Fundamental Design Study for Target/Ion Source to Produce ^{8}Li Beam

Jeong-Jeung Dang [a]*, Hyeok-Jung Kwon [a], Seung-Hyun Lee [a], Han-Sung Kim [a], Young-Gi Song [a],
Dae-Il Kim [a], Yong-Sub Cho [a]
[a] *Korea Multi-purpose Accelerator Complex/KAERI: 181 Mirae-ro, Gyeongju, 38180*
* *Corresponding author: jjdang@kaeri.re.kr*

1. Introduction

Radioactive isotope beam (RIB) can enhance an application field of a conventional radioactive isotope (RI), because RIB technique can control detail characteristics of RI such as a polarization or a penetration depth. For example, ^{8}Li is should be polarized and the energy of ^{8}Li should be controlled to be utilized in beta-detected nuclear magnetic resonance (β-NMR) technique which is a powerful tool to research material science. Thus, RIB is essential to utilize ^{8}Li in β-NMR technique.

^{9}Be(p, 2p)^{8}Li reaction driven by a 100-MeV proton accelerator is adopted in this work. The ^{8}Li can be produced in a beryllium oxide (BeO) target irradiated by a proton beam. The produced ^{8}Li is ionized and extracted in an ion source. These processes are occurred in a target/ion source (TIS). Thus, TIS is a key part of the RIB system.

This study is a fundamental design study and conducts a numerical analysis to deduce design parameters of TIS. The detail description and results of the numerical study and fundamental design of TIS will be presented in the following sections.

2. Numerical study for fundamental design of ^{8}Li TIS

This work adopts ^{9}Be(p,2p)^{8}Li reaction to generate ^{8}Li with 100-MeV proton accelerator. The cross section of this reaction evaluated by Talys code [1] is shown in Fig. 1. The cross section is rapidly increased over 24 MeV and peaked near 38 MeV. That is, there is no need to stop fully the proton beam in the BeO target. Also, the proton beam produces the neutrons by various nuclear reactions in the target. Thus, there is an optimum BeO target thickness which secures enough ^{8}Li production and minimizes the neutron production. In order to determine the optimal thickness of the beryllium oxide target, Monte Carlo simulation is conducted. In addition, an ionization efficiency of Li and other by-products in the surface ion source is calculated to determine a material of the surface ion source.

7.1. Monte Carlo Simulation Result

FLUKA code [2] is selected to conduct the Monte Carlo simulation in this work. Not only ^{8}Li but also various isotopes and the neutron production rates are calculated with the various BeO target thickness. The ^{8}Li and neutron production rates are depicted in Fig. 2. The ^{8}Li production rate is increased and saturated according to the target thickness because the cross section is decreased at the proton beam energy lower than 38 MeV. In contrast, the neutron production steadily increases. Thus, there is the optimal thickness which secures enough ^{8}Li generation and avoids unnecessary neutron production. The optimal thickness is about 24 mm. 24 mm thick BeO target can produce approximately 10^{10} particles of ^{8}Li per 1 μA of the 100-MeV proton beam.

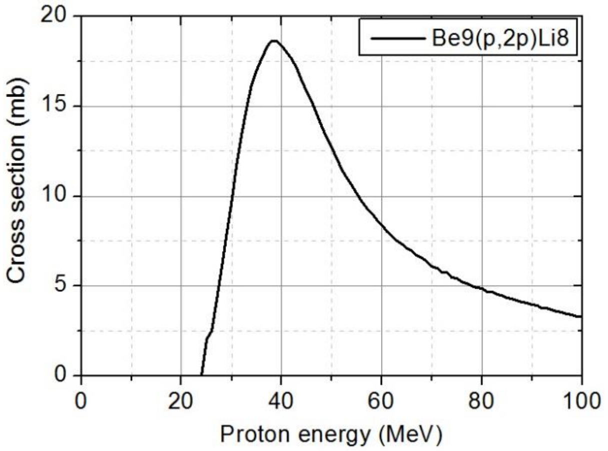

Fig.1. Cross section of ^{9}Be(p,2p)^{8}Li reaction

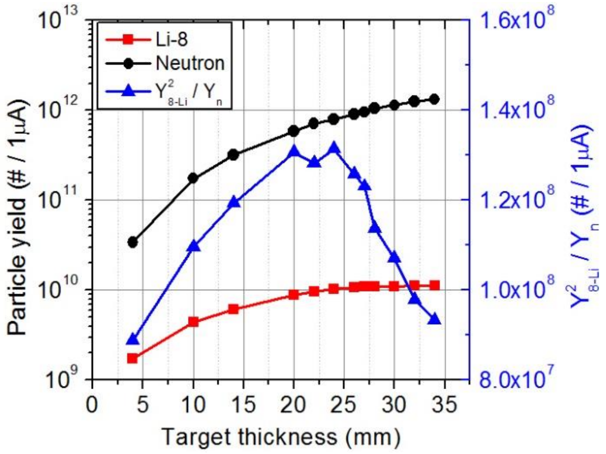

Fig.2. ^{8}Li and neutron production rates obtained by the FLUKA simulation with various BeO target thickness

7.2. Ionization Probability of ^{8}Li in Surface Ion Source

Helium, beryllium, boron and carbon isotopes also can be produced by the interaction between BeO and the proton. In order to increase a purity of Li beam, the ion source should ionize selectively. Thus, the surface ion source is adopted in this work. The ionization probabilities of these isotopes are calculated for candidate materials of the surface ion source. The surface ionization probability is obtained by the Langmuir-Saha equation [3]

$$p_i = \frac{n_i}{n_0+n_i} = \left[1 + \frac{g_0}{g_i} exp\{e(\varphi_i - W)/kT\}\right]^{-1} \qquad (1)$$

where g_i and g_0 are statistical weights of the ion and atom, φ_i is the ionization potential of the atom, W and T are the work function and the temperature of the surface ion source material, respectively. The ionization probabilities are presented in Table I. The rhenium ion source shows superior ionization characteristics. The ionization probability of the lithium is extremely larger than other species.

Table I: Surface ionization probabilities with various ion source conditions

Species	Ion source material	Ion source temperature (K)		
		1000	1500	2000
He	Ta	1E-103	3.0E-69	4.9E-52
	W	2E-101	9.9E-68	6.6E-51
	Re	2.6E-99	2.4E-66	7.2E-50
Li	Ta	1.6E-7	2.3E-5	2.8E-4
	W	2.9E-5	7.5E-4	3.8E-3
	Re	3.4E-3	1.8E-2	4.0E-2
Be	Ta	9.7E-27	5.7E-18	1.4E-13
	W	1.8E-24	1.9E-16	1.9E-12
	Re	2.1E-22	4.4E-15	2.1E-11
B	Ta	3.6E-22	4.0E-15	1.3E-11
	W	6.6E-20	1.3E-13	1.8E-10
	Re	7.7E-18	3.1E-12	2.0E-9
C	Ta	1.5E-36	1.7E-24	1.8E-18
	W	2.9E-34	5.5E-23	2.4E-17
	Re	3.3E-32	1.3E-21	2.6E-16

3. Conclusions

The fundamental design study for TIS to produce ^{8}Li beam is conducted in this study. ^{8}Li is produced by the 100-MeV proton accelerator with the beryllium oxide target. The optimum target thickness, which can achieve enough ^{8}Li production rate and avoid unnecessary neutron production, is determined by FLUKA simulation. The optimum thickness is about 24 mm. ^{8}Li production rate with the optimum thickness is about 10^{10} pps by 1 μA of the 100-MeV proton beam. Also, the lithium ionization efficiency of the several surface ion source materials. The rhenium is adopted to enhance the selective ionization effect.

This paper includes very fundamental results of the design study. More detail design study and computational analysis has been conducted. The TIS for ^{8}Li beam will be fabricated and examined by further experimental study.

ACKNOWLEDGMENTS

This work has been supported through KOMAC (Korea of Multi-purpose Accelerator Complex) operation fund of KAERI by MSIP (Ministry of Science, ICT and Future Planning).

REFERENCES

[1] www.talys.eu
[2] http://www.fluka.org/fluka.php
[3] B. Wolf, Handbook of Ion Sources, CRC Press, 1995, p. 10.