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THE SPIRAL PROJECT AT GANIL AND FUTURE OPPORTUNITIES

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Abstract

The present status of the project SPIRAL under construction at Ganil is described. Some of the specific future experimental devices such as Exogam and Vamos are shown. Future possible extensions of the SPIRAL project and, more generally, high intensity RIB-facilities are discussed

I - INTRODUCTION

The systematic and very successful use of high energy fragmentation at GANIL, the first operational high intensity heavy ion accelerator in the 50-100 MeV/nucleon domain, for exploring the structure of nuclei far from stability triggered the question how to proceed even further in this domain. Essentially two technical possibilities were considered

1) Increase of energy

As can be easily shown (ref. 1), the yield of nuclei by fragmentation and purified by a magnetic spectrometer of limited acceptance will increase as $E^{3.5}$, where E is the energy of the beam per nucleon. So increase of energy from 100 MeV/nucleon to, for example, 400 MeV/nucleon would give an increase of yield of about 2 orders of magnitude. This could be realised technically by adding a new cyclotron, CSS3 (ref. 2).

2) Fragmentation of the heavy ion beam in a thick target

In this case, the collection efficiency is 100 % and the target can be as thick as the range of the beam. The yield with respect to the selection by a magnetic spectrometer is increased by 2-3 orders of magnitude typically. However the energy of the products is zero, being stopped in the target, and they must be extracted from the target. If the objectif is to use them as secondary beam, the products must first be ionized and extracted. This is the well known ISOL method pioneered by CERN-Isolde. Then the ions have to be accelerated to the energy needed for the domain of physics to be studied. So an Isol-system plus an accelerator is needed.

The discussions of the physics that could and should be studied, showed that the main interest of the community involved was in the following fields :

- Coulomb excitation
- Spectroscopy by transfer reactions (d,p), (t,p), ...
- Fusion-evaporation + γ spectroscopy
- Near barrier physics with radioactive beams
- Astrophysics

These subjects are corresponding to a best energy range of 1-20 MeV/nucleon. This is why the second possibility was chosen and took a final form (ref. 3) as the project «SPIRAL», that will be described in the next chapter.

Even higher intensities are desirable for studying reactions induced by radioactive beams. Possible future developments will be discussed in chapter III.

II - THE SPIRAL PROJECT

The introduction of the acceleration of an ISOL-produced RIB in the context of the existing GANIL accelerator is shown on fig. 1 and can be seen in the upper right part of the figure. The beam of the second cyclotron CSS2 will hit a thick target incorporated in the ion source. This is the most critical part of the SPIRAL project. The ion source produces a charge state sufficiently high to accelerate directly the extracted beam by a conventional cyclotron. We will describe these two parts in some more detail below.

1) the Ion Source

The ion source of an ISOL system is quite problematic, due to the high power deposited by the beam, chemical properties of the wanted radioactive ions with respect to target and container materials and the location of the ion source in a hostile environment. This is qualitatively illustrated by fig. 2, that shows the schematics of the production and extraction of an ISOL beam (from ref. 4).

figure 1: General overview of the GANIL facility. In the upper left of the figure, the different accelerators producing the primary beam of up to 100MeV/nucleon are shown. In the upper right, the future SPIRAL for the acceleration of radioactive ISOL beams can be seen. In the lower part, the experimental areas are shown.

figure 2:
Schematics of the
ISOL-production
ion source system
(from reference 4)

In the actual SPIRAL project the beam power is limited to 6kW. This corresponds for example to about $2 \cdot 10^{15}$ particles/s for a ^{13}C beam. Such a high intensity implies strong activation of the target and ion source material and special care must be taken to keep the ensemble easy to dismount, dismantle and dispose.

Highest secondary beam intensities that may be expected are in the 10^8 particles/s range. At the beginning noble gases will be produced, He, Ne, Ar, Kr because they easily diffuse out of the target and are very efficiently ionised in an ECR-source that provides the high charge states necessary for acceleration.

Other chemical elements are much more difficult to produce with high efficiency. Actually two schemes are investigated for producing them.

One is to have the production target near the plasma of the ion source, and avoiding in this way the long sticking times in the transport tube connecting the target and the ion source. Very promising results have been obtained using the ion source Shypie (ref. 5).

Another way to produce high charge states was initially proposed for the PLAFÉ project (ref. 6). In this scheme a simple ion source (for example using surface ionisation) produces a beam of 1^+ ions. These ions are slowed down to some eV and injected in the plasma of a high quality ECR source, where they are bred to a high charge state. A strong R&D program is underway on this subject in collaboration between GANIL and Grenoble.

The working diagram of the Cyclotron CIME of the project SPIRAL is shown on figure 3. As can be seen, it is well watched to the physics program as defined in the introduction. At the moment (january 98) the ion source is completed and a stable beam of ^{18}O was successfully accelerated in the CIME cyclotron for the first time in dec. 98. First radioactive beams are sheduled for end 98.

As a future extension of the beams furnished by SPIRAL, deuteron induced fission products are a very interesting possibility. In order to decouple the beam from the production target, Argonne proposed (ref. 7) to use for exemple a Be target to convert the deuteron beam to a neutron beam, and the neutron beam induces the fission in a thick U-target. In order to estimate the potentiality of this method we performed calculations (ref. 8) using the LAHET code, that reproduces well the experimental results obtained at MSU with a 200 MeV deuteron beams (ref. 9). The d-beam produces 0.4 neutrons per deuteron at very forward angles. Let's consider ^{132}Sn as secondary beam. The probability that a 100 MeV neutron produces a ^{132}Sn in a 380 g/cm^2 U target is $3 \cdot 10^{-3}$. So with a 6 kW deuteron beam of 200 MeV compatible with the existing characteristics of GANIL, we expect an in target production of $2 \cdot 10^{14} \cdot 0.4 \cdot 3 \cdot 10^{-3} = 2.4 \cdot 10^{11}$ ^{132}Sn /s. This shows that a 2 to 3 orders of magnitude increase of secondary beam intensity is possible with respect to

figure 3: The working diagram of the CIME- cyclotron of the Spiral facility

the intensities expected from fragmentation of the target and/or the heavy ion beam.

It is instructive to compare this number to the one that is expected for reactor induced fission. Supposing 10^{14} fissions/s that produce a heat of 3 kW (already a quite high value for an ion source in the reactor core environment) and a fission probability leading to ^{132}Sn of $7 \cdot 10^{-3}$, an in-target yield of $7 \cdot 10^{11}$ ^{132}Sn /s is expected, this is the same order of magnitude as in the preceding case.

In order to compare different methods, it is important to take into account the efficiency of the ion-source, that may reduce considerably the final beam intensities, and may limit realistic maximum intensities as will be discussed in the next chapter.

III - FUTURE « *REALISTIC* » INTENSITIES

A significant increase of the intensities of RIB's will certainly open the access to new domain of physics. In this context, in the US there is a working group on a possible future IsoSpin Laboratory. A NUPECC working group was constituted in October 97, with R.H. Siemssen as chair person in order to prospect future possibilities for radioactive beams.

We may consider that it will be possible to use beams of several MWatts, that is about 3 orders of magnitude more than used at the moment in ISOL and fragmentation of the beam facilities, that are all below the 10 kW power limit. (Louvain 6 kW, Cern-Isolde 1-2kW, Ganil 6kW scheduled, Riken <10 kW scheduled, MSU < 4 kW scheduled, ...). However, proton beams of 150 kW are already available at the Rutherford Appleton Laboratory and more than 1 MW at PSI.

R&D to develop high intensity beams of several MW is in progress actually, partially stimulated by the projects of hybrid reactors (ref. 10).

However, increase of beam intensity not necessarily increases the intensity of a secondary RIB's, as was demonstrated by reference 11) and as is illustrated by figure 4.

If the target is cooled by black body radiation, the maximum admissible power increases as the surface, this is, as R^2 . However, the effusion efficiency, depending on the live-time, decreases with the radius. So finally the maximum yield will be obtained for a limited power as illustrated in figure 5 for ^{28}Ne . This shows that there may be quite severe limitations with respect to the admissible power on a target. This will be discussed below, as well as possible tricks to avoid these limitations.

figure 4: Expected ^{28}Ne intensities, as function of the ion source radius, that determines the maximum admissible power if black body radiation cools the target (from reference 11).

1) Direct Methods

We may illustrate different direct methods to produce secondary beams on figure 5.

1) ISOL

The first is the ISOL method, pioneered by CERN-Isolde. As already discussed, it seems difficult to go much above the 10 kW limit of power deposited in the target. The highest value is at the moment ~ 20kW for the RIST-target, tested thermally by heating (ref. 11).

2) Fragmentation

3) Reactors

figure 5: Direct methods for the production of RIB's

The second method is the production of nuclei far from stability by high energy fragmentation of heavy ion beams as pioneered by Berkeley, and extensively used with high intensity beams at GANIL, Riken, MSU and GSI. Highest power densities on target were obtained at GANIL, with up to 1 kW and a spot of 0.2 mm radius, which results in power densities of the order 100 kW/cm³.

There seems no fundamental problem to produce beams of several hundreds of kW, with a bigger focus than for the SISSI-device, and a fast rotating target. Hence in this device the main limitations will be the maximum beam power of the accelerator, and eventually radioprotection problems, that become of major importance at very high intensity.

The 3rd method is based on thermal neutron induced fission, as in the Piafe project (ref 12). Here the target ion-source assembly will have more or less the same power limitations as in the first case, in an even more difficult environment, the source being situated near the center of a high flux reactor. If one takes as an upper limit 10kW, this corresponds to $3 \cdot 10^{14}$ fissions/s. Most favorable branching ratios are in the 1% domain. This leads to an in-target production of $3 \cdot 10^{12}$ /s, this is, intensities comparable to primary beam intensities. However, this yield will be reduced strongly (typically by 2 orders of magnitude or more) due to losses during the transport of the particles from the inside of the reactor to the external accelerator, leaving none the less of the order of $3 \cdot 10^{10}$ particles/s, unreached intensities at the moment.

2) Combined Methods

The considerations above suggest that it might be promising to look for more complex methods, with the main aim to decouple the heat and/or radioactivity produced by the beam from the ion source that produces the RIB. The ones known to the author are schematized on figure 6. Others may be imagined in future. In the methods 1) and 3) on figure 6 the beam heat is decoupled from the ion source, and it should be possible to have beam powers of more than 100kW. Radioprotection/security will become of major importance, however one should

remember that beams of several hundreds of kW are routinely handled at the Rutherford-Appleton and the PSI laboratories. The fragmentation of secondary beams (method 2) is qualitatively different from the two other methods. It uses the fact that the fragmentation process has a memory of the entrance channel, and starting from projectiles far from stability will produce higher yields far from stability. Comparing, for example Zr yields from a stable ^{124}Sn to a radioactive ^{132}Sn beam, an increase of the yield of very neutron rich isotopes by two orders of magnitude is predicted from standard programs such as Intensity or Lise in favor of the neutron rich beam. This factor is not sufficient to compensate the intensity loss for the radioactive beam with respect to the stable beam, it may however give a much higher purity of the ternary beam, that may be essential for a lot of experiments. The predictions of the standard programs should be verified in some selected cases.

1) «Argonne» Method

2) Fragmentation of secondary Beams

a) high energy double fragmentation

b) reacceleration and fragmentation of fission products

3) Light (neutron rich) Fragments /ISOL

figure 6: Combined methods for the production of RIB's

IV. Experimental equipments

For a given experiment, the final useful number of particles detected is the product of the incoming beam intensity and the detection efficiency of the experimental device. Hence the optimisation of the detection device is as important as the intensity of the incoming beam. At Ganil, two major equipments will be constructed: Exogam and VAMOS, that will be described shortly below.

1) Exogam

γ -spectroscopy is a well established tool for nuclear spectroscopy. In the present context, the most important properties needed are: high resolution in order to have a quantitative information with a low number of counts; high detection efficiency; reasonable granularity in order to correct for Doppler shift. The optimisation of these constraints lead to the project Exogam. It consists of 16 Ge-clover detectors, with a total photo-peak efficiency of 20%. The device is illustrated in figure 7.

figure 7: A schematic view of the γ -detection device Exogam

2) Vamos

Present studies of properties of nuclei far from stability are in most cases related directly to the incident particle; hence the identification of the incoming particle is sufficient. Only few studies have been performed on well defined reactions induced by the RIB's. Mostly these are studies of elastic, inelastic, charge exchange reactions, knock-out (see for example the contributions of P.Roussel -Chomaz and N. Alamanos to this workshop). In the case of reactions near the barrier, quite a lot of reaction channels will be open and lead very often to unknown nuclei. So the efficient tagging of the reaction becomes very important. This is why a new type of spectrometer was designed and will be constructed for beams from Spiral.

This spectrometer associates a very high solid angle (100msr), with a variable optics: the spectrometer can be operated with the Q-poles powered only, giving a non-dispersive collection of reaction products, such as in the SOLENO device at Orsay. It can be operated in the combination of Q-poles with a dipole, and will work as a classical dispersive magnetic spectrometer. A small Wien-filter may be operated with the Q-poles, and will act as a velocity filter; adding the dipole, will allow to work as a mass-spectrometer. This is why it was named VARIABLE MOde high acceptance Spectrometer, VAMOS. The device is illustrated in figure 8.

figure 8: The high acceptance variable mode spectrometer VAMOS

3) Polarised H-D target

A polarised spin target is another important project for the study of spin-orbit interactions far from stability and as tool for transfer reactions, inelastic scattering,... The energy domain of Spiral and Ganil imply the development of thin ($1\text{-}10\text{mg/cm}^2$) solid H-D targets. A description of this project, using the frozen spin technique, can be found in reference 13.

V. Conclusion

The Spiral project of Ganil is scheduled to deliver first radioactive accelerated beams at the end of 1998. New detection devices such as Exogam and Vamos, will help to use most effectively these low and intermediate energy RIB's. This project, and other existing facilities such as Louvain la Neuve, or under construction such as Cern-Rex-Isolde, will deliver beams that will not overpass, except rare cases of beams very near stability, intensities of $10^8/\text{s}$. This allows to study cross-sections down to a level of 10mb . This corresponds to dominant reaction channels. Future extension of the present facilities such as Spiral 2, or the construction of new facilities, such as or similar to the the projects Piafe, Argonne, or other projects implying beam powers in the MW domain, should allow to reach intensities of the RIB's in the domain of 10^{12} particles/s, and thus the study of cross-sections down to the μb level. This would represent another important step in this quickly evolving domain.

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