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CALCULATION OF G-FACTORS FOR PU-241.

by C.H. Westcott and H.D. Lemmel

I. INTRODUCTION

During the preparation of the paper on the 2200 m/sec neutron data for fissile nuclides, a need for better values of the g-factors for Pu-241 (for both σ_a and σ_f) was encountered. The earlier values (Westcott 1960)* were based on the 1958 and 1960 editions of BNL-325, and at that time no reliable $\sigma_T(E)$ measurements were available; it was therefore assumed, f a u t e de m i e u x, that $g_a = g_f$.

As some new measurements are now available, a more exact calculation could be performed.

* AECL-1101

IAEA, Vienna,
10 August 1965

II THE MEASUREMENTS AND REFERENCES

A. total cross section

1. R.B. Schwartz, BNL
   -- Data given in: BNL-325
   Other reference: Bull.Am.Phys.Soc.Ser.II 3, 176, 1958
   This measurement is superseded and was not used.

2. O.D. Simpson, N.H. Marshall, MTR
   IDO-16679, 1961

3. D.S. Craig, C.H. Westcott, CRC
   AECL-1948, 1964

B. fission cross section

4. Y.B. Adamchuk et al., USSR
   Data given in: P.A. Egelstaff, NRDC 99, 1957
   Other reference: Y.B. Adamchuk et al., 1. ICPUAE 1955, Vol. 4, p. 645.
   This measurement was discussed but finally not used.

5. R. Richmond, B.T. Price, Harwell
   Data given in: BNL-325
   Other reference: J.Nucl.Eng. 2, 177, 1956.
   This measurement is superseded and was not used.

6. Hanford I
   E.J. Seppi, W.J. Friesen, B.R. Leonard Jr., HW-53492 p.25, 1957

7. Hanford II
   In BNL-325, data from Hanford with reference "unpublished" are given; these are different from Hanford I or Hanford III.

8. Hanford III
   B.R. Leonard Jr., S.J. Friesenhahn, HW-62727 p.19, 1959

9. G.D. James, Harwell
   Private communication 1964

10. T. Watanabe, O.D. Simpson
    IDO-16995, 1964

III THE PROCEDURE

1. The g-factors were calculated from the cross-section $\sigma(E)$ according to

$$g(T) = \frac{2}{\sqrt{\pi}} \frac{1}{\sqrt{E_o \sigma(E_o)}} \int_0^\infty \frac{1}{E_T} \frac{\sqrt{E}}{\sqrt{E_T}} e^{-\frac{E}{E_T}} \cdot \sqrt{E}\ \sigma(E)\, dE \qquad (1)$$

where $E_o = 0{,}0253$ eV

$E_T = E_o \frac{T}{T_o}$

$T_o = 293{,}6^oK$

2. Each measurement was treated separately and averages were taken only after the g-factors had been calculated for each measurement. This avoided having to take care of normalization problems.

3. The data for each measurement were plotted on a sufficiently large scale, and a Breit-Wigner-formula with central energy E_r, width Γ and coefficient h as free parameters was fitted by eye. The fit was then subtracted from the measured values. For all measurements, the Breit-Wigner parameters $E_r = 0{,}256$ eV and $\Gamma/2 = 0{,}056$ eV were used. Using these values, a smooth curve remained after subtraction of the B-W-fit.

4. The remaining rest (measured values minus B-W) was fitted to a polynomial of the fifth power. For this purpose, the energy scale was split up into several energy ranges with different polynomial fits in each. The energy ranges were 0, 0.04, 0.07, 0.1, 0.16, 0.28, 0.52, 0.76, 1.96, 10.0 eV. For reach energy range, six representative equidistant values were chosen by eye, and the polynomial was fitted to these representative values. As the error in the choice of the representative values was small against the statistical errors, this method appeared to be sufficiently accurate.

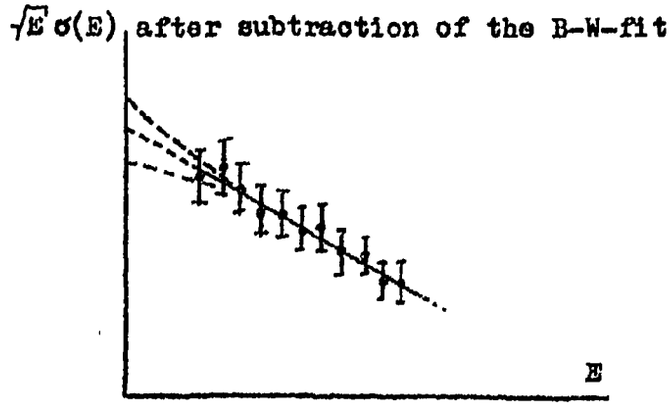
5. Thus, the cross section was fitted to:

$$\sqrt{E}\ \sigma(E) = a_{no} + a_{n1}E + a_{n2}E^2 + a_{n3}E^3 + a_{n4}E^4 + a_{n5}E^5 + \frac{h}{1+(\frac{E-E_r}{\Gamma/2})^2} \qquad (2)$$

where n indicates the energy range.

6. In most of the measurements, the lowest energy measured was near 0,02eV. Therefore, special care was needed in the extrapolation of the

measured values to zero energy. To estimate the influence of the extrapolation, g-factors were calculated for low, middle and high extrapolated values.



Example for different extrapolations to zero energy

7. A constant scattering cross-section of σ_s = 11 barns was assumed and subtracted from the total cross-section for the calculation of the absorption g-factor g_a.

IV RESULTS

A: <u>absorption</u>

T/°C	SIMPSON	CRAIG	60% CRAIG +40% SIMPSON	estimated standard error
20	1.032	1.029	1.030	± .2%
40	1.040	1.038	1.039	
60	1.050	1.047	1.048	
80	1.062	1.059	1.060	
100	1.075	1.071	1.073	± .2%
120	1.089	1.085	1.086	
140	1.105	1.101	1.103	
160	1.122	1.117	1.119	
180	1.140	1.135	1.137	
200	1.160	1.153	1.156	
220	1.180	1.173	1.176	
240	1.201	1.193	1.196	
260	1.223	1.214	1.218	
280	1.245	1.236	1.240	
300	1.268	1.258	1.262	
330	1.302	1.291	1.295	
360	1.337	1.325	1.330	
390	1.371	1.358	1.363	
420	1.406	1.391	1.397	
450	1.439	1.424	1.429	
480	1.472	1.456	1.462	
510	1.504	1.487	1.494	

A: absorption (cont'd)

T/°C	SIMPSON	CRAIG	60% CRAIG +40% SIMPSON	estimated standard error
540	1.534	1.516	1.523	
570	1.564	1.545	1.553	
600	1.591	1.572	1.580	± .7%

B: fission

T/°C	(Adamchuk)	Hanf. II	Hanf. III+II	James	(Watanabe)	.5 Hanf.III +.5 James	.75 Hanf.III .25 James	estimated stand.error
20	1.048	1.043	1.042	1.036	1.046	1.039	1.041	± .3%
40	1.059	1.052	1.052	1.045	1.056	1.049	1.050	
60	1.071	1.063	1.062	1.056	1.067	1.059	1.061	
80	1.084	1.075	1.074	1.068	1.080	1.071	1.073	
100	1.098	1.089	1.087	1.081	1.093	1.084	1.086	
120	1.112	1.103	1.102	1.095	1.108	1.099	1.100	
140	1.128	1.119	1.117	1.110	1.124	1.114	1.115	
160	1.144	1.136	1.134	1.126	1.141	1.130	1.132	
180	1.161	1.153	1.151	1.143	1.159	1.147	1.149	
200	1.179	1.172	1.170	1.160	1.178	1.165	1.168	
220	1.197	1.191	1.189	1.179	1.197	1.184	1.187	
240	1.216	1.211	1.208	1.197	1.217	1.203	1.205	
260	1.235	1.232	1.229	1.216	1.238	1.223	1.226	
280	1.254	1.253	1.249	1.236	1.259	1.243	1.246	
300	1.274	1.274	1.270	1.255	1.280	1.263	1.266	± .5%
330	1.303	1.307	1.302	1.285	1.313			
360	1.333	1.339	1.333	1.314	1.345			
390	1.362	1.371	1.365	1.344	1.377			
420	1.390	1.403	1.396	1.372	1.408			
450	1.418	1.434	1.426	1.400	1.439			
480	1.444	1.464	1.455	1.427	1.469			
510	1.470	1.493	1.483	1.452	1.497			
540	1.495	1.521	1.510	1.477	1.525			
570	1.518	1.548	1.536	1.500	1.551			
600	1.540	1.573	1.560	1.522	1.576	(1.541)	(1.551)	(± 1%)

V DISCUSSION

There are mainly three sources of error:

(i) due to normalization.

If the normalization of the entire $\sigma(E)$-curve is incorrect, this does not affect the calculation of g-factors. However, an uncertainty in the normalization value arises due to statistical fluctuations around the normalization point.

(ii) due to extrapolation to zero-energy.

This error could be estimated by using different extrapolations; it decreases considerably at higher temperatures.

(iii) due to the shape of the resonance.

Statistical errors in the $\sigma(E)$-curve do not affect the calculation of g-factors. However, any systematic error resulting in different peak-heights or peak shapes, may have a considerable influence on the g-factors.

A: absorption

Both measurements agree quite well. The estimated standard error due to normalization is in both cases $\pm$ 0.3%.

The estimated standard error due to extrapolation is in both cases 0.08% at 20°C, 0.007% at 600°C. The error due to the resonance shape is - by comparison of both measurements: $\pm$ 0.02% at 20°C, 1.3% at 600°C.

As the measurement of Craig appears a little better with respect to resolution and statistics, we would recommend an averaging of 60% Craig + 40% Simpson.

B: fission

After subtraction of the Breit-Wigner fit, the measurement of Adamchuk showed another peak at 0.303 eV, probably due to another isotope. This was subtracted and neglected. This measurement was used for comparison only.

In the measurement Hanford III, a very good sample (96.6% Pu-241) was used, but measurement was only done for E>0.1 eV. At lower energies

Hanford II was used, which agrees with Hanford III very well, despite in Hanford II a poor sample was used. Hanford II had to be renormalized by fitting the overlapping region to Hanford III.

The measurement of James extends to 0.008 eV, so that the extrapolation error is small. The peak shape of James does not agree with the Hanford measurements.

The measurement of Watanabe is apparently wrong in the energy region below 0.04 eV. Thus, an extrapolation to zero energy and a determination of the normalization value at 0.0253 eV can only be done by comparison with James. If one does so, the peak shape of Watanabe confirms that of Hanford rather than that of James.

The estimated standard error due to normalization is $\pm$ 0.4% in the cases of Hanford and James (Adamchuk: $\pm$ 1%, Watanabe: query).

The estimated standard error due to extrapolation is:
Hanford: $\pm$ 0.15% at 20°C, $\pm$ 0.02% at 600°C.
James: $\pm$ 0.07% at 20°C, $\pm$ 0.01% at 600°C.

Comparison of the Hanford and James $\sqrt{E}\,\sigma(E)$-curve shows a difference of 6% in the ratio of the peak cross-section to that at .0253 eV. This gives rise to a difference of g-factors of .5% at 20°C or 3% at 600°C. This is a systematic error. Comparison with Adamchuk and Watanabe suggests that the Hanford measurements may be the better ones.

Thus we would recommend:

(a) The discrepancy between James and the other results receive further study, preferably further measurements should be made.

(b) At temperatures below about 300°C, where the systematic error is in the order of magnitude of the statistical error, an "average" value could be recommended for use, with a weight of .75 given to Hanford and .25 to James.

(c) At temperatures above about 300°C, where the systematic error is dominant, we feel we cannot recommend the use of an averaged value since the g-factors obtained by using James' results differ too much from the others.

Note: In INDSWG-61 a 50:50 weighting was adopted; in fact, this makes little difference at or near room temperature.

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Fission and Absorption g-Factors of ^{241}Pu

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The effective cross-section of a Maxwellian neutron spectrum can be given as the product of the cross-section at 0.0253 eV and the "g-factor". Fission and absorption g-factors of ^{241}Pu are calculated from various cross-section measurements and tabulated in the temperature range 0° to $2000^{\circ}C$. Some discrepancies between different measurements are discussed.

I. INTRODUCTION

The effective cross-section $\hat{\sigma}$ (T) for neutrons having a pure Maxwellian distribution of energies n(E;T) for temperature T is given as the product of the cross-section at 0.0253 eV and the so-called g-factor (Westcott, 1955):

$$\hat{\sigma}\ (T) = \sigma\ (0.0253\ \text{eV})\ .\ g\ (T)$$

The g-factor is a function of temperature and can be calculated from the cross-section curve σ (E) in the region of thermal energies. Especially for the fissile nuclides, the g-factors g_f for the fission cross-section and g_a for the absorption cross-section are of considerable importance for the physics of thermal reactors.

During the preparation of the survey on the 2200 m/sec neutron data for fissile nuclides (Westcott et al., 1964; Westcott et al., 1965), a need for better values of the g-factors for ^{241}Pu, for both absorption and fission, was encountered. The earlier values calculated in 1960 and reprinted with corrections in 1962 (Westcott, 1960), were based on the 1958 and 1960 editions of BNL-325, and at that time no reliable measurements of the total cross-section σ_T(E) were available; it was therefore assumed that the g-factors for absorption and fission were equal.

Since new measurements have been made for the absorption cross-sections (see section II A below), more exact calculations based on these 1964 measurements are now possible; preliminary results of this work were reported to the International Nuclear Data Scientific Working Group (INDSWG) meeting in September 1965. With the encouragement of this group these calculations have now been extended to higher temperatures and, in the case of the Hanford measurements, modified after receiving more detailed information by private communication.

II. THE MEASUREMENTS

For the calculation of ^{241}Pu g-factors, the following measurements were used, whilst some others were found to be superseded with respect to their accuracy.

A. total cross-section:

1. O.D. Simpson and N.H. Marshall (1961), and other references cited in this paper, describe a time-of-flight measurement on an 81% enriched sample using the MTR fast chopper in the energy ranges 0.015 to 0.48 and 1.5 to 2000 eV. The detailed tabulated data for these measurements were obtained from IDO-16679 (unpublished).

2. D.S. Craig and C.H. Westcott (1964), for tabulated data see AECL-1948 (1964), a time-of-flight transmission measurement on an 80% enriched sample using the BNL-AECL fast chopper at Chalk River in the energy ranges 0.025 to 0.8 and 13.8 to 1000 eV.

B. fission cross-section:

3. Y.B. Adamchuk et al. (1955), tabulated data given by P.A. Egelstaff (1957), a time-of-flight measurement on an 88.5% enriched sample using a mechanical selector at the USSR RTP reactor and an ionization fission chamber in the energy range 0.01 to 800 eV.

4. Hanford, 1957-1959. Three measurements were made using the Hanford crystal spectrometer and a gas ionization fission chamber. The first (Seppi et al., 1957) was performed in the energy range 0.025 to 1.0 eV on a sample containing 19.24% Pu-241. The two other measurements using a 96.6% enriched sample, covered the energy ranges 0.0025 to 0.005 eV (Seppi et al., 1958) and 0.1 to 23 eV (Leonard and Friesenhahn, 1959). The tabulated data of the first and third measurements were received by private communication

5. G.D. James (1964), tabulated data by private communication, a time-of-flight measurement on samples enriched to 95 and 97% Pu-241, using the Harwell electron linac and a surface barrier semi-conductor as a fission fragment detector in the energy range 0.0084 to 3000 eV.

6. T. Watanabe and O.D. Simpson (1964), for tabulated data see IDO-16995 (1964), a time-of-flight measurement on an 80% enriched sample using the MTR fast chopper and a gas scintillation detector in the energy range 0.024 to 100 eV.

III. THE PROCEDURE

The g-factors $g(T)$ were calculated from the cross section $\sigma(E)$ according to

$$g(T) = \frac{2}{\sqrt{\pi}\sqrt{E_o}\,\sigma(E_o)} \int_o^\infty \sqrt{E}\,\sigma(E) \cdot \sqrt{\frac{E}{E_T}}\; e^{-\frac{E}{E_T}} \frac{dE}{E_T} \qquad (2)$$

where $E_o = 0.0253$ eV, $E_T = E_o\, T/T_o$, $T_o = 293.6^oK$.

The experimental cross-section values of each measurement were fitted to

$$\sqrt{E}\,\sigma(E) = a_{no} + a_{n1}E + a_{n2}E^2 + a_{n3}E^3 + a_{n4}E^4 + a_{n5}E^5 + R(E) \qquad (3)$$

$R(E)$ is a single-level Breit-Wigner formula

$$R(E) = \frac{h}{1 + \left(\frac{E-E_r}{\Gamma/2}\right)^2} \qquad (4)$$

with resonance energy $E_r = 0.256$ eV, width $\Gamma = 0.112$ eV, and amplitude h as a free parameter; for the polynomial fit, the energy scale was split up into a number of energy ranges indicated by the subscript n in equ. (3), and the six polynomial coefficients, a, were fitted to six representative cross-section values chosen by eye, separately in each energy range.

As the lowest energy of most of the measurements was near 0.02 eV, special care was needed in the extrapolation of the measured values to zero energy (see fig. 1). To estimate the influence of the extrapolation, g-factors were calculated for low, middle and high extrapolation, but only mean values are listed in the results (tables 1 and 2).

A constant scattering cross-section of $\sigma_s = 11$ barns was assumed and subtracted from the total cross-section for the calculation of the absorption g-factor g_a.

IV. RESULTS AND DISCUSSION

For the following discussion, it is useful to distinguish three main sources of error which, however, can be interdependent:

(i) due to normalization.

If the normalization of the entire $\sigma(E)$-curve is incorrect, this does not affect the calculation of g-factors, as $\sigma(E)$ in the numerator and $\sigma(E_o)$ in the denominator of equ. (2) are equally affected. However, statistical fluctuations around the normalization point cause an uncertainty in the normalization value $\sigma(E_o)$ which may increase or decrease the whole g(T)-curve by a constant factor.

(ii) due to extrapolation to zero energy (fig. 1).

This error could be estimated by using different extrapolations for the calculation of g-factors; its magnitude decreases considerably at higher temperatures. The errors due to extrapolation and normalization are not independent but can be distinguished by their different temperature dependence.

(iii) due to the shape of the resonance.

Statistical errors in the $\sigma(E)$-curve are eliminated by the integration of equ. (2). However, any systematic error resulting in different peak-heights or peak shapes of the 0.256 eV resonance, may have considerable influence on the g-factors, which can only be estimated by comparison of the g-factors of different measurements.

A. absorption

Table 1 shows the g-factors resulting from the absorption cross-section measurements of Simpson (1961) and Craig (1964) at various temperatures. Both measurements agree quite well. The estimated standard error due to normalization is in both cases $\pm$ 0.3%. The estimated standard error due to extrapolation is in both cases 0.08% at 20°C, 0.007% at 600°C, 0.002% at 2000°C. The error due to the resonance shape is - by comparison of both measurements: $\pm$ 0.02% at 20°C, 1.3% at 600°C, 1.5% at 2000°C.

As the measurement of Craig appears a little better with respect to resolution and statistics, we would recommend a weighted averaging of 60% Craig + 40% Simpson.

B. fission

Although there are more measurements on the fission cross-section than on the total cross-section, there are, in the case of fission, still some discrepancies in the peak shape of the resonance near

0.256 eV and also in the shape of the cross-section curve in the thermal energy range. Table 2 shows the g-factors for fission calculated from various measurements.

The measurement of Adamchuk (1955) showed, after subtraction of the Breit-Wigner fit, another peak at 0.303 eV, probably due to another isotope. This peak was subtracted and neglected, and the g-factors calculated from this measurement were used for comparison only.

The Hanford measurements were performed with two samples of different qualities with respect to the contamination of other isotopes. Both measurements agree quite well, except for some discrepancies in the peak shape of the 0.256 eV resonance which, however, have little influence on the g-factors. Table 2 shows the averaged g-factors of both Hanford measurements, which agree almost completely in the temperature ranges 0-100°C and 700-800°C and differ from their average by only ± 0.001 in the range 100-700°C and ± 0.005 at 1500°C. The Hanford measurements have good statistics, but the accuracy is limited by higher order contaminations in the neutron beam generated by the crystal spectrometer. The resulting higher order peaks are most evident when the data are plotted after subtraction of the Breit-Wigner fit (see fig. 2). In the calculation of g-factors, a smoothed curve was used, where the higher order peaks were cut off. However, the higher order contamination may still cause some error because of a possible influence on the monitoring and normalization.

The measurement of James (1964) extends to 0.008 eV, but bad statistics at this low energy still cause some uncertainty in the extrapolation to zero-energy. The peak shape of James does not agree with that of the Hanford measurement, so that there are considerable discrepancies in the g-factors at higher temperatures.

The measurement of Watanabe (1964) is apparently wrong in the energy region below 0.04 eV (see fig. 2). Thus, an extrapolation to zero energy and a determination of the normalization value at 0.0253 eV can only be done by comparison with one of the other measurements.

Fig. 2 illustrates the accuracy of the ^{241}Pu fission cross-section measurements in the energy range up to 0.3 eV. Plotted is $\sigma\sqrt{E}$ after subtraction of the Breit-Wigner fit R(E) to the 0.256 eV resonance. The uncertainties of the cross-sections give rise to the following estimated standard errors of the g-factors:

(i) <u>due to normalization:</u>

Adamchuck: ± 1%, Hanford: ± 0.1%, James: ± 0.4%, Watanabe: uncertain.

(ii) <u>due to extrapolation to zero-energy:</u>

Adamchuk: ± 0.15% at 20°C, ± 0.02% at 600°C,
Hanford: ± 0.02% at 20°C, negligible at higher temperatures,
James: ± 0.07 at 20°C, ± 0.01% at 600°C, Watanabe: uncertain.

(iii) <u>due to the shape of the resonance:</u> Comparison of the Hanford and James $\sqrt{E}\,\sigma(E)$-curve shows a difference of 7% in the ratio of the peak cross-section to that at 0.0253 eV. This gives rise to a difference of g-factors of 1% at 20°C, 5% at 600°C, and 7.5% at 1500°C. This is a systematic error, and it is difficult to decide which measurement is better. The Watanabe measurement confirms that of Hanford, whilst the Adamchuk measurement tends to confirm that of James, at least after neglecting Adamchuk's spurious 0.303 eV peak. However, the following arguments suggest that the Hanford measurement is the better one (compare fig. 2): 1. it extends to the lowest energy; 2. it has good statistics even at low energies; 3. it allows the best fit to a single-level Breit-Wigner formula. Thus, we have listed in table 2 a weighted average of 75% Hanford and 25% James. Incidentally, this average agrees excellently with the g-factors calculated from Watanabe's measurement, which, of course, are somewhat arbitrary because of the doubtful low energy cross-section values. Regarding the error width due to normalization, the g-factors of James could be raised by a factor of 0.4%. This would yield agreement of Hanford and James in the temperature region below 300°C, and would increase the average values by about 0.001. It should be pointed out, however, that at temperatures above about 300°C, where the systematic error is dominant, the use of an averaged value cannot be recommended since the g-factors from various measure-

ments differ too much. The discrepancy of the fission cross-section in the range of the 0.256 eV resonance receives further study, preferably further measurements should be made.

The authors are pleased to acknowledge the help of Mrs. P.M. Attree in programming this problem for the IBM 7040 computer.

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Captions to the figures:

Fig. 1: Typical low energy experimental points after subtraction of the Breit-Wigner fit R, showing three possible extrapolations to zero energy.

Fig. 2: Illustration of the accuracy of four ^{241}Pu fission cross-section measurements in the energy range up to 0.3 eV, after subtraction of a single-level Breit-Wigner fit R at the resonance energy $E_r = 0.256$ eV.

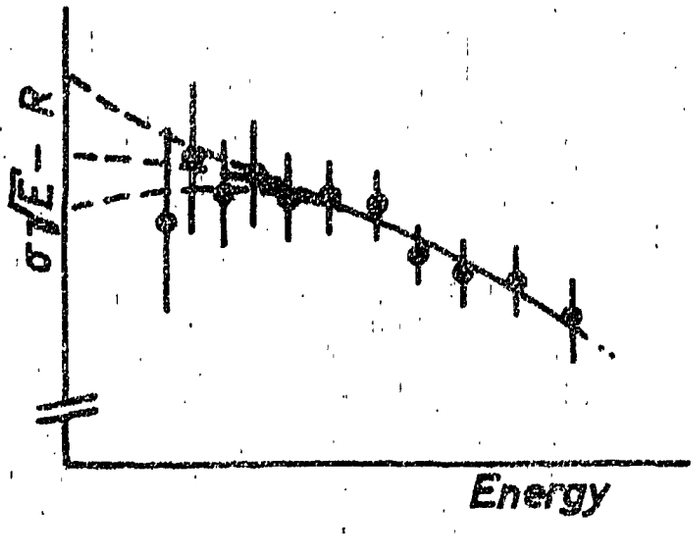

Fig. 1.

Fig. 1

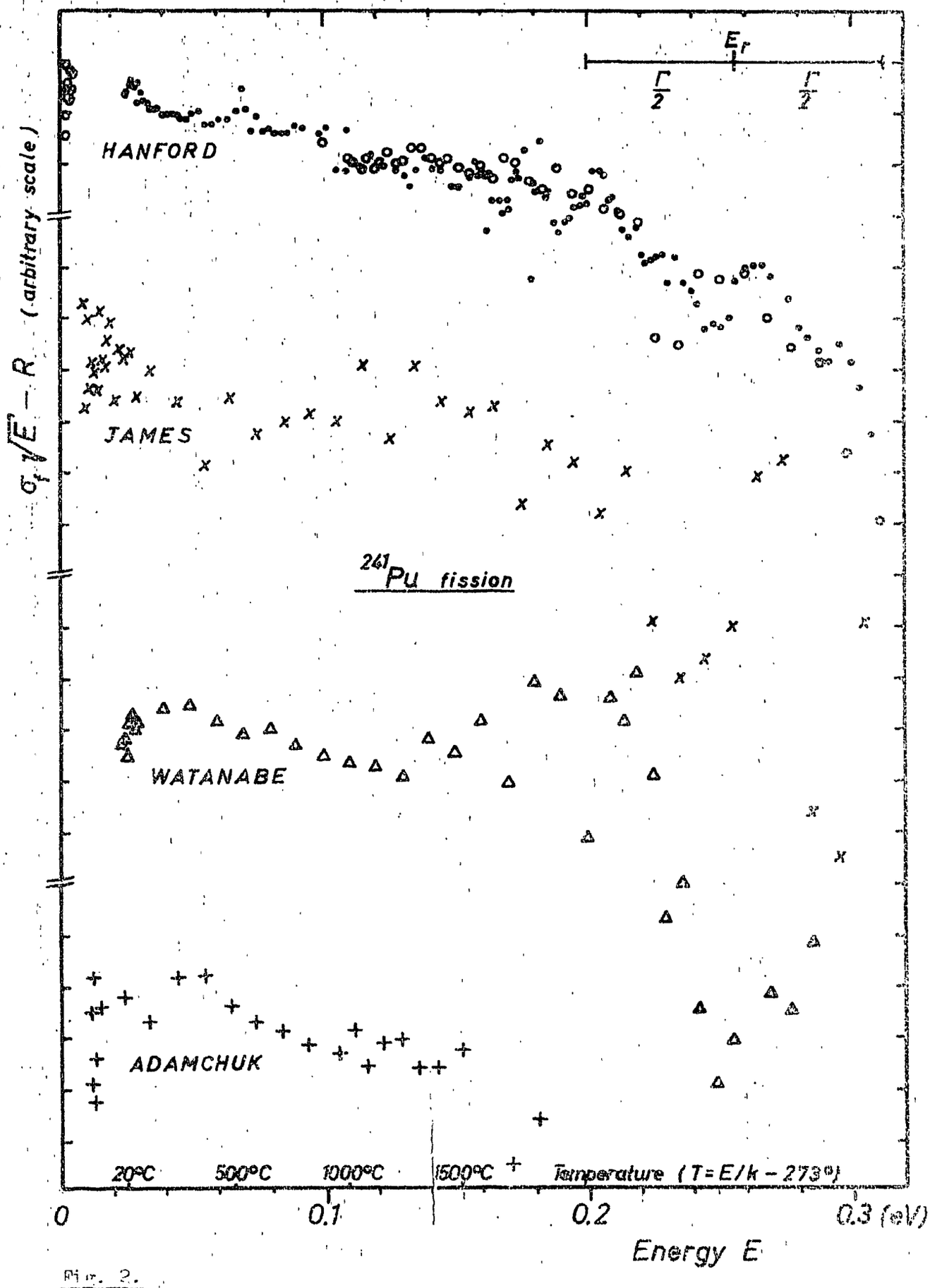
E_r
$\frac{\Gamma}{2}$
$\frac{\Gamma}{2}$
HANFORD
JAMES
^{241}Pu fission
WATANABE
ADAMCHUK
20°C
500°C
1000°C
1500°C
Temperature (T = E/k − 273°)
$\sigma_f \sqrt{E} - R$ (arbitrary scale)
0
0.1
0.2
0.3 (eV)
Energy E

Fig. 2.

T (°C)	SIMPSON	CRAIG	60% CRAIG +40% SIMPSON	estimated standard error
0	1.024	1.022	1.023	
20	1.032	1.029	1.030	± 0.2%
40	1.040	1.038	1.039	
60	1.050	1.047	1.048	
80	1.062	1.059	1.060	
100	1.075	1.071	1.073	± 0.2%
120	1.089	1.085	1.086	
140	1.105	1.101	1.103	
160	1.122	1.117	1.119	
180	1.140	1.135	1.137	
200	1.160	1.153	1.156	
220	1.180	1.173	1.176	
240	1.201	1.193	1.196	
260	1.223	1.214	1.218	
280	1.245	1.236	1.240	
300	1.268	1.258	1.262	± 0.4%
320	1.290	1.280	1.284	
340	1.314	1.302	1.307	
360	1.337	1.325	1.330	
380	1.360	1.347	1.352	
400	1.383	1.369	1.375	
420	1.406	1.391	1.397	
440	1.428	1.413	1.419	
460	1.450	1.435	1.441	
480	1.472	1.456	1.462	
500	1.493	1.477	1.483	
520	1.514	1.497	1.504	
540	1.534	1.516	1.523	
560	1.554	1.536	1.543	
580	1.573	1.554	1.562	
600	1.591	1.572	1.580	± 0.7%
650	1.635	1.614	1.622	
700	1.674	1.652	1.661	
750	1.709	1.686	1.695	
800	1.740	1.716	1.725	
850	1.766	1.742	1.752	
900	1.790	1.765	1.775	
950	1.809	1.784	1.794	
1000	1.825	1.800	1.810	
1100	1.849	1.822	1.833	
1200	1.861	1.835	1.845	
1300	1.865	1.839	1.849	
1400	1.861	1.835	1.846	
1500	1.852	1.826	1.836	± 0.8%
2000	1.749	1.727	1.735	

Table 1: The g-factor $g_a(T)$ for the ^{241}Pu absorption cross-section as function of temperature T.

T (°C)	(Adam-chuk)	Hanford	James	(Wata-nabe)	75% Hanford +25% James	estimated standard error
0	1.038	1.037	1.027	1.038	1.035	
20	1.048	1.046	1.036	1.046	1.044	± 0.4%
40	1.059	1.057	1.045	1.056	1.054	
60	1.071	1.069	1.056	1.067	1.066	
80	[illegible]	1.082	1.068	1.080	1.079	
100	[illegible]	1.097	1.081	1.093	1.093	± 0.6%
120	1.112	1.112	1.095	1.108	1.108	
140	1.128	1.129	1.110	1.124	1.124	
160	1.144	1.147	1.126	1.141	1.142	
180	1.161	1.166	1.143	1.159	1.160	
200	1.179	1.185	1.160	1.178	1.179	
220	1.197	1.206	1.179	1.197	1.199	
240	1.216	1.227	1.197	1.217	1.220	
260	1.235	1.248	1.216	1.238	1.240	
280	1.254	1.270	1.236	1.259	1.262	
300	1.274	1.292	1.255	1.280	1.283	± 1.2%
320	1.293	1.314	1.275	1.302	1.304	
340	1.313	1.336	1.295	1.323	1.326	
360	1.333	1.358	1.314	1.345	1.347	
380	1.352	1.380	1.334	1.366	1.369	
400	1.371	1.402	1.353	1.387	1.390	
420	1.390	1.424	1.372	1.408	1.411	
440	1.409	1.445	1.391	1.429	1.432	
460	1.427	1.466	1.409	1.449	1.452	
480	1.444	1.487	1.427	1.469	1.472	
500	1.462	1.507	1.444	1.488	1.491	
520	1.478	1.526	1.461	1.507	1.510	
540	1.495	1.545	1.477	1.525	1.528	
560	1.510	1.563	1.492	1.542	1.545	
580	1.526	1.580	1.507	1.559	1.562	
600	1.540	1.597	1.522	1.576	1.578	(± 1.5%)
650	1.574	1.637	1.556	1.614	1.617	
700	1.604	1.673	1.586	1.648	1.651	
750	1.631	1.704	1.612	1.678	1.681	
800	1.654	1.731	1.634	1.705	1.707	
850	1.674	1.755	1.654	1.728	1.730	
900	1.691	1.775	1.669	1.747	1.749	
950	1.704	1.791	1.682	1.763	1.764	
1000	1.715	1.805	1.693	1.775	1.777	
1100	1.729	1.823	1.705	1.792	1.794	
1200	1.735	1.831	1.709	1.800	1.801	
1300	1.733	1.831	1.706	1.799	1.800	
1400	1.725	1.825	1.697	1.792	1.793	
1500	1.713	1.813	1.684	1.779	1.781	(± 3%)
2000	1.609	1.703	1.575	1.669	1.671	

Table 2: The g-factor $g_f(T)$ for the ^{241}Pu fission cross-section as function of temperature T.