A RADIOACTIVE ION BEAM FACILITY AT LOUVAIN-LA-NEUVE

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Introduction

In the fall of 1987, the Belgian Government approved funding for an interuniversity collaboration project (involving the Université Libre de Bruxelles, the Katholieke Universiteit Leuven and the Université Catholique de Louvain) for the production and acceleration of Radioactive Ion Beams and their use in a series of experiments in the field of Nuclear Astrophysics.

The facility will use the two cyclotrons and experimental facilities existing at the Centre de Recherches du Cyclotron of the Catholic University in Louvain-la-Neuve. The total budget allocated to the program over a period of five years (1987-1991) amounts to 67 Million Belgian Francs (~ 1.8 M US$ - June '88).

Short lived isotopes occuring in the hot CNO cycle such as ^{13}N, ^{15}O, ^{18}F, ^{19}Ne will be produced with the prototype, high intensity isotope production cyclotron CYCLONE 30, extracted from the target and transported to an ECR source specially designed for the efficient production of low charge state ions (1^+, 2^+). The ions from the ECR source will then be injected axially into the multiparticle, variable energy cyclotron CYCLONE for acceleration to energies in the range of a few hundred keV per a.m.u. This paper describes the general facility layout and the development status of the different subsystems.

Facility description

A schematic view of the overall facility is shown in figure 1. CYCLONE 30 [1,2], is the prototype of a new kind of radioisotope production cyclotron, designed and built by the Centre de Recherches du Cyclotron and Ion Beam Applications Company. It accelerates H^- ions up to a maximum energy of 31.5 MeV with a total design intensity of 500 μA. The beam is extracted at variable energies between 15 and 31.5 MeV by remotely positioned carbon stripping foils and directed on external targets for the production of large amounts of radioisotopes.

CYCLONE[3] is a versatile, multiparticle, variable energy isochronous cyclotron used for nuclear physics and chemistry, radiobiology, neutron- therapy,... Its energy constant K equals 120 MeV (maximum proton energy = 90 MeV). It is equipped with both internal ion sources and an external ECR-source, OCTOPUS, for high charge state heavy ions.

Both cyclotrons are installed in adjacent vaults separated by three meters thick wall.

The proton transport line

The high intensity (350-500 μA) proton beam will be transported to a target located in the shielding wall between the two cyclotrons. This beam line is rising under an angle of 32 °, to allow the installation of the target at approximatively the height of the low energy transport line to CYCLONE and to direct the neutron flux behind the target mainly towards the opposite thick shielding wall, away from the existing beam transport system. The transport line consits of a doubly focusing, 90 ° bending magnet and a movable quadrupole doublet (to accomodate for the displacement with energy of the virtual object from CYCLONE 30) refocusing the beam on target.

Targetry

General considerations for a suitable target can be listed as follows :

- a high production yield under proton bombardment.
- the diffusion time of the radioactive product in the target material should be quite shorter than the mean nuclear lifetime.
- the target should stand the maximum intensity of the 30 MeV cyclotron, namely I_p = 500 μA, without breaking or

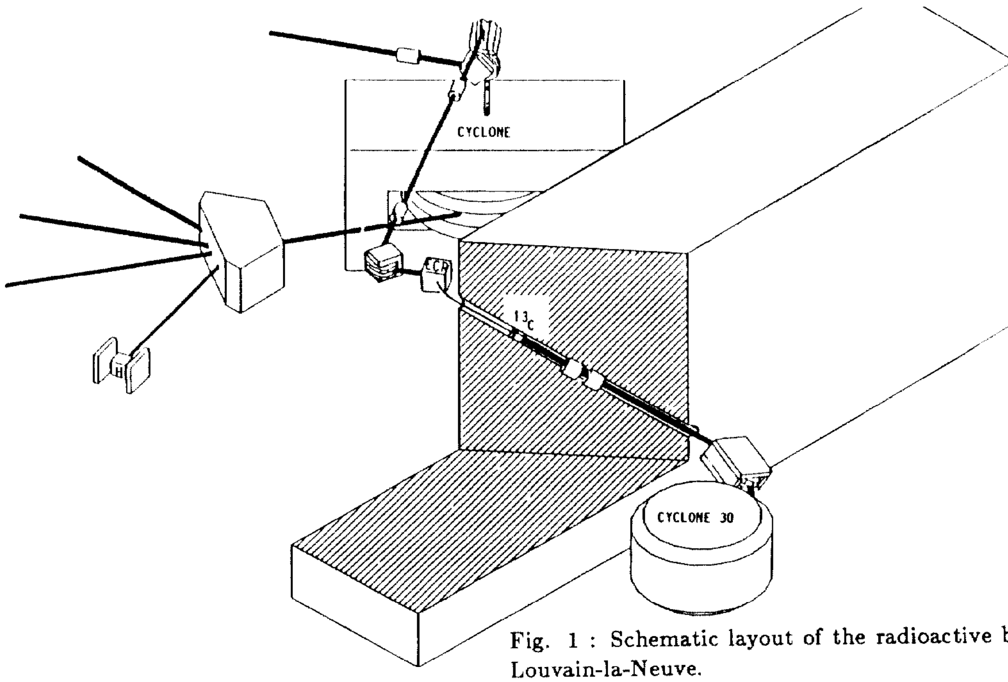

Fig. 1 : Schematic layout of the radioactive beam facility at Louvain-la-Neuve.

simply evaporating in a too big quantity, the admittance limit of the E.C.R. source being 1 scc/h. The beam power (~ 15 kW) must be dissipated by conduction and/or radiation, this fact excluding the use of a powder target.

- the highest yield is obtained with a single isotope target without chemical or isotope mixing.
- the selected target should not contain elements producing long term radioactivity.
- furthermore it should be available and easily feasible in the desired shape and structure.

The $^{13}N(p,\gamma)^{14}O$ reaction was choosen as the first to be studied. The required ^{13}N atoms can be obtained with high yield by the $^{13}C(p,n)^{13}N$ reaction using a graphite ^{13}C target. A series of experiments are under way to develop a target, able to stand the beam power and to access the extraction yield and transport efficiency to the ion source.

Until now only natural graphite was used in two different targets. In the first one, a graphite disk of 25 mm diameter and 5 mm thickness is placed in a graphite cylinder, itself surrounded by a water-cooled cylinder. In order to prevent the produced elements from being pumped by the cyclotron, the target is preceeded by a 5 μm thick molybdenum foil. This foil is itself protected against the target heat radiation by a 0.5 mm thick graphite thermal screen.

In the second target, the graphite cyclinder is removed and the steel cylinder replaced by copper, in order to decrease the overall target temperature. The target thickness is 5 mm and the diameter is 40 mm.

A maximum yield of 46 % has been obtained up to now. It was found that almost the whole activity comes out of the target as $^{13}N\,^{14}N$ molecules. Therefore, the use of some amount of "sweeping" N_2 gas will be provided to enhance the extraction from the target. However, a pure ^{13}C graphite target is not readily available, and has still to be made.

Another possibility would therefore be to use a (readily existing) BeO target, with the $^{16}O(p,\alpha)^{13}N$ reaction. However, the total yield at 30 MeV is about six times lower. On the other hand, no ^{13}C contamination in the extracted gas is to be expected.

The ECR-ion source

Since astrophysical reactions occur at low energies, low (1^+, 2^+) charge states suffice for acceleration of the elements under consideration in CYCLONE. These will be produced in an ECR-source, specially designed for high ionization efficiency.

The ECR-source layout is shown in figure 2. Similar to a source developed by V. Bechtold[4], it is a single stage source operating at 6.4 GHz, with an axial field produced by two watercooled solenoids having a nominal mirror-to-mirror length of 300 mm and a mirror ratio of 1.4, and a radial hexapolar field produced with 12 bars of radiation resistant $Sm_2\,Co_{17}$ permanent magnet material. The source, together with the target will be biased at approximatively 8 kV, depending on the final energy required. The goal is to reach an ionization efficiency of 25 %.

The low energy transport line

It consists of a 90° horizontal analysing magnet, a set of analysing slits, two cylindrical Glaser lenses assuring a quasi parallel transport to the top of the cyclotron yoke, and another 90° vertically bending magnet to bring the beam on the axis of the cyclotron.

From there on the beam is guided through the existing axial injection system. Special attention has to be paid to the pumping of the high activities behind the source. Under operation, the source, the analysing system and the beam line to the cyclotron will be pumped by cryogenic pumps, confining the activity to the vault. The activity lost in CYCLONE however and transferred through its pumping sytem has to be stored before release in the atmosphere, allowing for the necessary decay.

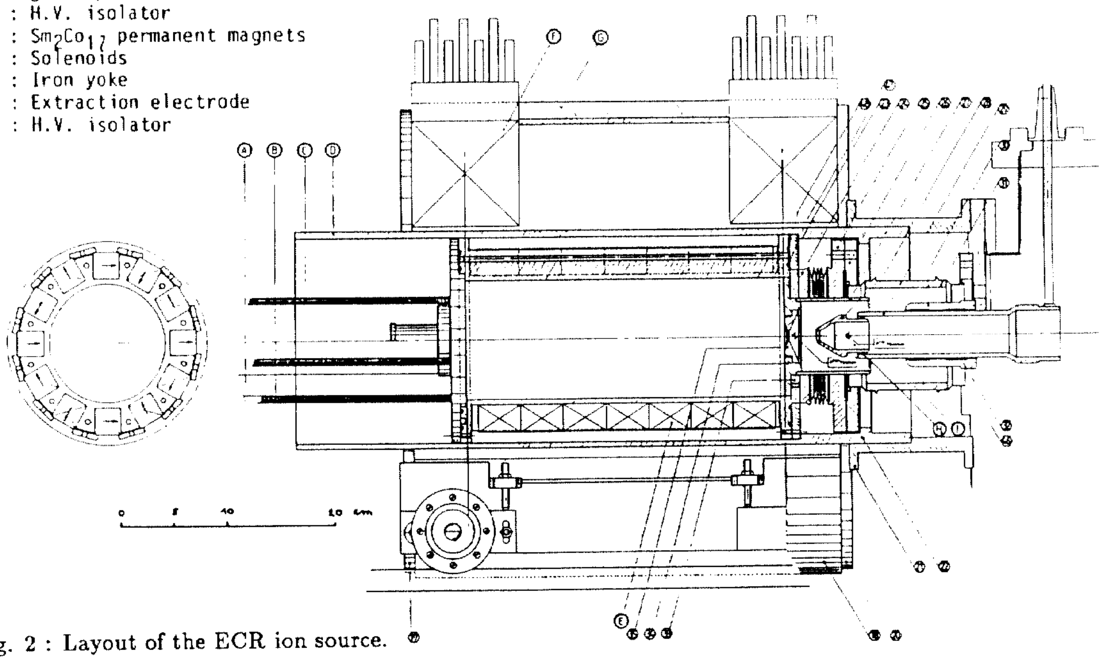

Fig. 2 : Layout of the ECR ion source.

Sixth harmonic mode acceleration in CYCLONE

CYCLONE was designed for a maximum proton energy of 90 MeV. The energy range choosen for the study of nuclear astrophysics reactions is around 0.5 MeV/a.m.u. Trim coil power is sufficient to produce an almost perfectly flat field. The RF system allows however only an excursion of a factor of 2. Lower energies are therefore obtained, using higher harmonic modes. The two 86° DEE system is well suited for sixth harmonic acceleration. But the electric field in the accelerating gaps extends over quite some distance in these gaps, due to their relatively large aperture both axially and radially. This leads to excessive transit times especially in the first gap, excluding any possible acceleration. The electric field has therefore to be confined at least in the first gap.

Since CYCLONE has to remain intact, able to accelerate all particles from high energy protons to very low energy heavy ions, no permanent modifications could be carried out which would jeopardize its performance. The first gap geometry is obtained by entering, through the existing internal ion source machanism, a movable slit which closes the gap on the dummy-dee side.

A movable puller is introduced through the existing puller mechanism. The inflector is classical and comes in through the usual inflector mechanism from beneath.

The acceleration has been tested successfully with different types of stable ion beams (Ar^{4+} at 24 MeV, $^{12}C^{1+}$ at 8 MeV and $^{13}C^{1+}$ at 8.7 MeV) using the OCTOPUS source as injector.

The efficiency obtained between the current injected in and extracted from the cyclotron has reached 6.5 % during the first tests. The overall efficiency of 10 % assumed for the project should be reached after some further beam development work.

Seventh harmonic mode, using the same central region geometry has still to be tried out.

Time schedule

- Sixth harmonic mode acceleration has been achieved in February 1988.
- Production cross sections were measured in early 1988.
- Target development should be completed by the end of 1988.
- The ECR source will be tested off-line in the fall of 1988.
- The beam lines, support structures, target introduction system and ECR-ion sources will be mounted during the period November 1988 - February 1989.
- First radioactive beam expected in March 1989.

References

[1] Y. Jongen, J.-L. Bol, A. Chevalier, M. Lacroix and G. Ryckewaert : Construction of the Louvain-la-Neuve 30 MeV 500 μA H^- Cyclotron, 11th Int. Conf. on Cyclotrons and their Applications, Tokyo, October 13-17, 1986.

[2] J.-L. Bol, A. Chevalier, E. Conard, Y. Jongen, G. Lannoye, G. Ryckewaert, S. Zaremba : Operational experience with the 500 μA H^- isotope production cyclotron CYCLONE 30, Proceedings of this conference.

[3] J.-L. Bol, A. Chevalier, Y. Jongen, M. Lacroix, F. Mathy and G. Ryckewaert : Operation experience with the CYCLONE-OCTOPUS combination, 11th Int. Conf. on Cyclotrons and their Applications, Tokyo, October 13-17, 1986.

[4] V. Bechtold, K.F.K., Karlsruhe, private communication.