Excitation Function of the $^{55}Fe(n, p)^{55}Mn$ reaction from threshold to 20 MeV

Bhawna Pandey[1*], P.M.Prajapati[1], S. Jakhar[1], R. Makwana[1],C.V.S. Rao[1],T.K. Basu [2], B.K.Nayak[3], A. Saxena[3], S.V.Suryanarayana[3]

1 Fusion Neutronics Laboratory, Institute for Plasma Research, Bhat, Gandhinagar – 382 428, India
2 Raja Ramanna Fellow of DAE, Institute for Plasma Research, Bhat, Gandhinagar – 382 428, India
3 Nuclear Physics Division, Bhabha Atomic Research Centre, Mumbai - 400 085, India
*bhawna.16p@gmail.com

Introduction

In the first generation fusion reactors, stainless steel will be used as the main structural material with iron (Fe) as main constituents. Iron based (SS) alloys are used in blanket shield modules, thin walled pipes, cooling manifolds, divertor body, cooling pipes, divertor support, fastening components etc. In a typical fusion reactor, few thousand tons of stainless steel will be used for different critical components of a fusion reactor. Iron has four stable isotopes [(^{54}Fe(5.845%),^{56}Fe(91.745%),^{57}Fe(2.119%),^{58}Fe(0.282 %)] in its natural form.

^{55}Fe ($t_{1/2}$ = 2.73 years) is one of the radio-nuclide which is produced in large quantities inside the fusion reactor via the threshold reaction ^{56}Fe(n, 2n) ^{55}Fe **[1], [2]** due to its high cross-section and amount in fusion environment**.** The produced ^{55}Fe acts as the target for neutrons and therefore neutron induced reaction cross-section on the generated ^{55}Fe is required for design of a fusion reactor components. Second step nuclear reactions are quite important for a fusion reactor as their amount is quite high. The amount of second generation products depends on the production cross-section of first step reaction and their half-life. Experimental data on such radioactive targets will also be very useful in ensuring that the best parameters are used for theory. IAEA-EXFOR **[3]** database indicates that there is no experimental measurement for ^{55}Fe(n, p)^{55}Mn reaction. Precise knowledge of such type of (n, p) reaction cross-section data are of prime importance from the view point of nuclear applications such as fusion reactor components design and fundamental problems of nuclear physics, such as the nuclear transmutation rate, nuclear heating, and radiation damage due to the hydrogen gas production in the potential first wall structural materials of the fusion reactors. Such type of neutron induced reaction cross-sections data are backbone for the Development and Designing of the upcoming Nuclear Fusion Reactors like: ITER, DEMO.

In present work the excitation function of (n,p) reaction from threshold to 20 MeV incident energy and proton emission spectra at E_n= 14 MeV from ^{55}Fe target are calculated using nuclear reaction modular codes EMPIRE-3.1**[4]** and TALYS-1.4**[5].** Calculated values are compared with the existing evaluated data files. The main purpose of the present work is to investigate the possibility of surrogate method for the ^{55}Fe(n,p)^{55}Mn reaction cross-section measurement**[6].**

Nuclear Model Calculations

The nuclear model calculations for ^{55}Fe(n,p)^{55}Mn is performed with two different nuclear reaction modular codes TALYS-1.4 and EMPIRE-3.0**.** Both codes use the Hauser-Feshbach statistical model with width fluctuation corrections and estimates of the direct and pre-equilibrium contributions. In our calculations we have studied the effect of level density and pre-equilibrium emission in both codes for ^{55}Fe(n,p)^{55}Mn reaction cross-section from threshold to 20 MeV. For neutron and proton we have used global optical model potential. Fig.1. shows the excitation function of ^{55}Fe(n,p)^{55}Mn reactions along with the contributions from the different reaction mechanism (Direct+ pre-equilibrium+Compound). At E_n~14 MeV the compound nucleus contribution in the total cross-section is ~ 83% while remaining is pre-equilibrium and direct part. The computed cross sections together with evaluated data files [ROSFOND, JEFF-3.1,EAF-2010] is shown in Fig.2. There are significant discrepancies in the cross-sections within the data files and calculated values.
We have also calculated the differential cross-section Fig.3, ($d\sigma/dE$, $d\sigma/d\Omega$) and double differential cross-

section (DDX) of the reaction $^{55}Fe(n,p)^{55}Mn$ to get more idea about the energy spectra and angular distribution of the outgoing protons.

Conclusions

From the present study it has been investigated that the measurement of $^{55}Fe(n,p)^{55}Mn$ cross-section is possible through surrogate method. Present results are also compared with the good systematics at 14 MeV neutron energy given by different authors i.e. Csikai, Qaim, Forrest, & Gardner etc. and shows good agreement. The theoretical study in the present work is an important step in the direction to measure the cross-section of $^{55}Fe(n, p)^{55}Mn$ reaction with surrogate method. It is finalized to measure cross-section of this reaction using surrogate method at BARC-TIFR Pelletron facility Mumbai.

Acknowledgments

The authors are thankful to Prof. Robin Forrest, Head Nuclear Data Section of IAEA for encouraging us to carry out this measurement. We are also grateful to Profs. S. Ganesan (BARC, Mumbai), V.M.Dattar (NPD, BARC), H.M. Agrawal (Pantnagar Univ.) for their valuable suggestion and guidance.

References

[1]A.Wallner et al., Production of Long-lived Radionuclides 10Be, 14C, 53Mn, 55Fe, 59Ni and 202gPb in Fusion Environment, Journal of the Korean Physicsl Society, Vol.59, No.2, pp. 1378-1381 (2011).

[2] R.A.Forrest, Data Requirements for neutron activation Part I: Cross-sections, Fusion Engineering and Design 81 pp. 2143-2156. (2006).

[3] IAEA-EXFORdatabase: http://www- nds.iaea.org/exfor

[4] J.E. Escher et al., Compound-nuclear reaction cross-sections from surrogate measurements. Rev.Mod.Phys. 84,353-397 (2012).

[5] Koning, A.J., et al., Talys User Manual , A nuclear reaction program, User Manual. NRG-1755 ZG Petten, The Netherlands (2011).

[6] Herman, M. et al., User's Manual: EMPIRE-3.1 Rivoli modular system for nuclear reaction calculations and nuclear data evaluation(2012).

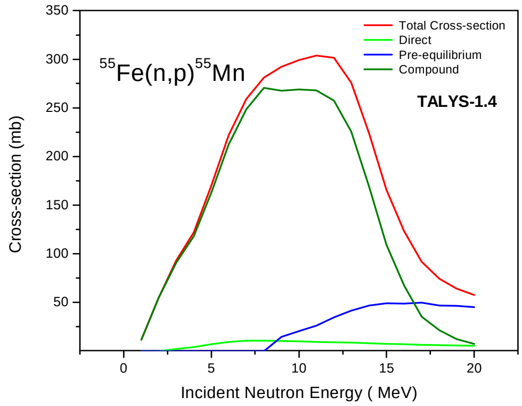

Fig.1.: Excitation function of $^{55}Fe(n,p)^{55}Mn$ reaction along with the contribution from the different reaction mechanism (Direct+ pre-equilibrium+Compound)

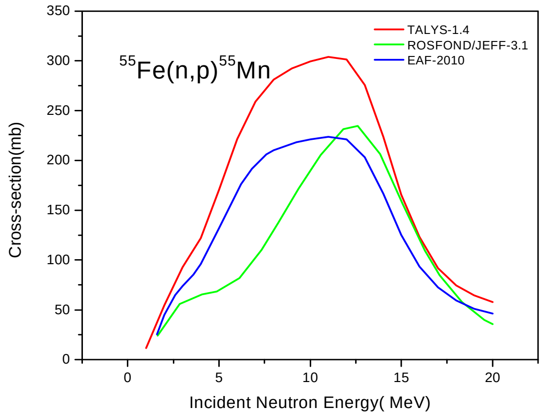

Fig.2.: Comparison of calculated excitation function of $^{55}Fe(n,p)^{55}Mn$ with evaluated data files.

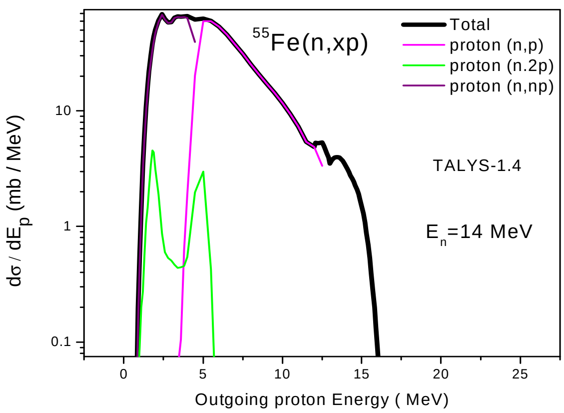

Fig.3.: Energy spectra of outgoing protons from $^{55}Fe(n,xp)$