Measurement of $^{88}Sr(n,2n)^{87m}Sr$ reaction cross-section using activation method

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Introduction

In fusion reactor different reaction channels i.e. (n,g), (n,p), (n,2n) were opened when 14 MeV neutrons interact with first-wall and different structural materials. The knowledge of neutron induced reaction cross-section of these materials is important for the study and operation of reactors. Strontium (Sr) is used as super conducting magnet material due to its super conducting properties. [1] In present case, the reaction cross-section of 88Sr(n,2n)87mSr has been measured at an average neutron energies 13.97±0.68 and 16.99±0.53 MeV respectively. The results were also compared with the previously published data in EXFOR data library as well as evaluated data and theoretically predicated data by TALYS-1.95 code. [2-4]

Experiments

The experimental work was carried out at 14UD BARC-BARC-TIFR (Bhabha Atomic Research Center-Tata Institute of Fundamental Research) 6 meter height Pelletron facility in Mumbai-India using the off line γ-ray spectroscopic technique. The protons of 16 and 19 MeV energies accelerated through natural lithium (Li) foil of thickness ~6.8 mg/cm^2 and generate neutrons of energies 13.97±0.68 and 16.99±0.53 MeV by $^7Li(p,n)^7Be$ reaction.[5,6] The energy spread for the proton beam at this port was 50–90 keV. A lithium foil was wrapped in between a Tantalum (Ta) foil of ~4 mg/cm^2 in the front and 0.1 mm Ta foil in the back.[7] The natural form Sr foil of thickness 0.3 mm and 10 x 10 mm^2 area were kept at a distance of 2.1 cm after Ta-Li-Ta stack in forward direction. Aluminium (Al) foil of thickness 0.1 mm and 10x10 mm^2 area were used as flux monitor via $^{27}Al(n,\alpha)^{24}Na$ reaction. The Al-Sr stack samples were wrapped in 0.025 mm thick Al-foil to avoid the radioactive contamination from one another during the irradiation. The samples were irradiated for 5-7 hours at desired neutron energies and kept cooled for sufficient time. Then the irradiated samples were mounted on Perspex plate and were taken for γ-ray spectrometry. Table-1 gives the experimental details of different sets of samples.

After irradiation, the γ-ray activity of samples and monitors was counted by a precalibrated 80 cm^3 HPGe detector coupled to a PC based 4K channel analyzer. The resolution of the detector had a FWHM of 1.82 keV at 1332 keV of ^{60}Co. The irradiated samples were kept at a suitable distance from the detector end cap to keep the dead time of the detector within 5% and to avoid the pile up effect. The energy and efficiency calibration of HPGe detector was done by ^{152}Eu multi gamma source. [8, 9]

Table-1 Summary of experimental details

	Irradiation-1	Irradiation-2
Proton Energy (MeV)	16	19
Neutron energy (MeV)	13.97±0.68	16.99±0.53
Irradiation Time (hh:mm)	5:30	7:30
Sr weight (gm)	0.7018	0.6386
Al monitor (gm)	0.0313	0.0309

Data analysis and results:

The $^{88}Sr(n,2n)^{87m}Sr$ reaction cross-section was measured by using the activation formula,

$$\sigma_r = <\sigma_m> \eta \frac{A_r \lambda_r a_m N_m I_m f_m}{A_m \lambda_m a_r N_r I_r f_r} \times \frac{C_r * N_{Corr\,(r)}}{C_m * N_{Corr\,(m)}}$$

$A_{r,m}$ = the photo-peak counts of product nuclei ^{87m}Sr and ^{24}Na recorded by HPGe detector, $\lambda_{r,m}$ = the decay constant (cm^{-1}), $N_{r,m}$ = the total number of atoms , η ($\varepsilon_m/\varepsilon_r$) = the detector efficiency ratio, $I_{r,m}$ = the γ-ray intensity, $a_{r,m}$ = the isotopic abundance of the target and monitor nuclei and $f_{r,m}$ = the timing factors of the sample and monitor reaction are given by:

$$f_{r,m} = \left(1 - e^{-\lambda t_{irr}}\right) e^{-\lambda t_{cool}} \left(1 - e^{-\lambda t_{count}}\right)$$

t_{irr} = the irradiation time, t_{cool} = the cool in time which is the time difference when the irradiation stop and the counting started time and t_{count} = the counting time. $C_{r,m}$ = the self-absorption correction factor and $N_{corr\ (r,m)}$ = the low energy neutron correction factor. The spectrum averaged monitor cross-section was calculated by formula:

$$< \sigma_m > = \frac{\int_{Ej,min}^{Ej,max} \Phi_i \sigma_m dE}{\int_{Ej,min}^{Ej,max} \Phi_i dE}$$

Where, σ_m = the $^{24}Al(n,\alpha)^{24}Na$ monitor reaction cross-section taken from the IRDFF-1.05 (International Reactor Dosimetry and Fusion File) library [10] folded with the neutron flux values (Φ_i) from the neutron flux energy spectrum generated by simulation code EPEN.[11] *Ej,min* and *Ej,max* are the lower and upper energy values of the energy spectrum. The neutron flux calculated from monitor reaction was 1.165×10^6 ncm^{2}s^{-1} at 13.97±0.68 MeV and 2.445×10^6 ncm^{2}s^{-1} at 16.99±0.53 MeV neutron energies, respectively by considering both correction factors. Theoretically the cross-section was predicated by TALYS-1.95 code with default parameters.

Table-2 Nuclear spectroscopic data [12]

Reaction	$^{27}Al(n,\alpha)$	$^{88}Sr(n,2n)$
Threshold energy (MeV)	3.249	8.926
Nuclide	^{24}Na	^{87m}Sr
Half-life	14.95h	2.815h
γ-ray energy(keV)	1368.626	388.53
γ-ray abundance (%)	99.9936	82.19

Conclusion:

In present experiment the $^{88}Sr(n,2n)^{87m}Sr$ reaction cross-section was calculated with $^{27}Al(n,\alpha)^{24}Na$ reference monitor reaction at an average neutron energies 13.97±0.68 MeV and 16.99±0.53 MeV. The comparison of present results were done with available literature data, evaluated data as well as theoretically predicated data by TALYS-1.95 as shown in Fig. 2. The results show that the cross-section data at 13.97±0.68 MeV was in good agreement with the previously measured data and data from JENDL/AD-2017 library. At 16.99±0.53 MeV, the measured cross-section of $^{88}Sr(n,2n)^{87m}Sr$ reaction is lower than the data available in evaluated data libraries. The present results are important for design and safety analysis of reactors.

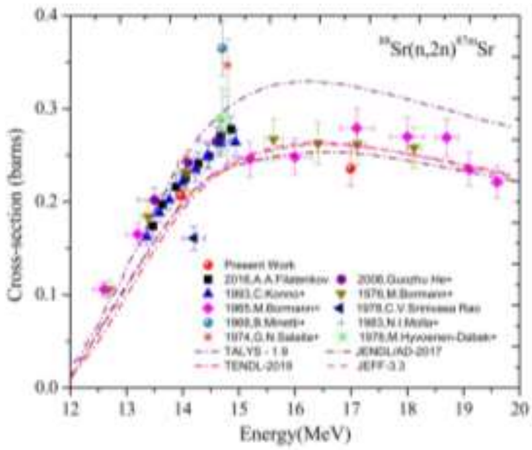

Fig. 1 Comparison of $^{88}Sr(n,2n)^{87m}Sr$ reaction cross-section with EXFOR,ENDF and TALYS-1.95 data

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