Light Radioactive Beam Production via Two Stage Irradiation Setup

Michael Hass

(Ph.D. Thesis of T. Hirsh)

Weizmann Institute, Rehovot, Israel
Soreq NRC, Yavne, Israel
GANIL, Caen, France
ISOLDE, Geneva, Switzerland
Objectives

High Yield Production of $^6$He and $^8$Li
Secondary n’s + fission
BUT
Also light RIB’s

$^{11}\text{B}(n,\alpha)^{8}\text{Li}$

$^{8}\text{Li} \rightarrow \beta^-$
$t_{0.5} = 838 \text{ ms}$

$^{9}\text{Be}(n,\alpha)^{6}\text{He}$

$^{6}\text{He} \rightarrow \beta^-$
$t_{0.5} = 807 \text{ ms}$
deuterons / protons
linear accelerator

5 MeV at Phase 1
with only 1 PSM (2008)

40 MeV at Phase 2
with 6 SMs (2013)

2 mA current
Astrophysics and Nuclear Physics with Light RIB

$^4\text{He}(^8\text{Li},n)^{11}\text{B}$ reaction


http://beta-beam.web.cern.ch/beta-beam/
Neutron Spectrum from a 40 MeV Deuteron Beam on a Thick Lithium Target

\[ E_d = 40 \text{ MeV} \]
\[ n = 8 \cdot 10^{14} \text{n/sec for 2 mA} \]
\[ n/d = 0.064 \]
\[ Q \text{ value for } ^7\text{Li}(d,n)^7\text{Be} \rightarrow 15.03 \text{ MeV} \]

Other possible converters:
Beryllium, Water, Heavy water
Optimization Calculations

\[ R = 5 \text{ cm} \quad L = 5 \text{ cm} \quad E_n [\text{MeV}] \]

\[ \sigma [\text{mb}] \quad \text{mean n flux [n/cm}^2/\text{sec}] \]

Mean neutrons flux on $^9$Be target by bombard of 40 MeV and 2 mA deuterons beam on thick Lithium target. This is a 2D slice in the middle of the target. The units are [n/sec/cm$^2$] and the calculations made using MCNP4b.
Simulations:

\(^6\)He yield density distribution \(^{(6)}\text{He/sec/cm}^3\) inside a 2D slice of the target for two positioning distances, the line represents a value of \(1.3 \times 10^{10} \text{ (^{6}He/sec/cm}^3\).

Cone shaped target

\(^6\)He production yield distribution inside 2D slice for \(R_T = 1 \text{ cm}\)

\(^6\)He production yields for a constant target volume and for different R to D ratios. These results are for a \(785.4 \text{ cm}^3\) cone target and for \(R_T = 5 \text{ cm}\).
What about $^{18}\text{Ne}$?..
Oxide Fibers

- BeO 2 mm disks
- 23 mm diameter
- Purity of 99.9% BeO
- ~500 ppm impurities
- 50%-75% density
- Grain size 20 micron

BeO, the most refractory Be compound (melting point 2520 °C), in form of fibers should provide an ideal target. For all oxide fiber targets discussed in this article ~80% of the produced He is released before its decay. BeO, which can be heated to even higher temperatures, should thus guarantee an efficient release also from large volume targets.

For short-lived isotopes of Cu, Ga and Xe the zirconia and ceria targets respectively provided significantly higher yields than any other target (metal foils, oxide powders, etc.) tested before.

Expected yields

\[^6\text{He}\]
- Expected Yields for a BeO target (useful for RNB extraction):
  - SARAF (40 MeV, 2 mA): \(8 \cdot 10^{12}\) [\(^6\text{He}/\text{sec}\)]
  - SPIRAL2 (40 MeV, 5 mA): \(2 \cdot 10^{13}\) [\(^6\text{He}/\text{sec}\)]

\[^8\text{Li}\]
- SPIRAL2 (40 MeV, 5 mA): \(2 \cdot 10^{12}\) [\(^8\text{Li}/\text{sec}\)]

Expected yield at SPIRAL2 for “just” neutrino production - \(2 \cdot 10^{14}\) [\(^6\text{He}/\text{sec}\)]

**NO** technological difficulties (like efficiencies of ionization, extraction...
Present and Future test Experiments

**Production and Extraction Processes**

- **$^{27}$Al(n,α)$^{24}$Na**
  - Production
  - Monte Carlo Simulations
  - $\gamma$ emission

- **$^{11}$BN(n,α)$^{8}$Li**
  - Production extraction
  - Monte Carlo Simulations
  - β emission

- **$^{9}$BeO(n,α)$^{6}$He**
  - Production extraction
  - Monte Carlo Simulations
  - β emission

**Monte Carlo Simulations**

- **$^{6}$He production and extraction numbers**

**Experiments**

- **15.2.2008 Aluminum cubes irradiation experiment number 1.**
  - Preliminary experiment for verification of target geometry in compare to Monte Carlo simulations.

- **28.4.2008 Aluminum cubes irradiation experiment number 2.**
  - Preliminary experiment for verification of target + reflector geometries in compare to Monte Carlo simulations and previous experiment.
Aluminum Cubes Experiment

Copper Foils

cps of each Al Cube at EOB using MCNP with z=7 mm (efficiency 1.1%) and as been measured by 60% Ge detector on 28/4/2008

 Cube Number
$^8$Li Production Experiment

- β detector
- Shielding
- Neutron Generator
- Fast Rabbit
- BN Target

3 sec irradiation
0.1 sec movement
3 sec measurement

Time
5.2 MeV and 2 mA deuterons beam.
Production of fast neutrons by placing a light isotopic target with high positive Q-value (probably $^{13}\text{C}/^{7}\text{Li}$).
We are planning to repeat the experiments of Aluminum and BN irradiation by using these neutrons.
Proposed ISOLDE Porous BeO Experiment

Option for experiment at Ganil:

Production and extraction of $^8$Li

Boron-Nitride powder target

Fast neutrons from $^{12}$C($^{12}$C, n) reactions

Porous BeO Disks

Spallation Neutrons

Ion Source

Products Beam

Mass Spectrometer

$^6$He
1. Presented simulations and tests for production of secondary-neutron induced RIB production.
2. Planned future experiments – including extraction and ionization yields.
3. Towards a specific design of a target for SPIRAL2 and/or SARAF.
4. $\beta$-Beams?...
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