Determination of the ^{59}Ni(n,xp) reaction cross-sections for fusion technology

Jyoti Pandey[1],* Bhawna Pandey[1], A. Pal[2,3], S. V. Suryanarayana[2], S. Santra[2,3], B. K. Nayak[2,3], E. T. Mirgule[2], Alok Saxena[2], D. Chattopadhyay[2,3], A. Kundu[2,3], V. V. Desai[2,4], A. Parihari[2,4], G. Mohanto[2], D. Sarkar[2], P. C. Rout[2,3], B. Srinivasan[2], K. Mahata[2,3], B. J. Roy[2,3], S. De[2], and H. M. Agrawal[1]
[1]*Department of Physics, G.B. Pant University of Agriculture and Technology, Pantnagar, Uttarakhand 263 145, India*
[2]*Nuclear Physics Division, Bhabha Atomic Research Centre, Mumbai 400 085, India*
[3]*Homi Bhabha National Institute, Anushaktinagar, Mumbai 400 094, India and*
[4]*Department of Physics, University of Mumbai, Mumbai 400 098, India*

Introduction

Investigations of neutron-induced reactions on medium mass radionuclides, emitting light charged particles, in the neutron energy range from 1-20 MeV are of considerable interest from the standpoint of nuclear energy applications. Such reactions lead to nuclear transmutations, which can affect the structural strength of the materials used in the design of fusion energy reactors. They also produce recoils from the lattice, leading to voids and missing lattice elements. Finally, they lead to buildup of hydrogen and helium gas and residual radioactivity [1]. It is desirable to have measurements of cross sections and spectra for various radio nuclides (A$\sim$50-60) which are formed in fusion reactor environment during its operation. Such direct particle counting technique of cross sections measurements as a function incident particle energy or angle, is useful in estimating nuclear recoil energies in the lattice. At neutron energies near 14 MeV, several reaction channels are likely to open. The ^{59}Ni(n,xp) cross sections is the sum of (n,p),(n,2p) and (n,np) channels. This is the measurement of total proton emission arising from ^{59}Ni(n,xp) reaction. Out of the entire neutron induced reactions the one that produce gaseous elements are of utmost importance. The ^{59}Ni, a long-lived radio-isotope of nickel ($T_{1/2}$= 7.6$\times$10^4 year), is produced during the reactor operation via the major pathways ^{58}Ni(n,γ)^{59}Ni and ^{60}Ni(n,2n)^{59}Ni. The generation of hydrogen and helium gases are mainly through (n,xp) and (n,xα) reactions. These reactions are induced on the first wall, structural and blanket components of the reactor. Therefore, it is important to measure total proton emission channels (n,xp) cross-sections of long-lived isotope ^{59}Ni, for which data is not available in EXFOR data library and various evaluated data libraries shows large discrepancies.

In the present work, the ^{59}Ni(n,xp) reaction cross section have been determined from the measurements of the ratio of proton decay probabilities of ^{60}Ni* and ^{61}Ni* compound nuclei over the excitation energy range 21.5 - 35.5 MeV. The ^{60}Ni* and ^{61}Ni* compound nuclei at similar excitation energy are produced in ^{56}Fe(^{6}Li, d)^{60}Ni* [surrogate of n + ^{59}Ni] and ^{59}Co(^{6}Li, α)^{61}Ni* [surrogate of n + ^{60}Ni] transfer reactions at E_{lab} = 35.9 and 40.5 MeV respectively. The evaluated cross sections of the ^{60}Ni(n,xp) reaction as a function of excitation energy from JENDL-4.0 have been used as the reference to determine the ^{59}Ni(n,xp) cross sections from the measured ratio of the proton decay probabilities of ^{61}Ni* and ^{60}Ni* compound systems.

Experimental details and Data analysis

Measurements were carried out using ^{6}Li beams obtained from BARC-TIFR Pelletron

*Electronic address: jiyapandey20@gmail.com

Accelerator Facility in Mumbai. The self-supporting thin metallic targets of ^{nat}Fe (abundance ^{56}Fe $\sim$ 92 %) and ^{59}Co (abundance $\sim$ 100 %) of thickness 700 μg/cm^2 prepared by rolling and thermal evaporation techniques respectively, were bombarded with ^{6}Li beam at incident energies of E_{lab} =35.9 and 40.5 MeV, respectively. Two ΔE-E silicon surface barrier (SSB) detector telescopes (T1 and T2) were mounted at angles of 25^o and 35^o with respect to the beam direction around the transfer grazing angle to identify the projectile-like fragments (PLFs) . Two large area Si strip telescopes have been placed at backward angles centered at 120^0 and 150^0 respectively, to catch the evaporated particles from the compound nuclei ^{60}Ni* and ^{61}Ni* in coincidence with the PLFs (detected in T1 and T2). The time correlation between projectile like fragements (PLF) and decay particles in strip detectors were recorded through a time to amplitude converter (TAC)[2]. For^{56}Fe(^{6}Li,d)^{60}Ni* and ^{59}Co(^{6}Li,α)^{61}Ni* transfer reactions the ground-state Q_{gg} are 4.817 and 13.65 MeV, respectively. The compound systems ^{60}Ni* and ^{61}Ni* are populated at overlapping excitation energies in the range of 21.5-35.5 MeV in ^{6}Li + ^{56}Fe $\rightarrow$ d + ^{60}Ni* transfer reaction [E_{lab}(^{6}Li) = 35.89 MeV] and ^{6}Li + ^{59}Co $\rightarrow$ α + ^{61}Ni* transfer reaction [E_{lab}(^{6}Li) = 40.5 MeV], respectively. The proton decay probabilities of ^{60}Ni* and ^{61}Ni* compound nuclei produced in the transfer reactions are obtained from Equation.

$$\Gamma_p^{CN}(E_{ex}) = \frac{N_{i-p}(E_{ex})}{N_i(E_{ex})} \tag{1}$$

Where i denotes the deuteron or alpha (PLF) channels. N_i and N_{i-p} denotes the singles and coincidence counts, respectively, at excitation energy E_{ex} [3].

Results and Discussion

We have measured the ^{59}Ni(n,xp) cross-sections by employing the surrogate ratio method. Experimentally measured cross-sections for ^{59}Ni(n,xp) reaction by surrogate technique are shown in Fig.1. These cross sections have been compared with the nuclear model calculations and different evaluated nuclear data libraries like ENDF-VIII, ROSFOND-2015 and TENDL-2015 as shown in Fig.1. Results from TALYS-1.8 code and the evaluations of ROSFOND-2015 are in qualitative agreement with our measured cross-section values in the neutron energy range from 11.9-15.8 MeV.

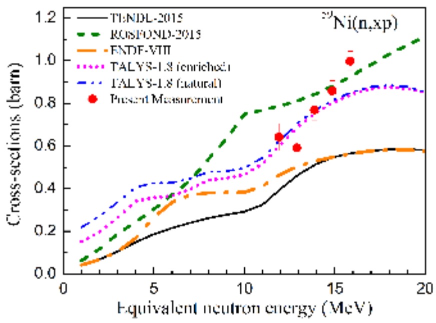

FIG. 1: The ^{59}Ni(n,xp) cross-section as a function of equivalent neutron energy along with various nuclear data libraries and TALYS-1.8 nuclear model calculations for cases of enriched and natural as discussed in text.

Acknowledgements

Authors acknowledge the financial support provided by Department of Science & Technology under project number (YSS/2015/001842). We are thankful to BARC-TIFR Pelletron Linac Facility staff for providing uninterrupted beams during the experiment.

References

[1] S.K. Saraf, C.E. Brient, P.M. Egun, S.M. Grimes, V. Mishra and R.S. Pedroni, Nuclear Science and Engineering **107**, 365-373(1991).

[2] B. K. Nayak, A. Saxena, D. C. Biswas, E. T. Mirgule, B. V. John, S. Santra, R. P. Vind, R. K. Choudhury, and S. Ganesan, Phys.Rev. C **78**, 061602 (2008).

[3] V. V. Desai, B. K. Nayak, A. Saxena, et. al., Phys. Rev. C **87**, 034604 (2013).