Measurement of ^{59}Ni(n,p) reaction cross section using Surrogate Reaction Method

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Introduction

Recent investigations on the impact of nuclear data uncertainties on performance characteristics of systems considered for waste transmutation and for Gen-IV reactors, fusion reactor (ITER) show that the accuracy and completeness of existing nuclear data is an important issue for the safety assessment of present-day and innovative nuclear energy systems for fission and fusion technologies [1, 2]. Reducing uncertainties and extending nuclear data sets by dedicated measurements is an important challenge. This demand holds in particular for long-lived radionuclides produced in a neutron environment and fast neutron induced reactions are such quantities. In natural nickel the five stable isotopes are the major source of He and H gases. Another major contribution arises from ^{59}Ni(n,p) and ^{59}Ni(n,α) reactions from the long lived radioisotope. ^{59}Ni ($t_{1/2}$ = 8×10^4 year) which is a prolific source of helium and hydrogen production[3, 4]. ^{59}Ni is produced during the reactor operation via the major pathways ^{58}Ni(n,γ)^{59}Ni, ^{60}Ni(n,2n)^{59}Ni [5]. The ^{59}Ni isotope produced by ^{58}Ni(n,γ)^{59}Ni and ^{60}Ni(n,2n)^{59}Ni reactions has three highly exothermic reaction, (n,γ) (n,p) and (n,α). There is no experimental data for ^{59}Ni(n,p) in EXFOR data library and there is a large discrepancy in available EAF-2010, TENDL-2014, ROSFOND-2010, ENDF/B-VII.b4 data libraries. Nuclear data evaluations often do not account well for the excitation functions of (n,p) reactions for radio-nuclides. Due to the critical need and importance of such type of reaction, we have taken up the present study of experimental measurement of ^{59}Ni(n,p)^{59}Co reaction cross-section. Measurement of neutron-induced cross-section of long-lived radionuclide is a major challenge for fusion technology applications. Direct measurements may encounter various difficulties : many of these nuclei are very difficult to produce with currently available experimental techniques or too short to serve as targets in a present day experimental setup [5]. As due to the non-availability of radio nuclides in nature, an indirect method such as the surrogate ratio method involving a stable target and projectile are employed to estimate the compound nuclear cross-section for the desired reaction.

Experimental details and data analysis

Measurements were carried out using ^{6}Li beams obtained from (BARC-TIFR) 14-MV Pelletron Accelerator Facility in Mumbai. The self-supporting thin metallic targets of ^{nat}Fe (abundance ^{56}Fe ~ 92 %) and ^{59}Co (abundance = 100 %) of thickness~700μg/cm^2 prepared by rolling and thermal evaporation technique respectively were bombarded with ^{6}Li beam at incident energies E_{lab} = 35.89 and 40.5 MeV, respectively . T1 and T2, two silicon surface barrier (SSB) ΔE-E detector telescope with δE detectors of thickness~150 μm and 100 μm and with identical E detectors of thickness of 1 mm 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). A Large area 16-strip solid-state detector was placed at a back angle 130^o with respect to the beam direction with an angular opening of 16^o to detect the decay proton in coincidence with PLFs. The time correlation between light charged particles and decay particles (proton) were recorded through a time to amplitude converter (TAC). In the present work, the ^{59}Ni(n,p) 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 17-40 MeV. The ^{60}Ni* and ^{61}Ni* compound nuclei at similar excitation energy (E_{exc}= 25 MeV) are produced in ^{56}Fe(^{6}Li, d)^{60}Ni* [surrogate of n + ^{59}Ni→(^{60}Ni)*→p+ ^{59}Co] and ^{59}Co(^{6}Li,α)^{61}Ni [surrogate of n + ^{60}Ni→ (^{61}Ni)*→p + ^{60}Co] transfer reactions at E_{lab} = 35.89 and 40.5 MeV respectively. The cross section value of the ^{60}Ni(n,p) reaction as a function of excitation energy has been used as the reference reaction to determine the ^{59}Ni(n,p) cross section from the measured ratio of the decay probabilities of ^{61}Ni* and ^{60}Ni* compound systems.

Nuclear model Calculations

TALYS-1.8 and EMPIRE-3.2.2 nuclear reaction modular codes have been used to calculate the ^{59}Ni(n,p) excitation function in the energy range threshold to 20 MeV neutron energy within the framework of Hauser-Feshbach statistical model with pre-equilibrium corrections.
The experimental results of ^{59}Ni(n,p) cross-section by surrogate reaction technique are compared with nuclear reaction model calculation TALYS-1.8, EMPIRE-3.2.2 and with evaluated data libraries as shown in Fig.1. Measured cross sections of ^{59}Ni(n,p) reaction are consistent with nuclear model codes EMPIRE-3.2.2 and TALYS-1.8 results. In EMPIRE3.2.2 code the ATILNO parameter value has been changed by 10% from default value. In TALYS-1.8 we used recent microscopic temperature-dependent Hartree Fock - Bogolyubov level density using Gogny interaction [6]. The measured experimental data is not consistent with evaluated data libraries. The observed discrepancy in different data libraries with our experimental data and theoretical model calculations indicate the need of new evaluations for this reaction.

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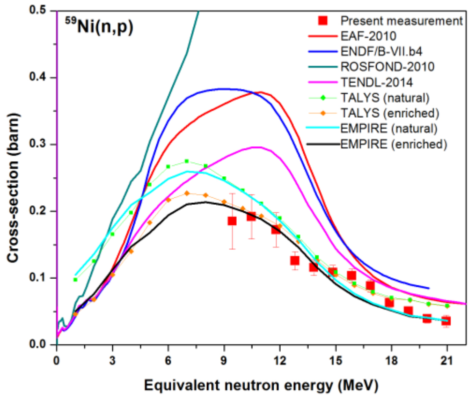

FIG. 1. The ^{59}Ni(n,p) cross-section as a function of equivalent neutron energy along with various nuclear data libraries and nuclear model calculations.

References

[1] Report Summary of European Facility for innovative reactor and transmutation neutron data, project report on 2013, Belgium ID:211499.
[2] ITER Physics Basis Editors et al., Nucl. Fusion 39, 2137(1999)
[3] L.R. Greenwood, F.A.Garner Journal of Nuclear materials 233-237 (1999)1530.
[4] H. Iida et al., ITER Nuclear Analysis Report (NAR), G73 DDD 2 W 0.2 July, 2004.
[5] R.A. Forrest , A Tabasso , C. Danani , S. Jakharand A.K. Shaw , EURATOM/UKAEA Fusion Association,UKAEA FUS 552(2009).
[6] A.J. Koning et al. , TALYS User Manual : A Nuclear Reaction Program , User Manual,NRG-1755 ZG Petten,The Netherlands (2011).