Heavy ion induced nuclear reactions: cross-section measurements and its applicability in thin layer activation analysis

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Thin layer activation (TLA) technique is one of the promising tools widely used for material performance studies such as surface wear, corrosion, erosion etc., in the micrometer range using the charged particle induced nuclear reactions [1]. In this technique, a small section of material is exposed to an energetic beam of charged particles, so as to produce a thin radioactive surface layer. Several developments have been made in TLA technique for the investigation of surface wear of newly up-coming technological improvements [2-3]. In the last two decades, several industries including nuclear reactor technology are using the TLA technique for material performance study. The sensitivity of this technique is high due to its capability of low level radioactivity detection by γ-ray spectroscopy. In the present work, TLA technique has been explored using γ-ray spectroscopy for several isotopes populated in different heavy ion (HI) reactions, which may be of interest for the reactor technology [4]. Since, HI beam loses energy very quickly in the material, so it produces an extremely thin layer of activity in the surface. Aiming to investigate the surface wear study, we have measured the cross-sections of various reactions from the ^{16}O induced reactions on isotopically pure targets ^{130}Te, ^{159}Tb, ^{169}Tm & ^{181}Ta in order to apply HI activation in the TLA technique. The experimental cross-sections of nuclear reactions leading to residues are very important to be known for the yields of the products before its application in a particular material.

The experiments have been performed, employing energetic $^{16}O^{7+}$ beam, from the 15UD-Pelletron accelerator, of the IUAC, New Delhi, India. For the measurement of cross-sections, targets of ^{130}Te, ^{159}Tb, ^{169}Tm & ^{181}Ta of thicknesses ≈1.5-2.0 mg/cm^2 have been used. After each target an Al foil of suitable thickness was used as catcher foil. The irradiations have been carried out in the General Purpose Scattering Chamber having in-vacuum transfer facility. The irradiations have been carried out for the duration of ≈8-12 h, with a beam current ≈3-6 pnA. Off-line γ-ray spectroscopy using a pre-calibrated HPGe spectrometer has been employed for the detection of activities in the sample. The reaction residues have been identified on the basis of their characteristic γ-ray energies and measured half-lives. The intensities of the γ-lines have been used to determine the production cross-sections of the residues populated via different reaction channels. In these experiments the stacked foil activation technique has been employed for the determination of the yield of the radioactive isotopes at different energies. The measured EFs have been used to provide the practical yield curves and the activity versus depth distribution curves, which can be used as a direct tool to investigate the surface wear of different materials.

The experimental cross-sections have been compared with theoretical calculations based on the code PACE4 to test the validity of the model predictions. It is known [5-6] that HI induced nuclear reactions are dominated by complete fusion (CF) and incomplete fusion reaction mechanism. At lower energies the reaction proceeds mostly through CF mechanism, where the entire angular momentum of projectile is transferred completely to the composite system. In the framework of a systematic study, activation technique has been used to measure

the yields of ^{194,193,192}Tl and $^{193,192,\ 191}$Hg, ^{141}Nd, ^{172,171,170}Ta and ^{171,170}Hf, ^{182,181}Ir and ^{182,181}Os isotopes at different energies ranging from Coulomb barrier to well above it i.e., at different depths.

Table 1: Experimentally measured cross-sections for the residues populated via xn (x=1-3) channels in the interaction of ^{16}O with the ^{181}Ta.

^{16}O+^{181}Ta system			
E_{Lab} (Mev)	σ(^{194}Tl) (mb)	σ(^{193}Tl) (mb)	σ(^{192}Tl) (mb)
76 ± 1.1	4 ± .6	26 ± 4	–
80 ± 1.5	12 ± 2	45 ± 7	44 ± 6.6
85 ± 1.2	8 ± 1	68 ± 10	122 ± 18
87 ± 1.0	6 ± 1	46 ± 7	88 ± 13
88 ± 1.6	4 ± .6	44 ± 6	182 ± 27
93 ± 1.1	4.5 ± .7	35 ± 5	368 ± 55
97 ± 1.0	3.5 ± .5	15 ± 2	342 ± 51
99 ± 0.9	2 ± .2	17 ± 2	444 ± 66

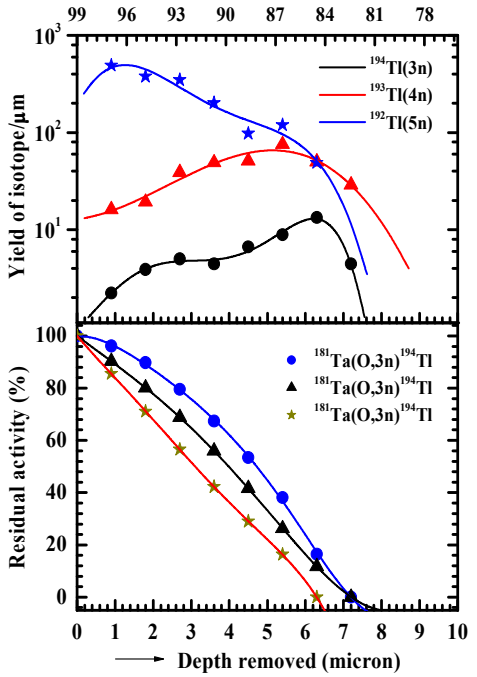

FIG. 1(a). The yield curves and (b) calibration curves for ^{194,193,192}Tl isotopes populated via ^{181}Ta(^{16}O,xn); x=1-3, reactions.

As a typical example, the yield per micron thickness against the depth as well as incident energy for ^{194,193,192}Tl isotope produced via ^{181}Ta(^{16}O,xn); x=1-3 reaction channels is shown in Fig.1(a). In order to compute the net yield of a particular isotope in the thick target by the absorption of different energies of ^{16}O, the integral area of the curve from the front surface to the final depth from where the given isotope's production threshold has been obtained. The calibration curves deduced from the yield curves have been plotted and is shown in Fig. 1(b), for ^{194,193,192}Tl isotopes populated via complete fusion channels. As a matter of fact, the calibration curve may be considered as to correspond to pure metal bombarded with approx 100 MeV ^{16}O beam normal to the beam direction. Further details of the technique, methodology adopted and results will be presented.

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REFERNCES

[1] D.P. Chowdhury et. al., Nuclear Instruments and Methods in Physics Research B 211 (2003) 288; 251 (2006) 484.
[2] F. Ditroi, I. Mahunka, Nucl. Instr. and Meth. B 113 (1996) 415.
[3] O. Lacroix, et al., Nucl. Instr. and Meth. B 122 (1997) 262.
[4] Rubbia C. et. al., 1995. Conceptual design of a fast neutron operated high power energy amplifier, Report, European Organization for Nuclear Research CERN/AT/95-44(ET).
[5] D. P. Singh et. al., Physical Review C 80, 014601 (2009); Physical Review C 89, 024612 (2014).
[6] M. K. Sharma et. al., Nuclear Physics A 776 (2006)83; Physical Review C 70, 044606 (2004).