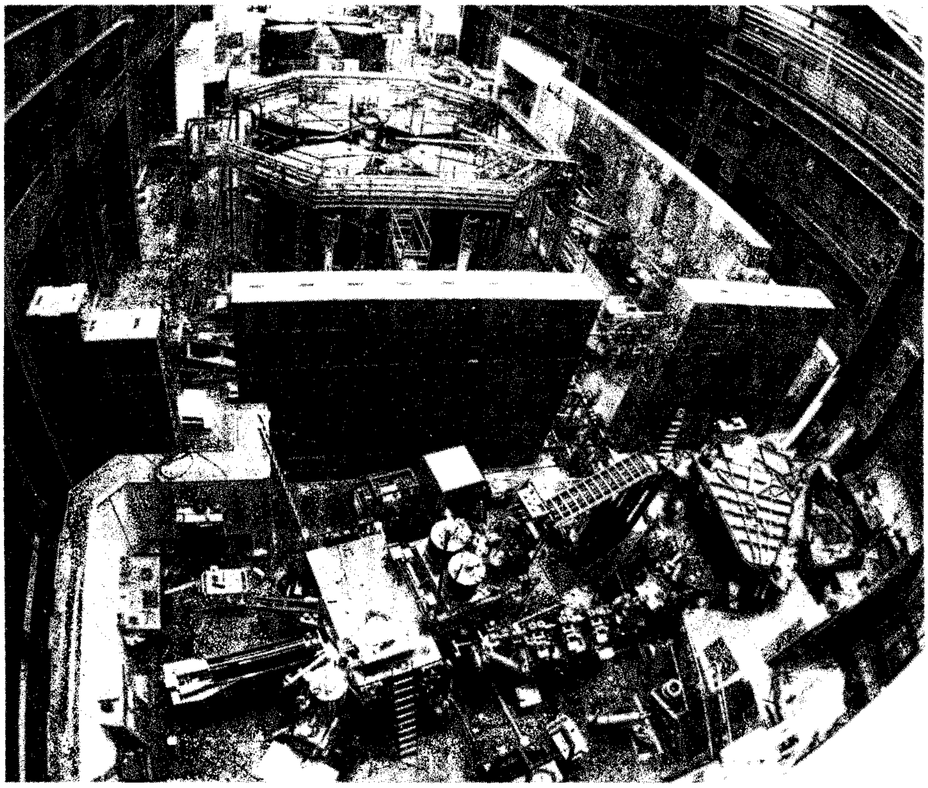
GANIL starts up

View of the GANIL cyclotron hall during the assembly period. The injector cyclotron can be seen in the foreground with the two separate sector cyclotrons in the background.



After six years of construction, the French GANIL (Grand Accélérateur National d'Ions Lourds) machine at Caen recently came on stream, accelerating a 50 nA beam of argon ions to an energy of 44 MeV/nucleon. (100 nA beams are now handled.) Today's physics interests amply confirm the thinking behind the launching of the GANIL project ten years ago.

GANIL's maximum energy varies from about 100 MeV/nucleon for light ions like carbon down to 10 MeV/nucleon for uranium. For each type of ion, it can supply beam from the maximum available energy down to about 5 MeV/nucleon.

GANIL is based on a sequence of three cyclotrons operating at the same frequency. The main difficulty with heavy ion acceleration is that the particles have to be sufficiently ionized for acceptable efficiency of the accelerator and magnet systems. The first two cyclotrons provide enough energy to ensure a large loss of peripheral electrons (the electric charge is multiplied on average by 3.5) when they pass through a carbon stripper, before being accelerated in the third cyclotron.

Cyclotrons 2 and 3 are of the separate sector type, providing good radial and vertical beam focusing, and with an injection radius of approximately 85 cm and ejection radius of 3 m, are virtually identical. The ratio between the radii is approximately the same as the factor by which the ion charge is multiplied during passage through the stripper. Cyclotron No. 1, the cyclotron injector, is considerably smaller and may be regarded as the centre of cyclotron No. 2, but located outside to improve access to the ion source. Cyclotrons 2 and 3 multiply energy by 13.6 and 12.3 respectively. A change in GANIL's output energy therefore involves adjustment of the entire machine including the source, cyclotron fields, r.f. frequency and the transfer line elements between the cyclotrons. This procedure is simplified by the control computers.

The major change to the original 1975 project is that, in the interests of beam usage, it was decided to have very small phase extensions, so that the flat-topping cavities, used to reduce energy dispersion and to provide comfortable phase acceptance, are no longer required. A phase compression process was evolved to reduce the natural energy dispersion by a factor of between 2 and 2.5 while conserving adequate phase acceptance. An alpha-shaped spectrometer was added to measure output energy dispersion and reduce it to a minimum of $\pm 5 \times 10^{-4}$.

Although GANIL is a classical machine using tried and tested techniques, its various components have presented a number of technical challenges.

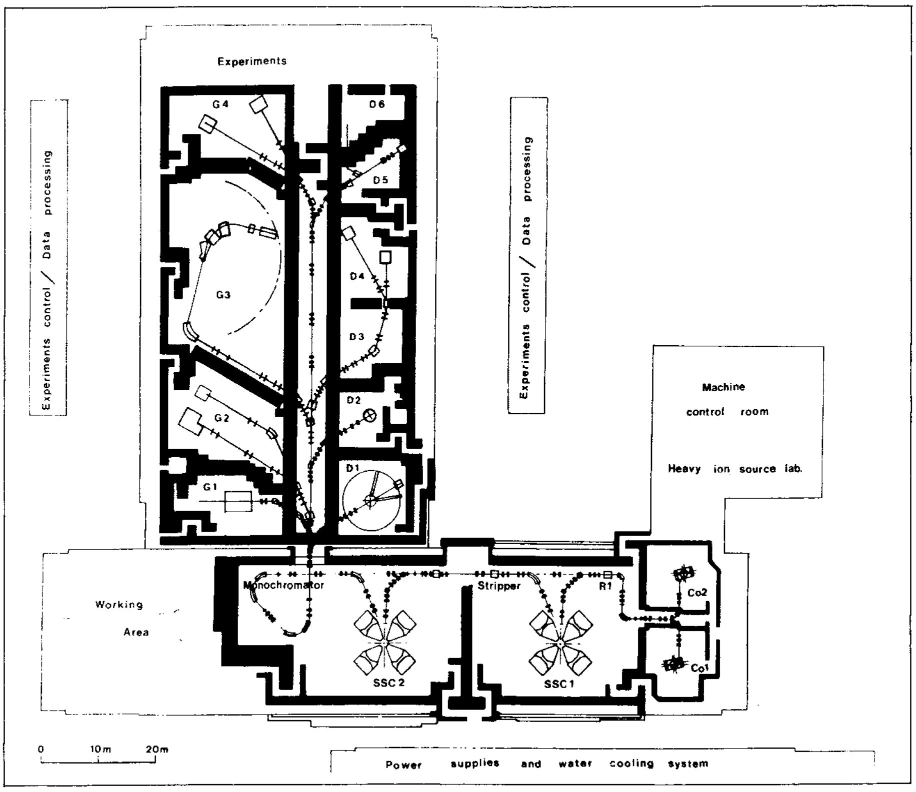
The original project included the installation of two alternating injectors, but only one, a compact cyclotron with flat poles, has so far been built. The PIG-type ion source requires frequent replacement, but its automated installation and removal and total vacuum re-restablishment can be accomplished in less than an hour. All types of ions complete 14 orbits in the cyclotron. The maximum voltage on the dee is 90 kV. The central geometry of the cyclotron was studied on a specially converted model of the CERN synchrocyclotron. It is currently delivering 2×10^{12} charge 4 argon ions per second, in an emittance of 45 π mm mradian with an energy dispersion of 6×10^{-3}.

The second cyclotron injector, currently under construction, will differ only in its ECR Minimafios-type source, now being built at the Centre d'Etudes Nucléaires at Grenoble. The source will naturally be located outside the cyclotron, into which ions will be injected axially. This type of source has two advantages: it has a very long life compared with the PIG sources, which have to be treated after some thirty hours of operation, and it provides charge states permitting constant operation at the maximum magnetic field imposed by the stripper. This means that the maximum energy of 100 MeV/nucleon can be conserved down to iron, that the energy of the semi-heavy ions can be doubled and that uranium can be obtained at 18 MeV/nucleon.

Each separate sector cyclotron consists of 4 magnetic sectors: two r.f. cavities in the 'valleys' between the sectors, the injection and ejection systems and the diagnostic systems. The four sectors complete with coils weigh 2 000 tonnes and consume 1 MW. The magnetic field in the sectors must ensure isochronous trajectories. Because of the relativistic correction, the field configuration must be modified from one energy to another. Both the sectors and the main coils are therefore filled with sheets of windings, each consisting of 15 so-called isochronism coils, in series on the four sectors, and of six independent correction coils. The coils of the sheets of windings, composed of pyrotenax conductors, are sealed in an envelope and the whole assembly is located inside the vacuum chamber. The conductors are fitted into grooves following the trajectories, a novel feature only possible with a numerically controlled machine.

To obtain a clear understanding of the magnets at different fields and different currents in the correction coils, 200 field maps of 36 000 points each were prepared using a Hall probe.

General layout of GANIL.



The magnet sectors, built by Alsthom Atlantique of Belfort, consist of eight horizontal laminations without bonding, each weighing no more than 60 tonnes so as to minimize handling difficulties. The polar block consists of 2 poles of 25 tonnes each. The air gaps are provided by three spacers and are linked to the yokes by three cross-frames cut to size after test fitting at the works (hyperstatic method). Under the effects of the magnetic field, each spacer bears an additional pressure of 200 tonnes and is compressed to between 2 and 10 mm. This induces relative movement between the magnets and the chamber which is absorbed by special antifriction devices (bronze micro ball bearings in a teflon/lead matrix).

The two identical vacuum chambers were designed at GANIL, in cooperation with an engineer seconded from CERN, and built by Neyrpic at Grenoble. They are one-piece mechanically welded assemblies with an average diameter of 9 m and a height of 4.50 m. The main joints were machined after all welding had been completed, necessitating very large machine tools. The chambers are made of stainless steel chosen for its non-magnetic qualities and its low out-gassing rate. Each weighs 57 tonnes and has a surface area of 230 m^2. The welding was checked by sweating at the works. Each chamber was carefully cleaned upon delivery at Caen, following its transportation by water via the Rhone and the Straits of Gibraltar.

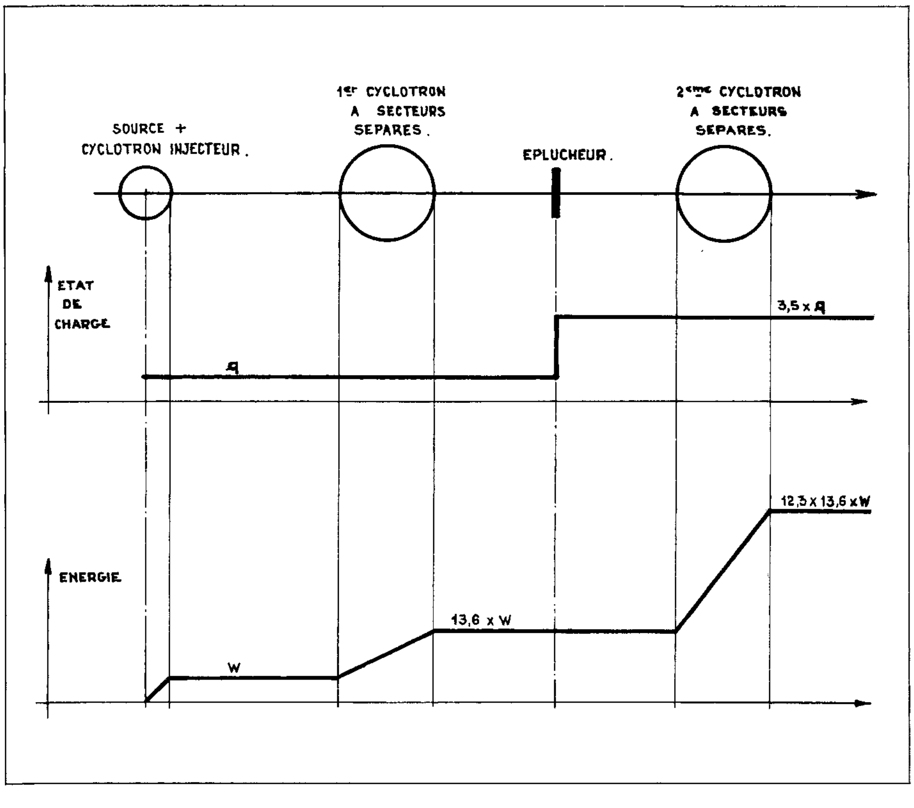
The chambers were designed using 'finite element' computer codes so as to minimize flange deformation during establishment of the vacuum. To improve vacuum quality, metal seals were used where possible in preference to elastomer ones, as they are far less prone to deformation. The vacuum required to accelerate the beam without loss (better than 10^{-5} Pascal: 1 atm = 1.013×10^5 Pascal) is most critical in the first separate sector cyclotron (SSC) and is achieved using seven cryogenic pumps at 20 K, without a liquid nitrogen screen, each with a pumping speed of 20 000 l/s for steam and 10 000 l/s for hydrogen. When air enters, the pressure climbs to 10^{-4} Pascal (which is enough for the r.f. power in the cavities) within two hours. After five hours, the pressure reaches 5×10^{-5} Pascal, which allows ions to be accelerated with a loss of only 20%.

GANIL incorporates seven r.f. cavities (two on each SSC, one on each cyclotron injector and a cavity acting as a buncher half-way between the injector cyclotrons and the first SSC) which can be tuned to any frequency within the 6.4 to 13.8 MHz range. Their novelty lies in their compactness, made possible by the use of removable capacitive panels, replacing the bulky quarter-wave lines normally used. They were built by SEIV in Paris following various technological studies at GANIL and technical research by CGRMEV.

The maximum voltage on the dee at the injection radius varies from between 100 to 250 kV, depending on the operating frequency. As the resonance ratio varies from 8 500 to 14 000, between 56 and 78 kW per cavity is required to obtain the maximum voltage. The cavities operate in continuous wave mode at a voltage stabilized at ± 10^{-4}. The tuning of each cavity and the phase regulation of one cavity with respect to the others is guaranteed to within ± 0.1 of a degree. The copper cleaning techniques used have made possible a very low rate of out-gassing and no difficulties were encountered in passing the multipactor areas.

The accelerator is controlled by a MITRA 125 computer and 15 JCAM 10 microprocessors linked by a CAMAC network. Most of the 300 stabilized power supplies and stepping motors used are linked directly to the central MITRA 125 computer via the CAMAC.

(We intend to publish a further article, describing the physics at GANIL, in a forthcoming edition.)



Operating principle of the new French GANIL heavy ion accelerating complex, showing how energy and ion charge are progressively increased.