Measurement of $^{55}Fe(n,\alpha)^{52}Cr$ using $^{52}Cr(^{6}Li,d)^{56}Fe$ by surrogate ratio method

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Introduction

Improved and accurate nuclear data are urgently required for the design of advanced reactor concepts (GenIV, ADS) and for fusion devices. This demand holds in particular for long-lived radionuclides produced in a neutron environment [1] and fast neutron induced reactions are such quantities. The long-lived radionuclides in the mass region 50-60 such as $^{53}Mn(T_{1/2} = 3.74\times10^{6}y)$,$^{55}Fe(T_{1/2} = 2.73$ y), $^{60}Fe(T_{1/2} = 1.5\times10^{6}$ y), $^{60}Co(T_{1/2} = 5.27$ y), ^{59}Ni ($T_{1/2} = 7.6\times10^{4}$y), ^{63}Ni ($T_{1/2} = 100.1$ y) are of primary concern as nuclear waste and radiation damage issues for future fusion devices. As neutron induced reaction on structural materials, plasma facing materials, lead to continuous production of long-lived radionuclides [2] .

^{55}Fe is a primary dominant nuclide produced by neutron induced reaction on Fe, Co and Ni elements by $^{56}Fe(n,2n)$, $^{54}Fe(n,\gamma)$, $^{59}Co(n,\alpha)^{56}Mn(\beta^{-})^{56}Fe(n,2n)$, and $^{58}Ni(n,\alpha)$ reactions [3]. Fusion neutronics studies have been done so far considering only the stable isotopes of Cr, Fe, and Ni. But in a D-T fusion reactor, large amount radio nuclides will be produced during reactor operation as well as after shutdown, which may affect neutronics of the reactor.For example, after reactor is shut down and when the reactor restarts, ^{55}Fe content is quite high in addition to primary radio nuclides. These nuclides will interact with slow and fast neutrons and produce large amount of hydrogen and helium which leads to the swelling and embrittlement of the structural and wall materials. Helium production effects are expected to be larger because of the higher neutron energy in fusion reactor. The neutron induced reaction cross-sections of $^{55}Fe(n,\alpha)$ is also crucial for the neutronics point of view [4].

Experimental details and data analysis

Fresh self-supporting ^{nat}Cr (abundance ^{52}Cr~ 84%) target of thickness 500 µg/cm2 were prepared with thermal evaporation technique and bombarded with a ^{6}Li beam of energy E_{lab}= 33.0 MeV, from a (14 MV) Pelletron-Linac Accelerator facility at BARC-TIFR, Mumbai. The $^{56}Fe^{*}$ compound nucleus is formed in $^{52}Cr(^{6}Li,d)^{56}Fe^{*}$ in transfer reaction, which serves as a compound system for both desired ($^{55}Fe(n,\alpha)$)and reference ($^{55}Fe(n,p)$) reactions. The two silicon surface barrier (SSB) ΔE-E detector telescope T1 and T2 with ΔE detector of thickness 150 and 100 µm respectively and with identical E detector of thickness of 1 mm were mounted at an angles of 25° and 35° with respect to beam direction around the transfer grazing angle to identify the projectile-like fragments (PLFs). The proton, deuteron, triton and alpha are uniquely identified by plotting E versus the residual energy in the E detector (E_{res}).

A Large area 16-strip solid-state detector was placed at a back angle 130° with respect to the beam direction with an angular opening of 16° to detect the decay proton in coincidence with PLFs. The time correlation between light charged particles and decay particles (proton) were recorded through a time to amplitude converter (TAC). In the present work, $^{55}Fe(n,\alpha)$ reaction cross-section has been obtained from measurements of the ratio of proton and alpha decay probabilities of $^{56}Fe^{*}$ compound nucleus over the excitation energy range 19 - 40 MeV. The $^{55}Fe(n, p)$ cross-section values as function of excitation energy were used as the reference to determine the cross section from the $R(E_{ex})$ measurement.

Results and discussion

Experimentally measured cross-sections by surrogate technique of $^{55}Fe(n,\alpha)$ have been compared with Nuclear model calculations and along with different evaluated nuclear data libraries ROSFOND-2010, TENDL-2014 and EAF-2010. There is no experimental data available in EXFOR data library for this reaction in this energy region. In EMPIRE3.2.2 code ATILNO parameter value has been changed by 10% from default value. In TALYS-1.8 we used recent microscopic temperature-dependent Hartree Fock-Bogolyubov level density using Gogny interaction. Results from TALYS-1.8 [5] code and EMPIRE3.2.2 are much higher by a factor of 2-2.5 with our measured cross-section values in the equivalent neutron energy range 9-21 MeV. The measured $^{55}Fe(n,\alpha)$ reaction cross sections also are much lower compared to all the four data libraries. The EAF-2010, TENDL2014. ROSFOND-2010 cross-sections show large discrepancy from each other and also without experimentally measured and model calculations values as shown in Figure 2. The experimentally measured cross section data is much lower than the statistical nuclear reaction model codes TALYS and EMPIRE and also the evaluated nuclear reaction data libraries, therefore, reanalysis of the experimental data is being carried out.

References

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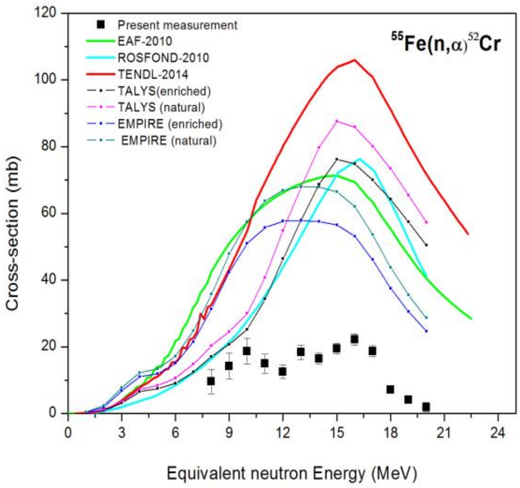

FIG.1. The $^{55}Fe(n,\alpha)$ cross-section as a function of equivalent neutron energy along with various data libraries and nuclear model calculations.