Development of Exotic Nuclear Beams at the 88-Inch Cyclotron

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There has been great interest in recent years in the potential use of radioactive nuclear beams for the study of nuclear science. Experiments have been proposed in nuclear astrophysics, nuclear reactions, nuclear spectroscopy and properties of nuclei near the drip lines . Initial measurements in these areas have required the construction of many prototype first generation RNB facilities. Many second generation facilities are in the planning and construction phases. In principle, a high intensity radioactive beam facility is the highest nuclear physics priority in the U.S. behind the timely completion of RHIC and the Jefferson Laboratory. With the exception of MSU and RIKEN, all other major facilities under construction in the world are using the ISOL approach; this necessitates that most of the technical development in this field has concentrated on target-ion source issues. Although many laboratories have studied post accelerators, most construction projects to date have been limited to fairly low energies (< 5 MeV/nucleon). Unfortunately, almost all experimental ideas involving low-energy beams also require extremely high RNB intensities; this possibility is a long term goal, but hardly realistic for the earliest experiments. Many nuclear reaction experiments can be performed with very small beam currents, but they must have much higher energies (> 15 MeV/nucleon).

We are proposing to build a modest demonstration project whereby we can produce a few beams with energies up to 20 MeV/nucleon utilizing the 88-Inch Cyclotron as the secondary accelerator. The primary machine is a small medical cyclotron located about 300 m away from the 88". This small cyclotron produces proton beams at 10 MeV and 30 microamps intensity. The basic idea is to transport these radionuclides via a gas-jet system down to the 88" for injection into an ECR source. Once injected into the ECR source, a fraction of the injected radioactivity will be ionized directly into an appropriate charge state, extracted, and injected into the 88-Inch Cyclotron for final acceleration. For example, ^{11}C is made in copious yield in the $^{14}N(p,a)$ reaction. It would be transported on organic based aerosols (heavy elements effectively poison the ECR ion source output of lighter species), extracted as $^{11}C^{4+}$, and accelerated to a maximum energy of 18.5 MeV/nucleon. In order to perform nuclear reaction studies with this beam, routine operation will strip this beam to +6 to permit its magnetic separation from ^{11}B beam impurities; the cyclotron cannot separate ^{11}C and ^{11}B.

To date we have performed several tests to ascertain the viability of this approach. These tests have included measuring the ^{11}C yields transported through a 25 m capillary, comparisons of these results with transport through a 300 m capillary, and yield measurements on the simultaneous production of ^{14}O for possible use as a second radioactive beam. Results of the yield tests along with some sample efficiencies are given in Table 1. The transit time through the 300 m capillary was measured to be 69 s; there were no measurable losses of ^{11}C activity. We are currently constructing a system to couple a gas-jet to the ECR to measure the efficiency for a beam extracted as $^{11}C^{4+}$. This system should be operational in mid 1997.

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Table 1. Yields and Efficiencies

Measured ^{11}C Yield (extrapolated from 1 mA)	9.0E08/s
Measured ^{14}O Yield (extrapolated from 1 mA)	4.8E07/s
Target Efficiency	50%
Transit Time	69 s
Skimmer Efficiency	50%
ECR Efficiency	1%
Cyclotron and Transport Eff.	30%
Proposed Initial ^{11}C Intensity	1.0E06/s