A low energy facility at SPIRAL-GANIL

G. Auger, F. Bocage, B. Jacquot

To cite this version:

G. Auger, F. Bocage, B. Jacquot. A low energy facility at SPIRAL-GANIL. 2000, pp.1-22. <in2p3-00413277>

HAL Id: in2p3-00413277
http://hal.in2p3.fr/in2p3-00413277

Submitted on 3 Sep 2009

GRAND ACCELERATEUR NATIONAL D'IONS LOURDS

GANIL

A LOW ENERGY FACILITY AT SPIRAL-GANIL

Technical report

G. Auger, F. Bocage, B. Jacquot

GANIL R 00 01

Laboratoire commun CEA / DSM - CNRS / IN^{2}P^3

B.P. N° 5027 - 14076 CAEN CEDEX 5 - TÉL. 02.31.45.46.47 - TÉLÉCOPIEUR 02.31.45.46.65
GROUPEMENT D'INTÉRÊT ÉCONOMIQUE RÉGI PAR L'ORDONNANCE N° 67.821 du 23.09.1967
Siège Social : Bd Henri Becquerel - 14000 CAEN (France) - R.C. Caen 997 888 300 C - Code APE 731Z - N° Siret 997 888 300 00016

INTRODUCTION

The SPIRAL facility [1-2] will shortly produce radioactive ion beams of high energy from 2.5 to 25 Mev/u. These radioactive beams are obtained with the so-called Isotopic Separation On-Line (ISOL) technique and are post-accelerated by a new dedicated cyclotron CIME. This facility, known as "SPIRAL Phase-I", is now constructed and is ready to start the radioactive beam production.

Several possibilities to increase the ability to manipulate radioactive ions are now under study at GANIL-SPIRAL. Three main possible upgrades of the SPIRAL facility are proposed [2]:

- A two step ionisation principle known as the "1+/n+" system [8-9] will allow to place the n+ source far away from the radioactive area and to increase the list of possible radioactive ions.

- The "SPIRAL Phase-II" project [12] consists in the production of neutron rich nuclei by fast neutron induced fission, the neutrons could be obtained by break-up of deuterons in a thick converter.

- The radioactive beams obtained with the target-source system can advantageously be used for low energy experiments. Such a "low energy facility" [15], which could complement the main SPIRAL beam line, is also studied.

This report focuses on the third point: the installation of a low energy facility at SPIRAL (LE facility hereafter) which would open up new scientific opportunities at SPIRAL. The purpose of this paper is to discuss the main requirements of this project in the context of the SPIRAL facility, in accordance with the other studied SPIRAL upgrades. The scientific committee of GANIL will soon give a decision on the future of SPIRAL and will define the priority between the different possible projects. Therefore, the intention of the present document is to provide the basis of the decision. In chapter I, we will describe in more detail the SPIRAL Phase-I facility and the three proposed SPIRAL upgrades. In chapter II, we propose various scenarios for the implantation of the new low energy beam line. We will especially discuss the possibility to run in parallel two beams, towards the cyclotron CIME and the low energy facility. We will then discuss in chapter III the beam handling and purification: three scenarios are proposed associated to medium (Rm=2000), high (Rm=5000) and very high-resolution mass spectrometer (Rm=20000 and higher). Finally, we present in chapter IV first cost estimates for the beam transport section and for two mass separation systems.

I) SPIRAL Facility and possible upgrades

A) SPIRAL Phase-I

The SPIRAL facility [1-2] produces exotic ion beams using the ISOL method. The GANIL heavy ion beam of high intensity will bombard a thick carbon target in order to produce radioactive species by projectile fragmentation. The geometry of the carbon target has been chosen to optimise the production yields. For the first experiments at SPIRAL, an Electron Cyclotron Resonance Ions Source (ECRIS) [3] with permanent magnet is used to obtain high charge state ions. The efficiency of this ECR ion source system is optimum for the production of noble gas: He, Ne, Ar, Kr, ... Secondary radioactive beam intensities up to 10^8 particles/s are expected. Because the target-source system is the crucial point in the ISOL technique, further R&D on ionisation sources are always performed [6-7]. In particular, other types of sources are studied for the production of a larger variety of radioactive ion beams: sources like SHyPIE for condensable element [5], or surface ionisation sources for alkali element [4]. However, until now, no universal source system is well suited for the production of all elements. After production and ionisation, the ion beam is transported in a low energy transport section and accelerated in the new compact isochronous CIME cyclotron (K=265). The beam extracted from the cyclotron is then conducted towards the GANIL experimental areas, after a selection in magnetic rigidity performed by the modified α-shaped spectrometer of GANIL.

B) "1+/n+" source systems

A collaboration between ISN Grenoble and GANIL studies a two step ionisation principle for SPIRAL [8-9]. The use of a primary ion source, associated with the carbon target, for the production of 1+ ions with a subsequent injection in an ECR ion source for charge breeding could present several advantages for SPIRAL. The target-ion source system, strongly activated during the experiments, has a reduced lifetime (2-3 months with a carbon target) and should be replaced often. In this two step ionisation mechanism, the ECRIS n+ ion source could be placed far away from the activated area. The 1+ source, which is coupled to the carbon target, is cheaper than an ECRIS and will thus strongly reduce the cost (from around 1/3) of the target-source system [6]. Moreover, a mass selection can be performed in between the two sources, which allows to increase the mass selectivity of the system. Although we can expect that the overall ionisation efficiency of this system for the noble gases will be smaller than with a single ECRIS, the use of n+ sources of greater performance could partly compensate this effect. It will also enlarge the list of possible radioactive ions: the 1+ source can be selected to ionise the most efficiently a given type of ion, like noble gas, metals, alkali or condensable elements,... [4,10].

C) SPIRAL Phase-II

A European R&D project called SPIRAL Phase-II investigates a novel technique for producing neutron rich nuclei [11]. This technique rely on fast neutron induced fission. Fast neutrons could be generated by break-ups of deuteron on a thick target (the converter). To obtain the necessary intense deuteron beam a new dedicated accelerator should be constructed. The neutrons generated in the converter impinge on very thick fissionable target [12-13]. After the resulting fission products have diffused out of the target, they are ionised, mass selected and post accelerated in the CIME cyclotron or could be even used in the future low energy beam line. If the release time of the fission products out of the target is short enough, an intense beam of short-lived exotic nuclei can be expected. For instance, using a Beryllium converter and a 6.kW deuteron beam at 200 Mev on a uranium target, 10^9 pps ^{91}Kr could be produced [14]. Thus, 2 or 3 orders of magnitude increase of the production yields may be obtained with respect to the "SPIRAL-Phase I" projectile fragmentation yields [2]. Moreover, a very efficient ion source will be needed in order to produce highly charged ions for the wide range a chemical species produced in the target. The efficiency of such a source should be taken into account to extrapolate the final beam intensities. This project would then increase considerably the possibilities of the present SPIRAL facility with a large variety of new radioactive ion beams.

D) A low energy facility at SPIRAL

While a great variety of ion beams and experimental devices can be used to study specific aspects of exotic ions, the pioneering efforts of ISOLDE at CERN have shown the interest in using low energy ion beams. The various and relatively intense radioactive beams produced with the target-source system of SPIRAL Phase-I, and maybe later of SPIRAL Phase-II, could be used before acceleration with the CIME cyclotron for low-energy experiments. Namely, an important community of European scientists has already demonstrated a great interest in the SPIRAL Low Energy facility during the Workshop held in Bordeaux on March 13 1999. The installation of the LE facility thus could present a scientific interest for the whole SPIRAL facility and also a technical interest for the development of the SPIRAL Phase-II project.

1) The scientific interest of the LE facility

The main advantage of SPIRAL with respect to other ISOL facilities, like TISOL, ISAC or ISOLDE is the obtained intensities which are more than competitive and may still increase with the 1+/n+ system [15]. The SPIRAL Phase-II- system could also give higher yields for heavy neutron-rich isotopes. Specific studies are in progress to estimate these production yields. The research program with such a facility may cover a large variety of research fields with diverse experiments described in greater detail in ref. [15]:

- nuclear structure: static properties (mass, spin, parity, quadrupole moment,...) and nuclear decays (βxp, βxn, astrophysical reactions, ...)
- fundamental interactions (test of the standard model, test of CPT, ...)
- solid-state physics and atomic physics (effects of impurity on semiconductor, stability of matrix for nuclear waste storage, Mössbauer spectroscopy, ...)

It is worthwhile to add that all these proposed experiments do not require the same beam properties. The nuclear decays and fundamental interactions studies need for example beams of great purity, when it is not the case for ion laser spectroscopy. Moreover, the mass measurements using trap will gain in precision with multi-charged ions, while the use of a radio-frequency quadrupole (RFQ) for cooling and bunching is only possible with mono-charged ions. It may then be necessary to let open all these possibilities.

Moreover, specific devices and detectors will be available in GANIL-SPIRAL and would therefore offer unique research possibilities at such a SPIRAL Low Energy facility. Let us for example mention:

- TONNERE [16-17]: a detector for delayed-neutron spectroscopy consisting of 32 long and curved scintillator bar (160 cm) placed at 120 cm around an implantation detector. The time of flight between this implantation detector and one of the scintillator gives the neutron energy. Each scintillator is also equipped with two photo-multiplier tubes, which allow a noise reduction and a position measurement of the detected neutrons.

- EXOGAM [18]: a new compact and highly segmented array for γ-spectroscopy is under construction at GANIL. Closely packed at 11 cm of the target, 16 segmented Clover detectors cover a large part of the whole geometric space. In order to optimise the overall efficiency of the array, each of these Clover detectors consists of four Ge crystals, placed in the same cryostat. Additional shields and collimators allow an increase of the peak-to-background ratio.

- A Paul Trap: A transparent Paul trap is currently developed, at LPC Caen, and aimed to test the standard model measuring β-ν correlations in Gamow-Teller β decay. Its large solid angle will allow to place a detection set-up all around the trap.

2) A technical interest of the LE beam line for SPIRAL Phase-II

The SPIRAL Phase-II project still requires an important R&D effort, and would certainly need a period of tests after its installation. For example, a new type of target-source system should be tested to optimise the production yields and the ionisation efficiency. Moreover, in order to adjust the CIME cyclotron for an efficient post-acceleration of low intensity exotic beams, the measurement of the production rates of different species extracted from the ion source is of prime importance. These measurements, based on the study of the radioactive decay of the produced nuclei, allow to identify the production rates for the desired ions as well as for the contaminants [19]. For this purpose, an identification station has been installed on the CIME injection beam line and may be used to test the SPIRAL – Phase II facility, but to the detriment of experiments with ion beams coming from cave 1 (see fig. 1) and accelerated by CIME. Insofar as the SPIRAL Phase-II project will be developed from cave 2 (see part II and fig. 1), with the construction of a new cyclotron dedicated to deuteron beams acceleration, the low energy beam line would permit to perform such tests and measurements: the association "SPIRAL Phase-II + low energy beam line" would constitute a facility independent of the combination "SPIRAL Phase-I + CIME". On the other hand, the new possibilities of radioactive elements, which could be obtained with SPIRAL Phase-II will also strongly increase the scientific opportunities for the low energy facility.

II) The low energy beam line

The low energy facility project could be divided in two sections which will be discussed respectively in part II and part III: the low energy beam line itself, from the target-ion source system to the experimental area, and the first elements present in the experimental area such as a magnetic spectrometer or a radio-frequency quadrupole. The figure 1 presents the various lines and elements which will be discussed in the following. Only the line between cave 1 and the CIME cyclotron (**box A on figure 1**) with the identification station has already been constructed.

The target-ion source system is housed in a shielded cave in the basement (cave 1). A second cave (cave 2 hereafter) is available for future developments of the SPIRAL project. The optimal location for the implantation of the low energy experimental area is actually the basement of the new building dedicated to the storage of the irradiated target-source components. This room of 200m^2, called "low energy experimental area" in the following, constitutes indeed a spacious experimental area, large enough to lodge some voluminous apparatus (the MISTRAL spectrometer [21] for instance) and several smaller experimental devices. This proposed location will neither imply any important modification of the building nor the installation of a very long and complex transfer line. The proximity of the cave 2 represents another strong argument for the implantation of the future low energy experiments in this room. Let us underline that no important modification of the "cave1-CIME" beam line can be considered for the moment: the construction of SPIRAL - Phase I is now completed and GANIL is waiting for the authorisation of the safety authority to start the experiments. Therefore, it seems difficult to envisage any major modification of the present beam line before its utilisation. Moreover, it would imply a supplementary delay, which is not acceptable.

As long as cave 2 is not used, the low energy facility should be installed downstream from cave 1 to take benefit of the produced ion beams. We will first envisage this solution, which could be seen as a first step for the development of a low energy facility. Then we will discuss several possible upgrades of this basic beam line, eventually linked to cave 2.

A) The simple beam transport section **(Box B on fig. 1)**

First, we propose to undertake the construction of the transport section for the low energy beam line from cave 1 to the proposed experimental area situated in the basement of the new building. This beam line would partly follow the way for the CIME injection line, between the cave 1 and the D3 dipole, and then will continue straight away directly to the "low energy experimental area. Within this configuration, the transfer line "Cave 1-CIME" does not need to be modified. Moreover, the work to be carried out does not affect the existing buildings, except for the widening of the access door to the new experimental area: the widening indeed make it possible a straight line design for the transfer beam line and allow an easy access, even for voluminous devices, through the trap door located in the ceiling of room 4.

Furthermore, a slow time-sharing can even be easily envisaged: while the use of the dipole D3 guides the beam towards CIME, if no magnetic field is present in the same dipole the beam goes directly towards the low energy experimental area. This solution is mainly limited by the time necessary to the disappearance of the magnetic field in the dipole, which is of the order of 10 s. If the desired frequency for this time-sharing is higher than possible with this simple solution, it remains possible to substitute the dipole D3 by a pulsed dipole ; the dipole D3 could then be used at the entrance of the experimental area (position D3bis) in order to obtain two separated beam lines towards different devices placed inside the experimental area (fig 1).

Transverse Emittances:	$E_H = 80$ π.mm.mrad $E_V = 80$ π.mm.mrad
Energy spread (with the ECRIS):	$\Delta W/W = 5 / U_{source}(V)$
Extraction voltage:	$10 < U_{source} < 34$ kV
Maximum magnetic rigidity:	$B\rho = 0.136$ Tm
Charge State:	n+ (with the present cave 1 target-source system)

Table 1: *Beam characteristics at the entrance of the beam transport section, given by the source system and the extraction voltage*

However, in the second possibility, the ions sent alternatively in the two beam lines are not completely independent, because the first magnetic dipole D1 realise a selection in magnetic rigidity of $R_{M/Q}=250$ for emittances of 80 π.mm.mrad in the two transverse planes. This means that the two beam lines will use ions with almost the same M/Q ratio. The large mass and charge state distributions produced in a target-source combination may suggest that a greater choice in the ion species would be obtained if two different ions could be sent in the two beam lines. Such a greater flexibility could be obtained by replacing all the elements between the target-source system and the dipole D3 with pulsed elements. However this solution need to modify the present SPIRAL beam lines (three magnetic quadrupoles and two dipoles) and has, thus, not been further studied in the following upgrades possibilities.

B) Possible upgrades of the simple transfer section

We have previously seen that the proposed beam guidance section for the Low Energy Facility at SPIRAL could easily ensure a time sharing operation with the CIME cyclotron beam line. Nevertheless, remember that the main advantage of such a low energy facility at SPIRAL, with respect to other ISOL facilities, is the competitive radioactive ions production yields. To keep these good intensities simultaneously in the two beam lines towards CIME and the low energy facility, we studied the possibility to send in parallel to different beams in these two lines. All the other upgrades that we proposed are connected to the fitting up of cave 2, in connection with one of the two other studied possible upgrades: the 1+/n+ and SPIRAL-phase II projects.

1) A "simultaneous operation" with a separator

The first envisaged upgrade will allow to run in parallel two beams towards CIME and the low energy experimental area. This parallel (or simultaneous) operating mode is obviously really interesting since it would double the "profitability" of the production source (one beam transformed into two beams): two experiments could use in parallel two different beams produced with the same target-source system. A separator should be specially designed to send a continuous beam of a given mass and charge ions (A1, Q1) in the CIME injection line while directing another continuous beam (A2, Q2) towards the Low Energy facility. Such a separator must keep as vast as possible the range of ions available at the same time for the two beam lines. The separation system should also be compact enough to be eventually inserted in the present beam line. Several devices ensuring this operation have been studied in a technical report written by B. Jacquot [20]. We will now summarise the main proposition given in this report, based on the previously proposed simple beam transport section.

Mainly, two separation systems can be applied:

- A sector magnet with a mobile septum
  A movable septum should collect the ions dedicated to the LE facility just after the first dipole of the line D1. The installation of the mobile section and of the beam guidance system for the LE facility in the narrow corridor 15, between the dipoles D1 and D3 (see fig. 1), in addition to the present beam line, could be difficult.

- A Wien filter and a septum with a fixed geometry
  A short Wien filter could be inserted in the beam line between the ionisation source of cave 1 and the first dipole D1. The value of the electric and magnetic fields would be carefully tuned in order not to deviate the trajectory of the ion dedicated to the cyclotron beam line, while deflecting the ions for the LE facility with a giving angle toward an electrostatic septum. The first problem with this solution is the space available in the corridor before the dipole D1. However, our evaluation seems to indicate the viability of this system.

The separation of the two beams should be performed before any purification of the beam produced by the target-ion source system to keep all the possibilities for the choice of the two ion species. This fact constraints strongly the location of the separation which, in the case of our simplest beam transport section, will have to be carried out either immediately after the source or in the first turn. The separation of the two beams could also be done after the first turn if the analysing dipole D1 is replaced by an electrostatic deflector. However, the beam line will then no longer be achromatic between the target-source system placed in cave 1 and the CIME injection line.

The two systems require the construction of a second beam line in the corridor 15. This installation in the very narrow corridor should be considered carefully. Any operation on one of the two beam lines could be difficult because of the remaining space. Moreover, in the current context, any important modification of the present facility can not be considered. For the time being, it has been judged unreasonable to carried out important modifications of the cyclotron injection beam line: indeed, the construction time of the new beam line should be added to the delay taken by the SPIRAL project because of the public inquiry.

2) Upgrades connected with the fitting up of cave 2 **(box C on fig. 1)**

Due to the public inquiry, the modification of the line between cave 1 and CIME seems difficult to envisage in order to produce simultaneously two beams. From cave 1, the time-sharing mode represents the only reasonable solution. Nevertheless, such a parallel operating mode could be performed from cave 2. It is also important to note that, for the same reason, the two other projects, 1+/n+ and SPIRAL-Phase 2, will certainly be developed from cave 2. In addition, the SPIRAL-Phase 2 project will need a two step (1+/n+) ionisation. We can also recall that the low energy beam line represents an opportunity to perform some tests and identifications on the beam produced within these projects, before their acceleration by CIME.

Therefore, we will now assume the fitting up of cave 2. Different scenarios are schematically envisaged on figure 2 and 3. The first proposed exit of cave 2, labelled ③ on figure 2, conduct directly the beam towards corridor 15. In the case of a single step ionisation (fig. 2), a separator could be placed before the first bending magnet, even if the small distance between the ionisation source and the first dipole render this installation rather difficult. For a two step ionisation (fig. 3 - 1+/n+ and SPIRAL-Phase 2 projects), the n+ source would be placed after the first dipole D1, in corridor 15, which would hinder to send radioactive ion beams from cave 1 towards the low energy experimental area. The use of a separator before the first bending magnet (as in a one step ionisation) would still allow to send a 1+ beam towards the low energy experimental area. Thus, this exit for the cave 2 would make it difficult the installation of a separator and limit the beam possibilities for the low energy facility. That is why, to get enough place to install comfortably such a separator, we propose to extract the beam out of the cave 2 in room 4 (see line ② on fig. 2) instead of corridor 15 (line ③). In this case, for safety reasons, the primary beam should arrive from the ground floor vertically into the target-source complex. Moreover, with this geometry a two step ionisation could be installed more easily without hindering the line between cave 1 and the low energy experimental area.

We will investigate two cases corresponding to a one or a two step ionisation, respectively presented on fig. 2 and 3. On this two figures, the left picture presents the beam lines towards CIME and the right picture the lines towards the low experimental area. First we look at the case of the one step ionisation presented on fig. 2. The beam lines labelled ① and ② on left picture permit to send radioactive beams towards CIME from the two caves. The ions produced in cave 1 can also be sent towards the low experimental area (line ① on the right picture) in a time-sharing mode. The separator S1 permits a parallel operating mode from cave 2 with the lines labelled ②. In order to let open all the separation possibilities, the first turn must be electrostatic: no M/Q selection should be performed before the separation of two beams. Coming from cave 1 or cave 2, the beams available in the low energy experimental area consist of multi-charged radioactive ions. It is also important to note that a large part of the beam lines labelled ① on fig A1 and A2 will conduct ions in the two ways: such a possibility should be carefully studied.

The two drawings of figure 3 concern the two steps ionisation. Two places, S1 and S2, are envisaged for a separator (or even for two separators). The n+ ionisation source is placed after the first bending magnet downstream to cave 2. While the two caves can still be used to produce accelerated beams with CIME (line ① and ② on the left picture), the possibilities to obtain low energy beams are much more opened (right picture). Firstly, the cave 1 can be used on a time-sharing basis (line ①). In addition, two independent and complementary lines are proposed from cave 2, on a parallel operation basis. While the separator S1 allows to conduct multi-charged ion beams towards the low experimental area (line ②), the separator S2 will give mono-charged ions (line ③). In the first case, the separation possibilities could be limited by the fact that a rough M/Q selection is performed between the two ionisation sources. Moreover, for the second possibility, it may be necessary to install a new aperture towards the low energy experimental area. Such two steps ionisation thus offers the interesting possibility to get either mono-charged or multi-charged radioactive ion beams in the low energy experimental area.

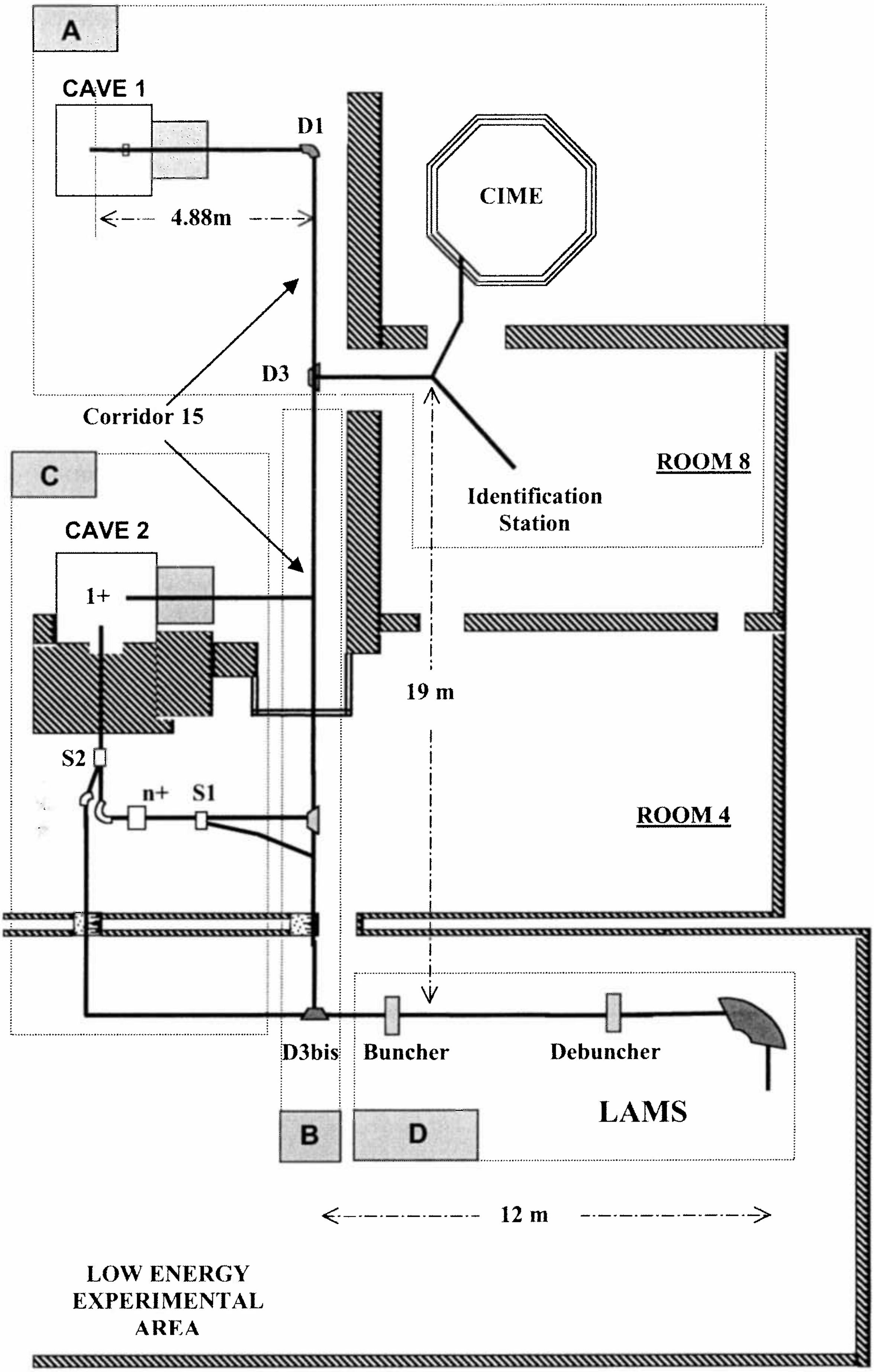
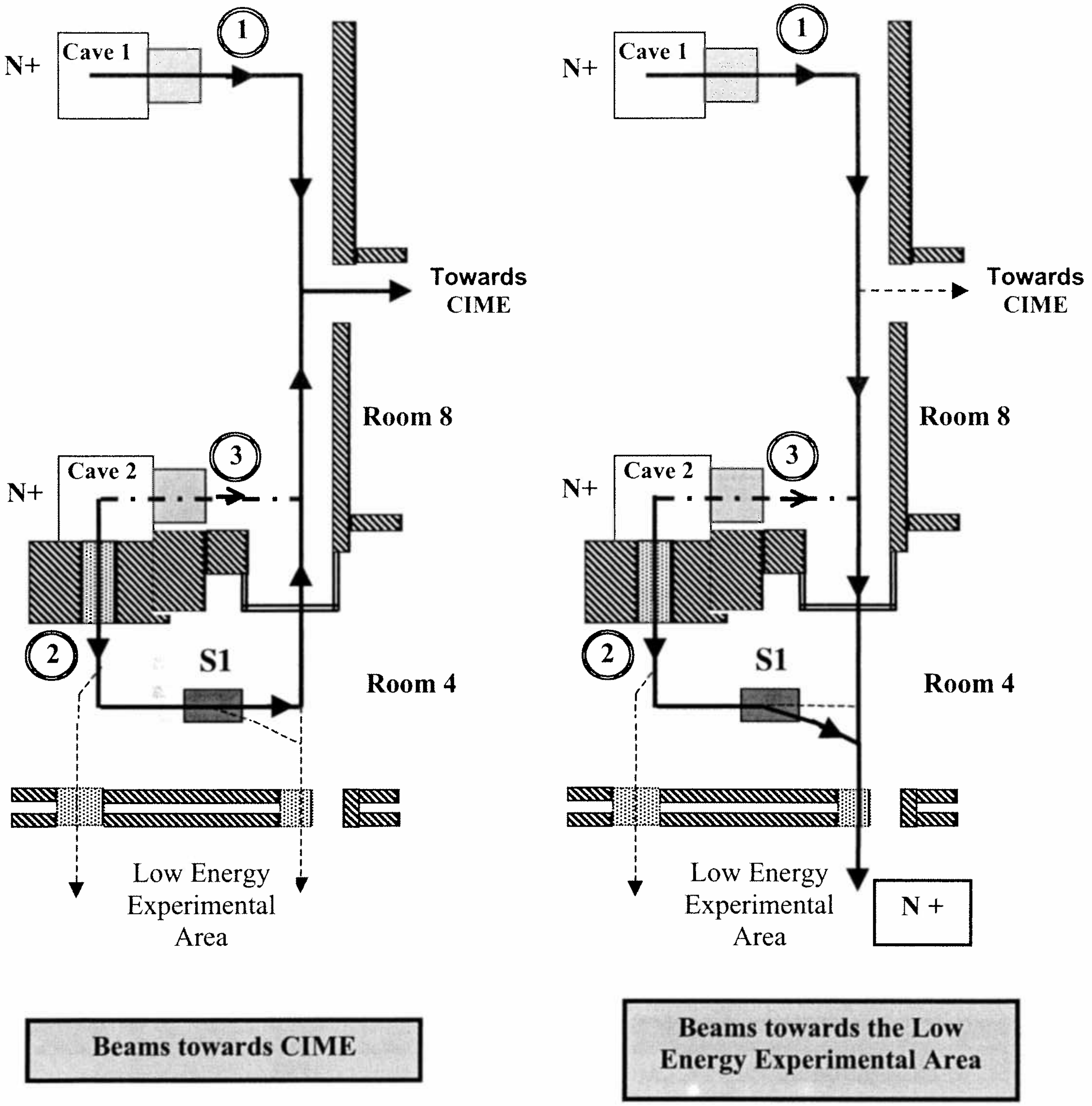


Figure 1: **Box A**: The present beam line of the SPIRAL facility. **Box B**: the simplest beam line which conduct the beam produced in cave 1 directly towards the low energy experimental area. **Box C**: the various beam lines proposed with the development of cave 2 and presented in greater detail in fig. 2 and 3. **Box D**: the location for a mass selective system discussed in part III.

One Step Ionisation from cave 2

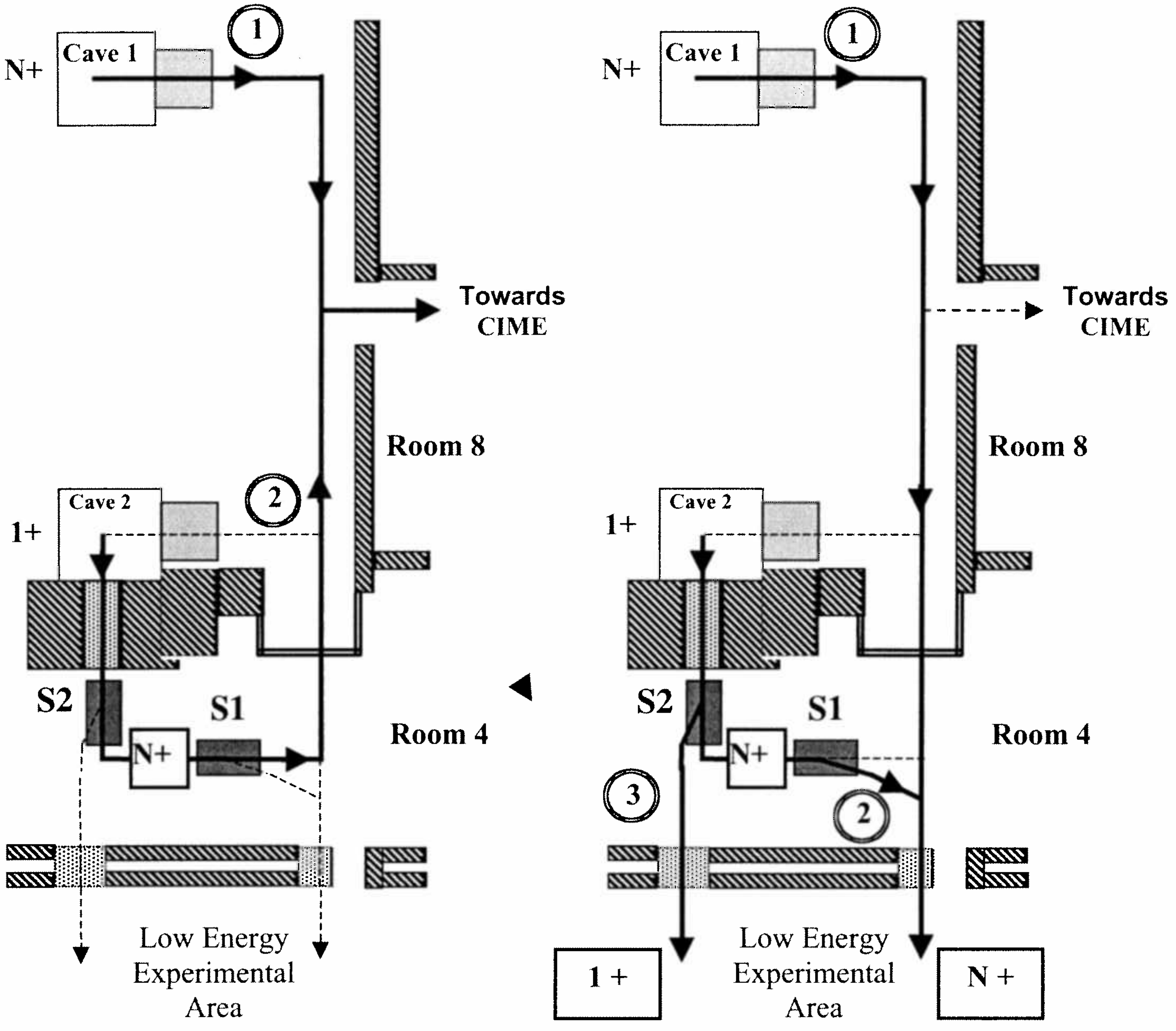


Beams towards CIME

Beams towards the Low Energy Experimental Area

Figure 2: **Beam lines towards the CIME cyclotron (left part) and towards the low energy experimental area (right part) associated with the setting up of cave 2 in the case of a one step ionisation.** On the two pictures, the beam lines ① correspond to the use of the beam produced in cave 1. The beam line labelled ③ represents the firstly proposed exit line of cave 2. In comparison with this first solution, the exit of cave 2 corresponding to the beam lines labelled ② give more space to install the separator S1. Thus the separator S1 allows to send the beam simultaneously towards CIME and in the low energy experimental area.

Two Step Ionisation from cave 2



Beams towards CIME

Beams towards the Low Energy Experimental Area

<u>Figure 3</u>: **Beam lines towards the CIME cyclotron (left part) and towards the low energy experimental area (right part) associated with the setting up of cave 2 in the case of a two step ionisation.** The 1+ ionisation source is placed in cave 2 and the n+ ECR source after the first bending magnet. On the two pictures, the beam lines ① correspond to the use of the beam produced in cave 1. On the left picture, the beam line ② send the beam produced in cave 2 towards CIME. Two locations are possible to place a separator, labelled S1 and S2, which are able to send simultaneously two beams towards CIME and the low energy experimental area On the right picture, the line ② send the beam ionised in the n+ source and separated with S1 towards the low energy experimental area. The line ③ send a 1+ beam, separated with S2, towards the low energy experimental area. These situations are complementary.

III) Beam handling and purification (Box D)

In this section, we address the problem of the beam purification for the SPIRAL low energy facility. The elimination of the contaminants is one of the basic requirements for a lot of experiments. Two types of contaminants can be considered: molecules coming from the ionisation source (example) and the produced radioactive elements, which represent no interest for a given experiment. The figure 4 considers only the second type of contaminants. These pictures present for each nucleus the resolving power R_M necessary to separate the different isobars for a given mass. A resolving power of 200 indeed allows the separation of the different masses up to A=200. The measured and extrapolated masses given by Audi in 1995 have been used to calculate the different resolving powers. The elements, which can not be extracted from the source, because of their lifetime less than 1 ms, are not taken into account. While the picture 4a does not consider any experimental tagging of the isobars, picture 4b suppose that the experimental devices allow to distinguish between proton-rich and neutron-rich nuclei. In this case, the stable elements (lifetime greater than 1 year) will not decay and are then not taken into account. It is also important to note that these resolving powers concern mono-charged ion beams. However, the choice of an adequate charge state conducts in most cases to the same needed resolving power for mono- and multi-charged ion beams. Only for some light elements with A<30, the resolving powers necessary to obtain the isobaric purity increase when using multi-charged ion beams. These two pictures show clearly that a very high resolving power is needed to get a good isobaric purity over a large range of mass.

We will discuss technical aspects and opportunities given by three kind of spectrometer: a medium resolving spectrometer ($R_{M/Q}$ # 2000), a high-resolution spectrometer ($R_{M/Q}$ # 5000) and a very high resolution spectrometer ($R_{M/Q}$ # 30000). It is important to note that we are dealing with the separation resolution, which allows a total separation of given ion species in-line with slits, and not with the analysing resolution, corresponding to a half maximum separation. To first order, the analysing resolving power is twice the separation resolving power.

Let us immediately point out that the poor beam quality, i.e. large transverse emittances, obtained with the ECR ion source currently used at SPIRAL would strongly limit the resolving power as well as the transmission of any spectrometer. We shall also remember that for a given spectrometer an increase in mass resolving power is obtained to the detriment of the transmission and reciprocally. As far as the study of exotic nuclei is concerned, the transmission is a parameter of the utmost importance in order to keep attractive the more than competitive production yields foreseen at SPIRAL. At the same time, the resolving power should permit to perform the proposed experiments with beams of sufficient purity. Thus, these two parameters, resolving power and transmission, are completely linked and should be discussed together. In the following, we assume the beam characteristics given by the ECR ionisation source presented in table 1.

A) A medium resolution spectrometer ($R_{M/Q}$ # 2000)

The construction of a medium resolution spectrometer ($R_{M/Q}$ # 2000) would represent a flexible, low cost machine for a minimal purification of the low energy beams: it would permit the elimination of a great number of contaminants, like molecules and ions having the same mass to charge ratio than the ion to study. However, the figure 4a shows that the purification would be achieved only for the light neutron rich nuclei, roughly up to Ne. The study of the decay products will allow to increase this mass selection, as shown for example by the figure 4b. For this purpose, a symmetric pair of sector magnets with a deflection of 60° and a radius of 75 cm is currently studied by F. Bocage in GANIL. A resolution of $R_{M/Q}$=2000 with a transmission of the order of 5 % of the beam emitted by the ionisation source could be expected in the case of the higher value of the source extraction voltage (34 kV). However, the energy spread of the beam produced by the ECR source will deteriorate significantly the resolution of the spectrometer, down to $R_{M/Q}$=1000 with the same transmission, when the extraction voltage of the source is near 10 kV. Moreover the increase of the radius of the bending magnets in this system represents no interest if the relative energy spread of the analysed beam is not simultaneously lowered.

We see that such a system will give very low transmission due to the poor quality of the beam obtained with an ECR ionisation source. Recently a new type of mass spectrometer has been proposed at GANIL [22]: the Large Acceptance Mass Spectrometer (LAMS). In this device, the process of mass selection consists of three steps. First, a buncher and a transfer line bunch the various kind of ions in the same phase width, with a mean phase depending on their charge-to-mass ratio. Along the transfer line, the deviation between the mean width associated to different charge-to-mass ratio is increasing due to their difference in mean energy. Then the debuncher will transform this phase difference in energy deviation, which will be further transformed into radial shifts by a standard magnetic spectrometer. A slit placed at the image focal plane of the magnetic spectrometer lastly allows to select the desired ions. To select a given M/Q, it is just necessary to change the phase of the debuncher, a much easier, faster and more reproducible operation than the tuning of magnetic dipoles as in classical spectrometer. This new kind of spectrometer presents the great advantage to accept larger emittances than the simple magnetic system. Thus, it will give the same resolution $R_{M/Q}$ # 2000 but with a better transmission, of the order of 30% for an extraction voltage of 34 kV. However, this transmission increase is obtained to the detriment of the beam energy spread and a second magnetic stage could be added to this spectrometer in order to compensate this energy spread.

B) A high resolution spectrometer (R#5000)

As we can see on fig. 4a, a mass resolving power of $R_{M/Q}$# 5000 allows a separation of the neighbouring isotopes in the region of neutron rich nuclei up to Ar, and up to Mn with an adequate experimental device (fig. 4b). This purification would open up much more opportunities than the previous proposal. We have already seen that a critical parameter is the energy spread of the beam extracted from the ECR source. Though the energy dispersion is rather small, around 5eV per charge, the extraction voltage of the source, set by the injection constraints of the cyclotron, evolves between 10 kV and 34 kV: the relative energy dispersion may then reach 1/2000 which reduced almost by a factor of two the resolution of the previously proposed spectrometer. The use of a high voltage platform of at least 60 kV for the spectrometer would strongly reduce the effect of the energy spread. The voltage of the low energy beam line could also be chosen independently of the extraction voltage of the ionisation source, which is adapted to the injection beam line of CIME. The use of a high voltage platform also permit to increase the radius of the spectrometer up to 1 m, without lowering the still weak magnetic fields, and thus its resolving power. Moreover, the combination of this high voltage platform with the availability of multi-charged ion beams would be suitable for solid state physics studies, which need higher energy for ion implantation.

While the high voltage platform will considerably lower the pernicious influence of the relative energy spread on the desired resolution, a strong reduction of the transverse emittances should also be envisaged to obtain a high transmission together with a good purification. It could also be a necessity for some specific experiments with traps and other systems like MISTRAL. For this purpose, the buffer gas cooling techniques, with for example a Radio Frequency Quadrupole (RFQ hereafter) [23], may help to obtain better optical quality for the analysed beam. Such a system would indeed drastically improve the beam transverse emittances and somehow reduce the beam energy spread. However, such a RFQ can only be applied with singly charged ions, otherwise the charge exchange processes inside the RF electric field will imply important losses. Therefore, if multi-charged ion beams are sent toward the low energy experimental area, the ions should be previously injected in a gas cell in order to be transformed in singly charged ions. The chemical mechanisms involve in such systems are not yet completely understood. Specific technical studies should be performed to obtain a realistic values of the transmissions, which could be of the order of 80% [24] for the gas cell with He gas and 70% for the RFQ. Similar systems are already developed at ISOLDE [25,26], Jyvaskyla [27] or Argonne [28]. A RFQ ion guide could be constructed at LPC Caen for a specific experiment [29], but may benefit to the whole scientific program of the low energy facility. With the characteristics of the beam obtain with a gas cell and a RFQ, and presented in table 2, the previously proposed magnetic spectrometer will give a resolving power greater than $R_{M/Q}$ # 5000 with 100% of transmission, and will no longer be limited by the beam energy spread. The overall transmission is then completely given by the charge exchange cell and the RFQ, of the order of 50% with the previously given estimation. It is also recommended to keep the possibility to use n+ beams in the spectrometer, by removing the gas cell and unplugging the RFQ, since some experiments would prefer the use of multi-charged ions at the expense of beam purity or transmission.

Transverse Emittances:	$E_H = 5$ π.mm.mrad $E_V = 5$ π.mm.mrad
Energy spread:	$\Delta W = 1$ eV
Extraction voltage of the RFQ	$U_{source} \geq 60$ kV
Charge State:	1+

Table 2: *Beam characteristics obtained after the charge-exchange cell and the RFQ and analysed by the spectrometer.*

C) A very high resolution spectrometer for SPIRAL ?

The previous system can still be improved by adding a second stage to make achromatic the whole system. This second stage is either electrostatic or magnetic biased at a voltage different from the first stage. Any way, such system would not reach a resolving power sufficient for the isobaric separation up to mass 100. For this purpose, two powerful beam lines are currently studied which are planed to reach a resolving power R_M # 20000-30000, EXCYT in Catania [30] and the Japanese Hadron Project [31]. This resolution guarantees the isobaric separation only for exotic nuclei near the neutron and proton drip-lines (see fig. 4b). Such complex systems would not fit in the GANIL building and a new area should be constructed. A more compact system could be envisaged: a Penning trap could at the same time purify the beam up to R_M # 10^5 and perform a cooling with the buffer gas method. Unfortunately, this purification is achieved by bunching a monocharged beam, which is not suited for all kind of experiments, especially for decay studies.

Besides, let us underline that the cyclotron CIME can performed a good purification of any beam with a high transmission. By itself, in the isochronous mode, the CIME cyclotron is a medium resolution separator (R_M=2000), and the elimination of remaining isobars can be achieved by using a stripping foil located upstream from the Alpha spectrometer. The global transmission of the line will be then, in this case, of the source to the exit of the Alpha spectrometer, of about 1/5 or 1/10 depending of the energy and of the mass of the nucleus. It is also possible to tune the cyclotron to eliminate a given contaminant during the acceleration: by detuning the correction coils, an isochronism fault can be introduced and a resolving power of R_M # 6000 can be expected with lower extraction efficiency. Moreover, with CIME it is also possible to separate off-line two ions species. Indeed two ions with different mass to charge ratio experience a phase shift during the acceleration stage, and the use of the RF signal of the cyclotron allow to tag different events with the time-of-flight. A maximum resolving power of R_M # 50000 can be expected [32].

Figure 4a

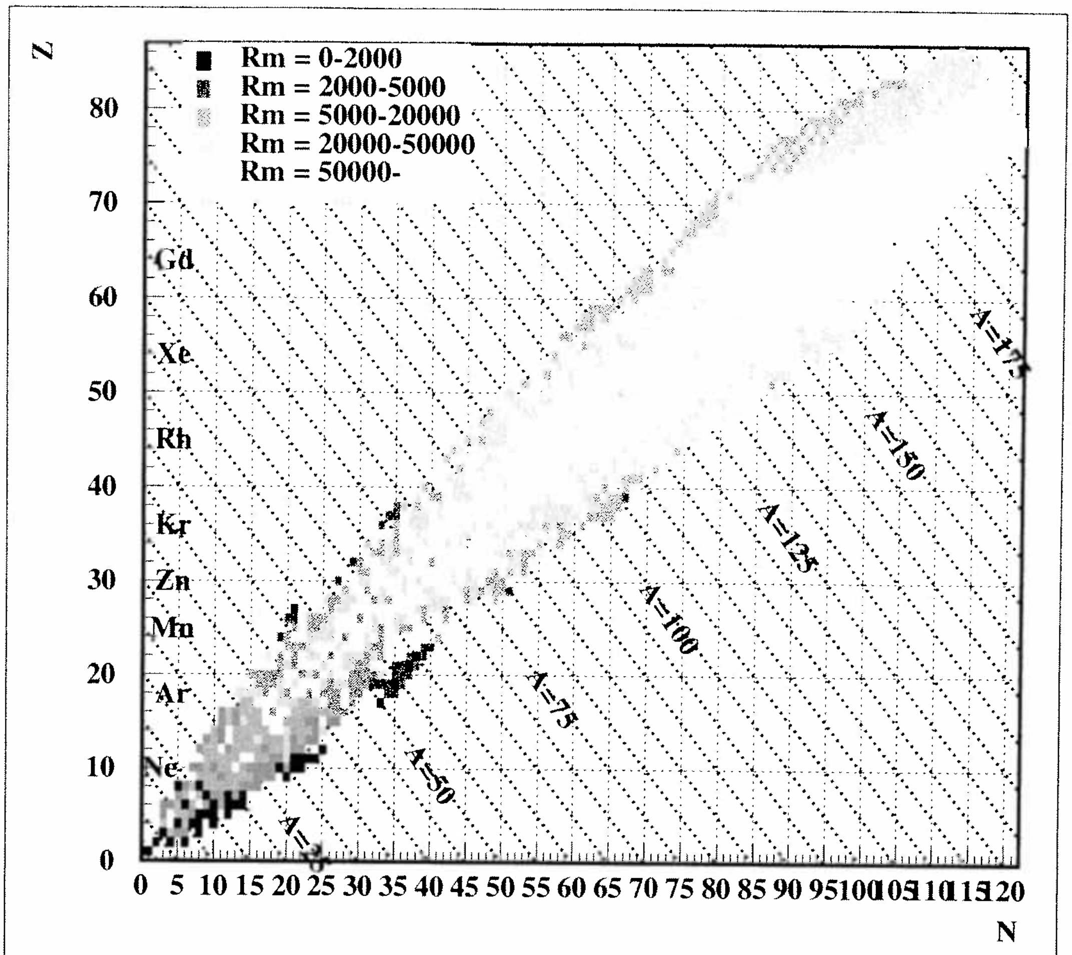
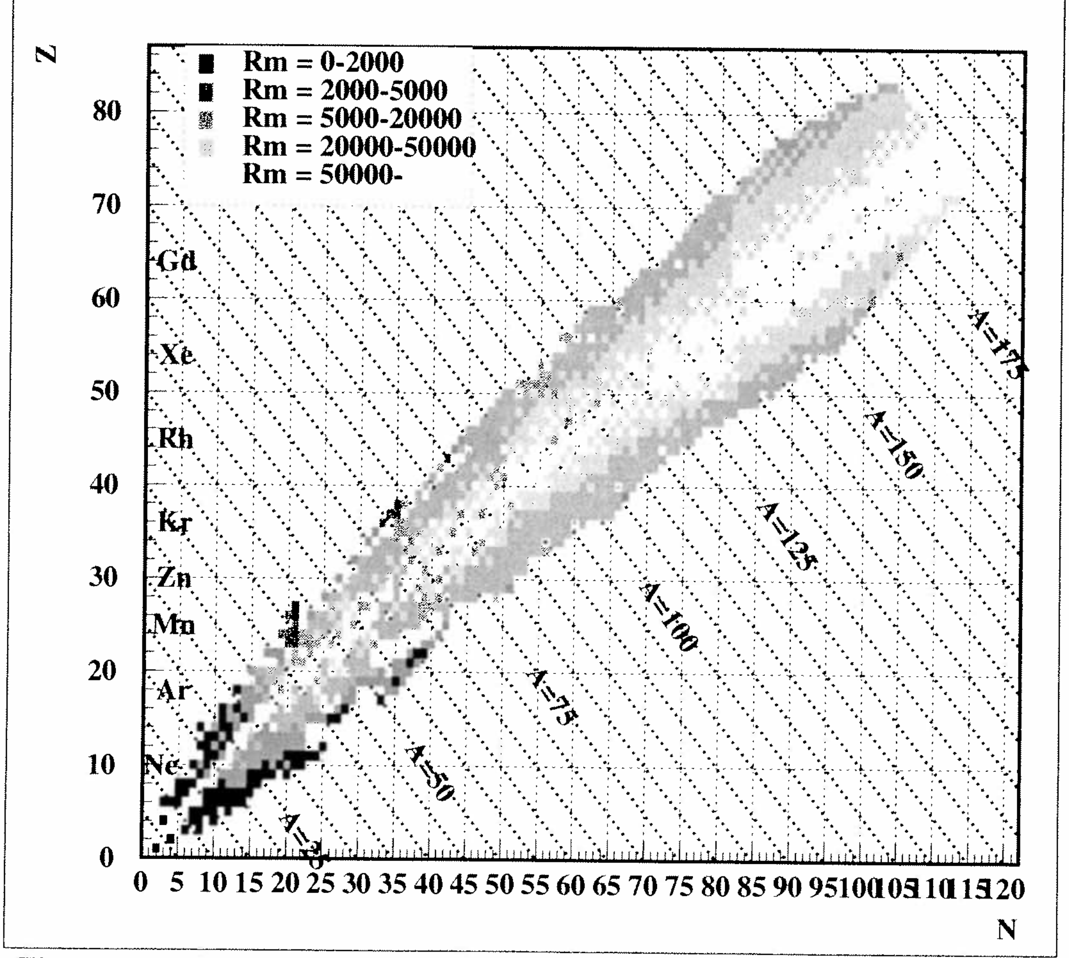


Figure 4b



<u>Figure 4</u>: **Resolving power needed to obtain an isobaric purity for a given nuclei.** The mass, measured or extrapolated, have been found in the tables published by Audi in 1995. The nuclei whose half live is less than 1 ms have not been taken into account. In the picture 4b, we additionnaly assumed that the experimental device allows to distinguish the neutron-rich, proton-rich and stable nuclei.

CONCLUSION

In this document, we investigate the implantation possibilities for a Low Energy facility at SPIRAL. This line would allow the use of the radioactive ions produced in the target-source ensemble of SPIRAL without the cyclotron CIME. We suggest to locate the Low Energy experimental area in the basement of the new building dedicated to the storage of the irradiated source components. In the public inquiry context, it has been judged unreasonable to carry out important modifications of the cyclotron injection beam line. We thus propose to undertake the construction of a simple transport section for the low energy beam line from cave 1 to the proposed experimental area situated in the basement of the new building. This beam line allows a time-sharing operation with the CIME beam line and may be reasonably installed during 2001. It seems very likely that the equipment of cave 2 will be performed in the case of a two step ionisation, within the 1+/n+ project. We thus propose to complete the previous line as shown in figure 3. Moreover, the installation of two separators (S_1 and S_2 on fig. 3) is particularly effective because it would provide at the same time a mono-charged and a multi-charged beams towards the low energy experimental area, and simultaneously with a beam accelerated by CIME. All these installations, fitting up of cave 2 and associated beam lines, could be performed in 2003 and could be later used within the SPIRAL-Phase 2 project.

This facility, in order to become attractive, has to perform a minimum purification of the exotic beams. Therefore, we propose the construction of a "general purpose spectrometer" useful to the whole physics program. The required resolution is still a matter of debate that is why we considered two systems: the first one is a LAMS spectrometer ensuring a mass resolving power of $R_{M/Q}$ # 2000 with a good transmission. A more powerful beam line could be envisaged in order to reach a resolving power of $R_{M/Q}$ # 5000. Such resolution could hardly be obtained with the emittances given by the ECR ionisation source without important intensity reduction. Therefore, it would be necessary to strongly reduce these emittances by means of a radio-frequency quadrupole. Such a RFQ can only be applied with singly charged ions, which can be obtained by injection of the multi-charged ions in a gas cell. However, this solution would need a strong effort of research and development. Because of the available space in the existing building, we have not considered the construction of a very complex beam line like EXCYT[30] in order to reach $R_{M/Q}$ # 30000. More compact system like Penning traps for cooling and mass selection would lead to $R_{M/Q}$ # 10^5, but would need a separate technical study.

The authors thanks warmly B. Bru, A. Chabert, W. Mittig, C. Ricaud, M.G. Saint-Laurent and A. Villari for fruitful discussions.

ANNEXE

A) The beam transport section

- Length of the beam line: L =19 m
- Civil engineering: widening of the door to access the new building.
- Main components:
    - 1 pulsated sector magnet ($\phi=90°$, $\rho=50$ cm)
    - 6 magnetic quadrupoles
- Cost: 4.8 MF (0.68 M€)

B) The spectrometer section

Location: basement of the building dedicated to the storage of irradiated source components

1) the medium resolution system

- Objective: producing an mass separation ($R_{M/Q}=2000$ with 5% of transmission)
- Length of the beam line L =12 m
- Main components:
    - 1 sector magnet ($\phi=90°$, $\rho=50$ cm): D3 can be used
    - 1 hexapole
    - 4 magnetic quadrupoles
    - 2 sector magnets ($\phi=60°$, $\rho=75$ cm)

- Cost: 5 MF (0.7 M€)

2) Large Acceptance Masse Spectrometer

- Objective: producing an mass separation ($R_{M/Q}=2000$ for 30% of transmission)
- Length of the beam line L =12 m
- Main components :
    - 1 sector magnet ($\phi=90°$, $\rho=50$ cm): D3 can be used
    - 1 buncher
    - 1 debuncher
    - 1 sector magnet ($\phi=90°$, $\rho=50$ cm)

- cost : 4 MF (0.57 M€)

3) The high resolving power beam line with charge exchange cell and RFQ ion guide

- Objectives:
    - n+ -> 1+ transformation with a gas cell
    - emittance reduction with a RFQ ion guide
    - producing an mass separation ($R_{M/Q}=4000$ for 5 π.mm.mrd)
- Length of the beam line L =14 m

- Main components:

1 pulsated sector (ϕ=90°, ρ =50 cm): D3 can be used
1 High voltage platform 60 kV
1 hexapole
2 magnetic quadrupoles
1 charge exchange cell with dedicated pumping system
2 magnetic quadrupoles
1 RFQ ion guides with differential pumping system
3 magnetic quadrupoles
2 sector magnets (ϕ=60°, ρ =1 m)

- Cost: 7 MF (1 M€)

REFERENCES:

SPIRAL Phase-I-:

[1] The SPIRAL radioactive ion beam facility, technical report, GANIL R/94/02
[2] The SPIRAL project at GANIL and future opportunities, W. Mittig, GANIL P 98-07 International Workshop on Physics with radioactive Nuclear Beams, Puri, India, January 12-17, 1998
[3] Radioactive ion beams at SPIRAL, A.C.C Villari et al., Nuclear Physics A588 (1995) 267, 1995
[4] L. Maunory, Phd Thesis, GANIL T 98-01
[5] N. Lecesne, Phd Thesis, GANIL T 97-08
[6] ECR development for accelerated radioactive ion beams, A.C.C. Villari, GANIL S 96-07 Nuclear Instruments and Methods in Physics Research B126 (1997) 35-44
[7] Ion source developments for stable and radioactive ion beams at GANIL, R. Leroy et al., GANIL S 99-01, 14th International Workshop on ECR Ion Sources, ECRIS 99, CERN, Geneva, Switzerland, 3-6 May 1999

1+/n+ system:

[8] 1+/n+: B. Vignon, in international workshop on research with fission fragments, World Scientific, Singapore 1997, p 7
[9] La transformation 1+ → n+: résultats et perspectives, N. Chauvin et al., rapport interne ISN 99.112, Novembre 1999
[10] The 1+/n+ solution for SPIRAL, A.C.C. Villari , Nouvelles du GANIL 60 (1997) 17.

SPIRAL Phase-II-:

[11] J. Nolen, 3rd International Conference on Radioactive Nuclear Beams, D.J. Morissey (Ed.), Editions frontières, Gif-sur-Yvette, 1993, p111
[12] SPIRAL Phase-II: a R&D program investigating the optimal conditions for producing neutron-rich radioactive beams by fast neutron induced fission, M.G. Saint-Laurent, Nouvelles de GANIL n°65, juillet 1999, p.9
[13] D. Ridikas, Phd Thesis, GANIL T 99-05
[14] RIB production with high energy neutrons from Be(d,xn) reactions, D. Ridikas, W Mittig, GANIL preprint P98-22

Low-energy facility project:

[15] A low energy facility for SPIRAL. G. Auger, B. Blank, C. Le Brun: Scientific Commitee
[16] TONNERE: report to the Scientific Council of GANIL, N. Orr, May 1998
[17] T. Martin, Phd Thesis, LPCC
[18] EXOGAM: F. Azaiez, Nouvelles du GANIL n°60, p.4
[19] La station d'identification Basse Energie, B. Launé, Nouvelles du GANIL 60 (1997) 25.
[20] B.Jacquot, A Chabert: Rapport technique .....

Beam handling and purification

[21] The Mistral Project , conf. on Atomic physics with stored hygly charged ions, published in hyperfine interactions (1996) vol 99, no 1-3 p 105-114
[22] A.Chabert, Ch. Ricaud, B.bru, NIM A351, p 371-377
[23] M.D. Lunney et al, J.Mod. Optics, 39 (1992) p 349
[24] H.Backe et al., NIM B 70 (1992) 521
[25] G. Bollen et al, Proc of the 2nd Int. Conf. on exotic nuclei and atomic masses (EMAM98)

[26] M.D. Lunney et Al., CSNSM internal repoprt 97-02 (1997) unpublished
[27] Status report of the Jyväskylä ion guide isotope separator on-line facility, H. Penttilä et Al., NIM B126 (1997) 213-217
[28] G. Savard et al., Nucl. Phys. A626 (1997) 353
[29] J. Szeripo, LPC CAEN, rapport interne
[30] Ciavola et al, NIM B126 (1996) p 258-261
[31] H. Sunaoshi et al., NIM B 70 (1992) p 421-426
[32] A.C.C. Villari, NIM B 126 (1997) 35-44