Quantifying Neutron Radiation Damage in Structural Elements from Evaluated Nuclear Data Using an Indigenous Computer Code - CRaD

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Introduction

The radiation damage of structural materials is an important aspect in the design of fast reactors. These materials often get degraded, due to drastic changes in their properties, to such an extent that they become unsuitable for further use in the high radiation environments. The damage due to neutron radiation among others has to be dealt with special importance because of high fast neutron flux in these reactors. Radiation damage in materials is generally quantified by the number of displacement per atom (dpa). The neutron dpa is estimated from the knowledge of a neutron dpa cross section database and the fluence of neutrons in the reactor location.

The study of radiation damage involves several parameters, like energy of primary knock on atoms (PKA), damage cross sections, radiation heating, gas production rates, dynamics of induced defects, etc., to be estimated either from irradiation experiments followed by microscopic measurements of changes in material properties or from the simulations using computer experiments. In general, the study of damage following neutron interactions is based on the reaction data from evaluated nuclear data libraries. An indigenous computer code, CRaD is developed at IGCAR to calculate the above damage parameters from nuclear data libraries. The present work briefly discusses about the dpa cross sections and PKA spectra of structural elements calculated from ENDF/B-VII.1 using CRaD. CRaD follows the basic neutron reaction kinematics to calculate the PKA spectra and dpa cross sections.

Neutron damage cross sections and PKA spectra

Depending on its energy, an incident neutron can interact with the target nucleus predominantly in any of the possible ways, viz. elastic, (n, n´), (n, γ), (n, xn), (n, p), (n, d), (n, t), (n, ^{3}He), (n, α), etc. While elastic scattering and radiative capture reactions take place at all energies (0–20 MeV), most other reactions are threshold type with a few target materials being exceptions. After the neutron interaction has occurred, the primary recoil atom is the one that can traverse through the medium dissipating its energy in electronic ionization and subsequent atom displacements. The latter is termed as damage energy, *T*. It is calculated from the Robinson partition function [1] based on the theory of energy partitioning of Lindhard, et al. The number of dpa due to this damage energy is predicted from analytical displacement damage model, ν(*T*) of Norgett, Robinson and Torrens [2]. The dpa cross section is calculated using Eq. (1). Knowledge of the PKA spectra is important to calculate the effective energies with which PKAs are formed in various locations of reactor. The PKA spectrum is calculated using Eq. (2) in a 175 to 175 neutron to recoil group matrices. In these calculations nuclear data from various files and sections of ENDF/B-VII.1 are used to account for anisotropy and other aspects of nuclear reactions [3, 4].

$$\sigma_D(E) = \sum_i \int \sigma_i(E, E_R)\nu_i[T(E_R)]dE_R \quad (1)$$

$$\frac{d\sigma(E, E_R)}{dE_R} = \sum_i \sigma_i(E) K_i(E, E_R) \quad (2)$$

E_R = recoil energy; K_i = i^{th} reaction kernel.

Results and discussions

The partial and total dpa cross sections from all neutron reactions in case of ^{58}Ni are shown in Fig. 1. The percentage contribution of various reactions out of total is shown in Fig. 2. These illustrate the importance of different reactions in different neutron energy ranges. The predominant contributor to damage at all energies is found to be the elastic scattering of neutrons with the target nucleus. At the high energies, threshold reactions contribute to large extents. The low energy neutron damage is primarily from the (n, γ) reaction. This is representative of the majority of structural elements.

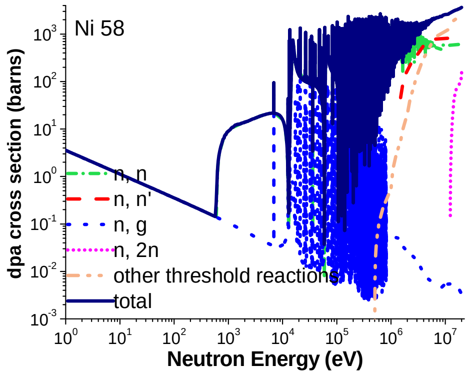

Fig. 1 total and partial dpa cross sections from various neutron reactions in ^{58}Ni

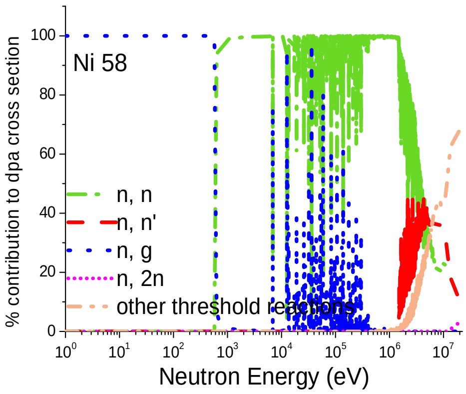

Fig. 2 percentage wise contributions of reactions to dpa

The PKA spectra matrices in Ni at a few energies are shown in Fig. 3. These are obtained by combining the spectra in the Ni isotopes with their respective abundances. The total PKA spectrum in each isotope is the addition of the same from all reactions. The spectrum from (n, γ) recoil is not considered here due to involved complexity. The average energy of recoils due to the capture gammas is found to be less than 1 keV in iron.

The neutron dpa in case of Fe, Ni and Cr at two different locations of Prototype Fast Breeder Reactor (PFBR) for three cycles (540 days) of full power operation are compared in Fig. 4. Because of higher neutron flux at the core centre,

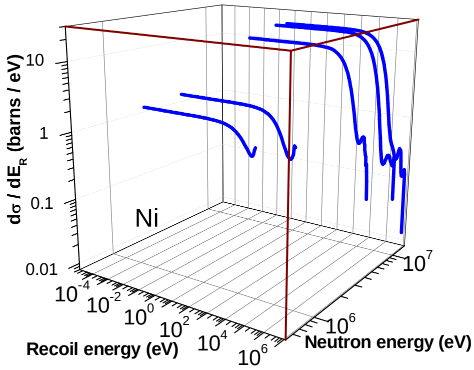

Fig. 3 Ni pka spectra for a few neutron energies

the values are higher here than at the radial blanket. Nickel experiences higher dpa than Fe and Cr due to larger dpa cross sections.

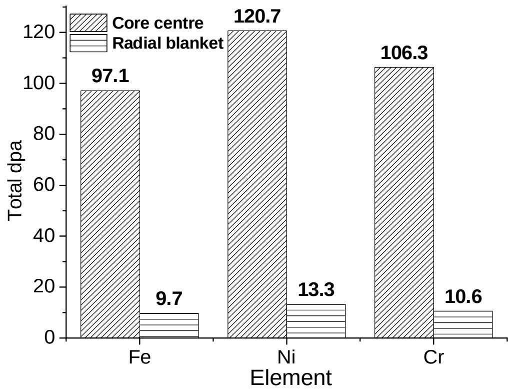

Fig. 4 total dpa at core centre and radial blanket

References

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