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LINEAR ACCELERATOR PROJECT

AEC Contract No. AT(11-1)-3058

PROGRESS REPORT

for

January 1, 1972 - March 31, 1972

Rensselaer Polytechnic Institute
Troy, New York 12181

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Erwin R. Gaerttner
Project Director

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NEUTRON CROSS SECTIONS
IRON-FILTERED NEUTRON BEAMS - A NEW APPROACH TO PRECISION 
TIME-OF-FLIGHT CROSS-SECTION MEASUREMENTS 

R. C. Block, N. N. Kaushal and R. W. Hockenbury 

The following is an abstract of a paper which has been submitted for presentation at the National Topical Meeting of the American Nuclear Society at Kiamesha Lake, New York, September 12-15, 1972.

ABSTRACT

By placing thick filters in a white-source time-of-flight neutron beam, it is possible to obtain a low-background transmitted beam of bands of neutrons with energies corresponding to the cross-section minima in the filter. Iron filters varying in thickness from 2 to 20 inches were placed in the 25-meter spectrometer of the RPI LINAC; for filters 6 inches and thicker, over ten distinct neutron energy bands were observed below 1 MeV. In particular, the band at 24.3 keV is ~2 keV wide and is separated by more than 45 keV from the next nearest energy band. In the upper half of Fig. 1 are plotted the relative neutron intensities near 24 keV for neutrons filtered by 2, 8, 14 and 20 inches of 'pure' Armco iron. A $^{10}$B-NaI detector was used for this measurement. For the thicker filters the peak counting rate is about 500 times greater than background (as measured in the wings), and this small background can readily be determined, permitting high accuracy cross-section measurements near 24 keV. Measurements using this technique have already been reported$^1$ for the total cross section of iron near the resonance-interference minima.

For capture cross-section measurements, 8 inches of iron was used for the filter, and a 1.25-meter liquid scintillator was used to detect neutron captures. These results are plotted in the lower half of Fig. 1 for two relatively short runs on the LINAC with samples of depleted U and Ta. The high peak-to-background ratios of 46:1 for Ta, and 9:1 for U provide an ideal low-background environment for capture measurements with a minimum of time-dependent background effects (caused by neutrons scattered into the scintillator).
A preliminary filtered-beam capture measurement was carried out for the following samples: 0.020" Au, 0.020" In, 0.020" Ta and 0.030" depleted U (99.8% $^{238}$U and 0.2% $^{235}$U). The capture detection efficiency was obtained by measuring the capture pulse-height spectra and by extrapolating to zero bias. The ratios of the measured capture cross sections near 24 keV were determined to be

$$\sigma(U): \sigma(Au): \sigma(In): \sigma(Ta) = (0.54): (0.68): (0.96): (1:00).$$

These ratios have not yet been corrected for multiple scattering, resonance self-shielding or gamma ray escape; an overall uncertainty of about ±8% is estimated for each number.

This technique provides us with an accurate effective cross-section measurement over a narrow energy interval. These data can then be used to normalize the data from continuous cross-section measurements. Since this filtered beam data is for a narrow but finite energy range, in order to obtain maximum accuracy, one must take into account the fluctuations from average in the cross section (±5% for $^{238}$U) resulting from a limited number of resonances sampled in this interval. Thus, the filtered-beam method must be complemented by high-resolution, white-source TOF measurements to pin down these fluctuations caused by nuclear statistics.

REFERENCE:


FIGURE CAPTION

Fig. 1 In the Upper Half of this Figure are plotted the $^{10}$B-NaI Neutron Counting Rate vs. Neutron Time-of-Flight for a Pulsed Neutron Beam passing through 2, 8, 14 and 20 inches of Iron. The peak transmission through each filter is shown in parentheses. In the lower half of this Figure are plotted the capture counting rate vs. neutron time-of-flight for capture in depleted U and Ta samples. Both sets of data were obtained with the LINAC operating at 500 pps and with pulse widths of 50 and 500 nsec respectively for the transmission and capture measurements.
RELATIVE NEUTRON INTENSITY FOR 2°, 8°, 14°, AND 20° IRON FILTERS

Figure 1
TOTAL NEUTRON CROSS SECTIONS ON $^6\text{Li}$ AND $^4\text{He}$ FROM 0.7 TO 30 MEV: PRELIMINARY-REPORT

C. A. Goulding,* J. M. Clement and P. Stoler

Total cross-section measurements of neutrons on $^6\text{Li}$ have recently been completed. The data was taken in two separate runs with the first taken in approximately twenty-four hours and the second in seventy-two hours. For each run the electron energy was 60 Mev with a burst width of 20 nsec. We chose the time-of-flight channel width to be 10.0 nsec in each case. As with previous data, the resolution was averaged to 30.0 nsec, or 0.13 nsec/meter.

As with the $^7\text{Li}$ data, layers of Pb and Cd were used to filter out the gamma flash and low energy neutrons. However, due to the smaller sample size, a 3/4-inch collimator was used before, and a 1/2-inch collimator was used after the sample.

The sample consisted of enriched $^6\text{Li}$ (4.3% $^7\text{Li}$) encapsulated in Al cans. The sample thickness was 0.351 atoms/barn. The correction for sample impurity was achieved by taking our previous $^7\text{Li}$ data and averaging to a channel width of 100 nsec to eliminate statistical uncertainties and then subtracting the appropriately weighted result from the calculated $^6\text{Li}$ cross section. Complete graphs will appear in the next report.

Preliminary work has been done on obtaining the $^4\text{He}$ total neutron cross section. Eighty hours of data were taken with an electron beam energy of 70 Mev and a pulse width of 20 nsec. Though the channel width was 10 nsec, the resolution was limited by jitter in the ADC. Therefore the energy resolution was averaged to 40 nsec per channel or 0.16 nsec/meter.

The data was taken in three runs. The first consisted of using two modules for eight hours. The second consisted of using one module and lasted for 48 hours. This reduced the background counting rate by a factor of two. The final 16 hours were used

*Based in part on the Ph.D. Thesis of C. A. Goulding.
to obtain better high energy statistics. The electron beam current was increased until the count rate was two neutrons/machine burst. Though this produced high deadtime losses at lower energies, the count rate at higher energies was doubled. Because of the deadtime losses, all data below 12 Mev was ignored in the analysis of the high intensity run.

The sample consisted of one of the stainless tubes used in earlier experiments\(^4\) filled to a pressure of 1809 psi. This gave a sample thickness of \(0.301\) atoms/barn. Graphs will appear in the next quarterly report.

REFERENCES:

2. Ibid., p. 5.
3. Ibid., p. 5.
KEV NEUTRON ELASTIC SCATTERING CROSS SECTION IN IRON

R. Zuhr,* Z. Bell and K. Min

In this report we present the differential elastic scattering cross section of natural iron with an energy resolution of 10% in the region from 10 to 600 keV. The data were measured at six angles from 45 to 150 degrees.

Figure 1 is a schematic diagram of the experimental apparatus. The RPI linear accelerator, operating at 65 MeV, with a 50 nsec pulse width, was used as the neutron source. The cross sections were measured relative to lead, using time-of-flight methods over a 27-meter path. A PDP-7 computer, with a channel width of 32 nsec was used for data-taking, as well as for the automatic cycling of the samples. Both the iron and lead samples were 3 1/8 by ½-inch disks, placed at 45° to the beam axis. The scattered neutrons were detected by a 5- by ½-inch lithium 6-glass scintillator.

The typical time-of-flight spectra for iron and lead are shown in Fig. 2. It should be noted that the broad peak above channel 500 observed in both spectra is due to the resonance in detector efficiency at 250 keV. Background was found using the method of black resonances, and the cross sections used for the standard lead sample were those of Lane, Langsdorf, Elwyn and Monahan.1 The results have been corrected for multiple scattering using a combined Monte Carlo analytical method based on the work of Lane and Miller.2 It includes energy dependent scattering through fourth order and is adequate for all energies except in the neighborhood of the 28 keV resonance, where sample thickness is such that even more extensive corrections are necessary.

Differential scattering cross sections as a function of the scattering angle in laboratory coordinates are shown in Figs. 3, 4 and 5. The solid lines represent the least square fits

of second order Legendre polynomial expansions. The interference between S- and P-waves begins to show appreciably at about 160 keV; and by 180 keV, the P-wave scattering makes an appreciable contribution. At several higher energies, comparison is made with the 1969 results of Elwyn and Monahan, indicated by the open circles. Their energy resolution is a constant 20 kilovolts.

Total elastic scattering cross section with an energy resolution of 10% is shown in Fig. 6. Since there are no directly comparable scattering results, the evaluated total cross section of Penny and Kinney is included for comparison. Within the experimental errors shown, our scattering data follow the rapid energy variations exhibited by the total cross section.

In order to compare directly with the 1957 results of Lane, Langsdorf and Monahan, we averaged our data over an energy bin of 100 kilovolts. These results are shown in Fig. 7. Also included are two total cross-section curves for iron, which show appreciable variation from one another. In general, both our data and the earlier results of Lane, Langsdorf and Monahan lie somewhat above the total cross sections.

Several methods to improve our counting rate are currently being tested, including a new collimation system and the use of two detectors for simultaneous measurements at two angles.

REFERENCES:
2. Lane and Miller, Nucl. Instr. and Methods, 16, 1 (1962).
FIGURE CAPTIONS

Fig. 1  Schematic Diagram of Experiment.
Fig. 2  Time-of-Flight Spectra for Iron and Lead (110°).
Fig. 3-5  Differential Elastic Scattering Cross Section as a Function of Laboratory Scattering Angle.
Fig. 6  Total Scattering Cross Section with an Energy Resolution of 10%.
Fig. 7  Total Scattering Cross Section with an Energy Resolution of 100 keV.
TIME OF FLIGHT MEASUREMENT OF SCATTERING CROSS-SECTIONS

Figure 1
Figure 2

Time of Flight Spectrum of Scattered Neutrons From Lead

Time of Flight Spectrum of Scattered Neutrons From Iron
DIFFERENTIAL CROSS SECTIONS

\( \sigma_\delta \) (BARN/STERADIAN)

- **180 KeV** ± 5%
- **160 KeV** ± 5%
- **110 KeV** ± 5%
- **60 KeV** ± 5%

\( \cos(\theta) \)

**Figure 3**
DIFFERENTIAL CROSS SECTONS

$\sigma_3$ (BARN/STERADIAN)

- $360$ KeV ± 5%
- $320$ KeV ± 5%
- $280$ KeV ± 5%
- $220$ KeV ± 5%

$\cos(\theta)$

$\theta = \text{ARGONNE, BNL 400, } \Delta E = 20$

Figure 4
Differential Cross Sections

$\sigma_s$ (Barns/Steradian)

600 keV ± 5%
520 keV ± 5%
440 keV ± 5%
400 keV ± 5%

O = Argonne, BNL 400, \( \Delta E = 20 \)

Figure 5
Iron
Total Elastic Scattering
\(\Delta E/E = 10\%\)

- Present Data

Figure 6
Iron
Total Scattering vs Energy
$\Delta E = 100$ KeV

- Present Data
- Langsdorf, Lane, Monahan, Phys Rev. 107
- $\sigma_T$, O.R.N.L. (S.K. Penny and W.E. Kinney)
- $\sigma_T$, C. Lubitz, Private Communication

Figure 7
The following are abstracts of papers which have been submitted for presentation at the Conference on Nuclear Structure Study with Neutrons, Budapest, Hungary, July 31 - August 5, 1972.

NEUTRON TOTAL, CAPTURE AND FISSION CROSS-SECTION MEASUREMENTS ON $^{240}$Pu

R. W. Hockenbury, W. R. Moyer and R. C. Block

Neutron total, capture and fission cross-section measurements were carried out upon $^{240}$Pu from 20 eV to 30 keV. Parameters were obtained for 35 s-wave resonances up to 500 eV, resulting in $<\Gamma_Y> = (29.5 \pm 1.5)$ meV and $S_0 = (1.10 \pm 0.27) \times 10^{-4}$. The observed level spacing for subthreshold fission is $(710 \pm 200)$ eV.

THE P-WAVE NEUTRON STRENGTH FUNCTION NEAR MASS 55 AND 160

P. J. Turinsky and R. C. Block

Two deep minima have been observed in the p-wave neutron strength function near mass 55 and 160. A spherical optical model potential with a rather sharp surface absorption can fit these minima, but at the expense of predicting too narrow maxima in both $S_0$ and $S_1$ and strong fluctuations in $R'$. 
TEMPERATURE-DEPENDENT TRANSMISSION AND SELF-INDICATION MEASUREMENTS UPON DEPLETED U IN THE UNRESOLVED REGION

T. Y. Byoun, R. C. Block and T. Semler

The following is an abstract of a paper which has been submitted for presentation at the National Topical Meeting of the American Nuclear Society at Kiamesha Lake, New York, September 12-15, 1972.

ABSTRACT

Neutron transmission and self-indication ratio measurements have been made at the RPI LINAC on depleted U (99.8% $^{238}\text{U}$ and 0.2% $^{235}\text{U}$) up to 100 keV in order to investigate the temperature dependence of resonance self-shielding. These measurements were carried out at 77°C, 295°C, and 973°C. The experimental method has been described in detail in a previous publication on Ta, except that a vacuum furnace was used in this experiment instead of the argon-flow furnace.

The experimental results are plotted in Fig. 1. The linear thermal expansion of the U samples was measured to be (1.7 ± 0.1)% between 295°C and 973°C, and -(0.20 ± 0.02)% between 295°C and 77°C. If corrections are made in Fig. 1 for the sample thickness changes, we can see that the average transmission and self-indication ratio become smaller as the sample temperature increases, as expected from the Doppler effect.

The average cross section and strength functions for s- and p-wave neutrons in the energy range 1 keV to 70 keV and the limited range 5.0 to 5.6 keV have been determined from the room-temperature transmission data by using the least squares method. A stochastic sampling method using the computer code DAISY was used to analyze the temperature-dependent transmission data in the energy range 5.0 keV to 5.6 keV. The results and the parameters used are listed in Table 1.

+Supported by NASA Grant NGR 33-018-134.
# NASA Lewis Research Center, Cleveland, Ohio 44135.
* Based in part on the Ph.D. Thesis of T. Y. Byoun.
REFERENCES:

FIGURE CAPTION

Fig. 1-A and B  Average Transmission and Self-Indication Ratio for Samples of U. No corrections are made for the sample thickness change resulting from thermal expansion. The data are averaged in 10% wide energy bins. The statistical accuracy of the transmission data is approximately 1% and approximately 2% in the self-indication ratio.
Figure 1
### Table 1. TRANSMISSION DATA ANALYSIS

<table>
<thead>
<tr>
<th>Sample Thickness (atom/barn)</th>
<th>Sample Temp. (°K)</th>
<th>Energy Range 5.0 to 5.6 keV</th>
<th>Energy Range 1 to 70 keV</th>
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<tr>
<td></td>
<td>Effective Ave. Cross Section (barns)</td>
<td>Parameters used in the DAISY Code (d), (e)</td>
<td>Strength Functions determined from Analytical Calculation</td>
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<td>Analytical</td>
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<tr>
<td>0.03155</td>
<td>77</td>
<td>12.8 ± 0.3</td>
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<td>0.03155</td>
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<td>13.3 ± 0.2</td>
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<td>0.03060</td>
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<tr>
<td>0.06206</td>
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<td>12.6 ± 0.3</td>
<td>12.39</td>
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<tr>
<td>0.06206</td>
<td>295</td>
<td>12.7 ± 0.1</td>
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<tr>
<td>0.06292</td>
<td>973</td>
<td>12.6 ± 0.1</td>
<td>12.88</td>
</tr>
</tbody>
</table>

(a) Measured at 295°K
(b) Local value of \( S_0 \) in the energy range 5.0 keV to 5.6 keV
(c) Doppler broadening of p-wave resonance has not been considered
(d) For a given potential cross section of 10.8 barn\(^3\) and the formula used is:

\[
\langle \sigma \rangle = 2n^2 k_k \sum_{l=0}^{1} (2l+1) S_l \langle \sigma_k \rangle \cos 2 \xi_k + \sigma_p
\]

(e) Least squares fit by using the following approximate formula:

\[
<T> = e^{-\frac{n_1}{T_0} \langle \sigma \rangle} \left[ 1 + \frac{1}{2} n_1^2 \langle \sigma_0 \rangle - \frac{\langle \sigma_T \rangle}{\langle \sigma_0 \rangle} \right] - \frac{1}{6} n_1^2 \langle (\sigma_T - \langle \sigma_0 \rangle)^2 \rangle
\]
Correlations Between Neutron and Radiation Widths

M. Lubert, * N. C. Francis # and R. C. Block

The $^{57}\text{Fe}(\gamma,\text{n})$ reaction has been recently measured. No correlation between the neutron and radiation widths was observed. The experimental results obtained at RPI for chromium do show strong correlations. In order to understand this paradox, the $^{57}\text{Fe}(\gamma,\text{n})$ cross section was calculated, using both the channel direct and the compound nucleus reaction amplitudes. The R-matrix phase shifts are given by the following equations:

$$R = \left\{ \sum_{\lambda} \frac{\gamma^2_{\lambda}}{E_{\lambda} - E} + R^\infty \right\}$$

$$\delta = \tan^{-1} RP - kR_0$$

To obtain the channel contribution, it is necessary to calculate the final state continuum s-state wave function. The required phase shift is calculated using R-matrix theory where $\gamma^2_{\lambda}$ is the reduced width, $R^\infty$ the contribution from non-explicit levels, $P$ the penetrability, $k$ the neutron wave number in the center-of-mass system and $R_0$ the nuclear radius. The resonance parameters produced a total $^{56}\text{Fe}$ cross section which agreed quite well with results presented in BNL-325. Baglan reports a non-resonant cross section of 0.052 mb at 26 keV for $^{57}\text{Fe}$. The theoretical value at this energy of 0.24 mb yields a reduced width factor of 0.22. This reduced width was used in calculating the thermal capture cross section for $^{56}\text{Fe}$ and the channel ground-state partial radiative widths for $^{57}\text{Fe}(\gamma,\text{n})$. The thermal $^{56}\text{Fe}(\text{n},\gamma)$, from detailed balance was 0.22 b. The experimental value, assuming a ground state transition fraction of 0.25 is 0.67 b. Consequently, the compound nucleus contribution cannot be neglected in calculating the thermal capture. The bulk of the thermal capture cross section stems from the bound level at -4.39 keV. The 28 keV level contributes only 0.057 b which is a factor of four smaller than the channel contribution. The channel partial radiative widths for

*Based in part on the Ph.D. Thesis of M. Lubert.

#Knolls Atomic Power Laboratory, Schenectady, New York.
transitions to the ground state obtained from area analysis are shown in Table I. The results of the analysis are interesting from several viewpoints. First, the theoretical calculation predicts a level at 80 keV with $\Gamma_{\gamma} = 0.14$ eV. This level is not observed in the experiments. The theoretical line shapes are asymmetric. It is expected that levels with large channel components would exhibit a marked asymmetry. The shapes computed for single levels show constructive interference on the low energy side of the resonance and destructive interference above the resonance. The level-level interference introduced by the R-matrix further distorts this line shape. The experimental cross sections do not in general look markedly asymmetric nor does the cross section appear to go through a minimum above the resonance as predicted by the theory. This can be attributed to two effects; namely, experimental resolution broadening and the contribution due to compound nucleus resonance amplitude. The interference between the channel and compound nucleus amplitudes affects the line shape. Further, it is possible that a level would not appear in the experimental results if the amplitudes cancelled. It can be shown that the partial ground state radiative width is given by

$$\Gamma_{\gamma o} = \Gamma_{\gamma o}^{\text{channel}} + \gamma_{o}^{2}\text{cpd} \pm 2\sqrt{\Gamma_{\gamma o}^{\text{channel}} \gamma_{o}^{2}\text{cpd}}.$$ 

Assuming the calculated channel contribution to be reasonable, the compound nucleus contribution to the partial radiation width can be estimated. The average compound nucleus reduced width amplitude for the ground state was found in this way to be 0.197. An estimate of the total capture channel radiative width including excited states can be obtained from the (d,p) strength data. This results in a factor of 4.6 which multiplies the ground state channel contributions given in Table I.

There are no correlations between $\Gamma_{n}$ and $\Gamma_{\gamma o}$ for the four levels where the experiments agree. Similar results for these relatively isolated levels were obtained from theoretical analysis. However, inclusion of the eleven levels listed in Table I yielded
rank and product-moment coefficients for $^{57}\text{Fe}$ of 0.97 and 0.25 respectively. The significant results obtained from the examination of $^{57}\text{Fe}$ are: first, the analysis of the experiments must include level-level effects, and second, that compound nucleus and channel interference can be of considerable importance when the channel contribution is large.

REFERENCES:

Table I. Resonance Parameters $^{57}\text{Fe}$

<table>
<thead>
<tr>
<th>$\text{E(keV)}^{(1)}$</th>
<th>$\text{E(keV)}^{(2)}$</th>
<th>$\Gamma_{\gamma\text{O}}^{(1)}$</th>
<th>$\Gamma_{\gamma\text{O}}^{(2)}$</th>
<th>$\Gamma_{\gamma\text{O}}$</th>
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NEUTRON CAPTURE GAMMA RAY EXPERIMENTS USING THE PDP-9/L DATA ACQUISITION SYSTEM AND THE PDP-15 INTERACTIVE GRAPHICS SYSTEM


The two-parameter hardware and corresponding software developed for use on the PDP-9/L computer is now complete. This will allow study of neutron capture gamma rays at the 12.65-meter flight station with up to 81 regions of neutron time of flight. Each region will have 2048 channels of ADC pulse height (gamma ray energy) information.

The hardware to be used consists of several versatile devices. The RPI Time Digitizer will be used to measure the neutron time-of-flight. This clock has a minimum 62.5 nsec channel width. A high speed hardware sorter determines what region of time-of-flight the clock data word represents. The ADC data is also hardware sorted into one of 32 core data buffers depending on its bit configuration. These hardware sort processes allow the data to be stored rapidly on-line on the PDP-9/L disk. The system is capable of storing a few hundred cts/sec of TOF X PHA data. In addition, a single parameter program (up to 8192 channels of TOF or ADC) allows count rates up to 1500 cts/sec to be stored on-line on the disk.

The data-taking programs have an on-line oscilloscope display and are interactive with a light pen allowing output to the teletype or the high speed Potter Printer. Final data analysis will be accomplished by transferring the data to the PDP-15 via a newly constructed PDP-9/L to PDP-15 interface. A data analysis program for the PDP-15 allows rapid calculation of areas under pulse height peaks. The PDP-15 Graphic-15 oscilloscope and light pen are used for this purpose. This allows analysis to proceed on the PDP-15 while data is being gathered on the PDP-9/L.

Preliminary experiments on W-186 targets indicate a typical resolution (using a 65 cc Ge(Li) crystal) of 12 keV FWHM for the DE peak of the 5.32 Mev gamma ray.

Measurements of fast neutron spectra in sodium were continued during the past quarter. Fabrication of all the "slugs" and "plugs" of sodium required for filling the reentrant holes in the assembly has been completed.\(^1\)

An air-cooled all-welded-construction LINAC output window made of 0.001-inch titanium has been fabricated and installed for use during fast neutron spectrum measurements. This window is considerably thinner than the previously used water-cooled aluminum windows and hence causes much less scattering of the electron beam at the output. Consequently there is now less than ten percent beam "rake off" in the electron beam stripper, and about ninety percent of the beam strikes the neutron production target. In addition to improving the quality of data (fewer neutrons are produced at points other than the neutron source), these changes have lead to a faster data-acquisition rate by virtue of efficient usage of the electron beam power.

A typical spectrum measured recently is shown in Fig. 1. The spectrum data shown extends from 1 keV to 10 MeV and is a composite of the data from a \(^{10}\)B-Vaseline detector for energies up to 0.7 MeV, and a proton-recoil liquid scintillator detector for higher energies. The data at low energies are averaged over several data points to improve statistical accuracy. The effect of the 2.6 keV resonance in sodium is apparent.

Attention is being given to further improving the statistical accuracy of the data below 10 keV by increasing the neutron source strength. This may be accomplished either by designing a new target or by increasing the power-handling capabilities of the present or a similar target. These efforts are described elsewhere in this report.\(^2\)

REFERENCES:
2. This report, p. 29.
PRELIMINARY DATA
FAST NEUTRON SPECTRUM IN SODIUM
$R=47$ cm.; $\mu = -0.84$

**Figure 1**
THE NEED FOR A MORE INTENSE NEUTRON SOURCE FOR FAST SPECTRUM MEASUREMENTS IN SODIUM
A. N. Mallen, * N. N. Kaushal, B. K. Malaviya and E. R. Gaerttner

The air-cooled Ta targets$^{1,2}$ currently being used for fast spectra measurements have proved adequate in the past for providing a sufficient number of isotropic-source neutrons to measure the neutron spectra in homogeneous assemblies.

The sodium assembly now under investigation, however, is considerably larger than previous assemblies and intensity problems have been encountered at points in the assembly far from the target. Additionally, the scope of spectral studies has been extended to include the energy region between 1 KeV and 10 KeV where the neutron intensity is rapidly decreasing.

Preliminary investigations have shown that the statistics between 1 KeV and 10 KeV are poor, especially at the minimum caused by the prominent 2.86 KeV resonance. At the minimum $R=10.5$ inches, $\theta=90^\circ$, the point closest to the source, the relative statistical error was 40% for an 8-hour run; the corresponding signal-to-background ratio was less than 0.5. At 1.24 KeV the signal-to-background ratio increased to 2.0 and the relative statistical error was 20% for a 1% energy spread. With increasing distance from the target, the signal-to-background ratio decreased rapidly and became intolerably low for positions far from the source.

The need for a more intense neutron target is thus clear. Additionally a target with a softer spectrum is desired to increase the proportion of neutrons in the region 1 to 10 KeV. New target designs conforming to these objectives are currently being considered for use with the sodium assembly.

REFERENCES:
*Based in part on the Ph.D. Thesis of A. N. Mallen.
The analysis and interpretation of fast neutron spectrum data have been continuing. A comprehensive paper describing the results of our studies of fast neutron transport in iron and the assessment of iron data files has been published recently and a similar paper on our studies on a uranium assembly has been accepted for publication.

Current efforts — in cooperation with the Theory Group — are devoted to the evaluation of new data files (such as Material 1124) and the extension of the analysis to incorporate anisotropic scattering, which principally affects the interpretation of high-energy data (above 0.5 MeV). Detailed comparisons of transport calculations with measurements for the aluminum assembly are also in progress.

REFERENCES:
REACTOR PHYSICS AND ENGINEERING - THEORETICAL
Initial calculations with anisotropic group constant matrices have been compared with experiment for iron (ENDF/B-I, Oak Ridge 1124 files), depleted uranium (ENDF/B-I, II), aluminum (ENDF/B-I). Initial comparisons indicate good spectral agreement in some directions, but not others, thereby raising the possibility of errors in angular distribution data. Firm conclusions have not yet been drawn. In depleted uranium, good spectral agreement is obtained for both files at small radii; but a larger radii there is a tendency for increasing overprediction of the flux. This is attributable, at least in part, to excessive low energy fluxes (leading to an unwarranted \( ^{235}\text{U} \) fission contribution) caused by previously identified inelastic scattering deficiencies in both files.

A multigroup cross-section set was obtained for lead for use in time-dependent spectrum calculations. The set had provisions for slowing down only by inelastic scattering, so we generated elastic matrices based on the total elastic cross sections and continuous slowing down theory. Space-and-time dependent spectra have been calculated. These spectra display very rapid attenuation with time at high energies (i.e., above the inelastic threshold) followed by very slow behavior at low energies where weak elastic scattering is the prime slowing down mechanism. Preliminary measurements on lead indicate this type of behavior, though quantitative comparison is not yet appropriate. Inspection of time-dependent solutions in materials with structured cross sections (iron, aluminum) indicates interesting transient behavior in the vicinities of resonances. This behavior will be studied more carefully to see if we can capitalize on it experimentally.

REFERENCE:

*Based in part on the Ph.D. Theses of A. Ginsberg and S. Kang.
Evaluation of elastic transfer matrices can be a time-consuming process, involving a large number of double integrals over rapidly fluctuating functions. Here we propose a method, based on the techniques of continuous slowing down theory, which would substantially reduce the number of integrals required. A previous RPI attempt to utilize continuous slowing down concepts for elastic removal to a single group in the transport approximation was quite successful.

Consider the group transfer cross section for the kth moment

\[ \sum_{k} \phi_{k}^{g} = \int_{u_{g-1}}^{u_{g}} du' \int_{u_{h-1}}^{u_{h}} du'' (u',U) \phi_{k}(u') \]

(1)

(where the limits of integration might not be over the full groups)

with \( U = u'' - u' \)

The cross section is given by

\[ \sum_{k} (u',U) = B_{k}(u')P_{k}[\mu_{o}(U)] \left[ - \frac{d\mu_{o}}{du} (U) \right] \]

(2)

where the standard notation of Ref. 2 is used. Using Eq. (3) in Eq. (1) yields

\[ \sum_{k} \phi_{k}^{g} = \int_{u_{g-1}}^{u_{g}} du' B_{k}(u') \phi_{k}(u') K_{k}(u',u) \]

(4)

\[ K_{k}(u',u) = \int_{u_{h-1}}^{u_{h}} du'' P_{k}[\mu_{o}(U)] \left[ - \frac{d\mu_{o}}{du} (U) \right] \]

(5)

In continuous slowing down theory we expand the collision density

\[ F_{k}(u') = B_{k}(u') \phi_{k}(u') = F_{k}(u_{g}) - (u_{g} - u') \frac{d}{du} F_{k}(u_{g}) \]

(6)
For simplicity in this report we consider the age theory assumption that we can take just the first term. We then obtain

$$\sum_{k} g^{g \leftarrow h} \phi_k^g = \sum_{h} g^{g \leftarrow h} B_k(u_g) \phi_k(u_g)$$  \hspace{1cm} (7)

where we have defined a group-transfer logarithmic energy decrement according to

$$g^{g \leftarrow h} = \int_{u_{g-1}}^{u_g} du' \int_{u_{h-1}}^{u_h} du'' P_k \left[ \frac{d \phi_0}{dU} \right]$$  \hspace{1cm} (8)

The scattering cross sections $B_k(u_g)$ in laboratory coordinates can then be related to those in center of mass by the standard transformation

$$B_k(u_g) = \sum_{k'} T_{kk'} B_{k'}^C(u_g)$$  \hspace{1cm} (9)

The implications of this approach are as follows. As in our previous work, the influence of the weighting spectrum is incorporated in the ratio of $\phi_k(u_g)$ to the group flux $\phi_k^g$. Most important is, that if one uses a uniform group structure, the $g^{g \leftarrow h}$ quantities are the same for all source groups ($g$ index). Therefore, integrations need to be evaluated for one group only.

It is anticipated that a code to generate one-hundred group libraries based on the Bondarenko scheme is to be developed under AEC auspices. Because of the two properties of our approach noted above, elastic transfer integrals would be required only for one group in the first problem (i.e., for one value of background cross section ($\sigma_0$)). Therefore, if this approach proves successful, it will imply a marked reduction in computer costs for elastic matrices. We plan to initiate testing shortly.

REFERENCES: