Consistency of Nuclear Data and Processing Codes for Calculation of Nuclear Heating in Fusion Reactors

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The calculation of nuclear heating and dose in fusion reactor blankets, magnet shields, superinsulators and magnets is of prime importance for both the heat transfer design and economics of fusion reactors. Calculation of heat generation requires neutron interaction data, gamma-ray production and interaction data and several processing codes. A study has been carried out, using conservation of energy as the criteria, to determine the consistency of processing codes and nuclear data sets for several CTR materials.

The following equation can be derived [1] from an energy balance for a segment of the reactor.

$$H_n + S_{E\gamma} = L_{nE} + \sum_i \sum_j R_{ij} Q_{ij} + \sum_{i'} \sum_{j'} R_{i'j} E_{Di'j} \qquad (1)$$

where H_n is the neutron heating rate, S_{E_γ} is the rate of photon energy production from neutron reactions, R_{ij} is the reaction rate in element j for reaction i in which conversion of kinetic energy into mass and vice versa occurs. All these quantities are integrated over energy and volume of the segment . L_{nE} is the net neutron leakage into the segment, Q represents the Q-value, and E_D is the energy deposition per reaction from radioactive decay. The right hand side of Equation 1 can be determined from transport calculations and must be equal to $H_n + S_{E\gamma}$ calculated from neutron kerma factors and gamma production cross sections if the energy is preserved in the basic nuclear data and processing codes involved.

Neutronics and photonics calculations were performed for a CTR system consisting of 17 zones; 250 cm plasma, 50 cm vacuum, 1 cm niobium, three zones of 95% Li plus 5% Nb, 25 cm iron, and one-meter of 35% Fe plus 35% Pb plus 30% B_4C divided into ten zones. All neutron multigroup cross sections were derived from ENDF/B3 [2] evaluations with SUPERTOG [3]. H_n was calculated from neutron kerma factors derived from the same evaluations with MACK [4&5]. Gamma production cross sections for lead and iron were processed from ENDF/B3 with LAPHANO [6]. Another set for iron was obtained from DNA evaluation Mod. 1. Li^6, Li^7, Nb and C gamma production cross sections are not provided in ENDF/B and were obtained from reference 7. The fluxes and currents were determined with ANISN [8]. Table 1 shows the results for selected zones. The percentage deviation represents the error in the energy balance resulting from the inconsistency of nuclear data and processing codes commonly used.

Table 1 shows that the nuclear heating is overestimated by about 16% in the first wall. Since H_n is small compared with $S_{E\gamma}$ it does not contribute significantly to this error. Hence, the gamma production cross sections of reference 7 are not consistent with the neutron data of ENDF/B3. The neutron and gamma data of ENDF/B3 for iron are consistent to within 2%. Energy deposition in iron calculated with gamma production from DNA and neutron data from ENDF/B has an error of 23%. The neutron heating in zone 10 is about eight times the gamma energy source and the energy is preserved in this zone. Hence, the neutron kerma factors from MACK are consistent with ENDF/B3 neutron data, and the results of the SUPERTOG and ANISN programs. It can also be noted from table 1 and other results that the consistency is best for zones which have low $S_{E\gamma}$ and high H_n which indicates that the neutron kerma factors from MACK are reliable.

Another check was devised to investigate the consistency of neutron interaction and gamma production data at any neutron energy. The results show that the data for Be and lead are consistent at almost all neutron energies. The gamma energy production data for Li^7 in reference 7 are overestimated by more than 500% at 15 MeV relative to results derived from ENDF/B3 neutron data.

As a partial remedy for preserving the energy it is suggested that: 1-gamma production cross sections be derived concurrently with the neutron kerma factors, and 2- neutron and gamma data in ENDF/B be checked to ensure that the energy conservation law is not violated.

TABLE 1

Consistency of Neutron Kerma Factors and Gamma Production Cross Sections
For Preserving The Energy in Calculation of Nuclear Heating

(Results normalized to one fusion (14 MeV) neutron and all energies are in units of MeV)

Zone and Composition	A^a	L_{nE}	$F_1{}^b$	H_n	$S_{E\gamma}$	$F_2{}^c$	% deviation[d]
Zone 3 1 cm niobium	-0.482	+3.701	2.2186	0.128	2.441	2.5685	15.77
Zone 4 95% Li + 5% Nb	0.638	7.244	7.8820	6.249	1.866	8.1148	2.95
Zone 7 25 cm Fe[e]	0.539	1.594	2.1323	0.356	1.845	2.2008	3.21
Zone 7 25 cm Fe[f]	0.539	1.594	2.1323	0.356	2.273	2.6289	23.29
Zone 10 35% Fe + 35% Pb + 30% B_4C	0.012	0.003	0.0157	0.014	0.002	0.0158	0.70

a- $A = \sum_j \sum_i R_{ij} Q_{ij} + \sum_j \sum_{i'} R_{i'j} E_{Di'j}$

b- $F_1 = A + L_{nE}$ (determined from reaction cross sections, fluxes, and Q-values)

c- $F_2 = H_n + S_{E\gamma}$ (determined from neutron kerma factors, gamma production cross sections and neutron fluxes)

d- $\% \text{ deviation} = \frac{F_2 - F_1}{F_1} \times 100$

e- gamma production cross sections from ENDF/B3

f- gamma production cross sections from DNA evaluation Mod. 1

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