</sup> C	95MeV/u	<sup>22</sup> Ne	79MeV/u	<sup>50</sup> Cr	88MeV/u	<sup>64</sup> Zn	83MeV/u
<sup>13</sup> C	82MeV/u	<sup>24</sup> Mg	95MeV/u	<sup>52</sup> Cr	81MeV/u	<sup>70</sup> Zn	70MeV/u
<sup>14</sup> N	95MeV/u	<sup>26</sup> Mg	82MeV/u	<sup>54</sup> Cr	75MeV/u	<sup>70</sup> Ge	79MeV/u
<sup>15</sup> N	83MeV/u	<sup>32</sup> S	95MeV/u	<sup>56</sup> Fe	82MeV/u	<sup>76</sup> Ge	67MeV/u
<sup>16</sup> O	95MeV/u	<sup>36</sup> S	78MeV/u	<sup>57</sup> Fe	79MeV/u	<sup>78</sup> Kr	81MeV/u
<sup>17</sup> O	85MeV/u	<sup>36</sup> Ar	95MeV/u	<sup>58</sup> Fe	76MeV/u	<sup>84</sup> Kr	70MeV/u
<sup>18</sup> O	76MeV/u	<sup>40</sup> Ar	77MeV/u	<sup>58</sup> Ni	90MeV/u	<sup>86</sup> Kr	67MeV/u
<sup>19</sup> F	86MeV/u	<sup>40</sup> Ca	95MeV/u	<sup>64</sup> Ni	73MeV/u	<sup>112</sup> Sn	76MeV/u
<sup>20</sup> Ne	95MeV/u	<sup>48</sup> Ca	69MeV/u	<sup>65</sup> Cu	76MeV/u	<sup>116</sup> Sn	71MeV/u

If new beams are required, they would be subject to a prior authorization request to the Safety Nuclear Authority (ASN). Otherwise, the limit of 15 days of irradiation to a maximum  $2 \times 10^{13}$  pps and power of 6 kW would be respected.

**1.3-LIRAT**

The LIRAT beam line can receive beams from the ion source of the CS1 cave (cave containing the SPIRAL 1 ECS) without limit for stable beams and the 4 radioactive beams for which the biological protection is sufficient, i.e.:

Authorized ions	<sup>6</sup> He	<sup>19</sup> Ne	<sup>32</sup> Ar	<sup>35</sup> Ar
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**Ions allowed in LIRAT**

The maximum energy beam at the exit of the cyclotron CIME is 25 MeV/u because of the characteristics of the accelerator. The intensity maximum of CIME ejection must be less than  $5 \times 10^{11}$  pps.

There is no limit (on A, period, etc.) on the radionuclides constituting the secondary beams.

**2. LIMITS IN EXPERIMENTAL AREAS**

The beams can be sent into experiments areas on any type of target within the limits of:

- the maximum intensities from the accelerator
- the biological protection of the experimental room receiving beam.

The second limitation is first expressed as the maximum intensity  $I_0$  of the most penalizing beam (<sup>12</sup>C at 95 MeV/u) admissible in the room. For the other beams (other ions and/or other energies) the maximum allowable in the room is calculated using the equation for  $I_{max}$  limiting the intensity as a function of energy E of the beam. These limitations are included, for each room in the table below.

Cave	$I_0$ (pps)	$I_{max}$ (pps)	Cave	$I_0$ (pps)	$I_{max}$ (pps)
D1	$2,61 \cdot 10^{11}$	$I=3,68 \cdot 10^{24} \cdot E^{-6,64}$	G1	$1,05 \cdot 10^9$	$I=7,46 \cdot 10^{18} \cdot E^{-4,97}$
D2	$2,10 \cdot 10^{12}$	$I=1,80 \cdot 10^{23} \cdot E^{-5,51}$	G2.1	$2,69 \cdot 10^{10}$	$I=2,84 \cdot 10^{18} \cdot E^{-4,05}$
D3	$2,10 \cdot 10^{12}$	$I=8,10 \cdot 10^{29} \cdot E^{-8,88}$	G2.2	$1,56 \cdot 10^{10}$	$I=5,00 \cdot 10^{23} \cdot E^{-6,82}$
D4 (LISE III)	$1,28 \cdot 10^9$	$I=1,44 \cdot 10^{17} \cdot E^{-4,07}$	G3	$1,70 \cdot 10^{10}$	$I=8,18 \cdot 10^{22} \cdot E^{-6,41}$
D4 (LISE 2000)	$8,70 \cdot 10^8$	$I=1,61 \cdot 10^{19} \cdot E^{-5,19}$	G4.1	$4,70 \cdot 10^9$	$I=1,45 \cdot 10^{19} \cdot E^{-4,85}$
D5	$5,10 \cdot 10^9$	$I=3,48 \cdot 10^{24} \cdot E^{-7,50}$	G4.2	$9,50 \cdot 10^8$	$I=5,78 \cdot 10^{18} \cdot E^{-4,94}$
D6	$1,65 \cdot 10^8$	$I=2,04 \cdot 10^{16} \cdot E^{-4,09}$	-	-	-

**Maximum intensity allowable in the experimental room (for a <sup>12</sup>C beam at 95 MeV/u)**

### 3. Limit in the use of targets

#### - SIRa

- Target in carbon
- Can receive the most penalizing beam ( $^{12}\text{C}$  at 95 MeV/u) up to the limit permitted in room D2 to produce a secondary beam.

#### - LISE

The target can receive the most penalizing the beam ( $^{12}\text{C}$  at 95 MeV/u) up to the intensity limit of the D3 room

- **Normal use**

- A maximum power of 80 W may be deposited in the target, without limit to duration of irradiation.

- **CLIM use**

The target of CLIM (the LISE target for maximum intensity) can receive the primary beam from  $^{12}\text{C}$  to  $^{78}\text{Kr}$  and  $^{86}\text{Kr}$  up to the maximum energy produced by the accelerators. (The realization of experiments using an incident beam of mass higher than 78 is subject to the approval of the ASN, except in the case of krypton-86, which is allowed).

The target is designed for a maximum power deposited of 800 W.

The primary beam can irradiate any type of target with a mass below that of  $^{181}\text{Ta}$  with a maximum of 15 days of irradiation in CLIM.

#### • Irradiation of Nuclear Material

IRRSUD line allows the irradiation of low-energy ( $\leq 1$  MeV/u):

- classic material,
- materials containing nuclear material in uranium, thorium or other actinide except plutonium.

In all the above cases the samples are massive.

The activity of nuclear material held in the hall IRRSUD should not exceed 2 MBq.