Study of low energy proton induced reaction on lead-bismuth eutectic target

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Introduction

Lead-bismuth eutectic (LBE), an alloy of ~45.5% of Pb and ~55.5% of Bi by weight, is a fascinating material from the design point of view. It is solid at room temperature. Due to its low melting point (398°K) and high boiling point (2013°K for Pb and 1833°K for Bi) it stays in the liquid phase over a wide range of temperature. Therefore, LBE was found suitable to be used as a coolant material; proton to neutron converter in the next generation EURISOL facility [1], etc.

Study of low energy proton induced reaction is of interest as it is expected as an end process while tons of LBE is bombarded by high energy protons of energy ~0.5–1.5 GeV. In order to understand the behaviour of the LBE target and the quantity of the products in the laboratory scale experiment, we have studied the low energy proton (9-18 MeV) induced reaction on thin LBE target.

Experimental

The proton beams of 8.9, 12, 15 and 18 MeV energy obtained from the Variable Energy Cyclotron Centre (VECC), Kolkata, India, was used to irradiate the LBE targets of 4.8 mg/cm^2 thickness and 1 cm radius. To prevent the damage of the target from the heating effect, the target was backed by the aluminium foil and was cooled by the circulated chilled water. The total dose of each reaction was measured by a Faraday cup placed at the rear of the target assembly and connected to a current integrator. The thickness of the LBE targets, energies of the proton beams, irradiation times and the proton dose have been listed in Table 1.

After the end of bombardment (EOB) the targets were assayed over a long period of time by γ-ray spectrometry using a p-type HPGe detector connected to a digital spectrum analyser (DSA-1000) and Genie-2K software. The detector was calibrated using the standard sources of known activity. The radionuclides produced in the LBE targets were identified following their decay and the characteristic γ-rays.

Table 1. Experimental details of p+LBE reaction

Beam energy (MeV)	LBE thickness (mg/cm^2)	Irradiation time (h)	Proton Dose (μC)
18	4.8	2.7	8580.9
15	4.8	2.8	21665.4
12	4.8	2.8	21567
8.9	4.8	2.5	18220.8

Results and discussion

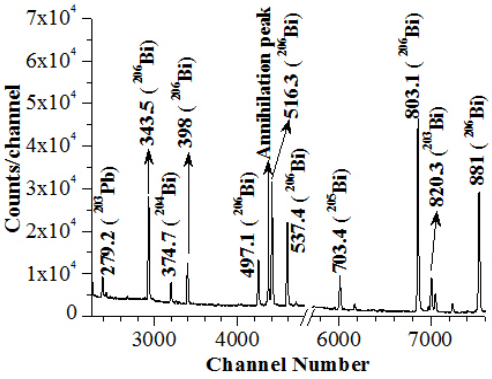

Fig. 1: A γ-ray spectrum of 18 MeV proton irradiated LBE after 2.3 h of EOB.

Analyzing the photo-peaks of the γ-ray spectra taken from the irradiated LBE targets, four radioisotopes of Bi: ^{206}Bi, ^{205}Bi, ^{204}Bi, ^{203}Bi and one radioisotope of Pb: ^{203}Pb(51.8 h), have been identified (Table 2). A γ-ray spectrum of 18 MeV protons irradiated LBE after 2.3 h of EOB

is shown in Fig. 1. ^{205}Bi(15.31 d) and ^{203}Bi(11.76 h) were produced by 15 and 18 MeV protons through the reactions ^{206}Pb(p,2n)^{205}Bi and ^{204}Pb(p,2n)^{203}Bi, respectively, while production of ^{206}Bi and ^{204}Bi were seen at all four proton energies. Possible reactions contributing to the products are listed in Table 2.

Table 2. List of radionuclides with production channels and threshold energy

Isotope ($T_{1/2}$)	Reaction	Threshold (MeV)
^{206}Bi (6.24 d)	^{206}Pb(p,n)	4.6
	^{207}Pb(p,2n)	11.3
^{205}Bi (15.31 d)	^{206}Pb(p,2n)	11.6
^{204}Bi (11.22 h)	^{204}Pb(p,n)	5.3
^{203}Bi (11.76 h)	^{204}Pb(p,2n)	12.5
^{203}Pb (51.9 h)	^{204}Pb(p,pn)	8.4

The yields of the product radionuclides at different proton energies are listed in Table 3.

Table 3. Yield of Bi and Pb radio-isotopes at various proton energies

Energy (MeV)	Yield at EOB (kBq)				
	^{206}Bi	^{205}Bi	^{204}Bi	^{203}Bi	^{203}Pb
8.9	1.3±0.1	-	1±0.1	-	-
12	8±0.6	-	4.5±0.3	-	-
15	25.9 ±1.8	9.8 ±0.8	7.6 ±0.6	9 ±0.7	0.5±0.1
18	72.7 ±4.9	34.8 ±2.6	4.7 ±0.5	44.5 ±3.1	3.2±0.2

In Fig. 2, the yields of the radionuclides at the EOB has been plotted with the energies of the proton beam. It is observed that yield of most of the radionuclides increase with the proton energy. Reletively lower yield of ^{204}Bi is estimated throughout the beam-energy set. The presence of ^{204m}Pb is suspected in the proton irradiated LBE target. However, ^{204m}Pb could not be identified because all of its intense characteristic peaks coincide with that of ^{204}Bi.

In case of ^{203}Pb, it has been observed from the γ-ray spectra that the activities of ^{203}Pb were growing with time as ^{203}Bi decays to ^{203}Pb via electron capture process, and it started to decay after 24 hours of the EOB. Thus, the quantity of estimated ^{203}Pb is the cumulative activity of ^{204}Pb(p,pn)^{203}Pb and ^{204}Pb(p,2n)^{203}Bi(EC)^{203}Pb.

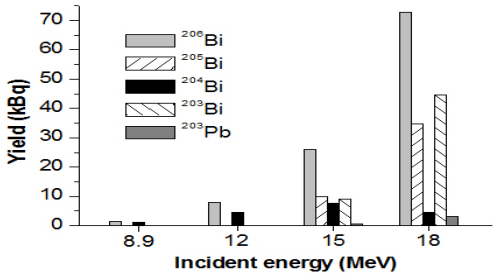

Fig. 2: Yield of the Bi and Pb-isotopes at the EOB as a function of proton energy.

Conclusion

This study indicates that the productions of radionuclides in the low energy proton induced reaction on LBE targets are dominated by neutron emission channels, as expected. Along with the identified radionuclides of Bi and Pb, there might be ^{204m}Pb, which possibly the decay product of ^{204}Bi, produced in the LBE targets. Yield of the radionuclides follows the trend of the excitation functions measured from the p+^{nat}Pb reaction [3,4].

Acknowledgement

Research grants from SERB-DST (SR/FTP/PS-111/2013), SINP-DAE 12 plan project TULIP, and fellowship from MHRD, Government of India, are gratefully acknowledged.

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