Measurement of neutron and bremsstrahlung induced activation cross-section for tantalum with statistical error analysis

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Introduction

Tantalum is used as bremsstrahlung target in Medical LINACs. ^{180}Ta has importance in nuclear physics as it is a classic example of spin trap isotope. The natural Tantalum consists of two isotopes, namely, ^{180m}Ta and ^{181}Ta with isotopic abundance 0.012% and 99.988% respectively. ^{181}Ta is a stable isotope, while ^{180m}Ta is in the meta stable state that decays to ^{180}Ta by isomeric transition. Neutron and bremsstrahlung-induced activation cross-sections of tantalum are needed as it is very crucial for both nuclear fission and fusion applications as well as nuclear database.

The activation cross-sections for the Tantalum have been reported by various authors, but most of them were obtained before 1992, furthermore, there was disagreement in those data with theoretical data from TALYS-1.9 and TENDL. In the present work, we have measured the formation cross-section of ^{181}Ta(n,2n)^{180}Ta nuclear reaction at 14.77 MeV neutron energy and flux weighted average cross-sections of ^{181}Ta(γ,n)^{180}Ta at 10 and 15 MeV bremsstrahlung end point energies using offline gamma spectrometry.

Experimental details

The samples consisted of 1 gram of pure (99.9%) Ta_2O_5 powder in its natural isotopic abundance. The samples were wrapped in Aluminum foil of 0.3 gm for neutron irradiation. The 14 MeV neutron generator of Department of Physics, Savitribai Phule Pune University, Pune was used. The samples were mounted at 0º corresponding to incident deuterium beam, where the energy of neutrons correspond to 14.77±0.17 MeV and irradiated for a period of 3600 seconds. The samples were wrapped in gold foil of 0.5 gm for bremsstrahlung irradiation. The Medical LINAC of Dr. Vikhe Patil Memorial Hospital, Ahmednagar, India was used. After irradiation, the samples were transferred to the counting room for gamma spectrometry. The gamma ray activity of the samples was measured with a lead shielded and pre-calibrated HPGe detector having 1.5 keV energy resolution at 1.33 MeV gamma energy. The data acquisition was carried out with an Ortec Manufactured Easy MCA 8k coupled with PC based Maestro software.

Data analysis

The neutron induced cross-sections of reaction ^{181}Ta(n,2n)^{180}Ta was measured using the activation Eq. (1):

$$\sigma_S = \sigma_m \frac{F_S C_S M_m a_m A_S \epsilon_m I_{\gamma m} f_{\lambda S}}{F_m C_m M_S a_S A_m \epsilon_S I_{\gamma S} f_{\lambda m}} \qquad (1)$$

Where, the subscript s and m corresponds to parameters belonging to Tantalum and monitor reaction of aluminum respectively. σ is the reaction cross-section for a nuclear reaction, F is total correction factor due self-absorption and true coincidence summing effect, C is counts under gamma peak, M is the mass of the samples, a is isotopic abundance, A is atomic mass, ε is detector efficiency at corresponding energies, I_γ is gamma peak intensity and f_λ is timing factor given in Eq. (2).

$$f_\lambda = \frac{\lambda}{(1-e^{-\lambda t_1})e^{-\lambda t_2}(1-e^{-\lambda t_3})} \qquad (2)$$

Where, λ is the decay constant, t_1, t_2 and t_3 are the irradiation, cooling and counting time respectively used for the samples. The ^{27}Al(n,α)^{24}Na reaction was used as neutron flux monitor and 1368.626 keV (99.99) was used. Product ^{24}Na has a half-life of 14.996 hours. The cross-section data was adopted from IRDFF-II library [1].

The flux weighted average cross-sections of bremsstrahlung induced nuclear reaction ^{181}Ta(γ,n)^{180}Ta was calculated by modifying the eq. 1 to get eq 3:

$$\sigma_S = \frac{<\sigma_{Au}>}{CF}\frac{F_S C_S M_{Au} a_{Au} A_S \epsilon_{Au} I_{\gamma Au} f_{\lambda S}}{F_{Au} C_{Au} M_S a_S A_{Au} \epsilon_S I_{\gamma S} f_{\lambda Au}} \quad (3)$$

Where all the parameters have the same meaning as in Eq. (1), except $<\sigma_{Au}>$ is the effective cross-section of the monitor reaction calculated with Geant4 [2] simulated bremsstrahlung curve and TALYS 1.95 cross-section [2], and CF is the flux correction factor for difference in the threshold energy of monitor and sample reaction. The ^{197}Au(γ,n)^{196}Au reaction was used as bremsstrahlung flux monitor and 355.73 keV (87%) was used. Product ^{196}Au has a half-life of 6.16 days. The uncertainty in the measured cross sections was estimated following the procedure described in literature [3,4]. The error $\Delta\sigma$ in the measured cross section σ can be obtained by quadratic summation of attributes of Eq.1.

Results and discussion

The measured cross-sections of the neutron induced reactions for ^{181}Ta are given in Table 1. The measured cross-sections are compared with all the cross-sections previously reported to EXFOR database and TENDL 2019 data library. The results agree with recent author Bhatia et al. (2013) [5].

Table 1: Measured Neutron induced nuclear reaction cross-sections for ^{181}Ta

Reaction	Cross-section (mb)	Talys 1.95 (mb)
^{181}Ta(n,2n)^{180}Ta	1247.75±102.9	1192.93

The measured cross-sections of the bremsstrahlung induced reactions on ^{181}Ta is given in Table. 2.

Table 2: Measured bremsstrahlung induced nuclear reaction cross-sections for ^{181}Ta

Reaction	10 MeV Energy		15 MeV Energy	
	Cross-section (mb)	Talys 1.95 (mb)	Cross-section (mb)	Talys 1.95 (mb)
^{181}Ta(γ, n)^{180}Ta	28.62	15.85 to 46.95	141.78	109.72 to 158.10

The figure 1 shows the current measured cross-sections along with the EXFOR data, TALYS 1.95 calculation and TENDL 2019 data for ^{181}Ta(n,2n)^{180}Ta reaction.

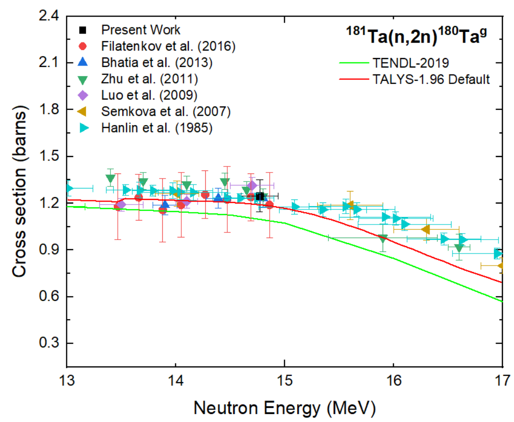

Fig. 1. Comparison of present ^{181}Ta(n,2n)^{180}Ta reaction cross-section with literature and evaluated data

The measured flux weighted average cross-section for ^{181}Ta(γ,n)^{180}Ta reaction is compared with TALYS 1.95 calculations with eight GSFs. The effect of level density model in the present calculations is negligible as compared to the same due to GSFs.

Conclusion

In the present work, we have reported the activation cross-sections for tantalum induced by neutron and bremsstrahlung radiation. Results are in good agreement with literature and theory. The results are important for nuclear database EXFOR.

References

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