UCRL- 95451
PREPRINT

OCT 1 4 1986

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DE87 000581

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This paper was prepared for submittal to
the Ninth Conference on Application of
Accelerators in Research and Industry
North Texas State University
Denton, Texas
November 10-12, 1986

September 1986

Lawrence Livermore National Laboratory

MASTER

RADIOACTIVE ION BEAM RESEARCH AT LAWRENCE LIVERMORE NATIONAL LABORATORY*

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Several modifications and additions have been made to improve the radioactive beam facility at Livermore(1) with the main aim of measuring the cross section for ^{7}Be(p,γ)^{8}B (which is important in determining the solar neutrino flux) and other reactions of astrophysical interest. The quadrupole sextuplet spectrometer has been upgraded by inserting an electrostatic deflection element near the midpoint and by installing a movable beam stop near the ^{7}Be production target. These changes have allowed an improvement in the purity, and a large increase in the intensity, of the ^{7}Be beam. Six large NaI(Tl) detectors and the gas cell from the OSU system along with its active and passive shielding(2) have been incorporated into the Lawrence Livermore facility.

True events are to be identified by a multiple coincidence. The first requirement is the detection of a γ-ray from the proton capture ^{7}Be(p,γ)^{8}B. After the candidate capture gamma is observed the ^{8}B decay signature is required. This signature is a positron (from $^{8}B \rightarrow {}^{8}Be^{*} + e^{+} + \nu$) along with the two α's from $^{8}Be \rightarrow \alpha + \alpha$ observed in a CaF_2 detector into which the ^{8}B have implanted. Also a detector telescope inside the gas cell monitors the incoming ^{7}Be beam. The current status of the ^{7}Be(p,γ)^{8}B measurement is discussed.

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Introduction

In stars nuclear reactions involving unstable nuclei can occur and can be important. To study reactions involving nuclei with short lifetimes in the laboratory one must use radioactive ion beam techniques. The LLNL and OSU groups have merged their efforts in the development of the technology to do such experiments.

The Radioactive Beam Facility

The experimental system can be logically separated into two parts, the beam production and transport subsystem and the detection subsystem. The application of the system is discussed using the $^7Be(p,\gamma)^8B$ reaction as the prototype. This reaction is of interest because it determines the production rate of ^8B in the sun and thus most of the solar neutrino flux to which the ^{37}Cl detector of Davis *et al.*(3) is sensitive. The ^7Be beam is produced by the $^7Li(p,n)^7Be$ reaction.

The major portion of the beam system has been described by Haight *et al.*(4,1,5). Three major changes have been made which have improved the intensity and purity of the radioactive beams. The first of these changes is a new beam stop. This beam stop can be easily moved upstream and downstream along the axis of the spectrometer by remote control. The position can be adjusted to find an optimal trade-off between eliminating the elastically scattered ^7Li from the beam, increasing the beam purity, and accepting the ^7Be reaction product, increasing the radioactive beam intensity.

The second addition to the transport system is a dispersive optical element. An electrostatic deflector has been added near the middle of the quadrupole sextuplet, before the midpoint aperture. By using the deflector to select only the $^{7}Be^{4+}$ ions the beam purity is improved. Since the scattered ^{7}Li ions have a maximum charge state of +3, they can be separated from the $^{7}Be^{4+}$ beam. Thus the electrostatic deflection improves the purity of the radioactive beam. The radioactive ion beam facility is depicted in Figure 1.

The ^{7}Be beam is produced by bombarding a stretched polypropylene foil (~ 1 mg/cm^2) with the ^{7}Li beam. Under typical experimental conditions (~500 charge nA of $^{7}Li^{+++}$) the target lifetimes were very short (a few seconds). This lifetime was extended by using long targets which were moved back and forth across the beam. The moving targets typically survived for one hour. By putting about 1000 A of Cu on each side of the targets the lifetime has been extended to days, which is quite satisfactory.

One of the most important problems to be solved in radioactive beam experiments is that of backgrounds in the detector system. When the count rates for valid events are tens per day elimination of false events is critical. Every bit of information possible about the reaction of interest must be used. In the ^{7}Be proton capture case the reaction is the following

$$^{7}Be(p,\gamma)^{8}B \rightarrow \beta^{+} + \underset{\hookrightarrow \alpha + \alpha}{^{8}Be^{*}}$$

The detection scheme is as follows: The capture γ-ray is detected in a set of six large (4" x 4" x 16") NaI(Tl) scintillators. When this occurs the ^{7}Be beam is shut off. The ^{8}B implants into a CaF_2 scintillator where it positron decays. The positron either enters the NaI array and is directly detected or annihilates and the annihilation radiation is detected. The ^{8}Be decays promptly and is observed in the CaF_2 in coincidence with the positron signal. An alternative to using the capture γ-ray signal to begin looking for the ^{8}B decay is to pulse the ^{7}Be beam (e.g. one second on, one second off) and look for the ^{8}B decay while the beam is off. This would eliminate false starts due to background counts in the NaI detectors.

Since backgrounds are a major a problem shielding for the detection system is necessary. The shielding in use includes about 3000 lbs. of low activity Pb around the entire detection system. Active shielding, for the rejection of cosmic rays, is provided by 2" thick plastic scintillators, inside the Pb shield, around the detection system. In the detection system the outputs of the six NaI detectors are added together. The energy resolution of the NaI array is quite good and the cosmic ray rejection is very effective.

The incoming ^{7}Be beam is monitored with a solid state detector telescope mounted inside the target gas cell. Beam particles elastically scattered from the entrance window are observed by these detectors.

Another step which will reduce backgrounds is to use a pulsed beam. A superconducting beam buncher capable of producing 70 picosecond beam bursts will be incorporated into the facility.

Present Status and Future Plans

Tests of the detection system are nearly completed. Background rates are high (150/sec in the NaI detectors) but probably acceptable. The ^{7}Be beam intensity is quite good. Rates of 5×10^5 ^{7}Be on target can be achieved with acceptable beam purity. A major contaminant beam is ^{8}Li, produced by the ^{7}Li(d,p)^{8}Li reaction in the production target. The decay of ^{8}Li is very similar to that of ^{8}B. The ^{8}Li problem will be cured by using deuterium depleted target foils.

The $^{7}Be(p,\gamma)^{8}B$ experiment should be operational soon after LLNL's new accelerator is installed. Future plans include other proton capture reaction studies e.g. $^{13}N(p,\gamma)^{14}O$ and charged particle reactions such as $^{14}O(p,\gamma)^{17}F$.

*Work performed under the auspices of the U.S. Department of Energy by the Lawrence Livermore National Laboratory under contract number W-7405-ENG-48 and of the NSF under grant number PHY-86-00749.

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Figure 1

Schematic diagram of the radioactive beam facility at LLNL showing the envelope of a ^{7}Be beam.

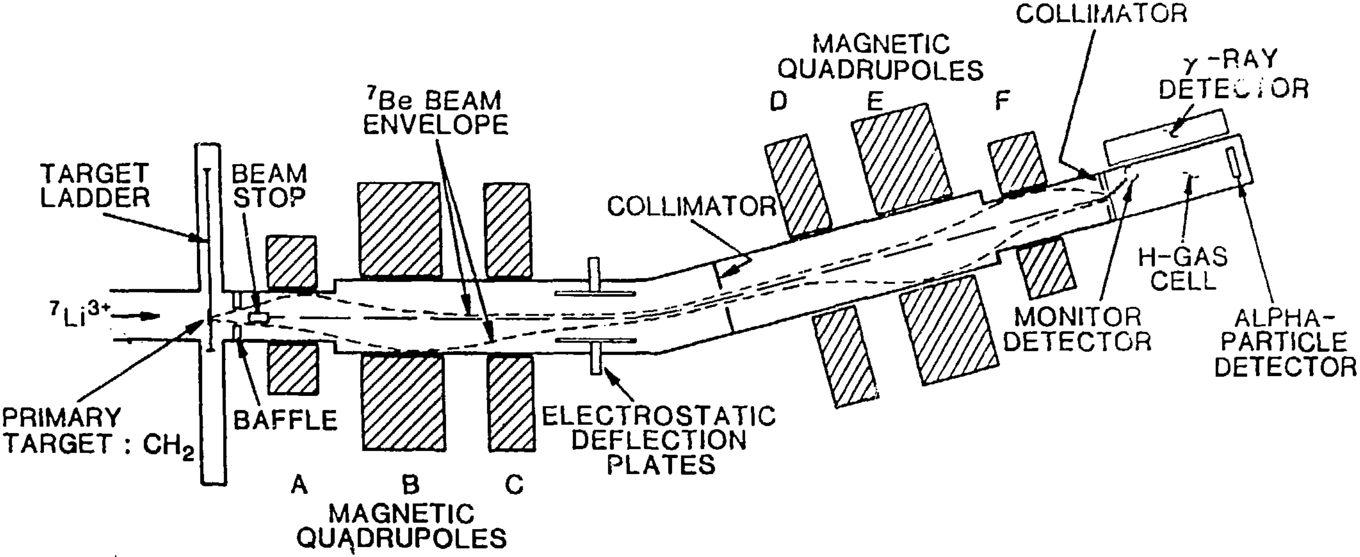
COLLIMATOR
MAGNETIC QUADRUPOLES
γ -RAY DETECTOR
D
E
F
^{7}Be BEAM ENVELOPE
TARGET LADDER
BEAM STOP
COLLIMATOR
^{7}Li^{3+}
H-GAS CELL
MONITOR DETECTOR
ALPHA-PARTICLE DETECTOR
PRIMARY TARGET : CH$_2$
BAFFLE
ELECTROSTATIC DEFLECTION PLATES
A
B
C
MAGNETIC QUADRUPOLES

Figure 1.