Estimation of (n,p) (n,α) reaction cross-section for unstable ^{59,63}Ni nuclides

Jyoti Pandey[1*], Bhawna Pandey[1], S.V. Suryanarayana[2], B.K. Nayak[2],
H.M. Agrawal[1], A. Saxena[2], P.M.Prajapati[3], R.Makwana[4], Mitul Abhangi[5],
S.Vala[5], P.V.Subhash[6]
[1]*Department of Physics, G.B. Pant University of Ag. & Tech., Pantnagar,Uttarakhand -263145 , INDIA*
[2]*Nuclear Physics Division, Bhabha Atomic Research Centre, Mumbai - 400085, INDIA*
[3]*Department of Nuclear Physics,Institute of Physics, Slovak Academy of Sciences, SLOVAK REPUBLIC*
[4]*Physics Department, Faculty of Science, M.S. University of Baroda-390002, Vadodara, INDIA*
[5]*Fusion Neutronics Laboratory, Institute for Plasma Research, Bhat, Gandhinagar – 382 428, INDIA*
[6]*ITER-India, Institute for Plasma Research, Bhat, Gandhinagar – 382 016, INDIA*
**Email:jiyapandey20@gmail.com*

Introduction

Stainless steel (SS) is used as a structural material having Fe, Ni, Cr as main constituents (in SS316 content of Fe~65%, Ni~12%, Cr~17%). The neutron induced transmutation reactions with these elements in the initial SS composition leads to the formation of large numbers of radionuclide. Nowadays a considerable interest in the (n,p) , (n,α) reaction cross-section for the radioactive isotopes in mass region 50-60 is shown. ^{59}Ni ($t_{½}$ = 8×10^{4} year) and ^{63}Ni ($t_{½}$= 100.1 year) are two important radioisotopes of nickel not found in natural nickel but produced during the reactor operation via the pathways **^{58}Ni(n,γ)^{59}Ni, ^{60}Ni(n,2n)^{59}Ni and ^{62}Ni(n,γ)^{63}Ni, ^{64}Ni(n,2n)^{63}Ni, ^{63}Cu(n,p)^{63}Ni** respectively **[1,2].** These radio nuclides have long half-lives and will contribute to nuclear waste. The neutron induced cross-section determination of these radio nuclides is important from fusion reactor point of view **[3].** The neutron induced reactions that produce gases are of at most importance. The generation of hydrogen and helium gases are mainly through (n,p) (n,n'p), (n,α), (n,n'α) reactions.

Direct experimental determinations of cross-sections for unstable long-lived radionuclide (^{59}Ni,^{63}Ni) are not possible as they do not exist in nature. There is no experimental data for ^{59,63}Ni(n,p) and ^{59},^{63}Ni(n,α) in EXFOR **[4]** data library. Since no experimental data exists for these nuclear reactions, the evaluations libraries of the cross-section data mostly rely either on nuclear model calculations or certain semi-empirical formula. However, both these approaches of evaluations are extrapolations from the results with stable targets. Therefore we have taken up a study of (n,p) and (n,α) reactions cross sections on radioisotopes of nickel both by nuclear model calculations and experimental measurements. The model calculations can provide the excitation function of the cross-sections from lower energy to several tens of MeV and also the contributions from all kinematically possible reactions simultaneously **[5,6].**

Nuclear Model Calculation

The ^{59,63}Ni(n,p) and ^{59,63}Ni(n,α) reaction cross-section have been calculated from TALYS-1.8 and EMPIRE-3.2.3 **[7].**The contributions coming from direct, pre-equilibrium and compound nuclear processes are also studied. Nuclear model calculations of ^{59,63}Ni(n,p) and (n,α) have been performed using the same optimized input parameter set as in the calculation of the adjacent stable nuclide $^{58,60-64}$Ni(n,p) cross-section. The present results of cross-section are also compared with the recent evaluated data libraries EAF-2010, ROSFOND-2010, JEFF-3.2 and also with the values based on semi-empirical formulae around 14 MeV. The illustrative cases are shown are in figures 1 & 2.

In the present work we have also studied the feasibility of indirect method (surrogate technique) **[8]** for cross-section measurement of ^{59}Ni(n,p)^{59}Co. We have selected ^{56}Fe(^{6}Li,d)^{60}Ni* as possible surrogate reaction. The surrogate method can only be used when the desired reaction (neutron induced reaction ^{59}Ni(n,p)^{59}Co] takes place through compound nucleus formation. It is found that the pre-equilibrium contribution to ^{59}Ni(n,p)reaction is ~16% whereas 84% takes place through compound nucleus formation at E_n ~ 14 MeV.

Compound nucleus excitation energy should be same in both desired reaction and surrogate reaction. The excitation energy of the compound nucleus ^{60}Ni* formed via ^{59}Ni(n,p)reaction at E_n~ 14 MeV and ^{60}Ni* formed via surrogate reaction ^{56}Fe(^{6}Li,d)^{60}Ni* at E_{Li} ~ 35 MeV are same (E_{exc} of ^{60}Ni* ~ 25 MeV). **[6]**

Experimental Plan

We proposed an experiment which will be carried out at PLF, TIFR Mumbai, where the cross-section of ^{59}Ni(n,p) reaction (E_n~10-15MeV will be measured by the surrogate reaction ^{56}Fe(^{6}Li,d)^{60}Ni* (E_{lab}) of ^{6}Li= 35 MeV by employing particle identification technique using silicon surface barrier (SSB) ΔE-E telescope detector. The size of the ΔE detector will be 150 μm whereas E detector will be around ~ 2mm. In the experiment, the evaporated protons will be detected in coincidence with deuterons.

References

[1] R.A. Forrest, Fus.Eng.Des. 81, 2143-2156 (2006)

[2] R. A Forrest et al., UKAEA FUS 552, EURATOM/UKAEA Fusion, March (2009).

[3] H.Iida et al., Nuclear Analysis Report (NAR) ITER, G73 DDD2 W0.2,(2004).

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

[5] A. Wallner et al., Journal of the Korean Physical Society 59 1378- 1381 (2011).

[6] Pandey et al. , PHYSICAL REVIEW C 93, 021602(R) (2016).

[7] http://www.nndc.bnl.gov/nndcscr/modelcodes/modlibs//

[8] J.E.Escher, et al., Rev.Mod.Phys. 84, 353-397 (2012).

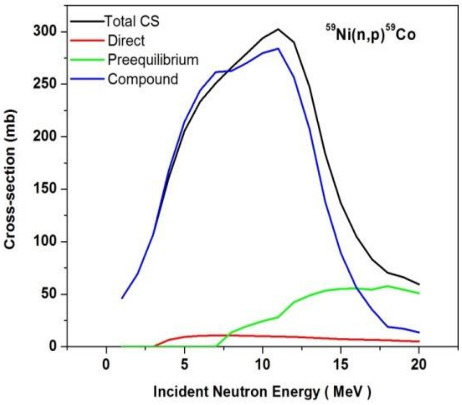

Fig. 1 Excitation function of ^{59}Ni(n,p) reaction along with the contribution from the different reaction mechanism (Direct + Pre-equilibrium +Compound)

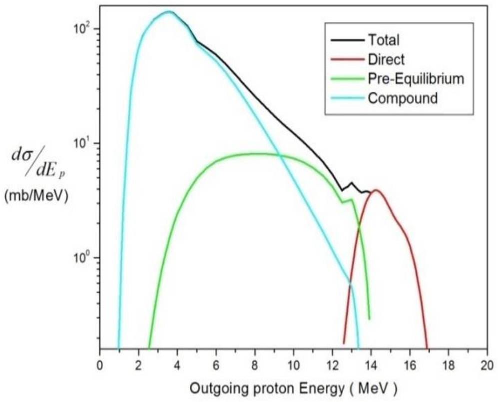

Fig. 2 Theoretical differential energy Spectra of emitted protons from ^{59}Ni(n , xp) reaction at 14 MeV neutrons along with different mechanism (Direct +Pre-equilibrium+Compound)