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FTR SHIELD DESIGN CROSS SECTIONS --
A PARTIAL EVALUATION

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FTR SHIELD DESIGN CROSS SECTIONS -- A PARTIAL EVALUATION

By

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Reactor and Plant Technology Department
FFTF Project

October 1969

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D. R. Marr and M. G. Zimmerman

ABSTRACT

Measured neutron transmission spectra for several thicknesses of iron, nickel, and stainless steel are compared to transport calculations using two cross section sets: the DLC-2 99-group set from ENDF/B made available by the Radiation Shielding Information Center and the locally generated 31-group HOMSET set used in the conceptual design of the FTR shields.

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FTR SHIELD DESIGN CROSS SECTIONS--A PARTIAL EVALUATION

INTRODUCTION

Calculations of the integral shielding quantities of interest in the design of the Fast Flux Test Facility (FFTF) require an ability to determine the neutron transmission through materials such as iron, nickel, stainless steel, and sodium. In this study, two cross section sets are evaluated by comparing calculated and measured transmission spectra over the energy range 1 eV to 1 MeV for iron, nickel, and stainless steel.

Computer codes being used for shield design require cross sections in a multigroup format for economy of operation. Reduction of experimental cross section data to such a multigroup set of average cross sections is dependent upon the spectrum within the group for all groups in which the cross section is not constant. Because of vast differences in spectra in FTR shield regions, and because the integral shielding quantities of interest have significantly different energy response functions, a universally applicable reduction cannot be made to a few group set. Materials with many resonances, such as iron, require hundreds of groups to describe the known cross section structure. For practical shielding applications, this vast amount of data must be reduced to a tenable structure that contains few groups, yet one that yields acceptably accurate results. Because of uncertainties in both the method of reduction and in the basic data, the reduced sets need to be evaluated using integral shielding experiments.

Of the two sets evaluated in this study, the 31-group HOMSET cross sections were used in FFTF conceptual design studies and this evaluation provides a measure of validity of the reported results. The 99-group DLC-2 set, derived from the Evaluated Nuclear Data File (ENDF), is evaluated as a basis for a possible successor to the currently used set.

SUMMARY

Calculated neutron transmission spectra through iron, stainless steel, and nickel slab shields compare favorably with measured spectra, using both the 31-group HOMSET cross sections and the 99-group DLC-2 set derived from ENDF. Conclusions are that HOMSET cross sections give adequate spectral agreement for use in survey design applications although some deficiencies exist. The ENDF cross sections give somewhat better overall agreement, primarily because of the finer energy mesh.

DISCUSSION

EXPERIMENT

Time of flight measurements⁽¹⁾ of the transmitted neutron spectra for various thicknesses of iron, nickel, and stainless steel have been made using a fast pulse reactor as a source. Resolution was 0.04 sec/m. The general arrangement of the experiment appears in Figure 1. The incident neutron spectrum is shown in Figure 2. Measurements were made for thicknesses of 30 and 48 cm of iron, 30 and 49 cm of stainless steel, and 31, 52, and 77 cm of nickel. Transverse dimensions of the samples were 80 x 80 cm for nickel and 70 x 80 cm for both iron and stainless steel. Samples were placed 30 cm from the 25 x 25 x 25 cm active zone of the reactor. Unspecified amounts of manganese in the iron, and both manganese and cobalt in the stainless steel, produced clearly visible depressions of the transmitted flux at the respective resonance energies (0.335, 1.1, and 2.35 keV for Mn and 132 eV for Co). However, these effects are localized in energy and do not appear to compromise the overall results. Absolute magnitude of the transmitted flux is not stated in the referenced report.

CALCULATIONS

Transmission spectra for each of the materials were calculated with the one-dimensional discrete ordinates transport code

FIGURE 1. *General Arrangement of the Experiment: 1) Scintillation Detector. 2) Collimator. 3) Boron Counter Detector. 4) Monitor on 50-m Base. 5) Prism of Material Studied 6) Active zone of IBR Reactor. 7) Monitor on 100-m Base.*

FIGURE 2. *"No Sample" Spectrum*

ANISN⁽²⁾ in slab geometry. Because the transverse dimensions are comparable to the sample thicknesses, adequate treatment of the transverse leakage is necessary. It was decided that the additional computer time required for Monte Carlo or two-dimensional transport calculations was not warranted for this study. Rather, the simple transverse buckling scheme for approximating the transverse leakage was used in the 1-d calculations.

The source was approximated as an isotropic incident current with a spectrum matching the measured "no sample" spectrum shown in Figure 2. Anisotropy of the incident current was found to have a negligible effect on the calculated results below 0.5 MeV. A symmetric S_{16} approximation was used, and the most forwardly directed emergent angular flux, representing 8.5 degrees, was compared to the measurements.

Calculations were made using both the 31-group HOMSET cross sections used for FFTF conceptual shield design and the 99-group DLC-2 set⁽³⁾ from ENDF.

The top 26 HOMSET groups cover the energy range 0.4 eV to 10 MeV. These cover the energies of interest here and were reduced from a 68-group library in HRG⁽⁴⁾ using the calculated slowing down spectrum in the material of interest. The lower 5 groups were converted from the last 5 groups of the 31-group MAC library.^(5,6) HOMSET cross sections have also been generated using the infinite media slowing down spectra in other material ratios for use in FFTF design calculations. HOMSET cross sections are in transport corrected P_0 form.

The DLC-2 set was generated at Oak Ridge and made available by the Radiation Shielding Information Center. A P_1 truncation of this infinite dilution set was selected as being most applicable for comparison with the HOMSET cross-section set and because of its calculational economy. Neglect of the higher orders was shown to be negligible over most of the energy range of interest here. The calculated difference in transmitted flux between

P_1 and P_3 treatments in 31 cm of nickel was less than 1% for energies below 0.5 MeV, rising to 5% at 1 MeV.

Manganese and cobalt impurities existing in unknown amounts in the iron and stainless steel samples were ignored in the calculations. For comparison, 1% manganese was added to one of the 30 cm iron calculations with ENDF cross sections. Although this group structure is too coarse for adequate treatment of such narrow resonances, the calculation did indicate that spectral effects due to the manganese impurity are quite local and that reasonable impurity concentrations would explain the depression measured.

As absolute experimental values were not available, the experimental points were normalized so as to give the same total transmitted flux as the HOMSET calculation. The HOMSET and ENDF calculations are directly comparable, each using a unit source.

RESULTS

Comparison of the experimental and calculated spectra are shown in Figures 3 through 9. Agreement is generally good with the ENDF cross sections providing better agreement than HOMSET cross sections, particularly for iron and hence stainless steel. ENDF cross section results are notably better in two respects. Because the ENDF set has a finer energy mesh, structure in the transmitted flux in the resonance region is treated more adequately. In addition, ENDF cross sections give much better agreement for iron and hence stainless steel at the lower energies, although HOMSET is more conservative in that it predicts more transmitted flux. Detailed discussions follow.

Iron (Figures 3 and 4)

ENDF provides remarkable overall spectral agreement. The only serious disagreement is in the range from 1 to 10 KeV where the calculation is notably high. Some of the difference

Neg 50360-5 -

FIGURE 3. 30 cm Iron Transmission Spectra

48 CM. IRON TRANSMISSION SPECTRA

Neg 50360-2

FIGURE 4. 48 cm Iron Transmission Spectra

30.6 CM. NICKEL TRANSMISSION SPECTRUM

Neg 50360-7

FIGURE 5. 30.6 cm Nickel Transmission Spectra

51.5 CM. NICKEL TRANSMISSION SPECTRUM

Neg 50360-6

FIGURE 6. 51.5 cm Nickel Transmission Spectra

77.0 CM. NICKEL TRANSMISSION SPECTRUM

Neg 50360-1

FIGURE 7. 77.0 cm Nickel Transmission Spectra

30 CM. STAINLESS STEEL TRANSMISSION SPECTRA

Neg 50360-3

FIGURE 8. 30 cm Stainless Steel Transmission Spectra

49 CM. STAINLESS STEEL TRANSMISSION SPECTRA

Neg 50360-4

FIGURE 9. 49 cm Stainless Steel Transmission Spectra

in this range is due to calculational neglect of the manganese impurity, whose resonances at 1.1 and 2.4 KeV increase the disagreement locally. There is also some disagreement at 0.1 MeV where the calculated flux is low.

HOMSET agrees well with both ENDF and the experimented results above the iron cross section minimum at 25 KeV, but is significantly higher below this energy. It produces a more conservative result with respect to transmitted flux at these lower energies than does ENDF.

Nickel (Figures 5, 6 and 7)

Calculations using both nickel cross section sets gave results which, judiciously used, are acceptable for design survey purposes.

Calculations using ENDF and HOMSET for the 30.6 cm thickness agree very well, but both disagree with experiment at the

lower energies. Neutrons at these energies are primarily down-scattered neutrons as opposed to original source neutrons, so this result indicates inability of both sets to correctly calculate downscattering through the resonance region. For the other thicknesses, ENDF calculations were not made. The HOMSET calculations yielded this same discrepancy at the lower energies for the 51.5 cm sample but surprisingly, gave good agreement for the 77 cm sample. There is good agreement between both calculations and the experiment above 10 KeV with some disagreement near 1 MeV where the experimental resolution was quite poor.

Stainless Steel (Figures 8 and 9)

Stainless steel, being primarily iron, exhibits essentially the same features shown in the iron comparison. There is better agreement in the resonance region where transmission peaks are not as large due to the other elements "filling in" the minima in the iron cross section. ENDF gives good agreement, while HOMSET provides results certainly adequate for design usage.

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