# The estimation of neutron kerma coefficients from evaluated nuclear data by using the CRaD code

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## Introduction

The generation of heat from radiation-matter interaction in the nuclear systems forms an important aspect from the point-of-view of their safe operation, efficient thermo-mechanical performance and protection of the materials from radiation. The estimation of radiation heating is also important for the quantification of biological dose received by the operators of these systems. In nuclear reactors, the heat energy deposited in the structural materials due to the interactions by neutrons and photons is an important quantity in the shielding design. The heating in the core-inner regions is primarily due to neutron interactions, while towards the peripheral regions gamma heating is dominant.

In this paper, we compute the neutron heating rates and kerma (kinetic energy release in matter) coefficients in structural materials of interest in nuclear reactors. The methodology developed within the indigenous code CRaD to calculate the neutron heating shall be discussed briefly. In the previous meetings of the Symposium, the development of the CRaD code to compute the atom-displacement damage and the spectra of primary knock-on atoms due to neutron interactions, by utilizing the evaluated nuclear reaction data in various ENDF-6 libraries [1] have been reported [2]. Recently, this code is extended of its capability to calculate the neutron kerma coefficients for structural materials.

## Methodology adapted to compute neutron heating

The heating as a result of neutron interactions is due to the energy carried away by various charged products of the reaction, which is eventually deposited in the medium. It is assumed that the charge neutral particles neutron and photons do not deposit their energies at least locally in the medium. Then the total heat energy deposited locally in the medium is the sum of the energies of the charged products, which multiplied with the cross section for the respective process, gives the kerma coefficient. The total kerma coefficient for a material $p$ at the neutron energy $E$ is defined as follows:

$$k_p(E) = \sum_q \sum_r \overline{E}_{pqr}(E)\sigma_{pq}(E) \qquad (1)$$

The quantities in the RHS of Eq. (1) denotes the kinetic energy carried away by $r^{\text{th}}$ secondary charged species ($\overline{E}$) multiplied with the cross section ($\sigma$) of the $q^{\text{th}}$ reaction process (elastic scattering, inelastic scattering, (n, γ), (n, p), etc.). The kinetic energy of the secondary particle is calculated by applying the laws of energy and momentum conservations and by using their energy and angular distributions data from an evaluated nuclear data file, like ENDF/B-VII.1 [3].

## Results and discussions

An extensive study has been carried out to compute the neutron heating cross sections in various structural elements of interest in fast reactors by using the CRaD code. We discuss here, as illustrations, the results obtained in case of iron, which is the most important structural element.

*(i) Comparison with NJOY-2016*

The neutron heating cross sections calculated for the isotopes $^{54, 56, 57, 58}$Fe by using the data in ENDF/B-VII.1 with CRaD and NJOY-2016 [4] codes are combined together with their abundances to find the cross sections in elemental Fe. These cross sections are then multi-grouped in VITAMIN-J 175 group structures for comparison, see Fig. 1.

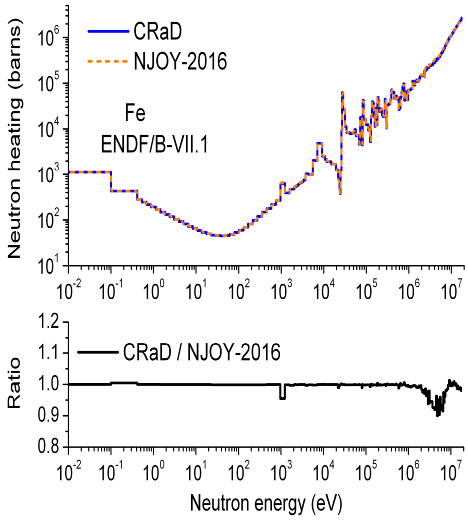


**Fig. 1**: Comparison of neutron heating cross sections between CRaD and NJOY-2016 codes.

It can be observed from the ratio plot that the agreement between the results from these two codes is within 10%.

*(ii) Neutron heating rates in different spectra*

The neutron kerma cross sections in Fe obtained by using the CRaD code are employed to determine the total heat deposited in the material subjected to PFBR [5] core centre, ITER-DT and PWR-RPV spectra. These estimates are presented in Table 1.

**Table 1**: Heat deposited in Fe by neutron interactions

| Fe | PFBR core centre | ITER-DT | PWR-RPV |
|---|---|---|---|
| Kerma (W/kg) | 548 | 151 | $1.16\times10^{-2}$ |

Note that the total neutron fluxes for the PFBR core centre, ITER-DT and PWR-RPV spectra are respectively $8.0\times10^{15}$, $2.1\times10^{14}$ and $1.12\times10^{11}$ n/cm$^2$s. The PFBR core centre spectrum is harder compared to the other two spectra. In ITER-DT, heating occurs dominantly due to the interactions of 14 MeV neutrons, whereas in PFBR core centre significant contributions come from neutrons around the hundreds of keV energy region.

*(iii) Nuclear data uncertainties in neutron kerma coefficients*

The physical quantities that are estimated using the evaluated nuclear data are uncertain due to the uncertainties present in the nuclear physics model parameters and experimental results. These uncertainties in neutron kerma coefficients are quantified here by applying the Total Monte Carlo method [6] for uncertainty propagation. It employs a large number random evaluated nuclear data files and the uncertainties along with the covariances of the data are derived after performing many identical calculations. A systematic study from about 500 random data files in TENDL-2017 is carried and the results are presented for $^{56}$Fe in Table 2, as an illustration. Depending on the neutron spectra considered here, the nuclear data uncertainties in total neutron kerma coefficients are found to vary from 2.5 % to 12 %.

**Table 2**: Nuclear data uncertainty in total neutron kerma coefficient of $^{56}$Fe

| Spectrum | Kerma ± uncertainty (W/kg) |
|---|---|
| PFBR core centre | 527 ± 13 |
| ITER-DT | 141 ± 17 |

## Summary

The indigenous code CRaD is extended with the capability to compute neutron kerma coefficients for the applications in nuclear structural materials.

## References

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