Low energy α-particle induced reaction on thick lead-bismuth eutectic target

M. Maiti[1],* S. Lahiri[2], D. Kumar[1], D. Choudhury[2], and A. Singh[1]
[1]*Department of Physics, Indian Institute of Technology Roorkee, Roorkee - 247667, Uttarakhand, INDIA and*
[2]*Saha Institute of Nuclear Physics, 1/AF Bidhannagar, Kolkata-700064, INDIA*

Introduction

Lead-bismuth-eutectic (LBE, Pb-44.5%, Bi-55.5%) alloy has found several applications in the designing of large facilities like spallation target in an accelerator driven subcritical system (ADSS); it has been proposed to use as a converter target in the next generation high power radioactive ion beam (RIB) facility [1]; as a coolant in advanced nuclear reactor [2], etc. It has become appealing because of its low melting point, high boiling point, efficient to generate intense neutron flux, less hazard, chemically inert in nature, and thermodynamic properties. Low energy light particle (A$\leq$4) induced reactions are assumed to be the end part of the reaction chain initiated by high energy (>500 MeV) proton spallation reaction on a very tick target. Study of proton/α-particle induced reactions on LBE target in the low region is therefore necessary to have detailed experimental knowledge on the reaction products and to explore the spallation reaction models.

In this paper, we report a systematic study to explore the interaction of α-particles with LBE target in the low energy range (upto 50 MeV).

Experimental

The experiment was carried out at the Variable Energy Cyclotron Center (VECC), Kolkata, India. Thick LBE foils (6.5 mg/cm^2), backed by aluminum foils of suitable thicknesses, were used as target and α-particle beam having 35-50 MeV energy was allowed to incident on it. Energy degradation in each foil was determined by Stopping and Range of Ions in Matter (SRIM) calculation. Projectile energy at the target is determined by averaging incident and outgoing

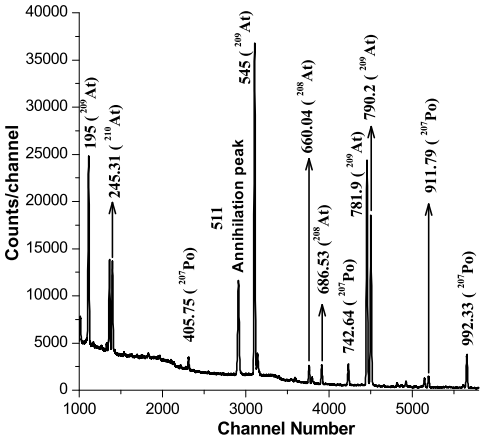

FIG. 1: The γ-ray spectrum of the 50 MeV α-particle activated LBE target after 1.35 h of EOB.

TABLE I: List of reactions leading to the production of major residues.

Nuclides($T_{1/2}$)	Reaction	E_{th}(MeV)
^{210}At(8.1 h)	^{209}Bi(α,3n)	28.6
^{209}At(5.4 h)	^{209}Bi(α,4n)	35.9
^{208}At(1.63 h)	^{209}Bi(α,5n)	44.5
^{207}Po(5.8 h)	^{204}Pb(α,n)	13.8
	^{206}Pb(α,3n)	28.9
	^{207}Pb(α,4n)	35.8
	^{208}Pb (α,5n)	43.3
	^{209}Bi (α,p5n)	47.2

*Electronic address: moumifph@iitr.ac.in

TABLE II: Yield of the radionuclides at various incident energies along with integral charge and irradiation time for 6.5 mg/cm^2 LBE thickness.

Energy (MeV)	Charge (μC)	Irr. time (h)	Yield (kBq) ^{210}At	^{209}At	^{208}At	^{207}Po
35.3	2005.4	0.98	95±12.1	-	-	16.6±2.7
39.8	6266.5	7.3	4061.2±492.9	193.3±29.1	-	993.4±132.8
44.8	2115.7	1.93	162.4±20.8	279.3±36.3	-	105.1±15.1
49.8	2006.8	3.07	85.4±11.2	645±81.4	109.6±15.1	169.2±22.3

beam energy. Beam intensity was measured by a current integrator connected with electron suppressed Faraday cup, situated at the back side of target assembly. After the end of bombardment (EOB), product residues were analyzed using γ-ray spectrometry using a p-type HPGe-detector.

Results and discussion

A γ-ray spectrum of the LBE target irradiated by 50 MeV α-particles is shown in Fig. 1 indicating the residual radionuclides. The possible reaction channels contributing to those products along with their threshold are summarized in Table I. Yields of the major products at various incident energies are tabulated in Table II. Although ^{206}Po (8.8 d), ^{205}Po (1.66 h),^{204}Po (3.53 h), ^{205}Bi (15.31 d) and ^{204}Bi (22.2 h) were identified at 50 MeV projectile energy, however, yield is not reported here because of their low counting statistics.

Although the tabulated yields are not normalized to compare the production of residues at various incident energies, but they follow the trend of cross sections expected from the nuclear model calculation [3]. The ^{207}Po production was contributed by various reaction channels due to the existence of various abundant Pb isotopes: ^{204}Pb(1.4%), ^{206}Pb(24.1%), ^{207}Pb(22.1%), ^{208}Pb(52.4%) in the target matrix (Table I). A significant production of ^{207}Po, which is the main concern due to its toxic properties, is observed at all the incident energies. It is obvious that yield of the residues will be low in LBE compared to that of pure Pb or Bi target.

Conclusion

This study confirms and quantifies the production of ^{210}At, ^{209}At, ^{208}At, and ^{207}Po radionuclides in low energy (35-50 MeV) α-induced reaction on LBE target. Measured yield follows the trend of the theoretical excitation functions of the At-radionuclides obtained from the Hauser-Feshbach model calculation. It also ensures the production of ^{206,205,204}Po, ^{205,204}Bi in α+LBE reaction at 50 MeV, however, their production will eventually increase with increasing energy of the α-particle.

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