Transmutation Nuclides and their Energy Spectra due to Interactions of Fusion Neutrons in ^{28}Si, ^{58}Ni and ^{184}W

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Introduction

The establishment of fusion power plant as clean source of energy to meet the requirements of future generations is one of the several big challenges that researchers across the globe are trying to solve. The deuterium-tritium fusion reaction produces a 14.1 MeV neutron and a 3.5 MeV α-particle. These neutrons undergo several types of interactions with the surrounding structural materials in the fusion system. SiC, Ni and W alloys are potential candidate materials for developing structural components of the fusion reactor [1]. As a result of neutron interactions, a large number of transmuted products are formed in the target material. These transmutation species can possess several keV to MeV kinetic energies and play important roles in the evolution of structural mechanical and chemical properties of the structural materials. The transmuted nuclides due to 14.1 MeV neutrons reactions in ^{28}Si, ^{58}Ni and ^{184}W isotopes along with their energy distributions are estimated and presented in this work.

Methodology

Neutrons of a particular energy can undergo different possible reactions with the target nucleus based on the cross sections of interactions. The elastic scattering is prevalent at all energies, whereas, inelastic scattering and other typical threshold reactions become increasingly dominant at higher energies. The radiative capture is generally dominant at low energies (10^{-5} eV to hundreds of keV), but very small at higher energies. Among the transmutation reactions are the neutron-induced charged particle out, (n, xn) where x = 2, 3, 4, etc and (n, γ) reactions.

The transmutation nuclides produced by reactions of neutron with an isotope are estimated by using the basic evaluated nuclear data libraries such as ENDF/B-VII.1, TENDL-2019, etc [2]. The different nuclear reactions are arranged into separate sections and different types of data on these reactions are arranged into separate files in these libraries. At higher incident energies where several threshold reaction channels open up, many reactions cannot be individually identified during the evaluation process, i.e., the particles / products obtained cannot be definitely ascribed to a particular type of reaction. The cross sections of all these reactions are lumped together and given along with the yields of various products in a single section according to the ENDF-6 formats [3]. In order to extract the required data and perform the necessary processing, computer codes TransmU and RecedU are written. In these codes, the heavy transmuted nuclides of explicitly given reactions are identified and the list of these nuclides are combined along with the nuclides obtained from the lumped data. There can be multiple occurrences of nuclides because of obtaining them in different reactions. These nuclides are counted ensuring that they appear only once in the list of transmuted nuclides. However, a particular nuclide produced from different reaction channels generally has different energy distributions, which is taken into account while computing the energy spectra of the transmuted nuclides.

Results and Discussion

The transmuted nuclides due to interactions of neutrons with ^{28}Si, ^{58}Ni and ^{184}W are estimated using the ENDF/B-VII.1 and TENDL-2019 nuclear data libraries. Fig. 1 (a), (b) and (c) show the transmuted nuclides produced from ^{28}Si, ^{58}Ni and ^{184}W, respectively, according to these sources of nuclear data. The estimated production of transmuted nuclides based on the two data sources are different. More number of transmuted nuclides are produced according to TENDL-2019 as compared to ENDF/B-VII.1, particularly with lower values of Z and with a broader range of isotopes for a given value of Z.

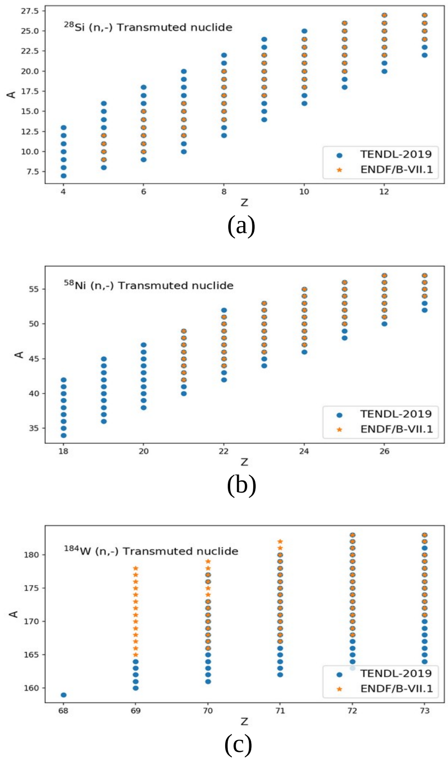

Fig. 1: Transmuted nuclides produced due to interactions of neutrons with (a) ^{28}Si, (b) ^{58}Ni and (c) ^{184}W, as estimated by TransmU code using TENDL-2019 and ENDF/B-VII.1 nuclear data libraries.

It is to be noted that most of the reactions feasible under 20 MeV neutron energy are explicitly identified and most of the transmuted nuclides obtained by processing the given lumped nuclear data are produced in reactions having thresholds beyond this energy. Hence, the yields of the products at various energies are important quantities to note while computing the energy spectra. Therefore, many of the transmuted nuclides shown in Fig. 1 are not produced under the fusion neutron spectrum (where neutrons are found maximum up to 20 MeV). The energy spectra of transmuted nuclides having non-zero formation cross sections are computed. Fig. 2 (a), (b) and (c) show the energy spectra of transmuted nuclides produced due to reactions of a 14.1 MeV neutron with ^{28}Si, ^{58}Ni and ^{184}W isotopes, respectively. The large cross sections for low energy (n, γ) reaction in ^{58}Ni and ^{184}W are evident from the spectra of ^{59}Ni and ^{185}W, respectively. The ^{29}Si recoils in case of ^{28}Si are formed mainly in the keV region. These energy spectra of transmuted nuclides serve as important inputs for designing and modeling of structural materials in nuclear reactors.

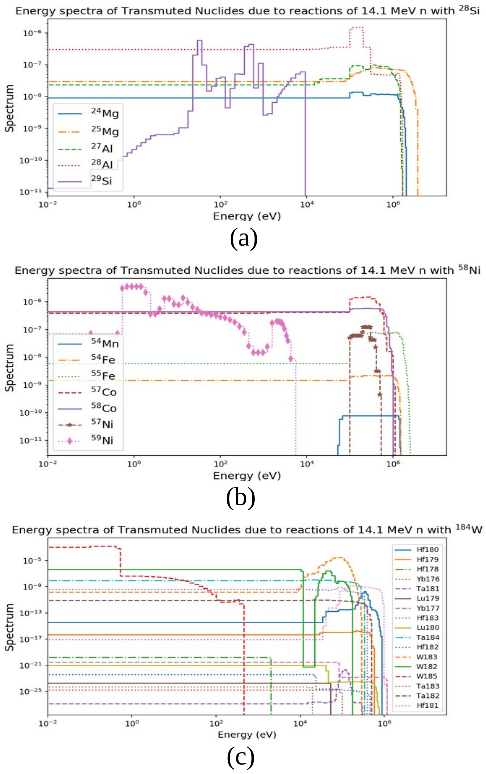

Fig. 2: Energy spectra of transmuted nuclides produced in interactions of a 14.1 MeV neutron with (a) ^{28}Si, (b) ^{58}Ni and (c) ^{184}W, as computed by the RecedU code using the nuclear data from ENDF/B-VII.1 and TENDL-2019.

References

[1] S. J. Zinkle, J. T. Busby, Materials Today 12 (11) (2009) 12 – 19.

[2] https://www-nds.iaea.org/

[3] A. Trkov et al., ENDF-6 Formats Manual, February, 2018.

This work has been performed as an independent researcher when not being affiliated to any organization.