Measurement of cross-section of ^{66,68}Zn isotopes at neutron energy of 14.96 ± 0.03 MeV

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Introduction

Zinc (Zn) is employed as a corrosion inhibitor and to prevent crack propagation in Pressurized Water Reactors (PWRs). The application of Zn as a coating material on components of PWRs markedly improves the system's stability and protective performance [1]. In water-cooled nuclear reactors, it plays an important part to reduce radioactivity as well as to reduce primary water stress corrosion cracking. In advanced fusion and fission nuclear reactors, Zn enhances the structural properties, so it is imperative to accurately determine the cross-section of isotopes of Zn along with the precise propagation of errors from various parameters.

In the present manuscript, the activation cross-section of ^{68}Zn(n,α)^{65}Ni and ^{66}Zn(n,2n)^{65}Zn reactions are studied at neutron energy of 14.96 ± 0.03 MeV along with previously published data from EXFOR [2] , latest Evaluated Libraries [3] and also with predicted data from theoretical simulation code (TALYS-2.0) [4]. The monoenergetic neutrons produced by D-T reaction (Q-value=17.6 MeV) are employed to induce radioactivity in the stable sample of Zn.

Experimental details

The irradiation was performed at the Neutron and Ion Irradiation Facility, Institute for Plasma Research, Gandhinagar, India [5]. A natural zinc pellet of purity (99.8%) and aluminium (Al) foil of thickness 0.025 cm were irradiated with neutron energy of 14.96 ± 0.03 MeV. The set of Zn-Al sample, at an angle of 0°, was irradiated for a time period of 4 hours, taking into account the half-lives of the product nuclei of the reactions.

A deuteron beam of energy 200 keV and beam current 2.5 mA was bombarded on the rotating Tritium-Titanium target to induce monoenergetic neutrons. Neutron flux of 1.07×10^8 n/cm^2/sec was estimated using the reference monitor reaction ^{27}Al(n,α)^{24}Na, and the yield produced was 8.35×10^9 n/s.

Table 1: Spectroscopic details of the analyzed reactions.

Nuclear Reaction	^{27}Al(n,α)	^{68}Zn(n,α)	^{66}Zn(n,2n)
Product	^{24}Na	^{65}Ni	^{65}Zn
Q-Value (keV)	-3132.56	765	-11058.5
$\tau_{1/2}$	14.956 h	2.5171 h	243.9 d
Eγ (keV)	1368.62	1481.84	1115.53
Iγ (%)	99.99 (3)	23.59	50.04 (10)

The cross-section (σ_u) evaluation for ^{66}Zn, ^{68}Zn was carried out relative to the monitor reaction cross-section (σ_{Al}). After appropriate cooling, samples were taken for counting in a pre-calibrated lead shielded HPGe detector having relative efficiency ≥ 50% and a resolution of ≤ 2.1 keV at 1.33 MeV γ-ray energy. Linear parametric model given in Eq. (1) [6] was used for the efficiency calibration of the detector by using a point size ^{152}Eu multi γ-ray source:

$$\ln(\varepsilon_i) = \sum_{k=1}^{m} p_k(\ln[E_i]^{k-1}) \quad (1)$$

Here, value of m depends upon the least square

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fitting method yielding the minimum value of the chi-square statistic ($\chi^2 = 1.08$).

The irradiated samples were placed at a distance of 3 cm from the detector to minimize the dead time and the coincidence summing effect. The counting statistics was acquired by the Canberra GENIE software package.

A natural sample of Zn was used for irradiation, the contribution of $^{68}Zn(n,\alpha)^{65}Ni$ at 1115.53 keV was eliminated by using Eq. (2) [7]:

$$R = \frac{C_{obs_{(n,2n)}}}{C_{obs_{(n,\alpha)}}} = \frac{a_{66}\sigma(n,2n)}{a_{68}\sigma(n,\alpha)} \qquad (2)$$

where $\sigma(n,2n)$ and $\sigma(n,\alpha)$ are the cross-sections from the ENDF-B/VIII library, and a_{66}, a_{68} are the isotopic abundances of ^{66}Zn (27.90%) and ^{68}Zn (67.92%), respectively. No other isotopic reaction of Zn produces ϒ-ray of characteristic energy 1115.53 keV or 1481.84 keV.

Results and discussion

The experimental determined cross-sections of $^{68}Zn(n,\alpha)^{65}Ni$ and $^{66}Zn(n,2n)^{65}Zn$ reactions are found to be 9.71 ±0.6 mb and 802.03 ± 47.6 mb respectively with fractional uncertainty of 5-7 % . Excitation function of reactions is compared with the evaluated data libraries and default TALYS 2.0 as depicted in **Fig (1) and Fig (2)**.

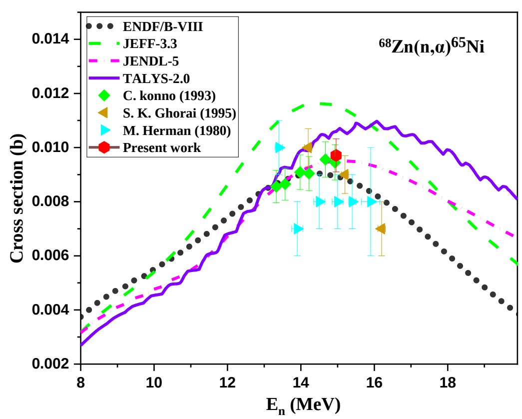

Fig. 1. Measured cross-section of $^{68}Zn(n,\alpha)^{65}Ni$

The present cross-section of $^{68}Zn(n,\alpha)^{65}Ni$ is consistent with the data reported by C. Konno (1993) [2] as shown in Fig. (1) and the study is very meagre since the last two decades. Fig. (1) revealed the reduction of overall uncertainty as compared to the previous reports and it may be due to the use of different detection techniques. The present work is in excellent agreement with the recently updated JENDL-5 library [3]. For the reaction cross-section of $^{66}Zn(n,2n)^{65}Zn$, the only datum at neutron energy of 14.9 MeV is the work of C. Konno (1993) [2] and is in agreement with present measured data. The present experimental value of cross-section lies close to the values predicted by TALYS-2.0 and ENDF/B-VIII.0 library. Recent evaluated file (TENDL-2023) predicts much lower values when compared with the previous as well as the present experimental data.

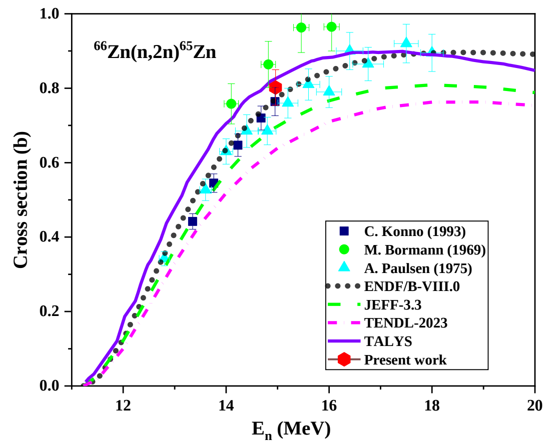

Fig.2 Measured cross-section of $^{66}Zn(n,2n)^{65}Zn$

The future studies will be focused on detailed covariance analysis to minimize the overall uncertainty of cross section.

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References

[1] E. Chajduk and A. Bojanowska-Czajka, Progress in Nuclear Energy 88, 1 (2016).

[2] https://www-nds.iaea.org/exfor/

[3] https://www-nds.iaea.org/exfor/endf.htm

[4] A.J. Koning, et al., Eur. Phys. J. A 59, 131 (2023).

[5] M. Abhangi, S. Vala, et al., Fusion Engineering and Design 204, (2024).

[6] L.P. Geraldo and D.L. Smith, Nuclear Instruments and Methods in Physics Research-A290 (1990).

[7] D.L. Smith, J.W. Meadows, P.A. Moldauer, and W.P. Poenitz, Nuclear Physics-A388 (1982).