Neutronics Study for Materials of Interest in Fusion Technology

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Introduction

Out of the many neutron induced reactions that take place inside a fusion reactor, the ones that produce gaseous elements like hydrogen and helium are of utmost importance for the study of structural integrity of reactor materials. The production of hydrogen and helium gases takes place mainly through (*n*, *xp*) and (*n, xα*) reactions. These reactions are induced on the first wall, structural and blanket materials of the fusion reactor. In addition to the production of hydrogen and helium, the other processes such as atomic displacements and transmutations can produce microstructural defects and modify physical properties of the materials. As there is no experimental and theoretical study on the neutron induced reactions of various radionuclides produced inside the reactor environment during the reactor operation. The materials suitable for the reactor structures are stainless steel with Cr, Fe, and Ni as main constituents (in SS316(LN)-IG content of Fe ≈ 65%, Ni ≈ 12%, Cr ≈ 17%). As the neutrons continuously coming from plasma interact with the various wall of the reactor made up of SS. There will be generation of various long-lived radionuclides like ^{55}Fe ($t_{1/2}$= 2.737 years), ^{59}Ni($t_{1/2}$= 7.6×10^{4}years), ^{59}Fe($t_{1/2}$= 44.5 days), ^{60}Co($t_{1/2}$= 5.27years), ^{60}Fe($t_{1/2}$= 2.6×10^{6} years), ^{53}Mn($t_{1/2}$=3.74×10^{6} y), ^{54}Mn($t_{1/2}$= 312.16 days) inside reactor environment. The neutrons coming from plasma interacts with various long-lived radionuclides already generated in reactor environment during its operation, such types of reaction are called second generation reaction. These radionuclides play crucial role in damage of the reactor material, because of their long time presence inside reactor. As they are radionuclide their properties such as decay heat, activity, dose rate, ingestion dose, inhalation dose, will effect normal lattice sites. The cross sections of the neutron induced reaction of various radionuclides are not measured and studied till now. So, there is a large gap in the nuclear data library .

Materials and methods

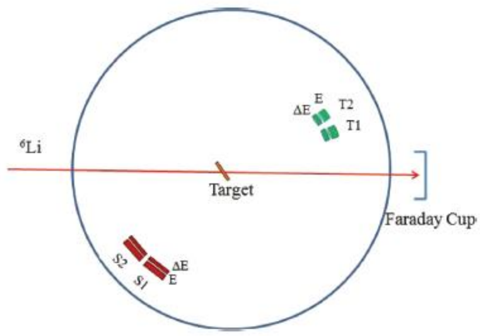

Fig.1. A schematic diagram of experimental setup inside a 1.5-m-diameter scattering chamber. Here, T1 and T2 are particle telescopes for detecting the projectile like fragments (PLFs) placed at distance of about 17 cm from the target center. The strip telescopes S1 and S2 have been used to identify the evaporated particles like proton and *α* and placed at about the same distance as T1 and T2.

Self supporting very thin feasible targets of iron, vanadium, chromium, manganese and cobalt of thickness 700 μg/cm^2, 600 μg/cm^2, 800 μg/cm^2, 500 μg/cm^2, 650 μg/cm^2 respectively, have been fabricated by using different technique like thermal evaporation, rolling, electron gun method at Tata Institute for Fundamental Research. Freshly prepared self-supporting target in the mass region A~ 50-60 fulfill one of the strong need of the measurement of neutron induced cross-section by direct particle counting method and by surrogate method, which play a significant role in fusion reactor technology. The code ACTYS is used for the calculation of major pathways of generation of radionuclides and the number of atoms of each radionuclides produced from 1 kg SS at different components of fusion reactor. The TALYS-1.8

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code is used to calculate optimized input parameters used during the nuclear model calculation were determined by fitting the (n,p) and (n,α) cross-sections to the experimental data for the stable and unstable nuclide for which no experimental data is available till now. The nuclear reaction parameters and nuclear reaction models is taken into consideration while doing this work.

Results and discussion

- The determination of reaction cross-section for long-lived radionuclide and short lived nuclei is a very challenging task . For the very first time, I have studied and experimentally verified the use of surrogate ratio method for the determination of (n,xp) reaction cross-sections. The cross-sections of ^{59}Ni(n,xp) ($t_{1/2} = 7.6 \times 10^4$ year) has been measured for the very first time using surrogate ratio method.
- There exist no experimental data for the neutron induced charged particle reaction on ^{60}Co. Excitation function of ^{60}Co(n,p)^{60}Fe and ^{60}Co(n,α) have been obtained from threshold to 20 MeV using Hauser Feshbach model calculations with pre-equilibrium contribution with TALYS code.
- Major pathways (nuclear reaction channels) and their production cross-section for the formation of long-lived radionuclides ^{55}Fe, ^{60}Co, ^{63}Ni, ^{59}Ni have been calculated using activation code-ACTYS and nuclear reaction modular codes TALYS-1.8 code.
- During the present study, it has been recognized that the ^{59}Ni(n,α)^{56}Fe and ^{55}Fe(n,α)^{52}Cr reactions may also generate significant displacement damage as the recoil energy of ^{56}Fe and ^{52}Cr are 2.476 MeV and 2.497 MeV (for fast neutrons), respectively.
- A two step neutron reaction sequence ^{58}Ni(n,γ)^{59}Ni(n,α)^{56}Feand ^{56}Fe(n,2n)^{55}Fe(n,α) results in an important contribution to the helium production in ITER grade SS316(LN)-IG material.

Summary and Conclusion

Neutronics study is the backbone for the reactor Physics design. In both, fission and fusion reactor neutrons play an important role to the generation of electricity, by the conversion of their kinetic energy to heat energy. Fission neutrons have a maximum energy 2-3 MeV, while fusion neutrons come from D-T plasma have a maximum energy of ~ 14.6 MeV. The Dynamics of fusion reactor neutrons is going to play a crucial role for the upcoming fusion reactor; International thermonuclear experimental reactor (ITER), DEMO, IFMIF and others. Cross-section data study (Simulation and Experimental determination via surrogate ratio method), Activation data and Damage data study mainly in the A ~ 50-60 are the main outcome of the work performed in the present thesis.

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