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Validation of ENDF/B-VI and JEF-2 Iron Cross-sections by Sensitivity and Adjustment Analysis*

I. A. Kodeli
CEA-CE-Saclay, France

Abstract

Validation of the iron cross-sections from the new evaluated nuclear data files like ENDF/B-VI and JEF-2.2 is described. Fast neutron energy range (above approximately 100 keV) was considered using ASPIS benchmark experiment. An extensive sensitivity, uncertainty and adjustment analysis was carried out to establish the quality of the cross-section data and to find the indications about the possible improvements to be introduced.

Introduction

Because of its excellent slowing down properties for neutrons in the upper MeV energy range, iron is most important structural and shielding material and is widely used in reactor technology. Integral checks of iron cross-sections, in particular of the inelastic scattering cross-sections are therefore of high interest. Benchmark experiments (like ASPIS) provide the reference for the validation of the basic nuclear data. ASPIS experiment (ref [1]) was designed to study neutron transport through more than 1 meter thick steel plate. ^{32}S, ^{103}Rh and ^{115}In reaction rates were measured at different distances in the steel shield.

Recently some new evaluations of the iron cross-sections have become available, like ENDF/B-VI and JEF-2. With the objective to compare the quality of these new data with respect to the older one, the ASPIS experiment was calculated using the ENDF/B-IV, /B-VI and JEF-2 cross-sections. Remarkable discrepancies were found between the different group constants. The sensitivity and adjustment analyses were therefore carried out to clarify these differencies. The calculational scheme presented in [2] and [3] was used for these studies. The relative sensitivity profiles of the Rh, In and S reaction rates with respect to the iron cross-sections were calculated using ENDF/B-IV data only, because the differencies between the cross-section evaluations were expected to effect little these relative values. ANISN and SUSD codes were used for the sensitivity calculations. The adjustment was on the contrary based on the C/E values, obtained by the exact Monte Carlo calculations.

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Adjustment analysis

If the adjustment is to provide the relevant information about the data base, the method uncertainties must be reduced as much as possible. Special attention has been paid to the treatment of resonancies in the production of the cross-section group data. Proper flux weighting and self shielding treatment have been found to play predominant role in the neutron flux calculations at the distancies beyond 20-30 cm of iron. Different group weighting results in this way in substantially different adjustments of the cross-sections, since they account for the cross-section processing error as well.

Other conditions to be satisfied for data adjustment are the following:

- Uncertainties of the experiment must be inferior to those of the calculation.
- The covariance matrices must be realistic.
- Since the linear theory was applied the data uncertainties must be relatively small.

Adjustment calculations were therefore based on the very precise Monte Carlo probability tables calculations. The results of the calculations by ENDF/B-VI and JEF-2.2 cross-sections, presented in the reference [4], were used.

The results of the transport calculations and the adjustment indicate that ENDF/B-VI data seem to be of very good quality. The calculated reaction rates are within 1 to 2 σ_0 of the experimental uncertainty (see Figure 1). This means that little new information can be deduced from the ASPIS experiment. Adjustment analysis suggested only some minor modifications of 1 - 2 % of the elastic and non-elastic cross-sections (Figure 3). The calculation was repeated with the adjusted iron cross-sections, leading to a slightly improved agreement with the experiment.

Concerning JEF-2 based calculations, only ^{103}Rh reaction rates are within the error bar of the experiment. ^{32}S and ^{115}In reaction rates are respectively over- and under-estimated by up to 40 % (Figure 2). Another problem concerning JEF-2 data is the absence of the covariance information in energy range below 0.8 MeV. Adjustments were therefore performed using three different covariance matrices:

- JEF-1 data, given in the ZZ-VITAMIN-J/COVA library [5], [6];
- EFF-2.1 Fe-56 data available only above $\sim$ 0.8 MeV [7]; 0 values were assumed below;
- ENDF/B-VI Fe-56 data [8].

As shown in Figure 4, adjustments depend greatly on the choice of the covariance matrices. Since EFF-2 covariances are not complete, the corresponding adjustment might not be realistic, in particular since they involve the modification of the total cross-sections. In general, the adjustments of the order of $\sim$ +5 % above 2 MeV, and up to $\sim$ -10 % below for the non-elastic, as well as the reduction of elastic cross-sections by few % are indicated in order to correct for the overestimation of ^{32}S reaction rates and the underestimation of ^{103}Rh and ^{115}In reaction rates. The calculation was this time not repeated by the adjusted cross-section sets. Only the reaction rates, estimated on the basis of the adjustments and the sensitivity profils (i.e. using linear theory) are therefore presented in Figure 2. In the case of ENDF/B-IV and /B-VI data (Figure 1) these estimations proved to be in good agreement with the actually calculated results.

Conclusions

The quality of the new iron evaluations for radiation shielding applications seem to be greatly improved with respect to older ENDF/B-IV data in the fast energy range between $\sim$ 100 keV and $\sim$ 15 MeV. In the case of ASPIS benchmark, all the reaction rates calculated by ENDF/B-VI iron data and ^{103}Rh reaction rates calculated by JEF-2 are within the error bar of the experiment (1 to 2 σ_0) whereas the JEF-2 ^{32}S and ^{115}In reaction rates are respectively over- and under-estimated. This means that practicaly no additional information can be drawn from the experiment concerning ENDF/B-VI iron cross-sections. In the case of JEF-2 ASPIS can contribute to the improvement of these data, provided the relevant covariance matrices are available. Some examples were given using three different covariance matrices.

References

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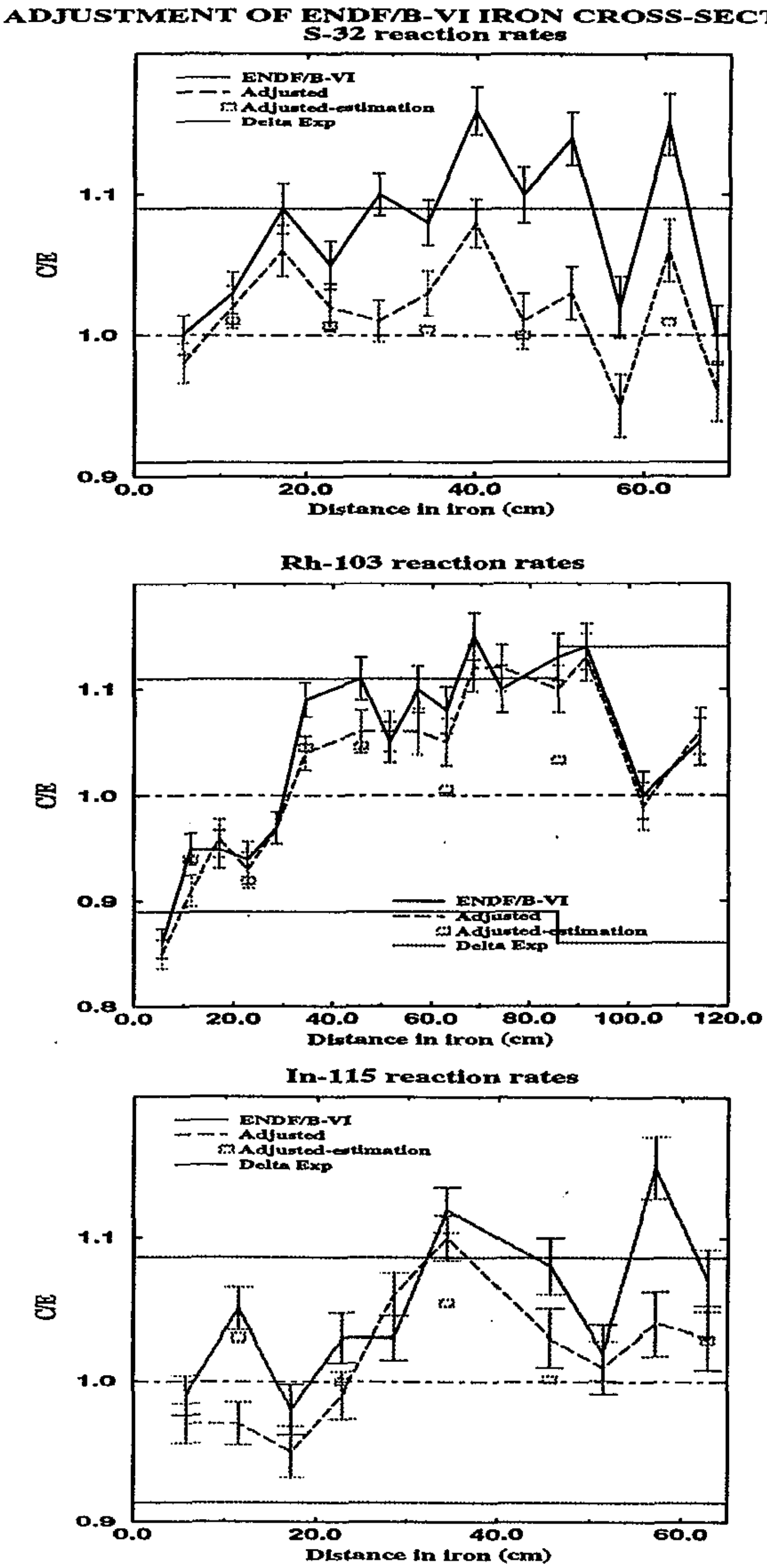

Figure 1: *C/E values for the reaction rates calculated using ENDF/B-VI original and adjusted cross-sections. M-C statistical error is shown as well. "Estimation" are the C/E values calculated by the adjustment code on the basis of the linear theory.*

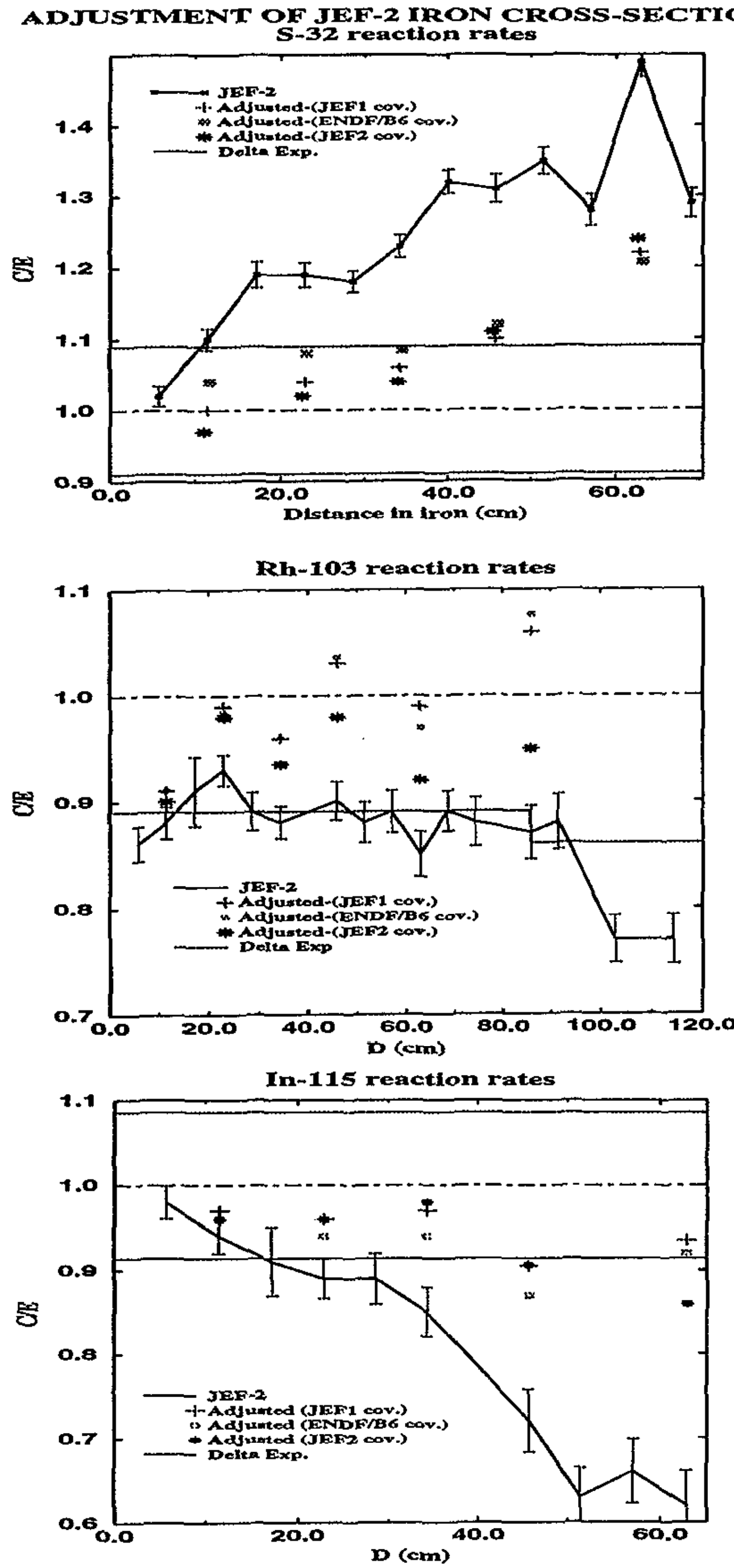

Figure 2: *C/E values, with the corresponding M-C statistical error, for the reaction rates calculated using JEF-2. The linear theory based estimated C/E for the adjusted JEF2 cross-sections, using different covariance matrices, are shown as well.*

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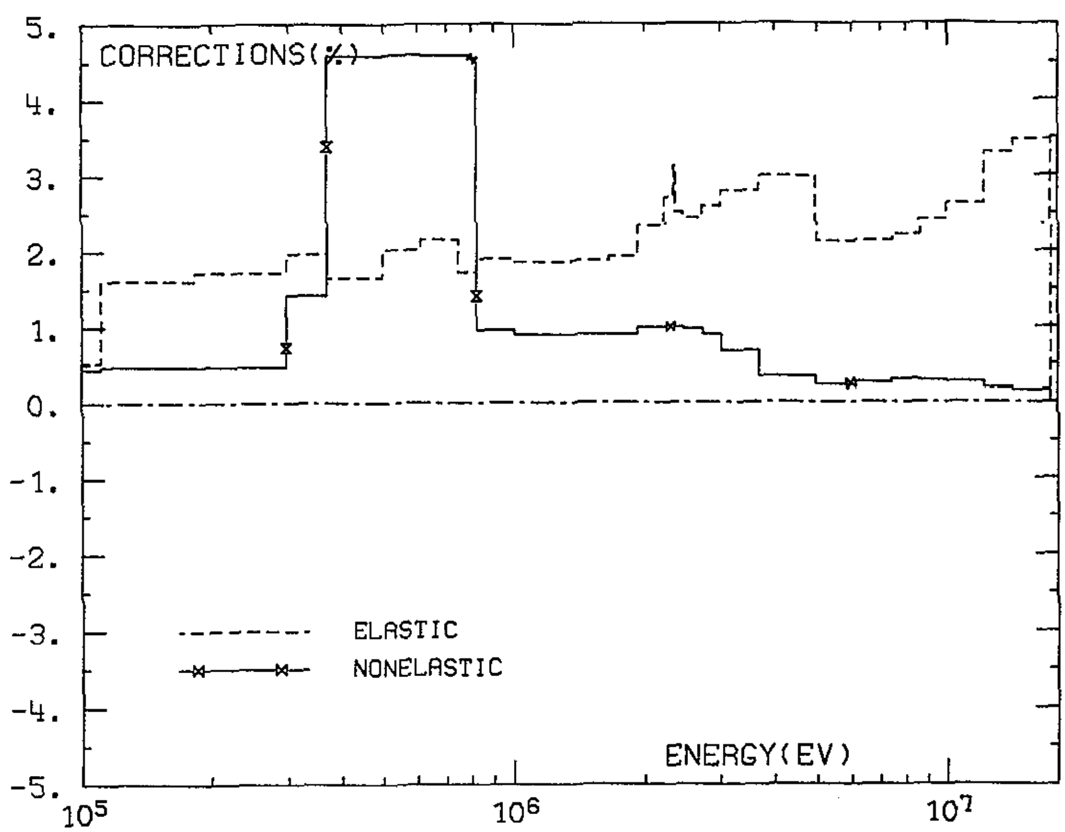

Figure 3: *Adjustements of the ENDF/B-VI iron cross-sections.*

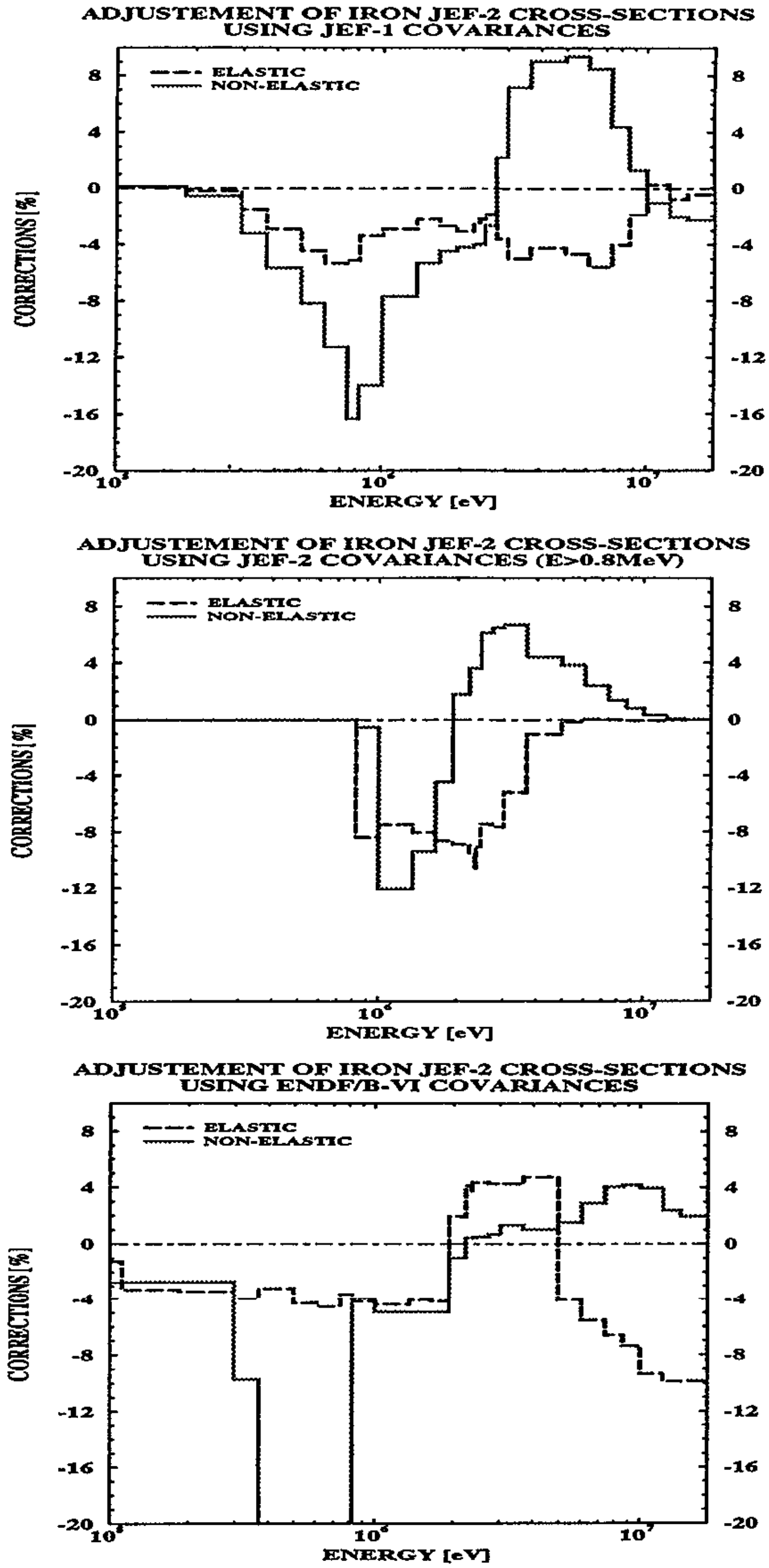

Figure 4: *Adjustements of the JEF2 iron cross-sections obtained using different covariance matrices.*