Differential and Double Differential Cross Sections for Neutron induced Reactions on Iron, Nickel, & Chromium

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Introduction

Efforts are on internationally for the development of dedicated nuclear data libraries covering the entire spectrum of materials and data types for the full energy range of interest. The ITER device requires evaluated, validated and reliable nuclear database for nuclear design calculations. Differential cross sections (DX) and Double differential cross section (DDX) are of importance in Fusion Technology. Differential cross section predicts the angular or energy distribution of ejectile while double differential cross section predicts the angular as well energy distribution of the ejectile. These quantities are crucial in evaluating nuclear responses of materials in fusion reactor components. Many reaction channels such as (n,p), (n,α), etc. are possible when projectile energy is high **[1]**. Different particles with different energy and angles will be ejected that will eventually lead to nuclear heating and energy release in materials of reactor components. Damage generated by the fusion neutron is also of great concern. The calculation of Damage in terms of Displacements per Atom (dpa), Gas production per atom and nuclear heating and transmutation in reactor material would require DX and DDX data. Neutron cross section data must be provided for all nuclides constituting the prospective materials to be used in fusion device, including breeders, neutron multipliers, coolants, shielding, structure, magnets and insulators.

Variety of materials, structural as well as functional will be used in the ITER. This includes materials of the Test Blanket Modules (TBM), the plasma facing components, the shield modules, the vacuum vessel, the super-conducting magnets, the bio-shield as well as other components. TBM materials includes the Eurofer reduced activation steel which consists of Fe, Cr, W, Ta, V, Mn, C and other elements in very low quantity. The shield modules and the vacuum vessel, is made of SS-316L with Fe, Cr, Ni, Mo, Mn, C, N as major constituents, SS 30467 (2% B) with Fe, Cr, Ni, Mo, Mn, B, C, N, P, S and H_2O. Cr is also a constituent element of the super-conducting magnet **[2]**. Be, Pb, Li, Si, O, Fe, Ni, Cr, W, Ta, Cu, Ti are considered as high priority elements for which well qualified evaluated data sets are required in the near future. Fe and Cr, both have four stable isotopes each (^{54}Fe, ^{56}Fe, ^{57}Fe, ^{58}Fe), (^{50}Cr, ^{52}Cr, ^{53}Cr, ^{54}Cr) and Ni has five stable isotopes (^{58}Ni, ^{60}Ni, ^{61}Ni, ^{62}Ni, ^{64}Ni). Various nuclear reaction channels will yield Proton, Alpha and other light charged particle. These light ions will accumulate in the material and eventually produce gas by picking-up electrons and will lead to degradation of mechanical properties.

Experimental DDX data for (n,p)+(n,n'p) reaction for ^{56}Fe, ^{58,60}Ni and ^{52}Cr is available but are old measurements **[1]** and requires updating. DDX data for (n,α) is available only for ^{58}Ni **[3]**. DDX data for (n,α) for Fe, Cr and ^{60}Ni is not available. In ITER these material will be used in their natural composition, so the DDX of their natural form will be required. Measurement of the DDX for natural materials would require the calculation of DDX for its individual constituent isotope.

At this intermediate energy region reaction can proceed through Compound nucleus formation, pre-equilibrium process as well as direct reaction mechanism. These three models are not exclusive for any particular reaction in this energy range. All the mechanisms would contribute substantially to the cross section. In order to estimate the theoretical cross sections, it is simulated simultaneously for all the processes and then the total cross section will be the sum of these three cross sections.

Experiments on DDX for (n,p) and (n,α) reactions will be performed at FNL-IPR in the recently installed Scattering chamber **[4].**

Theoretical model calculation

In the present work, excitation functions of σ, dσ/dE , $d^2\sigma/dEd\Omega$ for stable isotope of Fe, Cr, Ni is calculated using TALYS 1.6. These calculations are done using Hauser-Feshbach statistical model with Pre equilibrium and direct reaction effect.

Energy differential cross section (dσ/dE) and double differential cross sections ($d^2\sigma/dE.d\Omega$) for $^{56}Fe(n,p)^{56}Mn$ reaction are plotted in the Fig 1 and Fig 2.

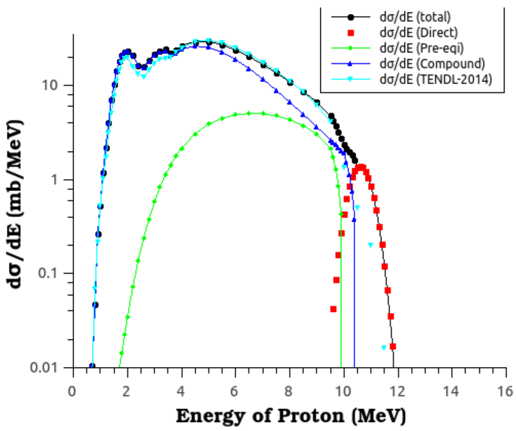

Fig 1- (color online) Theoretical differential energy spectra of emitted Protons from $^{56}Fe(n,p)^{56}Mn$ reaction at 14 MeV neutrons along with the TENDL-2014 data.

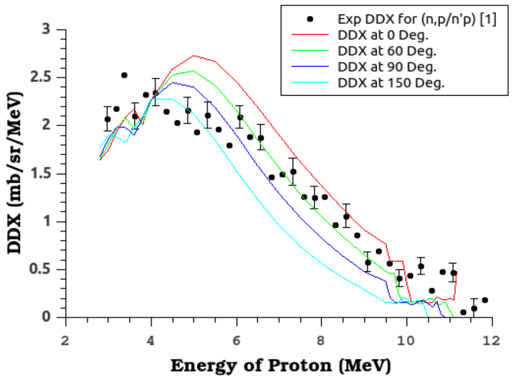

Fig 2- (color online) Theoretical double differential energy spectra of emitted Protons from $^{56}Fe(n,p)^{56}Mn$ reaction at 14 MeV neutrons along with the experiment data **[1]** for 14.1 MeV neutron.

Conclusion

Theoretical calculations of dσ/dE predicts that most probable energy proton are mainly emitted from compound nucleus mechanism whereas higher energy protons are mainly emitted due to pre-equilibrium and direct reaction mechanism. Calculated dσ/dE and $d^2\sigma/dE.d\Omega$ are compared with the TENDL-2014 data and Experiment data. Experiments are planned to measure $d^2\sigma/dE.d\Omega$ for natural samples of Fe, Ni and Cr.

References

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