Investigation on the production of evaporation residues in ^{11}B+ ^{nat}Y reaction: ^{97}Ru is a notable product

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Introduction

Ruthenium-97 (2.83d) is one of the well estimated radionuclides for clinical applications. It emits two characteristics gamma lines via EC decay mode corresponding to 215.70 keV (85.62%) and 324.49 keV (10.79 %) energy. Its suitable half-life, intense low lying γ-energy peaks and high chemical reactivity have enabled it for diagnostic as well as therapeutic purposes. ^{97}Ru-tagged compounds have already been used *in vivo* for diagnosis and to track delayed metabolic processes [1].

Due to its versatile applications attention is required to its simple, fast, efficient, and economical production. Neutron activation of ^{96}Ru may be the low cost method to produce ^{97}Ru, but it does not lead to the no-carrier-added product which is the prerequisite of *in vivo* studies. Moreover 100% enrichment of ^{96}Ru is hardly possible due to its low natural abundance (5.52%). Therefore ^{103}Ru will be present in the matrix as a contaminant. Production of ^{97}Ru have already been explored via light particle reactions like ^{nat}Ag(p,X)^{97}Ru, ^{nat}Rh(p,2p5n)^{97}Ru, ^{99}Tc(p, 3n)^{97}Ru, ^{nat}Mo(^{4}He,xn)^{97}Ru, ^{nat}Mo(^{3}He, xn)^{97}Ru etc., and heavy-ion induced reactions like ^{93}Nb(^{7}Li, xn)^{97}Ru [2], ^{nat}Y(^{12}C,xn)^{97}Ru [3], by several groups including us. Although proton induced reactions show high cross section but have several drawbacks such as requirement of high energy, use of radioactive target such as ^{99}Tc, etc. Similarly, α-induced reaction produces ^{97}Ru along with other Ru-radioisotopes and Tc-radionuclides. Therefore exploration of its production through heavy-ion induced reactions route became a necessity.

Theoretical estimation

In order to understand the possible production of residues in the ^{11}B + ^{89}Y reaction above the threshold, theoretical calculation was carried out using evaporation model code PACE4 that uses Houser-Feshbach compound nuclear reaction model. Gilbert-Cameron level density parameter is used because of low excitation energy. The cross sections of the residues estimated from PACE4 from ^{11}B + ^{89}Y nuclear reaction are shown in fig.1. It is observed from the figure that there is a large energy window (~30-48 MeV) for the production of ^{97}Ru. Although minute possibility of the production of ^{96}Tc and ^{93m}Mo along with ^{97}Ru are seen towards the high energy end (above 40 MeV), but pure ^{97}Ru can be produced within 30-40 MeV energy window with appreciable cross-section (~500 mb at 38 MeV). These facts prompted us for the study of above reaction experimentally.

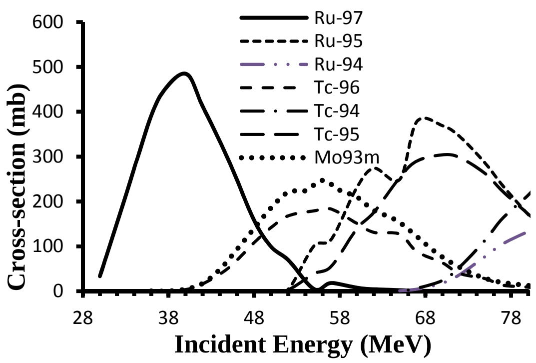

Fig. 1. Theoretical excitation functions of residues from (^{11}B+^{89}Y) reactions as obtained by PACE4

Experimental

The experiment was carried out at the BARC-TIFR Pelletron facility, Mumbai, India. Pure (99.9%) metal Y foils of thickness 2.80 mg/cm^2 were used as target material. A target stack was prepared coupling two of such Y metal foils with a proper Al backing (thickness of 1.70 mg/cm^2 behind them and 40 MeV boron beam (^{11}B^{4+}) was allowed to incident on the stack for 7.5 h up to a total dose of 267.82 μC. After the end of bombardment (EOB), γ-spectroscopic studies were carried out to analyze the residual products using an n-type HPGe detector coupled with a Digital spectrum analyzer (DSA) and GENIE-2K software (Canberra). An observed spectrum after 1.8 h of EOB is shown in fig.2.

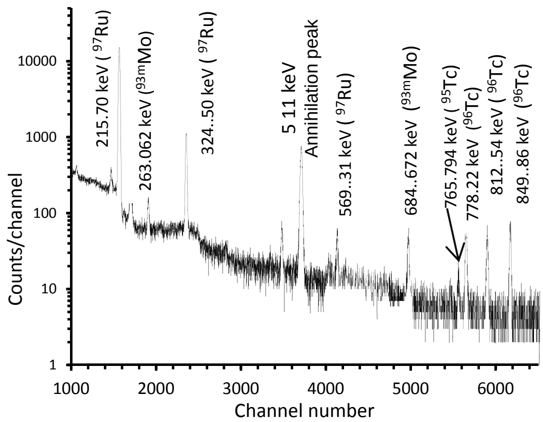

Fig. 2. The γ-ray spectrum of the 40 MeV ^{11}B activated yttrium foil after 1.8 h of the EOB.

Results and discussion

Production of neutron deficient ^{97}Ru was confirmed along with ^{96}Tc, ^{93m}Mo radionuclides in (^{11}B + ^{89}Y) reaction. Measured cross-sections of the residues at two energies: 40 and 33 MeV are compared with theoretical calculation of PACE4 in fig.3.

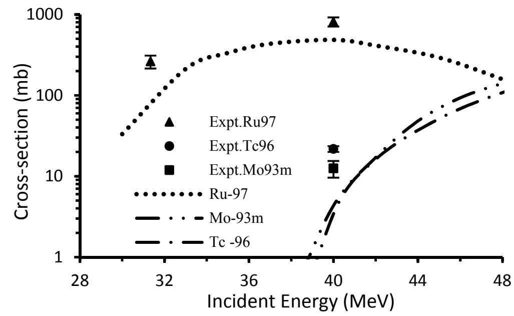

Fig.3. Comparison between measured cross-sections of ^{97}Ru, ^{96}Tc, ^{93m}Mo with theoretical predictions.

It is clear from fig. 3 that at 33 MeV incident energy, only ^{97}Ru radionuclide is produced as predicted by theoretical calculation and at 40 MeV incident energy, ^{96}Tc, ^{93m}Mo radionuclides are produced along with ^{97}Ru as predicted by the theoretical model. However experimental data slightly over predict the theoretical estimation. It is interesting to note that production cross-sections of ^{96}Tc, ^{93m}Mo are very small compared to ^{97}Ru (~800 mb) at 40 MeV (table. 1). The higher cross section obtained in the present experiment might be due to the contribution from direct or pre-equilibrium reactions occurred above the coulomb barrier. However the measurement confirms that no-carrier-added (nca) ^{97}Ru can be produced with maximum 2.5% contamination from ^{96}Tc in the projectile energy range 30 - 40 MeV.

Table 1. Nuclear spectroscopic data [4] & cross-section

Product ($T_{1/2}$)	E_γ(keV)(I_γ%)	Cross-section (mb) 33MeV	Cross-section (mb) 40MeV
^{97}Ru(2.83d)	215.70 (85.6)	262±47.6	814±103.8
^{96}Tc(4.28d)	812.54(82.0) 849.86(98.0)	---	21.7±1.4
^{93m}Mo(6.85h)	263.06(56.7) 684.67(99.7)	---	12.5±2.9

Conclusion

This study indicates that the ^{11}B induced reaction on natural Y is also an efficient route for the production of nca neutron deficient ^{97}Ru. Although cross-sectional data are obtained just at two energies and not sufficient to derive significant conclusion on the reaction mechanism, but the measured cross-sectional data are in agreement with Houser-Feshbach model estimation. The data also shed light on the compound nuclear reaction as a major contributor. We look forward to study the reaction in the energy range ~30-70 MeV in near future.

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References

[1] H.S. Shao, G.E., Meinken, S.C. Srivastava, D. Slosman, D.F. Sacker, P. Som, A.B. Brill, J. Nucl. Med. 27, 1044 (1986).
[2] M. Maiti, S. Lahiri, Radiochim Acta 99, 359 (2011).
[3] M. Maiti, Radiochim. Acta 101, 437 (2013).
[4] http://groups.nscl.msu.edu/lise