

EUR 3936 e

LIBRARY

EUROPEAN ATOMIC ENERGY COMMUNITY - EURATOM

**CALCULATION OF THE ABSORPTION AND
FISSION RESONANCE INTEGRALS
OF U-235 BY A FITTING PROCEDURE**

by

W. DE HAAN and S. STRAMACCIA

1968



**Joint Nuclear Research Center
Ispra Establishment - Italy**

**Reactor Physics Department
Reactor Theory and Analysis**

LEGAL NOTICE

This document was prepared under the sponsorship of the Commission of the European Communities.

Neither the Commission of the European Communities, its contractors nor any person acting on their behalf :

Make any warranty or representation, express or implied, with respect to the accuracy, completeness, or usefulness of the information contained in this document, or that the use of any information, apparatus, method, or process disclosed in this document may not infringe privately owned rights ; or

Assume any liability with respect to the use of, or for damages resulting from the use of any information, apparatus, method or process disclosed in this document.

This report is on sale at the addresses listed on cover page 4

at the price of FF 5.—	FB 50.—	DM 4.—	Lit. 620.—	Fl. 3.60
------------------------	---------	--------	------------	----------

When ordering, please quote the EUR number and the title, which are indicated on the cover of each report.

Printed by Vanmelle
Brussels, June 1968

This document was reproduced on the basis of the best available copy.

EUR 3936 e

EUROPEAN ATOMIC ENERGY COMMUNITY - EURATOM

**CALCULATION OF THE ABSORPTION AND
FISSION RESONANCE INTEGRALS
OF U-235 BY A FITTING PROCEDURE**

by

W. DE HAAN and S. STRAMACCIA

1968



**Joint Nuclear Research Center
Ispra Establishment - Italy**

**Reactor Physics Department
Reactor Theory and Analysis**

SUMMARY

A fitting procedure has been set-up to evaluate quickly the resonance integrals of fissile nuclides in multigroup neutron calculation models.

For this purpose, the results of resonance integrals calculated by the refined numerical Nordheim method (ZUT and TUZ codes) are fitted into a formula based on the classical resonance theory, thus determining for each nuclide and type of event a set of parameters (three) dealing with the energy group considered.

The U-235 values are reported for the energy group scheme of the lattice code PINOCCHIO.

KEYWORDS

RESONANCE INTEGRALS
GROUP THEORY
FISSIONABLE MATERIAL
NORDHEIM METHOD
Z-CODES

T-CODES
URANIUM 235
P-CODES
NEUTRON FLUX

Introduction

Numerical methods for resonance integral calculations have been largely developed (ref. 1-3) and compared with success to the experimental results. The use of these methods is nevertheless for cell reactivity calculations extremely limited by the important machine time required. As a matter of example, a ZUT-TUZ calculation for the U-238 resonance integral takes of the order of 5 minutes of execution time on the IBM-7090 which is a prohibitive time in comparison with the times needed for lattice cell design calculation codes.

In order to bypass this difficulty in the frame of the development of the PINOCCHIO cell reactivity code, a fitting procedure has been set-up to correlate the results of ZUT and TUZ calculations by means of the analytical expression derived from the theory of resonance integrals.

1. Derivation of the analytical formula

In homogeneous systems the resonance integral of an absorber can be generally written as:

$$I = \int \frac{\Sigma_p \sigma_a(u)}{N_a \sigma_t(u)} du \quad (1)$$

where:

$\frac{\Sigma_p}{N_a}$ is the potential scattering cross-section per atom of absorber.

$\sigma_a(u)$, $\sigma_t(u)$ are the lethargy dependent absorption and total cross-sections in the neighbourhood of the resonance. This formula can be evaluated after introduction of the Breit-Wigner equations and integration over the Energy Range into:

Manuscript received on March 28, 1968

$$I = \frac{\frac{1}{2} \pi \sigma_p \frac{\Gamma_r}{E_0}}{\sqrt{\frac{\sigma_p}{\sigma_0} \left(1 + \frac{\sigma_p}{\sigma_0} - \gamma \frac{1}{\sigma_p}\right)}} \quad (2)$$

with:

Γ_n the neutron (scattering) width of the resonance.

Γ_r the absorption width of the resonance.

E_0 the energy of the resonance centre.

σ_p the potential macroscopic in-scattering cross-sections of atoms which are able to contribute to a flat slowing down density spectrum into the resonance.

σ_0 the total cross-sections at the resonance centre.

$$\Gamma = \Gamma_n + \Gamma_r$$

$$\gamma = g_j \sigma_{pa} \frac{\Gamma_n}{\Gamma}$$

and:

σ_{pa} the potential absorber cross-section.

g_j the statistical spin factor.

This formula has been evaluated assuming that:

- 1) the resonance cross-section can be expressed as a function of the energy by Breit-Wigner's equations;
- 2) the resonance is situated sufficiently far from the neutron sources to guarantee that a flat slowing-down density in the resonance range can be assumed;
- 3) The lethargy increase per collision for the moderating atoms in consideration is sufficiently large compared with the resonance width (NR) to make more than one collision in the resonance very improbable. This means that the slowing-down density spectrum in the resonance range is very insensitive to the removal of neutrons so that again the source spectrum can be considered to be flat.

4) The resonance is sufficiently narrow that in the expressions the dependence on the energy of the maximum cross-section, reaction width and energy can be neglected.

5) The temperature is so low, that no Doppler broadening needs be assumed.

Moreover it has been shown by different authors, that only these atoms will have to be counted, which in reality are able to contribute to a flat slowing down density spectrum in the whole resonance region. Thus in the narrow resonance case, when the resonance is considered to be small with respect to the slowing down of energy of scattering nuclei, any of them has to be counted.

In the case of the NRIM, where only the absorber itself is considered not able to scatter into the resonance regions, indeed this contribution is not counted. It is evident that these cases are only the limiting ones and that more generally, the potential scattering may be formulated as:

$$\sigma_p = \sum_i \lambda_i \sigma_{pi}$$

where σ_{pi} is the potential macroscopic scattering cross-section per atom of absorber.

λ_i is the efficiency of the scatterer to contribute to a flat collision density spectrum in the resonance region. It may be shown that under certain conditions this value can be expressed as a function of the resonance practical width and the atomic mass of the scatterer in question.

If the resonance absorber is not homogeneously dispersed in the scattering medium (rod in moderator) it may be shown that another term has to be added to the potential cross-section, taking into account the heterogeneity effect. This term, ac-

According to Wigner rational approximation for the rod escape probability can be written as:

$$\sigma_{het} = \frac{1}{\bar{l} N_a}$$

where:

\bar{l} is the mean chord length;

N_a the absorber atom density (cm^{-3}).

Recalling:

$$N_a = \frac{\rho_F A E}{M_F} \quad \text{and} \quad \bar{l} = 2 R_{eff}$$

where:

ρ_F is the density of the fuel

A Avogadro's constant

E the enrichment

M_F the fuel molecular weight

R_{eff} the effective radius of the fuel rod when a cluster is considered (or the physical radius in the case of a single rod), one finds easily:

$$\sigma_{het} = \frac{M_F}{4 A E} \frac{S_{eff}}{M}$$

where:

S_{eff} is the effective surface of the clustered fuel (cm^2/cm)

M the mass of fuel per unit of height (gr/cm).

A very useful formula for clusters is (ref. 5) :

$$\frac{S_{eff}}{M} = \frac{S}{M} \left(\frac{1 - D}{1 + 0.1D} \right)$$

where D is Dancoff correction factor.

Summarising, the resonance integral for a single resonance in heterogeneous systems can be written in the following form:

$$I = \frac{C \sigma_p^*}{\sqrt{\frac{\sigma_p^*}{\sigma_o} \left(1 + \frac{\sigma_p^*}{\sigma_o} - \frac{\gamma}{\sigma_p^*} \right)}} \quad (3)$$

where

$$C \equiv \frac{1}{2} \pi \frac{\Gamma_\gamma}{E_o} \quad \text{and} \quad \gamma \equiv \frac{g_j \Gamma_n \sigma_{pa}}{\Gamma}$$

By putting $C' = C \sqrt{\sigma_o}$; $\sigma_p^* = \sigma_p + \sigma_{het}$
and $\delta = (\sigma_p^*)^{-1}$
one finds easily that:

$$I = \frac{C'}{\sqrt{\frac{1}{\sigma_o} + \frac{1}{\sigma_p^*} - \frac{\gamma}{\sigma_p^{*2}}}} \quad (4)$$

or:

$$I^{-2} = \frac{1}{C'^2} \left(\frac{1}{\sigma_o} + \delta - \gamma \delta^2 \right) \quad (5)$$

or:

$$I^{-2} = a_0 + a_1 \delta + a_2 \delta^2 \quad (6)$$

$$\text{with: } a_0 = \frac{1}{\sigma_0 c'^2} \quad ; \quad a_1 = \frac{1}{c'^2} \quad ; \quad a_2 = -\gamma a_1$$

$$\text{and: } \delta = \frac{1}{\sigma_p^*} = \left(\sum_i \lambda_i \sigma_{pi} + \frac{\mu_F}{4 A E} \frac{S_{eff}}{M} \right)^{-1}$$

The formula (6) has been taken as start-up point for the fitting procedure. It has been assumed that this expression, determined for a single resonance, would be valid for all the resonances belonging to each of the energy groups considered.

The coefficients a_0 , a_1 and a_2 have been determined as follows: a set of calculations with the Nordheim approach ZUT-TUZ have been carried out by varying the input parameters involved in the definition of (δ), here considered as the independent variable of the problem. The Nordheim approach can be considered today as one of the most refined numerical methods for resonance integral calculations. Starting from these results a fitting procedure has been set-up which determines the a_i values as follows.

3. The fitting program

This is based on the condition that the sum of the squares of the relative errors $\left(\frac{I_Z - I_F}{I_Z} \right)$ between the fitted (I_F) and the reference data (I_Z), is a minimum.

This gives rise to the equations:

$$S_n \left(\frac{I_F - I_Z}{I_Z} \right)^2 = \text{minimum}$$

or:

$$S_n \left[1 - \left(\frac{a_0 + a_1 \delta + a_2 \delta^2}{I_Z} \right) \right]^2 = \text{minimum}$$

After differentiating to a_i one obtains the equations:

$$Y_j = \sum_i a_{i-1} X_{ij} \quad (i \text{ and } j = 1 \rightarrow 3)$$

with:

$$Y_j = \frac{1}{I_Z} S_n \delta^{j-1}$$

$$X_{ij} = \frac{1}{I_Z^2} S_n \delta^{i+j-2}$$

where S_n is the sum over the number of values to be fitted. This set of linear equations can easily be solved by determinant methods.

3. Application to the U-235 Resonances

The calculations of the resonance integrals were performed by changing the following parameters:

- a) Temperature
- b) Energy group

- c) enrichment range (see next)
- d) chemical compound of U-235 U-238
- e) reaction type (fission, absorption)

Two problems arose however by fitting the results:

1) the efficiency factors λ_i for atoms i(25, 28, O and C) were not known "a priori". Therefore the root mean square values of the relative errors (standard deviations) were calculated for a number of λ_i values. It turned out, that the standard deviation was very sensitive to the U-235 and U-238 efficiencies (which were assumed to be equal). The influence of the Oxygen and Carbon efficiencies was much less.

2) Another problem was caused by the large range of the variables δ and I, which resulted in a low sensitivity of the a_i values to the extremes of the δ and I scales. Therefore the enrichment dimension was split-up into two overlapping parts; the high enrichment range from 100 to 4.98% and the low enrichment one from 13.5% to natural. For each of them a set of constants has been evaluated.

To cover the whole range of U-235 enrichments with a relatively small number of reference points and besides this, to decrease the mesh at the relatively more important enrichment range between natural and 10% calculations were chosen with enrichments of e^{-n} with n ranging between 0 and 5. Natural enrichment corresponds to $n = 4.945$. The effective U-235 atom fractions (with respect to the Uranium mixture 235 + 238) were then the following:

n	Enrichment	n	Enrichment
0	100%	3	4.98%
1	36.79%	4	1.83%
2	13.53%	5	.673%

To be able to fit the constants in the analytical formula (3) calculations were made for rod radii of 0.5, 1.5 and 2.5 cm radius. The shadowing effect in the fuel pins as a result of clustering was taken into account by introducing two different Dancoff correction factors (0; representing the unshadowed case, and 0.6 for rods in very compact clusters). The densities of the METAL, OXIDE and CARBIDE used in the calculations were 19.13; 10.11 and 12.55 respectively.

The potential cross-sections used in the ZUT calculations were respectively:

<u>Description</u>	<u>σ_p (barns)</u>
Uranium-235	12.5
Uranium-238	10.
Oxigen	3.
Carbon	4.65

Because of the resonance Doppler broadening three temperatures were chosen (20°, 820°, 1620°C resp.).

The statistical weight factor for U-235 was: .5.

Finally the resonance parameters used in the ZUT calculations are given in Table I. These resonances were collected into 3 groups as indicated in the following Table:

<u>Group No.</u>	<u>E max.</u>	<u>E min.</u>
5	36. eV	29. eV
6	29. eV	11. eV
7	11. eV	2.3eV

4. Results

As an example is given in Fig. 1 the plot of the standard deviations as a function of the efficiency factors for U-235 and U-238 for low enrichments at 293°K . It is clearly seen

that a minimum exists. Fig. 1 shows furthermore that there is a strong dependence of the optimal values on the group number (or medium energy). For higher energies the efficiency, although remaining small, increases. Moreover, it should be noted that the value of the minimum error (s.d.) decreases with energy. This is evidently due to the better adoptability of the analytical theory (smaller resonances, smaller Doppler broadening, energy dependence etc.). Figs. 2 and 3 give examples of plots of calculated and fitted points for the "adapted" case with the minimum s.d. and a less optimised case. For other temperatures and enrichment ranges the plots have a similar form. Tables II and III give the λ_i values and their standard deviations of the four nuclei for the high and low enrichment ranges in the fit for the absorption integral. Because the λ_i values which cause a minimum of the s.d. depend primarily on the total width of the resonances these values are the same for the absorption as well as the fission case.

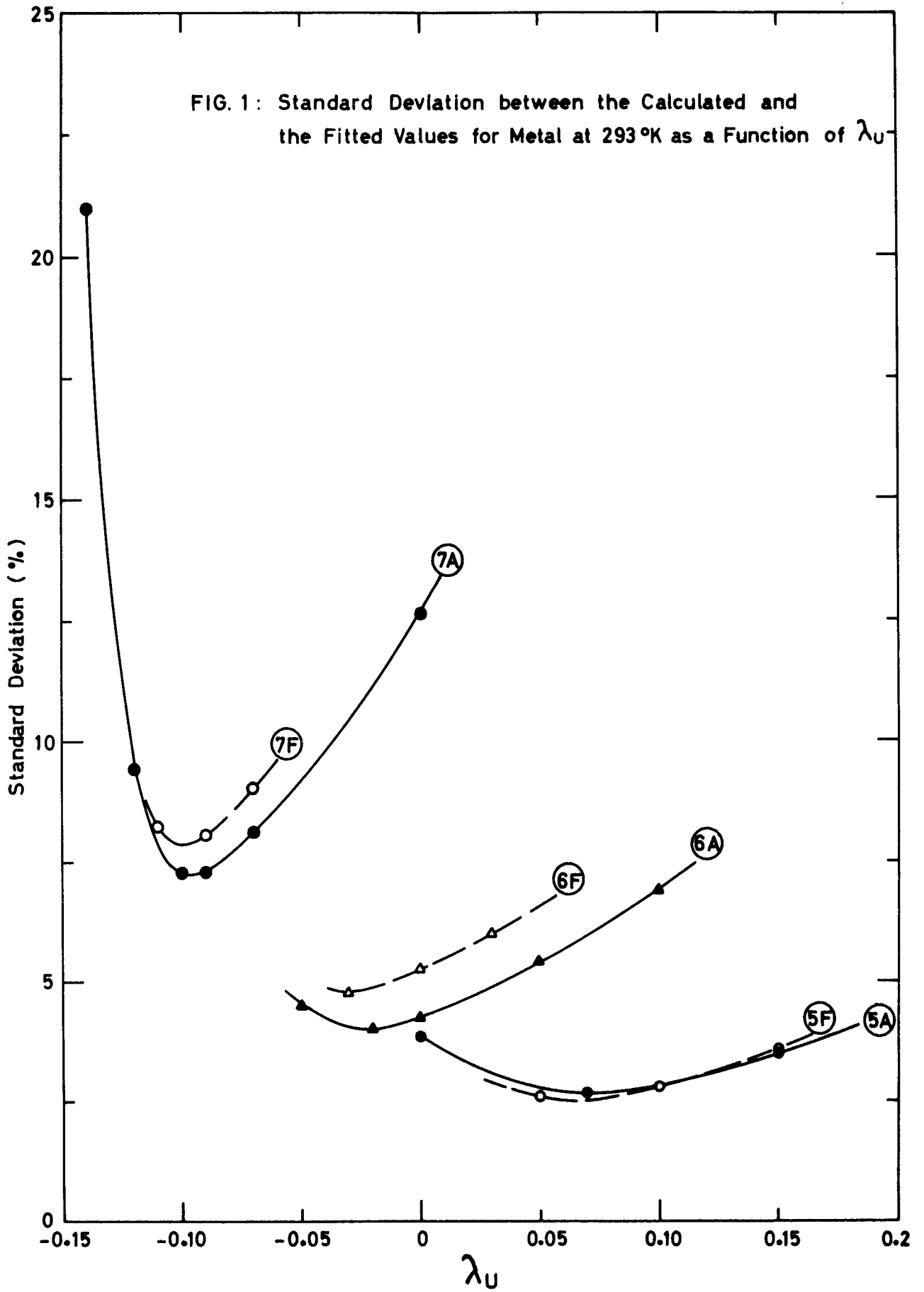
The standard deviations themselves depend on the gamma/total width ratio, and need not be the same for the absorption and fission integrals. The absorption integrals are calculated as formerly described and needed no change of the original ZUT program. The so found values of a_i are shown for the different temperatures, enrichment ranges and chemical compounds in Tables IV to IX. With respect to the fission integrals the difficulty appeared that these values could not be directly calculated because the total width Γ_f could not be entered separately.

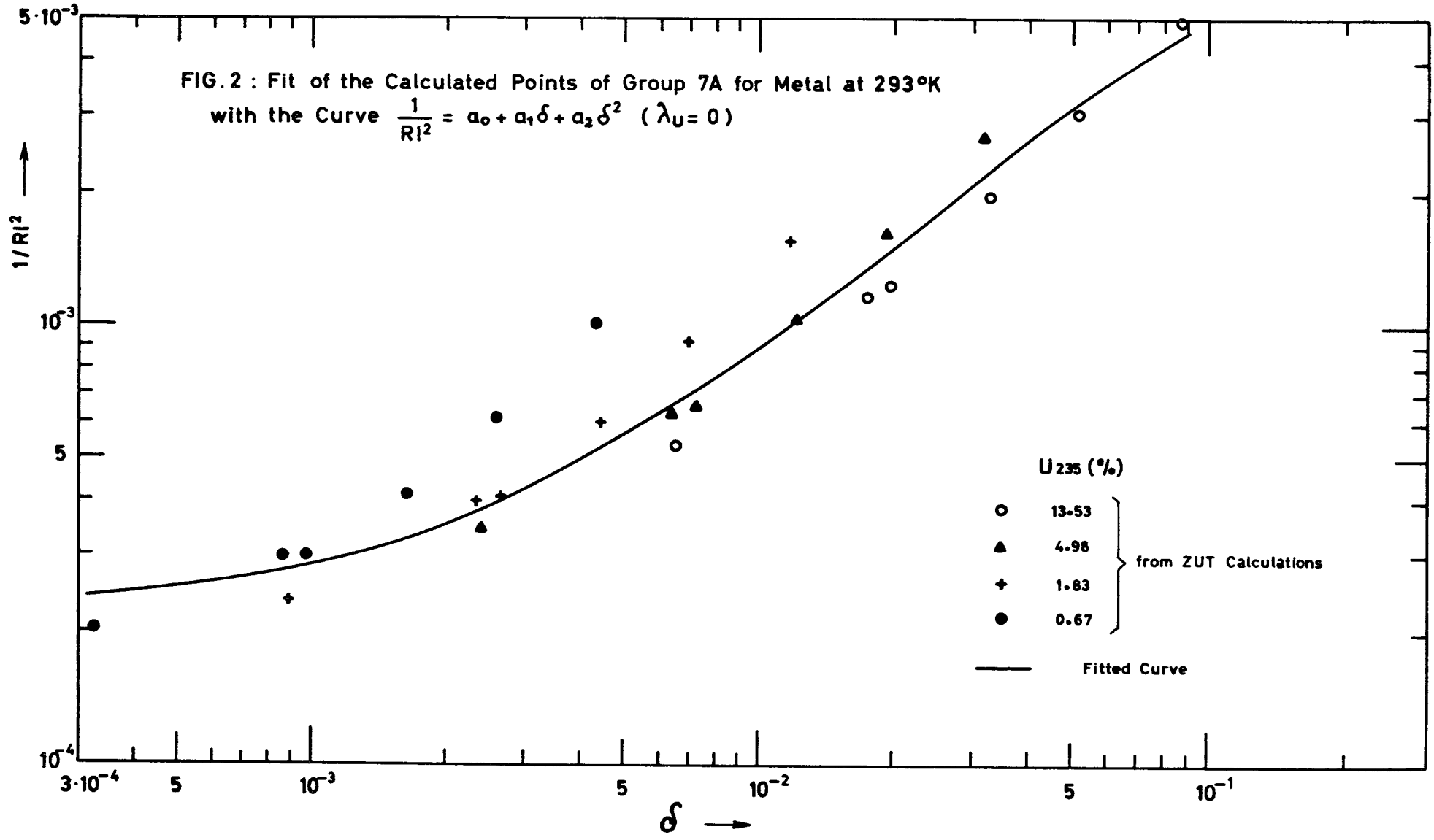
Insertion of Γ_f instead of Γ_r does not calculate properly the depletion of slowing down density in the resonance and

thus gives erroneous results. Therefore the calculation was done manually, by multiplying the absorption integral by the ratio of fission to absorption width. However, because of the large number of integrals (about 2000 per compound per temperature), this work has only been performed for one temperature (293°K). The resulting values were again fitted as formerly to obtain the respective a_1 fission values. A check has been made for group 7 at 1893°K. It turned out, as might be foreseen, that these values were a practical constant fraction of the absorption ones, about independent from the chemical compound and fuel temperature as shown in Table X for the high enrichment range. For this reason the calculation of the fission a_1 values for temperatures 1093 and 1893°K was made by multiplying the absorption ones by the ratios obtained at 293°K.

In the meantime, however, the ZUT program has been adapted, which will enable us to recalculate rigorously these data. The values so obtained for the fission integrals are shown in Tables XI to XVI.

In the Tables the coefficients whose absolute value is less than one are written as $\pm X.XXXX - Y$ to signify $\pm X.XXXX \cdot 10^{-Y}$.





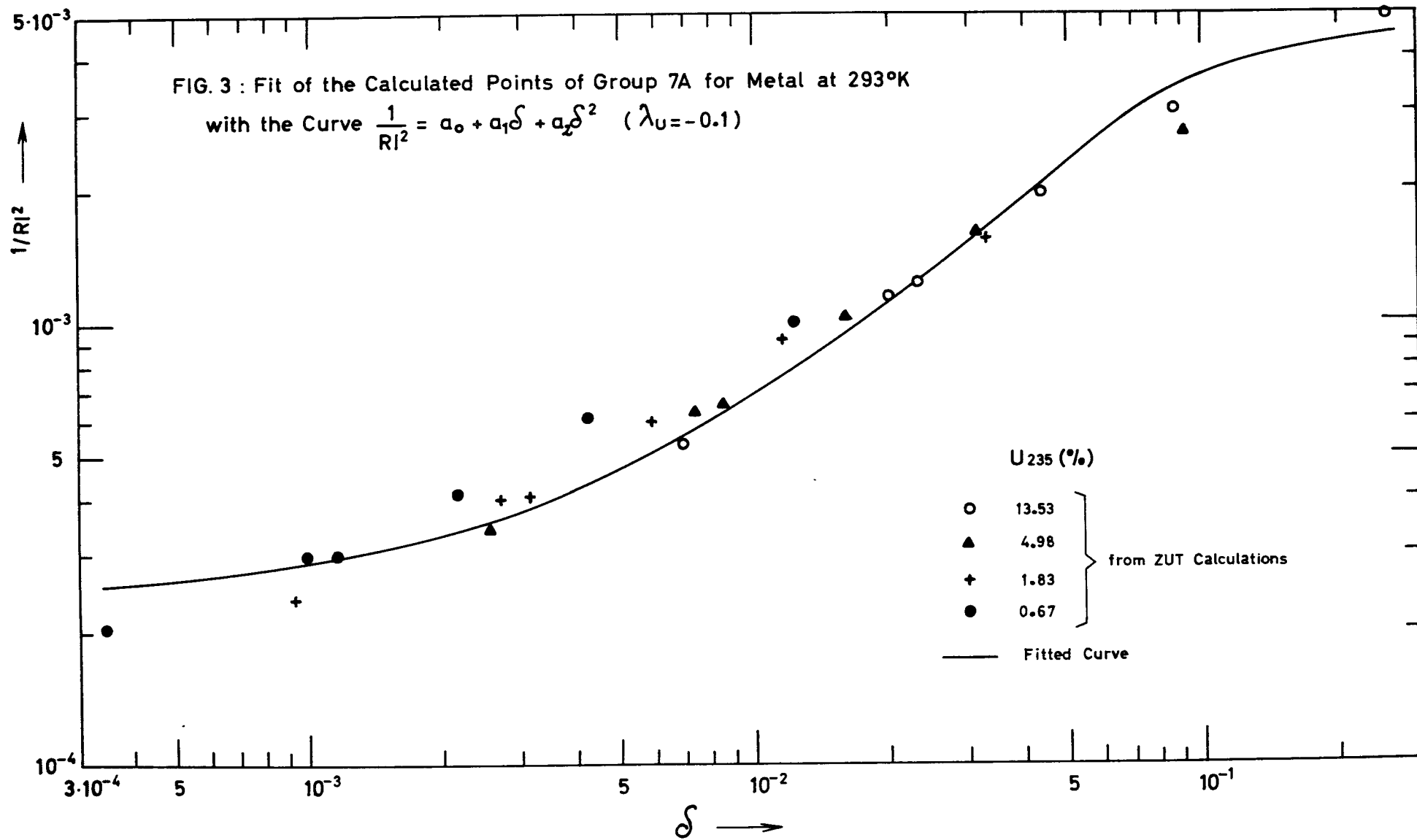


Table I

U^{235} Resonance Parameters

No.	E(eV)	$\Gamma_n(10^{-3}eV)$	$\Gamma_f(10^{-3}eV)$	$\Gamma_\gamma(10^{-3}eV)$
4	2.89	.005	100	140
5	3.15	.023	100	137
6	3.61	.047	45	87
7	4.85	.056	3.8	40.8
8	5.48	.022	330	370
9	5.84	.012	150	195
10	6.20	.042	130	170
11	6.40	.260	10	45
12	7.095	.120	28	64
13	8.795	1.18	82	132
14	9.28	.20	95	160
15	9.74	.04	140	180
16	10.18	.06	58	95
17	11.65	.63	4	40
18	12.39	1.29	24	68
19	12.86	.04	60	83
20	13.28	.04	51	91
21	13.71	.044	70	110
22	14.00	.42	400	440
23	14.53	.115	23	61
24	15.415	.250	49	98
25	16.095	.350	17	52
26	16.68	.265	86	132
27	18.05	.39	90	160
28	18.97	.10	25	65
29	19.29	3.1	52	102
30	20.13	.13	65	120
31	20.60	.23	33	92
32	21.06	1.58	21	68
33	22.93	.45	42	92
34	23.41	.69	8	40
35	23.61	.80	85	165
36	24.27	.33	52	92
37	25.62	.44	150	190
38	26.49	.43	150	190
39	27.05	.10	200	240
40	27.79	.76	60	123
41	28.34	.16	96	140
42	29.63	.18	22	67
43	30.59	.21	77	150
44	30.85	.49	17	59
45	32.06	1.95	38	90
46	33.51	1.80	20	60
47	34.38	1.80	40	90
48	34.81	1.05	49	109
49	35.19	4.30	120	183

Table II

Fitted efficiencies (λ) and standard deviations (Δ) for the high enrichment range

	293°K			1093°K			1893°K		
	λ_U	λ_O	λ_C	λ_U	λ_O	λ_C	λ_U	λ_O	λ_C
5.A	.20	.74	1.3	.12	1.1	1.47	.10	1.13	1.51
6.A	.10	.95	.95	.05	1.01	1.05	.04	1.03	1.08
7.A	-.05	.17	.30	-.05	.20	.30	-.05	0.13	.31
Δ (%)									
	Δ_{MET}	Δ_{OX}	Δ_{CAR}	Δ_{MET}	Δ_{OX}	Δ_{CAR}	Δ_{MET}	Δ_{OX}	Δ_{CAR}
5.A	2.82	2.51	2.85	3.15	2.17	2.64	3.75	2.04	2.47
6.A	6.49	2.30	4.09	7.18	2.46	4.41	7.71	2.34	4.21
7.A	8.47	4.71	3.33	8.86	4.74	3.02	9.10	4.74	3.03

Table III

Fitted efficiencies (λ) and standard deviations (Δ) for the low enrichment range

	293°K			1093°K			1893°K		
	λ_U	λ_O	λ_C	λ_U	λ_O	λ_C	λ_U	λ_O	λ_C
5.A	.1	.87	1.24	.02	1.24	1.69	0	1.2	1.73
6.A	0	.8	.9	-.04	1.07	1.14	-.06	1.16	1.29
7.A	-.09	.15	.22	-.1	.15	.2	-.1	.15	.15

Δ (%)

	Δ_{MET}	Δ_{OX}	Δ_{CAR}	Δ_{MET}	Δ_{OX}	Δ_{CAR}	Δ_{MET}	Δ_{OX}	Δ_{CAR}
5.A	.9	2.53	2.25	3.14	.68	1.34	3.46	.60	1.28
6.A	4.25	3.56	6.33	4.59	.64	2.68	4.90	.58	2.26
7.A	7.31	3.34	5.38	7.81	3.75	5.58	8.18	4.33	5.68

Table IV

Absorption a_i values of the different energy groups for high enrichments in different compounds at

TEMPERATURE 293°K

	a_0	a_1	a_2
<u>Group 5.A</u>			
Metal	2.2486 - 3	9.0267 - 1	- 2.3025
Oxide	2.3355 - 3	9.3464 - 1	- 3.3661
Carbide	1.9992 - 3	8.0081 - 1	- 4.388 - 1

<u>Group 6.A</u>			
Metal	2.691 - 4	4.6541 - 2	- 9.4619 - 2
Oxide	1.8302 - 4	4.9127 - 2	- 1.3668 - 1
Carbide	1.6967 - 4	4.3563 - 2	- 9.2331 - 1

<u>Group 7.A</u>			
Metal	3.5367 - 4	3.4511 - 2	- 2.3214 - 2
Oxide	2.4581 - 4	3.6645 - 2	- 8.1318 - 2
Carbide	2.3737 - 4	3.8338 - 2	- 6.9001 - 2

Table V

Absorption a_i values of the different energy groups for high enrichments in different compounds at

TEMPERATURE 1093°K

a_0 a_1 a_2

Group 5.A

Metal	2.4567 - 3	5.9578 - 1	- 1.2206
Oxide	2.3023 - 3	5.4524 - 1	4.1958 - 1
Carbide	2.0527 - 3	5.6190 - 1	2.3852 - 1

Group 6.A

Metal	2.5709 - 4	3.3327 - 2	- 5.4859 - 2
Oxide	1.6807 - 4	3.6722 - 2	- 9.0129 - 2
Carbide	1.5766 - 4	3.2473 - 2	- 6.4646 - 2

Group 7.A

Metal	3.0400 - 4	3.1564 - 2	- 2.1175 - 2
Oxide	2.2790 - 4	3.3303 - 2	- 7.3747 - 2
Carbide	2.2158 - 4	3.4043 - 2	- 5.9561 - 2

Table VI

Absorption a_i values of the different energy groups for high enrichments in different compounds at

TEMPERATURE 1893°K

a_0 a_1 a_2

Group 5.A

Metal	2.5628 - 3	4.8682 - 1	- 9.3862 - 1
Oxide	2.3095 - 3	4.4840 - 1	+ 4.9720 - 1
Carbide	2.0977 - 3	4.6275 - 1	+ 3.1670 - 1

Group 6.A

Metal	2.4936 - 4	2.8449 - 2	- 4.4545 - 2
Oxide	1.6323 - 4	3.1595 - 2	- 6.9737 - 2
Carbide	1.5357 - 4	2.8112 - 2	- 5.2067 - 2

Group 7.A

Metal	2.8883 - 4	2.9312 - 2	- 1.9557 - 2
Oxide	2.2525 - 4	2.8679 - 2	- 5.8116 - 2
Carbide	2.1510 - 4	3.1799 - 2	- 5.5527 - 2

Table VII

Absorption a_i values of the different energy groups for low enrichments in different compounds at

TEMPERATURE 293°K

a_0 a_1 a_2

Group 5.A

Metal	2.5569 - 3	7.9073 - 1	- 2.9609
Oxide	2.4160 - 3	9.5511 - 1	- 6.6181
Carbide	2.3714 - 3	6.1825 - 1	+ 2.0726

Group 6.A

Metal	1.8665 - 4	5.6680 - 2	- 3.2979 - 1
Oxide	1.7260 - 4	5.7897 - 2	- 1.6589
Carbide	1.8934 - 4	4.1517 - 2	- 5.8504 - 1

Group 7.A

Metal	2.3241 - 4	5.0572 - 2	- 1.4203 - 1
Oxide	1.9216 - 4	5.4516 - 2	- 7.2574 - 1
Carbide	2.1072 - 4	4.4638 - 2	- 3.4419 - 1

Table VIII

Absorption a_i values of the different energy groups for low enrichments in different compounds at

TEMPERATURE 1093°K

a_0 a_1 a_2

Group 5.A

Metal	2.5954 - 3	5.3014 - 1	- 2.2583
Oxide	2.3093 - 3	5.7356 - 1	- 7.1684
Carbide	2.3677 - 3	4.5202 - 1	+ 4.8226

Group 6.A

Metal	1.8520 - 4	4.1137 - 2	- 1.9544 - 1
Oxide	1.4821 - 4	4.6778 - 2	- 1.228
Carbide	1.5381 - 4	3.3495 - 2	- 4.0623 - 1

Group 7.A

Metal	2.2867 - 4	4.1759 - 2	- 1.0208 - 1
Oxide	1.9069 - 4	4.6239 - 2	- 5.8055 - 1
Carbide	2.0803 - 4	3.7109 - 2	- 2.6318 - 1

Table IX

Absorption a_i values of the different energy groups for low enrichments in different compounds at

TEMPERATURE 1893°K

a_0 a_1 a_2

Group 5.A

Metal	2.6112 - 3	4.4704 - 1	- 1.9099
Oxide	2.3148 - 3	4.6466 - 1	- 6.3100
Carbide	2.3638 - 3	3.7388 - 1	+ 3.8386

Group 6.A

Metal	1.8650 - 4	3.3697 - 2	- 1.4014 - 1
Oxide	1.4815 - 4	4.0261 - 2	- 1.0131
Carbide	1.5274 - 4	2.9300 - 2	- 3.1344 - 1

Group 7.A

Metal	2.2483 - 4	3.8908 - 2	- 9.3686 - 2
Oxide	1.9038 - 4	4.2560 - 2	- 5.1388 - 1
Carbide	2.0746 - 4	3.2749 - 2	- 2.1856 - 1

Table X

Ratios α_i of a_i values for fission and absorption for group 7
(2.38 - 11.eV) for 293 and 1893°K

	α_0	α_1	α_2
	TEMPERATURE 293°K		
Metal	3.6452	3.2850	3.0523
Oxide	3.8765	3.2043	3.1496
Carbide	3.9475	3.1968	3.0801

TEMPERATURE 1893°K

Metal	3.7970	3.4750	3.1951
Oxide	3.8767	3.4238	3.3894
Carbide	3.9454	3.4023	3.2798

The fission a_i values for 1093°K and 1893°K have been calculated in this way by multiplication of the absorption ones with the ratios at 293°K.

(Table XI- XVI).

Table XI

Fission a_i values of the different energy groups for high enrichments in different compounds at

TEMPERATURE 293°K

	a_0	a_1	a_2
<u>Group 5.F</u>			
Metal	9.4762 - 3	4.1453	- 10.846
Oxide	9.7996 - 3	4.2902	- 16.253
Carbide	8.3725 - 3	3.6292	- 2.5012
<u>Group 6.F</u>			
Metal	1.4375 - 3	1.7699 - 1	- 3.4558 - 1
Oxide	1.0179 - 3	1.9187 - 1	- 5.7734 - 1
Carbide	9.5980 - 4	1.7295 - 1	- 3.9841 - 1
<u>Group 7.F</u>			
Metal	1.2892 - 3	1.1337 - 1	- 7.0857 - 2
Oxide	9.5288 - 4	1.1742 - 1	- 2.5612 - 1
Carbide	9.3704 - 4	1.2256 - 1	- 2.1253 - 1

Table XII

Fission a_i values of the different energy groups for high enrichments in different compounds at

TEMPERATURE 1093°K

	a_0	a_1	a_2
<u>Group 5.F</u>			
Metal	1.0353 - 2	2.7357	- 5.7497
Oxide	9.6603 - 3	2.5028	+ 2.0259
Carbide	8.5965 - 3	2.5465	+ 1.3595
<u>Group 6.F</u>			
Metal	1.3732 - 3	1.2674 - 1	- 2.0036 - 1
Oxide	9.3475 - 4	1.4342 - 1	- 3.8071 - 1
Carbide	8.9186 - 4	1.2892 - 1	- 2.7895 - 1
<u>Group 7.F</u>			
Metal	1.1081 - 3	1.0369 - 1	- 6.4633 - 2
Oxide	8.8345 - 4	1.0671 - 1	- 2.3227 - 1
Carbide	8.7471 - 4	1.0883 - 1	- 1.8345 - 1

Table XIII

Fission a_i values of the different energy groups for high enrichments in different compounds at

TEMPERATURE 1893°K

a_0 a_1 a_2

Group 5.F

Metal	1.0800 - 2	2.2354	- 4.4214
Oxide	9.6905 - 3	2.0582	+ 2.4007
Carbide	8.7850 - 3	2.0971	+ 1.8051

Group 6.F

Metal	1.3319 - 3	1.0819 - 1	- 1.6269 - 1
Oxide	9.0783 - 4	1.2340 - 1	- 2.9457 - 1
Carbide	8.6872 - 4	1.1161 - 1	- 2.2467 - 1

Group 7.F

Metal	1.0528 - 3	9.6291 - 2	- 5.9695 - 2
Oxide	8.7318 - 4	9.1895 - 2	- 1.8304 - 1
Carbide	8.4913 - 4	1.0166 - 1	- 1.7103 - 1

Table XIV

Fission a_i values of the different energy groups for low enrichments in different compounds at

TEMPERATURE 293°K

a_0 a_1 a_2

Group 5.F

Metal	1.0733 - 2	3.6531	- 12.514
Oxide	1.0205 - 2	4.3443	- 25.356
Carbide	1.0047 - 2	2.7953	+ 9.8039

Group 6.F

Metal	1.0369 - 3	2.2937 - 1	- 1.3674
Oxide	9.3298 - 4	2.4666 - 1	- 7.5486
Carbide	1.0134 - 3	1.7536 - 1	- 2.6688

Group 7.F

Metal	8.7813 - 4	1.7103 - 1	- 4.7881 - 1
Oxide	7.2189 - 4	1.9191 - 1	- 2.6669
Carbide	7.8955 - 4	1.5741 - 1	- 1.3106

Table XV

Fission a_i values of the different energy groups for low enrichments in different compounds at

TEMPERATURE 1093°K

	a_0	a_1	a_2
<u>Group 5.F</u>			
Metal	1.0895 - 2	2.4492	- 9.5445
Oxide	9.7543 - 3	2.6088	- 27.464
Carbide	1.0031 - 2	2.0437	+ 22.812
<u>Group 6.F</u>			
Metal	1.0288 - 3	1.6647 - 1	- 8.1035 - 1
Oxide	8.0114 - 4	1.9929 - 1	- 5.5878
Carbide	8.2323 - 4	1.4148 - 1	- 1.8531
<u>Group 7.F</u>			
Metal	8.6400 - 4	1.4122 - 1	- 3.4413 - 1
Oxide	7.1636 - 4	1.6277 - 1	- 2.1334
Carbide	7.7947 - 4	1.3086 - 1	- 1.0021

Table XVI

Fission a_i values of the different energy groups for low enrichments in different compounds at

TEMPERATURE 1893°K

	a_0	a_1	a_2
		<u>Group 5.F</u>	
Metal	1.0961 - 2	2.0653	- 8.0720
Oxide	9.7775 - 3	2.1135	- 24.176
Carbide	1.0015 - 2	1.6904	+ 18.157
		<u>Group 6.F</u>	
Metal	1.0361 - 3	1.3636 - 1	- 5.8106 - 1
Oxide	8.0084 - 4	1.7152 - 1	- 4.6100
Carbide	8.1751 - 4	1.2376 - 1	- 1.4298
		<u>Group 7.F</u>	
Metal	8.4949 - 4	1.3158 - 1	- 3.1583 - 1
Oxide	7.1520 - 4	1.4982 - 1	- 1.8884
Carbide	7.7733 - 4	1.1548 - 1	- 8.3223 - 1

Acknowledgment

The author wishes to express his sincere thanks to Mr. R.Meelhuysen for the large number of ZUT calculations performed by him for this study.

References

1. L.W. NORDHEIM, G. KUNCIR: A program of research and calculation of resonance absorption.
2. L.W. NORDHEIM: The theory of resonance absorption GA638, Dec. 1959 - Nucl. Sc. and Engn. 12(1962) 457.
3. G.A. KUNCIR: A program for the calculation of resonance integrals, GA2525, Sept. 1961.
4. L. DRESNER: Resonance absorption in nuclear reactors, Pergamon Press 1960.
5. LEVINE: Resonance integral calculations for U-238 lattice, Nucl. Sc. and Engn. 16(1963) 271-279

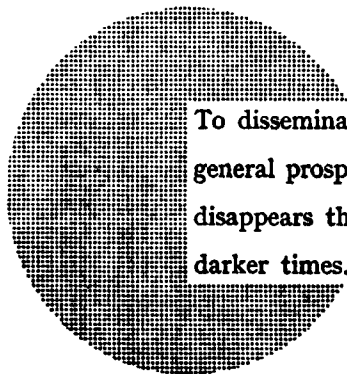
NOTICE TO THE READER

All Euratom reports are announced, as and when they are issued, in the monthly periodical **EURATOM INFORMATION**, edited by the Centre for Information and Documentation (CID). For subscription (1 year: US\$ 15, £ 6.5) or free specimen copies please write to :

Handelsblatt GmbH
"Euratom Information"
Postfach 1102
D-4 Düsseldorf (Germany)

or

Office central de vente des publications
des Communautés européennes
2, Place de Metz
Luxembourg



To disseminate knowledge is to disseminate prosperity — I mean general prosperity and not individual riches — and with prosperity disappears the greater part of the evil which is our heritage from darker times.

Alfred Nobel