Induced activity in ^{nat}Pb by 200 MeV proton beam

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Introduction

Accelerator driven subcritical system (ADSS), as a tool for nuclear energy generation, has induced interest among the nuclear engineering and technology community [1] after the work of Bowman [2] and Carlo Rubia [3] late in 1990's. ADSS which employs an accelerator coupled to a subcritical reactor is even more relevant in Indian context as the hybrid reactor system can use abundantly available ^{232}Th as fuel. An ADSS uses proton induced spallation reaction as the source of neutrons, at beam energies of several GeV with a few mA beam current. At such operating parameters, the ADSS target needs to fulfill certain criteria, like high neutron yield, hard neutron spectrum, high boiling point, low possibility of fire hazard, low yield of radio- and chemical toxicity [4,5]. Pb has turned out to be one of the suitable targets for ADSS satisfying these requirements. In ADSS, thick targets are used, such that the projectile beam is completely stopped inside the target and the full energy and flux of the primary beam can be used for production of neutrons. The target property studies for an ADS system are often carried out at energies of few tens to hundreds MeV which are easily available. In order to decide the operating parameters for such studies, for better planning of the experiment and final disposal of the radioactive target, one needs to know, among other factors, the amount of radioactivity generated in the system due to interaction of the proton beam and secondary neutrons. In the present work we have estimated the radioactivity induced in a thick ^{nat}Pb target, from 200 MeV, 1 mA proton beam and the secondary neutrons produced thereof, using the nuclear reaction model code ALICE91 [6].

Reaction model calculation

ALICE91 [6] is a well-known reaction model code used to calculate preequilibrium (PEQ) and equilibrium (EQ) reaction cross sections. We have estimated excitation functions of different radioisotopes formed in the thick ^{nat}Pb target by the incident proton beam and by the secondary neutrons produced using ALICE91. In calculating the EQ cross sections Fermi gas (FG) level density option has been chosen. Total yield of the product isotope and its activity are determined from the calculated excitation function. Attenuation of the projectile flux and energy at different depths inside the thick target is calculated using the computer package SRIM [7]. The total yield and activity of a radioisotope is determined from the weighted sum of the yield calculated from the production cross sections at varying projectile energies at different depths in the target [8].

Results and Discussion

We have followed the build-up of induced activity due to the product isotopes formed by the interaction of protons and secondary neutrons in a thick ^{nat}Pb target for irradiation periods of 5 hours to one month. The reaction model code ALICE91 used for the purpose calculates the total production cross section, but does not distinguish between formation in the ground state and in the excited state of the product. In such cases we have considered production of the isotope in a state so as to give a conservative estimate of the activity induced for that isotope. Our analysis shows that due to interaction of proton beam in the target, activity of the order of 10^4 – 10^7 MBq are produced for $^{201\text{-}208}$Bi, $^{200\text{-}203,205}$Pb, $^{199\text{-}202,204}$Tl, ^{197}Hg isotopes. For the irradiation period considered saturation activity is formed for $^{201\text{-}204}$Bi, $^{200\text{-}203}$Pb, $^{199\text{-}201}$Tl, ^{197}Hg. In table 1 we have given the half lives and decay modes of these isotopes. In figure 1 we have shown the build-up of activity for ^{201}Bi, ^{202}Pb and ^{204}Tl. Interaction of secondary neutrons also leads to the formation of $^{200-203,205}$Pb, $^{204,206-208}$Tl, ^{197}Hg radioisotopes in the Pb target with activities of the order of 10 – 10^5 MBq. Almost all the radioisotopes formed by the interaction of proton and secondary neutrons have characteristic γ emission above 200 keV. Precaution should be taken against external exposure from the target after accelerator operation is stopped. ^{201,202}Bi are alpha emitters. Hence these should be guarded against internal contamination.

Table 1: Half lives and decay modes

Isotope	Half life	Decay mode
^{201}Bi	108m	ε, α
^{202}Bi	1.72 h	ε, α
^{203}Bi	11.76 h	ε
^{204}Bi	11.22 h	ε
^{200}Pb	21.5 h	ε
^{201}Pb	9.33 h	ε
^{202}Pb	3.53 h	IT, ε
^{203}Pb	51.92 h	ε
^{199}Tl	7.42 h	ε
^{200}Tl	26.1 h	ε
^{201}Tl	72.9 h	ε
^{197}Hg	64.14 h	ε

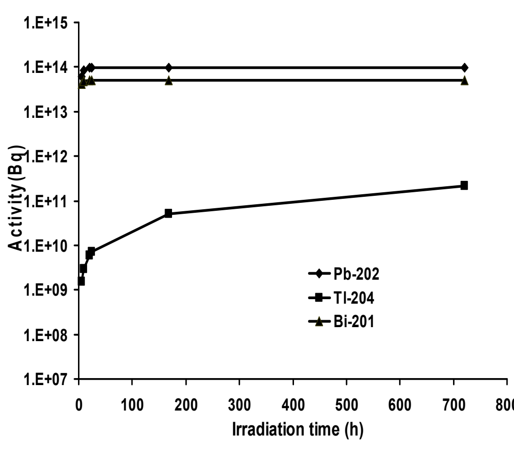

Fig. 1 Build-up of activity of ^{201}Bi, ^{202}Pb and ^{204}Tl from p + ^{nat}Pb reaction at 200 MeV, 1 mA

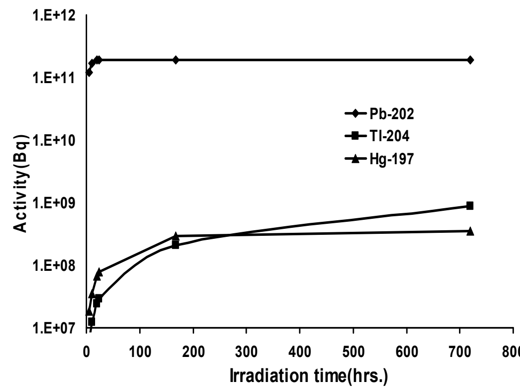

Fig. 2 Build-up of activity of ^{201}Bi, ^{202}Pb and ^{204}Tl due to secondary neutrons

Conclusion

From the present study it has been observed that significant activity of α and γ emitting radioisotopes are formed due to reaction induced by the primary proton beam and secondary neutrons in the thick Pb target at 200 MeV beam energy and 1 mA beam current. These results constitute important nuclear data for target property studies of an ADSS as Pb has turned out to be one of the preferred targets for ADSS.

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