Measurement of photo-neutron cross sections in ^{208}Pb with 50-70 MeV bremsstrahlung

H. Naik[a], G. Kim[b], D. Raj[c], S.V. Suryanarayana[d], Y.D. Oh[e], M.W. Lee[e], A. Goswami[a], S. Ganesan[c] and V.K. Manchanda[a]

[a] *Radiochemistry Division, Bhabha Atomic Research Centre, Mumbai-400085, India.*
[b] *Dept. of Physics, Kyungpook National University, Daegu 702-701, Republic of Korea.*
[c] *Reactor Physics Design Divisison,* [d] *Nuclear Physics Division, BARC, Mumbai-400085, India.*
[e] *Pohang Accelerator Laboratory, POSTEC, Pohang 790-784, Republic of Korea.*
E-mail: naikh@barc.gov.in

In ADSs high energy (GeV) proton from accelerator strikes a heavy element like Pb and Bi yielding large number of neutrons by spallation reaction. The spallation target becomes a source of neutrons, which drives fission chain in a sub-critical core. In the spallation processes, along with high-energy neutrons, high-energy photons are also produced, which can cause fission and different types of nuclear reactions of the Pb or Bi target and long-lived minor actinides in the sub-critical core. Among the different types of nuclear reactions, photo-neutron emission is one of the important exit channels. The photo-neutron can add to the neutron flux resulting from spallation, which can cause an increase of the total neutron flux. Thus it is important to measure the photo-neutron cross-section in the high energy photon-induced reaction of Pb and Bi. In view of this, in the present work the (γ,5n) reaction cross-sections (σ_R) of ^{208}Pb induced by 50, 60 and 70 MeV bremsstrahlung have been measured for the first time using off-line γ-ray spectrometric technique in the 100 MeV electron linac at the Pohang Accelerator Laboratory [1].

Experimentally bremsstrahlung was generated by impinging electron beam on a 0.1 mm thick W metal foil of size 10 cm x 10 cm placed at a distance of 18 cm from the beam exit window. A vacuum deposited metal target of ^{208}Pb of thickness 2 mg/cm^2 on Al backing along with 0.1 mm thick Cu foil was wrapped with Al foil and was fixed at a distance of 12 cm behind the W metal foil [1]. Different set of target of ^{208}Pb and Cu were made for different irradiation. The target assembly was irradiated for 2-4 hours with bremsstrahlung photon produced by bombarding the 50-70 MeV electrons on the tungsten foil. The current of the electron beam during irradiation was 10-15 mA at 3.75 Hz with a beam width of 1.5 μs. The irradiated target was cooled for 30 minutes. Then the irradiated target of Pb and Cu metal along with the wrapper were taken out from the irradiated assembly and were mounted separately on different Perspex plates [1]. The γ-ray counting of the reaction products from ^{208}Pb and ^{63,65}Cu were done in live mode by using an pre-calibrated HPGe detector coupled to a PC based 4K-channel analyzer. The resolution of the detector system was 1.8 keV at 1332.5 keV of ^{60}Co.

The photo-peak area of the 279.2 keV γ-ray of reaction product ^{203}Pb having half-life of 51.87 h was calculated by subtracting the linear Compton background from their total net area. The numbers of detected γ-rays (N_{obs}) under the photo-peak of individual nuclide are related to the photo-neutron reaction cross-section (σ_R) as

$$N_{obs} = n\sigma_R \Phi a\, \varepsilon\, (1 - e^{-\lambda t})\, e^{-\lambda T}\, (1 - e^{-\lambda \Delta T})/\lambda$$

where n is the number of target atoms, Φ is the photon flux. The t, T and ΔT are the irradiation, cooling time and counting time respectively. 'ε' and 'a' are the efficiency and branching intensity [2] of the γ-rays of reaction product. The photon flux Φ during individual irradiation was obtained from the N_{obs} of the 1345.8 keV γ-line of ^{64}Cu from ^{65}Cu(γ, n) reaction and using the σ_R value from ref. [3]. Using the data of n, Φ, a, ε the ^{208}Pb (γ, 5n) reaction cross-section induced by bremsstrahlung photon at 50-70 MeV were determined using Eq. (1) and given in Table 1.The (γ,5n) reaction cross-section in the 50, 60 and 70 MeV bremsstrahlung induced reaction of ^{208}Pb were also calculated theoretically using TALYS 1.0 code [4] and are given in Table 1 along with experimental values.

It can be seen from Table 1 that the theoretical values are in good agreement with the experimental

data. It can be also seen from Table 1 that both theoretical and experimental data of (γ,5n) reaction cross-sections in bremsstrahlung induced reaction of ^{208}Pb increases from 50 MeV to 70 MeV, which indicates the role of excitation energy. The ^{208}Pb(γ,5n) reaction at bremsstrahlung energy of 50, 60 and 70 MeV was also compared with the data of ^{209}Bi(γ,5n) reaction from ref. [5]. At all energies both theoretical and experimental (γ,5n) reaction cross-sections of ^{208}Pb is higher than the value in ^{209}Bi. The nuclei $_{82}$Pb^{126} is doubly magic shell nucleus, whereas the $_{83}$Bi^{126} is singly magic shell nucleus. Thus at the end point bremsstrahlung energy of 50-70 MeV, the (γ,5n) reaction cross-section of ^{208}Pb should be less than ^{209}Bi from the magic shell point of view. This opposite observation may be either due to the fact that the shell effect is washed out at higher excitation energy or due to the competition between fission and neutron emission. It is known from TALYS calculation [4] that at same excitation energy ^{208}Pb has lower fission cross-section compared to ^{209}Bi because of the lower fissility parameter of the former than later. Thus at the same excitation energy, the (γ,xn) reaction cross-section of ^{208}Pb has to be higher than that of ^{209}Bi due to lower fission cross-section of the former than later. These data are important from ADS point of view because ^{nat}Pb and ^{209}Bi are proposed spallation source for neutron (gamma) production.

Acknowledgement

The authors would like to express their sincere thanks to the staff of the PAL, POSTEC for their co-operation during experiment. One of the author (Dr. H. Naik) thankful to Dr. V. Venugopal, the Director of RC & I Group, BARC for giving him permission to visit the PAL, Pohang to carry out the experiment.

References

[1]. H. Naik et al., Eur. Phys. J A **41**, 323 (2009).
[2]. E. Browne and R. B. Firestone, Table of Radioactive Isotopes, ed. V.S.Shirley(1986); R. B. Firestone, L. P. Ekstrom, Table of Radioactive Isotopes, 2004.
[3]. S. Shibata et al., Phys. Rev. C **35**, 254 (1987).
[4]. A.J. Koning, S. Hilaire and M.C. Duijvestijn, "TALYS: Comprehensive nuclear reaction modeling" Proc. of the International Conf. on Nuclear Data for Science and Technology-ND 2004, AIP Vol. 769, eds. R.C. Haight, M.B. Chadwick, T. Kawano and P. Talou, Sept. 26- Oct. 1, 2004, Santa Fe, USA P. 1154 (2005).
[5] H. Naik et al., Int. Sym on NAC-IV, 15- 19 November 2010, BARC, Mumbai.

Table1. The ^{208}Pb (γ,5n) and ^{209}Bi (γ,5n) cross-sections in bremsstrahlung induced reaction.

	^{208}Pb(γ,5n)		^{209}Bi(γ,5n)	
E_γ (MeV)	Expt.σ (mb) Present work	Theoretical σ (mb) fromTALYS	Expt.σ (mb) Ref. [5]	Theoretical σ (mb) from TALYS
50	0.055±0.010	0.05062	0.058±0.006	0.04178
60	0.145±0.025	0.16461	0.149±0.015	0.15030
70	0.187±0.024	0.20909	0.171±0.019	0.19544