PRODUCTION OF AN INTENSE ^{13}N RADIOACTIVE ION BEAM

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Abstract : *An intense (1.5 10^8 particles per sec) beam of radioactive $^{13}N^{1+}$ ions (half life ≅ 10 min) has been produced and accelerated to 0.65 MeV/nucleon by the two cyclotrons at Louvain-la-Neuve. The ^{13}N nuclei are produced by the $^{13}C(p,n)^{13}N$ reaction using the high intensity (up to 500 μA) 30 MeV proton beam from the small cyclotron, CYCLONE 30. Radioactive $^{13}N^{1+}$ ions are generated by a high efficiency single stage Electron Cyclotron Resonance ion source. The ^{13}N-beam is then injected axially at about 8 keV and accelerated on 6th harmonic mode in the large cyclotron, CYCLONE. Intense, low energy radioactive ion beams are essential for the measurement of reaction cross sections of interest for nuclear astrophysics. The first one that will be studied is the $^{13}N(p,\gamma)^{14}O$ reaction. This paper describes the status of the project, current improvements, and future plans.*

Introduction

Various aspects of the Radioactive Ion Beam (RIB) project at Louvain-la-Neuve have been described in earlier papers[1-3]. The facility layout is shown schematically in figure 1. Large beams (up to 500 μA) of protons in the energy range between 15 and 30 MeV produced by CYCLONE 30 are transported to the target. This target consists of a natural grapite matrix containing a set of small fairly pure carbon-13 "pills" obtained from powder by graphitization.

The produced ^{13}N is "blown" out of the target by a small flow (~ 1 st. cc/hour) of natural nitrogen carrier gas into the ECR-source. The parameters of the source have been optimized for an efficient conversion of the incoming gas into an outgoing 1+ ion beam. The source current is mass analysed, transported to the cyclotron and injected axially. Source voltage is 8 kV. The ions are then accelerated on 6th harmonic mode in CYCLONE to an energy of 0.6 MeV/nucleon and transported to the final target. In successive runs, the beam intensity on target was already optimised up to 1.5 10^8 particles per second of ^{13}N. This production process involves a series of intricate steps, all of which have to some extent been optimised separately and which have to be run now all simultanenously.

The table shows a comparison between what could be expected from the separate tests off-line and what has been obtained up to now during on-line runs of the whole system. In the first section, these different steps will be discussed.

Status of the ^{13}N-beam production

The 30 MeV proton beam

Extracted beam intensities of over 500 μA have been obtained with CYCLONE 30. However, up to now, the full intensity could not be used on the special enriched ^{13}C target : the specific power density has to be limited to about 600 W/cm^2. Larger total beam currents could be used with a larger target together with a fast sweeping of the beam to spread the power more uniformly. A 50 Hz sweeping magnet, to be located at the exit of the quadrupole doublet at about 1 m from the target, is under construction.

^{13}N Production yield

The choosen $^{13}C(p,n)^{13}N$ reaction is one of the most efficient prodution reactions at low energy. The total yield at 30 MeV was measured to be 1.6 10^{-3} atoms of ^{13}N per incident proton. However, besides requiring enriched target material, (p,n) reactions in general result in a contamination of the produced beam by ions from the target material. These have very close charge-to-mass ratios which cannot be easily separated. This point will be discussed in a next section.

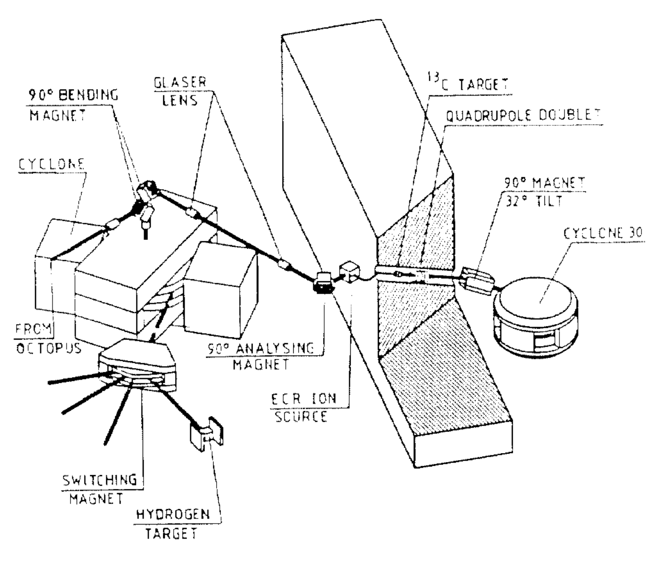

Figure 1 : Schematic layout of the RIB-facility.

Table : Production of $^{13}N^{1+}$ beam at 8.5 MeV

Quantity definition		On-line	Off-line
- Proton beam at 30 MeV	Ip (μA)	125	520
- ^{13}N Production yield at 30 MeV	N(^{13}N)/N(p)	1.6 10^{-3}	
- Extraction from the target	$\varepsilon_{extraction}$ (%)	9	80
- Ionisation efficiency in the ECR-source	$\varepsilon_{ionisation}$ (%)	4	15
- Transport efficiency between the source and the cyclotron centre	$\varepsilon_{low\ energy\ transport}$ (%)	50	80
- Acceleration efficiency (with bunching ; gain factor ≅ 3)	$\varepsilon_{acceleration}$ (%)	10	15
- Extraction from the cyclotron	$\varepsilon_{extraction}$ (%)	70	85
- Number of $^{13}N^{1+}$	N (p.p.s)	1.5 10^{8}	6 10^{10}
	(p.nA)	0.025	10

Extraction from the target

This quantity is measured by deviating the gas flux outside the cyclotron vault to a counting station. It appears that after an initial outgassing period there is an optimum target temperature and support gas flow.

The extraction efficiency quoted for the on-line runs includes the fact that the production target is not made out of 100 % pure carbon-13.

Ionisation efficiency in the ECR-source[4,5]

Off-line tests have shown that the ionisation efficiency sharply increases when the pressure drops in the source. Figure 2 shows measured yields as a function of pressure.

It follows that during on-line tests, a global optimisation leads to a decrease of the support gas flow through the target from its optimum value and a compromise is obtained where the separate yields are both lower than the best obtainable.

It also appears clearly that any other gas component than nitrogen coming out of the target should be prevented from entering the ion source.

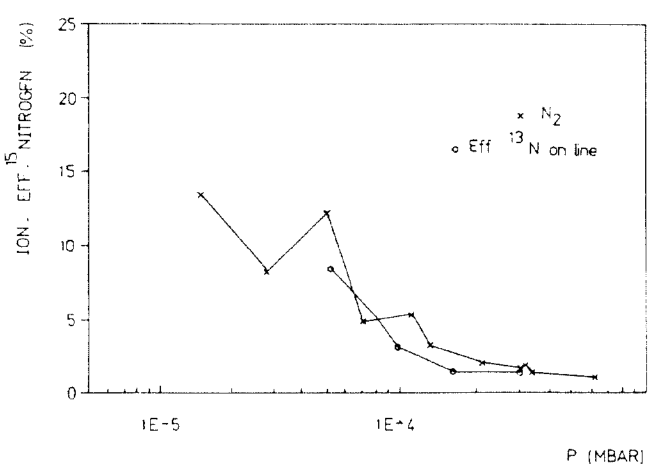

Figure 2 : Measured ion source yields for nitrogen.

Another important effect which has to do with sticking of the nitrogen on the copper source walls has been observed. The delay in ionisation introduced by this sticking allows part of the ^{13}N to decay, reducing the overall efficiency of the source. This effect has been greatly cancelled by introducing a quartz tube in the plasma chamber. Furthermore, oxygen coming from the quartz tube seems to further improve the ionisation efficiency.

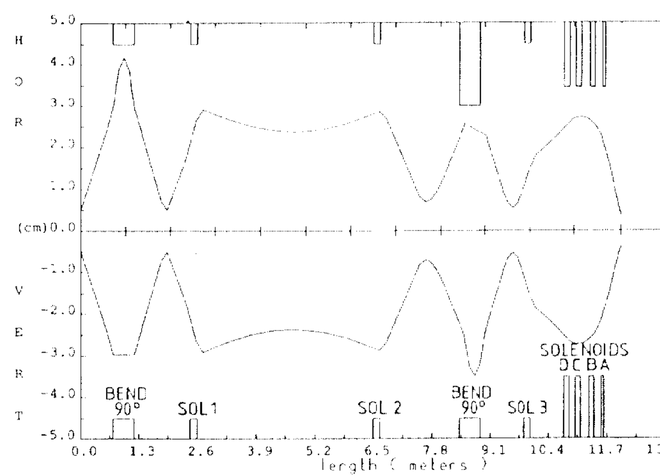

Figure 3 : Beam envelopes in the low energy beam line.

Transport from the source to the cyclotron

The envelopes of the beam are shown in figure 3. The beam line contains in fact two analysing magnets and is therefore strongly dispersive. Hence, highly stable power supplies for the source voltage and the two 90° bending magnets are required and beam transport adjustment becomes very critical. Without bunching, a variation of ± 2 % of the source voltage results in a reduction by a factor of 10 of the intensity in the cyclotron.

Acceleration efficiency in the cyclotron

This is limited mainly by two factors : the vacuum in the inflector and central region and the optical matching between the cyclotron acceptance and the optics imposed by the inflector.

Purity of the ^{13}N-beam

As mentioned earlier, the ^{13}N-beam is strongly contaminated by ^{13}C coming from the target and from other locations. In fact, this beam is used to set up and tune the whole transport and acceleration system. The difference in mass-to-charge ratio between ^{13}C and ^{13}N is so small ($1.8\ 10^{-4}$) that even after extraction from CYCLONE the two beams cannot be separated, making the beam useless for experiments. Therefore, different ways to purify the beam are under development.

The most radical method consists in stripping the beam in the main beam line after the cyclotron and tuning the switching magnet to the $^{13}N^{7+}$ beam. However, the energy is quite low so that the yield of 7+ ions is only a few percent.

Another method consists in purifying the gas between the target and the source. This has the additional advantage that the source efficiency will be increased. However, here the difficulty consists in finding a system that traps all composites of carbon without noticeably affecting the nitrogen throughput.

Testing two different trapping systems has started recently : one is based on the selective properties of certain Titanium alloys when passivated with nitrogen, the other uses the difference in partial vapor pressures of different gases at cryogenic temperatures.

It is however too early to give any conclusion on the effectiveness of either method.

Future plans

Although it appears from the above considerations that there is still a lot of development work to be done on the actual production system, it is worthwhile to look what will be next.

Nuclear astrophysicsts have a long list of reaction cross-sections involving other radioactive elements at different energies they would like to measure. On the other hand, the production scheme outlined here has its limitations. The lower limit in energy is at 0.54 MeV/nucleon and one would like to go below. This would only be possible by using a still higher harmonic mode (10^{th} !). This mode is perfectly accelerating but poses a serious challenge from the point of view of central region design.

On the production side, disposing of protons only, limits the choice of production reactions. This will be partly overcome by the planned extension[6] to deuterons also, although the energy remains small.

Therefore, it was suggested to study a dedicated low energy (0.1 - 1.2 MeV/nucleon) accelerator for radioactive elements up to mass 30. In this way, both CYCLONE 30 and CYCLONE (eventually equipped with an internal target) could be used as production machines, using also high energy protons, deuterons, alpha particles and, for some very low intensity exotic elements, heavy ions.

The new accelerator should further :
- have a high acceleration efficiency,
- produce good beam quality,
- be flexible, allowing fast, eventually continuous energy variation.

Very preliminary studies have been initiated in two possible directions : a specially designed low energy, classical cyclotron or an RFQ-linac combination. In both cases the machine size depends directly on the highest mass-to-charge ratio to be accelerated.

Therefore the present developments in the target-ion source field will be crucial for future developments.

Acknowledgement

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