Proceedings of the 2nd International Conference on Exotic Nuclei and Atomic Masses (ENAM98)
23-27 June, 1998, Bellaire Michigan USA
American Institute of Physics, Conference Proceedings (in press)

BNL-65658
CONF-980672--

BEARS: Radioactive Ion Beams at LBNL

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BEARS is an initiative to develop a radioactive ion-beam capability at Lawrence Berkeley National Laboratory. The aim is to produce isotopes at an existing medical cyclotron and to accelerate them at the 88" Cyclotron. To overcome the 300-meter physical separation of these two accelerators, a carrier-gas transport system will be used. At the terminus of the capillary, the carrier gas will be separated and the isotopes will be injected into the 88" Cyclotron's Electron Cyclotron Resonance (ECR) ion source. The first radioactive beams to be developed will include 20-min ^{11}C and 70-sec ^{14}O, produced by (p,n) and (p,α) reactions on low-Z targets. A test program is currently being conducted at the 88" Cyclotron to develop the parts of the BEARS system. Preliminary results of these tests lead to projections of initial ^{11}C beams of up to 2.5 x 10^7 ions/sec and ^{14}O beams of 3 x 10^5 ions/sec.

There is currently extensive world-wide activity in the development and construction of radioactive ion-beam facilities of various types. The availability of beams of unstable nuclei offers exciting new opportunities for research into nuclear structure and nuclear astrophysics. BEARS, or Berkeley Experiments with Accelerated Radioactive Species, is an initiative to develop a radioactive ion-beam capability at LBNL.

The basic concept for an initial BEARS system involves the coupling of isotope production at an existing medical cyclotron in building 56 of LBNL (see Fig. 1) with post-acceleration by the 88" Cyclotron. These accelerators are separated by a distance of about 300 m; isotopes will be transported between the two via a gas-jet capillary. Carrier gas would be pumped by a high-throughput Roots blower at the building 88 end. Preliminary tests have shown that a total transport time of less than a minute is easily achieved, and times as short as 10 sec may be possible.

After transport, the radioisotopes are to be injected into one of the ECR ion sources of the 88" Cyclotron. These sources can achieve good ionization efficiencies at high charge states; however, they require vacuums of the order of 10^{-6} torr to operate. Therefore the central technical challenge of BEARS is the coupling of a gas transport system to an ECR ion source. Two separate techniques are being explored.

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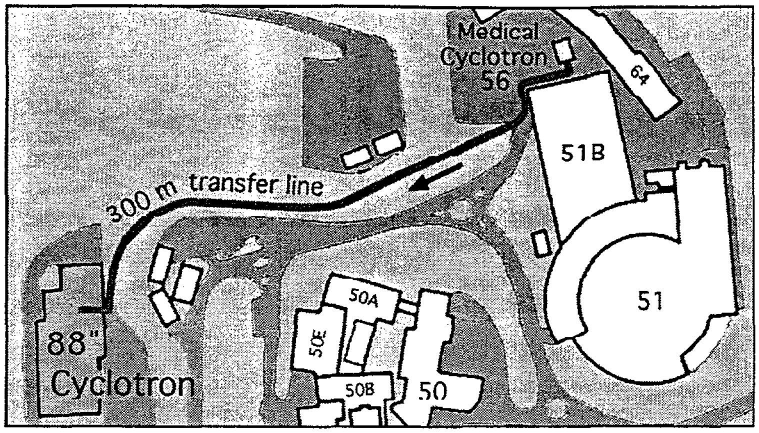

FIGURE 1. Map showing proposed transfer line between buildings 56 and 88.

The first involves transport of activity attached to small aerosol clusters suspended in the carrier gas (1). This is a standard technique that can achieve very high transport efficiencies. At the ECR, the vast majority of the carrier gas is skimmed away in a multi-stage differential-pumping system. The aerosol clusters, due to their high mass, pass though the skimming system into the high vacuum region. This technique has the potential for being broadly applicable to many isotopes, but does not work with volatile compounds.

The second technique involves separation of the radioactivity from the carrier gas by cryogenic trapping at liquid-nitrogen temperatures (1). After separation, the trapped gas is bled into the ECR plasma region. This method has the advantage of simplicity although it requires that the isotope of interest be in a suitable gaseous chemical form. It is expected that the two methods will complement each other.

The medical cyclotron produces a 10 MeV proton beam with typical intensities of 40 μA. Several light proton-rich isotopes can be produced, via (p,n) and (p,α) reactions on light-Z targets. Initially, we have focused on the production of ^{11}C ($t_{1/2}$=20 min) and ^{14}O ($t_{1/2}$=71 sec), both produced from ^{14}N. The target is either N_2, which doubles as the transport-system carrier gas, or a solid material such as boron nitride (BN).

Several tests of the various parts of the BEARS system have been carried out. As the 300 m transfer line has yet to be constructed, the 88" Cyclotron has been used to mimic the medical cyclotron, producing up to 5 μA of 10 MeV proton beams. Activity produced in our prototype target chamber is transported in one of the above described manners to one of two ECR ion sources (the other being used to supply the proton beam).

For the aerosol transport technique, a four stage differentially-pumped skimming system was constructed and coupled directly to the ECR. This is shown in Fig. 2. Aerosol clusters and carrier gas enter the first stage in a jet of near-sonic velocity. The

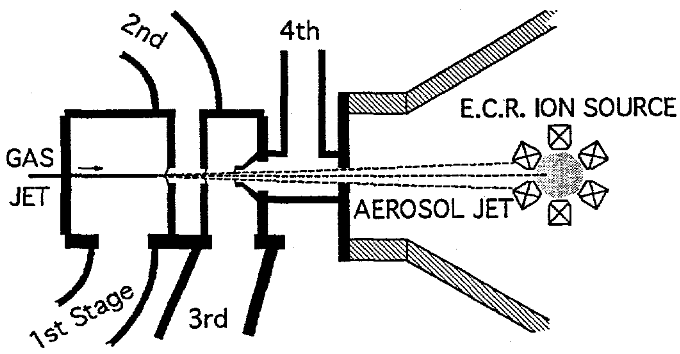

FIGURE 2. Skimming system for injecting aerosols into the ECR ion source.

heavier clusters exit in a narrower cone than the expanding gas, allowing then to pass through the small holes in the three skimmers. Once inside the ECR, the aerosols are caught on heated surfaces, to vaporize the activity. Tests have shown that, with a full gas load, ECR performance is not significantly degraded.

Unfortunately, it was found that this system failed to transport significant amounts of ^{11}C or ^{14}O, the initial BEARS production isotopes. This was traced to the majority of the activity forming gaseous compounds and thus not attaching to the aerosol clusters. The fraction of ^{11}C in a chemical form that could be transported was only on the order of 0.1-0.5%. However, this small amount of activity was successfully injected into the ECR, and an extracted beam of ^{11}C was identified, although at very low intensities.

The cryogenic trapping technique was found to be much more effective for transporting ^{11}C and ^{14}O; about 15% of the total produced activity being successfully trapped and then released into the ECR. The N_2 target/carrier gas was passed through a coil of 1/8" o. d. stainless steel tubing, about 1.5 m long, submerged in liquid nitrogen. After stopping the gas flow and allowing the remaining nitrogen to be pumped away, the trap was connected to the ECR. The liquid nitrogen was then replaced by an alcohol bath containing dry ice, quickly raising the temperature to 195 K. This

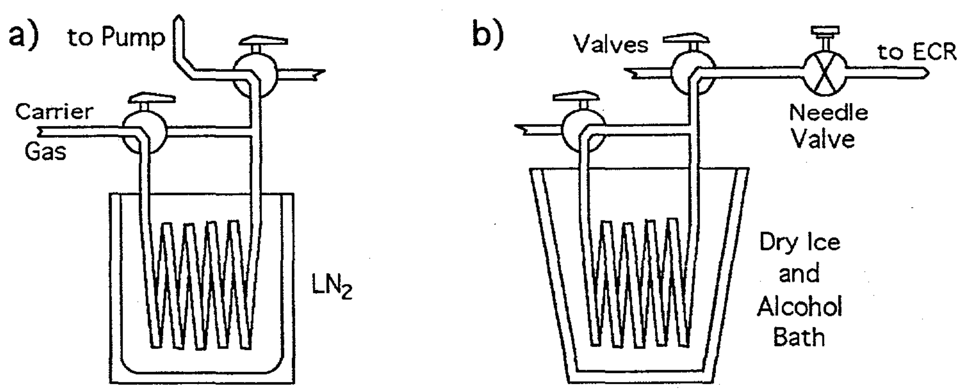

FIGURE 3. Cryogenic trapping system: (a) trapping and (b) release at dry ice temperatures into the ECR ion source.

temperature increase releases 90% of the trapped ^{11}C ($^{11}CO_2$) and about 40% of the trapped ^{14}O (believed to be $N^{14}O$ or $N_2{}^{14}O$). The released gas was then bled directly into the ECR plasma region through an adjustable needle valve.

Care had to be taken to minimize the amount of non-radioactive gas that was trapped and introduced to the ECR along with the radioactivity. With too great a gas load, ionization efficiencies at high charge states are greatly reduced. By using the dry-ice/alcohol bath, rather than warming the coil to room temperature, reduced the resulting ECR gas load by 90%.

Beams of both ^{11}C and ^{14}O were successfully extracted from the ECR in charge states of up to 5+. The ionization efficiency for $^{11}C^{4+}$ was measured to be 0.7%. Similar results were found for 1+, 2+ and 3+ charge states, while the efficiency for $^{11}C^{5+}$ was about 0.1%, due to the difficulty in stripping an S-shell electron. Initial measurements of ^{14}O in 3+, 4+ and 5+ charge states indicate efficiencies in the range of 0.4 to 1%. Future developments, including the use of the 88" Cyclotron's second, advanced ECR ion-source (the AECR-U), are expected to increase these efficiencies to a range of 1 to 4%.

Beam transport efficiency through the 88" Cyclotron is estimated to be 10-25% for energies of 65 to 180 MeV (with $^{11}C^{3+,4+}$ ions) and 5-15% for 11-50 MeV (with $^{11}C^{1+,2+}$). With these and the above measured efficiencies, and starting with the known ^{11}C production at the medical cyclotron of 1.0×10^{11} atoms/sec (3), a ^{11}C beam intensity of 0.5 to 2.5×10^7 ions/sec can be projected for the completed BEARS system, with a reasonable expectation of greater than 10^8 ions/sec with expected future improvements in trapping and ECR efficiencies. For comparison, the Louvain-la-Neuve facility reports a current available $^{11}C^{1+}$ beam of 10^7 ions/sec in an energy range of 6.2-10 MeV (2). Similar projections for ^{14}O lead to initial beams of 3×10^5 ions/sec.

The transfer line between the two cyclotrons is to be built over the remainder of 1998. During this time, further tests will be conducted to maximize efficiencies and minimize transport times and ECR gas load. In addition, we will begin tests to develop other light-mass proton-rich ion beams, such as ^{13}N, ^{15}O, ^{17}F, ^{18}F, and possibly ^{10}C.

ACKNOWLEDGMENTS

This work supported by USDOE, under contracts DE-AC03-76SF00098 and DE-AC02-98CH10886. One of the authors, R. Joosten, would like to acknowledge the support of the German Academic Exchange Service (DAAD).

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