Degradation of Lithium fluoride thin targets on Carbon Backing Irradiated with 68 MeV ^{17}O Beams at EMMA Facility of TRIUMF

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1. Introduction

An experiment was conducted to investigate the possible influence of a reaction on the astrophysical *s* process. To study the states dominating the $^{17}O(\alpha,\gamma)^{21}Ne$ reaction rate indirectly, $^{7}Li(^{17}O,t)^{21}Ne^{*}(\gamma)^{21}Ne$ reaction was measured. ^{17}O beam accelerated to 68 MeV at ISAC-II was impinged on a thin lithium fluoride (LiF) target on carbon backing for populating states in ^{21}Ne through the $^{7}Li(^{17}O,t)^{21}Ne$ reaction.

In the experiment, failures caused by lattice damage caused by radiation in all the targets occurred during the beam running time. A study was conducted to analyze the cause of target destruction of the target so that the next same experiment could be conducted again efficiently with the prediction of target lifetime.

2. Methods and Results

2.1. Experimental settings

Continuous $^{17}O^{4+}$ beam with 1 mm beam diameter (FWHM: 0.8 mm) accelerated to 68 MeV at ISAC-II was continuously impinged perpendicularly on a thin LiF target on carbon backing. LiF films with a thickness of 100 μg/cm^2 and density of 2.635 g/cm^3 were deposited on carbon backing films of thickness 30 μg/cm^2 and density 2.25 g/cm^3. The same three target samples (#1, #2 and #3) were used in the experiments. The area to which the beam is irradiated for each target was divided into three: left, center and right. Targets were mounted onto target frames which were fixed to the rotatable target wheel in a target chamber under 10^{-6} Torr vacuum. A Faraday cup inside the target chamber can be maneuvered into the beam path periodically to measure the absolute beam current. During the experiments, the currents were measured as around from 1.0 to 6.6 nA corresponding to 1.6×10^{9} to 1.0×10^{10} ions/s.

2.2. Calculation of target lifetime

Yntema and Nickel have made a significant contribution to the development of the model for destruction of the thin target in heavy ion beam. The durability of solid target when bombarded with heavy ions is mainly determined by sputtering, thermal evaporation and lattice damage caused by radiation [1].

The energy loss of energetic heavy ions caused by elastic atomic collisions with target atoms, which is named as nuclear stopping power $(\frac{dE}{dx})_n$, can lead to atomic displacements in solid state targets. The lifetime (t_D) of thin targets as determined by lattice damage and stress was suggested by Nickel et al. (1969) [1] to be

$$t_D \approx \frac{N_0}{2\dot{N}_D}. \tag{1}$$

$\dot{N}_D$ is the time rate of atomic displacements per unit volume caused by heavy ions. N_0 is the atomic density of the target. The calculated lifetime from the equation (1) is in agreement within an order of magnitude with the measurements at low target temperature.

Electronic stopping powers in C and LiF film calculated by TRIM [2] are 1.10 kev/nm and 1.14 kev/nm, respectively, but they cannot exceed the thresholds for electronic sputtering of LiF [3] and C [4]. Also, nuclear sputtering yields in both C and LiF films are negligible as they are less than 0.0 using TRIM.

The temperatures for sublimation of LiF and graphite estimated by using Clausius-Clapeyron relation were around 513 and 1970℃, respectively, given the pressure 1.0×10^{-6} torr from the experience. When the continuous beam intensity is 1.0×10^{10} ions/s, the calculated maximum temperature is 42.7℃ at the center of beam path. It is small compared to the sublimation temperatures for LiF and graphite, and thermal sublimation(evaporation) rates of LiF and graphite are calculated as zero using Hertz–Knudsen equation. It was calculated that sputtering and thermal evaporation did not affect the target lifetime under the given experimental conditions.

Table I: Comparison of calculated lifetime and time to rejection in the experiment

	Sample#1 center	**Sample#1 right**	**Sample#1 left**	**Sample#2 center**	**Sample#2 right**	**Sample#3 center**
Fluence (ions/cm^2)	4.59E+16	4.82E+16	3.73E+16	4.34E+16	2.90E+16	1.19E+16
DPA (Displacement/atom)	6.23E-01	6.54E-01	5.06E-01	5.89E-01	3.93E-01	1.61E-01
Average intensity (ion/s)	4.39E+09	4.72E+09	6.07E+09	5.35E+09	3.18E+09	5.39E+09
Experimental lifetime (hour)	22.8	22.3	13.4	17.7	19.9	4.8
Calculated lifetime (hour)	20.3	18.9	14.7	16.6	28.0	16.5

For the estimation of the lifetime of the target as determined by lattice damage, $\dot{N}_D$ (displacements/cm^3/s) for each material could be derived from Monte Carlo Calculation of TRIM using full cascade model and FLUKA [5]. 1.4 eV [6] and 21 eV [7] of displacement energies for LiF and graphite were taken in the calculation, respectively. Displacement energy in alkali halides such as LiF could be much less than that in metal, semi-conductor and II-VI compounds [6]. The average lifetime in beam diameter spot determined derived from the equation (1) can be expressed as a function of beam intensity as shown below in Fig. 1.

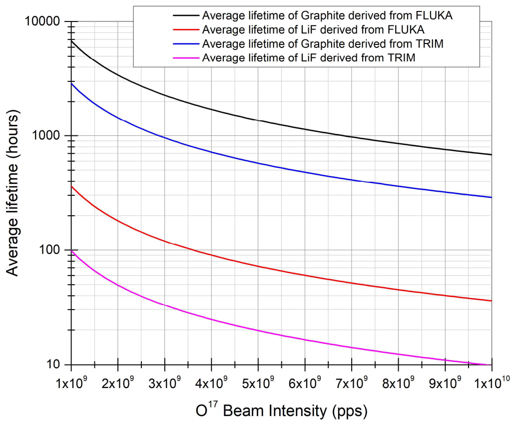

Fig. 1. Average lifetime of carbon and LiF in beam diameter spot as a function of ^{17}O beam intensity.

2.3. Results

Target areas exposed to different intensities and different fluences at beam diameter spot were degraded and perforated in around beam diameter spot size by lattice damage. Using equation (1), lifetime of the target was calculated with $\dot{N}_D$ obtained from TRIM. And calculated lifetime of the target is compared to the experimental lifetime which is the period of being used before disposal as shown in table I. Calculated lifetime of the target with LiF deposited on carbon is determined as the calculated lifetime of only LiF film, not carbon film due to long lifetime as shown in Fig. 1. LiF film is degraded due to lattice damage, and the moment LiF film may be perforated or torn, carbon film which has been intact may be also torn together. Calculated lifetime of each target area is quite in agreement with the time taken until the disposal of the target in the experiment except the cases of sample#3 center and sample#2 right. There is no clear definition that when the target should be discarded, and equation (1) also has an error of one order, so the difference between calculated and experimental lifetime is inevitable to some extent.

3. Conclusions

There is big difference of about two order of magnitude in the target lifetime derived by TRIM and FLUKA. Industry-graded Monte Carolo codes such as FLUKA, PHITS, etc other than TRIM do not attempt to simulate displacement cascades atomistically. There was a prior study [8] which reported a quite difference in the displacement obtained with FLUKA and TRIM as well. One cannot say that any of these values is definitely right or wrong, but in this study, TRIM gives better agreement with experimental data in calculation of the lifetime of target.

The lifetime of thin LiF film as determined by lattice damage was calculated for the first time using the equation (1) Nickel et al. suggested, and there was good agreement between the calculated and the experimental lifetime.

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