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MEASUREMENT AND CALCULATION
OF NEUTRON SPECTRA
IN THE FTR
ENGINEERING MOCKUP CRITICAL

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J. V. Nelson
E. P. Lippincott
R. A. Bennett
W. N. McElroy
J. W. Daughtry

February 1977

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ABSTRACT

The neutron spectrum in the FTR Engineering Mockup Critical has been measured at six locations using proton-recoil techniques. At three of these locations, multiple foil irradiations were also conducted. Two-dimensional diffusion theory calculations using 42 energy group ENDF/B-III cross section data were made and the spectra from these calculations were compared to the proton-recoil data and spectra inferred from analyses of the irradiated foils. In general, the diffusion theory results agree quite well with the proton-recoil results. Good agreement was also obtained using the multiple foil technique for in-core locations. However, low fluence levels led to unreliable multiple foil results for the shield location.

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1.0 Introduction

Neutron spectrum measurements at a number of locations in the Fast Test Reactor (FTR) Engineering Mockup Critical (EMC) have been performed. Measurement techniques included use of proton-recoil proportional counters and foil packets. The purpose of this experiment was to provide information about the neutron flux-spectral environment in FTR, to verify the multiple foil irradiation techniques planned for use in the FTR Reactor Characterization Program, to determine the spatial variation of the neutron flux spectrum in the EMC, and to verify or evaluate calculational techniques to be used for FTR.

This report describes the analysis of the spectrum measurements. Section 2.0 contains a summary of the work done. Section 3.0 contains descriptions of the measurements and the core configurations in which they were made. Section 4.0 contains a description of the analyses performed.

The results of the measurements and analyses are the subject of Section 5.0 and conclusions and recommendations are given in Section 6.0.

2.0 Summary

Measurements of the neutron flux spectrum in EMC beginning-of-life configurations were made using proton-recoil techniques at six locations: at the core center, in two test loops (GP-201 and SP-625), at the core-reflector interface, in the reflector region and at a simulated low level flux monitor (LLFM) position in the shield sector. Under identical conditions, multiple foil irradiations were made in the two test loops and in the shield.

Two-dimensional diffusion theory calculations with 42 energy group cross-section data were performed. In general, the results of these calculations agree quite well with the proton-recoil measurements at all six locations. This indicates that broad group diffusion theory calculations can be used to follow spectral shifts in the FTR from the core center out into the shield.

Data obtained from the multiple foil irradiations have been analyzed and spectra unfolded. Comparisons with calculated and proton-recoil spectra have been made and good agreement is obtained for the two locations in the core. Results from the third location in the shield were not sufficiently accurate for comparison due to the low fluence obtainable. However, the results for the in-core locations provide further validation of the accuracy of the multiple foil technique for the FTR Reactor Characterization Program.

3.0 Measurements

Experimental measurements of the neutron spectra were made at six different locations in two core configurations of the EMC that are based on the BOL-REF-5S loading (described in Refs. 1 and 2). The six locations are given in Table 3.1. Measurements were made at all locations using the proton-recoil technique described in Reference 3. Also, multiple foil irradiations were made at three of the six locations as indicated in Table 3.1. Neutron spectra at these locations were inferred from postirradiation analysis of the foil data and SAND-II⁽⁴⁾ calculations. Details of the core configurations involved and measurement techniques employed are discussed in the following sections.

TABLE 3.1
LOCATIONS OF SPECTRUM MEASUREMENTS

Location	ZPR-9 Matrix Position	Measurements*	
		Proton-Recoil	Foil Irradiations
Core Center	23-23	X	
GP-201	23-20	X	X
SP-625	32-24	X	X
Core-Reflector Interface	18-13	X	
Reflector	29-35	X	
Shield (LLFM position)	36-38	X	X

*The effective axial location of all measurements was 4-1/2 inches from the front of the drawers in the movable half (i.e., 4-1/2 inches above the core midplane).

3.1 Core Configurations

For measurements made at the core center, in the two test loop positions (GP-201 and SP-625) and at the core-reflector interface, the BOL-REF-5S configuration was modified by putting sodium channel composition in GP-201 and SP-625, and adding six peripheral shim rods (PSR) giving a total of nine. The resulting configuration is shown in Figure 3.1. The extra PSRs, designated 705, 717, 729, 736, 712 and 724 in Figure 3.1, were inserted to reduce the subcritical flux to a level where proton-recoil measurements could be made. The reactivity of this configuration is approximately -2100 lh (i.e., $\sim 2.1\% \Delta k/k$ or $\sim 7\%$ subcritical).

With the hydrogen chamber inserted, measurements were made with the core at this reactivity. With the more sensitive methane chamber inserted, measurements were made with all fuel-bearing control rods withdrawn and boron rods 1, 3, 7, 9, 10 and 12 inserted so that the reactivity was approximately -4300 lh, or $\sim 14\%$ subcritical. These chambers, which were used in the proton-recoil measurements, are described in Reference 3 and discussed briefly in Section 3.2.

For measurements in the radial reflector location, the BOL-REF-5S configuration was modified such that GP-201 and SP-625 contained sodium channel, as in the configuration previously described, and matrix positions 13-30 and 14-30 contained outer core material. With the methane chamber inserted, only fuel-bearing rods 2, 4, 6 and 9 were withdrawn and the core reactivity was -350 lh. With the hydrogen chamber inserted, only fuel-bearing rods 2 and 6 were withdrawn and the reactivity was -160 lh.

This configuration, with only fuel-bearing rods 2 and 6 withdrawn, was also used for the measurements in the LLFM location made with the methane chamber. The core reactivity was -164 lh. However, when the hydrogen chamber was used for the LLFM measurements, GP composition was loaded into the GP-201 drawers and a Kirn-type fission counter placed in matrix position 23-23. This configuration was near critical.

Figure 3.1. EMC Configuration for In-Core Spectrum Measurements

ID	INNER DRIVER	SR	SAFETY ROD
OD	OUTER DRIVER	CR	CONTROL ROD
GP	GENERAL PURPOSE LOOP	PSR	PERIPHERAL SHIM ROD
SP	SPECIAL PURPOSE LOOP	MT	MATERIAL TEST

Figure 3.2. EMC Configuration for Reflector and Shield Spectrum Measurements

The three locations at which foil irradiations were made are: GP-201, SP-625 and the LLFM shield location (see Table 3.1). The core configurations during these irradiations were identical to those used for corresponding proton-recoil measurements except that the foils and holder replaced the chamber. For all measurements, available platelets were used to duplicate as closely as possible the average drawer material composition in the vicinity of the experiment and hence to create conditions most amenable for comparison with calculated spectra.

3.2 Proton-Recoil Measurements

The proton recoil technique employed by ANL for the spectrum measurements in the EMC is described in detail in Reference 3 and the measurements in the EMC are described in Reference 5. A brief summary of these measurements is contained in the following paragraphs.

Two types of counting tubes were used, one filled with hydrogen gas and the other filled with methane in order to extend the energy range in which reliable experimental data could be obtained. Proton-recoil chambers were placed in the lower right-hand corner of the drawers with respect to Figures 3.1 and 3.2. In this way, the chambers were as close as possible to the center of the four-drawer clusters constituting the GP-201 and SP-625 positions. In all cases, the drawers containing the proton recoil chambers were loaded such that the perturbations caused by the material rearrangements necessary to accommodate the chambers were minimized.

The two largest sources of systematic error in proton-recoil measurements occur at the low- and high-energy extremes. For energies below about 6 keV (for protons in hydrogen), variations in the energy lost by a proton per ion pair formed, W , will affect the results. However, W from protons stopping in hydrogen is reasonably constant to very low energies and the assumption of a constant W everywhere is justified on this basis.

For higher-energy neutrons, wall-end effects, wherein a proton leaves the active volume of the detector before stopping, will cause measurement errors. This effect sets in strongly at about 1 MeV and, for the counters used in these experiments, effectively terminates the measurements at 2 to

3 MeV. Proton-recoil data were reported in Reference 5 only for energies where the wall-end correction procedure employed indicated a correction of less than 20% (~ 1.6 MeV).

For the energy range (10 KeV to 1 MeV), the proton-recoil technique is not subject to wall-end effects or variations in W and should yield very reliable results.

3.3 Multiple Foil Irradiations

Because of the importance of the multiple foil technique to the FTR Reactor Characterization Program, foil irradiations were made at three of the locations used for proton recoil measurements, as indicated in Table 3.1. The three locations are:

Position 1 - near the core center in GP-201

Position 2 - just inside the core-reflector interface in SP-625

Position 3 - at a simulated LLFM position in the radial shield sector.

The drawers at these locations were identical for both types of measurements, except for the substitution of the foil packets for the proton recoil counters.

Foils were chosen to include reactions which respond to the entire range of neutron energies at each position. Unfortunately, due to the low amount of fluence obtainable in the EMC, not all of the reactions normally included in high-power irradiations could be used; therefore some other reactions with shorter half-lives had to be substituted. In addition, the dosimeters irradiated contained, of necessity, much larger amounts of material in order to obtain suitable counting rates, thereby increasing resonance self-shielding and spatial neutron flux spectrum perturbations. At the LLFM position, only an even more limited set of reactions produced adequate counting rates due to the very low flux at this position. Especially difficult were measurements of higher energy flux using threshold reactions. The foils included in each set are listed in Tables 3.2 and 3.3.

TABLE 3.2

FOIL SET DESCRIPTION - EMC POSITIONS 1 AND 2

Material	Description	Thickness (mils)	Material Wt (gms)		Remarks
			EMC-1	EMC-2	
Fe	0.5" Dia. Foil Natural Fe	50.0	1.2884	1.28572	
Co	0.5" Dia. Foil ⁵⁹ Co	0.5	0.014736	0.014375	Wrapped in Aluminum
Ni	0.5" Dia. Foil Natural Ni	10.0	0.29659	0.29430	
Ti	0.5" Dia. Foil Natural Ti	10.0	0.15748	0.15778	
Cu	0.5" Dia. Foil Natural Cu	5.0	0.15248	0.15248	
Au	0.5" Dia. Foil ¹⁹⁷ Au	0.5	0.038090	0.038671	Wrapped in Aluminum
S	0.5" Dia. Pellet Natural S	36.0	0.22922	0.21795	Wrapped in Aluminum
Al	0.5" Dia. Foil ²⁷ Al	5.0	0.04618	0.04603	
Sc	0.5" Dia. Foil ⁴⁵ Sc	5.0	0.04795	0.04986	Wrapped in Aluminum
In	0.5" Dia. Foil ¹¹⁵ In	2.0	0.04894	0.05020	Wrapped in Aluminum
Fe	0.5" Dia. Foil Natural Fe	50.0	1.28813	1.2854	
I	0.5" Dia. Pellet KI	62.0	0.61929	0.60260	Wrapped in Aluminum
Na	0.5" Dia. Pellet NaCl	78.0	0.53054	0.53578	Wrapped in Aluminum
Ta	Wire Loop Natural Ta		0.06974	0.06795	Dia. 15 Mils
U	0.5" Dia. Foil ²³⁸ U	10.0	0.615280	0.612460	Wrapped in Aluminum
U	0.5" Dia. Foil ²³⁵ U	5.0	0.314755	0.312785	Wrapped in Aluminum
Np	0.5" Dia. Foil ²³⁷ Np	5.0	0.307645	0.365630	Encapsulated in Aluminum O.D. = 0.75"
Pu	0.425" Dia. Foil ²³⁹ Pu 95%	5.0	0.17794	0.17481	Encapsulated in 0.005" Aluminum O.D. = 0.5"

TABLE 3.3

FOIL SET DESCRIPTION - EMC POSITION 3 - LLFM

<u>Material</u>		<u>Thickness (mils)</u>	<u>Material Wt. (gms)</u>	<u>Remarks</u>
Fe	0.5" Dia. Foil Natural Fe	50.0	1.28422	
Co	0.5" Dia. Foil ⁵⁹ Co	0.5	0.014735	Wrapped in Aluminum
Cu	0.5" Dia. Foil Natural Cu	5.0	0.15365	
Au	0.5" Dia. Foil ¹⁹⁷ Au	0.5	0.031616	Wrapped in Aluminum
S	0.5" Dia. Pellet Natural S	82.0	0.53300	Wrapped in Aluminum
Al	0.5" Dia. Foil ²⁷ Al	20.0	0.18723	
Sc	0.5" Dia. Foil ⁴⁵ Sc	5.0	0.04935	Wrapped in Aluminum
In	0.5" Dia. Foil ¹¹⁵ In	2.0	0.04882	Wrapped in Aluminum
Fe	0.5" Dia. Foil Natural Fe	50.0	1.28683	
Na	0.5" Dia. Pellet NaCl	77.0	0.51541	Wrapped in Aluminum
Ta	Wire Loop Natural Ta		0.06571	Dia. 15 mils
U	0.5" Dia. Foil ²³⁸ U	10.0	0.601215	Wrapped in Aluminum
U	0.5" Dia. Foil ²³⁵ U	5.0	0.302425	Wrapped in Aluminum
Np	0.5" Dia. Foil ²³⁷ Np	5.0	0.455427	Encapsulated in Aluminum O.D. = 0.75"
Pu	0.425" Dia. Foil 95% ²³⁹ Pu	5.0	0.16915	Encapsulated in 0.005" Aluminum O.D. = 0.5"

The irradiation was carried out on January 30, 1974 and terminated at 12:18 pm after 86 minutes at a nominal power of 1750 Watts. After the irradiation, the foils were recovered and divided into two groups. The first group included all reactions with a half-life of less than one day and selected others. This group was counted at ANL and the longer half-life foils were shipped to HEDL for counting at a later time. The second group of foils was sent to HEDL immediately and was available for counting on the day following the irradiation.

4.0 Analytical Methods

Calculations on the EMC configurations in which spectrum measurements were made were performed using the two-dimensional diffusion theory program, 2DBS,⁽⁶⁾ with 42 energy group cross-section data. Neutron spectra at all six locations where proton-recoil measurements were made were extracted from these calculations and compared to the proton-recoil data. For three positions, comparisons were also made with neutron spectra inferred via the foil irradiations from SAND-II analyses.

In the following paragraphs, the details of the SAND-II analyses and the diffusion theory calculations along with a brief description of fine-group spectrum calculations performed by ANL are given.

4.1 Analyses of Irradiated Foils

Flux and fluence characterization by the multiple foil technique utilizes measured reaction rates and an iterative code, SAND-II,⁽⁴⁾ to determine the neutron spectrum and the absolute flux level.

The accuracy of the spectrum determined in this way is not only dependent on the reaction rate measurement accuracy and the adequacy of the input spectrum but also the cross sections. Therefore, validation of these cross sections for self-consistency in benchmark spectra⁽⁷⁾ and in EBR-II⁽⁸⁾ is an important goal of current dosimetry efforts.^(9,10)

In addition, a number of direct comparisons have been made between multiple foil spectral determinations, differential measurement techniques, and calculations. The comparisons with differential measurements are of

necessity made in low-power nuclear facilities because high-power reactors such as EBR-II and FFTF are not generally accessible for differential spectrum measurements. Comparisons of multiple foil measurements with calculations have been made at a number of locations in EBR-II⁽¹¹⁾ and will be made in FFTF as part of the FFTF Reactor Characterization Program. These comparisons, in general, show good relative agreement within the reactor core away from large perturbations and boundaries.⁽¹¹⁾

Comparisons of differential measurements with multiple foil results in fast reactor-type benchmark spectra have been made in ECEL core 16 with proton-recoil,⁽¹²⁾ in CFRMF with proton-recoil⁽⁷⁾ and more recently ⁶Li spectrometry,⁽¹³⁾ in ΣΣ with proton-recoil, ³He and ⁶Li,⁽¹³⁾ and in BIG-10 with proton-recoil and ⁶Li.⁽¹³⁾ In addition, recent comparisons with measurements of the ²³⁵U and ²⁵²Cf fission spectra have been made.⁽¹⁰⁾

The results of these comparisons have varied. In some cases, good agreement was obtained and in others biases were observed. Some of these biases tended to indicate an energy shift between multiple foil and proton recoil but the shapes appeared similar. In other cases, such as the fission spectra, differences in certain regions occurred, indicating either a consistent spectral measurement error (e.g., neglect of scattering in the ²³⁵U target) or an error in the cross sections of reactions covering that energy range.⁽¹⁰⁾

The SAND-II program starts with an input spectral estimate, usually from a multigroup calculation, and modifies this estimate to derive an inferred neutron flux spectrum $\phi(E)$ such that calculated reaction rates R_i as determined by the equation

$$R_i = \int \phi(E) \sigma_i(E) dE \quad (1)$$

are in agreement with the measured values. Constraints imposed by the program, however, prevent an exact solution being reached when reaction rates which are sensitive to the same neutron energies are inconsistent. In other words, the amount of spurious structure in the spectrum that can be introduced by data inconsistencies is limited both in regions where good

overlap of reactions occurs and in energy regions of poor foil coverage. For this study a new version of the SAND-II Monte Carlo code was used which utilized reaction rate and cross section uncertainty weighting to achieve a best solution.^(14,15)

4.2 ANL Fine-Group Calculations

Calculations of the EMC spectrum at the core center were performed by ANL^(5,16) using the SDX⁽¹⁷⁾ program and a 132-group cross section set ($\Delta u=0.1$). A comparison of the calculated results plotted in References 5 and 16 will reveal some differences. The earlier calculations (Reference 16) lacked a heterogeneity correction, while the results reported in Reference 5 (and reproduced in Section 5.0 of this report) included this correction. Correcting for heterogeneity had the effect of softening the calculated spectrum and improving the agreement with the proton-recoil measurements.

4.3 Broad Group Spectrum Calculations

The 42-group 2DBS⁽⁶⁾ (2-D) diffusion theory calculations performed as a part of this analysis were based on cross-section data and modeling techniques consistent with other HEDL analyses of EMC experiments.^(2,18,19) These cross section data and calculational models are described below.

4.3.1 Cross-Section Data

The 42-group cross-section data employed in this analysis originated with the FTR Set 300-S library.⁽²⁰⁾ This library contains 42-group infinitely dilute cross-section data together with tables of F-factors in the Bondarenko⁽²¹⁾ format. The Set 300-S library was generated with the ETOX⁽²²⁾ program from ENDF/B-II data and subsequently modified such that it is nearly consistent with ENDF/B-III data.

The bounds of the 42 energy groups are shown in Table 4.1. The lethargy width of each group is 0.5 with the exception of groups 7 and 8 which encompass the 440 KeV oxygen resonance, groups 13, 14 and 15 which isolate the iron "window" at about 24 KeV, groups 19, 20 and 21 which span the large sodium resonance at about 3 KeV, and group 42, which is the thermal group.

TABLE 4.1

42-GROUP ENERGY STRUCTURE

<u>GROUP</u>	<u>LOWER ENERGY BOUNDARY * (ev)</u>	<u>LETHARGY INTERVAL</u>
1	6.065 + 6	.5
2	3.679 + 6	.5
3	2.231 + 6	.5
4	1.353 + 6	.5
5	8.208 + 5	.5
6	4.979 + 5	.5
7	3.877 + 5	.25
8	3.020 + 5	.25
9	1.832 + 5	.5
10	1.111 + 5	.5
11	6.738 + 4	.5
12	4.087 + 4	.5
13	2.554 + 4	.47
14	1.989 + 4	.25
15	1.503 + 4	.28
16	9.119 + 3	.5
17	5.531 + 3	.5
18	3.355 + 3	.5
19	2.840 + 3	.167
20	2.404 + 3	.167
21	2.035 + 3	.167
22	1.234 + 3	.5
23	7.485 + 2	.5
24	4.540 + 2	.5
25	2.754 + 2	.5
26	1.670 + 2	.5
27	1.013 + 2	.5
28	6.144 + 1	.5
29	3.727 + 1	.5
30	2.260 + 1	.5
31	1.371 + 1	.5
32	8.315 + 0	.5
33	5.043 + 0	.5
34	3.059 + 0	.5
35	1.855 + 0	.5
36	1.125 + 0	.5
37	6.826 - 1	.5
38	4.140 - 1	.5
39	2.511 - 1	.5
40	1.523 - 1	.5
41	9.237 - 2	.5
42	Thermal +	

* Highest energy is 10 Mev.

+ Thermal values were taken from a group whose energy boundaries were .0252 to .02521 ev.

Details of the procedures used to obtain effective cross-section data from the Set 300-S library data are given in Reference 18, and are summarized briefly here.

All heavy element cross sections were heterogeneously resonance self-shielded. Asymmetric plate Dancoff factors were computed explicitly for each typical fuel plate in the EMC inner and outer two-drawer cells. The fuel cross sections were then elastic-removal corrected over the appropriate spectra using a one-dimensional model of the EMC and the 1DX⁽²³⁾ program. Finally, the fuel cross sections were corrected by energy group for the spatial structure of the cell group fluxes using the one-dimensional transport theory code DTF-IV.⁽²⁴⁾ The core structural materials, test loops, reflectors and shields are homogeneously resonance self-shielded and elastic-removal corrected separately in a single pass through 1DX. The cell-homogenized fuel cross sections and homogeneous nonfuel isotopes are combined to serve as input cross sections for the 2DBS reactor calculations.

4.3.2 Calculational Models

Calculational models employed in this analysis were two-dimensional midplane representations of the EMC. In general, the models contained one nodal point per EMC drawer (i.e., the mesh spacing was ~ 2 " in both X and Y directions). However, there are two exceptions, which are:

- 1) Each drawer constituting SP-625 contained four nodal points (~ 1 " mesh spacing).
- 2) The region in and around the ZPR-9 matrix position 18-13 (at the core-reflector interface) had one-inch mesh spacing.

The finer mesh structure was used at these two measurement locations because they are both near the core-radial reflector boundary, where rapid spectral shifts can occur.

Two calculational models were employed, one for each of the two basic configurations used in the course of the experiments (see Section 3.1). Both were based on the BOL-REF-5S loading with sodium channel in GP-201 and SP-625. The first contained a total of nine peripheral shim rods, as shown

in Figure 3.1, while the second contained only three, as shown in Figure 3.2. Space-energy-independent axial buckling values of 0.000567 and 0.000565 cm^{-2} were used for the first and second models, respectively. These values were based on a buckling study reported in Appendix C of Reference 25.

5.0 Comparison of Results and Discussion

Comparisons of results obtained by the experimental and calculational techniques described above are presented in the following sections. These comparisons are divided into four parts. In Section 5.1, a comparison of the ANL fine group calculation with the proton-recoil results is made. In Section 5.2, results of SAND-II analyses of the multiple foil irradiations are presented and comparisons with the proton-recoil measurements and broad group diffusion theory results are made. In Section 5.3, the results of the broad group diffusion theory calculations are compared to proton-recoil results. Finally, in Section 5.4, comparisons illustrating the spectral shifts with spatial location are presented.

5.1 Comparison of ANL Fine-Group Calculations to Proton-Recoil Measurements

Calculations of the EMC spectrum at the core center using a fine group energy structure were performed by ANL as described in Section 4.2. The results of this calculation are compared to the spectrum obtained from proton-recoil measurements in Figure 5.1, which is reproduced from Reference 5. Error bars on the measured data in this figure, and in others to follow, reflect only statistical uncertainty.

The measured and calculated spectra plotted in Figure 5.1 have been normalized such that $\int \phi(E) dE = C$ over the energy range of the experimental data, where C is an arbitrary constant.

In general, the agreement between calculation and measurement in Figure 5.1 is very good. The most significant disagreement is near the high-energy limit and around 100 KeV. At energies above 1 MeV, systematic errors in the proton-recoil measurements occur, as discussed in Section 3.2. Thus, the high-energy discrepancy between calculation and experiment could well be attributable to experimental errors. However other studies⁽¹⁰⁾ have consistently shown that calculations give too few high-energy neutrons above 1 to 2 MeV.

Figure 5.1. Comparison of Proton-Recoil Measurement and Fine Group Calculation of the Core Center Spectrum.

5.2 Results of Multiple Foil Analysis

The measured reaction rates resulting from the foil irradiations are presented in Tables 5.1, 5.2 and 5.3. Each reaction rate is reported according to which laboratory did the counting. The reaction rates measured at both laboratories indicate inconsistencies of 10-20% for some foils, but others are much larger. This is due in part to calibration differences between the HEDL and ANL laboratories. In general, greater reliance was placed on the HEDL results because of the intercalibration with the ILRR program.⁽²⁶⁾ The ANL results were achieved with less well calibrated systems and with a geometry that was not identical with available calibration sources.

Because of the low counting rates obtainable for many of the reactions, particularly for the longer half-life reactions counted at HEDL, obtaining accurate results presented great difficulties. This is especially true for the LLFM position which will be discussed separately.

To obtain adequate reactions, the foils used were thick enough that reaction self-shielding was not negligible for nonthreshold reactions. No detailed self-shielding calculations for these foils in the EMC were available, but rough estimates indicated corrections of ~10-20% for $^{197}\text{Au}(n,\gamma)$, $^{181}\text{Ta}(n,\gamma)$, $^{63}\text{Cu}(n,\gamma)$ and $^{59}\text{Co}(n,\gamma)$.

The starting spectra for SAND-II unfolding were obtained from the 42-group diffusion theory calculations described in Section 4.3. These groups were expanded by SAND to 620 groups. This expansion utilizes a fission spectrum shape at the high energy end and maintains integral consistency with the 42-group fluxes.

Spectra from GP-201 and SP-625 were first unfolded using all foils which were reasonably consistent with the starting spectrum. The reaction rates for these foils are underlined in Tables 5.1 and 5.2. Ones showing a deviation larger than about 50% from the mean were deleted as being erroneous. The foils used and the final calculated activities are shown in Tables 5.4 and 5.5 and compared with the experimental values. The cross sections used were taken from the SAND-II library⁽²⁷⁾ except for the ^{235}U ,

TABLE 5.1
REACTION RATES - EMC POSITION 1 - GP201
Reaction Rate^a

Reaction	HEDL	% Error ^d	ANL	Ratio ANL/HEDL
$^{23}\text{Na}(n,\gamma)^{24}\text{Na}$			1.437-17	
$^{27}\text{Al}(n,\alpha)^{24}\text{Na}$			<u>2.119-18</u>	
$^{32}\text{S}(n,p)^{32}\text{P}$	<u>2.142-16</u>	3.0		
$^{45}\text{Sc}(n,\gamma)^{46}\text{Sc}$	<u>1.239-15</u>	3.0		
$^{47}\text{Ti}(n,p)^{47}\text{Sc}$	<u>6.91-17</u>	6.0		
$^{48}\text{Ti}(n,p)^{48}\text{Sc}$	<u>9.62-19</u>	3.8		
$^{54}\text{Fe}(n,p)^{54}\text{Mn}$	<u>2.485-16</u>	5.9	2.904-15	11.6
$^{56}\text{Fe}(n,p)^{56}\text{Mn}$			<u>3.328-18</u>	
$^{58}\text{Fe}(n,\gamma)^{59}\text{Fe}$	not detectable			
$^{59}\text{Co}(n,\alpha)^{56}\text{Mn}$			<u>4.847-19</u>	
$^{59}\text{Co}(n,\gamma)^{60}\text{Co}$	<u>4.088-15</u>	3.3	6.235-15	1.53
$^{58}\text{Ni}(n,p)^{58}\text{Co}$	<u>3.981-16</u>	3.2	5.903-16	1.48
$^{63}\text{Cu}(n,\gamma)^{64}\text{Cu}$	<u>2.282-15</u>	2.4	2.535-15	1.11
$^{115}\text{In}(n,n')^{115\text{m}}\text{In}$			<u>1.009-15</u>	
$^{115}\text{In}(n,\gamma)^{116}\text{In}$			<u>1.257-14</u>	
$^{127}\text{I}(n,2n)^{126}\text{I}$	not available			
$^{181}\text{Ta}(n,\gamma)^{182}\text{Ta}$	<u>3.463-14</u>	3.1		
$^{197}\text{Au}(n,\gamma)^{198}\text{Au}$	<u>2.849-14</u>	2.2	3.494-14	1.23
$^{235}\text{U}(n,f)\text{FP}^b$	<u>7.183-14</u>	2.1		
$^{238}\text{U}(n,f)\text{FP}^b$	<u>1.454-15</u>	3.1		
$^{238}\text{U}(n,\gamma)^{239}\text{Np}$	<u>1.083-14</u>	4.7		
$^{237}\text{Np}(n,f)\text{FP}^c$	<u>9.848-15</u>	4.0		
$^{239}\text{Pu}(n,f)\text{FP}^c$	<u>6.663-14</u>	5.8		

- a. Reactions per nucleus per sec. The notation 2.142-16 is equivalent to 2.142×10^{-16} . Underlined reaction rate values are those used in the SAND-II unfolding.
- b. Average of reaction rate as determined from ^{140}Ba , ^{95}Zr , and ^{103}Ru .
- c. Reaction rate determined from ^{140}Ba .
- d. Counting uncertainty only.

TABLE 5.2

REACTION RATES - EMC POSITION 2 - SP-625

Reaction	Reaction Rate ^a			Ratio ANL/HEDL
	HEDL	% Error	ANL	
$^{23}\text{Na}(n,\gamma)^{24}\text{Na}$			1.097-17	
$^{27}\text{Al}(n,\alpha)^{24}\text{Na}$			1.303-18	
$^{32}\text{S}(n,p)^{32}\text{P}$	2.585-16	3.0		
$^{45}\text{Sc}(n,\gamma)^{46}\text{Sc}$	<u>9.315-16</u>	3.8		
$^{47}\text{Ti}(n,p)^{47}\text{Sc}$	<u>4.44-17</u>	10.4		
$^{48}\text{Ti}(n,p)^{48}\text{Sc}$	<u>4.07-19</u>	5.0		
$^{54}\text{Fe}(n,p)^{54}\text{Mn}$	<u>1.453-16</u>	7.5	1.958-15	13.5
$^{56}\text{Fe}(n,p)^{56}\text{Mn}$			<u>2.133-18</u>	
$^{58}\text{Fe}(n,\gamma)^{59}\text{Fe}$	not detectable		7.520-14	
$^{59}\text{Co}(n,\alpha)^{56}\text{Mn}$			<u>2.985-19</u>	
$^{59}\text{Co}(n,\gamma)^{60}\text{Co}$	<u>5.974-15</u>	5.6	6.170-15	1.03
$^{58}\text{Ni}(n,p)^{58}\text{Co}$	<u>2.358-16</u>	3.4	3.506-16	1.49
$^{63}\text{Cu}(n,\gamma)^{64}\text{Cu}$	<u>1.575-15</u>	2.5	1.831-15	1.16
$^{115}\text{In}(n,n')^{115\text{m}}\text{In}$			<u>6.384-16</u>	
$^{115}\text{In}(n,\gamma)^{116}\text{In}$			<u>1.274-14</u>	
$^{127}\text{I}(n,2n)^{126}\text{I}$	<u>2.611-18</u>	4.1		
$^{181}\text{Ta}(n,\gamma)^{182}\text{Ta}$	<u>3.002-14</u>	3.1		
$^{197}\text{Au}(n,\gamma)^{198}\text{Au}$	<u>3.212-14</u>	2.1	3.663-14	1.14
$^{235}\text{U}(n,f)\text{FP}^{\text{b}}$	<u>5.242-14</u>	2.1		
$^{238}\text{U}(n,f)\text{FP}^{\text{b}}$	<u>8.970-16</u>	3.5		
$^{238}\text{U}(n,\gamma)^{239}\text{Np}$	8.749-15	3.7		
$^{237}\text{Np}(n,f)\text{FP}^{\text{c}}$	<u>5.972-15</u>	6.6		
$^{239}\text{Pu}(n,f)\text{FP}^{\text{c}}$	<u>4.805-14</u>	4.2		

a. Reactions per nucleus per sec. The notation 2.142-16 is equivalent to 2.142×10^{-16} . Underlined reaction rate values are those used in the SAND-II unfolding.

b. Average of reaction rate as determined from ^{140}Ba , ^{95}Zr , and ^{103}Ru .

c. Reaction rate determined from ^{140}Ba .

TABLE 5.3

REACTION RATES - EMC POSITION 3 - LLFM

<u>Reaction</u>	<u>Reaction Rate^a</u>			<u>Ratio ANL/HEDL</u>
	<u>HEDL</u>	<u>% Error^e</u>	<u>ANL</u>	
$^{23}\text{Na}(n,\gamma)^{24}\text{Na}$			1.766-18	
$^{27}\text{Al}(n,\alpha)^{24}\text{Na}$			not detectable	
$^{32}\text{S}(n,p)^{32}\text{P}$	3.057-17	3.5		
$^{45}\text{Sc}(n,\gamma)^{46}\text{Sc}$	<u>1.574-16</u>	3.6		
$^{54}\text{Fe}(n,p)^{54}\text{Mn}$	not detectable		3.466-16	
$^{56}\text{Fe}(n,p)^{56}\text{Mn}$			1.070-19	
$^{59}\text{Co}(n,\gamma)^{60}\text{Co}$	<u>1.439-15</u>	6.4		
$^{63}\text{Cu}(n,\gamma)^{64}\text{Cu}$	1.279-15	2.5	1.919-16	0.15
$^{115}\text{In}(n,n')^{115\text{m}}\text{In}$			<u>1.492-18</u>	
$^{115}\text{In}(n,\gamma)^{116}\text{In}$			<u>4.563-15</u>	
$^{181}\text{Ta}(n,\gamma)^{182}\text{Ta}$	4.953-15	3.1		
$^{197}\text{Au}(n,\gamma)^{198}\text{Au}$	<u>1.177-14</u>	2.5	1.249-14	1.06
$^{235}\text{U}(n,f)\text{FP}^{\text{b}}$	<u>5.934-15</u>	2.7		
$^{238}\text{U}(n,f)\text{FPC}$	5.40-17	8.0		
$^{238}\text{U}(n,\gamma)^{239}\text{Np}$	1.141-15	6.0		
$^{237}\text{Np}(n,f)\text{FP}$	not available			
$^{239}\text{Pu}(n,f)\text{FP}^{\text{d}}$	2.606-14	5.3		

a. Reactions per nucleus per sec. The notation 2.142-16 is equivalent to 2.142×10^{-16} . Underlined reaction rate values are those used in the SAND-II unfolding.

b. Average of reaction rate as determined from ^{140}Ba , ^{95}Zr , and ^{103}Ru .

c. Weighted average of ^{140}Ba and ^{95}Zr fission products.

d. Reaction rate determined from ^{140}Ba .

e. Counting uncertainty only.

^{238}U , and ^{239}Pu fission reactions which were from ENDF/B-IV. Cross-section uncertainties are from McElroy and Kellogg.⁽⁷⁾ The unfolding process weighted each foil according to assigned reaction rate measurement and cross-section uncertainties.^(7,14)

A number of inconsistencies are noted after the unfolding process. These remain because constraints in the SAND-II code prevent complete convergence to zero deviations when foil data covering the same energy range appear inconsistent. Spectral adjustment in these cases, if not prevented by smoothness criteria, will introduce spurious structure into the spectrum to force a fit. Examples of these data inconsistencies are the 27% difference between $^{181}\text{Ta}(n,\gamma)$ and $^{197}\text{Au}(n,\gamma)$ at position 1 (GP-201) and the 15% difference between $^{115}\text{In}(n,n')$ and $^{237}\text{Np}(n,f)$ at position 2 (SP-625).

A second unfolding run was made using a selected set of seven foils chosen from the most reliable reactions to give the most consistent agreement from Tables 5.4 and 5.5 and giving good spectral coverage. The results of these unfolding runs are shown in Tables 5.6 and 5.7. Much greater consistency was obtained with the limited set. However, as expected because of the weighting procedure, the resultant spectra were little changed. The total fluxes agreed to within 5% and mean energies to within 10% for the two analyses.

Comparisons with the input spectrum and uncertainties in the unfolded spectra are shown in Figures 5.2 and 5.3 for the seven foil cases. It is noted that agreement is obtained within 1σ throughout most of the spectral range on a group-averaged basis and all points fall within about 2σ of the calculations.

The analysis of flux spectrum at the LLFM position had to rely on a smaller number of reactions which had low counting rates and large errors. Data from the various reactions were very inconsistent and it was not obvious which measurements were in error. It was particularly difficult to gain a reasonable estimate of the fast flux using the threshold reactions selected for the greatest sensitivity. The results of the best unfolding run using six foils are presented in Table 5.8.

TABLE 5.4

SAND MONTE CARLO UNFOLDING RESULTS - POSITION 1 - GP-201

RESULTS OBTAINED AFTER 20 ITERATION LIMIT

FOIL REACTION	SATURATED MEASURED ACTIVITY (DPS/NUCLEUS)	SATURATED CALCULATED ACTIVITY (DPS/NUCLEUS)	NOMINAL 5.00 PERCENT ACTIVITY LIMITS (MEV)		RATIO MEASURED TO CALCULATED ACTIVITIES	DEVIATION OF MEASURED FROM CALCULATED ACTIVITY (PERCENT)
			LOWER	UPPER		
U235(N,F)FP6	7.183E-14	6.709E-14	3.800E-04	1.500E+00	1.0706	7.06
U238(N,F)FP6	1.454E-15	1.472E-15	1.400E+00	5.800E+00	.9877	-1.23
PU239(N,F)FP6	6.663E-14	6.495E-14	4.000E-04	2.000E+00	1.0259	2.59
TA181(N,G)TA182	3.463E-14	2.895E-14	1.000E-04	3.400E-01	1.1960	19.60
C059(N,A)MN56	4.847E-19	4.948E-19	5.900E+00	1.300E+01	.9795	-2.05
N158(N,P)C058	3.981E-16	3.799E-16	1.900E+00	7.300E+00	1.0479	4.79
SC45(N,G)SC46	1.239E-15	1.124E-15	8.000E-04	4.750E-01	1.1026	10.26
U238(N,G)U239	1.083E-14	1.133E-14	6.600E-05	6.600E-01	.9558	-4.42
AU197(N,G)AU198	2.849E-14	3.084E-14	1.600E-04	2.800E-01	.9239	-7.61
C059(N,G)C060	4.088E-15	4.180E-15	1.200E-04	1.600E-01	.9779	-2.21
IN115(N,G)C060	1.257E-14	1.418E-14	3.400E-04	8.000E-01	.8865	-11.35
CU63(N,G)CU64	2.282E-15	2.619E-15	5.750E-04	3.200E-01	.8714	-12.86
FE54(N,P)MN54	2.485E-16	2.679E-16	2.000E+00	7.800E+00	.9276	-7.24
S32(N,P)P32	2.142E-16	2.174E-16	2.300E+00	7.400E+00	.9852	-1.48
TI47(N,P)SC47	6.910E-17	6.978E-17	2.000E+00	6.600E+00	.9902	-.98
TI48(N,P)SC48	9.620E-19	8.869E-19	6.800E+00	1.400E+01	1.0846	8.46
FE56(N,P)MN56	3.328E-18	3.435E-18	5.500E+00	1.210E+01	.9689	-3.11
NP237(N,F)FP	9.848E-15	1.065E-14	3.400E-01	4.000E+00	.9243	-7.57
AL27(N,A)NA24	2.119E-18	2.285E-18	6.500E+00	1.280E+01	.9274	-7.26
IN115(N,N)M	1.009E-15	9.827E-16	8.000E-01	5.100E+00	1.0264	2.64

STANDARD DEVIATION OF MEASURED ACTIVITIES (PERCENT) 7.96

TABLE 5.5

SAND MONTE CARLO UNFOLDING RESULTS - POSITION 2 - SP-625

RESULTS OBTAINED AFTER 20 ITERATION LIMIT

FOIL REACTION	SATURATED MEASURED ACTIVITY (DPS/NUCLEUS)	SATURATED CALCULATED ACTIVITY (DPS/NUCLEUS)	NOMINAL 5.00 PERCENT ACTIVITY LIMITS (MEV)		RATIO MEASURED TO CALCULATED ACTIVITIES	DEVIATION OF MEASURED FROM CALCULATED ACTIVITY (PERCENT)
			LOWER	UPPER		
U235(N,F)FP6	5.242E-14	4.937E-14	3.200E-05	1.200E+00	1.0618	6.18
U238(N,F)FP6	8.970E-16	9.010E-16	1.400E+00	5.800E+00	.9956	-.44
PU239(N,F)FP6	4.805E-14	4.826E-14	1.500E-05	1.800E+00	.9956	-.44
TA181(N,G)TA182	3.002E-14	3.165E-14	4.500E-06	2.100E-01	.9484	-5.16
CO59(N,A)MN56	2.985E-19	2.816E-19	5.800E+00	1.300E+01	1.0600	6.00
NI58(N,P)CO58	2.358E-16	2.283E-16	1.900E+00	7.100E+00	1.0330	3.30
SC45(N,G)SC46	9.315E-16	8.378E-16	1.900E-05	4.000E-01	1.1119	11.19
AU197(N,G)AU198	3.212E-14	3.169E-14	4.750E-06	1.900E-01	1.0134	1.34
CO59(N,G)CO60	5.974E-15	6.042E-15	1.100E-04	4.250E-02	.9887	-1.13
IN115(N,G)IN116M	1.274E-14	1.422E-14	1.350E-06	5.250E-01	.8958	-10.42
CU63(N,G)CU64	1.575E-15	1.783E-15	5.750E-04	2.800E-01	.8835	-11.65
FE54(N,P)MN54	1.453E-16	1.605E-16	1.900E+00	7.500E+00	.9051	-9.49
I127(N,2N)I126	2.611E-18	2.364E-18	1.020E+01	1.500E+01	1.1043	10.43
TI47(N,P)SC47	4.440E-17	4.203E-17	1.900E+00	6.500E+00	1.0564	5.64
TI48(N,P)SC48	4.070E-19	4.919E-19	6.600E+00	1.390E+01	.8274	-17.26
FE56(N,P)MN56	2.133E-18	2.034E-18	5.500E+00	1.220E+01	1.0489	4.89
NP237(N,F)FP	5.972E-15	6.479E-15	3.200E-01	4.000E+00	.9217	-7.83
AL27(N,A)NA24	1.303E-18	1.262E-18	6.400E+00	1.300E+01	1.0323	3.23
IN115(N,N)M	6.384E-16	5.999E-16	8.000E-01	5.100E+00	1.0641	6.41

STANDARD DEVIATION OF MEASURED ACTIVITIES (PERCENT) 7.99

TABLE 5.6

SAND MONTE CARLO UNFOLDING RESULTS - POSITION 1 - GP-201 USING SELECTED SET OF FOILS

RESULTS OBTAINED AFTER 20 ITERATION LIMIT

FOIL REACTION	SATURATED MEASURED ACTIVITY (DPS/NUCLEUS)	SATURATED CALCULATED ACTIVITY (DPS/NUCLEUS)	NOMINAL 5.00 PERCENT ACTIVITY LIMITS (MEV)		RATIO MEASURED TO CALCULATED ACTIVITIES	DEVIATION OF MEASURED FROM CALCULATED ACTIVITY (PERCENT)
			LOWER	UPPER		
U235(N,F)FP6	7.183E-14	7.137E-14	4.000E-04	1.400E+00	1.0065	.65
U238(N,F)FP6	1.454E-15	1.468E-15	1.400E+00	6.300E+00	.9903	-.97
PU239(N,F)FP6	6.663E-14	6.697E-14	4.250E-04	2.000E+00	.9950	-.50
NI58(N,P)C058	3.981E-16	3.973E-16	1.900E+00	7.500E+00	1.0020	.20
C059(N,G)C060	4.088E-15	4.127E-15	1.200E-04	1.500E-01	.9906	-.94
TI47(N,P)SC47	6.910E-17	7.004E-17	1.900E+00	6.900E+00	.9866	-1.34
IN115(N,N)M	1.009E-15	9.923E-16	7.600E-01	5.400E+00	1.0164	1.64
STANDARD DEVIATION OF MEASURED ACTIVITIES (PERCENT)						1.08

24

TABLE 5.7

SAND MONTE CARLO UNFOLDING RESULTS - POSITION 2 - SP-625 USING SELECTED SET OF FOILS

U235(N,F)FP6	5.242E-14	5.166E-14	3.200E-05	1.200E+00	1.0147	1.47
U238(N,F)FP6	8.970E-16	9.124E-16	1.400E+00	6.200E+00	.9832	-1.68
PU239(N,F)FP6	4.805E-14	4.894E-14	1.500E-05	1.800E+00	.9819	-1.81
NI58(N,P)C058	2.358E-16	2.369E-16	1.900E+00	7.500E+00	.9953	-.47
C059(N,G)C060	5.974E-15	5.989E-15	1.050E-04	3.000E-02	.9975	-.25
TI47(N,P)SC47	4.440E-17	4.246E-17	1.900E+00	6.900E+00	1.0457	4.57
IN115(N,N)M	6.384E-16	6.200E-16	7.600E-01	5.300E+00	1.0297	2.97
STANDARD DEVIATION OF MEASURED ACTIVITIES (PERCENT)						2.52

TABLE 5.8

SAND-II UNFOLDING RESULTS - EMC POSITION 3 - LLFM

U235(N,F)FP6	5.934E-15	6.275E-15	7.200E-07	1.050E-01	.9457	-5.43
SC45(N,G)SC46	1.574E-16	1.401E-16	3.600E-07	5.750E-02	1.1237	12.37
AU197(N,G)AU198	1.177E-14	1.187E-14	4.500E-06	5.000E-03	.9914	-.86
C059(N,G)C060	1.439E-15	1.448E-15	1.350E-05	4.250E-03	.9938	-.62
IN115(N,G)IN116M	4.563E-15	4.818E-15	7.200E-07	1.900E-02	.9471	-5.29
IN115(N,N)M	1.492E-18	1.495E-18	4.750E-01	3.400E+00	.9983	-.17

STANDARD DEVIATION OF MEASURED ACTIVITIES (PERCENT) 6.50

Figure 5.2. SAND Monte Carlo Unfolded Spectrum - GP-201.

Figure 5.3. SAND Monte Carlo Unfolded Spectrum - SP-625.

The final unfolding results for flux, flux with $E > 0.1$ MeV, and $\bar{E}$ are shown in Table 5.9. The values of total flux, flux > 0.1 MeV, and $\bar{E}$ (in MeV) for GP-201 and SP-625 are estimated to be accurate to 5%, 7%, and 5% (1σ), respectively, using the SAND-II Monte Carlo code. The inconsistency of the data, however, indicates that the uncertainties input to this procedure are underestimated and therefore the above uncertainties are a lower bound. True uncertainties may be as much as twice the above. For the LLFM position uncertainties were not assigned in the SAND-II unfolding, but a reasonable estimate is a 1σ uncertainty of $\sim 30\%$.

TABLE 5.9
MULTIPLE FOIL RESULTS

	GP-201	SP-625	LLFM
Total Flux*	3.46×10^{10}	2.11×10^{10}	9.43×10^8
Flux ($E > 0.1$ MeV)*	2.11×10^{10}	1.26×10^{10}	2.38×10^8
Mean Energy ($\bar{E}$) (MeV)	0.45	0.45	0.10
* Flux values are in units of neutrons/cm ² -sec.			

Final unfolded spectra for all three positions are compared with the multigroup calculation and with the proton-recoil results in Figures 5.4 through 5.6.

These plots are on a log-log scale which shows overall spectral shapes, but limits resolution of variations near the maximum flux. Detailed comparisons of the broad group calculations with the proton-recoil measurements on a linear scale are made in the next section.

For the GP-201 and SP-625 positions, good agreement between the SAND results and the broad group results is observed as noted above. Also, the general shapes of the computed spectra are in good agreement with the proton-recoil results. However, details of specific maxima in the proton-recoil spectra are not reproduced and deviations above 1 MeV are observed, where the proton-recoil begins to lose accuracy.

Figure 5.4. Comparison of SAND, Proton-Recoil, and Calculated Spectra - GP-201.

Figure 5.5. Comparison of SAND, Proton-Recoil, and Calculated Spectra - SP-625.

Figure 5.6. Comparison of SAND, Proton-Recoil, and Calculated Spectra - LLFM.

For the LLFM position, comparisons are only approximate, as stated above. The multiple foil result falls below the calculation over most of the range below 2 KeV, which is probably due to neglect of self-shielding effects.

Between 20 KeV and 1 MeV, the three curves in Figure 5.6 fall close together. Above 1 MeV, the multiple foil results indicate a significantly higher flux than diffusion theory results, but this region depends on the threshold reaction data, which have rather large uncertainties at this position.

5.3 Comparisons of Broad Group Diffusion Theory Calculations and Proton-Recoil Measurements

Neutron spectra calculated with 42-group diffusion theory, as described in Section 4.2, are compared to the proton-recoil results for the six experimental locations in Figures 5.7 through 5.12. As before, both the calculated and measured data in these figures have been normalized such that $\int \phi(E) dE = C$ over the energy range of the measurements, where C is an arbitrary constant. (For Figures 5.7 through 5.12, $C=20$.) The unnormalized proton-recoil data are tabulated in Appendix A, while the 42-group flux data are tabulated in Appendix B. In order to facilitate comparison of calculated and measured spectra, the normalized proton-recoil data were collapsed to the group structure of the calculation. These results are also plotted in Figures 5.7 through 5.12.

In general, the agreement seen between calculation and experiment is quite good, even in the reflector and shield locations. For locations in the core or near the core boundary, the calculated spectra are slightly harder than the measured spectra. The discrepancy between calculation and experiment is particularly noticeable in group 9 (183 to 302 KeV), where the calculated flux peaks.

For the reflector and shield locations, even though some of the flux fine structure due to scattering resonances in nickel and iron is lost in the broad group calculations, the general agreement between calculation and experiment is very good. This agreement indicates that the 42-group diffusion

theory calculations accurately follow the spectral shifts that occur between the core center and the radial shield. ANL has previously reported⁽²⁸⁾ that this was the case for their 29-group diffusion theory calculations.

Figure 5.7. Comparison of Proton-Recoil and Calculated Spectra at Core Center.

Figure 5.8. Comparison of Proton-Recoil and Calculated Spectra - GP-201.

Figure 5.9. Comparison of Proton-Recoil and Calculated Spectra - SP-625.

Figure 5.10. Comparison of Proton-Recoil and Calculated Spectra at the Core-Reflector Boundary.

Figure 5.11. Comparison of Proton-Recoil and Calculated Spectra in the Reflector.

Figure 5.12. Comparison of Proton-Recoil and Calculated Spectra in the Shield.

5.4 Spectral Shifts in the EMC

One of the purposes of this experiment was to characterize the spatial variations in the EMC spectrum. In this section, spectra obtained for the six measurement points are compared to show these spatial variations. In Figure 5.13 (obtained from ANL), the proton-recoil data for the core center and SP-625 locations have been visually fitted. The spectra at these two locations are very close, but as can be seen at the lower energies, the spectrum in SP-625 is slightly softer. A similar comparison of spectra at GP-201 and the core center showed that there is very little difference between these locations.

In Figure 5.14, 42-group calculated spectra for the core center, SP-625 and the core-reflector interface, are compared. In all three cases, the energy-dependent fluxes were normalized such that $\int \phi(u)du=1$. Although not large, a progressive softening of the spectrum can be seen. Especially noticeable in this figure is the effect of the strong 15 KeV scattering resonance in nickel on the spectrum at the core-reflector interface. Again, the spectrum in GP-201 is not shown because it is so close to the core center spectrum.

In Figure 5.15, 42-group calculated spectra at the core-reflector interface, in the reflector, and in the shield are compared, and a large spectral shift in progressing from the core-reflector interface to the middle of the radial reflector is apparent. Also, a further spectral shift can be seen between the reflector and the shield, where scattering resonances in iron have a pronounced effect.

6.0 Conclusions, Recommendations and Applications

From the results of 42-group diffusion theory comparisons with experiments, it can be concluded that such calculations can be used to obtain reasonable predictions of the flux spectrum in the FTR from the core out into the shield, within the resolution permitted by the broad group structure. However, there is much fine structure in the flux, particularly in the reflector and shield regions, that is lost with the broad group calculations.

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Figure 5.13. Comparison of Proton-Recoil Spectra for Core Center and SP-625.

Figure 5.14. Comparison of Calculated Spectra at Core Center, SP-625 and Core-Reflector Interface.

Figure 5.15. Comparison of Calculated Spectra at Core-Reflector Interface, Reflector and Shield.

The accuracy of results obtained from analysis of the foil irradiations did not reach the level routinely obtainable in high-power facilities. This was due to the low fluence available and the resultant low counting rates. These difficulties arose from the necessity to keep activation of the EMC core to acceptable levels as required by other parts of the experimental program. In addition, self-shielding calculations for EMC were not available for the analysis -- such calculations would have been useful for the experiment design. Even with these difficulties, reasonable results were obtained for the in-core positions that show consistency between multiple foil techniques and proton-recoil. Results from this experiment will also be useful in design of low-power experiments for the FFTF Reactor Characterization Program.

7.0 Acknowledgement

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APPENDIX A

RESULTS OF PROTON-RECOIL MEASUREMENTS

Experimental data obtained from proton-recoil measurements at the six locations (see Table 3.1) are listed below. Each line of printout contains two points. For each point, the energy, flux, flux error (rms) and full-width-half-maximum energy resolution are given in that order.

NORMAL COMPOSITION, CORE CENTER (13,23)

1612.141	.1295E	08	.418E	06	.093	1533.553	.1388E	08	.446E	06	.093
1458.761	.1391F	08	.491E	06	.093	1367.616	.1481E	08	.454E	06	.093
1319.942	.1409F	08	.416E	06	.093	1255.567	.1381E	08	.292E	06	.093
1194.333	.1330E	08	.330E	06	.093	1136.085	.1240E	08	.307E	06	.093
1080.677	.1241E	08	.282E	06	.093	1027.372	.1318E	08	.274E	06	.093
977.237	.1390E	08	.267E	06	.093	931.148	.1481F	08	.291E	06	.093
884.784	.1659F	08	.273E	06	.094	841.633	.1682E	08	.255E	06	.094
801.586	.1703E	08	.317E	06	.094	761.541	.1768E	08	.297E	06	.094
724.407	.1825F	08	.230E	06	.094	689.071	.1949E	08	.209E	06	.094
655.464	.1973E	08	.350E	06	.094	623.497	.2040E	08	.428E	06	.094
593.089	.2093E	08	.484F	06	.094	564.164	.2150E	08	.454E	06	.094
536.640	.2147E	08	.345E	06	.094	510.476	.2123E	08	.392E	06	.094
485.580	.1269E	08	.400E	06	.094	461.394	.1831E	08	.423E	06	.094
439.371	.1739F	08	.309E	06	.094	417.943	.1641E	08	.356E	06	.094
397.560	.1793E	08	.436E	06	.094	378.170	.1808E	08	.301E	06	.094
359.727	.1934E	08	.260E	06	.094	342.163	.2096E	08	.302E	06	.094
325.494	.2335E	08	.288E	06	.094	309.520	.2272E	08	.706E	06	.094
294.521	.2371E	08	.657E	06	.095	280.156	.2457E	08	.609E	06	.095
266.492	.2336E	08	.643E	06	.095	253.495	.2425E	08	.689E	06	.095
241.132	.2458F	08	.636E	06	.095	229.372	.2321E	08	.548E	06	.095
218.186	.2303E	08	.545E	06	.095	207.545	.2339E	08	.568E	06	.095
197.423	.2466E	08	.601E	06	.095	187.794	.2332E	08	.503E	06	.095
179.635	.2268E	08	.552E	06	.095	169.923	.2403E	08	.509E	06	.096
161.636	.2447E	08	.472E	06	.096	153.753	.2533E	08	.533E	06	.096
146.254	.2633F	08	.453E	06	.096	139.121	.2465E	08	.417E	06	.096
132.336	.2566E	08	.477E	06	.096	125.582	.2708E	08	.451E	06	.096
119.743	.2778E	08	.417E	06	.097	113.903	.2751E	08	.386E	06	.097
108.340	.2656E	08	.366E	06	.097	103.164	.2583E	08	.339E	06	.097
98.037	.2413E	08	.404E	06	.097	93.256	.2469E	08	.510E	06	.098
89.708	.2741F	08	.972E	06	.098	84.381	.2164E	08	.903E	06	.098
81.066	.2294E	08	.827E	06	.098	76.352	.2437E	08	.914E	06	.099
72.628	.2318E	08	.841E	06	.099	69.088	.2230E	08	.776E	06	.099
65.716	.2210E	08	.873E	06	.099	62.511	.2170E	08	.656E	06	.100
59.463	.2133E	08	.739E	06	.100	56.563	.1912E	08	.639E	06	.100
53.504	.1743E	08	.528E	06	.101	51.181	.1565E	08	.498E	06	.101
48.684	.1536E	08	.457E	06	.101	46.310	.1584E	08	.492E	06	.102
44.051	.1698E	08	.471E	06	.102	41.903	.1722E	08	.434E	06	.103
39.859	.1634E	08	.478E	06	.103	37.915	.1393E	08	.464E	06	.104
36.066	.1284E	08	.728E	06	.105	34.307	.1154E	08	.781E	06	.107
32.634	.1110E	08	.715E	06	.108	31.042	.1008E	08	.601E	06	.109
29.524	.9385E	07	.594E	06	.110	28.188	.9512E	07	.651E	06	.112
26.718	.1130E	08	.729E	06	.113	25.415	.1519E	08	.546E	06	.114
24.176	.1439E	08	.616E	06	.116	22.997	.1446E	08	.573E	06	.117
21.875	.1370E	08	.429E	06	.119	20.806	.1323E	08	.408E	06	.121
19.793	.1273E	08	.457E	06	.122	18.428	.1080E	08	.421E	06	.124
17.910	.1040E	08	.403E	06	.126	17.036	.1019E	08	.360E	06	.128
16.206	.9436E	07	.338E	06	.130	15.415	.9637E	07	.390E	06	.132
14.663	.1016E	08	.603E	06	.134	13.948	.9666E	07	.636E	06	.136
13.268	.9849E	07	.585E	06	.139	12.621	.1011E	08	.631E	06	.141
12.005	.9514E	07	.581E	06	.143	11.420	.9148E	07	.533E	06	.146
10.863	.8888E	07	.588E	06	.148	10.333	.9402E	07	.541E	06	.151
9.825	.7876E	07	.454E	06	.154	9.350	.7248E	07	.457E	06	.157

3.894	.6515E 07	.511F 06	.160	8.460	.5928E 07	.468E 06	.163
8.047	.5874E 07	.342E 06	.166	7.655	.5562E 07	.324E 06	.169
7.282	.5377E 07	.342E 06	.172	6.926	.5354E 07	.327E 06	.176
6.589	.4485E 07	.312E 06	.179	6.267	.4894E 07	.246E 06	.183
5.962	.4795E 07	.269E 06	.187	5.671	.4664E 07	.467E 06	.191
5.394	.3548E 07	.426E 06	.195	5.131	.2826E 07	.390E 06	.199
4.881	.3054E 07	.45E 06	.203	4.643	.2994E 07	.426E 06	.207
4.417	.2377E 07	.337E 06	.212	4.201	.2754E 07	.346E 06	.216
3.996	.2191E 07	.323E 06	.221	3.901	.1471E 07	.344E 06	.226
3.616	.1246E 07	.314E 06	.231	3.440	.1145E 07	.256E 06	.236
3.272	.7728E 06	.215E 06	.242	3.112	.4197E 06	.218E 06	.247
2.960	.2739E 06	.204E 06	.253	2.816	.2377E 06	.191E 06	.258
2.679	.1168E 06	.173E 06	.264	2.548	.2252E 06	.161E 06	.271
2.424	.3009E 06	.167E 06	.277	2.306	.2583E 06	.158E 06	.283
2.193	.9036E 06	.143E 06	.291	2.086	.1553E 07	.271E 06	.295
1.984	.2182E 07	.220E 06	.303	1.888	.2403E 07	.228E 06	.311
1.796	.2512E 07	.209E 06	.318	1.708	.3009E 07	.134E 06	.325
1.625	.3912E 07	.205E 06	.333	1.546	.3877E 07	.149E 06	.341
1.471	.3929E 07	.177E 06	.349	1.398	.3731E 07	.189E 06	.358
1.330	.3749E 07	.175E 06	.366				
TFST LOOP, SP-625 (72,24)							
1612.181	.7745E 07	.304E 06	.093	1533.553	.8124E 07	.337E 06	.093
1455.761	.7654E 07	.308E 06	.093	1387.616	.7044E 07	.285E 06	.093
1319.942	.7773E 07	.187E 06	.093	1255.567	.7984E 07	.191E 06	.093
1194.333	.7588E 07	.198E 06	.093	1136.085	.7135E 07	.184E 06	.093
1080.677	.6854E 07	.179E 06	.093	1027.972	.7104E 07	.200E 06	.093
977.837	.7500E 07	.185E 06	.093	930.148	.7665E 07	.173E 06	.093
884.784	.8228E 07	.161E 06	.094	841.633	.8310E 07	.170E 06	.094
800.586	.8709E 07	.160E 06	.094	761.541	.8673E 07	.174E 06	.094
724.400	.9326E 07	.164E 06	.094	689.071	.9408E 07	.223E 06	.094
655.464	.1036E 08	.249E 06	.094	623.497	.1130E 08	.203E 06	.094
593.089	.1170E 08	.265E 06	.094	564.164	.1195E 08	.222E 06	.094
536.649	.1257E 08	.231E 06	.094	517.476	.1241E 08	.273E 06	.094
485.580	.1192E 08	.252E 06	.094	461.898	.1114E 08	.186E 06	.094
439.371	.1014E 08	.171E 06	.094	417.943	.9208E 07	.264E 06	.094
397.560	.9490E 07	.182E 06	.094	375.170	.1069E 08	.152E 06	.094
359.727	.1108E 08	.178E 06	.094	342.183	.1113E 08	.166E 06	.094
325.494	.1173E 08	.317E 06	.094	309.620	.1339E 08	.377E 06	.094
294.520	.1372E 08	.307E 06	.095	280.156	.1347E 08	.324E 06	.095
266.492	.1411E 08	.348E 06	.095	253.495	.1296E 08	.322E 06	.095
241.132	.1223E 08	.347E 06	.095	229.372	.1299E 08	.321E 06	.095
219.186	.1220E 08	.294E 06	.095	207.545	.1180E 08	.325E 06	.095
197.423	.1166E 08	.298E 06	.095	187.794	.1196E 08	.274E 06	.095
179.635	.1289E 08	.254E 06	.095	169.923	.1366E 08	.235E 06	.096
161.636	.1392E 08	.266E 06	.096	153.753	.1326E 08	.244E 06	.096
146.254	.1455E 08	.217E 06	.096	139.121	.1448E 08	.200E 06	.096
132.336	.1412E 08	.187E 06	.096	125.882	.1536E 08	.219E 06	.096
119.743	.1533E 08	.256E 06	.097	113.903	.1473E 08	.238E 06	.097
108.348	.1412E 08	.173E 06	.097	103.064	.1329E 08	.225E 06	.097
98.037	.1157E 08	.614E 06	.097	93.256	.1407E 08	.569E 06	.098
88.708	.1529E 08	.610E 06	.098	84.381	.1263E 08	.566E 06	.098
80.260	.1259E 08	.519E 06	.098	76.352	.1247E 08	.572E 06	.098
72.624	.1293E 08	.526E 06	.099	69.086	.1224E 08	.485E 06	.099

65.716	.1166E 08	.544E 06	.199	62.511	.1112E 08	.409E 06	.100
59.463	.1079E 08	.459E 06	.100	56.563	.1022E 08	.396E 06	.100
53.804	.8497E 07	.326E 06	.101	51.180	.8194E 07	.308E 06	.101
48.684	.9191E 07	.282E 06	.101	46.310	.9938E 07	.305E 06	.102
44.051	.9729E 07	.292E 06	.102	41.903	.8496E 07	.269E 06	.103
39.850	.7910E 07	.296E 06	.103	37.915	.7844E 07	.287E 06	.104
36.066	.7737E 07	.450E 06	.105	34.307	.7090E 07	.482E 06	.107
32.634	.4897E 07	.442E 06	.108	31.042	.4656E 07	.402E 06	.109
29.528	.5160E 07	.366E 06	.110	28.088	.6661E 07	.403E 06	.112
26.718	.7863E 07	.451E 06	.113	25.415	.8088E 07	.340E 06	.114
24.176	.7953E 07	.384E 06	.116	22.997	.7205E 07	.356E 06	.117
21.875	.7165E 07	.273E 06	.119	20.808	.7124E 07	.258E 06	.121
19.793	.6121E 07	.291E 06	.122	18.828	.5649E 07	.267E 06	.124
17.917	.5236E 07	.254E 06	.126	17.036	.4727E 07	.238E 06	.128
16.206	.5113E 07	.213E 06	.130	15.415	.4994E 07	.247E 06	.132
14.663	.5012E 07	.399E 06	.134	13.948	.4644E 07	.421E 06	.136
13.268	.4888E 07	.387E 06	.139	12.621	.5098E 07	.417E 06	.141
12.005	.5225E 07	.383E 06	.143	11.420	.5161E 07	.352E 06	.146
11.863	.5198E 07	.389E 06	.148	10.333	.4992E 07	.358E 06	.151
9.829	.4685E 07	.328E 06	.154	9.350	.4169E 07	.302E 06	.157
8.894	.4049E 07	.340E 06	.160	8.460	.3756E 07	.311E 06	.163
8.047	.3002E 07	.228E 06	.166	7.655	.3035E 07	.216E 06	.169
7.282	.3178E 07	.229E 06	.172	6.926	.3164E 07	.219E 06	.176
6.589	.2406E 07	.208E 06	.179	6.267	.2642E 07	.191E 06	.183
5.962	.2424E 07	.181E 06	.187	5.671	.1960E 07	.312E 06	.191
5.394	.2096E 07	.286E 06	.195	5.131	.2086E 07	.261E 06	.199
4.881	.1498E 07	.271E 06	.203	4.643	.1332E 07	.286E 06	.207
4.417	.1138E 07	.226E 06	.212	4.201	.7092E 06	.237E 06	.210
3.996	.8821E 06	.216E 06	.221	3.801	.1091E 07	.229E 06	.226
3.616	.8039E 06	.208E 06	.231	3.440	.3682E 05	.156E 06	.236
3.272	.1571E 07	.134E 06	.242	3.112	-.4031E 05	.134E 06	.247
2.960	-.9771E 05	.126E 06	.253	2.816	.1111E 06	.118E 06	.258
2.679	.2445E 06	.107E 06	.264	2.548	.1012E 06	.101E 06	.270
2.424	.3728E 06	.104E 06	.277	2.306	.7591E 06	.990E 05	.283
2.193	.1038E 07	.902E 05	.290	2.086	.1272E 07	.154E 06	.296
1.984	.1543E 07	.126E 06	.303	1.888	.2052E 07	.131E 06	.311
1.796	.2169E 07	.121E 06	.314	1.708	.2382E 07	.113E 06	.325
1.625	.2377E 07	.120E 06	.333	1.546	.2414E 07	.111E 06	.341
1.470	.2781E 07	.105E 06	.349	1.398	.2717E 07	.112E 06	.358
1.330	.2318E 07	.104E 06	.366				

TEST LOOP GP-201 (23,20)

1612.180	.1223E 08	.363E 06	.093	1533.553	.1308E 08	.390E 06	.093
1458.761	.1288E 08	.429E 06	.093	1387.616	.1283E 08	.396E 06	.093
1319.942	.1290E 08	.364E 06	.093	1255.567	.1291E 08	.261E 06	.093
1194.333	.1232E 08	.295E 06	.093	1136.085	.1173E 08	.276E 06	.093
1080.677	.1139E 08	.253E 06	.093	1027.972	.1233E 08	.246E 06	.093
977.837	.1277E 08	.239E 06	.093	930.148	.1297E 08	.261E 06	.093
884.784	.1367E 08	.244E 06	.094	841.633	.1446E 08	.228E 06	.094
800.586	.1391E 08	.281E 06	.094	761.541	.1543E 08	.264E 06	.094
724.400	.1590E 08	.202E 06	.094	689.071	.1656E 08	.228E 06	.094
655.464	.1725E 08	.343E 06	.094	623.497	.1871E 08	.307E 06	.094
593.089	.1980E 08	.438E 06	.094	564.164	.2058E 08	.413E 06	.094
536.649	.2129E 08	.315E 06	.094	510.476	.2083E 08	.360E 06	.094

485.580	.2018F	08	.425F	06	.094	461.898	.1908F	08	.392F	06	.94
439.371	.1795F	08	.289E	06	.094	417.943	.1650E	08	.332E	06	.094
307.567	.1718F	08	.409E	06	.094	378.170	.1794F	08	.243F	06	.094
319.707	.1951F	08	.233F	06	.094	342.183	.1980F	08	.264F	06	.094
325.494	.2161F	08	.255F	06	.094	309.620	.2206F	08	.519E	06	.094
294.523	.2265E	08	.474E	06	.095	280.156	.2358E	08	.440E	06	.095
266.492	.2273F	08	.465F	06	.095	253.495	.2279E	08	.439E	06	.095
241.132	.2331E	08	.461E	06	.095	229.372	.2147F	08	.405E	06	.095
218.186	.2101E	08	.394F	06	.095	207.545	.2186F	08	.425F	06	.095
197.423	.2144F	08	.469F	06	.095	187.794	.2285F	08	.364E	06	.095
179.635	.2253F	08	.398E	06	.095	169.923	.2292F	08	.369E	06	.096
161.636	.2422E	08	.342E	06	.096	153.753	.2439E	08	.366E	06	.096
146.254	.2488F	08	.361E	06	.096	139.121	.2458E	08	.313E	06	.096
130.336	.2562F	08	.361F	06	.096	125.882	.2634E	08	.334E	06	.096
119.743	.2645E	08	.310E	06	.097	113.903	.2575E	08	.211E	06	.097
118.348	.2535E	06	.274E	06	.097	103.064	.2537E	08	.254E	06	.097
98.037	.2378E	08	.304E	06	.097	93.256	.2248E	08	.831E	06	.098
88.708	.2340F	08	.764F	06	.098	84.381	.2362E	08	.706E	06	.098
80.266	.2415E	08	.763F	06	.098	76.352	.2327F	08	.841E	06	.099
72.628	.2210E	08	.774E	06	.099	69.986	.2314E	08	.712E	06	.099
65.716	.2170E	08	.658F	06	.099	62.511	.1983F	08	.738E	06	.100
59.463	.1833F	08	.682E	06	.100	56.563	.1739E	06	.621E	06	.100
53.804	.1470F	08	.470E	06	.101	51.180	.1446E	06	.443F	06	.101
49.684	.1596E	08	.406F	06	.101	46.310	.1732E	08	.456E	06	.102
44.051	.1677E	08	.420E	06	.102	41.903	.1556E	08	.482E	06	.103
39.859	.1481F	08	.365F	06	.103	37.915	.1415F	08	.349E	06	.104
36.066	.1297F	08	.391E	06	.105	34.307	.1273F	08	.622E	06	.107
32.634	.9577F	07	.665E	06	.108	31.042	.7851F	07	.609E	06	.109
29.528	.9211E	07	.554E	06	.110	28.088	.1141E	08	.508E	06	.112
26.718	.1407E	08	.556E	06	.113	25.415	.1477E	08	.513E	06	.114
24.176	.1486E	08	.476E	06	.116	22.997	.1504F	08	.538E	06	.117
21.875	.1292E	06	.493E	06	.119	20.808	.1215E	08	.391E	06	.121
19.793	.1180E	08	.359E	06	.122	18.828	.1103E	08	.330E	06	.124
17.910	.9827E	07	.311E	06	.126	17.036	.9142E	07	.338E	06	.128
16.200	.8964E	07	.321E	06	.130	15.415	.8981E	07	.296E	06	.132
14.663	.9247F	07	.343E	06	.134	13.948	.9613F	07	.546E	06	.136
13.268	.9243E	07	.577E	06	.139	12.621	.9734E	07	.533E	06	.141
12.005	.9006E	07	.573E	06	.143	11.423	.7837E	07	.528E	06	.146
10.863	.9654E	07	.487E	06	.148	10.333	.8435E	07	.534E	06	.151
9.829	.7008E	07	.489E	06	.154	9.350	.6317E	07	.450E	06	.157
8.894	.5586E	07	.411E	06	.160	8.460	.4847E	07	.377E	06	.163
8.047	.5740F	07	.423E	06	.166	7.655	.5327E	07	.340E	06	.169
7.282	.4807E	07	.311E	06	.172	6.926	.4406E	07	.285E	06	.176
6.589	.4393F	07	.266E	06	.179	6.267	.4214E	07	.248E	06	.183
5.962	.3888E	07	.274E	06	.187	5.671	.3015F	07	.256E	06	.191
5.394	.2459F	07	.290E	06	.195	5.131	.3570E	07	.495E	06	.199
4.981	.2271E	07	.514E	06	.203	4.643	.1817E	07	.408E	06	.207
4.417	.2554E	07	.426E	06	.212	4.201	.1377E	07	.447E	06	.216
3.996	.1391E	07	.418E	06	.221	3.801	.1254E	07	.370E	06	.226
3.616	.1454E	07	.394E	06	.231	3.440	.1229F	07	.358E	06	.236
3.272	.4156E	06	.277E	06	.242	3.112	.4013E	06	.227E	06	.247
2.960	.1522F	06	.236E	06	.253	2.816	.5222E	06	.223E	06	.258
2.679	.2735F	06	.212E	06	.264	2.548	.4794E	06	.189E	06	.270

2.424	.1822E	06	.178E	06	.277	2.306	.6677E	06	.176E	06	.283
2.193	.7155E	06	.174E	06	.290	2.086	.1628E	07	.159E	06	.296
1.984	.2758E	07	.252E	06	.303	1.888	.2426E	07	.230E	06	.311
1.796	.2775E	07	.241E	06	.318	1.708	.3188E	07	.223E	06	.325
1.625	.3753E	07	.206E	06	.333	1.546	.3742E	07	.219E	06	.341
1.470	.3455E	07	.201E	06	.349	1.398	.3654E	07	.188E	06	.359
1.330	.3941E	07	.202E	06	.366						

CORE-REFL BOUNDARY (18,13)

1612.183	.7699E	06	.387E	05	.093	1533.553	.7938E	06	.432E	05	.093
1458.761	.7535E	06	.390E	05	.093	1387.616	.6849E	06	.385E	05	.093
1319.942	.8090E	06	.255E	05	.093	1255.567	.8679E	06	.259E	05	.093
1194.333	.7832E	06	.272E	05	.093	1136.085	.7762E	06	.255E	05	.093
1080.677	.7822E	06	.247E	05	.093	1027.972	.8075E	06	.278E	05	.093
977.837	.7978E	06	.258E	05	.093	930.148	.8558E	06	.242E	05	.093
884.784	.8820E	06	.226E	05	.094	841.633	.9285E	06	.235E	05	.094
800.596	.9794E	06	.221E	05	.094	761.541	.1013E	07	.246E	05	.094
724.400	.1040E	07	.233E	05	.094	689.071	.1047E	07	.341E	05	.094
655.464	.1242E	07	.383E	05	.094	623.497	.1206E	07	.434E	05	.094
593.089	.1215E	07	.408E	05	.094	564.164	.1269E	07	.309E	05	.094
536.649	.1235E	07	.352E	05	.094	510.476	.1186E	07	.414E	05	.094
485.580	.1176E	07	.381E	05	.094	461.898	.1118E	07	.280E	05	.094
439.371	.1053E	07	.258E	05	.094	417.943	.1087E	07	.397E	05	.094
397.560	.1037E	07	.274E	05	.094	378.170	.1060E	07	.232E	05	.094
359.727	.1053E	07	.271E	05	.094	342.183	.1148E	07	.253E	05	.094
325.494	.1215E	07	.409E	05	.094	309.620	.1282E	07	.595E	05	.094
294.527	.1339E	07	.481E	05	.095	280.156	.1341E	07	.509E	05	.095
266.492	.1359E	07	.545E	05	.095	253.495	.1430E	07	.504E	05	.095
241.132	.1230E	07	.544E	05	.095	229.372	.1277E	07	.503E	05	.095
215.186	.1242E	07	.462E	05	.095	207.545	.1211E	07	.508E	05	.095
197.423	.1321E	07	.469E	05	.095	187.794	.1347E	07	.432E	05	.095
178.635	.1357E	07	.400E	05	.095	169.923	.1409E	07	.371E	05	.096
161.636	.1369E	07	.418E	05	.096	153.753	.1381E	07	.384E	05	.096
146.254	.1454E	07	.358E	05	.096	139.121	.1454E	07	.295E	05	.096
132.336	.1469E	07	.273E	05	.096	125.882	.1626E	07	.313E	05	.096
119.743	.1659E	07	.365E	05	.097	113.903	.1666E	07	.339E	05	.097
108.348	.1508E	07	.254E	05	.097	103.064	.1433E	07	.300E	05	.097
98.037	.1357E	07	.636E	05	.097	93.256	.1136E	07	.583E	05	.098
88.705	.1386E	07	.538E	05	.098	84.381	.1368E	07	.577E	05	.098
80.266	.1299E	07	.535E	05	.098	76.352	.1280E	07	.490E	05	.099
72.628	.1229E	07	.540E	05	.099	69.086	.1158E	07	.495E	05	.099
65.716	.1134E	07	.455E	05	.099	62.511	.1053E	07	.510E	05	.100
59.463	.1175E	07	.472E	05	.100	56.563	.1314E	07	.432E	05	.100
53.804	.1250E	07	.375E	05	.101	51.180	.1099E	07	.311E	05	.101
48.684	.1011E	07	.286E	05	.101	46.310	.9897E	06	.270E	05	.102
44.051	.9667E	06	.347E	05	.102	41.303	.9459E	06	.280E	05	.103
39.859	.9259E	06	.258E	05	.103	37.915	.8668E	06	.284E	05	.104
36.066	.7833E	06	.275E	05	.105	34.307	.7068E	06	.431E	05	.107
32.634	.7015E	06	.394E	05	.108	31.042	.4687E	06	.422E	05	.109
29.528	.3945E	06	.384E	05	.110	28.088	.4895E	06	.418E	05	.112
26.718	.6125E	06	.383E	05	.113	25.415	.7228E	06	.429E	05	.114
24.176	.7836E	06	.322E	05	.116	22.997	.6867E	06	.362E	05	.117
21.875	.6718E	06	.336E	05	.119	20.808	.6776E	06	.246E	05	.121
19.793	.5921E	06	.234E	05	.122	18.826	.4922E	06	.280E	05	.124

17.910	.4695E 06	.238E 05	.126	17.136	.5126E 06	.228E 05	.128
16.206	.3799E 06	.247E 05	.130	15.415	.3572E 06	.190E 05	.132
14.663	.3911E 06	.218E 05	.134	13.948	.4372E 06	.322E 05	.136
13.268	.4091E 06	.341E 05	.139	12.621	.5040E 06	.314E 05	.141
12.005	.5153E 06	.338E 05	.143	11.420	.5792E 06	.312E 05	.146
10.863	.6084E 06	.287E 05	.148	1.333	.6233E 06	.319E 05	.151
9.829	.6139E 06	.295E 05	.154	9.350	.5451E 06	.271E 05	.157
8.894	.5194E 06	.251E 05	.160	8.460	.4571E 06	.283E 05	.163
8.047	.4417E 06	.260E 05	.166	7.655	.4368E 06	.199E 05	.169
7.282	.4297E 06	.183E 05	.172	6.926	.4174E 06	.168E 05	.176
6.589	.3807E 06	.186E 05	.179	6.267	.3425E 06	.178E 05	.183
5.962	.3130E 06	.184E 05	.187	5.671	.3055E 06	.155E 05	.191
5.394	.2983E 06	.269E 05	.195	5.131	.2393E 06	.247E 05	.199
4.881	.2080E 06	.258E 05	.203	4.643	.2191E 06	.235E 05	.207
4.417	.2604E 06	.215E 05	.212	4.201	.2259E 06	.227E 05	.216
3.996	.1897E 06	.208E 05	.221	3.801	.1740E 06	.190E 05	.226
3.616	.1582E 06	.203E 05	.231	3.440	.1283E 06	.155E 05	.236
3.272	.9026E 05	.148E 05	.242	3.112	.7359E 05	.121E 05	.247
2.960	.7655E 05	.127E 05	.253	2.816	.6871E 05	.120E 05	.258
2.679	.7342E 05	.109E 05	.264	2.548	.5574E 05	.102E 05	.270
2.424	.5221E 05	.958E 04	.277	2.306	.5539E 05	.958E 04	.283
2.193	.8337E 05	.947E 04	.290	2.086	.1277E 06	.867E 04	.296
1.984	.1550E 06	.139E 05	.303	1.888	.1753E 06	.127E 05	.311
1.796	.2020E 06	.133E 05	.318	1.708	.2275E 06	.122E 05	.325
1.625	.2357E 06	.113E 05	.333	1.546	.2706E 06	.121E 05	.341
1.470	.2694E 06	.111E 05	.349	1.398	.2707E 06	.104E 05	.358
1.330	.2667E 06	.111E 05	.366				

REFLECTOR (29,35)

1458.761	.6576E 05	.451E 04	.093	1387.616	.9068E 05	.421E 04	.093
1319.942	.1078E 06	.289E 04	.093	1255.567	.1142E 06	.300E 04	.093
1194.333	.1247E 06	.320E 04	.093	1136.085	.1333E 06	.308E 04	.093
1080.677	.1341E 06	.306E 04	.093	1027.972	.1425E 06	.351E 04	.093
977.837	.1440E 06	.334E 04	.093	930.148	.1647E 06	.323E 04	.093
884.784	.1696E 06	.307E 04	.094	841.633	.1750E 06	.329E 04	.094
800.586	.1998E 06	.316E 04	.094	761.541	.2126E 06	.356E 04	.094
724.400	.2221E 06	.344E 04	.094	689.071	.2190E 06	.500E 04	.094
655.464	.2640E 06	.571E 04	.094	623.497	.2767E 06	.655E 04	.094
593.089	.2876E 06	.626E 04	.094	564.164	.2898E 06	.482E 04	.094
536.649	.2915E 06	.556E 04	.094	510.476	.2836E 06	.660E 04	.094
485.580	.2855E 06	.614E 04	.094	461.898	.2899E 06	.457E 04	.094
439.371	.2870E 06	.426E 04	.094	417.943	.3072E 06	.664E 04	.094
397.561	.3033E 06	.462E 04	.094	378.170	.2984E 06	.378E 04	.094
359.727	.2847E 06	.441E 04	.094	342.183	.2958E 06	.412E 04	.094
325.494	.3024E 06	.691E 04	.094	309.620	.2981E 06	.825E 04	.094
294.520	.3178E 06	.667E 04	.095	280.156	.3153E 06	.704E 04	.095
266.492	.3253E 06	.756E 04	.095	253.495	.3422E 06	.700E 04	.095
241.132	.3217E 06	.755E 04	.095	229.372	.3036E 06	.700E 04	.095
218.186	.3062E 06	.643E 04	.095	207.545	.3107E 06	.709E 04	.095
197.423	.3127E 06	.654E 04	.095	187.794	.3196E 06	.604E 04	.095
178.635	.3390E 06	.560E 04	.095	169.923	.3722E 06	.522E 04	.096
161.636	.3775E 06	.591E 04	.096	153.753	.3770E 06	.545E 04	.096
146.254	.4379E 06	.477E 04	.096	139.121	.4587E 06	.443E 04	.096
132.336	.4878E 06	.420E 04	.096	125.882	.5357E 06	.495E 04	.096

119.743	.5359E 06	.577E 04	.097	113.903	.5189E 06	.542E 04	.097
108.348	.4727E 06	.406E 04	.097	103.064	.4368E 06	.477E 04	.097
98.037	.4233E 06	.120E 05	.097	93.256	.4105E 06	.111E 05	.098
88.708	.3771E 06	.120E 05	.098	84.381	.3382E 06	.110E 05	.098
80.266	.3197E 06	.101E 05	.098	76.352	.2949E 06	.111E 05	.099
72.628	.2712E 06	.101E 05	.099	69.086	.2361E 06	.925E 04	.099
65.716	.1947E 06	.103E 05	.099	62.511	.3029E 06	.776E 04	.100
59.463	.4400E 06	.876E 04	.100	56.563	.5009E 06	.755E 04	.100
53.804	.4212E 06	.635E 04	.101	51.180	.3638E 06	.619E 04	.101
48.684	.3279E 06	.562E 04	.101	46.310	.3074E 06	.606E 04	.102
44.051	.2957E 06	.584E 04	.102	41.903	.2836E 06	.538E 04	.103
39.859	.2496E 06	.589E 04	.103	37.915	.2321E 06	.574E 04	.104
36.066	.2158E 06	.876E 04	.105	34.307	.1806E 06	.939E 04	.107
32.634	.1630E 06	.859E 04	.104	31.042	.1475E 06	.752E 04	.109
29.528	.1421E 06	.713E 04	.110	28.088	.1397E 06	.778E 04	.112
26.718	.1473E 06	.869E 04	.113	25.415	.1745E 06	.648E 04	.114
24.176	.1744E 06	.727E 04	.116	22.997	.1542E 06	.669E 04	.117
21.875	.1267E 06	.499E 04	.119	20.808	.1215E 06	.470E 04	.121
19.793	.1074E 06	.522E 04	.122	18.828	.6962E 05	.476E 04	.124
17.910	.7717E 05	.450E 04	.126	17.036	.7003E 05	.422E 04	.128
16.206	.6305E 05	.372E 04	.130	15.415	.5833E 05	.426E 04	.132
14.663	.8133E 05	.649E 04	.134	13.948	.7565E 05	.684E 04	.136
13.268	.7905E 05	.625E 04	.139	12.621	.9302E 05	.671E 04	.141
12.005	.1240E 06	.615E 04	.143	11.420	.1443E 06	.567E 04	.140
10.863	.1604E 06	.629E 04	.148	10.333	.1809E 06	.586E 04	.151
9.829	.1795E 06	.540E 04	.154	9.350	.1622E 06	.504E 04	.157
8.894	.1507E 06	.572E 04	.160	8.460	.1456E 06	.527E 04	.163
8.047	.1464E 06	.384E 04	.166	7.655	.1437E 06	.367E 04	.169
7.282	.1261E 06	.389E 04	.172	6.926	.1253E 06	.376E 04	.176
6.589	.1199E 06	.362E 04	.179	6.267	.1079E 06	.334E 04	.183
5.962	.9661E 05	.318E 04	.187	5.671	.8871E 05	.526E 04	.191
5.394	.8391E 05	.483E 04	.195	5.131	.7362E 05	.443E 04	.199
4.881	.6173E 05	.462E 04	.203	4.643	.6796E 05	.488E 04	.207
4.417	.8097E 05	.369E 04	.212	4.201	.7483E 05	.411E 04	.216
3.996	.6771E 05	.378E 04	.221	3.801	.6505E 05	.406E 04	.226
3.616	.8287E 05	.373E 04	.231	3.440	.5927E 05	.331E 04	.236
3.272	.5619E 05	.274E 04	.242	3.112	.5245E 05	.286E 04	.247
2.960	.4586E 05	.268E 04	.253	2.816	.4173E 05	.251E 04	.258
2.679	.4009E 05	.229E 04	.264	2.548	.3582E 05	.214E 04	.270
2.424	.3922E 05	.228E 04	.277	2.306	.5128E 05	.216E 04	.283
2.193	.6959E 05	.199E 04	.290	2.086	.7178E 05	.434E 04	.296
1.984	.6799E 05	.353E 04	.303	1.888	.7606E 05	.371E 04	.311
1.796	.8696E 05	.343E 04	.318	1.708	.1033E 06	.318E 04	.325
1.625	.1099E 06	.340E 04	.333	1.546	.1104E 06	.315E 04	.341
1.470	.1190E 06	.296E 04	.349	1.398	.1208E 06	.318E 04	.358
1.330	.1118E 06	.296E 04	.360				

SHIELD (36,38)

1612.180	.1936E 03	.711E 02	.093	1333.553	.6409E 03	.776E 02	.093
1458.761	.8147E 03	.938E 02	.093	1387.616	.1062E 04	.960E 02	.093
1319.942	.1334E 04	.966E 02	.093	1255.567	.1550E 04	.766E 02	.093
1194.333	.1919E 04	.944E 02	.093	1136.085	.2325E 04	.986E 02	.093
1080.677	.2851E 04	.982E 02	.093	1027.972	.3579E 04	.106E 03	.093
977.837	.4223E 04	.112E 03	.093	930.148	.4333E 04	.130E 03	.093

864.784	.4802E 04	.130E 03	.094	841.633	.5748E 04	.128E 03	.094
800.586	.5875E 04	.165E 03	.094	761.541	.7506E 04	.165E 03	.094
724.400	.8994E 04	.135E 03	.094	689.071	.1105E 05	.161E 03	.094
655.464	.1293E 05	.257E 03	.094	623.497	.1382E 05	.306E 03	.094
593.089	.1381E 05	.363E 03	.094	564.164	.1454E 05	.354E 03	.094
536.640	.1520E 05	.279E 03	.094	510.476	.1577E 05	.327E 03	.094
485.580	.1611E 05	.396E 03	.094	461.896	.1620E 05	.373E 03	.094
439.371	.1647E 05	.283E 03	.094	417.943	.1666E 05	.332E 03	.094
397.560	.1987E 05	.422E 03	.094	376.170	.2142E 05	.301E 03	.094
359.727	.2491E 05	.270E 03	.094	342.183	.2723E 05	.324E 03	.094
325.494	.3068E 05	.321E 03	.094	309.620	.3126E 05	.834E 03	.094
294.520	.3347E 05	.794E 03	.095	280.156	.3478E 05	.702E 03	.095
266.492	.3697E 05	.825E 03	.095	253.495	.3747E 05	.907E 03	.095
241.132	.3629E 05	.853E 03	.095	229.372	.3395E 05	.803E 03	.095
218.186	.3200E 05	.753E 03	.095	207.545	.3203E 05	.820E 03	.095
197.423	.3218E 05	.913E 03	.095	187.794	.3155E 05	.712E 03	.095
178.635	.3108E 05	.784E 03	.095	169.923	.3413E 05	.728E 03	.096
161.636	.3503E 05	.681E 03	.096	153.753	.3629E 05	.773E 03	.096
146.254	.4034E 05	.729E 03	.096	139.121	.4126E 05	.603E 03	.096
132.336	.4524E 05	.676E 03	.096	125.882	.5497E 05	.657E 03	.096
119.743	.5985E 05	.638E 03	.097	113.903	.6003E 05	.604E 03	.097
108.348	.5630E 05	.571E 03	.097	103.064	.5265E 05	.551E 03	.097
98.037	.4943E 05	.660E 03	.097	93.256	.3832E 05	.133E 04	.098
88.708	.3562E 05	.123E 04	.098	84.381	.3475E 05	.133E 04	.098
80.266	.4272E 05	.123E 04	.098	76.352	.5417E 05	.115E 04	.099
72.628	.5456E 05	.128E 04	.099	69.086	.5391E 05	.120E 04	.099
65.716	.5879E 05	.112E 04	.099	62.511	.5568E 05	.128E 04	.100
59.463	.5263E 05	.120E 04	.100	56.763	.4921E 05	.111E 04	.100
53.804	.4679E 05	.987E 03	.101	51.160	.4152E 05	.814E 03	.101
48.684	.4035E 05	.752E 03	.101	46.310	.4334E 05	.715E 03	.102
44.051	.4572E 05	.933E 03	.102	41.903	.4509E 05	.752E 03	.103
39.859	.3962E 05	.697E 03	.103	37.915	.3433E 05	.775E 03	.104
35.066	.3016E 05	.751E 03	.105	34.307	.2505E 05	.121E 04	.107
32.634	.2358E 05	.111E 04	.108	31.042	.2132E 05	.119E 04	.109
29.528	.1790E 05	.108E 04	.110	28.088	.2164E 05	.119E 04	.112
26.718	.3851E 05	.110E 04	.113	25.415	.5398E 05	.125E 04	.114
24.176	.6821E 05	.900E 03	.116	22.997	.7144E 05	.111E 04	.117
21.875	.6132E 05	.106E 04	.119	20.908	.5473E 05	.815E 03	.121
19.793	.4975E 05	.781E 03	.122	18.828	.4454E 05	.888E 03	.124
17.910	.3974E 05	.822E 03	.126	17.036	.3507E 05	.789E 03	.128
16.206	.2952E 05	.871E 03	.130	15.415	.2878E 05	.606E 03	.132
14.663	.2868E 05	.771E 03	.134	13.946	.3265E 05	.120E 04	.136
13.268	.3181E 05	.128E 04	.139	12.621	.3055E 05	.118E 04	.141
12.005	.3200E 05	.127E 04	.143	11.420	.3156E 05	.117E 04	.146
10.863	.3378E 05	.108E 04	.148	10.333	.3051E 05	.120E 04	.151
9.829	.2778E 05	.111E 04	.154	9.350	.2427E 05	.101E 04	.157
8.894	.2042E 05	.933E 03	.160	8.460	.1961E 05	.105E 04	.163
8.047	.1723E 05	.956E 03	.166	7.655	.1646E 05	.709E 03	.169
7.282	.1653E 05	.648E 03	.172	6.926	.1543E 05	.593E 03	.176
6.589	.1550E 05	.652E 03	.179	6.267	.1590E 05	.623E 03	.183
5.962	.1584E 05	.572E 03	.187	5.671	.1534E 05	.544E 03	.191
5.394	.1246E 05	.899E 03	.195	5.131	.1458E 05	.826E 03	.199
4.881	.1597E 05	.864E 03	.203	4.643	.1314E 05	.792E 03	.207

4.417	.1349E 05	.728E 03	.212
3.996	.1546E 05	.708E 03	.221
3.616	.1299E 05	.698E 03	.231
3.272	.1219E 05	.510E 03	.242
2.960	.9400E 04	.446E 03	.253
2.679	.8545E 04	.387E 03	.264
2.424	.7764E 04	.347E 03	.277
2.193	.9322E 04	.346E 03	.290
1.984	.1356E 05	.507E 03	.303
1.796	.1477E 05	.488E 03	.318
1.625	.1738E 05	.418E 03	.333
1.470	.1877E 05	.412E 03	.349
1.330	.1956E 05	.415E 03	.366

4.201	.1515E 05	.771E 03	.216
3.801	.1435E 05	.650E 03	.226
3.440	.1360E 05	.643E 03	.236
3.112	.1064E 05	.423E 03	.247
2.816	.8126E 04	.423E 03	.258
2.548	.8636E 04	.366E 03	.270
2.306	.7870E 04	.347E 03	.283
2.086	.1160E 05	.319E 03	.296
1.888	.1401E 05	.465E 03	.311
1.708	.1618E 05	.451E 03	.325
1.546	.1855E 05	.447E 03	.341
1.398	.1955E 05	.386E 03	.358

APPENDIX B

RESULTS OF 42-GROUP SPECTRUM CALCULATIONS

Tabulated below are the spectra obtained from the 42-group diffusion theory calculations made with the 2DBS program. These calculations are described in Section 4.2 and the results summarized in Section 5.3. The locations for which data are given are defined in Table 3.1 and the energy bounds of each of the 42 groups are given in Table 4.1.

GROUP	CORE CENTER	GP-201	SF-625
1	.63500E-02	.52540E-02	.52760E-02
2	.25080E-01	.20490E-01	.20520E-01
3	.59480E-01	.51560E-01	.51440E-01
4	.93570E-01	.86910E-01	.88340E-01
5	.11960E+00	.10730E+00	.11050E+00
6	.19170E+00	.18410E+00	.19220E+00
7	.16260E+00	.16330E+00	.16660E+00
8	.23850E+00	.22770E+00	.22220E+00
9	.26120E+00	.25620E+00	.24660E+00
10	.24270E+00	.24450E+00	.23320E+00
11	.21100E+00	.21060E+00	.19930E+00
12	.14170E+00	.14250E+00	.14190E+00
13	.11920E+00	.12630E+00	.12310E+00
14	.13750E+00	.14210E+00	.13410E+00
15	.98750E-01	.10390E+00	.97830E-01
16	.73080E-01	.78600E-01	.74090E-01
17	.41390E-01	.43110E-01	.43820E-01
18	.24300E-01	.19300E-01	.19440E-01
19	.54120E-02	.34830E-02	.35000E-02
20	.51000E-02	.42290E-02	.42500E-02
21	.15880E-01	.18000E-01	.18640E-01
22	.26660E-01	.40110E-01	.45570E-01
23	.18050E-01	.27730E-01	.32340E-01
24	.98800E-02	.14740E-01	.18770E-01
25	.46040E-02	.70300E-02	.10160E-01
26	.29580E-02	.45640E-02	.82780E-02
27	.12680E-02	.20050E-02	.52220E-02
28	.51480E-03	.82120E-03	.35440E-02
29	.16290E-03	.27780E-03	.22920E-02
30	.95730E-04	.13270E-03	.20500E-02
31	.23000E-04	.39960E-04	.13320E-02
32	.21430E-05	.13940E-04	.10190E-02
33	.19870E-05	.35950E-05	.64130E-03
34	.14870E-05	.17240E-05	.56320E-03
35	.81900E-06	.93690E-06	.43090E-03
36	.17200E-06	.28880E-06	.22500E-03
37	.23110E-07	.63320E-07	.10240E-03
38	.41000E-08	.13400E-07	.47050E-04
39	.61730E-09	.24720E-08	.18470E-04
40	.10520E-09	.43760E-09	.64160E-05
41	.18350E-10	.73810E-10	.19290E-05
42	.25310E-11	.10500E-10	.38240E-06

GROUP	CORE-REFL. INTERFACE	REFLECTOR	SHIFT
1	.47640E-02	.43500E-03	.39820E-05
2	.18231E-01	.14370E-02	.67830E-05
3	.45210E-01	.52210E-02	.67170E-04
4	.83120E-01	.22000E-01	.82700E-02
5	.11670E+01	.53090E-01	.52170E-02
6	.20230E+00	.16710E+00	.74780E-01
7	.16430E+00	.14660E+00	.66280E-01
8	.21220E+00	.15150E+00	.12530E+00
9	.23540E+00	.17180E+00	.13030E+00
10	.22630E+00	.21360E+00	.17670E+00
11	.19590E+00	.19090E+00	.17430E+00
12	.15010E+00	.18050E+00	.17010E+00
13	.09070E-01	.89590E-01	.14770E+00
14	.10020E+00	.73770E-01	.28920E+00
15	.47500E-01	.28810E-01	.97150E-01
16	.77630E-01	.59610E-01	.74000E-01
17	.64530E-01	.70040E-01	.69600E-01
18	.35740E-01	.42640E-01	.67250E-01
19	.20070E-01	.26640E-01	.41130E-01
20	.19030E-01	.25790E-01	.31060E-01
21	.32320E-01	.46330E-01	.49170E-01
22	.30590E-01	.61730E-01	.77600E-01
23	.30590E-01	.55540E-01	.62590E-01
24	.23520E-01	.54730E-01	.55650E-01
25	.14990E-01	.41730E-01	.38130E-01
26	.13270E-01	.45570E-01	.48290E-01
27	.09790E-02	.42310E-01	.46310E-01
28	.7670E-02	.39140E-01	.44050E-01
29	.6240E-02	.34820E-01	.39020E-01
30	.46690E-02	.31640E-01	.35380E-01
31	.33100E-02	.26160E-01	.31930E-01
32	.25600E-02	.21510E-01	.27160E-01
33	.17230E-02	.16670E-01	.22110E-01
34	.13850E-02	.12670E-01	.16020E-01
35	.17490E-03	.95370E-02	.11970E-01
36	.54720E-03	.53140E-02	.76710E-02
37	.26540E-03	.29410E-02	.43570E-02
38	.11910E-03	.14140E-02	.21300E-02
39	.45270E-04	.57680E-03	.98850E-03
40	.14675E-04	.10450E-03	.32370E-03
41	.41040E-05	.56710E-04	.89410E-04
42	.59680E-06	.81340E-05	.12970E-04