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SUMMARY OF SOME NEW NUCLEAR DATA

P. R. Kasten

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NUCLEAR CONSTANTS

Since the issuance of BNL 325, new data concerning nuclear constants have become available. A summary of results obtained by different investigators is given here.

Measurements of eta and other fission parameters for U^{233}, Pu^{239}, and Pu^{241}, relative to U^{235} have been measured[1] at sub-cadmium neutron energies. These measurements were conducted in the TTR and are thus based on the neutron spectrum in that reactor. The values used for U^{235} were considered constant over the sub-cadmium range and were:

$$\bar{\eta}(25) = 2.08; \quad 1 + \overline{\alpha(25)} = 1.184; \quad \overline{\nu(25)} = 2.46$$

The results obtained are given in Table 1.

TABLE 1

Sub-Cd Nuclear Values for 25, 49 and 41

Nuclide	$\bar{\eta}$	$\bar{\nu}$	$1 + \bar{\alpha}$
U^{233}	2.25	2.50	1.115
Pu^{239}	1.93	3.08	1.592
Pu^{241}	2.23	3.21	1.442

In the above the η's were determined with the greatest precision. The method used to determine η involved two "reactivity type" measurements to separate σ_a and η, while previous measurements have involved one reactivity type measurement in combination with cross section data and the particular neutron spectrum. It is felt that the KAPL experiments should give the best values, since the neutron spectrums in both reactivity

measurements were the same, and thus eliminated the difficulties associated with accurately determining the neutron spectrum. However, for comparison purposes, the neutron spectrum in the TTR was obtained and found to be given by

$$\phi(E) = \frac{1}{(.0272)^2} E e^{-\frac{E}{.0272}}$$

$$\left(+ \frac{.054}{E} \text{ if } E > .13 \text{ ev} \right)$$

where E is in ev.

(The integral of the Maxwellian component is unity in the above equation.)

During the experiments the physical temperature in the TTR corresponded to 301 - 302°K (28°C, .0259 ev); however, the average neutron energy (energy of Maxwellian at peak value) was found to be .0272 ev $\simeq$ 316°K (42°C).

Average sub-cadmium fission cross sections were obtained by activation measurements based on an average sub-Cd value of 440 barns for $\bar{\sigma}_f(25)$ $\left[\sigma_a(25) = 520 \text{ b}\right]$, and are given in Table 2. Other calculated values are also given.

TABLE 2

Average Sub-Cadmium Fission Cross-Sections

	"Activation"	"Calculated"	
Nuclide	$\bar{\sigma}_f$ (barns)	$\bar{\sigma}_f$ (barns)	$\bar{\sigma}_a$ (barns)
U^{233}	417	413 (BNL 325)	453
Pu^{239}	667	672 (BNL 325)	994
Pu^{241}	733	811 (Harwell and USSR) ~925 (ANL)	

The average cross sections in column 3 of Table 2 were calculated by taking essentially the BNL 325 cross-section data and weighting it with the TTR neutron spectrum. The σ values for Pu^{241} were taken from the supplement to BNL 325, but renormalized to $\sigma_f(41) = 950$ b at 2200 m/sec (mean value between Harwell and USSR values); and $\sigma_a(41) = 1.44\ \sigma_f(41)$ (based on above results). In these calculations, an average cross-section was obtained separately for the Maxwellian component and for the $\frac{1}{E}$ component. Both of these averages included self-shielding effects, and the $\sqrt{\pi}/2$ factor was included in the average of the Maxwellian component. The $\frac{1}{E}$ component of the flux up to Cd cut off was .06 based on a Maxwellian component of 1.00. The $\frac{1}{E}$ spectral component and the self-shielding factors were significant, particularly in the case of Pu^{239}.

Using the "calculated" average cross sections given in Table 2 and experimental results to obtain the epi-cadmium reactivity effect, the presently accepted values of η (see BNL 325) are shifted in a direction to give closer agreement with the above KAPL results. The actual values obtained by this method are given in Table 3.

TABLE 3

Average Sub-Cadmium values for $\bar{\eta}$ in TTR using BNL 325 Cross Sections, and correcting for Epi-Cadmium Reactivity Effects

Nuclide	$\bar{\eta}$	$\bar{\nu}$
U^{233}	2.27	2.53
Pu^{239}	1.98	3.05

(The values for ν just bear out that the σ_f from activation measurements are in fair agreement with those in BNL 325.)

The applicable KAPL data were also treated in apparently the same manner as previous workers. In these calculations, η was calculated using an effective σ_a (sub-Cd) for the pile (as calculated from the σ appropriate for the most probable neutron energy, the non $\frac{1}{v}$ correction factor, and a pure Maxwellian flux peaked at the most probable energy). These values were in good agreement with previous values, as illustrated in Table 4.

TABLE 4

Average Sub-Cadmium η's as Calculated by the Method of Previous Workers

Nuclide	$\bar{\eta}$ (using KAPL data)	$\bar{\eta}$ (BNL 325)
U^{233}	2.31	2.31
Pu^{239}	2.04	2.03

Thus, it appears that the $\frac{1}{E}$ tail in the sub-Cd region, and self shielding should be considered in evaluating η. For example, BNL 325 values of $\sigma_a(49)$ and $\sigma_f(49)$, with constant $\nu(49)$, indicate that $\bar{\eta}$ (49) sub-Cd is 2.7% less in the TTR spectrum than in a pure Maxwellian spectrum having the same neutron temperature.

Identical η's by each type of measurement can be obtained only if the σ_a's of Pu^{239} and U^{233} are increased by 6.6% and 2.4%, respectively, above BNL 325 values.

Consistent nuclear constants obtained from the KAPL studies are summarized in Table 5.

TABLE 5

Nuclear Constants as Obtained from TTR Data*

A. Sub-Cadmium Averages in TTR Spectrum

Nuclide	$\bar{\eta}$	$\bar{\sigma}_a$(barns)	$\bar{\nu}$	$\bar{\sigma}_f$(barns)	$1 + \overline{\alpha}$
U^{233}	2.25	464	2.50	417	1.113
Pu^{239}	1.93	1060	3.08	667	1.589
Pu^{241}	2.23	1057	3.21	733	1.442

B. 2200 m/sec (.0253 ev) values

Nuclide	η	σ_a	ν	σ_f	$1 + \alpha$
U^{233}	2.25	599	2.50	544	1.101
Pu^{239}	2.02	1133	3.08	742	1.527
Pu^{241}			3.21	858	

* Based on following U^{235} values:

$$\left[\begin{array}{l} \eta\left(2200\ \frac{m}{sec}\right) = 2.08\ ;\quad \nu\left(2200\ \frac{m}{sec}\right) = 2.46;\quad \sigma_a\left(2200\ \frac{m}{sec}\ ;\ .0253\ ev\right) = 690\ b \\ \bar{\eta}_{sub\text{-}Cd} = 2.08\ ;\ \bar{\nu}_{sub\text{-}Cd} = 2.46;\ \sigma_f\left(2200\ \frac{m}{sec}\right) = 583\ b \end{array}\right.$$

Some of the Russian values for η have been presented in a recent speech.[2] These are given in Table 6 for U^{233} and U^{235}.

TABLE 6

Values of $\eta(23)$ and $\eta(25)$ as a Function of Energy as Determined in USSR

Neutron energy region	$\eta(23)$	$\eta(25)$
Thermal	2.28 ± .02	2.06 ± .02
0.15 - 0.5 ev	2.28 ± .09	2.06 ± .06
0.4 - 3 ev	2.24 ± .05	1.60 ± .04
0.6 - 6 ev	2.24 ± .05	1.50 ± .04
2.5 - 25 ev	2.28 ± .05	1.52 ± .04
8 - 130 ev	2.28 ± .05	1.48 ± .04
30 kev	2.25 ± .07	1.86 ± .04
140 kev	2.43 ± .12	2.12 ± .10
250 kev	2.45 ± .12	2.21 ± .15
900 kev	2.60 ± .13	2.28 ± .08

Experiments have been conducted at Chalk River to determine the cross-sections of plutonium isotopes. The cross-sections of Pu^{239} and Pu^{240} have been determined in the thermal and epi-Cd regions.[3] The variation of total to fission cross sections with energy is given in Table 7.

TABLE 7

Variation of $\sigma_T(49)/\sigma_f(49)$ with Energy

Neutron Energy	$\frac{\sigma_T(49)}{\sigma_f(49)}$ CRC 633	BNL 325
NRX Reactor Neutrons	1.43	
.028 ev		1.41
0.45 ev	1.60	1.59
6 - 100 ev	1.48	1.50

The resonance integral of Pu^{240} was found to be 8700 ± 800 barns, compared with a value of ~ 280 barns for the fission resonance integral of Pu^{239}

$$\left[\int_{.4\ ev}^{\infty} \sigma_a(40)\frac{dE}{E} = 8700 \pm 800\ b; \quad \int_{2\ ev}^{\infty} \sigma_f(49)\frac{dE}{E} = 250\ b; \quad \int_{.1''\ Cd}^{2\ ev} \sigma_f(49)\frac{dE}{E} = 30\ b \right]$$

The value of the Pu^{240} resonance integral as obtained by different investigators is summarized in Table 8.

TABLE 8

Values Obtained for the Pu^{240} Resonance Integral

Investigator	Γ(ev)	σ_o(b)	E_o(ev)	$\int_{.4\ ev}^{\infty} \sigma_a(40)\frac{dE}{E}$, b
USSR	.042	1.78×10^5	1.075	10,900 ± 1500
UK	.039	1.30×10^5	1.056	7540 ± 700
US	.045	1.70×10^5	1.06	11,340 ± 6000
CRC633				8700 ± 800

A summary of results is given in Table 9.

TABLE 9

Summary of CRC 633 Results Based on NRX Neutrons Spectrum

Sample	$\frac{\sigma_f(49)}{\sigma_c(49)}$	$\frac{\sigma_T(49)}{\sigma_f(49)}$	$\frac{\sigma_c(49)}{\sigma_T(49)}$	R^*			
				$R\left[\sigma_T(49)\right]$	$R\left[\sigma_f(49)\right]$	$R\left[\sigma_c(49)\right]$	$R\left[\sigma_T(40)\right]$
Unwrapped	2.32	1.43	.301				
.025" Cd $\left[x \approx .5 \text{ ev}^*\right]$	1.97	1.52	.334	656 ± 26	434 ± 18	221 ± 11	8700 ± 800
.100" Cd $\left[x \approx .8 \text{ ev}^*\right]$	2.11	1.48	.321	414 ± 17	280 calc	133 ± 10	

$$^*R = \int_x^{\infty} \sigma \frac{dE}{E}$$

Based on activation, a value of $\sigma_c(40) = 250 \pm 35$ b has been obtained for reactor thermal neutrons. This value is to be used in the expression:

$$\text{rate of reaction} \propto \sigma\, n_T\, v_o$$

where n_T = total neutron density (Maxwellian and resonance)

v_o = 2200 m/sec

Chalk River investigators[4] have also studied σ_a of Pu^{238}, Pu^{242} and Am^{243}. The values obtained with NRX pile neutrons were relative to $\sigma_a(Co) = 36.4$ b $\left[\text{based on } \sigma_a(Au) = 99 \text{ b}\right]$, and are given in Table 10.

TABLE 10

Cross Sections of Pu^{238}, Pu^{242} and Am^{243} for NRX Pile Neutrons

Isotope	$\sigma(n,\gamma)$ b	σ_T b	Cadmium Ratio	$\sigma\left(2200 \frac{m}{sec}\right)$ b	$\int_{.4\ ev}^{\infty} \sigma \frac{dE}{E}$
Pu^{238}	484 ± 7		16.1 ± 2.0	454 ± 8	950 ± 130
Pu^{242}	50.6 ± .7	64 ± 15	1.83 ± .03	22.9 ± 8	870 ± 50
Am^{243}	131.8 ± 1.7		2.63 ± .05	81.6 ± 1.8	1580 ± 50

As reported at a NCSAG meeting,[5] preliminary values for thermal neutron fission of Th^{233} and U^{239} are: $\sigma_f\left(Th^{233}\right) = 15 \pm 2$ b; $\sigma_f\left(U^{239}\right) = 15 \pm 3$ b.

The thermal σ_a for Np^{237} has been reported by UK investigators[6] as $\bar{\sigma}_a\left(Np^{237}\right) = 172 \pm 7$ b for sub-Cadmium neutrons in BEPO. The ratio of epi-Cd activity to sub-Cd activity $\left(\text{for } Np^{237}\right)$ was found to be 0.24.

The value of ϵ has been determined in ZEEP.[7] With $\phi_{th} = 2 \times 10^7$, ϵ was found to be $1.080 \pm .003$ in a natural U, heavy water lattice with the volume ratio of $\frac{D_2O}{U} = 2.32$, the rod diameter being 1.280".

REFERENCES

1. McMillan, D. E., M. E. Jones, J. B. Sampson, E. R. Gaerttner, T. M. Snyder, "A Measurement of eta and other Fission Parameters for U^{233}, Pu^{239}, Pu^{241}, Relative to U^{235} at Sub-Cadmium Neutron Energies." KAPL 1464, December 15, 1955. Unclassified.

2. Kurchatov, I. V., "Some Aspects of Atomic Power Development in the USSR," talk at Harwell, England, 1956.

3. Cornish and Loundsbury, "Cross Sections of Pu^{239} and Pu^{240} in the Thermal and Epi-Cadmium Regions." CRC 633, March 1, 1956. Unclassified.

4. Bulter, Lounsbury, and Merritt, "Determination of σ_a of Pu^{242}, Pu^{238}, and Am^{243}." CRC 628, January 1956. Unclassified.

5. NCSAG Report February 22-23, 1956 - Unclassified Portion.

6. Brown and Hall, "The Thermal Neutron Capture Cross Section of Np^{237}. AERE C/R 1799, December 1955. Unclassified.

7. Hanna, G. C., and P. R. Tunnichiffe, "Fast Fission Factor Experiments." CRRP 623, January 4, 1956. Unclassified.