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# NEUTRON CROSS SECTION EVALUATION GROUP

## Cross Sections for Transuranium Element Production



May 1966

BROOKHAVEN NATIONAL LABORATORY
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## Cross Sections for Transuranium Element Production

CFSTI PRICES

S. PEARLSTEIN

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BROOKHAVEN NATIONAL LABORATORY
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ABSTRACT

An evaluation of cross sections useful for determining the production of transuranium elements is presented. The measured thermal cross sections and resonance integrals for the heavy elements beginning with $U^{234}$ were collected. Resonance parameters reported in BNL-325 were used in a single level formalism to reconstruct the total and partial neutron cross sections as a function of energy for the nuclides $U^{236}$, $Np^{237}$, $Pu^{238}$, $Pu^{240}$, $Pu^{241}$, $Pu^{242}$, $Am^{241}$, $Am^{243}$, and $Cm^{244}$. A single scattering radius, adjusted for best fit in the valleys between resonances, was used and a 1/v background cross section added to account for the low energy tails of the unresolved resonances. Good fits to the measured total and partial cross sections were observed throughout the resolved resonance region for most nuclides, but strong resonance-resonance interference effects were noted for $Pu^{241}$.

An integral over energy of the product of the absorption or fission cross section and a 1/E flux from a low energy limit of 0.55 eV was calculated as a function of energy in the resolved resonance region. An extrapolation to high energies allowed comparison with measured resonance integrals. Good agreement between extrapolated resonance integrals and measurements was noted for all cases except $Pu^{238}$ and $Np^{237}$. New information is reported for the capture integrals of $Pu^{241}$, $Am^{241}$, and $Cm^{244}$, and the fission integral of $Am^{241}$.

## I. INTRODUCTION

Preliminary studies[1] have shown that the buildup of transuranium elements by successive activation of nuclides may be performed more effectively in epithermal reactors than in thermal reactors. However, there is much uncertainty about many of the neutron cross sections in the epithermal region. These uncertainties can seriously affect the fuel reprocessing cycle since the optimum time for nuclide buildup is strongly dependent on the formation and disappearance cross section. In some cases, a two-group calculation containing thermal neutron cross sections and resonance integrals is sufficient to predict the transuranium element production. The experimental information collected showed the data to be sparse and sometimes discrepant. The status of the experimental results prompted calculation of the resonance integrals using the resonance parameters to look for new information and to test for consistency between differential and integral measurements.

In addition to providing a check on the experimental information, an analytic cross section representation facilitiates analyses where spacial and energy self-shielding and temperature effects are important. It also provides a convenient way to generate multigroup reactor cross sections. In this report the fit of the resonance parameters reported in BNL-325 to the experimental data is displayed.

A summary of the experimental information on the thermal cross sections and resonance integrals is presented in Section II of this report. In Section III the differential experimental data are analyzed, and the resonance parameters reported in BNL-325 are used in a Breit-Wigner single-level (BWSL) formalism to construct the partial and total cross sections in the resolved resonance region. Resonance integrals for capture and fission are computed over the resolved resonance region in Section IV to note whether an extrapolation to higher energies would yield results consistent with measured integrals. Discrepancies between the differential and integral measurements are discussed in Section V, while Section VI attempts to present a practical set of two-group cross sections to be used for transuranium isotope calculations. The conclusions of this study are presented in Section VII.

## II. SUMMARY OF THERMAL AND INTEGRAL MEASUREMENTS

The thermal cross sections and resonance integrals measured for nuclides, starting with $U^{234}$, are summarized in Table I. These results have been extracted from BNL-325[1] and CINDA[2]. No attempt has been made to check all the references to remove duplications and inaccuracies. In many cases there exists only a single measurement of the cross section, while in other instances several investigations of the cross sections have been made. For $U^{235}$, $U^{238}$, and $Pu^{239}$ only the BNL-325 recommended values are listed.

There is wide scatter in the experimental data for the thermal cross sections of $Pu^{240}$, $Pu^{242}$, $Am^{243}$, and the resonance absorption integral of $Am^{243}$. The production of the $Pu^{238}$ nuclide (important for space application) relies on an accurate knowledge of the $Np^{237}$ and $Pu^{238}$ resonance integrals, there being only one measurement reported for each nuclide.

## III. PARAMETRIC FITTING OF TOTAL AND PARTIAL CROSS SECTIONS

Differential thermal and epithermal neutron cross section data exists for many of the fissile nuclides. If the resonances are experimentally resolved, it is possible for each resonance to be analyzed to obtain resonance parameters. By superimposing the shape of each resonance according to its parameters, it is possible to reconstruct the cross section throughout the energy range of the resolved resonance

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[1] Neutron Cross Sections, 1st Edition (1955); 2nd Edition (1958); Supplement 2, Vol. I (1964); Supplement 2, Vol. III (1965).

[2] An Index to the Literature on Microscopic Neutron Data, Columbia University and ENEA Neutron Data Compilation Centre, May 1, 1965; 1st Supplement, October 15, 1965.

region. Once a parametric representation of the cross section is achieved, group-averaged cross sections and resonance integrals can readily be calculated.

Where resonances are closely spaced, interference between levels may occur that will require a multilevel formalism to analyze the cross section data. However, if interference effects are not too severe, the BWSL formula may offer sufficient flexibility to parametrically fit the measured cross sections. In this section the single-level parameters reported in BNL-325 are used to build up the total cross section throughout the resolved resonance region.

A. Single Level Formula

The expression used to generate the Doppler-broadened total cross sections in the laboratory system consists of resonance, potential scattering, and 1/v components. The resonance part is formed by summing for each resonance the following terms:

$$\sigma_{res}(E) = \left(\frac{A+1}{A}\right)^2 \sigma_R \left\{ \left[ \sqrt{\frac{E_R}{E}} \; \frac{\Gamma_\gamma + \Gamma_F}{\Gamma(E)} + \frac{\Gamma_N}{\Gamma(E)} \right] \psi[X(E),T(E)] + \frac{4\pi RA}{\lambda(A+1)} \; \chi[X(E),T(E)] \right\} ,$$

where

$$\sigma_R = g \frac{\lambda^2}{\pi} \frac{\Gamma_N}{\Gamma} ,$$

$$\Gamma(E) = \Gamma_N \sqrt{E/E_R} + \Gamma_\gamma + \Gamma_F ,$$

R = spin and resonance independent nuclear scattering radius,

$$X(E) = \frac{2(E-E_R)}{\Gamma(E)} ,$$

$$T(E) = \frac{4(KT)E}{(A+1)\Gamma(E)^2} ,$$

$$\psi(X,T) = \frac{1}{2\pi T} \int_{-\infty}^{\infty} \frac{e^{-(X-y)^2/4T}\,dy}{1+y^2} ,$$

$$\chi(X,T) = \frac{1}{2\pi T} \int_{-\infty}^{\infty} \frac{e^{-(X-y)^2/4T}\,ydy}{1+y^2} ,$$

and A = mass ratio of target nucleus to neutron.

The parameters $\lambda$, $\Gamma_N$, $\Gamma_\gamma$, and $\Gamma_F$ are evaluated at the resonance energy. The potential scattering cross section, $\sigma_p$, is constant with energy.

$$\sigma_p = 4\pi R^2$$

where

$$R = r_0 A^{\frac{1}{3}} \times 10^{-13} \text{ cm}.$$

The tails of the higher energy unresolved resonances are assumed to collectively contribute in a 1/v manner to the capture and fission cross sections at low energies.

$$\sigma_{1/v}(E) = \sigma_{co}\sqrt{\frac{.0253}{E}} + \sigma_{fo}\sqrt{\frac{.0253}{E}} .$$

The quantities $\sigma_{co}$ and $\sigma_{fo}$ are that amount of capture and fission cross section respectively that must be added at .0253 eV to account for measured 2200-meter cross sections.

This description of the cross section includes interference between resonance and potential scattering but does not include interference between resonances. Although Doppler broadening at room temperature is included, broadening due to imperfect experimental resolution has been ignored.

B. Resonance Parameters

In general, the number of parameters available to fit the measured cross section in the resolved resonance region are $r_0$, $\sigma_{co}$, and $\sigma_{fo}$ and four additional parameters for each resonance, namely, $E_R$, $\Gamma_N$, $\Gamma_\gamma$, and $\Gamma_F$. The statistical spin factor, g, was 1.0 for the zero spin nuclides $U^{234}$, $U^{236}$, $Pu^{238}$, $Pu^{240}$, $Pu^{242}$, and $Cm^{244}$ and 0.5 for the remainder of those investigated. The resonance parameters are summarized in Table II.

C. Fits to Experimental Data

Initially the data for each nuclide were fitted with $r_0 = 1.4$, and $\sigma_{co}$ and $\sigma_{fo}$ equal to 0. If the total cross section generated did not agree with the measured values between the higher energy resonances, the scattering cross section was adjusted through $r_0$ until better agreement was attained. If the total or partial cross section generated at .0253 eV was lower than measured values, a 1/v cross section was added through the parameters $\sigma_{co}$ and $\sigma_{fo}$. The values for the fitting constants $r_0$, $\sigma_{co}$, and $\sigma_{fo}$ are listed in Table II, together with the figures in which the calculated curve is compared with experiment. From the curves appearing in Figures 1 through 22 it may be seen that satisfactory fits are obtained in many cases to the experimental data at room temperature using the BWSL formalism. A detailed discussion is reserved for Section V.

V. PARTIAL RESONANCE INTEGRALS

In the previous section it was shown that resonance parameters could be used in the single level formalism to satisfactorily fit the measured partial or total cross section for most nuclides over the resolved resonance region. In this section figures describing an integral over energy of the product of the absorption or fission cross section and a 1/E flux from a lower energy limit of 0.55 eV[3] are presented.

[3] Recommended standarization of lower limit of resonance integral by H. Goldstein, et al., in EANDC-12 (1961).

Between energy mesh points a quadratic shape was assumed for this integrand. Since satisfactory fits to the differential cross section were demonstrated only over the resolved resonance region, the integral is terminated after inclusion of the last resonance. Because of the reduced weighting of the high energy resonances, the curve saturates and approaches the high energy limit of the resonance integral where extrapolation allows comparison with measured resonance integrals.

The calculated results, extrapolated values, measured integrals, and the figures in which they may be seen are listed in Table III.

The measurement of integrals of elements having low energy resonances in the vicinity of the cadmium resonance at 0.178 eV must contain corrections to obtain a lower limit of the resonance integral at 0.55 eV. Calculated cadmium cutoffs, assuming a 40-mil cadmium cover and the Doppler-broadened absorption cross section of 16 resolved resonances in cadmium, are listed in Table III, together with calculated contributions to the resonance integral between 0.55 eV and the cadmium cutoff, $E_c$. This correction may be positive or negative, depending on whether $E_c$ is above or below 0.55 eV.

## V. COMPARISON OF CALCULATIONS AND EXPERIMENT

The agreement between the measured cross sections and resonance integrals and the calculated curves generated from resonance parameters is discussed separately for each nuclide. The figures showing the measured and calculated data are listed in Tables III and IV.

In general the calculated curves for the total and partial cross sections track the experimental points at low energies rather well, as they should since the resonance parameters were generated from the data. However, exceptions occur when strong resonance-resonance interference occurs as in $Pu^{241}$, showing the inadequacy of the BWSL description, and in low energy tails where negative resonance parameters have not been completely determined as for $Am^{241}$. In addition, where measurements have been made by different experimenters whose energy scales do not agree, an educated choice has been made in BNL-325 to select the recommended values used in these calculations. In these cases the calculated curve cannot be expected to pass through all data points. At higher energies broadening of the data occurs because of the deteriorating experimental resolution, but this does not seriously affect the determination of the resonance parameters. The calculated curve shows the line shape Doppler-broadened by a temperature of 68° F (.0253 eV).

$U^{234}$: The calculated total cross section passes through the data points at thermal energies, tracks the first resonance well, and shows that the experimental resolution falters at the second positive energy resonance at 31.4 eV. More work is suggested for evaluating additional negative resonance parameters to obtain better agreement between 0.1 and 1.0 eV.

The extrapolated capture resonance integral of 640 barns is in good agreement with the measured values of 710 and 700±70 barns. The fission width observed for the 5.19-eV resonance gives rise to a 2200-meter fission cross section of 0.006 barns and a fission resonance integral of 0.5 barns.

$U^{236}$: The generated curve passes through the scattered data points at low energies, tracks the first resonance well, and rises above the data points at the 30.2-eV resonance where the experimental resolution becomes poor.

The experimental values for the resonance integral range from a low limit of 363 to a maximum limit of 480 barns, a range that does not include the extrapolated value of 310 barns.

$Np^{237}$: The good fit to the measured data appears throughout the low energy range except at the threshold of the first peak. A negative resonance might improve the fit. At about 21 eV discrepancies between the curve generated from the recommended values and the experimental data appear.

The extrapolated resonance integral of 500 barns is a factor of two below the single measurement available of about 943 barns (adjusted from a non-1/v measurement of 870 barns). The fission widths observed for the 0.489-, 1.33-, and 1.48-eV resonances contribute 0.0005 barns and 0.007 barns to the thermal cross section at .0253 eV and fission resonance integral, respectively.

$Pu^{238}$: The thermal cross section and resonance data about 2.89, 9.98, and 18.57 eV have been reported. Resolution broadening affects the comparison between the calculated curve and experimental data at the 9.98- and 18.57-eV resonances. The thermal cross section is almost entirely due to the negative resonance proposed at -0.5 eV. Fission widths have been evaluated but no fission cross section data published except at thermal energies.

An extrapolation of the resonance integral, risky because not enough resonances have been resolved to show saturation, indicates a resonance integral in the neighborhood of 150 barns which is in serious disagreement with the measured value of 3260±280 barns.

$Pu^{240}$: Good agreement is observed between the calculated curve and the experimental data throughout the resolved resonance range for both the total and fission cross section. A Maxwellian averaged capture and fission cross section of 246 and 0.06 barns was obtained. Measured values range from 240±35 to 530±50 barns and 0.030±0.045 to 8±7 barns for the capture and fission cross sections, respectively.

There is good agreement between the extrapolated resonance integral of 8000 barns and measured values ranging from a low limit of 7900 to a high limit of 15,000 barns (including experimental error). A fission resonance integral of 1.5 barns was calculated as the contribution from the first two resonances.

$Pu^{241}$: The calculated curve deviates considerably from the data between 0.5 and 1.5 eV and also in the valley between the 4.58- and 5.92-eV resonances. The shape discrepancy between the resonances is due to the inadequacy of the single level formula to account for interference effects. Very strong interference between these resonances is required to describe the data[2]. The discrepancy between the calculated and measured fission cross section in the 1-eV region may in part be due to $Pu^{240}$ contamination in the measurement sample. Throughout the resolved resonance region the discrepancies between the calculated and measured total cross section are largely due to the failure to generate the correct fission cross section.

The running resonance integral is near saturation extrapolating to 630 barns for the fission integral which compares with an experimental range of 516 to 590 barns (including experimental errors). This discrepancy is mainly due to differences between the calculated and experimental differential cross section in the 0.55- to 5.0-eV range. The capture integral extrapolates to 260 barns for which no measured value has been reported.

$Pu^{242}$: Only the peak data are available for comparison. The fit is good for the 2.66-eV resonance and shows the effect of experimental broadening at the 53.6-eV resonance. The calculated 2200-meter capture cross section is 17.5 barns, which is in agreement with the measured value of 22±9 barns.

The computed capture integral extrapolates to 1150 barns, which compares favorably with the measurements of 1275±30, 1055±170, and 870±50 barns.

$Am^{241}$: The total cross section shows need of a negative energy resonance to produce agreement between the calculated curve and measured data. A negative resonance is indicated at -0.66 eV[(3)], but a set of resonance parameters have not been evaluated. The calculated curve falls short of the measured peak at 0.576 eV where the data points reach 5200 barns. This discrepancy is due to incorrect parameters for that resonance, since the unbroadened peak calculated from these parameters is only 4200 barns. The fit to the fission cross section in the energy range from 0.02 to 2.0 eV is very good. Large scatter in the data points above 2.0 eV prevents substantive remarks.

The capture integral to all the final states of $Am^{242}$ and the fission integral have not been measured. Extrapolated values are 1600 and 8.5 barns, respectively.

$Am^{243}$: A reasonably good fit to the total cross section data is obtained throughout the resolved resonance region. The 2200-meter capture cross section formed by the resonance tails was 180 barns, which can be compared with measured values of 183±8, 73.6±0.6, and 81.6±1.8 barns.

The extrapolated capture integral of 1400 barns is favored by the first two of a set of measured integrals of 1470±135, 1580±50, and 2290±50 barns.

$Cm^{244}$: The resonances are widely separated and the peak data were satisfactorily fit by the calculated curve. Deviations were noted only for narrow resonances or high energy resonances where the data are resolution broadened. The calculated thermal cross section is 9 barns as compared with a measurement of 20 barns.

The extrapolated capture integral is 650 barns for which no measurement has been reported.

## VI. TWO GROUP CROSS SECTIONS

For the isotopes investigated it is possible to supplement the experimental information contained in Table I with calculated thermal cross sections and resonance integrals. New information is obtained for the capture integrals of $Pu^{241}$, $Am^{241}$, and $Cm^{244}$, the fission integral of $Am^{241}$, and the thermal cross section of $Cm^{244}$. In addition, where the calculations were in agreement with experiment, greater weight could be given to certain measurements.

The two group cross sections are listed in Table IV and are grouped according to the thermal cross section, resonance integral, and the fission spectrum averaged (n,2n) cross section[4]. The thermal cross section is averaged over both a Maxwellian neutron distribution of characteristic energy of .0253 eV and a reactor distribution characterized by adding to the Maxwellian a 1/E spectrum of amplitude 0.1 down to a joining point of 0.1265 eV. The latter spectrum is characteristic of a somewhat epithermal reactor with a moderating ratio $\xi\frac{\Sigma_s}{\Sigma_a}$ equal to ten. The averaging was performed over the energy range from 0 to 0.55 eV.

If a multigroup analysis is required, the figures describing the running capture and fission integrals may be used to obtain group averaged cross sections in the resolved resonance region. The average cross section, $\bar{\sigma}$, defined by

$$\bar{\sigma} = \frac{\int_{E_1}^{E_2} \frac{\sigma(E)dE}{E}}{\int_{E_1}^{E_2} \frac{dE}{E}}$$

in a region having energy limits $E_1$ and $E_2$ may be obtained by subtracting the ordinates appearing at energy $E_1$ from that read at $E_2$ and dividing by the log $E_2/E_1$.

In some cases the nuclide concentrations may be so great as to make suspect the assumption that the infinite dilution resonance integrals are appropriate for calculation of the nuclide buildup, and energy self-shielded effective resonance integrals should be used.

## VII. CONCLUSIONS

The Breit-Wigner single level formula has proved to be a useful tool for testing the consistency between differential and integral measurements and for generating new information. A multilevel formalism, while more correct for those nuclides whose resonances are closely spaced, requires additional parameters to generate the cross section. This additional effort causes the multilevel formalism to be an unwieldy mechanism for the type of evaluation performed in this report. Only in the case of $Pu^{241}$ did it appear that the BWSL formula was inadequate to describe the data for the purposes of generating reactor cross sections. Additional analytical work to determine single level parameters is needed for $Np^{237}$, $Am^{241}$, and $Am^{243}$, and more parameters and experiments are necessary to ascertain the resonance integral of $Pu^{238}$.

The procedure for calculating and plotting cross sections generated from single level parameters is mechanized, and a general survey of data that can be satisfactorily fitted by this formalism is planned.

## REFERENCES


1. L. G. Epel, et al., ANS Transactions 8 (No. 1), 57 (1965).
2. O. D. Simpson and N. H. Marshall, IDO-16679, 6 (1961).
3. C. D. Bowman, et al., Phys. Rev. 137, B326-B331 (1965).
4. S. Pearlstein, Nuclear Sci. Eng. 23, 238-251 (1965).

TABLE I

Summary of Experimental Thermal Cross Sections and Resonance Integrals

| Nuclide | $\sigma_c$ Thermal Capture (barns) | $\sigma_f$ Thermal Fission (barns) | $I_c$ Capture Integral (barns) | $I_f$ Fission Integral (barns) | Reference |
|---|---|---|---|---|---|
| $U^{234}$ | 103 ± 8[B] | | | | JNE 6, 181 (1958) |
| | 92 ± 5[B] | | | | NSE 8, 112 (1960) |
| | | | 710 | | BAPS 1, 187 (1956) |
| | | | 700± 70 | | PIC 2-16, 64 (1958) |
| $U^{235}$ | 101 ± 2[A] | 577.1± 9[A] | 144± 5 | 274±10 | BNL 325 recommended |
| $U^{236}$ | 17.1 ± .5[C] | | 397± 34 | | JNE 7, 81 (1958) |
| | 34 ± 6[C] | | | | NSE 3, 395 (1958) |
| | 8.1 ± 1.8[A] | | | | JNE 6, 181 (1958) |
| | 26 ± 7[C] | | | | JPR 17, 564 (1956) |
| | 24.6 ± 6.0[C] | | | | AE 1, 130 (1956) |
| | 9.1[C] | | | | ANL 4873, 9 (1952) |
| | 6 ± 2[B] | | | | ORNL CF-51-12-151 |
| | | | 450± 30 | | PIC 2-16, 64 (1958) |
| | | | 400 | | WASH 191 (1957) |
| | | | 381 | | WASH 1041, 37 (1962) |
| $U^{238}$ | 2.73± .04[A] | | 280± 12 | | BNL 325 recommended |
| $U^{239}$ | 22[C] | | | | ANL 4667 (1951) |
| | | <20[A] | | | NSE 2, 33 (1951) |
| | | 15 ± 3[C] | | | NCSAG 2 (1956) |
| $Np^{234}$ | | 900 ±300[B] | | | ANL 415, 2 (1948) |
| $Np^{236}$ | | 2500 ±150[B] | | | ANL 6600, 125 (1961) |
| $Np^{237}$ | 169 ± 3[B] | | 870±130(non-$\frac{1}{v}$) | | JNE A12, 32 (1960) |
| | 169 ± 8[B] | | | | IDO 16225 (1955) |
| | 172 ± 7[B] | | | | AERE-CR 1799 |
| $Np^{238}$ | | 1600 ±100[B] | | | CF-3762 (1947) |
| | | 1500[B] | | | RL 4-5-51 |
| $Np^{239}$ | 80 ±15[C] | | | | NSE 1, 108 (1956) |
| $Pu^{237}$ | | 2500 ±500[B] | | | PR 115, 1271 (1959) |
| | | 2200[A] | | | WASH 1033, 28 (1961) |
| $Pu^{238}$ | 520 ±40[C] | 18[A] | | | PR 107, 1294 (1957) |
| | 489 ± 3[C] | 17[A] | 3260±280 | | CJP 35, 147 (1957) |
| | 455 ±50[C] | | | | ANL 4215, 17 (1948) |

TABLE I, page 2

| Nuclide | $\sigma_c$ Thermal Capture (barns) | $\sigma_f$ Thermal Fission (barns) | $I_c$ Capture Integral (barns) | $I_f$ Fission Integral (barns) | Reference |
|---|---|---|---|---|---|
| $Pu^{238}$ | 588 ±15[A] | | | | BAPS 7, 305 (1962) |
| (con't) | 454 ± 8[A] | | | | CRC 628 (1956) |
| | | | | 25± 5 | PIC 2-16, 54 (1958) |
| $Pu^{239}$ | 273.9± 4[A] | 740.6 ±3.5[A] | | 333±15 | BNL 325 recommended |
| $Pu^{240}$ | | 4 ±7[C] | | | WASH 190 (1956) |
| | | 8 ±7[B] | | | CJP 36, 503 (1958) |
| | | .030± .045[B] | | | CJP 36, 507 (1958) |
| | | | 11,000±4000 | | PIC 1-5, 173 (1956) |
| | | | 8,700± 800 | | CRC 633 (1956) |
| | | | 8,780± 550 | | CJP 38, 157 (1960) |
| | 530 ±50[C] | | | | NSE 1, 62 (1956) |
| | 530[B] | | | | NSE 1, 204 (1956) |
| | 290 ±30[B] | | | | PIC 2-16, 64 (1958) |
| | | | 9,000±3000 | | JNE 4, 86 (1957) |
| | 370 ±40[B] | | 11,300(non-$\frac{1}{v}$) | | JNE A12, 32 (1960) |
| $Pu^{241}$ | 390 ±80[C] | 1060 ±210[C] | | | NSE 1, 62 (1956) |
| | | 962 ± 38[A] | | | IDO 16995 (1964) |
| | | 1146[C] | | 532±16 | CRRP 1183 (1964) |
| | | 930 ± 40[B] } 956 ± 40[C] } | | | AERE-R2998 (1959) |
| | | 935 ± 42[A] | | | HW 62727 (1959) |
| | | 1006 ± 8[B] | | | PIC 2-16, 204 (1958) |
| | | 858[C] | | | KAPL 1464 (1955) |
| | | | | 557±33 | NSE 9, 341 (1961) |
| | 340 ±30[B] | | | | PIC 2-15, 446 (1958) |
| | 350[B] | | | | NSE 1, 204 (1956) |
| | | 920 ± 45[A] | | | HW-48893, 98 (1957) |
| | | 987 ± 42[A] | | | PIC 1-4, 187 (1955) |
| $Pu^{242}$ | 30[B] } 52.1± .7[C] } | | | | NSE 1, 204 (1956) |
| | 18.6± .8[B] | | 1,275± 30 | | CJP 35, 147 (1957) |
| | 17.5± 4[B] | | 1,055± 170 | | PIC 2-16, 685 (1958) |
| | 22 ± 9[A] } 50.6± .7[C] } | | 870± 50 | | CRC 628 (1956) |
| | 30 ±10[C] | | | | NSE 1, 62 (1956) |
| $Pu^{243}$ | 170 ±90[C] | | | | NSE 1, 62 (1956) |
| $Pu^{244}$ | 1.5± .3[B] | | | | NSE 1, 62 (1956) |
| | 2.1± .3[C] | | | | PR 103, 634 (1956) |
| $Pu^{245}$ | 260 ±145[C] | | | | NSE 1, 62 (1956) |

TABLE I, page 3

| Nuclide | $\sigma_c$ Thermal Capture (barns) | $\sigma_f$ Thermal Fission (barns) | $I_c$ Capture Integral (barns) | $I_f$ Fission Integral (barns) | Reference |
|---|---|---|---|---|---|
| $Am^{241}$ | | 3[A] | 900($Am^{242g}$) | | WASH 1053, 76 (1964) |
| | 737[C] | | | | JNE 8, 224 (1959) |
| | 582[A] | | | | PIC 1-4, 645 (1955) |
| | 622 ± 35[B] | | | | ORNL 1879, 50 (1955) |
| | 844[C] | | | | PR 81, 486 (1951) |
| $Am^{242g}$ | | 2950[B] | | | PR 94, 735 (1954) |
| | | 1700[B] | | | PR 85, 135 (1952) |
| $Am^{242m}$ | 2000[C] | 6000[B] | | | PR 85, 135 (1952) |
| | | 6110±500[B] | | | PR 107, 1294 (1957) |
| | | 3000[B] | | | PR 81, 893 (1951) |
| $Am^{243}$ | 183 ± 8[A] | | 1470±135 | | PR 114, 505 (1959) |
| | 73.6± .6[A]<br>133.8± .8[C] } | | 2290± 50 | | CJP 35, 147 (1957) |
| | 140 ± 50[C] | | | | PR 95, 581 (1954) |
| | 115 ± 20[C] | | | | PR 94, 974 (1954) |
| | 81.6± 1.8[A]<br>131.8± 1.7[C] } | | 1580± 50 | | CRC 628 (1956) |
| | 115[C] | | | | NSE 1, 204 (1956) |
| $Am^{244g}$ | | 1440[A] | | | WASH 1033, 28 (1961) |
| | | 2300±300[B] | | | JINC 23, 187 (1961) |
| $Cm^{242}$ | 20 ± 10[B] | | | | UCRL PC 1-51 |
| | | <5[B] | | | PR 81, 893 (1951) |
| $Cm^{243}$ | 250 ±150[B] | 690± 50[B] | | | PR 107, 1294 (1957) |
| $Cm^{244}$ | 20[B] | | | | NSE 1, 204 (1956) |
| | 30[C] | | | | CJP 35, 147 (1957) |
| $Cm^{245}$ | 200[B] | 1800[B] | | | NSE 1, 204 (1956) |
| $Cm^{246}$ | 15 ± 10[B] | | | | PR 94, 974 (1954) |
| $Cm^{247}$ | 180[C] | | | | PIC 1-7, 261 (1955) |
| $Cm^{248}$ | 6 ± 4[B] | | | | JINC 6, 261 (1958) |
| $Bk^{249}$ | 300 ±150[B] | | | | PR 96, 1576 (1954) |
| $Cf^{249}$ | | 1735± 70[B] | | | JINC 27, 33 (1965) |
| | | 630[C] | | | PR 95, 581 (1954) |

TABLE I, page 4

| Nuclide | $\sigma_c$ Thermal Capture (barns) | $\sigma_f$ Thermal Fission (barns) | $I_c$ Capture Integral (barns) | $I_f$ Fission Integral (barns) | Reference |
|---|---|---|---|---|---|
| $Cf^{250}$ | | <350[B] | | | p.c., H. Diamond, ANL (1964) |
| $Cf^{251}$ | | 3000±260[B] | | | JINC 27, 33 (1965) |
| $Cf^{254}$ | 40[C] | | | | JINC 6, 1 (1958) |

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[A] Adjusted to .0253 eV

[B] Measured in Maxwellian spectrum

[C] Measured in Reactor spectrum

TABLE II

Resonance Parameters

| Nuclide | $r_o$ | $\sigma_{co}$ | $\sigma_{fo}$ | Figure | $E_R$ | $\Gamma_N$ (mV) | $\Gamma_\gamma$ (mV) | $\Gamma_F$ (mV) |
|---|---|---|---|---|---|---|---|---|
| $U^{234}$ | 1.54 | 20.0 | 0 | 1 | -2.0 | 3.2[A] | 25 | 0 |
| | | | | | 5.19 | 4.1 | 25 | .022 |
| | | | | | 31.4 | 7.7 | 25 | 0 |
| | | | | | 46.4 | .07 | 25 | 0 |
| | | | | | 49.4 | 11 | 25 | 0 |
| | | | | | 78.3 | 6.4 | 25 | 0 |
| | | | | | 88.7 | .9 | 25 | 0 |
| | | | | | 95.3 | 28 | 25 | 0 |
| | | | | | 106.9 | 3.1 | 25 | 0 |
| | | | | | 112.1 | 13 | 25 | 0 |
| | | | | | 132.9 | 14 | 25 | 0 |
| | | | | | 145.9 | 17 | 25 | 0 |
| | | | | | 154.0 | 19 | 25 | 0 |
| | | | | | 179.0 | 70 | 25 | 0 |
| | | | | | 184.0 | 20 | 25 | 0 |
| | | | | | 191 | 110 | 25 | 0 |
| | | | | | 274 | 26 | 25 | 0 |
| | | | | | 295 | 80 | 25 | 0 |
| | | | | | 319 | 110 | 25 | 0 |
| | | | | | 357 | 30 | 25 | 0 |
| | | | | | 369 | 220 | 25 | 0 |
| $U^{236}$ | 1.58 | 6.1 | 0 | 2 | 5.49 | 1.8 | 29 | 0 |
| | | | | | 30.2 | .61 | 25 | 0 |
| | | | | | 34.6 | 2.6 | 25 | 0 |
| | | | | | 44.5 | 19 | 25 | 0 |
| | | | | | 72.3 | 40 | 25 | 0 |
| | | | | | 87.4 | 44 | 25 | 0 |
| | | | | | 121.0 | 53 | 25 | 0 |
| | | | | | 126.0 | 8 | 25 | 0 |
| | | | | | 198 | 94 | 25 | 0 |
| | | | | | 216 | 80 | 25 | 0 |
| | | | | | 280 | 100 | 25 | 0 |
| | | | | | 308 | 130 | 25 | 0 |
| | | | | | 384 | 190 | 25 | 0 |
| $Np^{237}$ | 1.68 | 147.0 | 0 | 3 | .489 | .0325 | 34 | .00075 |
| | | | | | 1.33 | .031 | 34 | .004 |
| | | | | | 1.48 | .125 | 34 | .0006 |
| | | | | | 1.97 | .0150 | 32 | 0 |
| | | | | | 3.89 | .24 | 32 | 0 |
| | | | | | 4.29 | .025 | 32 | 0 |
| | | | | | 4.89 | .028 | 32 | 0 |
| | | | | | 5.81 | .65 | 32 | 0 |

TABLE II, page 2

| Nuclide | $r_o$ | $\sigma_{co}$ | $\sigma_{fo}$ | Figure | $E_R$ | $\Gamma_N'$ (mV) | $\Gamma_\gamma$ (mV) | $\Gamma_F$ (mV) |
|---|---|---|---|---|---|---|---|---|
| $Np^{237}$ (con't) | 1.68 | 147.0 | 0 | 3 | 6.41 | .09 | 32 | 0 |
| | | | | | 6.73 | .013 | 32 | 0 |
| | | | | | 7.46 | .131 | 32 | 0 |
| | | | | | 8.37 | .08 | 32 | 0 |
| | | | | | 9.02 | .11 | 32 | 0 |
| | | | | | 9.33 | .40 | 32 | 0 |
| | | | | | 10.84 | 1.3 | 32 | 0 |
| | | | | | 11.10 | 1.3 | 32 | 0 |
| | | | | | 12.25 | .05 | 32 | 0 |
| | | | | | 12.63 | .85 | 32 | 0 |
| | | | | | 16.10 | 1.04 | 32 | 0 |
| | | | | | 16.88 | .25 | 32 | 0 |
| | | | | | 17.62 | .25 | 32 | 0 |
| | | | | | 19.22 | .04 | 32 | 0 |
| | | | | | 19.89 | .11 | 32 | 0 |
| | | | | | 22.04 | .127 | 32 | 0 |
| | | | | | 22.88 | .38 | 32 | 0 |
| | | | | | 23.71 | 2.1 | 32 | 0 |
| | | | | | 25.01 | 5.1 | 32 | 0 |
| | | | | | 26.59 | 3.2 | 32 | 0 |
| | | | | | 30.47 | 4.2 | 32 | 0 |
| | | | | | 31.34 | .10 | 32 | 0 |
| | | | | | 33.50 | .50 | 32 | 0 |
| | | | | | 34.05 | .34 | 32 | 0 |
| | | | | | 35.24 | .37 | 32 | 0 |
| $Pu^{238}$ | 1.48 | 0 | 0 | 4 | -.50 | .87[A] | 45 | 0 |
| | | | | | 2.89 | .070 | 45 | 0 |
| | | | | | 9.98 | .205 | 75 | 0 |
| | | | | | 18.57 | 1.51 | 175 | 0 |
| $Pu^{240}$ | 2.66 | 0 | 0 | 5-7 | 1.056 | 2.3 | 31 | .006 |
| | | | | | 20.4 | 2.3 | 30 | 2 |
| | | | | | 38.1 | 15 | 30 | |
| | | | | | 41.6 | 1.9 | 30 | |
| | | | | | 66.3 | 45 | 30 | |
| | | | | | 72.4 | 29 | 30 | |
| | | | | | 90.0 | 17 | 30 | |
| | | | | | 104.3 | 60 | 30 | |
| | | | | | 120 | 50 | 30 | |
| $Pu^{241}$ | .7 | 275 | 320 | 8015 | -.160 | .0725[A] | 40 | 60 |
| | | | | | .260 | .051 | 35 | 75 |
| | | | | | 4.30 | .66 | 38 | 32 |
| | | | | | 4.58 | .43 | 40 | 160 |
| | | | | | 5.92 | 2.43 | 40 | 1350 |
| | | | | | 6.93 | .71 | 40 | 95 |
| | | | | | 8.60 | 1.0 | 40 | 80 |
| | | | | | 9.5 | .18 | 40 | 120 |

TABLE II, page 3

| Nuclide | $r_o$ | $\sigma_{co}$ | $\sigma_{fo}$ | Figure | $E_R$ | $\Gamma_N$ (mV) | $\Gamma_\gamma$ (mV) | $\Gamma_F$ (mV) |
|---|---|---|---|---|---|---|---|---|
| $Pu^{241}$ (con't) | .7 | 275 | 320 | 8-15 | 10.1 | 1.5 | 40 | 900 |
| | | | | | 12.78 | .79 | 40 | 235 |
| | | | | | 13.40 | 2.2 | 30 | 39 |
| | | | | | 14.75 | 6.2 | 28 | 120 |
| | | | | | 15.98 | 1.52 | 40 | 465 |
| | | | | | 16.69 | 1.23 | 40 | 180 |
| | | | | | 17.83 | 3.2 | 33 | 23 |
| | | | | | 20.7 | .34 | 40 | 50 |
| | | | | | 21.9 | .15 | 40 | 0 |
| | | | | | 23.0 | 1.2 | 40 | 320 |
| | | | | | 24.0 | 1.6 | 40 | 180 |
| | | | | | 26.4 | 4.4 | 40 | 260 |
| | | | | | 28.8 | 4.8 | 40 | 660 |
| | | | | | 29.4 | .7 | 50 | 40 |
| | | | | | 30.9 | 2.9 | 40 | 310 |
| | | | | | 35.0 | 2.1 | 40 | 700 |
| $Pu^{242}$ | 1.40 | 0 | 0 | 16 | 2.66 | 1.9 | 25 | .02 |
| | | | | | 53.6 | 44.9 | 25.1 | 0 |
| $Am^{241}$ | 1.40 | 417 | 205 | 17-19 | .308 | .060 | 41 | .29 |
| | | | | | .576 | .075 | 40 | .17 |
| | | | | | 1.27 | .39 | 44 | .30 |
| | | | | | 1.93 | .125 | 40 | .07 |
| | | | | | 2.36 | .080 | 40 | .15 |
| | | | | | 2.59 | .20 | 40 | .10 |
| | | | | | 3.99 | .26 | 40 | .011 |
| | | | | | 4.40 | .027 | 40 | .08 |
| | | | | | 5.03 | .21 | 40 | .03 |
| | | | | | 5.42 | 1.08 | 40 | .38 |
| | | | | | 6.10 | .13 | 40 | .03 |
| | | | | | 6.78 | .21 | 40 | 0 |
| | | | | | 8.11 | .9 | 40 | 0 |
| | | | | | 9.13 | .42 | 40 | .05 |
| | | | | | 9.90 | .35 | 40 | 1.0 |
| | | | | | 10.38 | .35 | 40 | 0 |
| | | | | | 10.99 | .36 | 40 | 0 |
| | | | | | 12.86 | .18 | 40 | 0 |
| | | | | | 14.75 | 2.7 | 40 | .27 |
| | | | | | 15.62 | .20 | 40 | 0 |
| | | | | | 16.38 | 1.1 | 40 | 0 |
| | | | | | 16.82 | .5 | 40 | 0 |

TABLE II, page 4

| Nuclide | $r_o$ | $\sigma_{co}$ | $\sigma_{fo}$ | Figure | $E_R$ | $\Gamma_N$ (mV) | $\Gamma_\gamma$ (mV) | $\Gamma_F$ (mV) |
|---|---|---|---|---|---|---|---|---|
| $Am^{243}$ | 1.40 | 0 | 0 | 20 | .0107 | .0001 | 34 | 0 |
| | | | | | .976 | .017 | 78 | 0 |
| | | | | | 1.353 | .82 | 43 | 0 |
| | | | | | 1.74 | .18 | 30.2 | 0 |
| | | | | | 3.42 | .21 | 42 | 0 |
| | | | | | 5.12 | .22 | 42 | 0 |
| | | | | | 6.54 | .83 | 42 | 0 |
| | | | | | 7.84 | .93 | 42 | 0 |
| | | | | | 10.3 | .23 | 42 | 0 |
| | | | | | 12.8 | 1.50 | 42 | 0 |
| | | | | | 13.1 | .80 | 42 | 0 |
| | | | | | 15.3 | .63 | 42 | 0 |
| $Cm^{244}$ | 1.4 | 0 | 0 | 21, 22 | 7.73 | 10.3 | 37.2 | 0 |
| | | | | | 16.9 | 2.00 | 37.0 | 0 |
| | | | | | 22.9 | .97 | 37 | 0 |
| | | | | | 35.0 | 4.03 | 43.5 | 0 |
| | | | | | 52.8 | .70 | 37 | 0 |
| | | | | | 69.9 | .48 | 37 | 0 |
| | | | | | 86.0 | 20.0 | 37 | 0 |
| | | | | | 96.0 | 6.2 | 37 | 0 |
| | | | | | 133 | 15.1 | 37 | 0 |
| | | | | | 182 | 8.8 | 37 | 0 |
| | | | | | 197 | 22.0 | 37 | 0 |
| | | | | | 211 | 42.7 | 37 | 0 |
| | | | | | 222 | 39 | 37 | 0 |
| | | | | | 231 | 18.3 | 37 | 0 |
| | | | | | 273 | 43 | 37 | 0 |

[A] For negative energy resonances, $\Gamma_n^{\,o}$(mV - $eV^{\frac{1}{2}}$) is listed.

TABLE III

Resonance Integrals

| Nuclide | Reaction Type | Calculated R.I. (barns) | Extrapolated R.I. (barns) | Measured[A] R.I. (barns) | Cd Cutoff[B] $E_c$ (eV) | R.I. Correction (barns) $.55-E_c$ | Figure |
|---|---|---|---|---|---|---|---|
| $U^{234}$ | c | 626 | 640 | 710<br>700± 70 | | | 23 |
| $U^{236}$ | c | 299 | 310 | 397± 34<br>450± 30<br>400<br>381 | | | 24 |
| $Np^{237}$ | c | 444 | 500 | 943 ($\frac{1}{v}$ part included) | .523 | -19.4 | 25 |
| $Pu^{238}$ | c | 79 | 150 | 3,260± 280 | | | 26 |
| $Pu^{240}$ | c | 7960 | 8000 | 11,000±4000<br>8,700± 800<br>8,780± 550<br>9,000±3000 | 1.000 | +878 | 27 |
| $Pu^{241}$ | c | 228 | 260 | | .548 | -.30 | 28 |
| | f | 581 | 630 | 532± 16<br>557± 33 | | | |
| $Pu^{242}$ | c | 1060 | 1150 | 1,275± 30<br>1,055± 170<br>870± 50 | | | 30 |
| $Am^{241}$ | c | 1390 | 1600 | | .602 | +264 | 31 |
| | f | 7.05 | 8.5 | | .602 | +1.14 | 32 |
| $Am^{243}$ | c | 1230 | 1400 | 1,470± 135<br>2,290± 50<br>1,580± 50 | 1.28 | +131 | 33 |
| $Cm^{244}$ | c | 629 | 650 | | | | 34 |

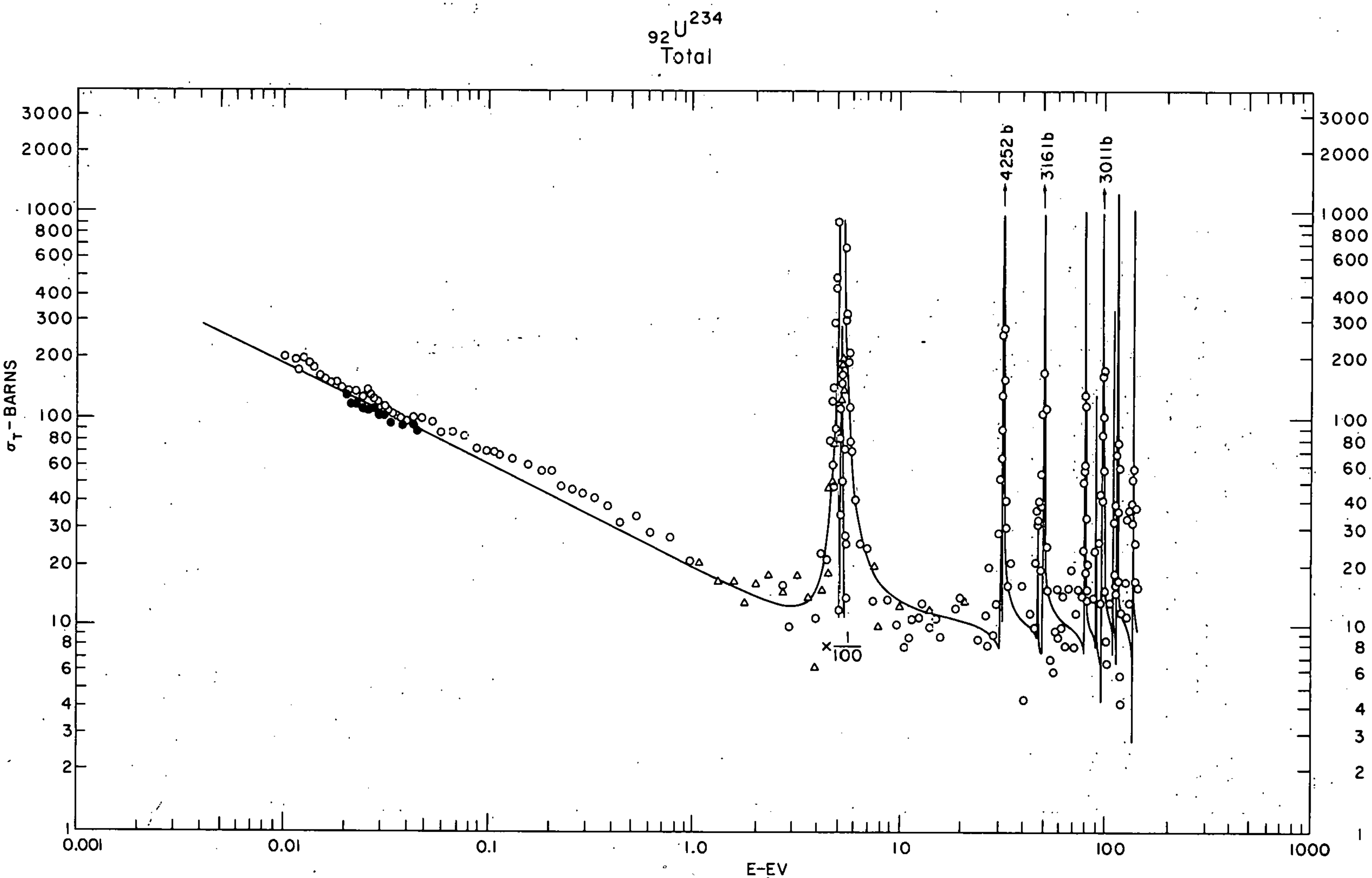
[A] See Table I for references.

[B] Calculated for plane foils covered with 0.04 inches cadmium in an isotropic cavity.

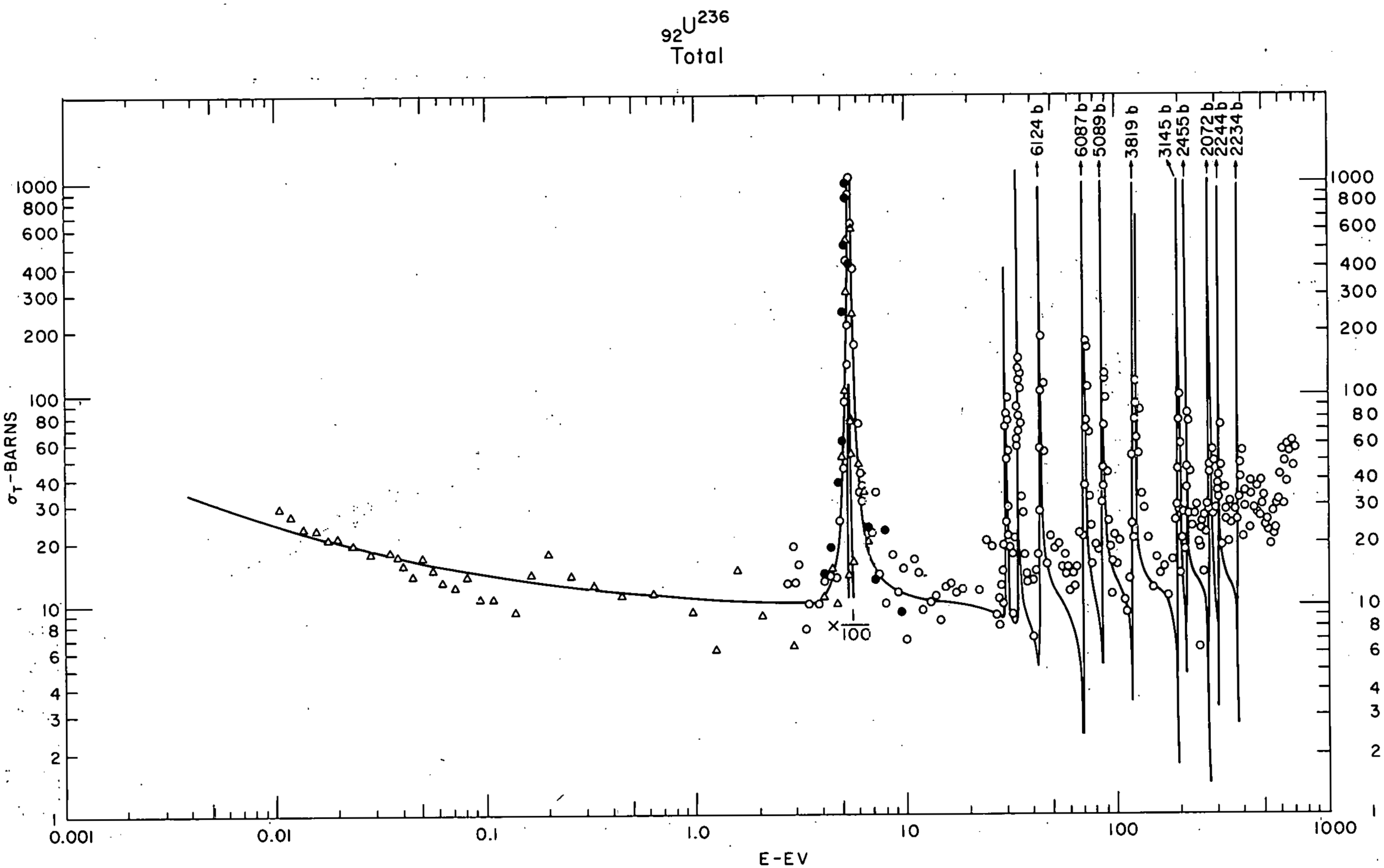
TABLE IV

Thermal Cross Sections and Resonance Integrals

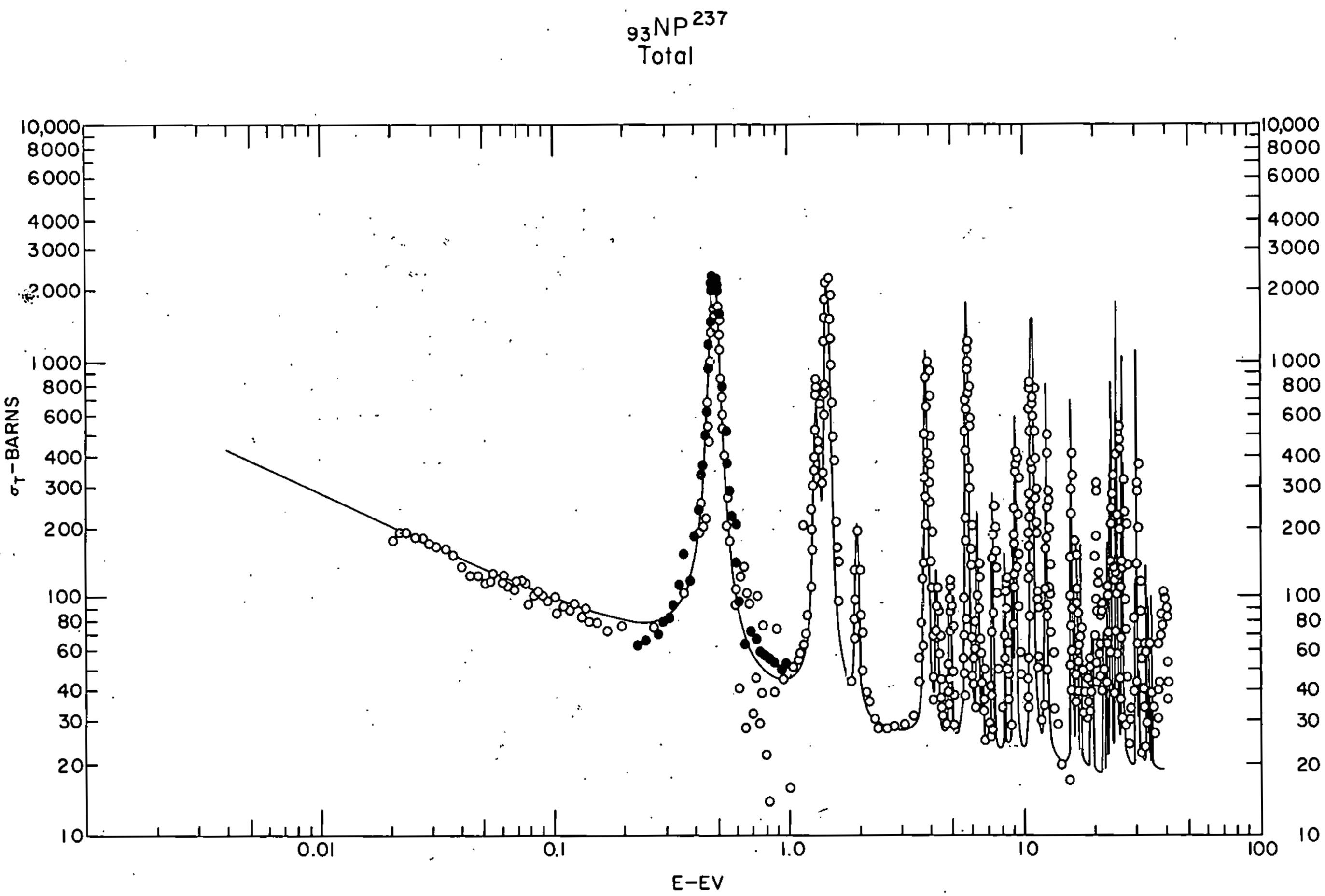
| Nuclide | Thermal Cross Section (barns) | | | | Resonance Integral (barns) | | $\sigma_{n,2n}$ (mb) |
|---|---|---|---|---|---|---|---|
| | Maxwellian | | Reactor Spectrum | | | | |
| | Capture | Fission | Capture | Fission | Capture | Fission | |
| $U^{234}$ | 94.7 | 0 | 84.1 | 0 | 700 | 0 | 7.0 |
| $U^{236}$ | 8.54 | 0 | 7.66 | 0 | 400 | 0 | 6.3 |
| $Np^{237}$ | 151 | --- | 161 | --- | 500 | --- | 1.3 |
| $Pu^{238}$ | 500 | 17.5 | 434 | --- | 150 | 25 | 0 |
| $Pu^{240}$ | 246 | .06 | 235 | .05 | 8000 | --- | 0 |
| $Pu^{241}$ | 345 | 950 | 390 | 1030 | 260 | 545 | 10 |
| $Pu^{242}$ | 15.7 | --- | 14.3 | --- | 1150 | --- | --- |
| $Am^{241}$ | 622 | 2.91 | 800 | 3.49 | 1600 | 8.5 | 0 |
| $Am^{243}$ | 142 | 0 | 127 | 0 | 1400 | 0 | --- |
| $Cm^{244}$ | 9 | 0 | 8 | 0 | 650 | 0 | --- |



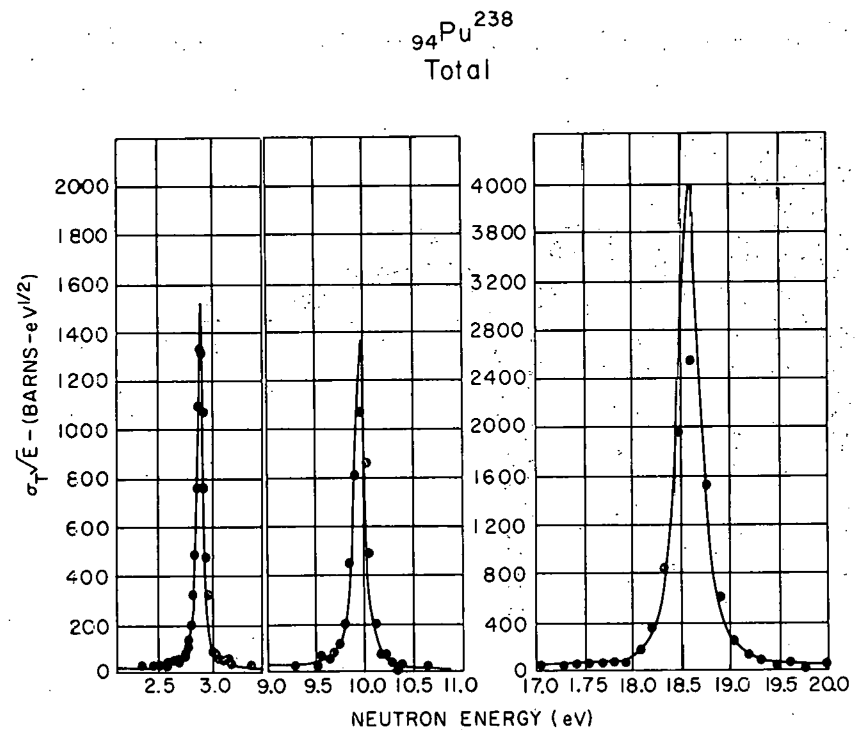

1. $U^{234}$ total cross section. For explanation of symbols, see BNL-325, 2nd Edition (1958), p. 328 and 1st Supplement (1960), p. 115.



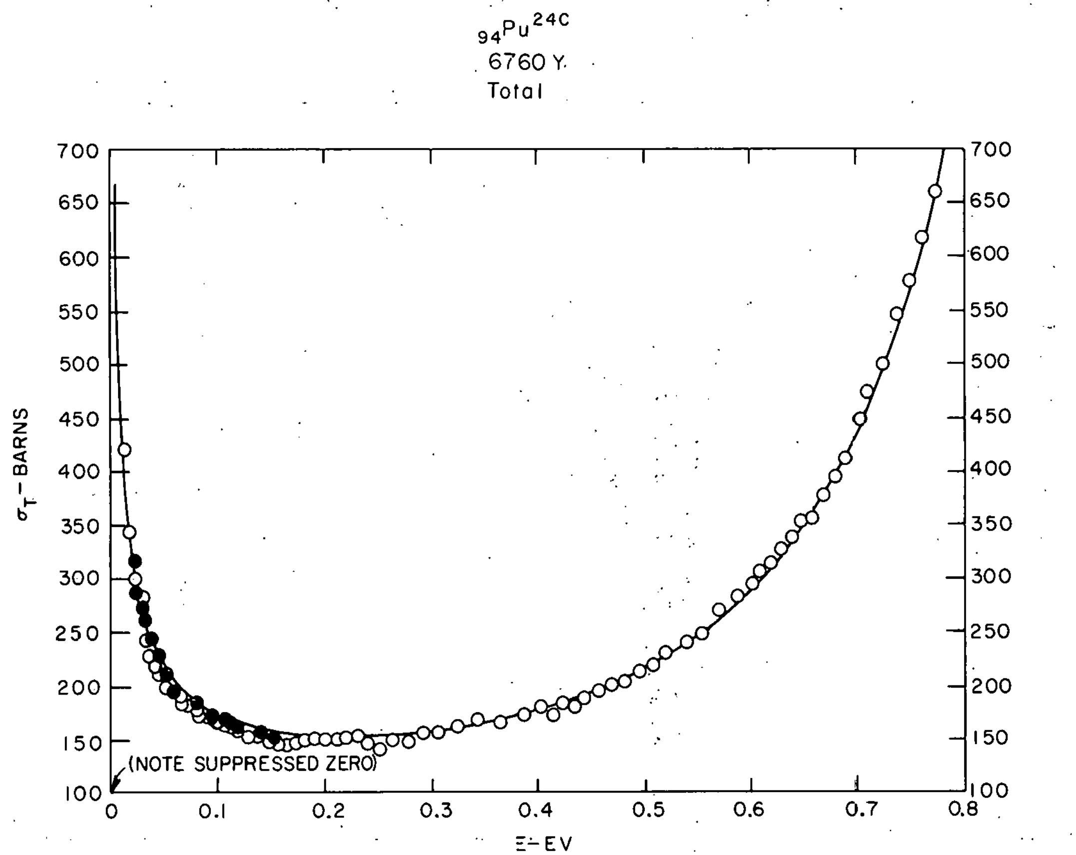

2. $U^{236}$ total cross section. For explanation of symbols, see BNL-325, 2nd Edition (1958), pp. 337, 338.



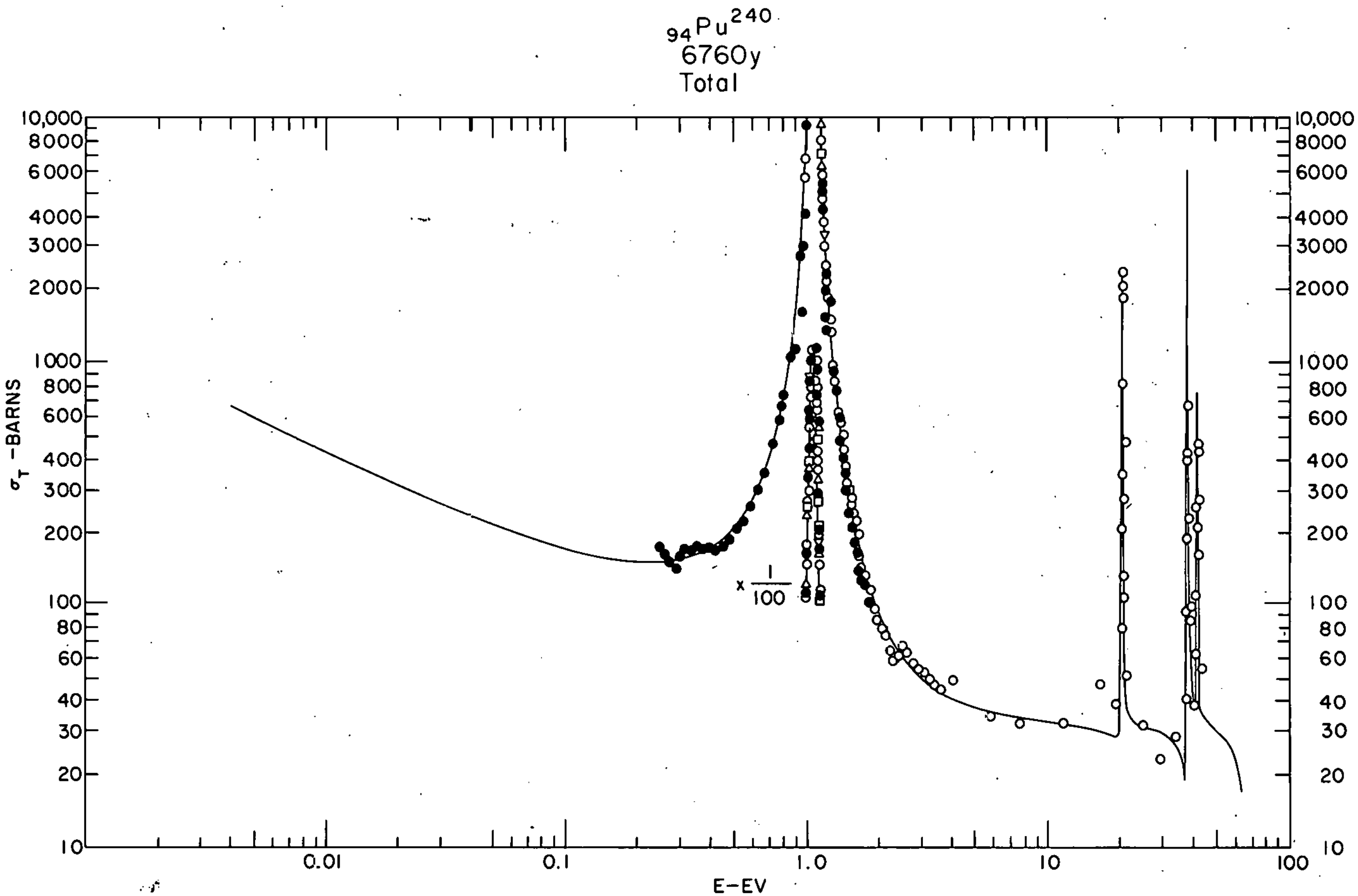

3. Np[237] total cross section. For explanation of symbols, see BNL-325, 2nd Edition, 1st Supplement (1960), pp. 120, 122.



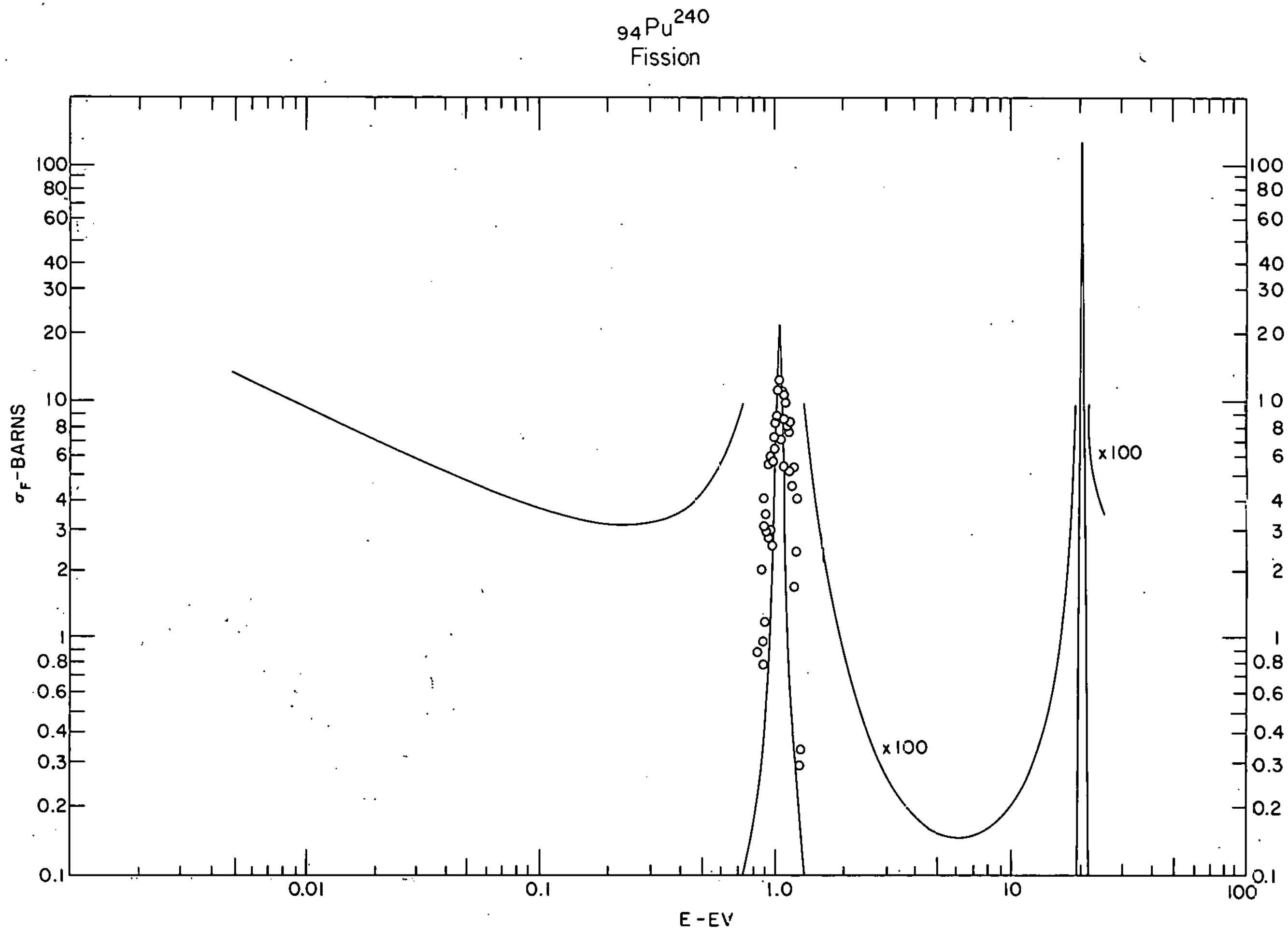

4. $Pu^{238}$ total cross section. Experimental data reported in IDO-166805, p. 8 (1962).



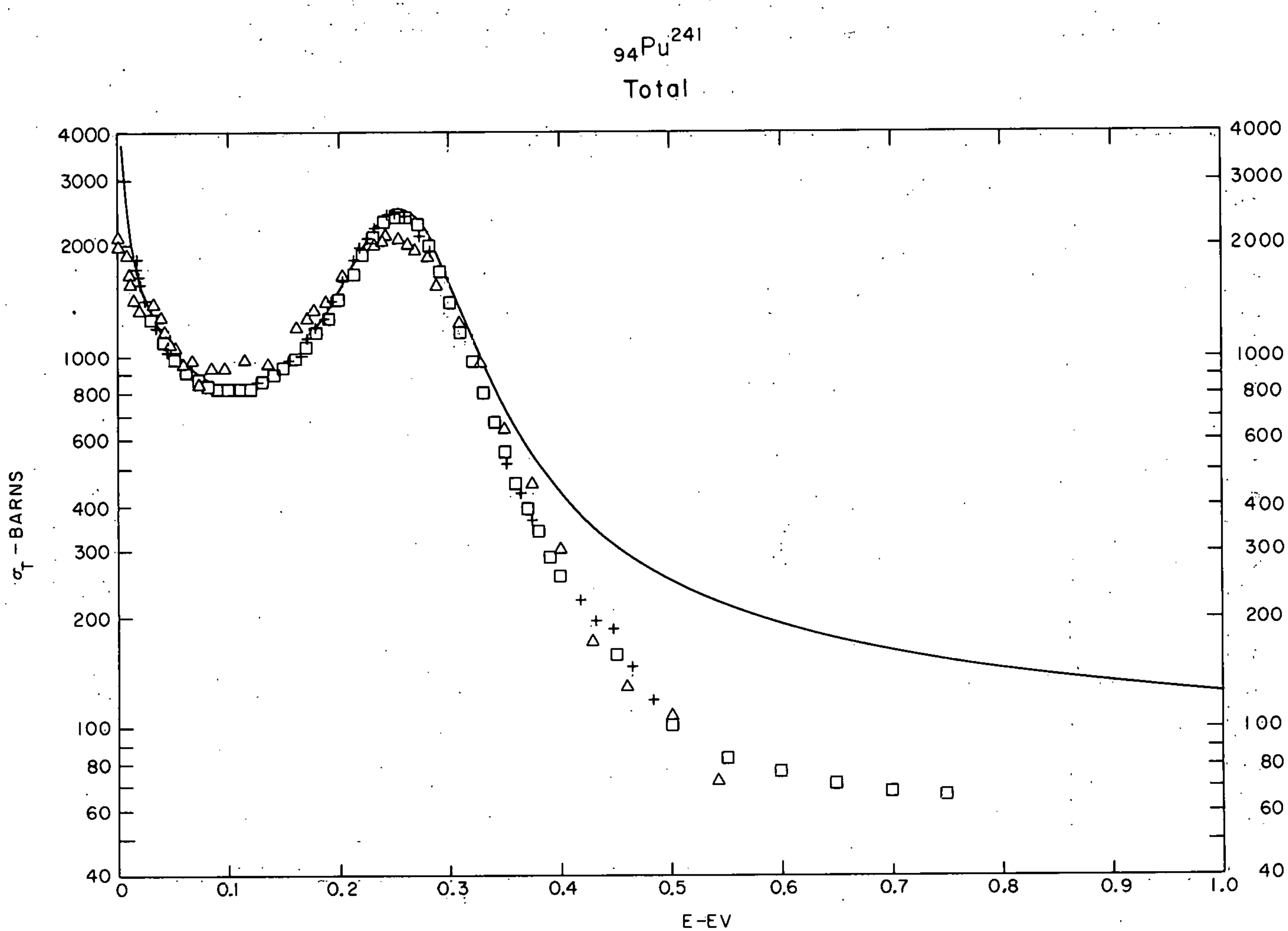

5. $Pu^{240}$(6707-y) total cross section, 0.0 to 0.8 eV. For explanation of symbols, see BNL-325, 2nd Edition, 2nd Supplement (1965), p. 94-240-3.



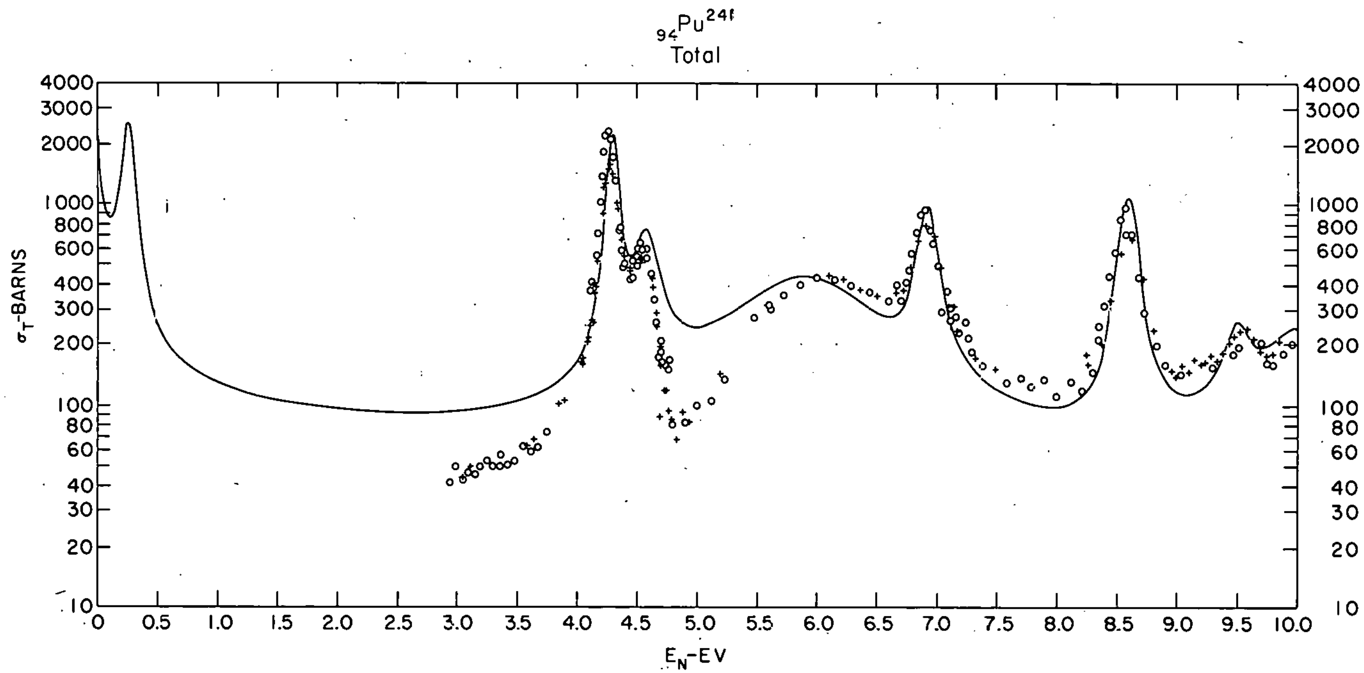

6. $Pu^{240}$(6707-y) total cross section. For explanation of symbols, see BNL-325, 2nd Edition, 1st Supplement (1960), p. 125.



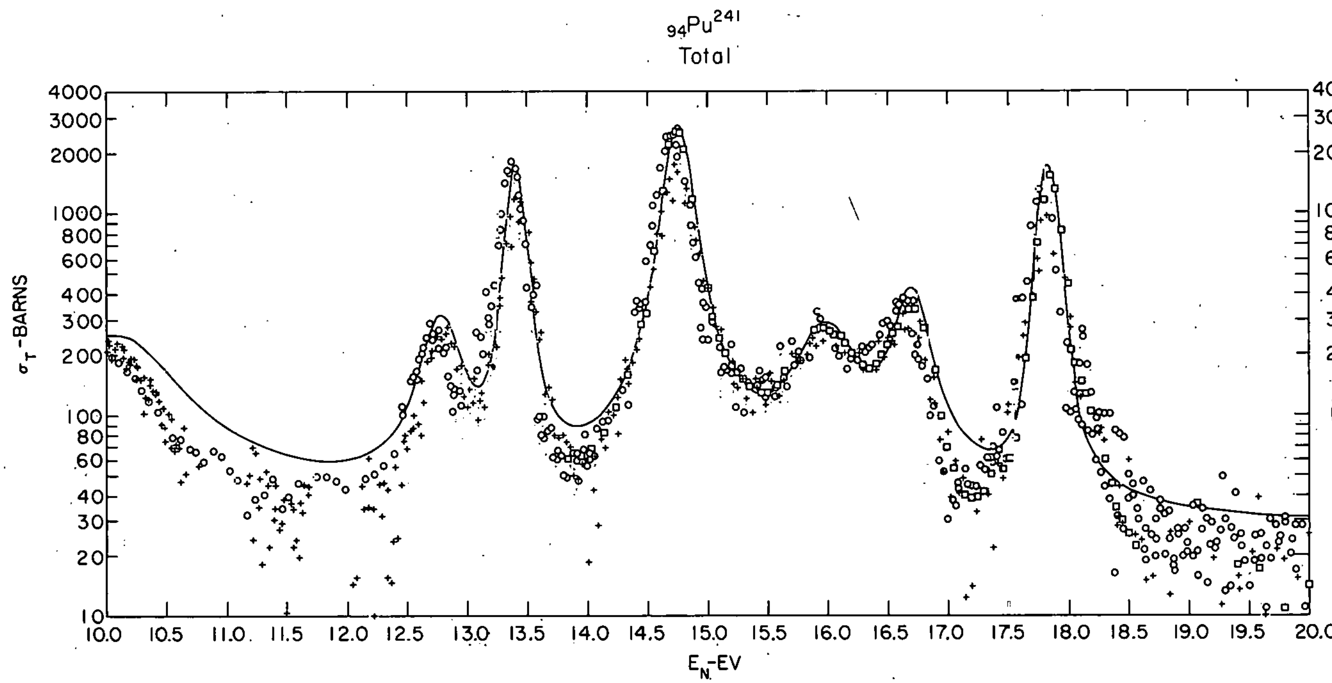

7. $Pu^{240}$ (6707-y) fission cross section. For explanation of symbols, see BNL-325, 2nd Edition (1958), p. 354



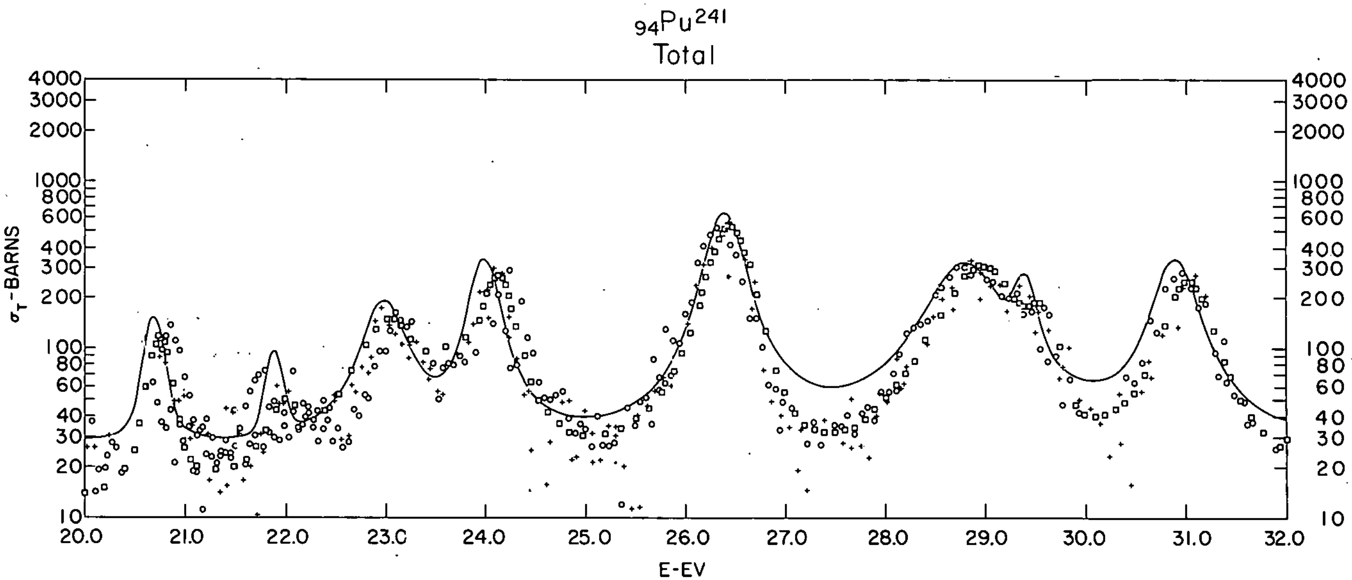

8. $Pu^{241}$ total cross section, 0.0 to 1.0 eV. For explanation of symbols, see BNL-325, 2nd Edition, 2nd Supplement (1965), p. 94-241-9.



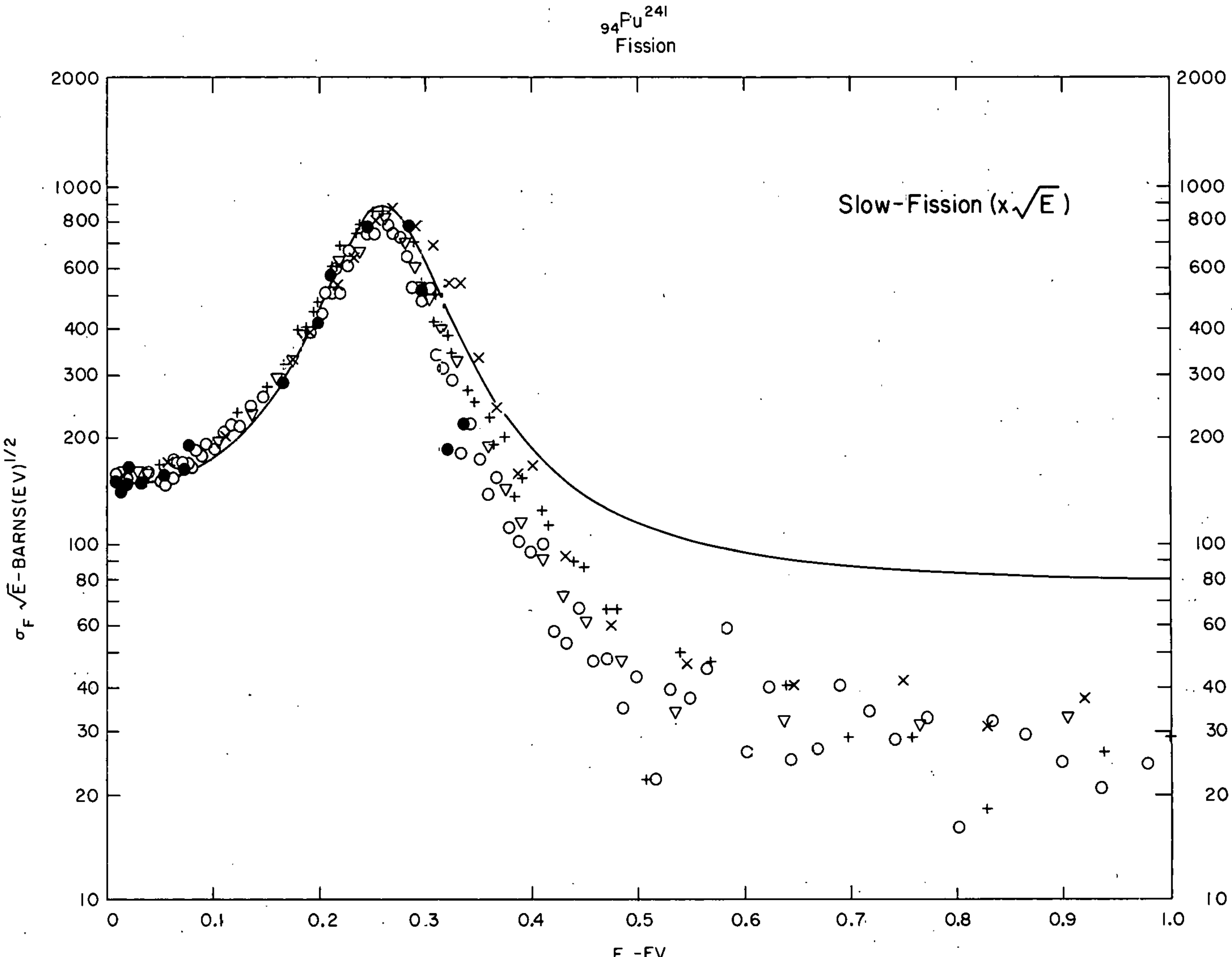

9. $Pu^{241}$ total cross section, 0.0 to 10.0 eV. For explanation of symbols, see BNL-325, 2nd Edition, 2nd Supplement (1965), p. 94-241-11.



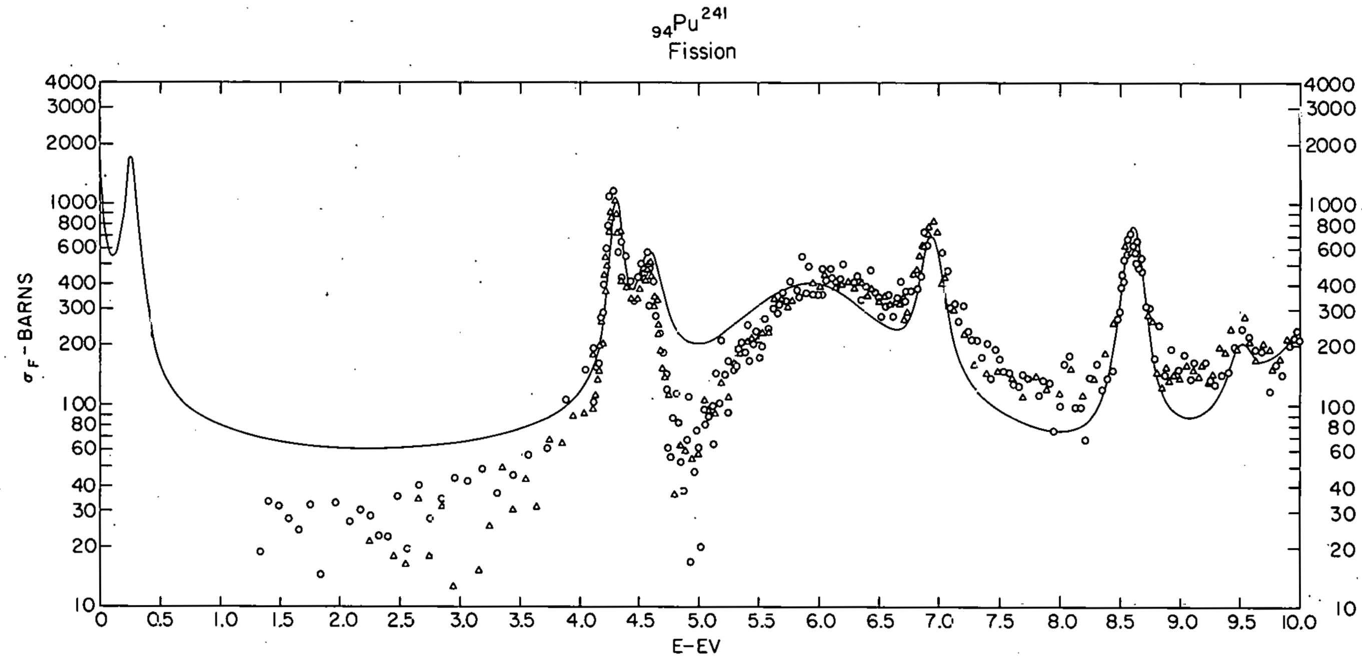

10. Pu$^{241}$ total cross section, 10.0 to 20.0 eV. For explanation of symbols, see BNL-325, 2nd Edition, 2nd Supplement (1965), p. 94-241-11.



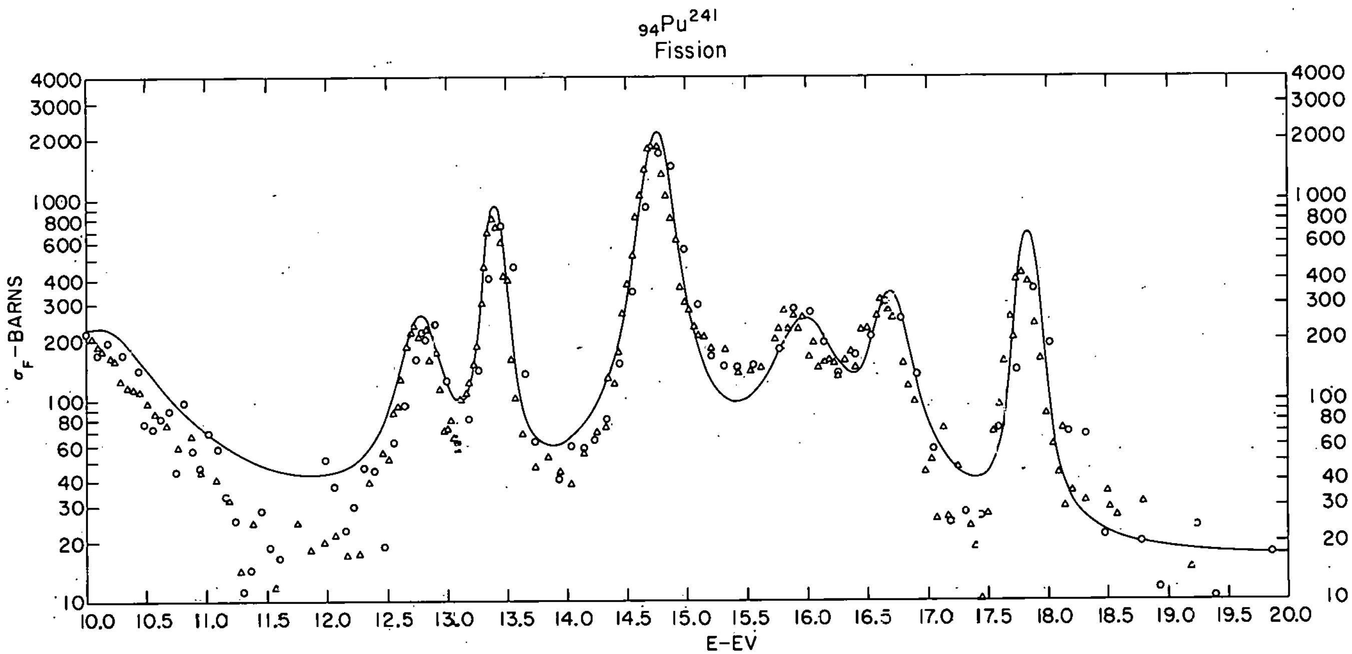

11. $Pu^{241}$ total cross section, 20.0 to 32.0 eV. For explanation of symbols, see BNL-325, 2nd Edition, 2nd Supplement (1965), p. 94-241-11.



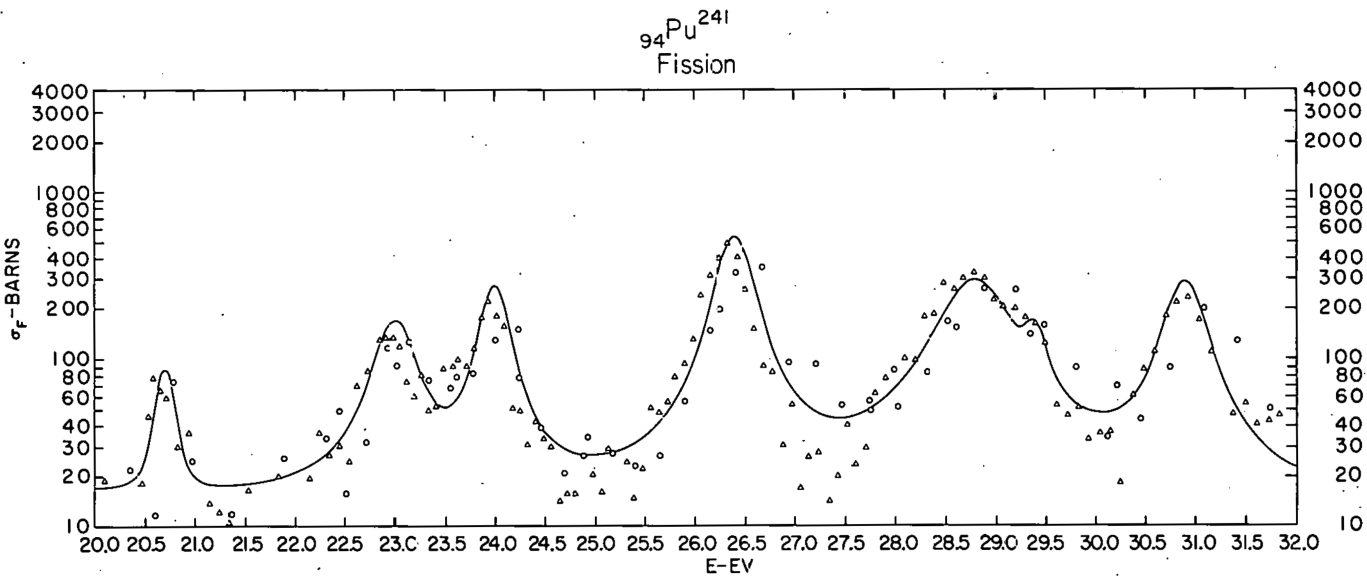

12. Pu$^{241}$ fission cross section, 0.0 to 1.0 eV. For explanation of symbols, see BNL-325, 2nd Edition, 2nd Supplement (1965), p. 94-241-10.



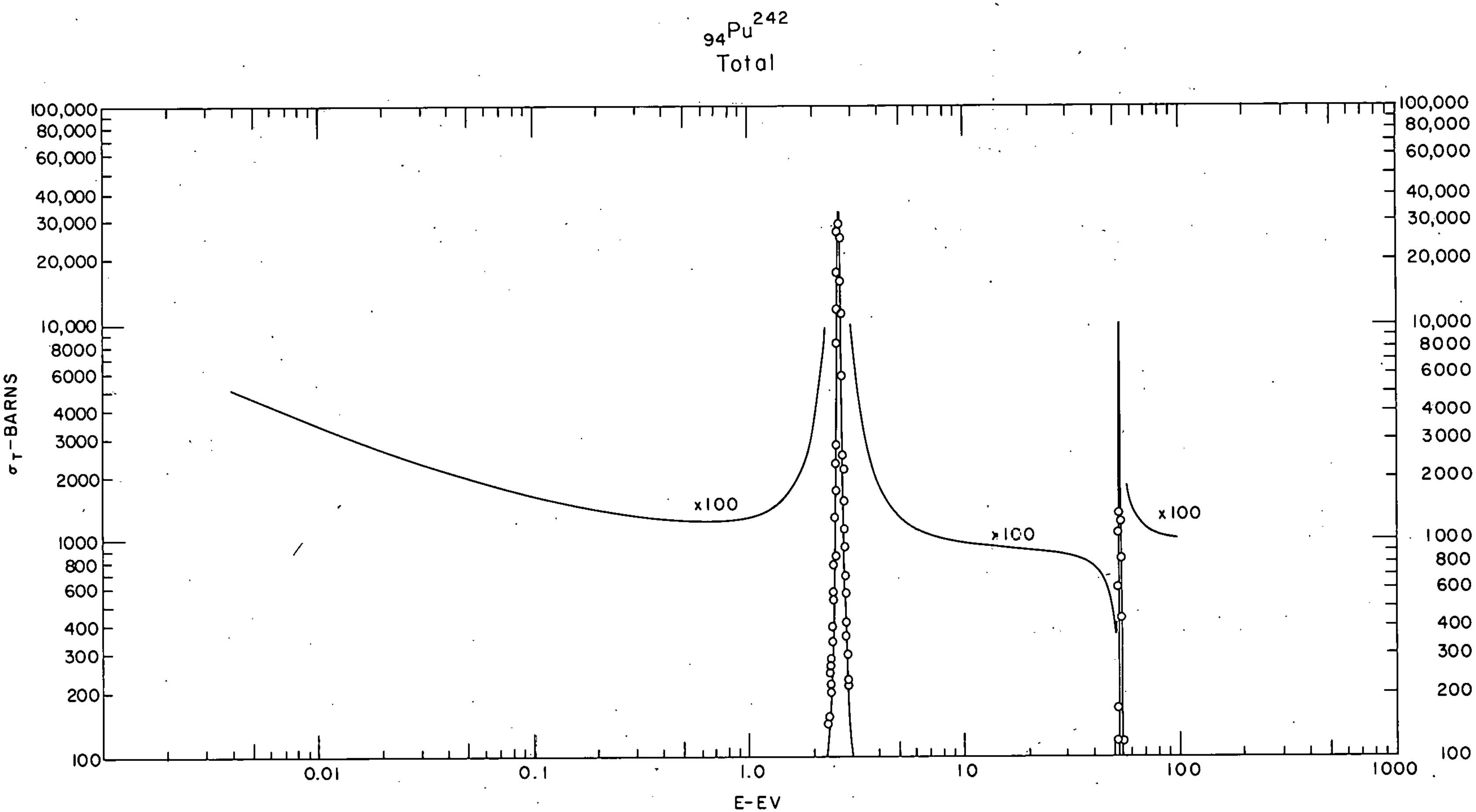

13. $Pu^{241}$ fission cross section, 0.0 to 10.0 eV. For explanation of symbols, see BNL-325, 2nd Edition, 2nd Supplement (1965), p. 94-241-13.



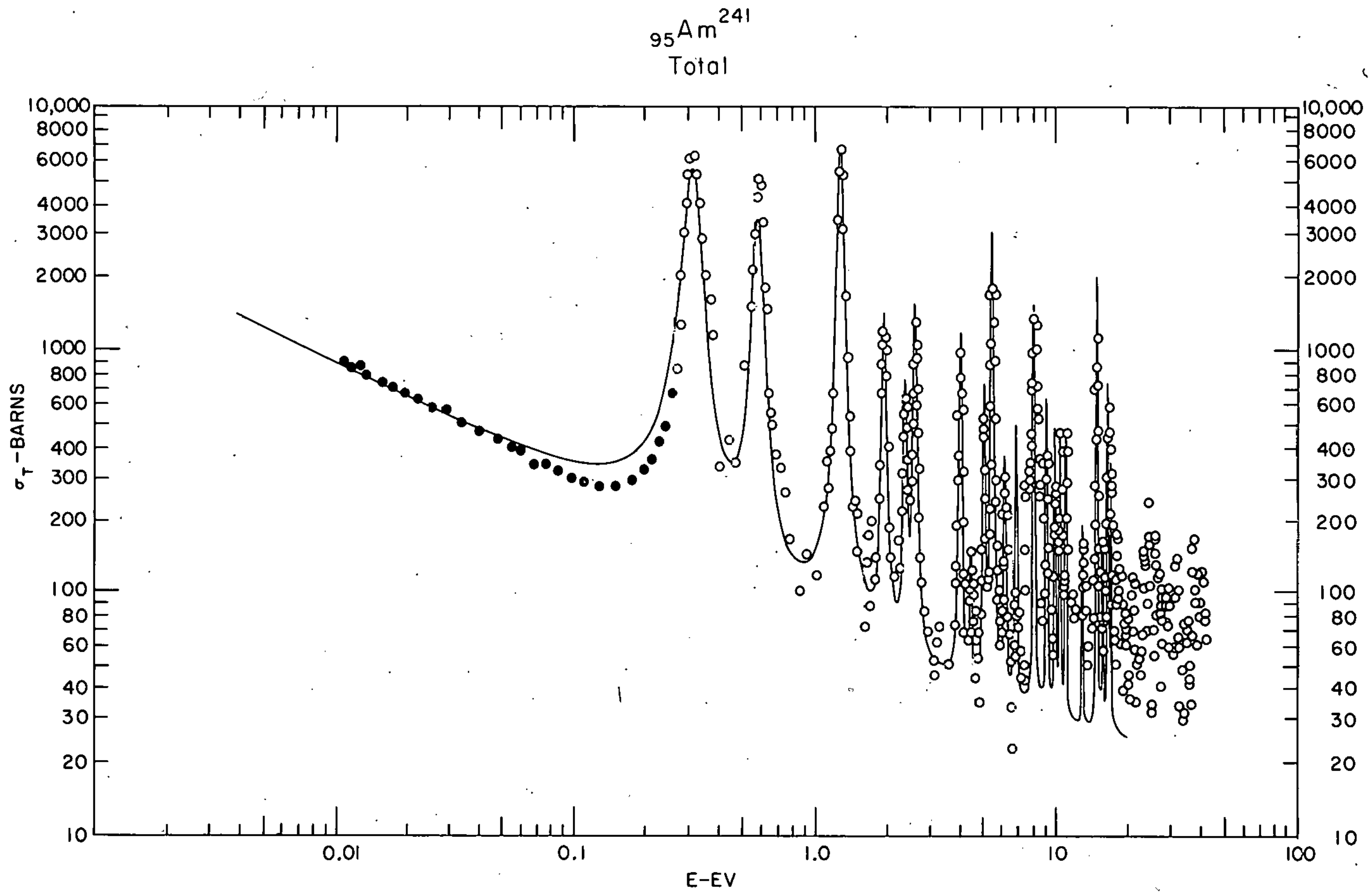

14. $Pu^{241}$ fission cross section, 10.0 to 20.0 eV. For explanation of symbols, see BNL-325, 2nd Edition, 2nd Supplement (1965), p. 94-241-13.



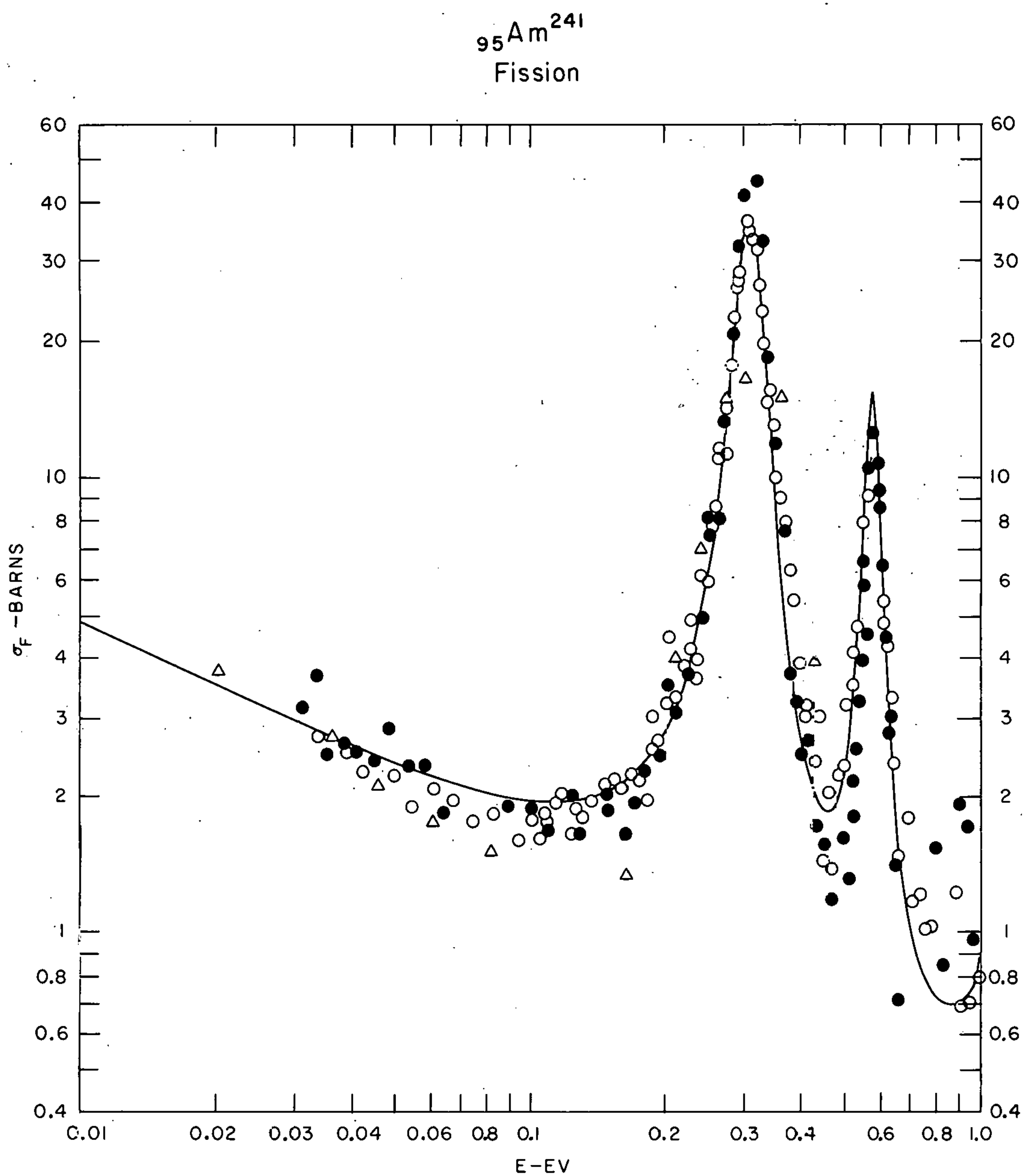

15. $Pu^{241}$ fission cross section, 20.0 to 32.0 eV. For explanation of symbols, see BNL-325, 2nd Edition, 2nd Supplement (1965), p. 94-241-13.



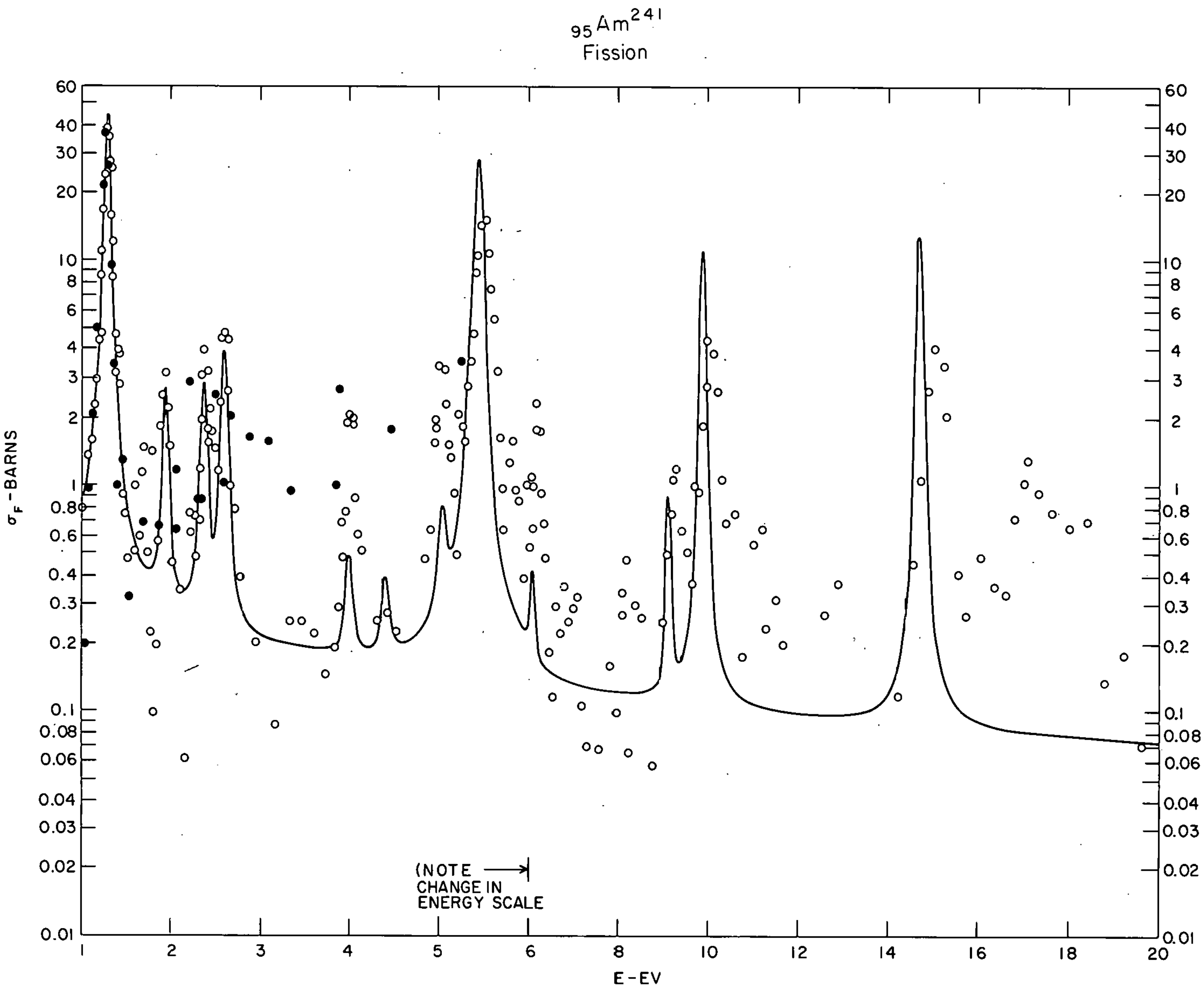

16. $Pu^{242}$ total cross section. For explanation of symbols, see BNL-325, 2nd Edition (1958), p. 358.



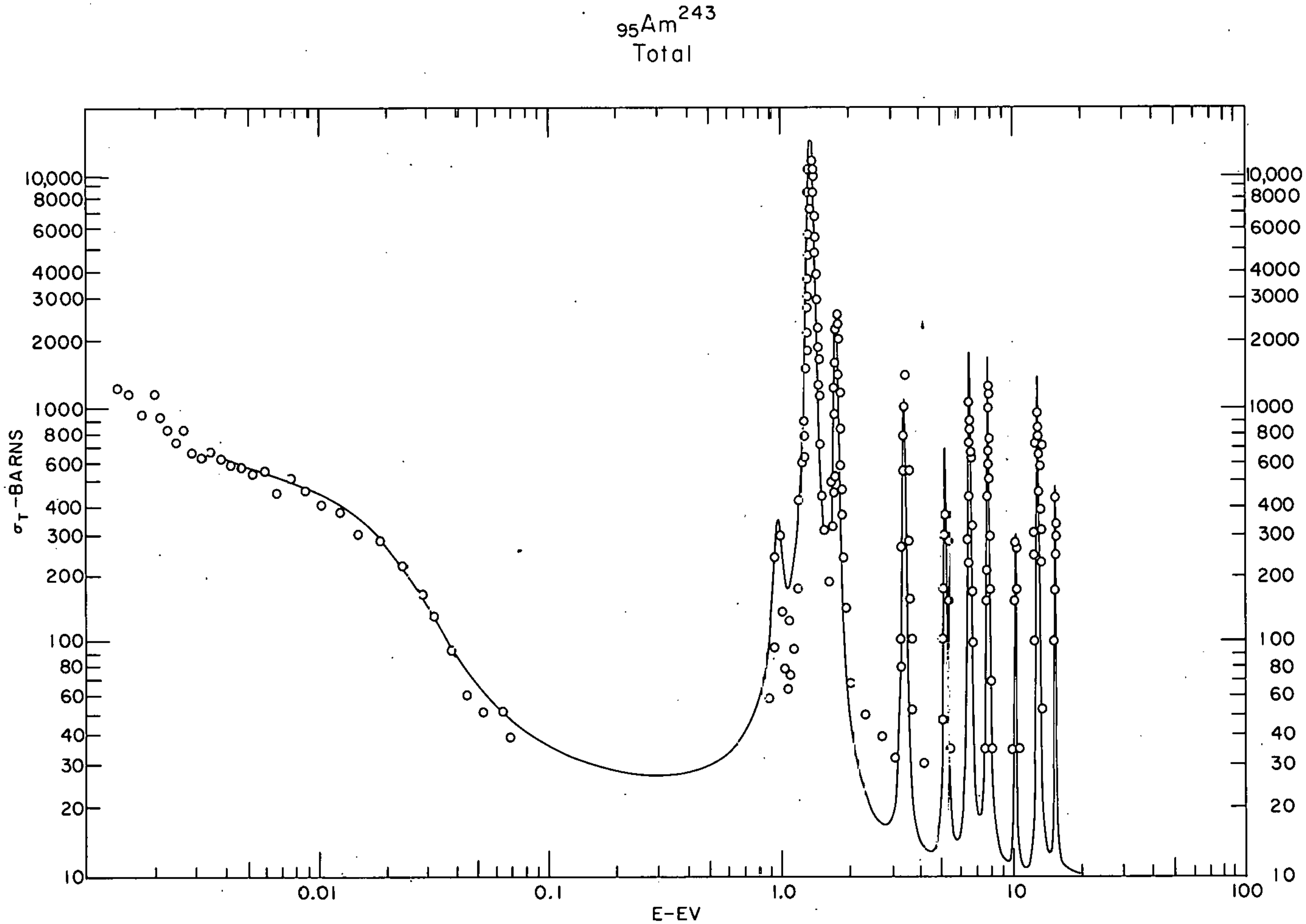

17. Am$^{241}$ total cross section. For explanation of symbols, see BNL-325, 2nd Edition, 1st Supplement (1960), p. 126.



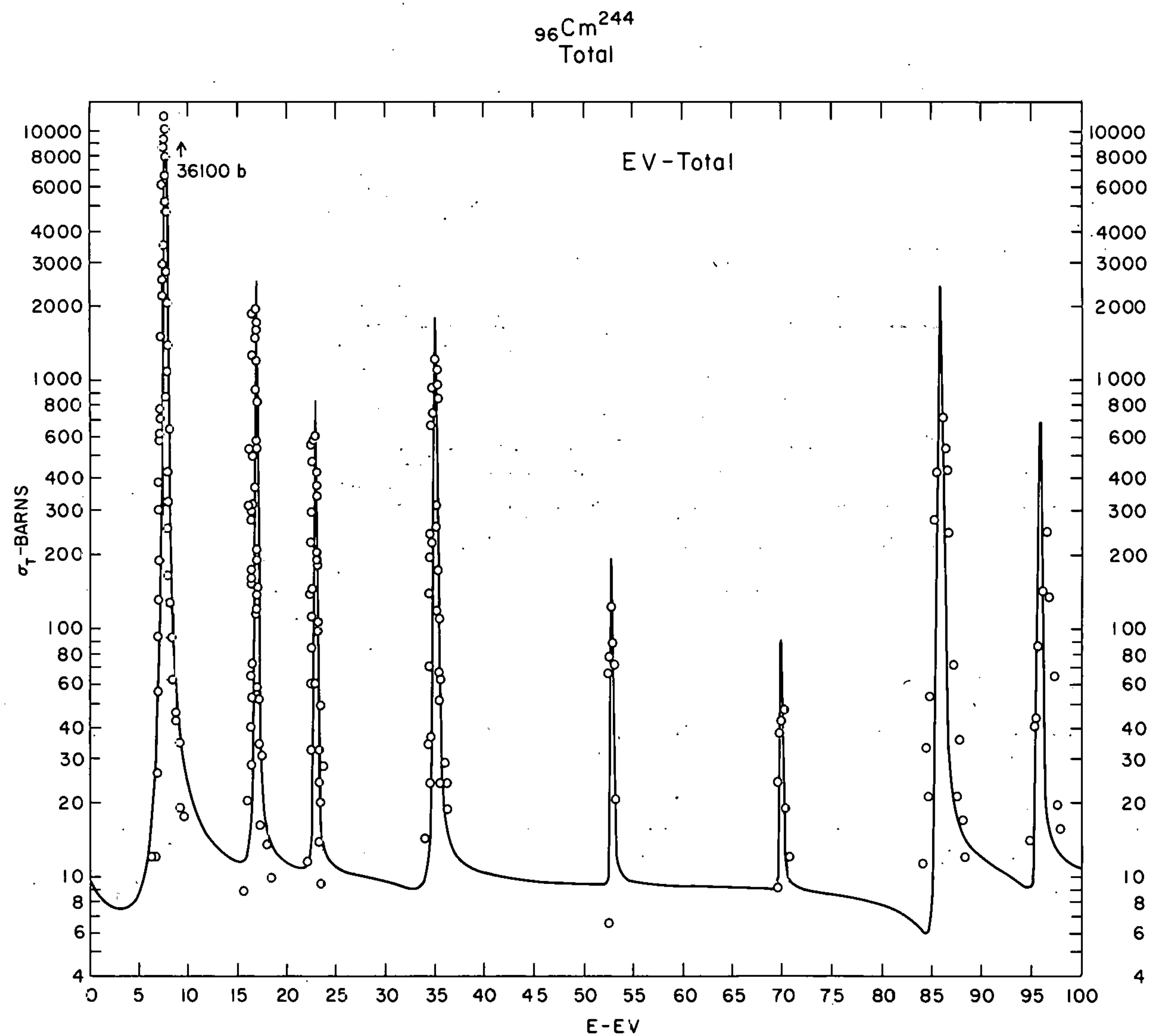

18. $Am^{241}$ fission cross section, 0.0 to 1.0 eV. For explanation of symbols, see BNL-325, 2nd Edition, 2nd Supplement (1965), p. 95-241-6.



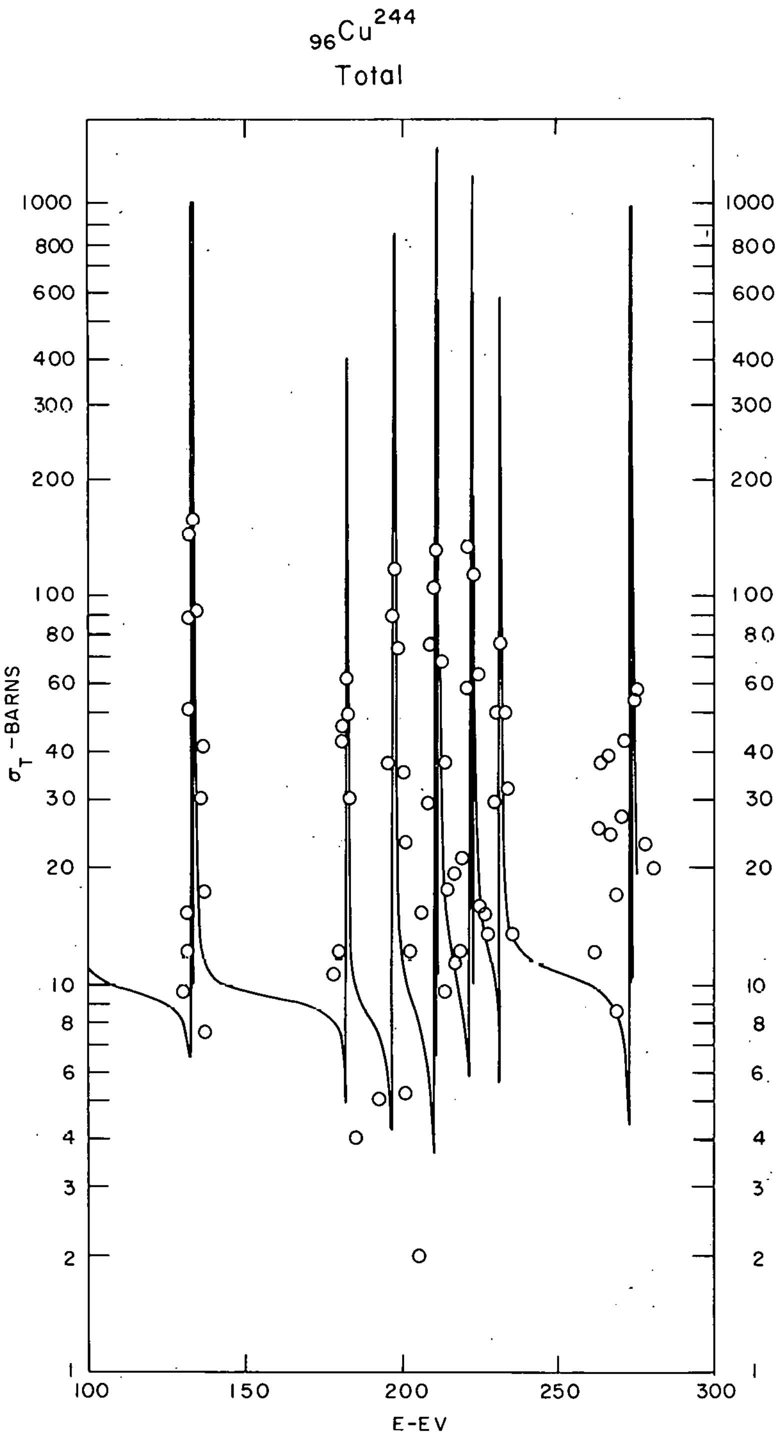

19. $Am^{241}$ fission cross section, 1.0 to 20.0 eV. For explanation of symbols, see BNL-325, 2nd Edition, 2nd Supplement (1965), p. 95-241-7.



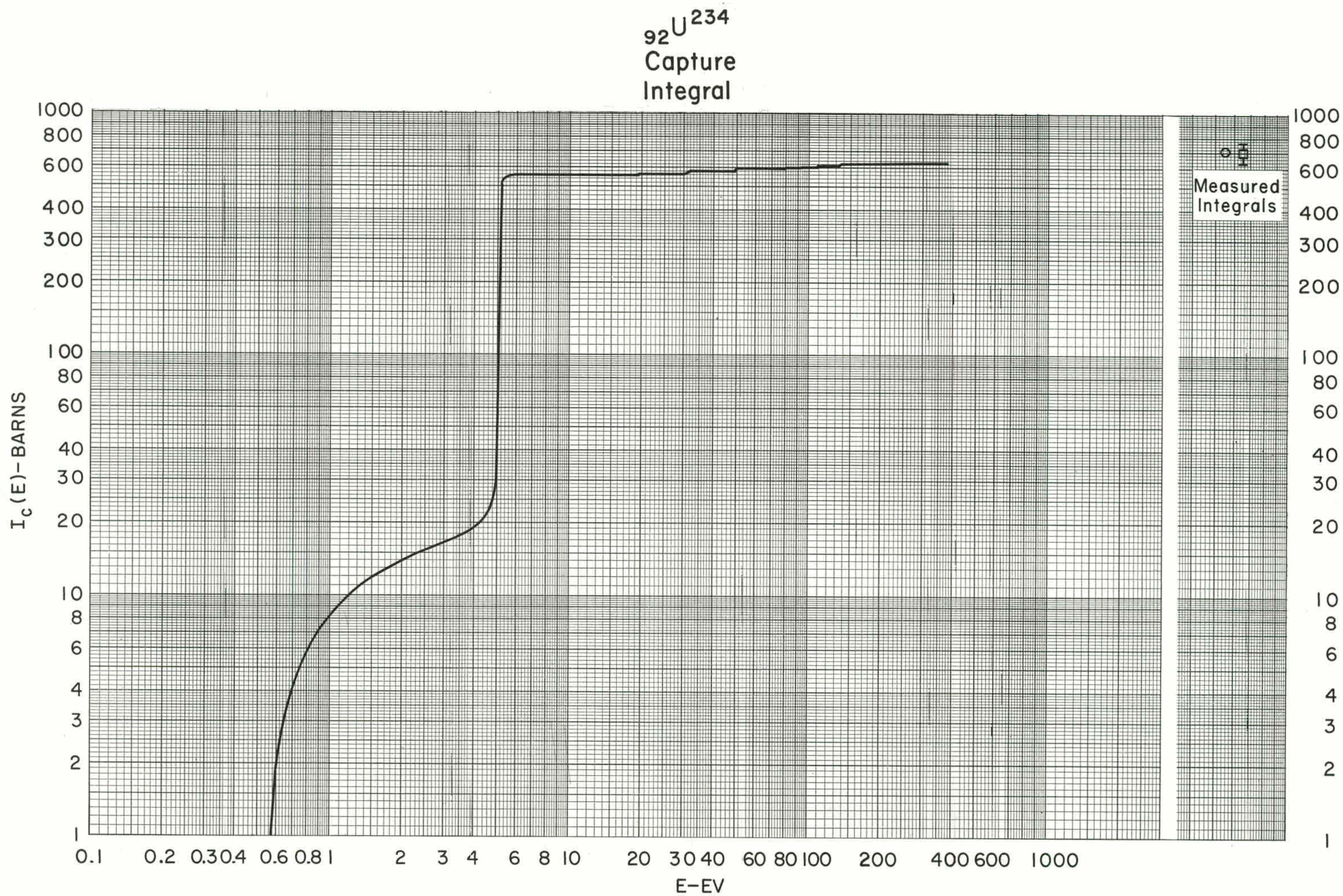

20. $Am^{243}$ total cross section. For explanation of symbols, see BNL-325, 2nd Edition (1958), pp. 361, 362.




21. $Cm^{244}$ total cross section, 0.0 to 100.0 eV. For explanation of symbols, see BNL-325, 2nd Edition, 2nd Supplement (1965), p. 96-244-2.

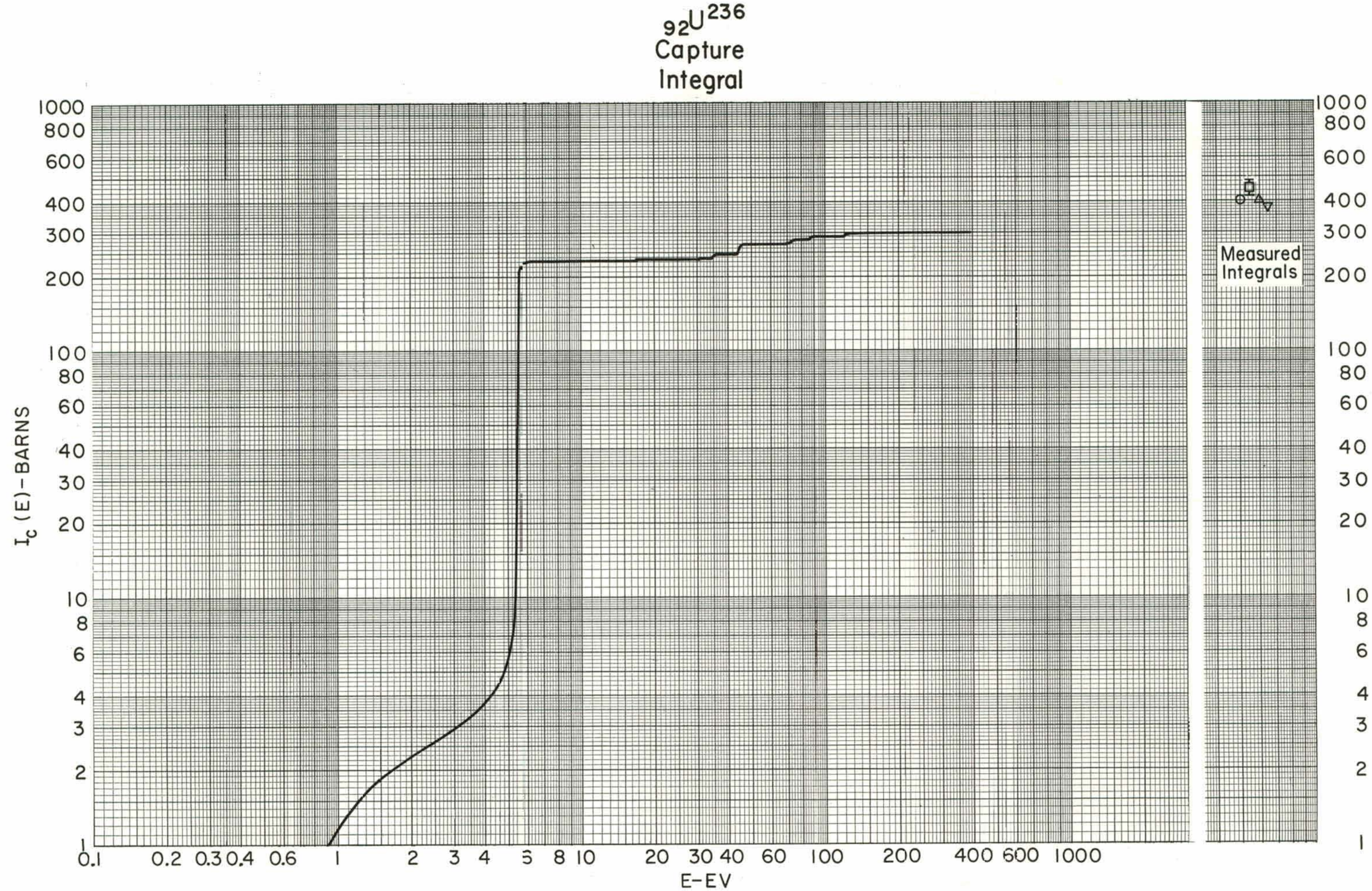



22. $Cm^{244}$ total cross section, 100.0 to 300.0 eV. For explanation of symbols, see BNL-325, 2nd Edition, 2nd Supplement (1965), p. 96-244-3.



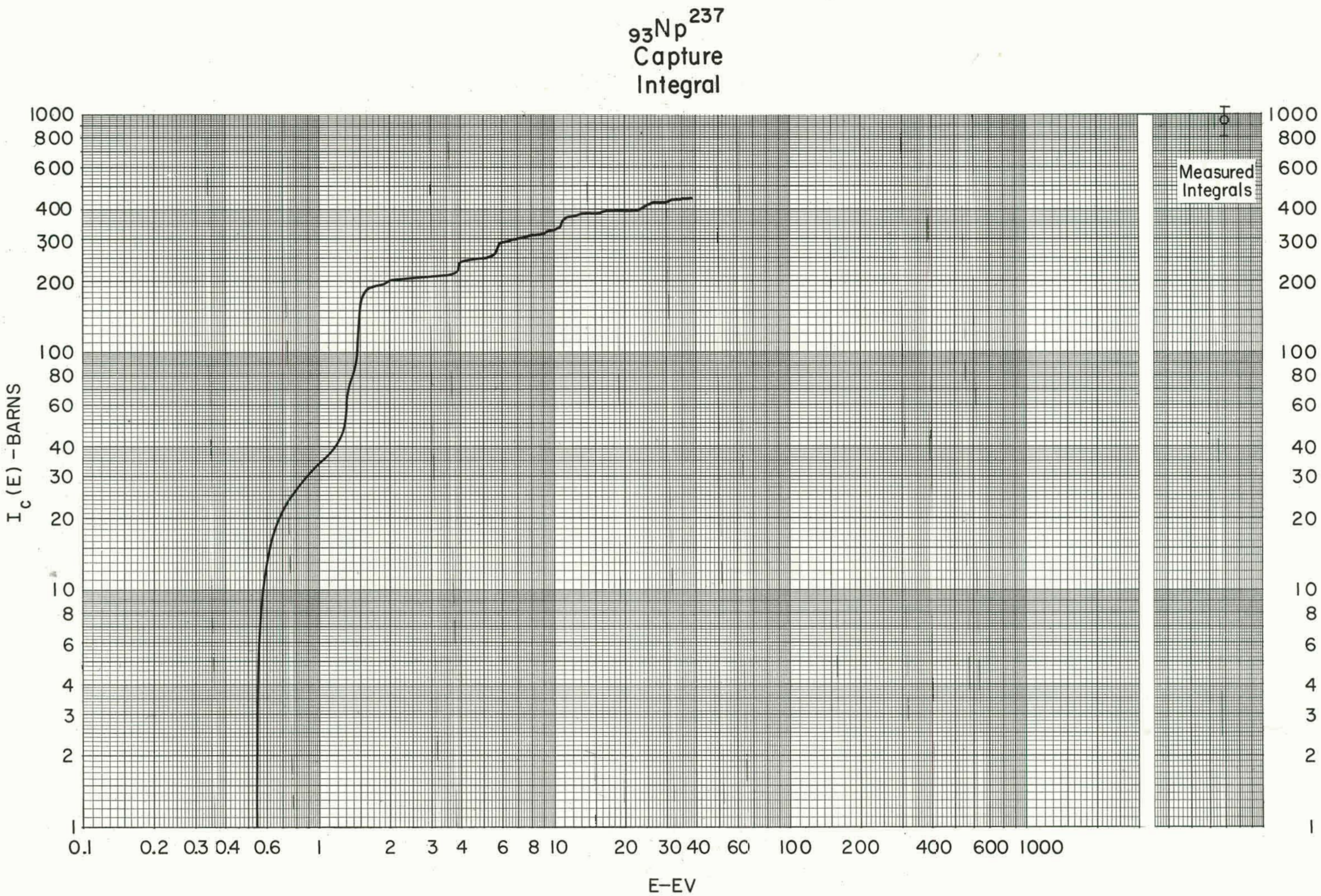

23. $U^{234}$ capture integral.

o - BAPS 1, 187 (1956)
□ - PIC 2-16, 64 (1958)



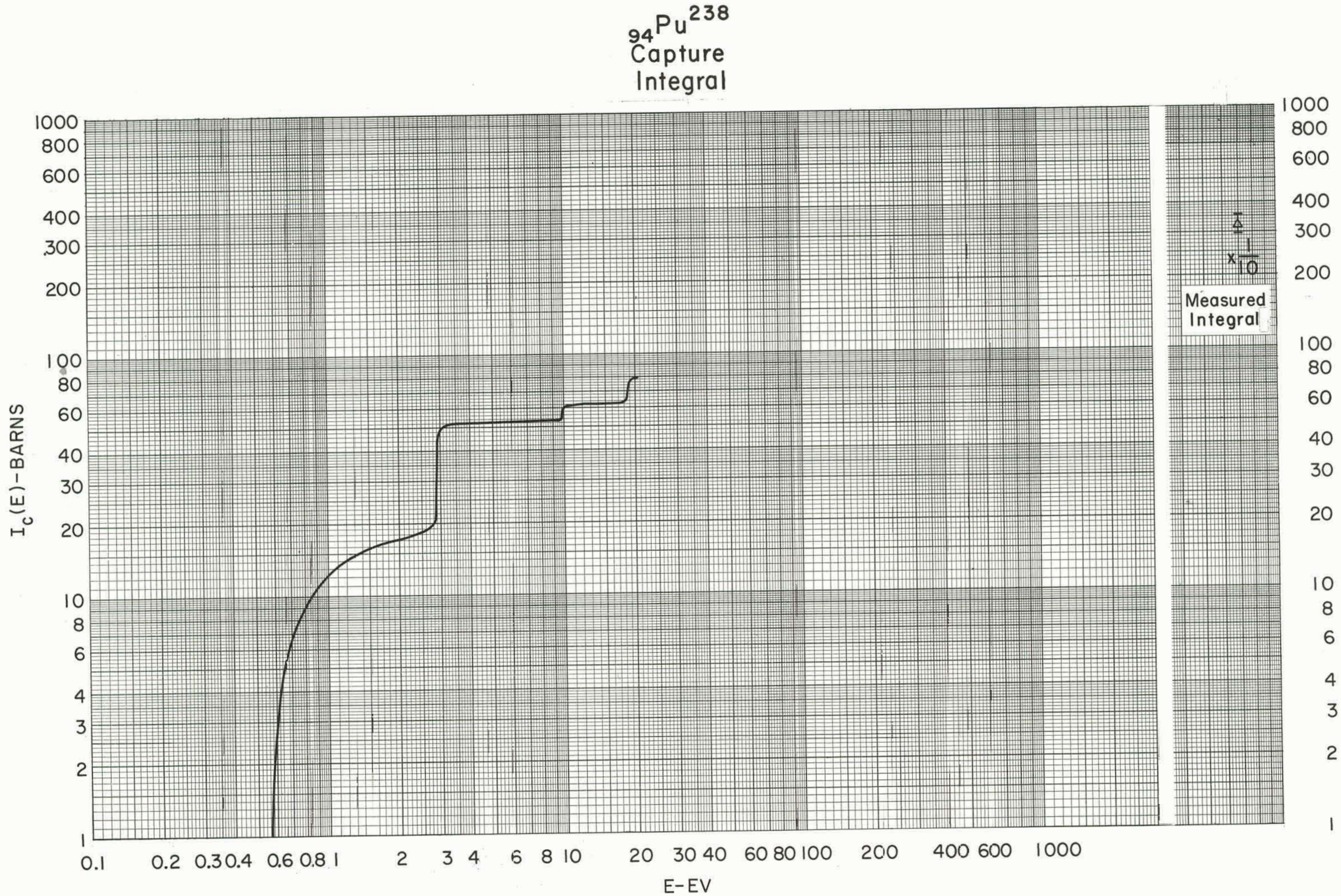

24. $U^{236}$ capture integral.

o - JNE 7, 81 (1958)
□ - PIC 2-16, 64 (1958)
Δ - WASH-191 (1957)
▽ - WASH-1041, 37 (1962)



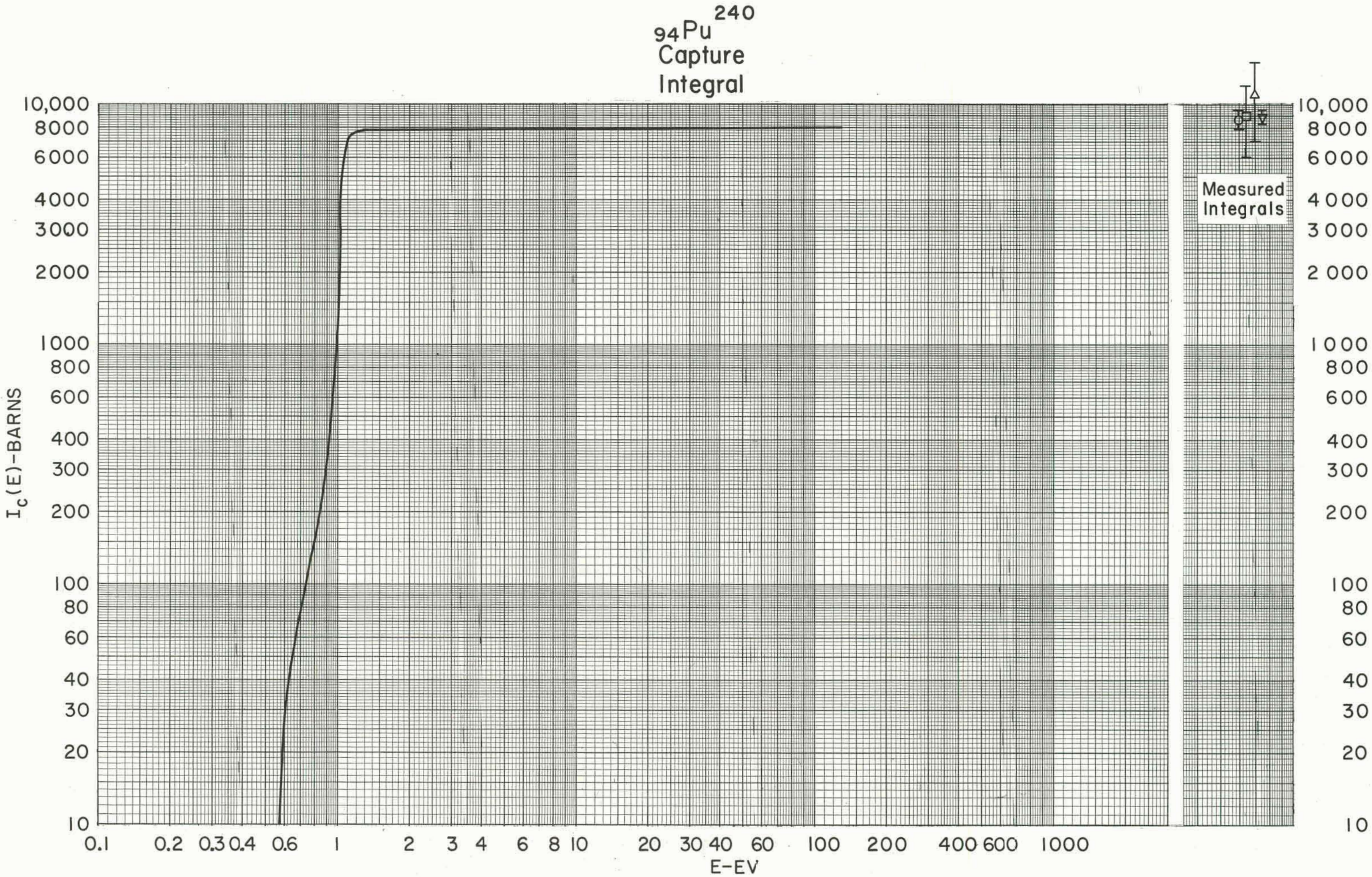

25. $Np^{237}$ capture integral.

o - (includes 1/v component) JNE A12, 32 (1960)



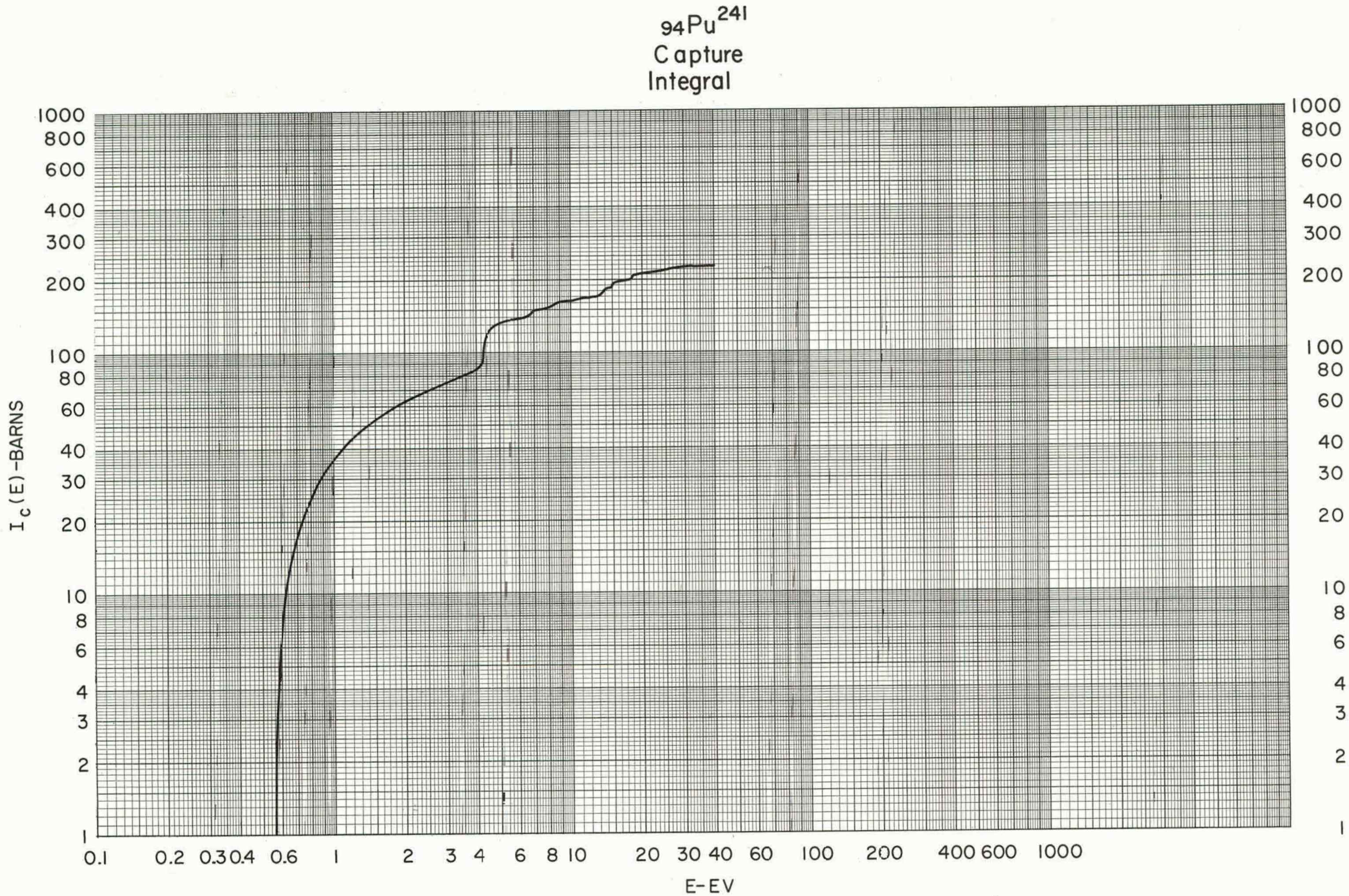

26. $Pu^{238}$ capture integral.

Δ - CJP 35, 147 (1957)

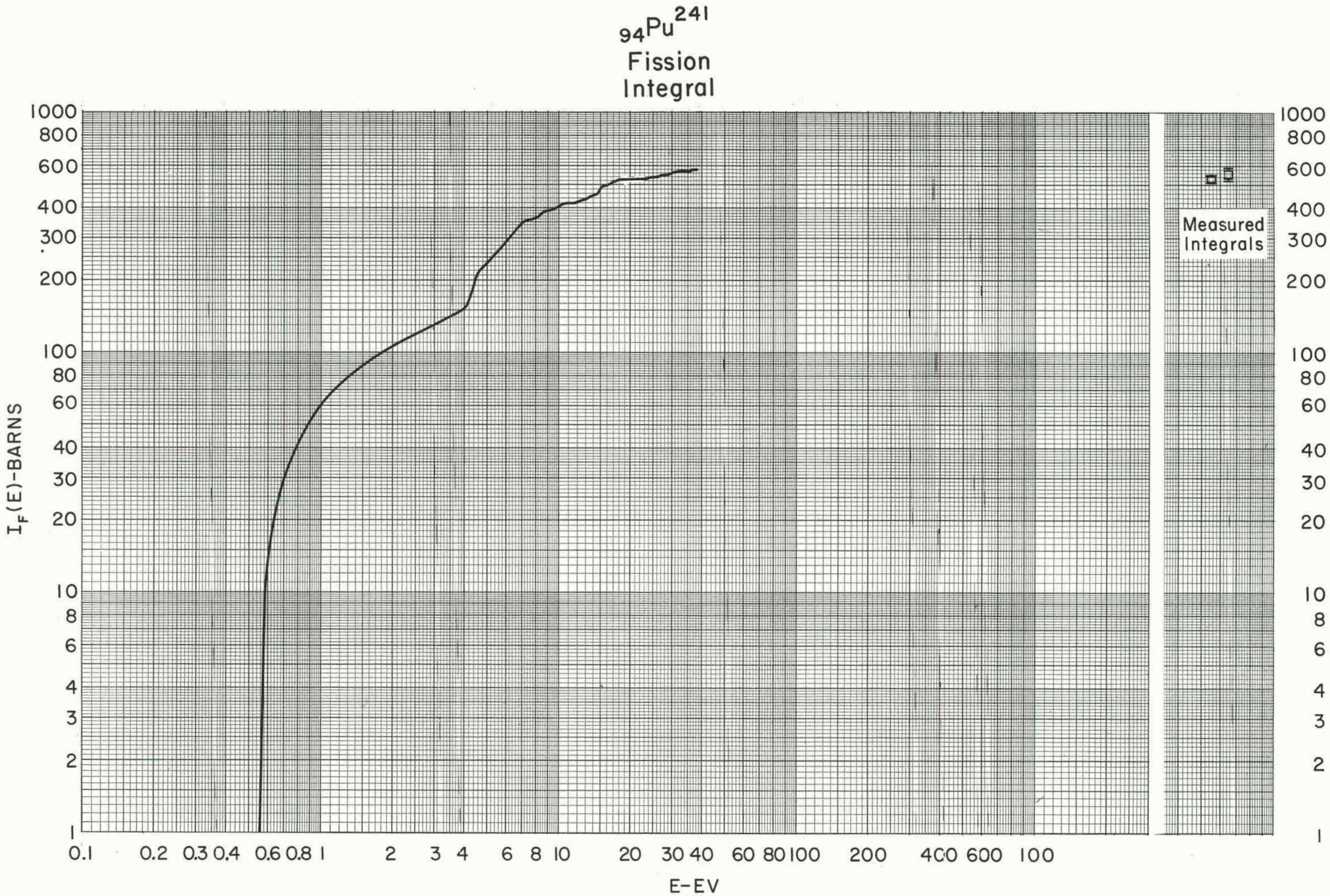



27. $Pu^{240}$ capture integral.

o - CRC 633 (1956)
□ - JNE 4, 86 (1957)
Δ - PIC 1-5, 173 (1956)
▽ - CJP 38, 157 (1960)

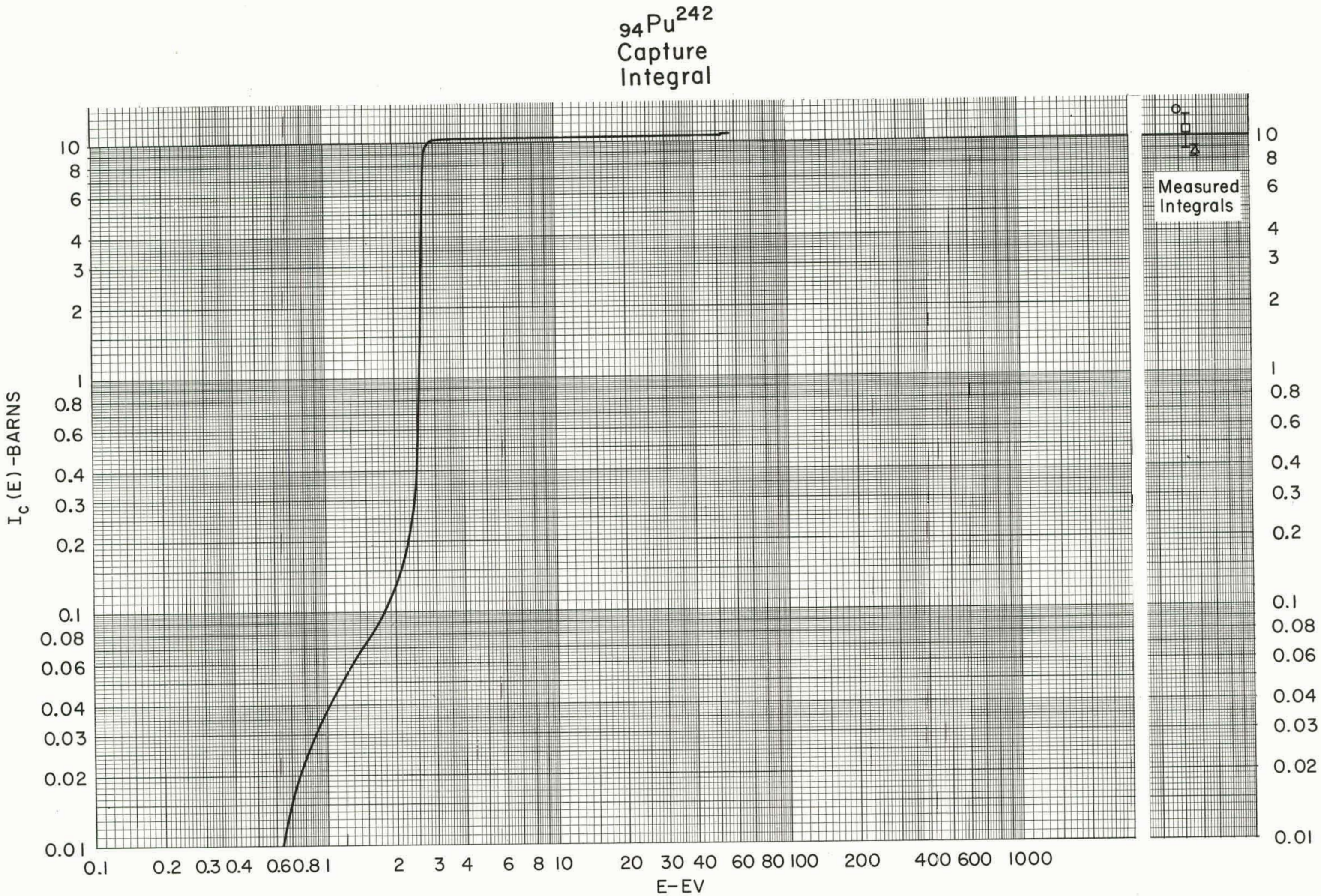



28. $Pu^{241}$ capture integral.




29. $Pu^{241}$ fission integral.

o - CRRP-1883 (1964)
□ - NSE 9, 341 (1961)

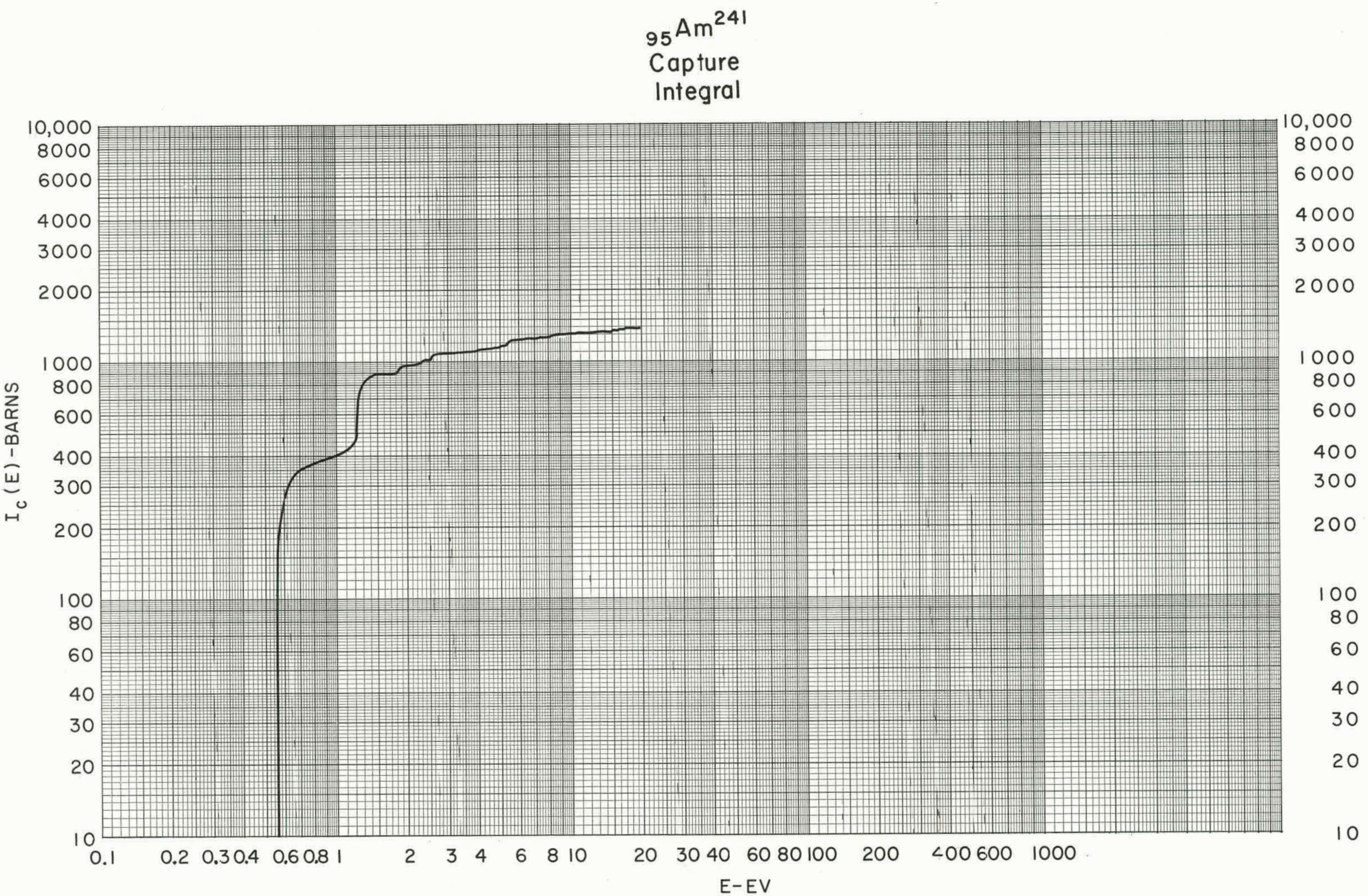



30. $Pu^{242}$ capture integral.

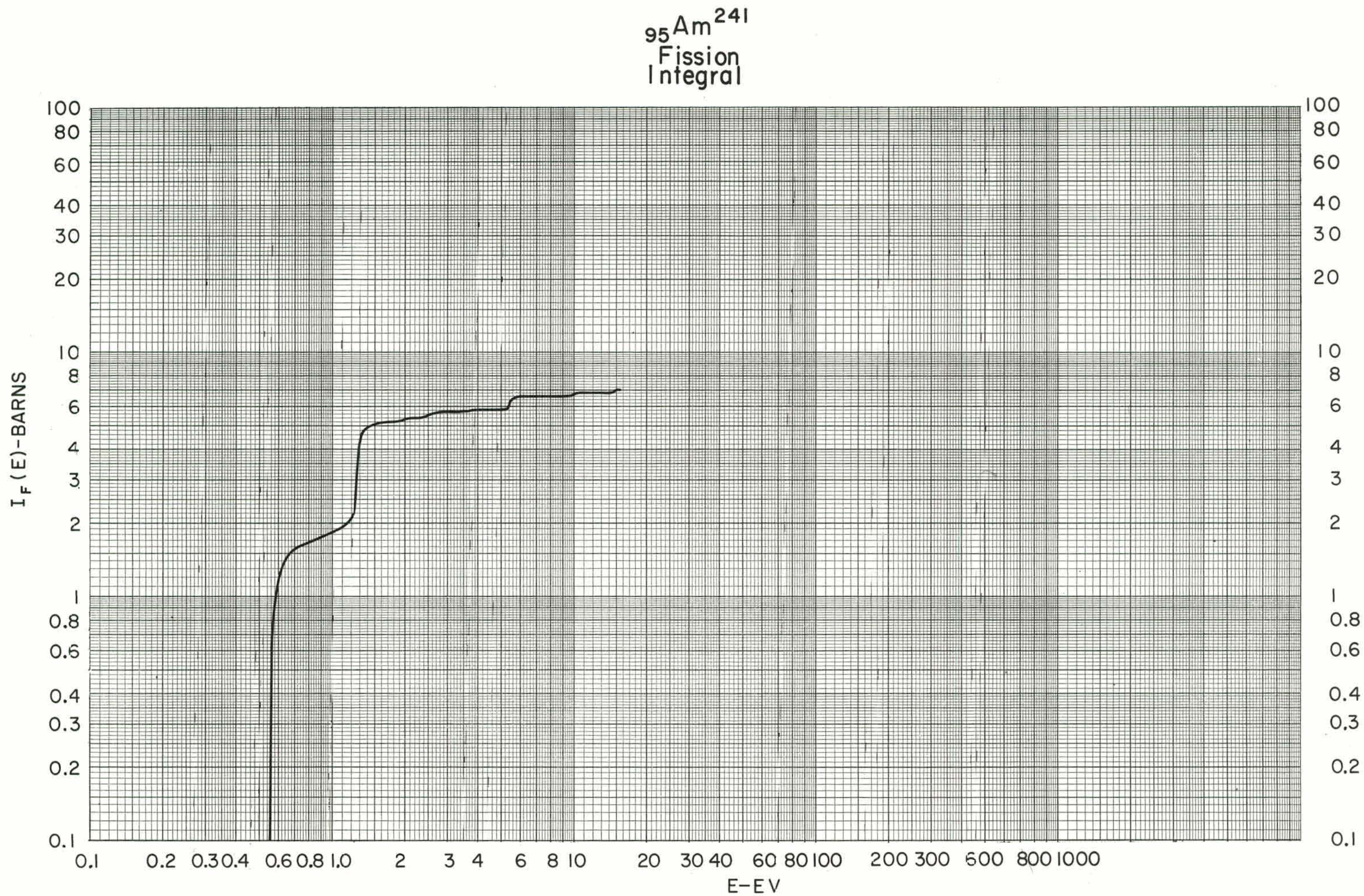
o - CJP 35, 147 (1957)

□ - PIC 2-16, 685 (1958)

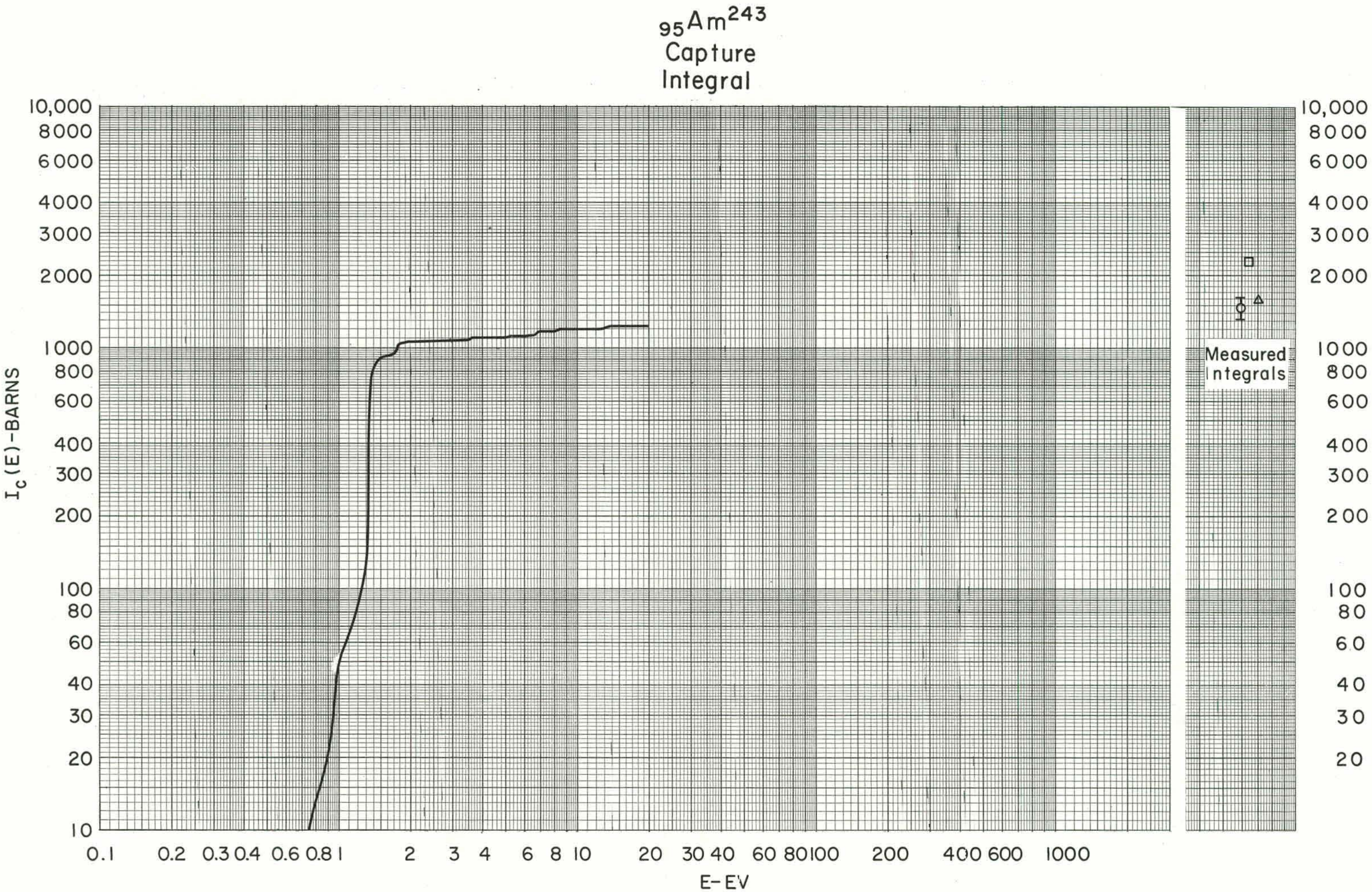
Δ - CRC 628 (1956)




31. $Am^{241}$ capture integral.

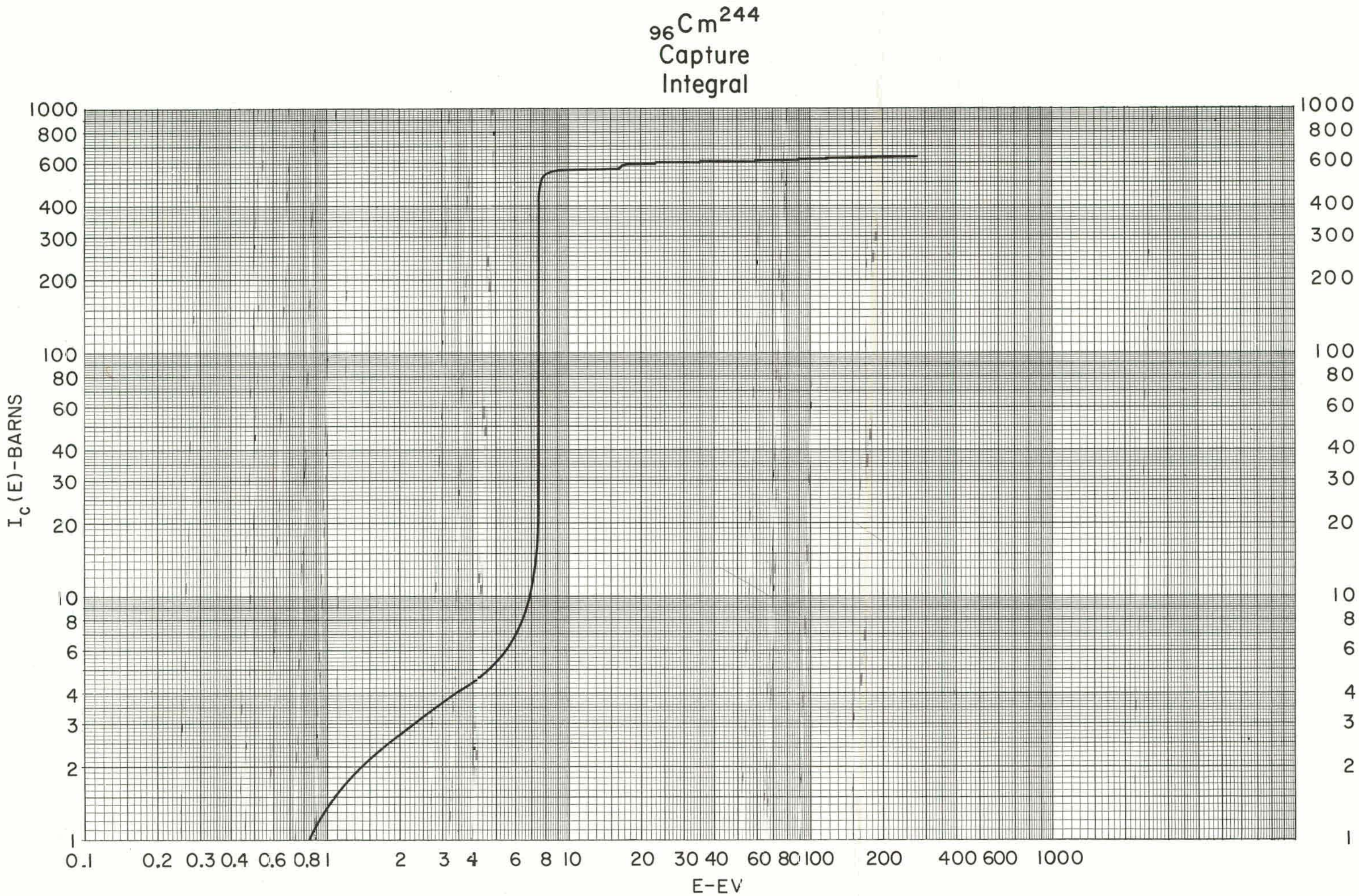



32. $Am^{241}$ fission integral.




33. $Am^{243}$ capture integral.

o - PR 114, 505 (1959)
□ - CJP 35, 147 (1957)
Δ - CRC 628 (1956)




34. $Cm^{244}$ capture integral.