ORNL/TM--11762

DE91 012135

Engineering Physics and Mathematics Division

# MULTILEVEL RESONANCE ANALYSIS OF $^{59}$Co NEUTRON TRANSMISSION MEASUREMENTS

G. de Saussure, N. M. Larson, J. A. Harvey and N. W. Hill

DATE PUBLISHED — May 1991

Prepared for the
Office of Energy Research
Division of Nuclear Physics
and
Defense Nuclear Agency

Prepared by the
OAK RIDGE NATIONAL LABORATORY
Oak Ridge, Tennessee 37831
managed by
MARTIN MARIETTA ENERGY SYSTEMS, INC.
for the
U.S. DEPARTMENT OF ENERGY
under contract DE-AC05-84OR21400

# CONTENTS

# LIST OF FIGURES

# ACKNOWLEDGMENTS

The authors thank R. Q. Wright for considerable help with the comparison of the ENDF/B evaluations and D. C. Larson and R. W. Peelle for helpful reviews and many suggestions. The authors are grateful to S. R. Damewood for her patience in retyping the successive editions of this report. This research was sponsored by the Office of Energy Research, Division of Nuclear Physics, U.S. Department of Energy, under Contract No. DE-AC05-84OR21400 with Martin Marietta Energy Systems, Inc., and under Interagency Agreement No. 0046-C083-A1 with the Defense Nuclear Agency.

# ABSTRACT

High-resolution neutron transmission measurements through several thicknesses of $^{59}Co$ were performed in 1986 at the Oak Ridge Electron Linear Accelerator (ORELA) in conjunction with the ENDF/B-VI evaluation of $^{59}Co$ done at Argonne National Laboratory. These measurements have much better energy resolution than previously published transmission measurements. The results of one of the measurements were used in the ENDF/B-VI evaluation of the total cross section above 100 keV, but the data were not used below 100 keV, where the ENDF/B-VI cross sections are represented by resolved resonance parameters based on a compilation of Mughabghab et al.

The ENDF/B-VI resolved resonance parameters were used to compute the transmission for the sample thicknesses used in the ORELA measurements, and large discrepancies were observed between these computations and the results of the measurements. Consequently, all six ORELA transmission measurements were analyzed, in the neutron energy range from 200 eV to 100 keV, using the multilevel $R$-matrix computer code SAMMY which utilizes Bayes' theorem for the fitting process.

The spin $J$ of most resonances and the orbital angular momentum $\ell$ for the smaller resonances cannot be determined from the data and were assigned somewhat arbitrarily so as to make the $s$-wave level density proportional to $2J + 1$ and to satisfy the Dyson-Metha $\Delta_3$ statistics. Calculations with the resonance parameters obtained in the analysis reproduce well the results of the ORELA transmission measurements which were done at 80 m and 200 m with sample thicknesses varying from 0.005 to 0.3 atoms/barn.

The transmission measurements are not very sensitive to the values of the resonance capture widths; therefore, the capture widths obtained in this analysis have large uncertainties. An attempt was made to adjust the capture widths to give capture areas consistent with the capture areas reported by Spencer et al. However, the attempt was not successful because the correspondence between the resonances observed in transmission and those observed in capture is not always unambiguous and because the capture areas measured by Spencer et al. often have large and uncertain multiple scattering contributions. Resonance parameters are required to properly estimate these contributions.

# 1. INTRODUCTION

The resonance parameters describing the low-energy neutron cross sections of $^{59}$Co are of considerable interest, not only because $^{59}$Co is used as a structural material in nuclear technology but also because the thermal capture cross section and the capture resonance integral of $^{59}$Co are widely used as standards and for dosimetry.[1]

High-resolution neutron transmission measurements through several thicknesses of $^{59}$Co were performed in 1986 at the Oak Ridge Electron Linear Accelerator (ORELA), in conjunction with the ENDF-B-VI evaluation of $^{59}$Co done at Argonne National Laboratory. These measurements have much better energy resolution than previously published measurements.[2,3] The results of one of these measurements were used in the ENDF/B-VI evaluation of the $^{59}$Co total cross section above 100 keV,[4,5] but the data were not used below 100 keV where the ENDF/B-VI cross sections are represented by resolved resonance parameters based on a recent compilation of Mughabghab et al.[6]

The ENDF/B-VI resolved resonance parameters were used to compute values of transmission on the same energy scale as the ORELA transmission measurements; large discrepancies were observed between the computed and measured transmissions, indicating that the ENDF/B-VI resolved resonance parameters were inadequate. Therefore, all six transmission measurements were analyzed with the code SAMMY,[7] and new resonance parameters were obtained which are consistent with the high resolution ORELA transmission measurements.

The next section of this report is a comparison and discussion of the recent ENDF/B evaluations of $^{59}$Co in the resolved resonance region. In the third section the experimental conditions of the ORELA transmission measurements are given, and it is shown that the ENDF/B-VI resolved resonance parameters are inconsistent with the results of these measurements. In the last section the resonance analysis with the code SAMMY is described and the new resolved resonance parameters are discussed.

# 2. COMPARISON OF RECENT $^{59}$Co EVALUATIONS IN THE RESOLVED RESONANCE REGION

## 2.1 DOCUMENTATION

The ENDF/B-VI $^{59}$Co evaluation (MAT 2725) was done by A. B. Smith, D. Smith, P. Guenter, J. Meadows, R. Lawson, R. Howerton, and M. Sugimoto at Argonne National Laboratory and is documented in Ref. 4. Reference 4 provides an extensive discussion of the evaluation above 100 keV (clearly the region of most interest to these authors), but the region below 100 keV, described by resonance parameters, is barely discussed: the total discussion in Ref. 4 concerning the region below 100 keV consists of the following paragraph:

> "The present evaluation uses the resonance parameters of Mughabghab[6] with modifications of Dunford and Mughabghab[8] to describe the neutron elastic-scattering and capture cross sections up to incident neutron energies of 100 keV. A small background was introduced to assure continuity at the matching energy. The neutron elastic-scattering and radiative-capture cross sections were constructed from the resonance parameters, using the computer code RECENT.[9] Of course, these combine to provide the neutron total sections, which were compared with the totality of the experimental data available from Ref. 10, regardless of experimental conditions. The agreement was reasonably good, given the wide variation in experimental results, as illustrated in Fig. 1. The present resonance results are qualitatively similar to those of ENDF/B-V, as the experimental data base has not greatly changed in the intervening years, but they benefit from the improved interpretation of Ref. 6."

and the following comment in the Summary Section:

> "A comprehensive study of the resonance region is warranted. This should include reinterpretation of the best available experimental information and, as warranted, new measurements to provide improved definition."

(Reference numbers in the quote refer to references at the end of this paper. The numbers have been changed for purposes of self-consistency within this report, but the actual references are the same as those given in Ref. 4. Figure 1 is reproduced here; it shows the total cross section from 1 to 10 keV.)

Fortunately the documentation for the resonance region for ENDF/B-IV (MAT 6199) and ENDF/B-V (MAT 1327) is very good: ENDF/B-IV below 100 keV is discussed in Refs. 11 and 12; ENDF/B-V in Ref. 13.

The following discussion is essentially a comparison of ENDF/B-IV, V, and VI in the region below 100 keV, with other recent evaluations and recent data.

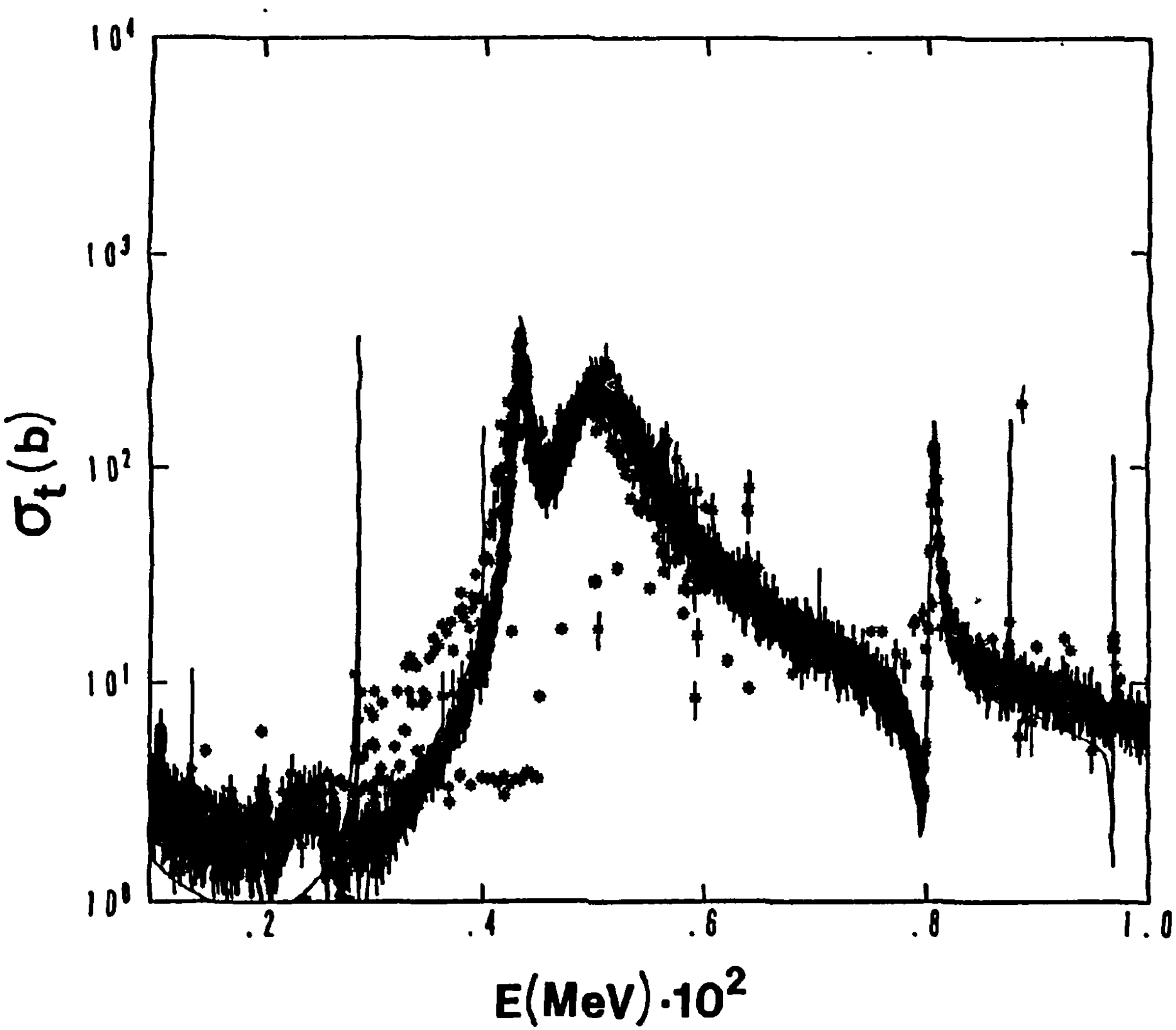


Fig. 1. Illustrative comparisons of the evaluated resonance region (curve) with the totality of experimental results available from Ref. 10 (symbols), irrespective of experimental conditions or quality. [From ANL/NDM-107 (ref. 4).]

## 2.2 THERMAL CROSS SECTIONS AND CAPTURE RESONANCE INTEGRAL

In Table 1, the 2200 m/s cross sections, the Westcott g-factors, the capture resonance integral, and the channel radius of the three evaluations are compared. The most important dosimetry data are the 2200 m/s capture cross section, $\sigma_{n\gamma}$, and the capture resonance integral, $RI_\gamma$. In 1981 N. E. Holden[1] performed a careful review of 24 measurements of $\sigma_{n\gamma}$ and 12 measurements of $RI_\gamma$ leading to his recommended values:

$$\sigma_{n\gamma} = 37.18 \pm 0.06 \text{ barns}; \quad RI_\gamma = 74 \pm 2 \text{ barns}$$

Since no measurements of these quantities after 1978 are listed in CINDA,[14] the above best values need no updating. The ENDF/B-V and VI values of the parameters are fully consistent with Holden's evaluation.

Table 1. Comparison of thermal cross sections and capture resonance integrals for $^{59}$Co

| ENDF-Version | IV | V | VI |
|---|---|---|---|
| MAT | 6199 | 1327 | 2725 |
| Distribution date | 1975 | March 1983 | January 1990 |
| Cross sections at 0.0253 eV | | | |
| $\sigma_t$ (b) | 43.84[a] | 42.597[c] | 43.143[g] |
| $\sigma_{n\gamma}$ (b) | 37.22[a] | 37.233[c] | 37.190[g] |
| $\sigma_s$ (b) | 6.62[a] | 5.364[c] | 5.953[g] |
| Westcott $g$-factors | | | |
| Total | | 1.0162[e] | 1.0193[f] |
| Capture | 0.99996[a] | 1.0000[e] | 1.0019[f] |
| Channel radius, AP, $10^{-12}$ cm | 0.68[b] | 0.68[c] | 0.62[d] |
| Capture resonance integral $RI_\gamma$ (b) | 76.7[b] | 73.78[c] | 75.7186[g] |

[a]From Ref. 11.
[b]From Ref. 12.
[c]Files 1 and 2 of MAT 1327.
[d]File 2 MAT 2725.
[e]From Ref. 15.
[f]S. Pearlstein, via R. Q. Wright (6/19/90).
[g]Code PSYCHE, via R. Q. Wright.

The capture resonance integral can be computed from the thermal capture cross section and the resonance parameters

$$RI_\gamma \equiv \int_{0.5\,\text{eV}} \sigma_{n\gamma}(E)\,\frac{dE}{E}$$

$$= 0.45\,\sigma_{n\gamma}(0.0253 \text{ eV}) + \frac{\pi}{2} * 2.608 \times 10^6 \left(\frac{A+1}{A}\right)^2 \sum_\lambda g_\lambda \frac{\Gamma_{\gamma\lambda}\Gamma_{n\lambda}}{E_\lambda^2 \Gamma_\lambda}$$

Most of the resonance contribution comes from the resonance at 132 eV. (The next level is at 1.38 keV). Table 2 shows the values of $\sigma_{n\gamma}$ (0.0253) and of the resonance parameters of the level at 132 eV, and the resulting values of $RI_\gamma$.

Table 2. $^{59}$Co $RI_\gamma$ computed from parameters of the resonance at 132 eV

| | ENDF/B-IV | ENDF/B-V | ENDF/B-VI |
|---|---|---|---|
| $\sigma_{n\gamma}$ (b) | 37.22 | 37.233 | 37.190 |
| $E_o$ (eV)[a] | 132 | 132 | 132 |
| $\Gamma_n$ (eV) | 5.12 | 5.12 | 5.15 |
| $\Gamma_\gamma$ (eV) | 0.48 | 0.46 | 0.47 |
| 0.45 $\sigma_{n\gamma}$ (b) | 16.749 | 16.75485 | 16.7355 |
| $RI_\gamma$ (b) | 76.7728 | 74.4839 | 75.6397 |

[a]Note that $g_J = (2J+1)/2(2I+1)$ is equal to $g_{I+1/2} = (I+1)(2I+1) = 9/16$ for $J = 4$, $A = 59$.

In summary, the $^{59}$Co parameters relevant to dosimetry are very well known. The thermal capture cross section is known to better than 0.2% and the capture resonance integral to better than 3%. These two parameters are considered as standards and their values have been confirmed by numerous measurements. The region above the 132 eV resonance is in much poorer shape, and we now turn our attention to a resonance parameter analysis of this region.

## 2.3 RESOLVED RESONANCE PARAMETERS

Some parameters of the resolved resonance range of the three last ENDF/B evaluations of $^{59}$Co are compared in Table 3.

According to Ref. 11, the resolved resonance region was reduced from 100 keV in ENDF/B-IV to 85 keV in ENDF/B-V "because of the important contribution of *p*-wave capture as measured by Spencer et al.[16,17]," presumably because that contribution could not be properly represented with resonance parameters.

In ENDF/B-V the weak resonances observed by Spencer et al.[16,17] were assumed to be *p*-wave resonances; a capture width of 0.22 eV was assumed for these resonances and the neutron widths were derived from the values of $g\Gamma_n\Gamma_\gamma/\Gamma$ reported by Spencer et al.

In ENDF/B-VI the resonance region was again extended to 100 keV (as in ENDF/B-IV). The resonance parameters were taken (somewhat literally) from the compilation of Ref. 6. For many of the small resonances observed in the capture measurements of Spencer et al.[16,17] only the capture area $g\Gamma_n\Gamma_\gamma/\Gamma$ was obtained and listed in Ref. 6. Whereas in ENDF/B-V an attempt was made to estimate the parameters of these small resonances using an average value of $\Gamma_\gamma$, in ENDF/B-VI these resonances were simply left out of the evaluation, therefore ENDF/B-VI describes the range up to 100 keV with 117 $s$-wave and one $p$-wave levels whereas ENDF/B-V describes the shorter range up to 85 keV with 73 $s$-wave and 107 $p$-wave levels (see Table 3).

The histograms of the number of levels vs energy for $s$-wave levels of $J = 3$ and $J = 4$ for ENDF/B-VI are shown in Fig. 2. Over a small energy interval, such that the expected average level density is constant, if only a few levels are missed or misassigned such histograms should be nearly linear.[18]

Table 3. Comparison of ENDF/B evaluations of resonance region[a]

| | ENDF/B-IV | ENDF/B-V | ENDF/B-VI |
|---|---|---|---|
| Resolved resonance region (eV) | $10^{-5}$ to $10^{5}$ | $10^{-5}$ to 85000. | $10^{-5}$ to $10^{5}$ |
| Number of $s$-wave levels | 92 | 73 | 117 |
| Number of $p$-wave levels | 0 | 107 | 1 |
| $\ell = 0$ | | | |
| $< \Gamma_n^0 >$ (eV) | | 0.7764 | 0.8226 |
| $< \Gamma_\gamma >$ (eV) | | 0.4615 | 0.4445 |
| Average level spacing (eV), D | | 1177.6 | 1033.6 |
| Strength function, $< \Gamma_n^0 >/D$ | | $3.240 \times 10^{-4}$ | $3.926 \times 10^{-4}$ |
| $\ell = 1$ | | | |
| $< \Gamma_n^1 >$ (eV) | | 0.1489 | 2.806 |
| $< \Gamma_\gamma >$ (eV) | | 0.2618 | 0.37 |
| Average level spacing (eV) | | 753.3 | |
| Strength function | | $0.3437 \times 10^{-4}$ | |
| Bound levels (eV) | $J = 3$, −521 | $J = 3$, −367 | $J = 3$, −500<br>$J = 4$, −475 |

[a] All three evaluations use the multilevel Breit-Wigner Formalism and negligible File 3 contributions.

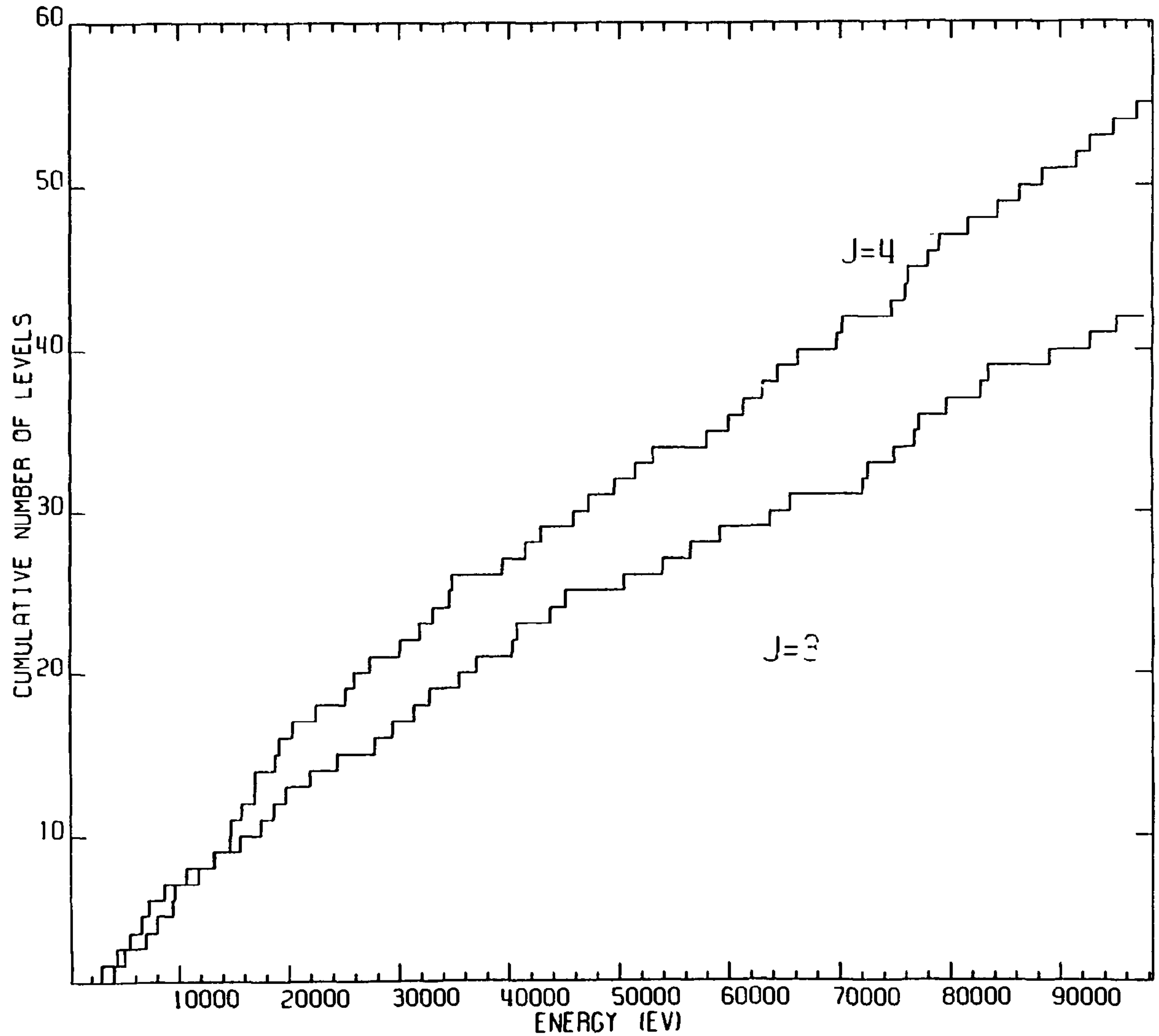


**Fig. 2. Cumulative number of *s*-wave levels versus energy, for $J = 3$ and for $J = 4$, from ENDF/B-VI.** If only a few levels are missed or misassigned, such histograms should be nearly "linear." For comparison, see Fig. 13, the corresponding histograms for the analysis reported here.

# 3. THE HIGH RESOLUTION TRANSMISSION MEASUREMENTS

Between 1 and 100 keV, the resonance parameters of ENDF/B-V and -VI and of the compilation in Ref. 11 are essentially based on the 1964 transmission data of Columbia University[2,19] and of Saclay.[3] The capture areas reported by Spencer et al.[16,17] were also used; however, the measured capture areas often have large multiple scattering contributions that cannot be properly estimated without a knowledge of the resonance parameters.

In 1986 a series of high-resolution transmission measurements was performed at ORELA through several thicknesses of $^{59}$Co and under various resolution conditions, partly at the request of A. B. Smith for the ENDF/B-VI evaluation.[4,5] Only one of these measurements was processed at the time: Run 10454TS. This run was done with a very thick sample, 0.3 atoms/barn, at a flight path length of 200 m and with the collimation selecting the unmoderated photoneutrons produced in the Ta target. This run is mostly useful at high energy and indeed was used only to define the total cross section above 100 keV in ENDF/B-VI.

All six runs have now been reduced to transmission versus energy. The experimental parameters of the six runs are summarized in Table 4. Two of these runs with sample thicknesses of 0.3 and 0.075 atoms/b used a flight path length of 200 m with the collimation looking at the unmoderated neutrons from the Ta target; the remaining four runs used a flight path length of 80 m looking at the water moderator, and samples varying in thickness from 0.005 to 0.3 atoms/barn. The samples were kept at the physical temperature of 293 K; for a Debye temperature of $^{59}$Co of 445 K, the effective temperature is computed as 330 K. All these runs have considerably better time resolution than the previously published transmission measurements.[3,19]

Table 4. Experimental Parameters of the Transmission Measurements

| Run No. | Flight path length (m) | Sample thickness (atoms/b) | Detector | Collimation | Linac burst width |
|---|---|---|---|---|---|
| 10454TS | 201.575 | 0.3008 | NE-110 | Unmoderated Ta target | 5-6 ns |
| 10460TS | 201.575 | 0.0750 | | Unmoderated Ta target | 5-6 ns |
| 10432T1 | 80.394 | 0.3008 | 1/2 in. $^{6}$Li glass | Water moderator | 12 ns |
| 10432T2 | 80.394 | 0.0750 | | Water moderator | |
| 10428T1 | 80.394 | 0.0210 | | Water moderator | |
| 10428T2 | 80.394 | 0.0050 | | Water moderator | |

In order to evaluate the ENDF/B-VI resonance parameters, the transmissions for the sample thicknesses used in the measurements were computed from these resonance parameters with the code SAMMY, using the "no fit" option of the code. The comparisons of these computed transmission ratios with the measurements showed rather large discrepancies, indicating that the ENDF/B-VI resonance parameters were inadequate. Examples of the comparison are shown in Figs. 3 and 4.

Figure 3 shows a comparison between the computed transmission ratio (solid line) and the measurement of run 10432T1 (see Table 4) in the neutron energy range 2 to 3 keV. The small resonance at 2.28 keV is not in ENDF/B-VI, probably because it is too weak to have been detected in previous transmission measurements, which had poorer resolution. The resonance at 2.85 keV has clearly wrong parameters, perhaps the result of a typographical error. As stated in the previous section, the resonance parameters of ENDF/B-VI were taken somewhat literally from Ref. 6, and indeed the parameters of the resonance at 2.86 keV are as given in that reference (neutron width of 3.497 eV, capture width of 0.11 eV). However, in ENDF/B-V as well as in previous evaluations[11–13] or in previous editions of the neutron cross-section compilation BNL-325,[20] the neutron width of that resonance is always given as approximately 0.1 eV. The source of the error in Ref. 6 and in ENDF/B-VI was not traced further.

Figure 4 shows a comparison between the transmission ratio computed with ENDF/B-VI and the measurement of run 10454TS over the neutron energy range from 60 to 70 keV. The figure illustrates the large discrepancies typical above 60 keV. The origin of these discrepancies could not be completely explained; in that energy region the resonance parameters published in Refs. 2 and 3 are inconsistent and ENDF/B-VI is not consistent with either of these references.

Because of the discrepancies just discussed between the experimental measurements and the calculations based on ENDF/B-VI, it was decided to analyze the six ORELA transmission measurements, using the Reich-Moore approximation and the resonance analysis code SAMMY. The assumptions of this analysis and its results are the subject of the next section.

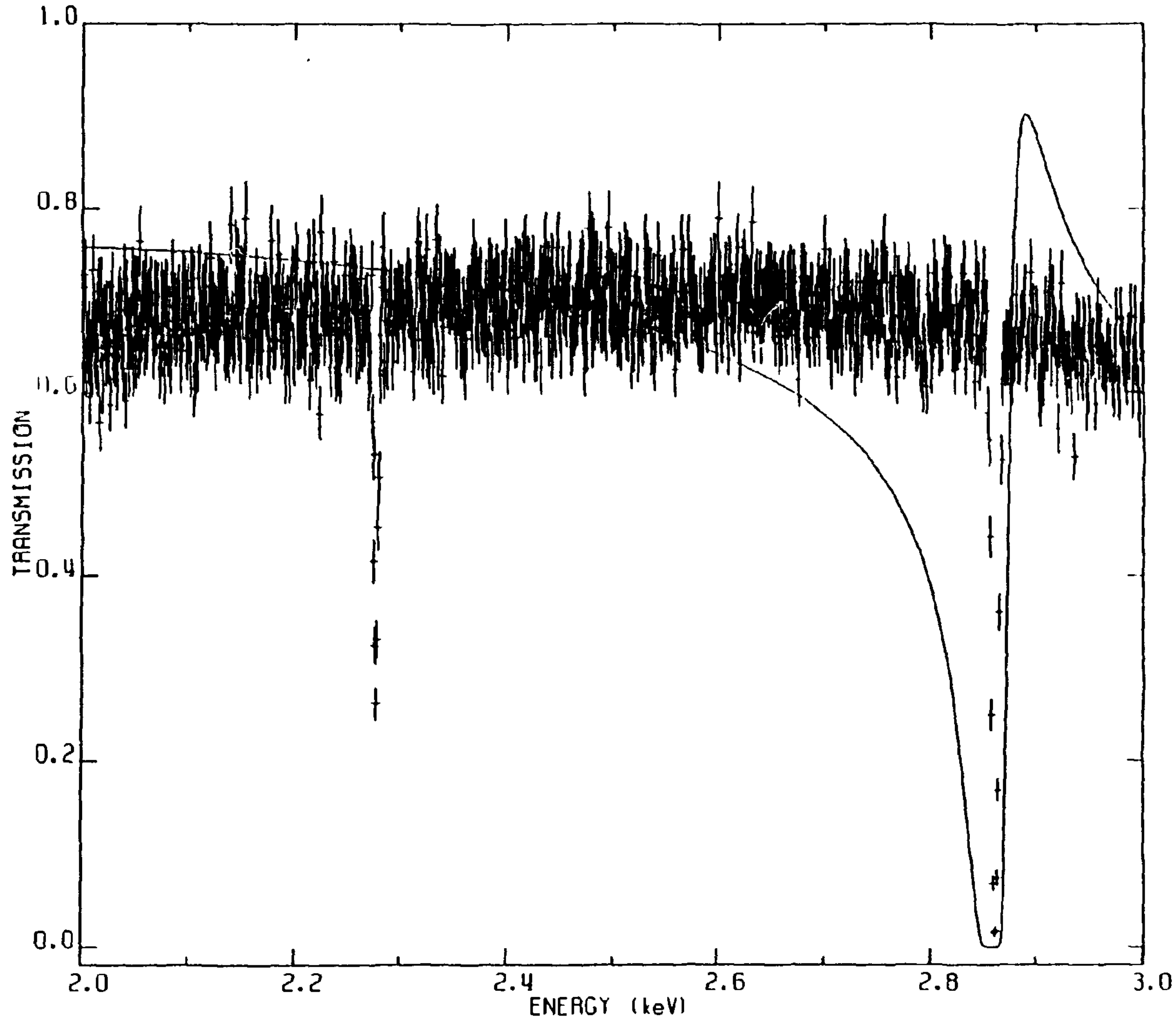


**Fig. 3. Measured and computed transmission through 0.3 atom/barn of $^{59}$Co between 2 and 3 keV.** The crosses represent the ORELA measurement (Run 10432T1). The solid line is computed with ENDF/B-VI. Figure 5 shows the same experimental data with the computation based on the resonance parameters obtained in the analysis reported here.

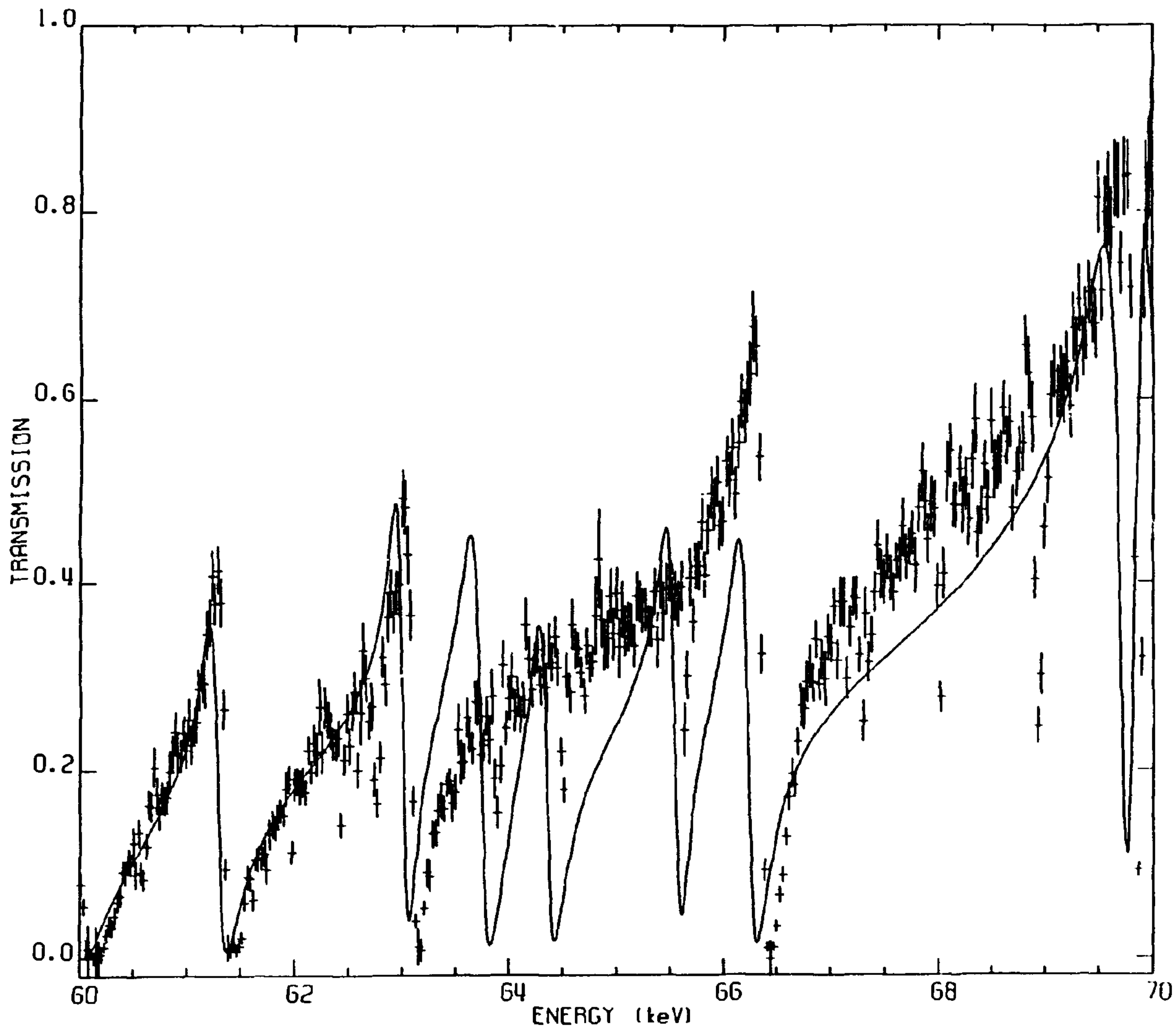


**Fig. 4. Measured and computed transmission through 0.3 atom/barn of $^{59}Co$ between 60 and 70 keV.** The crosses represent the ORELA measurement (Run 10454TS). The solid line is computed with ENDF/B-VI. Figure 6 shows the same experimental data with the computation based on the resonance parameters obtained in the analysis reported here.

# 4. RESONANCE ANALYSIS OF $^{59}$Co TRANSMISSION DATA

The spin $J$ of most resonances and the orbital angular momentum $\ell$ for the smaller resonances cannot be determined from the data and were assigned somewhat arbitrarily as follows: (1) All the observed resonances were assumed to be due either to $s$-wave or to $p$-wave neutrons, a reasonable assumption. (2) Those resonances for which the neutron width divided by the square root of the neutron energy was larger than $0.1\sqrt{(\mathrm{eV})}$ were taken to be $s$-wave resonances; in many cases, the characteristic $s$-wave interference pattern between resonance and potential scattering can be observed. (3) Most $s$-wave levels were assigned a spin consistent with the assignment of Ref. 6, and therefore with ENDF/B-VI. (4) Some smaller resonances were also taken to be $s$-wave; these were selected so as to satisfy the long-range level spacings correlation implied by the Dyson-Metha $\Delta_3$ statistics.[18] (5) Since $^{59}$Co has a spin of 3.5, the interaction with $p$-wave neutrons can lead to the resonance spin $J = 2, 3, 4,$ or 5; however, for simplicity, all $p$-wave resonances were arbitrarily assigned spins of 3 or 4, as was also done in ENDF/B-V and ENDF/B-VI. All $\ell = 1$ potential scattering was included, however.

The neutron widths of ten large resonances above 100 keV were adjusted to account for the contribution below 100 keV of all the levels above that energy. Similarly, the parameters of four fictitious-bound levels were adjusted to account for the contribution of the bound levels and to reproduce the evaluated cross sections in the thermal region. The resonance parameters of the first resonance, at 132 eV, were not searched, because these parameters are well known (see Section 2), and because the ORELA transmission measurements were not optimized for that low-energy range.

The scattering length was determined from the fit to the transmission and a value of 6.67 fm was obtained, in good agreement with the value $6.80 \pm 0.70$ fm given in Ref. 6. The set of resonance parameters obtained is consistent with the ORELA transmission measurements, as illustrated in Figs. 5 and 6 which correspond to Figs. 3 and 4 of the previous section and show that the resonance parameters obtained here are more consistent with the measurements than are the ENDF/B-VI parameters. In Table 5 the value of $\chi^2$ per degree of freedom for the six transmission ratios is given: these values are close to unity, indicating consistency between the resonance parameters and the measurements. For comparison the table also lists corresponding values of $\chi^2$ per degree of freedom obtained with calculations made with ENDF/B-VI and ENDF/B-V. Figures 7 to 12 illustrate graphically the agreement between the calculations with the resonance parameters obtained and the measured transmission ratios. In Table 6 the statistical properties and thermal parameters of the present evaluation are compared to the ENDF/B-VI values and to values given in the compilation of Ref. 6. The Appendix lists the resonance parameters in ENDF/B-VI format.

Table 5. Chi-squared per degree of freedom

| Run No.[a] | Region Analyzed | $\chi^2$/DF This evaluation | $\chi^2$/DF ENDF/B-VI | $\chi^2$/DF ENDF/B-V |
|---|---|---|---|---|
| 10454TS | 35–100 keV | 1.249 | 18.26 | 32.3 |
| 10460TS | 45–100 keV | 1.122 | 2.78 | 5.62 |
| 10432T1 | 30 eV - 100 keV | 0.885 | 11.06 | 7.46 |
| 10432T2 | 30 eV - 100 keV | 0.944 | 2.93 | 2.84 |
| 10428T1 | 30 eV - 100 keV | 1.002 | 2.53 | 2.22 |
| 10428T2 | 30 eV - 100 keV | 1.016 | 1.15 | 1.10 |

[a]See Table 4.

Table 6. Comparison of the present evaluation with ENDF/B-VI and with the compilation of ref. 6

| | Present evaluation | ENDF/B-VI | Reference 6 |
|---|---|---|---|
| Number of $s$-wave levels | 80 | 117 | |
| $<\Gamma_n^0>$ (eV) | 0.941 | 0.8226 | |
| $<\Gamma_\gamma>$ (eV) for $\ell = 0$ | 0.4488 | 0.4445 | $0.56 \pm 0.10$ |
| Average $s$-wave level spacing (eV) | 1299 | 1034 | $1100 \pm 100$ |
| $s$-wave strength function | $3.83 \times 10^{-4}$ | $3.93 \times 10^{-4}$ | $(3.9 \pm 0.5) \times 10^{-4}$ |
| Number of $p$-wave levels | 65 | 1 | |
| $<\Gamma_n^1>$ (eV) | 0.237 | 2.806 | |
| $<\Gamma_\gamma>$ (eV) for $\ell = 1$ | 0.36 | 0.37 | |
| Average $p$-wave level spacing (eV) | 1562.5 | | |
| $p$-wave strength function | $0.25 \times 10^{-4}$ | | |
| Cross sections at 0.0253 eV | | | |
| $\sigma_t$ (b) | 43.150 | 43.143 | $43.18 \pm 0.006$ |
| $\sigma_{n\gamma}$ (b) | 37.170 | 37.190 | $37.18 \pm 0.06$ |
| $\sigma_s$ (b) | 5.980 | 5.953 | $6.00 \pm 0.06$ |
| Westcott $g_\gamma$ factor | 1.0000 | 1.0019 | 1.0 |
| Channel radius ($10^{-12}$ cm) | 0.6672 | 0.620 | $0.68 \pm 0.07$ |
| Capture resonance integral (b) | 75.74 | 75.7186 | $74 \pm 2$ |

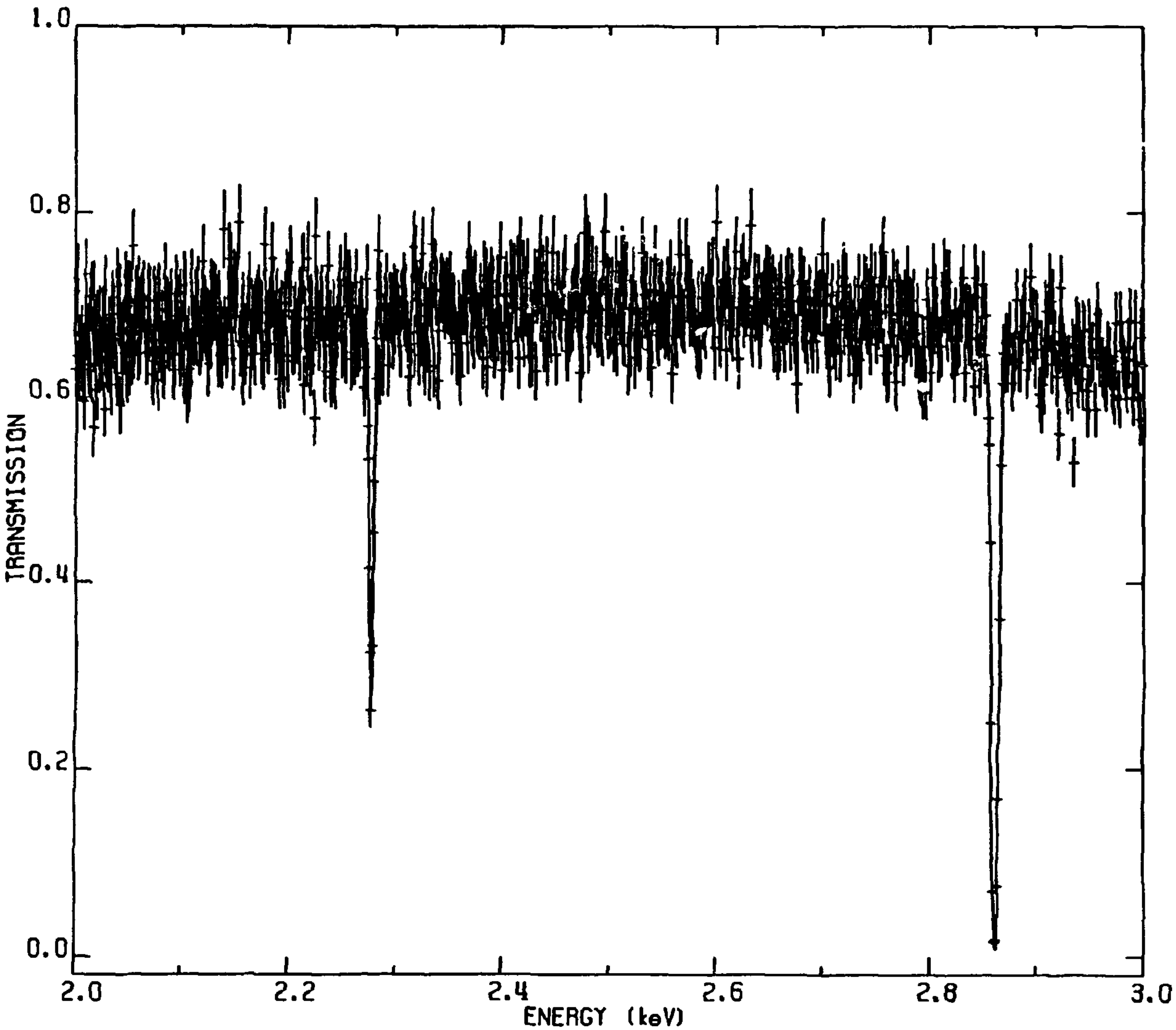


**Fig. 5. Measured and computed transmission through 0.3 atom/barn of $^{59}Co$ between 2 and 3 keV.** The crosses represent the ORELA measurement (Run 10432T1). The solid line is computed with the resonance parameters obtained in the analysis reported here. Compare with Fig. 3 of the previous section.

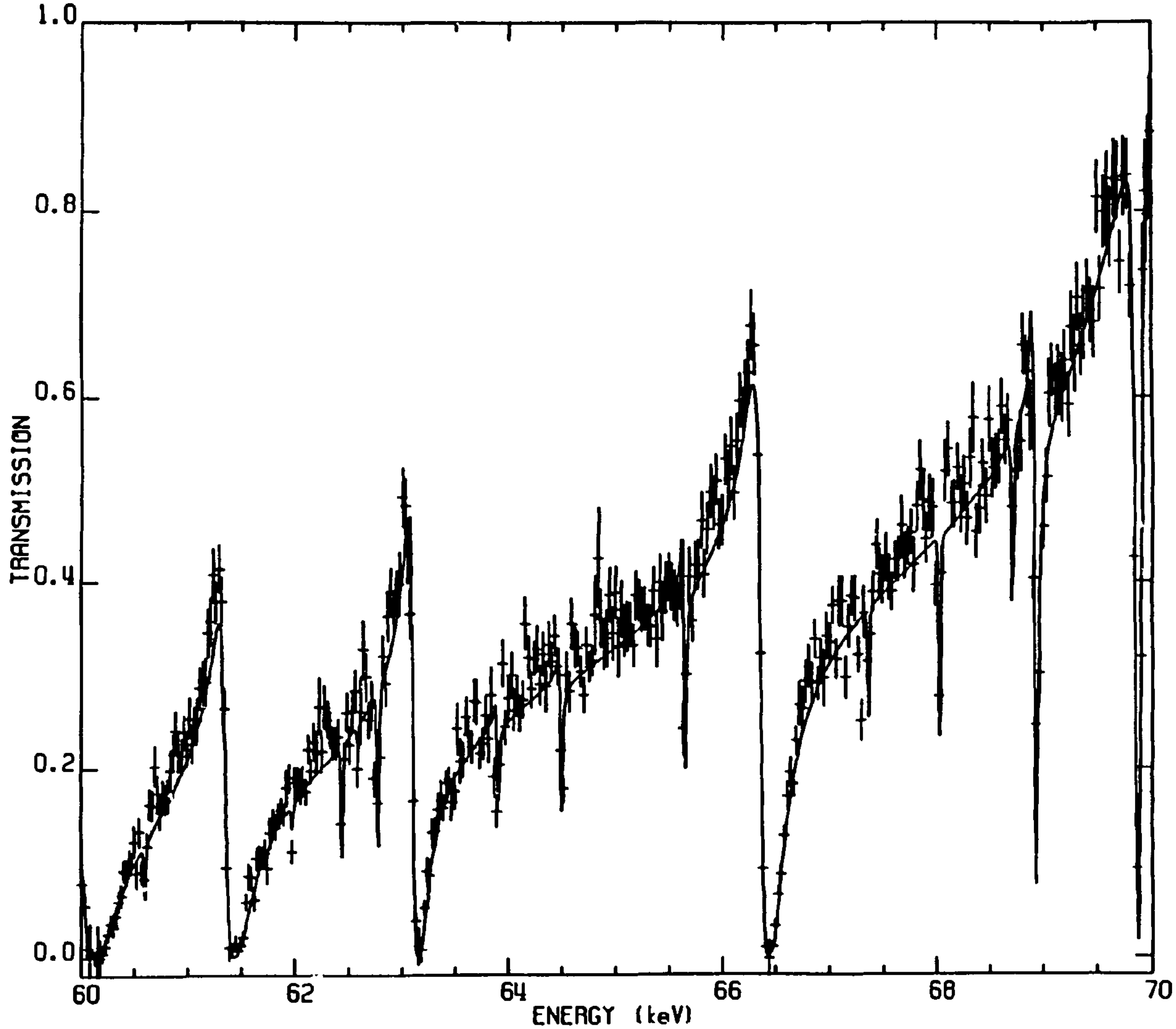


**Fig. 6. Measured and computed transmission through 0.3 atom/barn of $^{59}Co$ between 60 and 70 keV.** The crosses represent the ORELA measurement (Run 10454TS). The solid line is computed with the resonance parameters obtained in the analysis reported here. Compare with Fig. 4 of the previous section.

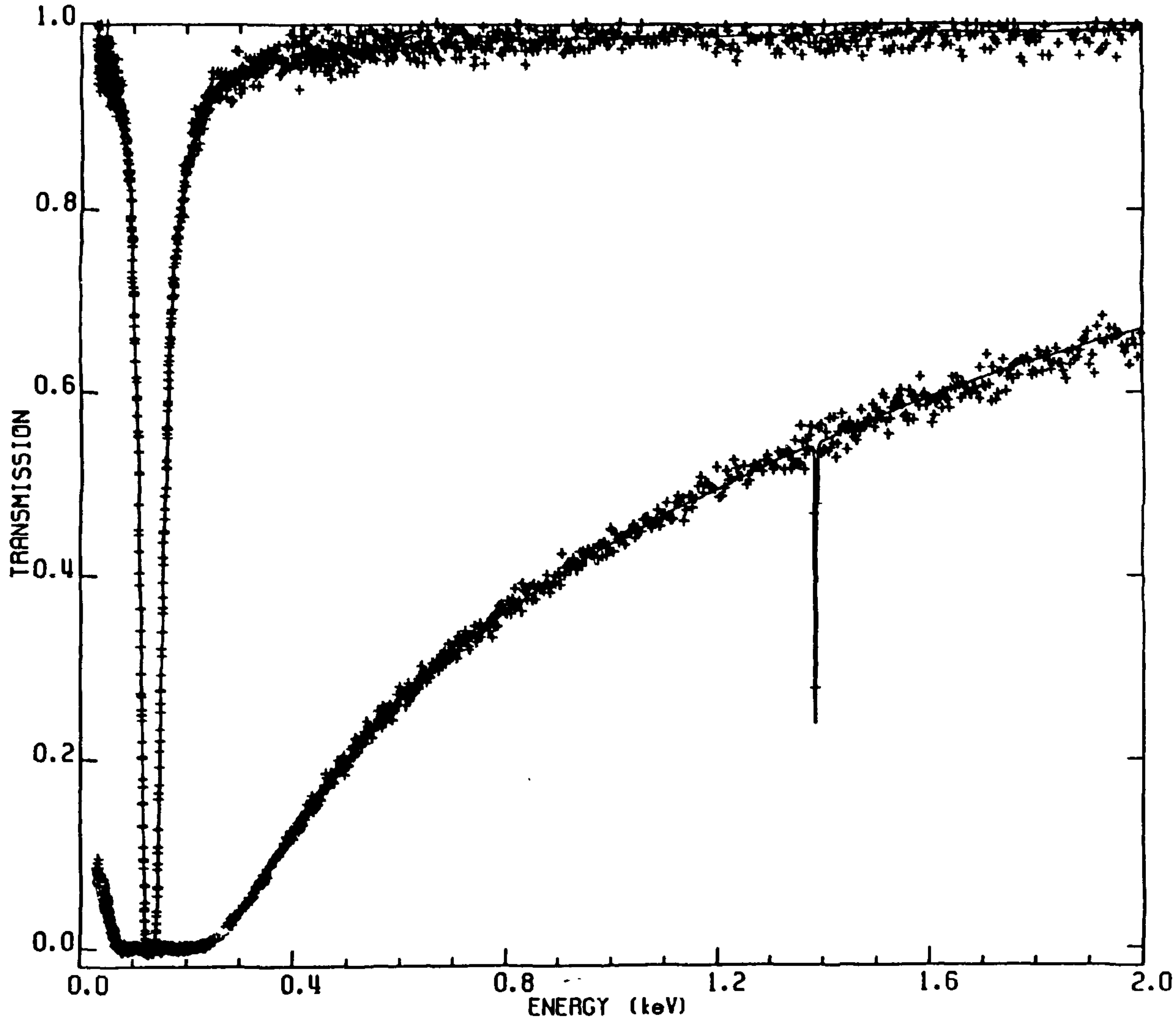


**Fig. 7. Measured and computed transmission through 0.005 atom/barn (upper curve) and 0.3 atom/barn (lower curve) of $^{59}$Co between 30 eV and 2 keV.** The crosses represent the ORELA measurements (Runs 10428T2 and 10432T1). The solid lines are computed with the resonance parameters obtained in the analysis reported here.

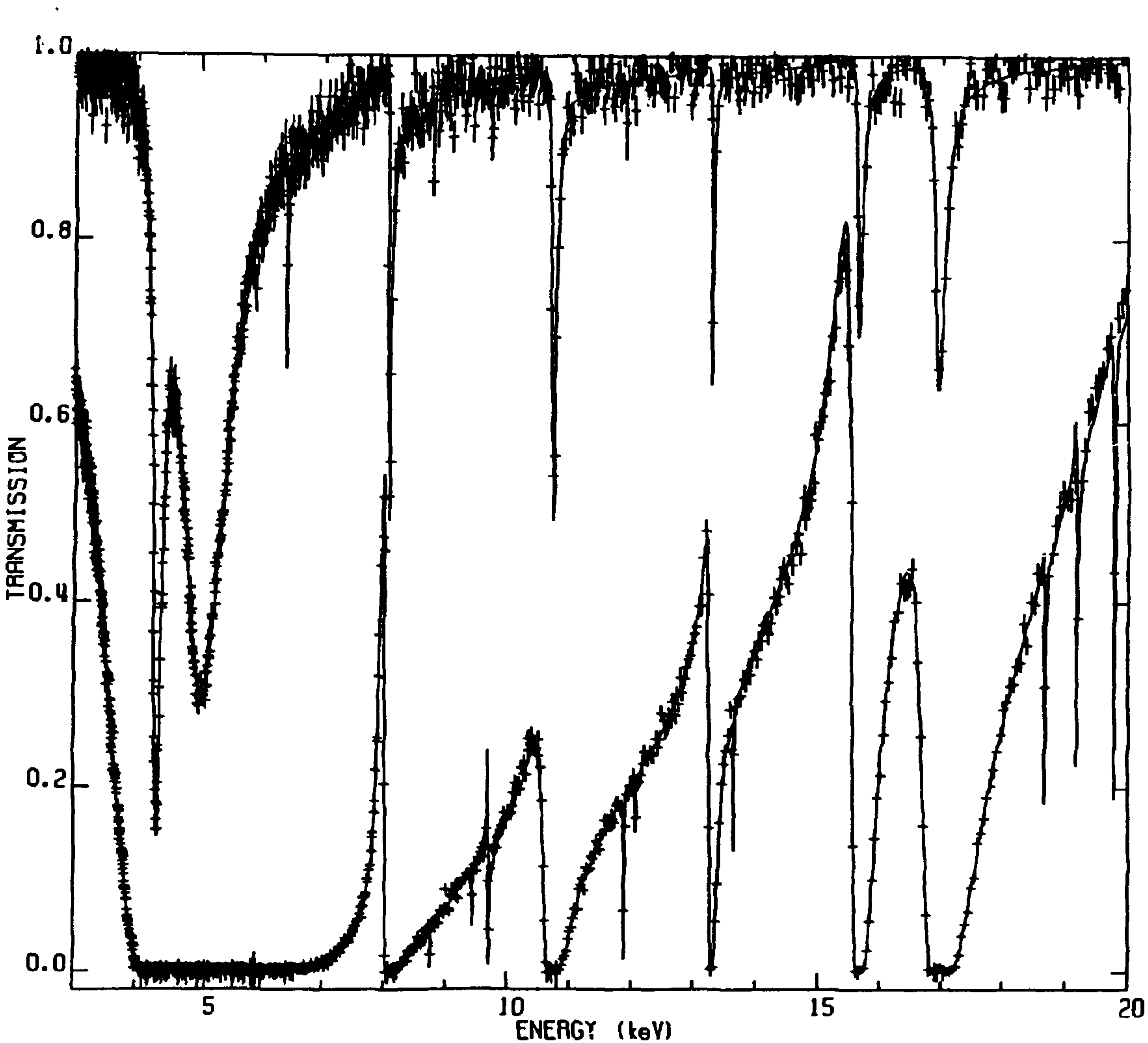


**Fig. 8. Measured and computed transmission through 0.005 atom/barn (upper curve) and 0.3 atom/barn (lower curve) of $^{59}$Co between 3 and 20 keV.** The crosses represent the ORELA measurements (Runs *10428T2* and *10432T1*). The solid *lines are computed with the resonance parameters obtained in the analysis reported here.*

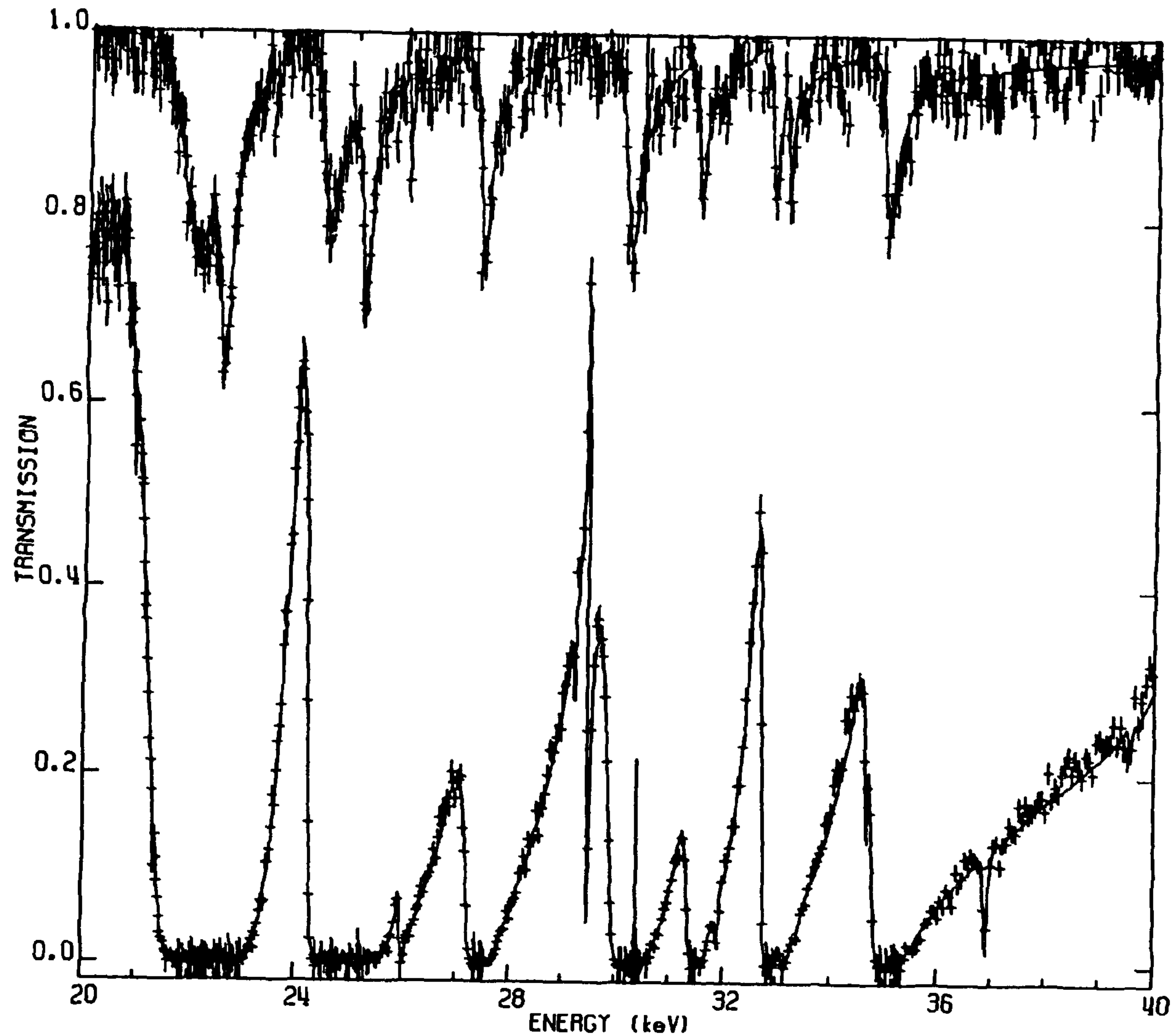


**Fig. 9. Measured and computed transmission through 0.005 atom/barn (upper curve) and 0.3 atom/barn (lower curve) of $^{59}$*Co* between 20 and 40 keV.** The crosses represent the ORELA measurements (Run 10428T2 and 10432T1). The solid lines are computed with the resonance parameters obtained in the analysis reported here.

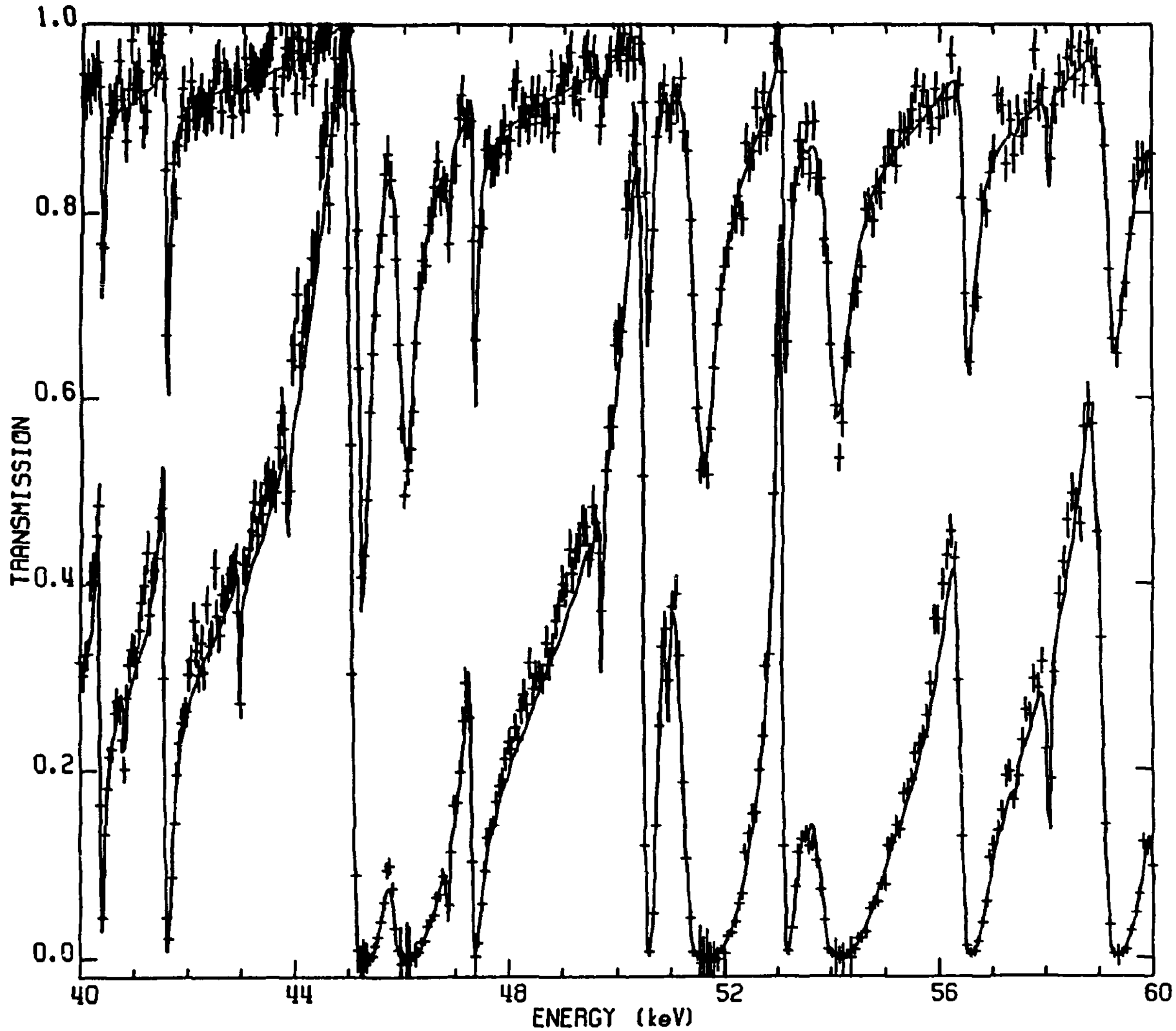


***Fig. 10.*** ***Measured*** **and computed transmission through 0.021 atom/barn (upper curve) and 0.3 atom/barn (lower curve) of $^{59}$Co between 40 and 60 keV.** The crosses represent the ORELA measurements (Runs 10428T1 and 10432T1). The solid lines are computed with the resonance parameters obtained in the analysis reported here.

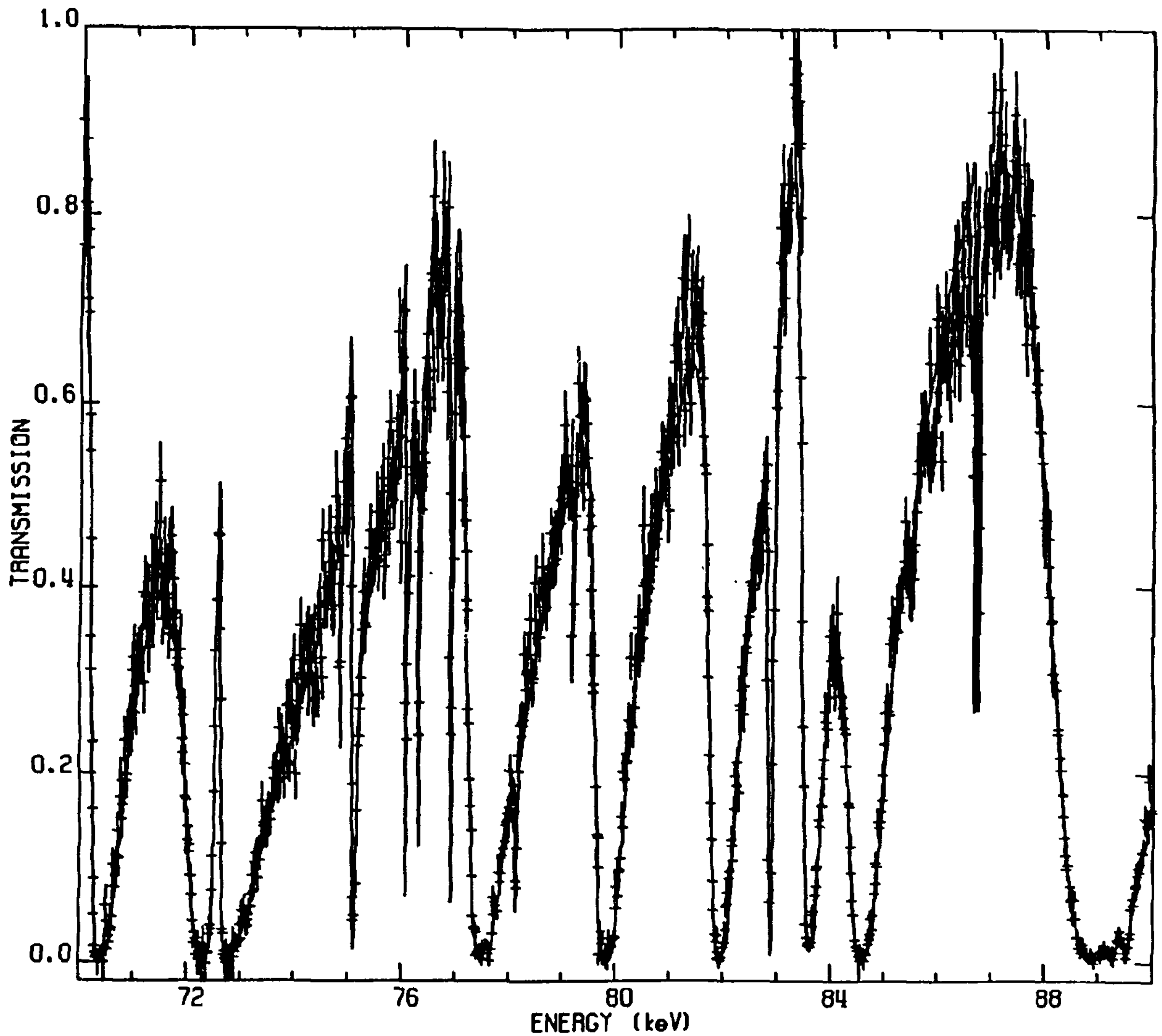


**Fig. 11.** **Measured and computed transmission through 0.3 atom/barn of $^{59}$Co between 70 and 90 keV.** The crosses represent the 200-m flight-path ORELA measurement (Run 10454TS). The solid line is computed with the resonance parameters obtained in the analysis reported here.

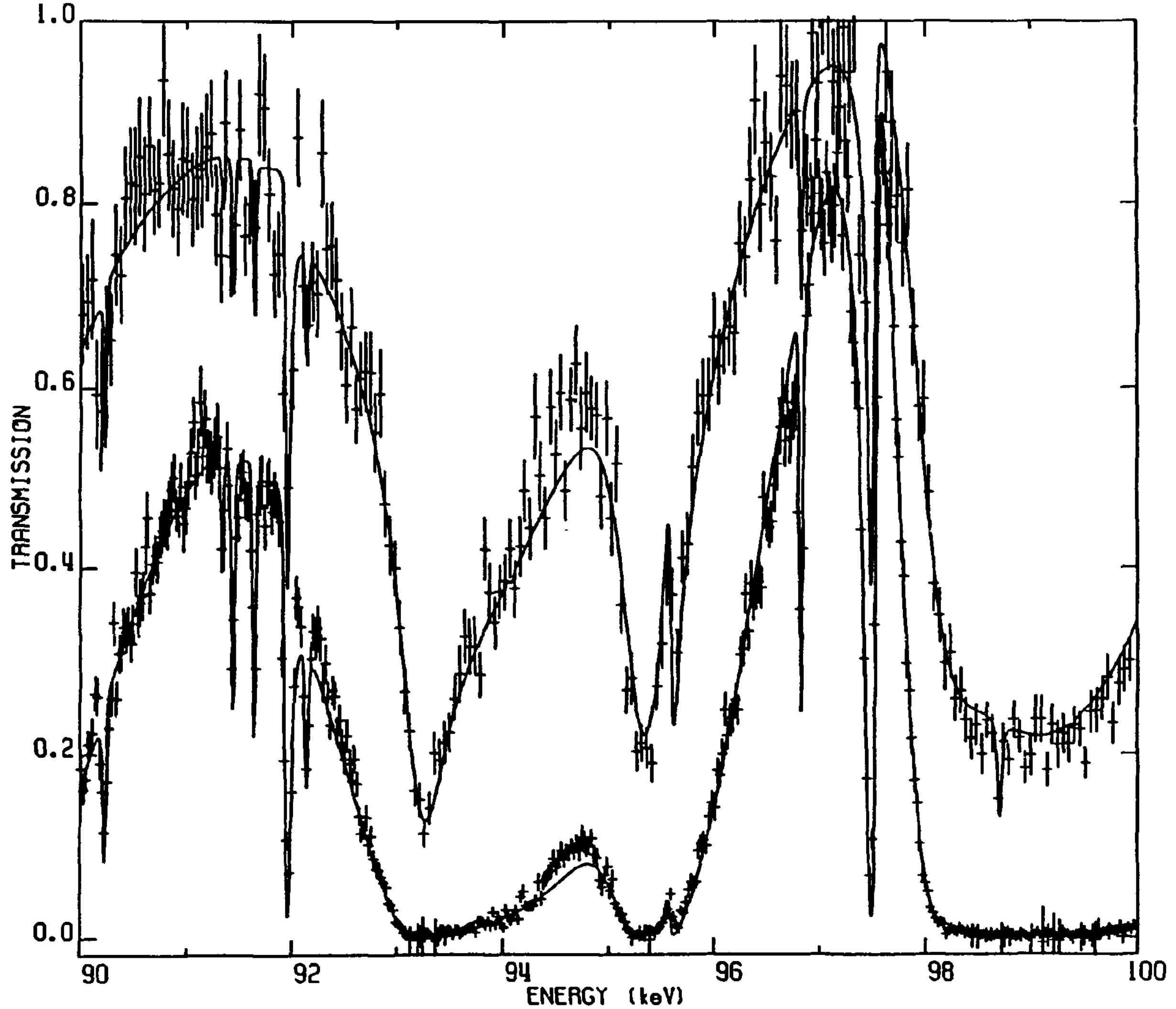


**Fig. 12. Measured and computed transmission through 0.07 atom/barn (upper curve) and 0.3 atom/barn (lower curve) of $^{59}$Co between 90 and 100 keV.** *The crosses represent the 200-m flight-path ORELA measurements* (Runs 10460TS and 10454TS). The solid lines are computed with the resonance parameters obtained in the analysis reported here.

The histograms of the number of $s$-wave resonances vs energy for the two spin states are shown in Fig. 13. There are 35 $J = 3$ and 45 $J = 4$ levels in the 0–100 keV interval. This ratio satisfies the $2J + 1$ density law. The linear behavior of the histograms suggests that most levels have been correctly assigned. The Dyson and Metha $\Delta_3$ statistics[18] give a value $\Delta_3 = 0.369$ for an expected value $< \Delta_3 >= 0.353 \pm 0.109$ for the $J = 3$ histogram, and a value of $\Delta_3 = 0.357$ for an expected value $< \Delta_3 >= 0.379 \pm 0.109$ for the $J = 4$ histogram.

The transmission measurements are not very sensitive to the value of the capture widths; therefore, the capture widths obtained in this analysis have large uncertainties. An attempt was made to adjust the capture widths to give the capture areas reported by Spencer et al.;[16,17] however, the attempt was not successful because the correspondence between the resonances observed in transmission and those reported with the capture measurements are not unambiguous; many multiplets are not resolved in the capture measurements. The problem is complicated by the large (20 to 40%) multiple scattering corrections that were made by Spencer et al. on the capture areas which had to assume prior values of the resonance parameters. A direct analysis of capture data with the code SAMMY cannot be done until SAMMY is modified to handle multiple scattering effects, an effort which is currently underway.

The capture cross section averaged over 10-keV intervals from 1 to 100 keV is given in Table 7 to facilitate future evaluation work. The average capture cross section at 30 keV (averaged from 23–37 keV) is 36.9 mb, compared with $88 \pm 30$ mb of Gibbons et al.[21] and $48 \pm 5$ mb from Stroud et al.[22] The average capture from 85–100 keV is 15.3 mb, compared with $18.0 \pm 0.6$ mb given by Spencer and Macklin[17] over that energy interval.

Table 7. Capture cross section averaged over 10-keV intervals

| Energy Interval (keV) | Cross Section (mb) |
|---|---|
| 1 - 10 | 88.8 |
| 10 - 20 | 32.1 |
| 20 - 30 | 35.9 |
| 30 - 40 | 27.3 |
| 40 - 50 | 16.7 |
| 50 - 60 | 19.9 |
| 60 - 70 | 19.6 |
| 70 - 80 | 18.5 |
| 80 - 90 | 14.7 |
| 90 - 100 | 15.8 |

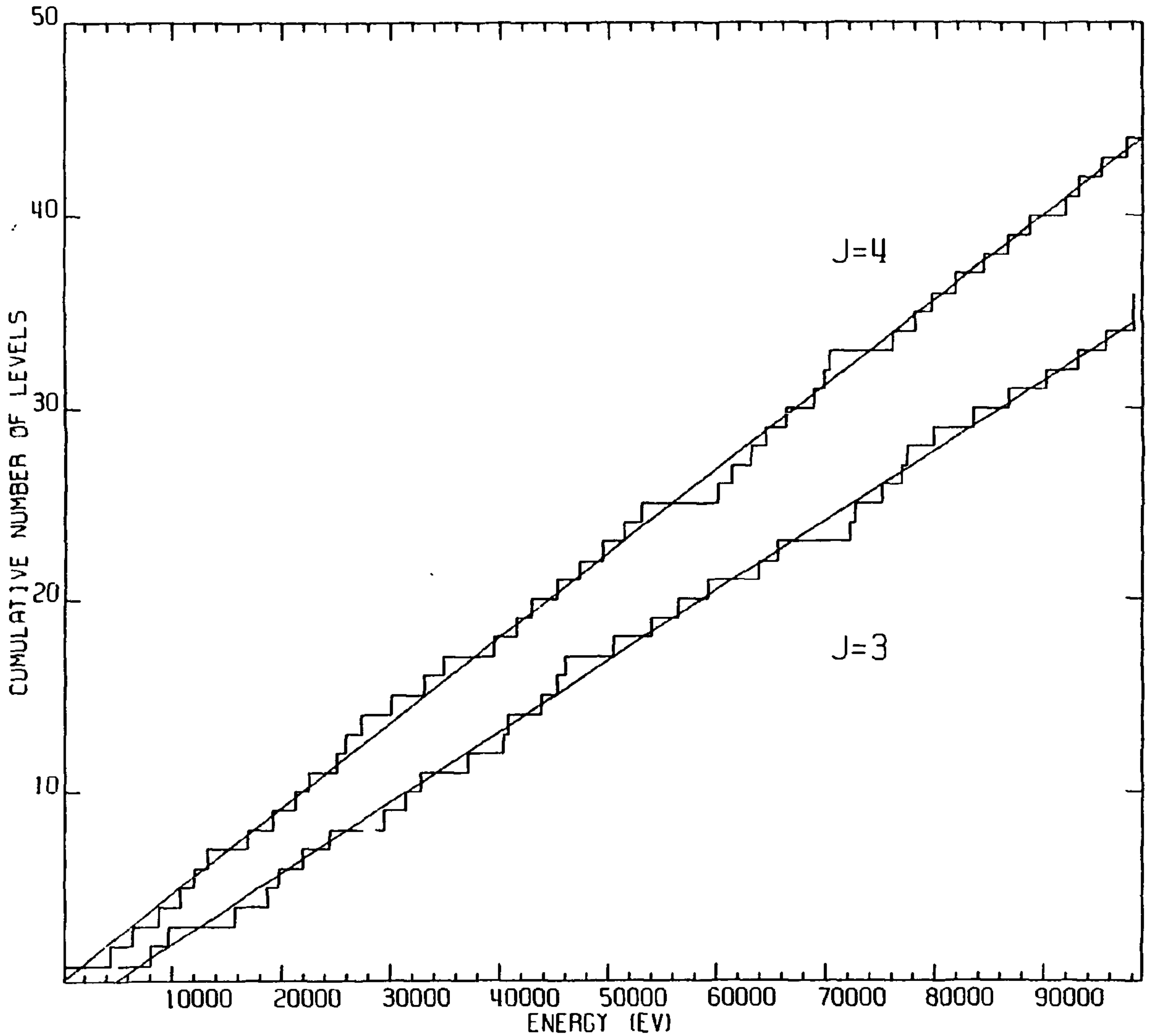


**Fig. 13. Cumulative number of *s*-wave levels versus energy for $J = 3$ and for $J = 4$ for the resonance parameters reported here.** The linearity of the histograms is consistent with the Dyson and Metha $\Delta_3$ statistics, suggesting that most levels have been correctly assigned.

# 5. CONCLUSIONS

The investigations described in this report indicate that the representation of the neutron interactions with $^{59}$Co in ENDF/B-VI is unsatisfactory below 100 keV, although the thermal cross sections are correctly reproduced. Indeed ENDF/B-VI fails to describe properly the most recent ORELA transmission ratio measurements. These transmission measurements were analyzed with the resonance analysis code SAMMY and a set of resonance parameters was obtained that is consistent with those transmission measurements. It is believed that these resonance parameters are an improvement over ENDF/B-VI. An additional improvement could be achieved by the analysis of relevant capture measurements. Such an analysis would require a treatment of multiple scattering not yet available in the resonance analysis code SAMMY. The resonance parameters obtained from this work, together with the previously determined parameters of the 132-eV resonance, provide an accurate total cross section from $10^{-5}$ eV to 100 keV. Use of a background in File 3/1 is not necessary. The capture cross section is reproduced at thermal. Further analysis of the capture data from 132 eV to 100 keV is warranted.

## REFERENCES


1. N. E. Holden, BNL-NCS-51388 (1981). Neutron Capture Cross-Section Standards for BNL-325 Fourth Edition.
2. J. B. Garg, *Nucl. Sci. and Eng.* **65**, 76 (1978).
3. J. Morgenstern et al., *Nucl. Phys.* **A102**, 602 (1963).
4. P. Guenther, R. Lawson, J. Meadows, M. Sugimoto, A. Smith, D. Smith, and R. Howerton, ANL/NDM-107 (1988). An evaluated neutronic data file for elemental cobalt.
5. Data available at the NNDC.
6. S. Mughabghab, M. Divadeenam, and N. E. Holden, *Neutron Cross Sections*, Vol.-1, Part-A, Academic Press, New York (1981).
7. N. M. Larson, "Updated Users' Guide for SAMMY: Multilevel R-Matrix Fits to Neutron Data Using Bayes' Equations," ORNL/TM-9179 (August 1984). Also ORNL/TM-9179/R1 (July 1985) and ORNL/TM-9179/R2 (June 1989). See also N. M. Larson and F. G. Perey, "Resonance Parameter Analysis with SAMMY," *Proc. Int. Conf. Nuclear Data for Sci. and Tech., Mito, Japan, May 30–June 3, 1988*, p. 573 (1988).
8. C. Dunford, private communication (1985).
9. D. Cullen, Lawrence Livermore Laboratory Report UCRL-50400, Vol. 17, Part-C (1979).
10. CSISRS, Experimental Data File, National Nuclear Data Center, Brookhaven National Laboratory.
11. S. F. Mughabghab and T. J. Krieger, BNL-NCS-50468 (1975), Neutron Cross Sections of $^{59}$Co below 100 keV.
12. B. A. Magurno, Ed., BNL-NCS-50446 (1975), ENDF/B-IV Dosimetry File.
13. R. Kinsey, Ed., BNL-NCS-17541 (1979), ENDF/B Summary Documentation (Section 27-Co-59 for MAT 1327, $^{59}$Co, by S. F. Mughabghab).
14. CINDA, Computerized Index to Nuclear Data, IAEA Press, Vienna (1987).
15. B. A. Magurno, R. R. Kinsey, F. M. Scheffel, BNL-NCS-31451 (also EPRI-NP-2510; 1982). Guidebook for the ENDF/B-V Nuclear Data.
16. R. R. Spencer and H. Beer, *Nucl. Sci. and Eng.* **60**,390 (1976).
17. R. R. Spencer and R. L. Macklin, *Nucl. Sci. and Eng.* **61**, 346 (1976).
18. F. J. Dyson and M. L. Metha, *J. Math. Phys.* **4**, 107 (1963).
19. J. B. Garg, J. Rainwater, and W. W. Havens, CR-1860 (1964),"High Resolution Neutron Spectroscopy in the keV Region."
20. S. F. Mughabghab and D. I. Garber, *Neutron Cross Sections. Vol. 1. Resonance Parameters.* BNL-325, Brookhaven National Laboratory (July 1973).
21. J. H. Gibbons, R. L. Macklin, P. D. Miller, and J. H. Neiler, *Phys. Rev.* **122**, 182 (1961).

22. B. J. Allen, quoted from thesis of Stroud, CSISRS AN/SAN 30506.007, available from the National Nuclear Data Center, Brookhaven National Laboratory.

# APPENDIX. $^{59}$Co FILE 2 IN ENDF/B-VI FORMAT

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 2.7059E+04 | 5.84269+01 | 0 | 0 | 1 | 0 | 99 | 2151 | 1 |
| 2.7059E+04 | 1.0000E+00 | 0 | 0 | 1 | 0 | 99 | 2151 | 2 |
| 1.0000E-05 | 1.0000E+06 | 1 | 3 | 0 | 1 | 99 | 2151 | 3 |
| 3.5000E+00 | 6.6720E-01 | 1 | 0 | 2 | 3 | 99 | 2151 | 4 |
| 5.84269+01 | 6.6720E-01 | 0 | 0 | 600 | 100 | 99 | 2151 | 5 |
| -5.0000E+03 | 3.0000E+00 | 5.5768E+02 | 9.2151E+00 | 0.0000E+00 | 0.0000E+00 | 99 | 2151 | 6 |
| -5.0000E+03 | 4.0000E+00 | 1.8981E+02 | 1.8682E-01 | 0.0000E+00 | 0.0000E+00 | 99 | 2151 | 7 |
| -4.7670E+02 | 4.0000E+00 | 1.9490E-02 | 2.1489E+00 | 0.0000E+00 | 0.0000E+00 | 99 | 2151 | 8 |
| -2.2588E+02 | 3.0000E+00 | 9.1644E+00 | 5.2141E-02 | 0.0000E+00 | 0.0000E+00 | 99 | 2151 | 9 |
| 1.3200E+02 | 4.0000E+00 | 5.2701E+00 | 4.7000E-01 | 0.0000E+00 | 0.0000E+00 | 99 | 2151 | 10 |
| 4.3231E+03 | 4.0000E+00 | 1.0414E+02 | 4.1737E-01 | 0.0000E+00 | 0.0000E+00 | 99 | 2151 | 11 |
| 5.0160E+03 | 3.0000E+00 | 6.7896E+02 | 1.3322E+00 | 0.0000E+00 | 0.0000E+00 | 99 | 2151 | 12 |
| 6.3897E+03 | 4.0000E+00 | 1.6811E+00 | 3.1556E-01 | 0.0000E+00 | 0.0000E+00 | 99 | 2151 | 13 |
| 8.0619E+03 | 3.0000E+00 | 4.0833E+01 | 4.0780E-01 | 0.0000E+00 | 0.0000E+00 | 99 | 2151 | 14 |
| 8.7566E+03 | 4.0000E+00 | 6.6596E-01 | 1.7524E-01 | 0.0000E+00 | 0.0000E+00 | 99 | 2151 | 15 |
| 9.6962E+03 | 3.0000E+00 | 1.5042E+00 | 8.9112E-01 | 0.0000E+00 | 0.0000E+00 | 99 | 2151 | 16 |
| 1.0713E+04 | 4.0000E+00 | 6.5774E+01 | 3.2805E-01 | 0.0000E+00 | 0.0000E+00 | 99 | 2151 | 17 |
| 1.2065E+04 | 4.0000E+00 | 9.4719E-02 | 2.2617E-01 | 0.0000E+00 | 0.0000E+00 | 99 | 2151 | 18 |
| 1.3292E+04 | 4.0000E+00 | 1.9601E+01 | 5.3148E-01 | 0.0000E+00 | 0.0000E+00 | 99 | 2151 | 19 |
| 1.5655E+04 | 3.0000E+00 | 7.6165E+01 | 9.1691E-01 | 0.0000E+00 | 0.0000E+00 | 99 | 2151 | 20 |
| 1.6943E+04 | 4.0000E+00 | 1.7162E+02 | 4.9355E-01 | 0.0000E+00 | 0.0000E+00 | 99 | 2151 | 21 |
| 1.8671E+04 | 3.0000E+00 | 9.8771E-01 | 3.2506E-01 | 0.0000E+00 | 0.0000E+00 | 99 | 2151 | 22 |
| 1.9175E+04 | 4.0000E+00 | 9.3925E-01 | 2.0109E-01 | 0.0000E+00 | 0.0000E+00 | 99 | 2151 | 23 |
| 1.9779E+04 | 3.0000E+00 | 2.1631E+00 | 2.5115E-01 | 0.0000E+00 | 0.0000E+00 | 99 | 2151 | 24 |
| 2.1327E+04 | 4.0000E+00 | 5.6260E-01 | 2.2009E-01 | 0.0000E+00 | 0.0000E+00 | 99 | 2151 | 25 |
| 2.1956E+04 | 3.0000E+00 | 7.1816E+02 | 5.3120E-01 | 0.0000E+00 | 0.0000E+00 | 99 | 2151 | 26 |
| 2.2538E+04 | 4.0000E+00 | 2.6414E+02 | 2.6041E-01 | 0.0000E+00 | 0.0000E+00 | 99 | 2151 | 27 |
| 2.4478E+04 | 3.0000E+00 | 3.5885E+02 | 6.5075E-01 | 0.0000E+00 | 0.0000E+00 | 99 | 2151 | 28 |
| 2.5174E+04 | 4.0000E+00 | 1.7910E+02 | 5.5116E-01 | 0.0000E+00 | 0.0000E+00 | 99 | 2151 | 29 |
| 2.5969E+04 | 4.0000E+00 | 1.7893E+01 | 5.8043E-01 | 0.0000E+00 | 0.0000E+00 | 99 | 2151 | 30 |
| 2.7377E+04 | 4.0000E+00 | 1.8220E+02 | 5.0939E-01 | 0.0000E+00 | 0.0000E+00 | 99 | 2151 | 31 |
| 2.9454E+04 | 3.0000E+00 | 1.1665E+01 | 4.1705E-01 | 0.0000E+00 | 0.0000E+00 | 99 | 2151 | 32 |
| 3.0139E+04 | 4.0000E+00 | 3.1350E+02 | 5.1844E-01 | 0.0000E+00 | 0.0000E+00 | 99 | 2151 | 33 |
| 3.1442E+04 | 3.0000E+00 | 1.3514E+02 | 5.7198E-01 | 0.0000E+00 | 0.0000E+00 | 99 | 2151 | 34 |
| 3.2811E+04 | 3.0000E+00 | 1.3937E+02 | 6.9913E-01 | 0.0000E+00 | 0.0000E+00 | 99 | 2151 | 35 |
| 3.3101E+04 | 4.0000E+00 | 3.9267E+01 | 3.1017E-01 | 0.0000E+00 | 0.0000E+00 | 99 | 2151 | 36 |
| 3.4957E+04 | 4.0000E+00 | 2.4156E+02 | 3.9997E-01 | 0.0000E+00 | 0.0000E+00 | 99 | 2151 | 37 |
| 3.7194E+04 | 3.0000E+00 | 3.3716E-01 | 2.1999E-01 | 0.0000E+00 | 0.0000E+00 | 99 | 2151 | 38 |
| 3.9547E+04 | 4.0000E+00 | 5.5378E-01 | 1.9999E-01 | 0.0000E+00 | 0.0000E+00 | 99 | 2151 | 39 |
| 4.0376E+04 | 3.0000E+00 | 2.3354E+01 | 3.7323E-01 | 0.0000E+00 | 0.0000E+00 | 99 | 2151 | 40 |
| 4.0806E+04 | 3.0000E+00 | 1.2969E+00 | 4.2004E-01 | 0.0000E+00 | 0.0000E+00 | 99 | 2151 | 41 |
| 4.1595E+04 | 4.0000E+00 | 3.5803E+01 | 3.0046E-01 | 0.0000E+00 | 0.0000E+00 | 99 | 2151 | 42 |
| 4.2970E+04 | 4.0000E+00 | 1.6870E+00 | 1.8006E-01 | 0.0000E+00 | 0.0000E+00 | 99 | 2151 | 43 |
| 4.3843E+04 | 3.0000E+00 | 1.0532E+00 | 3.5999E-01 | 0.0000E+00 | 0.0000E+00 | 99 | 2151 | 44 |
| 4.5227E+04 | 3.0000E+00 | 6.9063E+01 | 1.8400E-01 | 0.0000E+00 | 0.0000E+00 | 99 | 2151 | 45 |
| 4.5258E+04 | 4.0000E+00 | 2.5887E+02 | 1.7855E-01 | 0.0000E+00 | 0.0000E+00 | 99 | 2151 | 46 |
| 4.6017E+04 | 3.0000E+00 | 3.0998E+02 | 4.5557E-01 | 0.0000E+00 | 0.0000E+00 | 99 | 2151 | 47 |
| 4.7339E+04 | 4.0000E+00 | 4.7506E+01 | 3.5165E-01 | 0.0000E+00 | 0.0000E+00 | 99 | 2151 | 48 |
| 4.9487E+04 | 4.0000E+00 | 4.2362E-01 | 1.7000E-01 | 0.0000E+00 | 0.0000E+00 | 99 | 2151 | 49 |
| 5.0556E+04 | 3.0000E+00 | 1.0210E+02 | 3.8509E-01 | 0.0000E+00 | 0.0000E+00 | 99 | 2151 | 50 |
| 5.1532E+04 | 4.0000E+00 | 4.5775E+02 | 7.7920E-01 | 0.0000E+00 | 0.0000E+00 | 99 | 2151 | 51 |
| 5.3130E+04 | 4.0000E+00 | 7.0961E+01 | 5.1069E-01 | 0.0000E+00 | 0.0000E+00 | 99 | 2151 | 52 |
| 5.4068E+04 | 3.0000E+00 | 4.3183E+02 | 9.5969E-01 | 0.0000E+00 | 0.0000E+00 | 99 | 2151 | 53 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 5.6529E+04 | 3.0000E+00 | 1.9455E+02 | 9.9981E-02 | 0.0000E+00 | 0.0000E+00 | 99 | 2151 | 54 |
| 5.9254E+04 | 3.0000E+00 | 3.4764E+02 | 6.7988E-01 | 0.0000E+00 | 0.0000E+00 | 99 | 2151 | 55 |
| 6.0090E+04 | 4.0000E+00 | 9.2431E+01 | 3.1073E-01 | 0.0000E+00 | 0.0000E+00 | 99 | 2151 | 56 |
| 6.1407E+04 | 4.0000E+00 | 7.8584E+01 | 5.4012E-01 | 0.0000E+00 | 0.0000E+00 | 99 | 2151 | 57 |
| 6.3136E+04 | 4.0000E+00 | 4.9768E+01 | 4.3042E-01 | 0.0000E+00 | 0.0000E+00 | 99 | 2151 | 58 |
| 6.3899E+04 | 3.0000E+00 | 1.1943E+00 | 3.2002E-01 | 0.0000E+00 | 0.0000E+00 | 99 | 2151 | 59 |
| 6.4486E+04 | 4.0000E+00 | 1.5615E+00 | 1.8003E-01 | 0.0000E+00 | 0.0000E+00 | 99 | 2151 | 60 |
| 6.5641E+04 | 3.0000E+00 | 2.4336E+00 | 5.5011E-01 | 0.0000E+00 | 0.0000E+00 | 99 | 2151 | 61 |
| 6.6415E+04 | 4.0000E+00 | 7.9333E+01 | 2.5685E-01 | 0.0000E+00 | 0.0000E+00 | 99 | 2151 | 62 |
| 6.8929E+04 | 4.0000E+00 | 6.9616E+00 | 4.9161E-01 | 0.0000E+00 | 0.0000E+00 | 99 | 2151 | 63 |
| 6.9866E+04 | 4.0000E+00 | 1.9628E+01 | 4.7111E-01 | 0.0000E+00 | 0.0000E+00 | 99 | 2151 | 64 |
| 7.0342E+04 | 4.0000E+00 | 2.4314E+02 | 3.9004E-01 | 0.0000E+00 | 0.0000E+00 | 99 | 2151 | 65 |
| 7.2227E+04 | 3.0000E+00 | 4.5622E+02 | 1.3096E+00 | 0.0000E+00 | 0.0000E+00 | 99 | 2151 | 66 |
| 7.2699E+04 | 3.0000E+00 | 2.4358E+02 | 3.2172E-01 | 0.0000E+00 | 0.0000E+00 | 99 | 2151 | 67 |
| 7.5085E+04 | 3.0000E+00 | 3.6901E+01 | 5.5232E-01 | 0.0000E+00 | 0.0000E+00 | 99 | 2151 | 68 |
| 7.6061E+04 | 4.0000E+00 | 8.9928E+00 | 3.9039E-01 | 0.0000E+00 | 0.0000E+00 | 99 | 2151 | 69 |
| 7.6915E+04 | 3.0000E+00 | 1.9801E+01 | 2.2026E-01 | 0.0000E+00 | 0.0000E+00 | 99 | 2151 | 70 |
| 7.7400E+04 | 3.0000E+00 | 4.1876E+02 | 6.6605E-01 | 0.0000E+00 | 0.0000E+00 | 99 | 2151 | 71 |
| 7.8128E+04 | 4.0000E+00 | 5.2248E+00 | 4.1179E-01 | 0.0000E+00 | 0.0000E+00 | 99 | 2151 | 72 |
| 7.9739E+04 | 4.0000E+00 | 2.2644E+02 | 6.4030E-01 | 0.0000E+00 | 0.0000E+00 | 99 | 2151 | 73 |
| 7.9874E+04 | 3.0000E+00 | 7.2898E+01 | 2.1965E-01 | 0.0000E+00 | 0.0000E+00 | 99 | 2151 | 74 |
| 8.1890E+04 | 4.0000E+00 | 2.6678E+02 | 3.7565E-01 | 0.0000E+00 | 0.0000E+00 | 99 | 2151 | 75 |
| 8.3567E+04 | 3.0000E+00 | 2.2735E+02 | 5.7917E-01 | 0.0000E+00 | 0.0000E+00 | 99 | 2151 | 76 |
| 8.4508E+04 | 4.0000E+00 | 3.5231E+02 | 7.2039E-01 | 0.0000E+00 | 0.0000E+00 | 99 | 2151 | 77 |
| 8.6692E+04 | 4.0000E+00 | 6.3939E+00 | 4.4538E-01 | 0.0000E+00 | 0.0000E+00 | 99 | 2151 | 78 |
| 8.6765E+04 | 3.0000E+00 | 7.1725E+00 | 4.4562E-01 | 0.0000E+00 | 0.0000E+00 | 99 | 2151 | 79 |
| 8.8726E+04 | 4.0000E+00 | 1.1932E+03 | 4.7247E-01 | 0.0000E+00 | 0.0000E+00 | 99 | 2151 | 80 |
| 9.0228E+04 | 3.0000E+00 | 9.1334E+00 | 4.4469E-01 | 0.0000E+00 | 0.0000E+00 | 99 | 2151 | 81 |
| 9.1946E+04 | 4.0000E+00 | 2.5621E+01 | 4.4534E-01 | 0.0000E+00 | 0.0000E+00 | 99 | 2151 | 82 |
| 9.3131E+04 | 3.0000E+00 | 2.6337E+03 | 4.4726E-01 | 0.0000E+00 | 0.0000E+00 | 99 | 2151 | 83 |
| 9.3172E+04 | 4.0000E+00 | 4.0929E+02 | 3.4881E-01 | 0.0000E+00 | 0.0000E+00 | 99 | 2151 | 84 |
| 9.5247E+04 | 4.0000E+00 | 5.1611E+02 | 3.5762E-01 | 0.0000E+00 | 0.0000E+00 | 99 | 2151 | 85 |
| 9.5599E+04 | 3.0000E+00 | 5.0376E+01 | 6.6657E-01 | 0.0000E+00 | 0.0000E+00 | 99 | 2151 | 86 |
| 9.7471E+04 | 4.0000E+00 | 7.4570E+01 | 6.1119E-01 | 0.0000E+00 | 0.0000E+00 | 99 | 2151 | 87 |
| 9.8109E+04 | 3.0000E+00 | 8.0773E+02 | 3.7789E-01 | 0.0000E+00 | 0.0000E+00 | 99 | 2151 | 88 |
| 9.8837E+04 | 4.0000E+00 | 2.0759E+03 | 4.4453E-01 | 0.0000E+00 | 0.0000E+00 | 99 | 2151 | 89 |
| 1.0028E+05 | 3.0000E+00 | 2.7601E-02 | 4.4451E-01 | 0.0000E+00 | 0.0000E+00 | 99 | 2151 | 90 |
| 1.0164E+05 | 3.0000E+00 | 8.2197E+00 | 4.4451E-01 | 0.0000E+00 | 0.0000E+00 | 99 | 2151 | 91 |
| 1.0533E+05 | 3.0000E+00 | 4.1242E+03 | 4.4451E-01 | 0.0000E+00 | 0.0000E+00 | 99 | 2151 | 92 |
| 1.0663E+05 | 4.0000E+00 | 4.8468E+03 | 4.4451E-01 | 0.0000E+00 | 0.0000E+00 | 99 | 2151 | 93 |
| 1.0883E+05 | 4.0000E+00 | 1.9995E+02 | 4.4451E-01 | 0.0000E+00 | 0.0000E+00 | 99 | 2151 | 94 |
| 1.1005E+05 | 4.0000E+00 | 1.4486E+02 | 4.4451E-01 | 0.0000E+00 | 0.0000E+00 | 99 | 2151 | 95 |
| 1.1095E+05 | 4.0000E+00 | 6.7843E+01 | 4.4451E-01 | 0.0000E+00 | 0.0000E+00 | 99 | 2151 | 96 |
| 1.1140E+05 | 3.0000E+00 | 2.1904E+01 | 4.4451E-01 | 0.0000E+00 | 0.0000E+00 | 99 | 2151 | 97 |
| 1.1212E+05 | 4.0000E+00 | 1.0706E+02 | 4.4451E-01 | 0.0000E+00 | 0.0000E+00 | 99 | 2151 | 98 |
| 1.1321E+05 | 3.0000E+00 | 1.8322E+02 | 4.4451E-01 | 0.0000E+00 | 0.0000E+00 | 99 | 2151 | 99 |
| 1.1411E+05 | 4.0000E+00 | 1.3265E+01 | 4.4451E-01 | 0.0000E+00 | 0.0000E+00 | 99 | 2151 | 100 |
| 1.1487E+05 | 3.0000E+00 | 1.6922E+03 | 4.4451E-01 | 0.0000E+00 | 0.0000E+00 | 99 | 2151 | 101 |
| 1.1644E+05 | 4.0000E+00 | 8.3767E+01 | 4.4451E-01 | 0.0000E+00 | 0.0000E+00 | 99 | 2151 | 102 |
| 1.1726E+05 | 4.0000E+00 | 6.0864E+02 | 4.4451E-01 | 0.0000E+00 | 0.0000E+00 | 99 | 2151 | 103 |
| 1.1863E+05 | 3.0000E+00 | 2.1343E+03 | 4.4451E-01 | 0.0000E+00 | 0.0000E+00 | 99 | 2151 | 104 |
| 1.1940E+05 | 4.0000E+00 | 4.0196E+02 | 4.4451E-01 | 0.0000E+00 | 0.0000E+00 | 99 | 2151 | 105 |
| 5.8493E+01 | 6.6720E-01 | 1 | 0 | 390 | 65 | 99 | 2151 | 106 |
| 1.3858E+03 | 3.0000E+00 | 7.6800E-03 | 4.9312E-01 | 0.0000E+00 | 0.0000E+00 | 99 | 2151 | 107 |
| 2.2772E+03 | 4.0000E+00 | 1.4306E-02 | 4.9002E-01 | 0.0000E+00 | 0.0000E+00 | 99 | 2151 | 108 |
| 2.8615E+03 | 3.0000E+00 | 1.7718E-01 | 4.7215E-01 | 0.0000E+00 | 0.0000E+00 | 99 | 2151 | 109 |
| 3.9882E+03 | 4.0000E+00 | 9.8229E-02 | 2.0944E-01 | 0.0000E+00 | 0.0000E+00 | 99 | 2151 | 110 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 9.4392E+03 | 3.0000E+00 | 2.0684E-01 | 4.2233E-01 | 0.0000E+00 | 0.0000E+00 | 99 | 2151 | 111 |
| 1.1678E+04 | 4.0000E+00 | 2.1304E-02 | 2.1994E-01 | 0.0000E+00 | 0.0000E+00 | 99 | 2151 | 112 |
| 1.1872E+04 | 3.0000E+00 | 2.0034E+00 | 2.9847E-01 | 0.0000E+00 | 0.0000E+00 | 99 | 2151 | 113 |
| 1.3232E+04 | 3.0000E+00 | 1.0734E-01 | 2.4811E-01 | 0.0000E+00 | 0.0000E+00 | 99 | 2151 | 114 |
| 1.3656E+04 | 4.0000E+00 | 3.1706E-01 | 2.1997E-01 | 0.0000E+00 | 0.0000E+00 | 99 | 2151 | 115 |
| 2.0887E+04 | 3.0000E+00 | 2.5446E-01 | 2.1997E-01 | 0.0000E+00 | 0.0000E+00 | 99 | 2151 | 116 |
| 2.7240E+04 | 4.0000E+00 | 1.5801E+00 | 2.2003E-01 | 0.0000E+00 | 0.0000E+00 | 99 | 2151 | 117 |
| 2.9210E+04 | 3.0000E+00 | 5.9473E-01 | 2.1989E-01 | 0.0000E+00 | 0.0000E+00 | 99 | 2151 | 118 |
| 2.9956E+04 | 4.0000E+00 | 2.0172E-02 | 2.2000E-01 | 0.0000E+00 | 0.0000E+00 | 99 | 2151 | 119 |
| 3.1897E+04 | 4.0000E+00 | 6.3895E+00 | 4.0008E-01 | 0.0000E+00 | 0.0000E+00 | 99 | 2151 | 120 |
| 3.3388E+04 | 3.0000E+00 | 6.5747E-01 | 3.0997E-01 | 0.0000E+00 | 0.0000E+00 | 99 | 2151 | 121 |
| 3.4666E+04 | 4.0000E+00 | 2.9890E+00 | 2.5993E-01 | 0.0000E+00 | 0.0000E+00 | 99 | 2151 | 122 |
| 3.5586E+04 | 4.0000E+00 | 5.7795E-01 | 4.6000E-01 | 0.0000E+00 | 0.0000E+00 | 99 | 2151 | 123 |
| 3.6271E+04 | 3.0000E+00 | 1.1601E+00 | 2.2000E-01 | 0.0000E+00 | 0.0000E+00 | 99 | 2151 | 124 |
| 3.6908E+04 | 3.0000E+00 | 1.8267E+01 | 3.7000E-01 | 0.0000E+00 | 0.0000E+00 | 99 | 2151 | 125 |
| 3.9748E+04 | 4.0000E+00 | 1.2189E-01 | 2.2000E-01 | 0.0000E+00 | 0.0000E+00 | 99 | 2151 | 126 |
| 4.6367E+04 | 3.0000E+00 | 1.1455E+00 | 2.4000E-01 | 0.0000E+00 | 0.0000E+00 | 99 | 2151 | 127 |
| 4.6566E+04 | 3.0000E+00 | 1.0160E+00 | 2.4000E-01 | 0.0000E+00 | 0.0000E+00 | 99 | 2151 | 128 |
| 4.6852E+04 | 3.0000E+00 | 1.0787E+01 | 2.2001E-01 | 0.0000E+00 | 0.0000E+00 | 99 | 2151 | 129 |
| 4.7728E+04 | 4.0000E+00 | 1.4128E-01 | 2.8000E-01 | 0.0000E+00 | 0.0000E+00 | 99 | 2151 | 130 |
| 4.7977E+04 | 4.0000E+00 | 6.0650E-02 | 2.2000E-01 | 0.0000E+00 | 0.0000E+00 | 99 | 2151 | 131 |
| 4.9707E+04 | 3.0000E+00 | 4.6530E+00 | 1.7004E-01 | 0.0000E+00 | 0.0000E+00 | 99 | 2151 | 132 |
| 5.0378E+04 | 3.0000E+00 | 5.6686E-01 | 1.7000E-01 | 0.0000E+00 | 0.0000E+00 | 99 | 2151 | 133 |
| 5.0959E+04 | 4.0000E+00 | 2.8529E+00 | 2.2030E-01 | 0.0000E+00 | 0.0000E+00 | 99 | 2151 | 134 |
| 5.1263E+04 | 3.0000E+00 | 2.4242E-01 | 3.8500E-01 | 0.0000E+00 | 0.0000E+00 | 99 | 2151 | 135 |
| 5.3567E+04 | 4.0000E+00 | 9.2353E-01 | 5.0999E-01 | 0.0000E+00 | 0.0000E+00 | 99 | 2151 | 136 |
| 5.6761E+04 | 4.0000E+00 | 2.1786E+00 | 1.0000E-01 | 0.0000E+00 | 0.0000E+00 | 99 | 2151 | 137 |
| 5.7434E+04 | 4.0000E+00 | 9.7101E-01 | 9.9998E-02 | 0.0000E+00 | 0.0000E+00 | 99 | 2151 | 138 |
| 5.8070E+04 | 4.0000E+00 | 1.3303E+01 | 3.6009E-01 | 0.0000E+00 | 0.0000E+00 | 99 | 2151 | 139 |
| 5.8308E+04 | 3.0000E+00 | 2.1454E-01 | 3.6006E-01 | 0.0000E+00 | 0.0000E+00 | 99 | 2151 | 140 |
| 5.8922E+04 | 4.0000E+00 | 1.0018E+00 | 3.5991E-01 | 0.0000E+00 | 0.0000E+00 | 99 | 2151 | 141 |
| 6.0600E+04 | 4.0000E+00 | 1.3537E+00 | 2.9003E-01 | 0.0000E+00 | 0.0000E+00 | 99 | 2151 | 142 |
| 6.1329E+04 | 3.0000E+00 | 4.2346E-01 | 2.9002E-01 | 0.0000E+00 | 0.0000E+00 | 99 | 2151 | 143 |
| 6.1973E+04 | 4.0000E+00 | 3.8367E-01 | 5.2995E-01 | 0.0000E+00 | 0.0000E+00 | 99 | 2151 | 144 |
| 6.2437E+04 | 3.0000E+00 | 2.2014E+00 | 2.5999E-01 | 0.0000E+00 | 0.0000E+00 | 99 | 2151 | 145 |
| 6.2585E+04 | 4.0000E+00 | 2.5802E-01 | 5.3002E-01 | 0.0000E+00 | 0.0000E+00 | 99 | 2151 | 146 |
| 6.2772E+04 | 3.0000E+00 | 2.6178E+00 | 5.3017E-01 | 0.0000E+00 | 0.0000E+00 | 99 | 2151 | 147 |
| 6.7367E+04 | 3.0000E+00 | 1.2689E+00 | 4.7002E-01 | 0.0000E+00 | 0.0000E+00 | 99 | 2151 | 148 |
| 6.8033E+04 | 4.0000E+00 | 1.7625E+00 | 4.7016E-01 | 0.0000E+00 | 0.0000E+00 | 99 | 2151 | 149 |
| 6.8708E+04 | 3.0000E+00 | 1.2606E+00 | 3.0001E-01 | 0.0000E+00 | 0.0000E+00 | 99 | 2151 | 150 |
| 7.4853E+04 | 3.0000E+00 | 2.9148E+00 | 2.6004E-01 | 0.0000E+00 | 0.0000E+00 | 99 | 2151 | 151 |
| 7.6314E+04 | 4.0000E+00 | 6.2293E+00 | 6.7160E-01 | 0.0000E+00 | 0.0000E+00 | 99 | 2151 | 152 |
| 7.7653E+04 | 3.0000E+00 | 1.4589E+01 | 4.6152E-01 | 0.0000E+00 | 0.0000E+00 | 99 | 2151 | 153 |
| 7.9201E+04 | 3.0000E+00 | 2.7100E+00 | 5.4185E-01 | 0.0000E+00 | 0.0000E+00 | 99 | 2151 | 154 |
| 7.9388E+04 | 4.0000E+00 | 2.0063E-01 | 3.4858E-01 | 0.0000E+00 | 0.0000E+00 | 99 | 2151 | 155 |
| 7.9512E+04 | 3.0000E+00 | 2.2453E-01 | 3.3020E-01 | 0.0000E+00 | 0.0000E+00 | 99 | 2151 | 156 |
| 8.2674E+04 | 3.0000E+00 | 1.0575E+00 | 4.6039E-01 | 0.0000E+00 | 0.0000E+00 | 99 | 2151 | 157 |
| 8.2881E+04 | 4.0000E+00 | 3.5664E+01 | 6.2139E-01 | 0.0000E+00 | 0.0000E+00 | 99 | 2151 | 158 |
| 8.4760E+04 | 3.0000E+00 | 7.2265E-01 | 3.9000E-01 | 0.0000E+00 | 0.0000E+00 | 99 | 2151 | 159 |
| 8.5503E+04 | 4.0000E+00 | 9.6409E-01 | 3.6003E-01 | 0.0000E+00 | 0.0000E+00 | 99 | 2151 | 160 |
| 8.8924E+04 | 3.0000E+00 | 1.5739E+00 | 4.4451E-01 | 0.0000E+00 | 0.0000E+00 | 99 | 2151 | 161 |
| 8.9298E+04 | 4.0000E+00 | 8.5020E+00 | 4.4453E-01 | 0.0000E+00 | 0.0000E+00 | 99 | 2151 | 162 |
| 8.9511E+04 | 4.0000E+00 | 3.1431E+01 | 4.4461E-01 | 0.0000E+00 | 0.0000E+00 | 99 | 2151 | 163 |
| 9.1338E+04 | 4.0000E+00 | 1.1665E+00 | 4.4452E-01 | 0.0000E+00 | 0.0000E+00 | 99 | 2151 | 164 |
| 9.1438E+04 | 3.0000E+00 | 5.0063E+00 | 4.4472E-01 | 0.0000E+00 | 0.0000E+00 | 99 | 2151 | 165 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 9.1636E+04 | 4.0000E+00 | 3.9151E+00 | 4.4482E-01 | 0.0000E+00 | 0.0000E+00 | 99 | 2151 | 166 |
| 9.2133E+04 | 3.0000E+00 | 3.9342E+00 | 4.5098E-01 | 0.0000E+00 | 0.0000E+00 | 99 | 2151 | 167 |
| 9.4080E+04 | 3.0000E+00 | 4.9873E-01 | 4.3446E-01 | 0.0000E+00 | 0.0000E+00 | 99 | 2151 | 168 |
| 9.6820E+04 | 4.0000E+00 | 5.8607E+00 | 6.8504E-01 | 0.0000E+00 | 0.0000E+00 | 99 | 2151 | 169 |
| 9.8704E+04 | 3.0000E+00 | 2.8036E+01 | 4.4531E-01 | 0.0000E+00 | 0.0000E+00 | 99 | 2151 | 170 |
| 9.9389E+04 | 4.0000E+00 | 5.9426E-01 | 4.4451E-01 | 0.0000E+00 | 0.0000E+00 | 99 | 2151 | 171 |