Differential Cross-section of Iron using TALYS 1.9

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Abstract— In this paper, we have calculated differential cross-sections (DX) for the neutron induced reactions on some isotopes of Iron(^{54}Fe and ^{56}Fe), for the energies 14.1MeV and 14.6MeV by using nuclear modular code TALYS-1.9. TALYS-1.9 is a nuclear modular code and provides complete description related to a specific nuclear reaction. Various reaction channels are possible at a given projectile energy, but we have done our calculations for (n,p) and (n,α) channels because charge particle emission differential cross-sectional data is of utmost importance for finding radiation damage in structural materials used in fusion reactors. This data can be used to calculate important parameters like Primary knock on atoms (PKA), displacement per atom (DPA), nuclear level heating etc. We have calculated the differential cross-section with respect to energy (dσ/dE) as a function of energy of outgoing particle (E_{out}). Calculations are carried only for those isotopes for which experimental data are available at EXFOR data library. We have also shown the contribution of compound, direct and pre-equilibrium reactions to the total differential cross-section and found that compound reactions dominate at lower energies while at higher energies, direct reactions are pre-dominant. We also found that for (n,α) reaction, we are getting a peak in the energy range 7-9 MeV while for (n,p) reaction, we are getting a peak at around 3MeV. The differential cross-section data were also compared with the available experimental data taken from EXFOR and they are found to be in good agreement with our calculations that are based on TALYS.

Keywords—*differential cross-section, fusion structural material, TALY-1.9, components*

1. INTRODUCTION

The neutron plays an important role in many nuclear reactions. Knowledge of neutrons and their interaction with nuclie is of great importance in many areas of physics particularly for understanding basic nuclear physics, nuclear astrophysics and in the development of nuclear reactors**.** One of the essential tools in neutronics is finding the differential and double differential cross section of neutron induced nuclear reactions **[1]**. Differential Cross section (DX) and double differential cross section (DDX) data can be used to extract very useful information about a particular nuclear reaction. Differential cross-section predicts the angular or energy distribution of the ejectile while double differential cross-section predicts the angular as well energy distribution of the ejectile. DX and DDX data are the key inputs for modeling of fusion reactors **[2].**The energy-producing mechanism in a fusion reactor is the fusion of two light atomic nuclei to produce a heavier one. When two nuclei fuse, a small amount of mass is converted into a large amount of energy in accordance with the Einstein's mass energy relation: $E=\Delta mc\mathbf{2}$ where, Δm is the change in mass of nuclei and c = speed of light in vaccum.

The most feasible reaction for power generation in nuclear fusion reactors is D-T fusion. The neutrons of very high energy (14MeV) are generated in this reaction. Along-with this harsh irradiation environment, very high heat energy and high pressure is associated with fusion reactor. Most of the materials present in nature can't tolerate such a high heat and neutron flux. Some alloys of stainless steel having high heat tolerance, higher swelling resistance, higher thermal conductivity, lower thermal expansion, and better liquid-metal compatibility. **[3]** have been proposed as suitable structural materials for fusion reactors. The major constituents of such materials are nickel, chromium , iron , manganese etc. One such proposed material is RAFM(Reduced Activation Ferritic-Martenistic Steel) **[4]**. Many reaction channels such as (n,p), (n,α) etc. are possible when projectile energy is as high as 14MeV. Different ejectiles emitted during these reactions produce radiation damage on colliding with the structural materials. Different kinds of damages to structural materials such as embrittlement, creep etc. are produced. Other phenomena like gas production and nuclear transmutation also take place. The parameters like primary knock-on atom (PKA), displacement per atom (DPA) are a measure of radiation damage caused to these materials. Nuclear data must be available for candidate structural materials around 14MeV, so as to estimate nuclear heating, gas production and other important factors. Double-differential charged-particle emission cross section (DDXc) is needed, because they are indispensable to calculate primary knock-on atom (PKA) spectra, gas production per atom (GPA) and displacement per atom (DPA) cross-sections **[5]**.The high performance structural materials of fusion nuclear reactors are composed mainly of Chromium, Mangenese, Iron, Cobalt and Nickle, which makes the study of differential cross-section of neutron induced reactions in Iron of primary importance for fusion reactor technology .Parallel to the experiment there is a great need to improve the status of available nuclear data for the double differential cross-section on the basis of nuclear reaction model calculation with optimizing input parameters **[6]**. The objective of the present work is to find the DX for neutron induced charged particle nuclear reactions on fusion reactors related structural materials. DX calculation for various isotopes of Fe is carried out with nuclear model calculations, using TALYS-1.9. These values are then be compared to the available experimental data, which were found to be in good agreement.

2. Results and Discussion

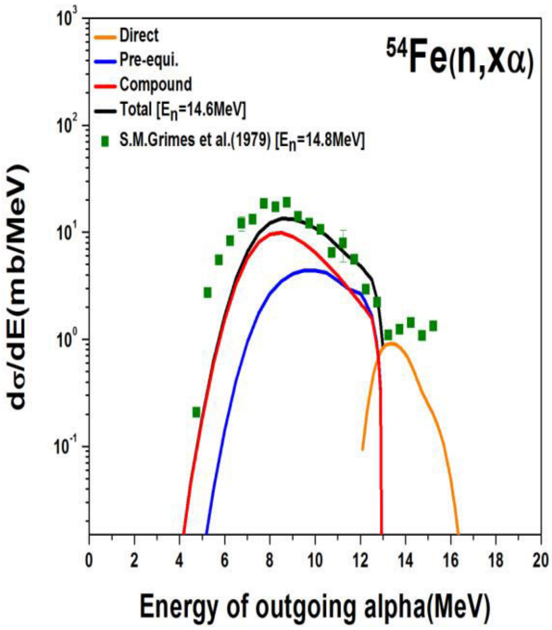

Fig.1.1 Differential cross-section with respect to energy (dσ/dE) versus energy of outgoing alpha particle (in MeV) at 14.6MeV for ^{54}Fe

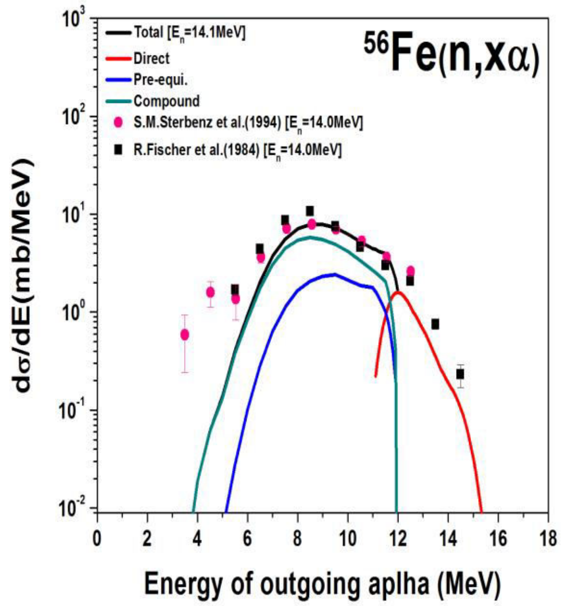

Fig.1.3 Differential cross-section with respect to energy (dσ/dE) versus energy of outgoing alpha particle (in MeV) at 14.1MeV for ^{56}Fe

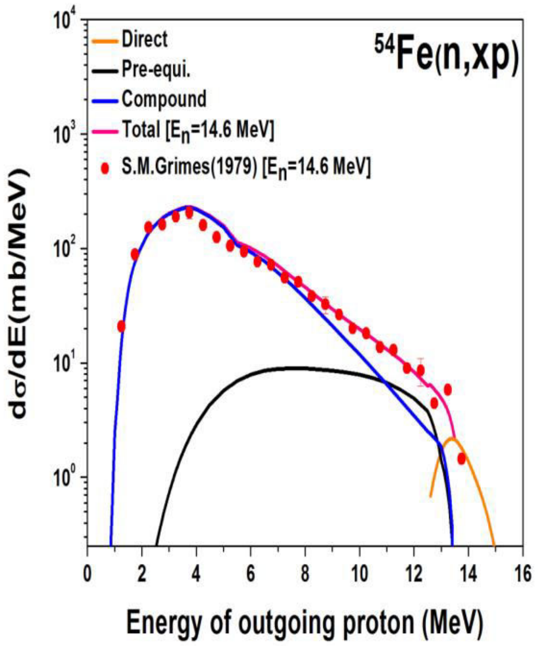

Fig.1.2 Differential cross-section with respect to energy (dσ/dE) versus energy of outgoing proton (in MeV) at 14.6MeV for ^{54}Fe

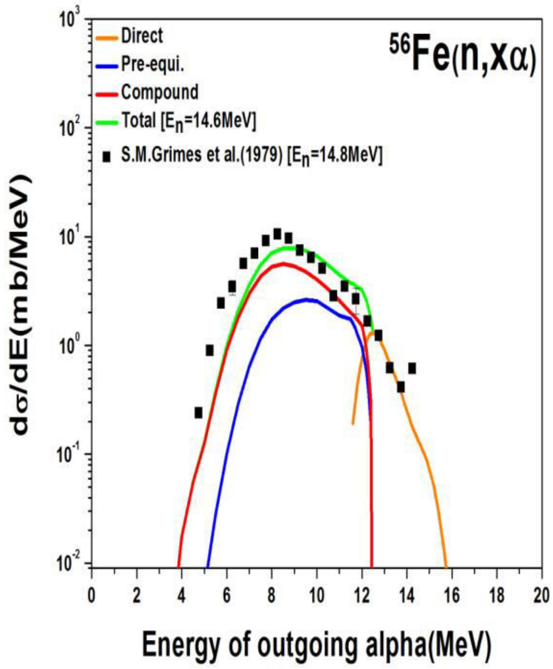

Fig.1.4 Differential cross-section with respect to energy (dσ/dE) versus energy of outgoing alpha particle (in MeV) at 14.6MeV for ^{56}Fe

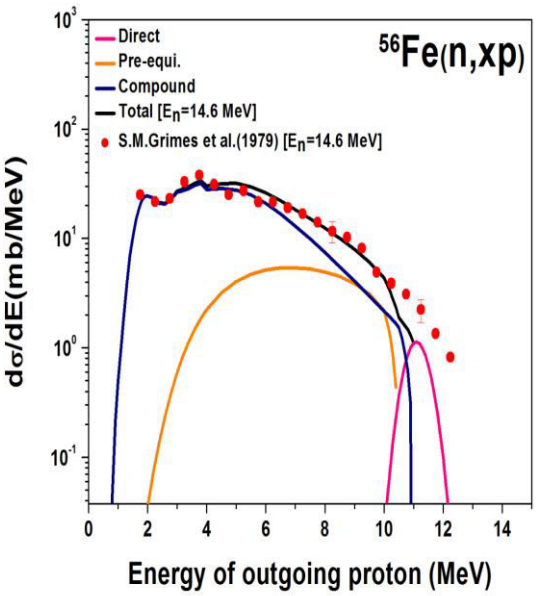

Fig.1.5 Differential cross-section with respect to energy (dσ/dE) versus energy of outgoing proton (in MeV) at 14.6MeV for ^{56}Fe

The differential cross-sections for (n,xp) and (n,xα) reactions are calculated as a function of energy of outgoing particle based on TALYS-1.9. DX calculation has been carried out for neutron induced reactions on isotopes of Iron (^{54}Fe and ^{56}Fe). In all the figures, the contribution of direct, compound and pre-equilibrium can be seen. At low energies compound is pre-dominant while at high energies direct reaction is pre-dominant and pre-equilibrium reactions show highest contribution at middle energy region. The emission probability for protons of energy 3-5MeV is highest for Fe(n,xp) reaction, while for Fe(n,xα) reaction, alpha particles of 7-9MeV are emitted with maximum probability. For ^{54}Fe(n,xα), ^{54}Fe(n,xp), ^{56}Fe(n,xp), ^{56}Fe(n,xα) the experimental data measured by S.M. Grimes et al. is available at projectile energy 14.6MeV and for ^{56}Fe(n,xα) the experimental data measured by S.M. Sterbenz et al., and R. Fischer et al., is available at energy 14.1MeV. The experimental values have been taken from EXFOR data library and are in a well agreement with the calculation of TALYS.

3. Summary and Conclusion

In this paper, differential cross-section is calculated as a function of energy of ejectile, for neutron induced reaction on isotopes of Iron (^{54}Fe and ^{56Fe}) at energies 14.1 and 14.6MeV. Calculation is carried out only for those isotopes for which experimental data is available. It can be seen from all the graphs that the distribution comes out to be Maxwellian. The contributions of direct, pre-equilibrium and compound reactions are also shown in graphs. From the above figures it can be seen that the peak for (n,a) type reactions is found at around 8MeV and the peak for (n,p) type reaction is found at around 3MeV.

4. References

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