SHORT NOTE

Doppler Effect of Structural Materials in Fast Reactors

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In a fast reactor, a large quantities of Fe, Cr and Ni are contained as cladding or structural materials in the core, blanket and reflector. The experiments and analyses for the structural material Doppler effect have been performed and a strong Doppler effect has been observed in stainless steel\(^{(1)}\)~\(^{(3)}\). However, the calculated Doppler effects showed a considerable underestimate to the experimental results\(^{(2)}\)~\(^{(3)}\).

The temperature dependence of capture cross sections for the structural materials is mainly due to \(p\)-wave neutron resonances and seen in the energy range of 1~300 keV, where lies the important range of neutron spectrum in fast reactor. However, the temperature dependence of the cross sections has not been considered in the group constants library such as JFS-II\(^{(4)}\), LIB-IV\(^{(5)}\) and/or JENDL-2B\(^{(6)}\), that is, the cross sections at the zero temperature \((T=0\ K)\) are used in fast reactor calculations. Benchmark tests of the group constants libraries have been performed\(^{(6)}\)~\(^{(4)}\) by using the cross sections of the structural materials for \(T=0\ K\).

In this note, the structural material Doppler effects for the temperature rise from 0 to 300 K are calculated for 23 fast critical assemblies. The correction factors for the \(k_{\text{eff}}\)-values in the benchmark calculations are evaluated from the calculated Doppler effects. As for a practical temperature rise of the structural materials, the Doppler effect is studied by analyzing the whole core Doppler experiment in SEFOR assembly. In order to test the temperature dependence of the capture cross sections, furthermore, the sample Doppler experiments in FCA assemblies are analyzed by using the nuclear data of JENDL-2\(^{(1)}\) and ENDF/B-IV\(^{(8)}\), which are not used in the calculation of Refs. (1)~(3). For this purpose, the temperature dependent self-shielding factors of Fe, Cr and Ni are calculated with the assumption of collision density constant by using the PROF GROUCH G-II code\(^{(4)}\). The group constants are produced with the 70 group structure of JFS-III\(^{(9)}\), in which the energy range below 10 MeV is divided with an equal lethargy width 0.25.

1. Effective Multiplication Factors in Benchmark Calculations

The benchmark calculations for the 23 fast critical assemblies used in the benchmark tests of JFS-II\(^{(4)}\) were performed with one-dimensional diffusion theory by using the group constants library generated from the JENDL-2 compilation. The calculated effective multiplication factors \(k_{\text{eff}}\) are shown in Table 1. The \(k_{\text{eff}}\)-values are corrected by the necessary factors such as heterogeneity and transport effects taken from Ref. (10). Table 1 shows also the structural material Doppler effect for the temperature rise from 0 to 300 K. The magnitude of the Doppler effects varies depending on the assemblies, i.e. the core size, compositions and neutron spectra. Especially, the effects become larger for the assemblies with large core volume such as MZB, ZPR-2, ZPR-6-7 and ZPR-6-6A in which the concentration of the structural materials is comparatively high. The Doppler effects on \(k_{\text{eff}}\) are more than 0.2% for these assemblies, and the effects are comparable to the transport correction factors\(^{(10)}\).

We also calculated the Doppler effect for

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2. Isothermal Doppler Coefficient in SEFOR Assembly

The Doppler effect of cladding or structural material has been estimated to 15~20% of that of U metal, which may be of importance, at least in the isothermal case\(^{(1)}\). In the SEFOR experiments, the isothermal Doppler coefficient was measured by determining the reactivity change due to the power increase from 0 to 20 MW, while holding the coolant temperature constant\(^{(12)}\). The calculation of Doppler effect was performed by using one-dimensional spherical model in the benchmark specification\(^{(12)}\).

Figure 1 shows the fuel and structural material Doppler effects. The structural material Doppler effect calculated from the nuclear data of JENDL-2 is about 8% of the fuel Doppler effect, but the results calculated with ENDF/B-IV data are smaller. On the other hand, the ratio of the calculated values \((T=677\rightarrow 1,365 \text{ K})\) to the experiments of the isothermal Doppler coefficient is 1.18. Thus, the calculated value still tends to overestimate when the structural material Doppler effect is accounted for.

![Figure 1](image1)

**Figure 1** Comparison of isothermal Doppler reactivities for fuel and structural materials included in core region in SEFOR

Figure 2 shows the groupwise contribution of the total and structural material Doppler reactivity worths calculated by the use of the JENDL-2 data. It is seen from

![Figure 2](image2)

**Figure 2** Groupwise contribution of fuel and structural material Doppler reactivity worths for temperature change from 300 to 500 K in SEFOR assembly
this figure that the structural material Doppler effect is mainly caused by the \( p \)-wave resonance of Fe at 1.15 keV.

3. Analysis of Sample Doppler Experiment

The Doppler experiments for natural iron and stainless steel (74% Fe, 18% Cr and 8% Ni) were performed in FCA-V and VI assemblies\(^{(11)(13)}\). The Doppler reactivity change was measured at the core center by the small-sample oscillation, using the reactivity difference method. The Doppler samples are cylindrical, 25 mm in diameter and 156 mm long, and contained in a stainless steel capsule of 0.5 mm thick. The analyses of these Doppler experiments were performed\(^{(2)(3)}\) by a first-order perturbation theory using several nuclear data of ENDF/B-II, -III and UK\(^{(14)}\) for Fe, Cr and Ni. The calculated results considerably underestimated the Doppler effect of the structural material.

In order to test the temperature dependence of cross sections of Fe, Cr and Ni in JENDL-2 and ENDF/B-IV, we again performed the analyses of the sample Doppler experiments. The calculated results are shown in Figs. 3~5(a),(b) including the experimental results. As seen from these figures, the results calculated with the nuclear data of JENDL-2 overestimate considerably the Doppler coefficients in FCA-V-1 and -2, while they give a good estimate for FCA-VI-2. On the other hand, the results of ENDF/B-IV are in good agreement with the experimental values in FCA-V-1 and -2, while they underestimate for FCA-VI-2. Very large discrepancies are seen between the results for JENDL-2 and ENDF/B-IV and especially for the Doppler coefficient of natural iron. The main cause for these discrepancies can be considered as follows:

The neutron spectra in cores of small assemblies FCA-V-1 and -2 are harder than those of FCA-VI-2. As seen from Fig. 6, furthermore, the capture cross sections for Fe of JENDL-2 are larger than those of ENDF/B-IV in the high energy range, and smaller in lower energy side, especially for resonance.
cross section at 1.15 keV.

![Graph](image)

**Fig. 6** Comparison of capture cross sections of Fe of JENDL-2 and ENDF/B-IV

4. Concluding Remarks

In the class of prototype fast reactors such as MZB, the Doppler effects of the structural materials for the temperature rise from 0 to 300K on the effective multiplication factors were about 0.2%. Furthermore, the structural material Doppler effect may contribute by about 8% to the isothermal Doppler coefficient in SEFOR, though an exact estimate is not possible due to the ambiguity in the temperature of cladding and structural materials. From these results, we can remark that the cross sections of the structural materials should be calculated by considering the Doppler effect, especially when we consider the goal accuracies ($\pm 0.3\%$\(^{(15)}\) for $k_{\text{eff}}$ and $\pm 7\%$\(^{(16)}\) to $15\%$\(^{(15)}\) for Doppler effect) required from LMFBR design study. Hence, the temperature dependent self-shielding factors for the structural materials were taken into account in the JFS-III\(^{(3)}\) group constant library produced recently at JAERI.

From the analyses of the sample-Doppler experiments, on the other hand, it was shown that the effect of the uncertainty in the nuclear data of the structural materials on the Doppler coefficients was very large. This will demand an accurate evaluation of the nuclear data for the structural materials, particularly for resonances of Fe in the energy range below 200 keV.

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**References**