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NEUTRON DETECTOR TRAVERSES IN THE TOPSY AND GODIVA CRITICAL ASSEMBLIES

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ABSTRACT

Neutron detector traverses of the untamped Oy (Godiva) and the Tu- or Ni-tamped Oy (Topsy) metal critical assemblies have been obtained by counting the following types of radiation:

1) γ-activity of U^{235} and U^{238} fission products;

2) fission fragments of Np^{237} in a spiral chamber;

3) and β -activity of Au and S.

At a few positions within the assemblies, and for the U^{235} fission spectrum, cross section ratios of a number of pairs of fissionable isotopes were determined by means of a comparison fission chamber. At the center of Godiva, $\sigma_f(25)/\sigma_f(28) = 6.2$, and this ratio for the Topsy Oy-Tu assembly ranges from 6.8 at the center to 76 at a radius of 8-1/4".

Results of radiochemical analyses for fission and other reaction products, by Group J-11, are listed in an appendix.

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I. INTRODUCTION

Sufficient interest exists in the neutron spectrum characteristics of chain-reacting U^{235} metal assemblies to warrant publishing a collection of the various data obtained with several different detectors placed in two of such assemblies. The data presented here pertain to two extremes of design: the untamped Oy (~ 94%) spherical metal assembly known as Godiva;[1] and the tamped (with 8-1/2" thick normal uranium or nickel) pseudospherical Oy (~ 94%) metal assembly known as Topsy.[2] Both assemblies are provided with radial access holes and appropriate plugs to permit the introduction of neutron detectors while keeping perturbations of the systems to a minimum.

No attempt has been made to deduce neutron spectra directly from these data. Their greatest usefulness derives from furnishing spectral indices which permit checks on multigroup calculations of the neutron behavior of the assemblies involved. Also, more directly, the data on fissionable isotope reactions, particularly in Topsy, have proven to be of interest to neutron economy considerations of fast breeder reactors.

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(1) LA-1614; LADY GODIVA - An Unreflected U-235 Critical Assembly; Peterson.

(2) LA-1579; TOPSY - A Remotely-Controlled Machine for the Study of Critical Assemblies; White.

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II. DETECTORS AND METHODS USED

The reactions that have been used are described below, along with a short account of how measurements and calibrations were made.

<u>γ-Counting: U^{235} and U^{238} ($\sim$ 1 Mev Threshold) Fissions</u>

Fissions were detected in metallic foils (approximately one-half inch in diameter by ten mils thick) of these isotopes by observing, subsequent to irradiation, the fission product γ-activity with a NaI(Tl)-photomultiplier (RCA-5819) scintillation counter. The crystal, 1/2" x 1/2" x 1/4", was potted in mineral oil in a lucite container and mounted in a lead shield. Cd (0.032" thick) and Al (0.003" thick), between the activated foil and crystal, absorbed β's. Standardized irradiation times and counting techniques circumvent the difficulties arising from the fact that the gross fission product activity is a superposition of several periods. Activities 2 hrs. after the end of a 1/2 hr. irradiation were taken from extended decay curves. U^{235} to U^{238} activity ratios are somewhat arbitrary as the decay curves do not parallel precisely. Initial attempts to apply this method to Pu^{239} and Np^{237} led to inconsistent results, possibly because, with counting system adjustments suitable for U^{235} and U^{238}, apparent background activities were abnormally high.

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Spiral Fission Chamber: Np^{237} (~ 0.4 Mev Threshold) Fissions

The Topsy curve of fission rate dependence on radius was obtained with a small spiral fission counter. The curve was normalized to the other detector results by means of a double, parallel-plate, comparison chamber which gave the ratio of Np^{237}/U^{238} at the center (1/4") of Topsy.

β-Counting: $Au^{197}(n,\gamma)$ and $S^{32}(n,p)$ ~ 2 Mev Threshold

The resulting 65.5 hr. β-activity of Au^{198} was counted in a methane gas-flow type proportional counter (Nuclear Instrument and Chemical Corp.). Counts from foils of Au and U^{235} simultaneously irradiated in a flux of thermal neutrons give the relation between the ratio (Au β-response)/(U^{235} γ-response) and the known ratio of thermal cross sections. Thus for any spectrum, the ratio (disintegrations per atom of Au)/(fissions per atom of U^{235}) can be obtained.

The P^{32} β-activity (14.3 days) was counted on the methane counter. The sulphur was irradiated and counted in the form of a compacted pellet about one-half inch diameter by approximately one-sixteenth inch thick. A calibration of the counter for the pellet form of sulphur samples was obtained by irradiating the samples in a known flux of 14 Mev neutrons and assuming a cross section of 0.3 barn, an extrapolation of values determined by Klema [Phys. Rev. 73, 106 (1948)].

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Comparison Fission Chamber: U^{234}, U^{235}, U^{236}, U^{238}, Np^{237}, and Pu^{239} Fissions

Fission rates of any desired pair of foils were determined simultaneously in a demountable parallel plate comparison chamber. The chamber was housed in a brass can 1" long x 7/8" diam. Each active material (50 to 540 μgm) was deposited on a 0.005" thick Pt foil and covered an area of ~ 0.7 cm^2. Within the chamber, foils mounted back-to-back were separated by only 0.015" thick brass, so that the active areas should see essentially the same neutron flux. Differences in response of the electronic systems, arising from different discrimination levels and different amplifier gains, were cancelled out by interchanging the two electronics systems at the fission chamber.

Fission rate ratios were measured not only in Topsy and Godiva, but in the U^{235} fission spectrum from a 6-1/4" x 4-1/4" x 0.030" thick plate of Oy (~ 93%) irradiated by neutrons from the thermal column of the water boiler.[(1)] For the latter measurements, the chamber was ~ 3" from the fission plate, and, in addition to B^{10} and Cd shielding about the thermal beam, the chamber was enclosed in Cd.

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(1) The co-operation of Group P-2 is acknowledged.

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After the completion of measurements (several series, to permit estimates of relative probable error), active material weights were determined by Group J-11. The α-counting method was used for the U^{233}, U^{234}, and Np^{237} determinations, and thermal fission counting for U^{233}, U^{234} (4.4% U^{235}), U^{235}, and U^{236} (4.63% U^{235}). A probable error of ± 1% is claimed for each of these methods. Fluorometric analysis, with an indicated probable error of ± 2-1/2%, was applied to each of the uranium samples. Only the initial weight estimate is available for the Pu^{239} foil, as the identity of the material was lost before a satisfactory analysis was obtained.

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III. RESULTS

The data in the body of this report are derived from foil activation results and fission counter measurements. For comparison, results of radiochemical analyses performed by J. Sattizahn and co-workers of Group J-11 are tabulated in an appendix. Indeed, these data give the more convincing spectral indices for the centers of Godiva and Topsy and the only results for U^{238} and Th^{232} capture and n,2n reactions.

Tables I and II and Figure 1 give the results for the Topsy assembly; likewise Tables III and IV and Figure 2 for Godiva. The numbers are on a per atom basis for the indicated isotopes and are arbitrarily normalized to unity for U^{238} fission at the center of each assembly. Tables II and IV, listing the results of the double fission chamber work, include measurements made in a fission spectrum for comparison.

For the sake of qualitative comparisons, a few detectors were irradiated in Topsy, using a nickel tamper. The results are shown in Figure 3. The β-activity of cellophane fission fragment catchers was used as the index for U^{235} and U^{238} fissions. In general, calibrations may be in considerable error. There is definite evidence of a greater proportion of lower energy tamper neutrons than was experienced in the

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uranium tamper. Their presence presumably must be attributed to increased energy degradation through inelastic scattering by nickel. As an added example of the influence of these low energy neutrons, Pd activities (arbitrary scale) are given in Figure 4.

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TABLE I.

Disintegrations per atom of various detectors in Topsy

Foil Activation (γ-Counting)			Spiral Fission Counter		Foil Activation (β-Counting)		
R(in.)	Fission U^{235}	Fission U^{238}	R(in.)	Fission Np^{237}	R(in.)	n,γ Au^{197}	n,p S^{32}
0.25	6.88	1.000	0.25	5.0	0.25		0.24
0.72	6.72	0.99	0.35	4.9	0.29	0.81[1]	
1.23	6.16	0.87	0.79	4.8	1.17		0.20
1.74	5.23	0.70	1.27	4.2	1.33	0.73	
2.27	4.11	0.41	1.76	3.4	2.32		0.085
3.15	2.72	0.143	2.69	1.61	2.45	0.56	
4.17	1.83	0.061	3.69	0.78	2.95		0.041
6.19	0.90	0.0159	5.75	0.242	3.10	0.47	
8.22	0.42	0.0051	7.75	0.088	4.10		0.0149
10.24	0.15	0.0016	9.25	0.040	5.25	0.25	0.0067
					7.40	0.123	0.00179
					9.55	0.052	0.00055

[1] Normalized according to $\sigma_{n,\gamma}(Au)/\sigma_f(25) = 0.0923$ at Godiva center, as determined recently by C. Byers.

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TABLE II.

Topsy Oy - Tu

(Oy radius 2.39", Tu outside radius 11")

Comparison fission chamber

	Topsy		
	1/4" radius	8-1/4" radius	fission spectrum
$\sigma_f(25)/\sigma_f(28)$ (1)	6.83	75.8	3.94
$\sigma_f(37)/\sigma_f(28)$ (2)	5.02	12.8	4.08
$\sigma_f(49)/\sigma_f(25)$ (3)	1.44	1.12	1.54
$\sigma_f(23)/\sigma_f(25)$ (4)	1.63	1.60	1.65
$\sigma_f(24)/\sigma_f(28)$ (5)	5.15	14.1	4.25
$\sigma_f(26)/\sigma_f(25)$ (6)	0.285	0.0305	0.401

(1) Probable errors: relative ± 2%; absolute ± 3-1/2%.

(2) Probable errors: relative ± 2%; absolute ± 4% claimed, though poor check on 37 foil weight.

(3) Probable errors: relative ± 2-1/2%; absolute unknown - no precision 49 foil weight before foil accidentally destroyed.

(4) Probable errors: relative ± 3%; absolute ± 3-1/2%.

(5) Probable errors: relative ± 2-1/2%; no 28 weight check

(6) Probable errors: relative ± 3%; absolute ± 4%.

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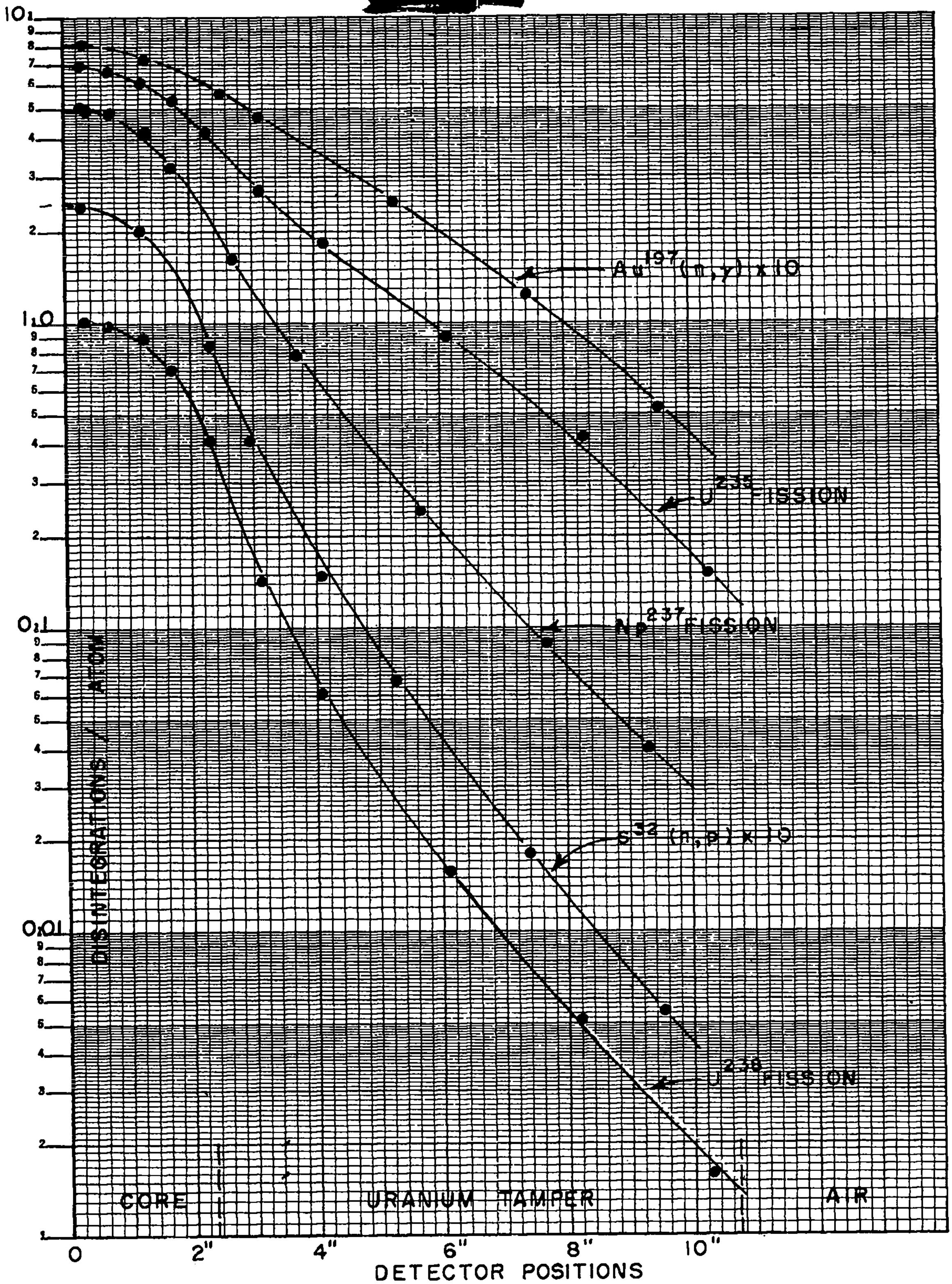

FIG. 1. Relative disintegration rates of detectors in Topsy.

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TABLE III.

Disintegrations per atom of various detectors in Godiva

Foil Activation (γ-Counting)

R(in.)	Fission U^{235}	Fission U^{238}
0.02	6.54	1.000
0.50	6.42	0.99
1.02	5.90	0.94
1.56	5.07	0.81
2.08	4.14	0.66
2.62	3.01	0.50
3.15	1.86	0.31

Foil Activation (β-Counting)

R(in.)	n,γ Au^{197}	n,p S^{32}
0.05	0.60(1)	0.24
0.70	0.57	0.23
1.35	0.51	0.20
2.00	0.40	0.163
2.65	0.27	0.113
3.30	0.138	0.061

The fission ratio Np^{237}/U^{238} = 4.49 at R = 0(2)

(1) Normalized according to $\sigma_{n,\gamma}(Au)/\sigma_f(25) = 0.0923$ at R = 0, as determined recently by C. Byers.

(2) Recent measurement by J. A. Grundl.

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TABLE IV.

Godiva, Oy (94%) untamped (radius 3.44")

Comparison fission chamber

	Godiva 3.0" radius	Godiva estimated(1) center	fission spectrum
$\sigma_f(25)/\sigma_f(28)$ (2)	5.52	6.1_7	3.94
$\sigma_f(37)/\sigma_f(28)$ (3)	4.65	4.8_2	4.08
$\sigma_f(49)/\sigma_f(25)$ (4)	1.42	1.4_3	1.54
$\sigma_f(23)/\sigma_f(25)$ (5)	1.71	1.6_7	1.65
$\sigma_f(24)/\sigma_f(28)$ (6)	5.01	5.0_8	4.25
$\sigma_f(26)/\sigma_f(25)$ (7)	0.310	0.29_8	0.401

(1) 25/28 corrected from 3" to center by data of Figure 2. Others obtained by interpolation (against 25/28) between Godiva 3" and Topsy 1/4" values.

(2) Probable errors: relative ± 2%; absolute ± 3-1/2%.

(3) Probable errors: relative ± 2%; absolute ± 4% claimed, though poor check on 37 foil weight.

(4) Probable errors: relative ± 2-1/2%; absolute unknown - no precision 49 foil weight before foil accidentally destroyed.

(5) Probable errors: relative ± 3%; absolute ± 3-1/2%.

(6) Probable errors: relative ± 2-1/2%; no 28 weight check.

(7) Probable errors: relative ± 3%; absolute ± 4%.

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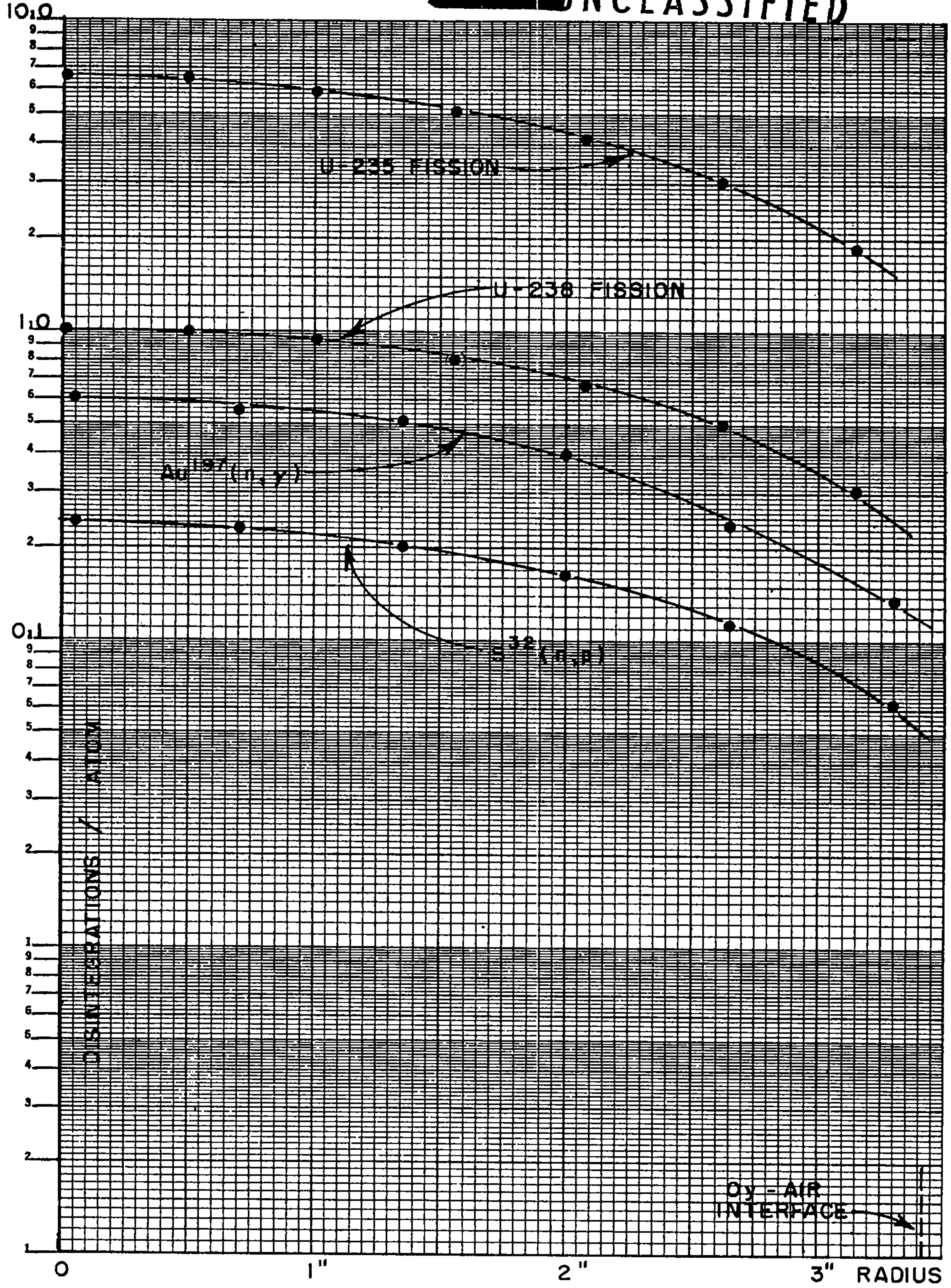

FIG. 2. Relative disintegration rates of detectors in Godiva.

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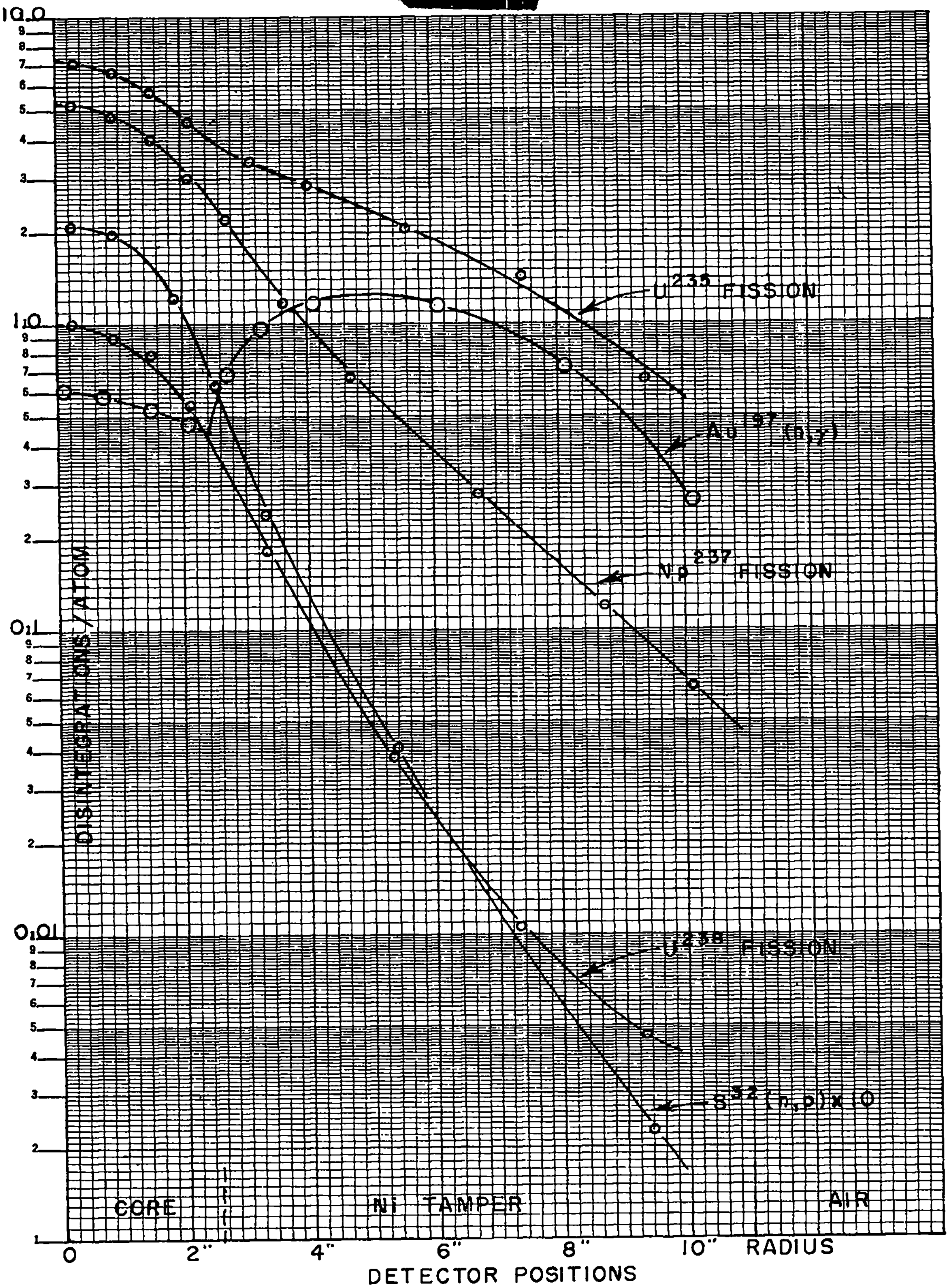

FIG. 3. Relative disintegration rates of detectors in Topsy Ni-tamped assembly.

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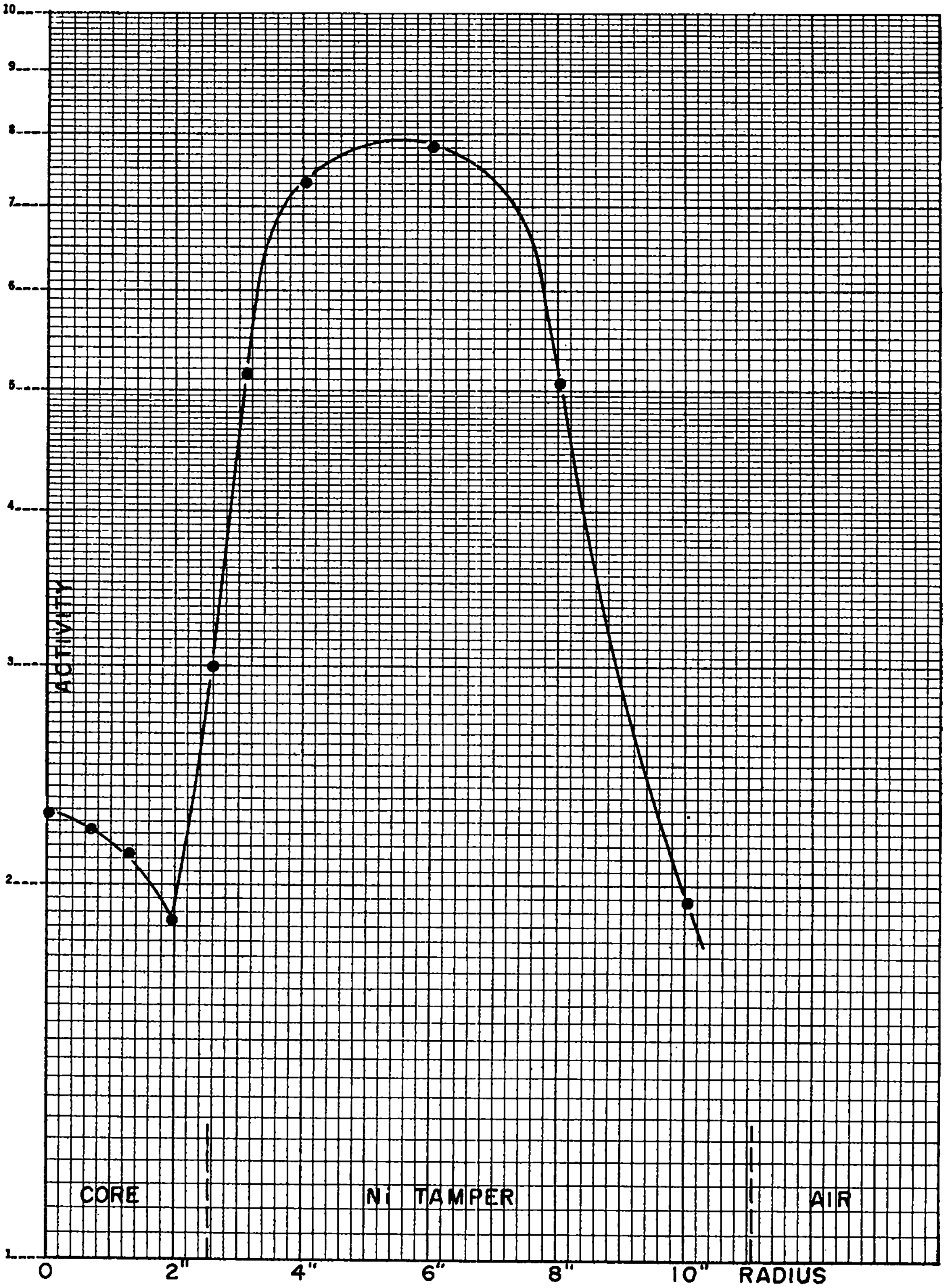

FIG. 4. Disintegration rates of 0.3 mil thick Pd detectors in Topsy Ni-tamped assembly.

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TABLE V.

Topsy Oy (94%) - Tu

(Oy radius 2.39", Tu outside radius 11")

Radiochemical analysis

radius (in.)	relative activity/nucleus 25	28	49	$\sigma_f(25)/\sigma_f(28)$	$\sigma_f(49)/\sigma_f(25)$
irradiation of 11/2/53:					
0.09	6.67	1.000[1]	10.39	6.6_7	1.55_8
1.15	--	1.012	9.57	--	--
2.21	4.78	0.559	6.27	8.5_6	1.31_0
3.52	2.54	0.1309	3.35	19.4_3	1.31_9
5.08	1.463	0.0406	1.818	36.1	1.24_3
irradiation of 11/18/53:					
0.09	6.56	1.000[1]	10.14	6.5_6	1.54_6
2.16	4.22	0.532	6.29	7.9_2	1.49_1
3.97	1.854	0.0771	2.54	24.0	1.36_9
6.07	0.896	0.01936	1.138	46.3	1.27_0
7.97	0.469	0.00625	0.561	$75._0$	1.19_5
9.97	0.1867	0.00212	0.232	$88._1$	1.24_2

[1] Normalization for 25, 28, 49.

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TABLE V. - (continued)

radius (in.)	relative activity/nucleus 25	28	$\frac{\sigma_f(25)}{\sigma_f(28)}$	$\frac{\sigma_{n,\gamma}(28)}{\sigma_f(28)}$	$\frac{\sigma_{n,2n}(28)}{\sigma_f(28)}$
irradiation of 11/23/53:					
0.09	6.52	1.000[1]	6.5_2	0.52_9	0.048_7
1.14	5.85	1.018	5.7_5	--	--
2.21	4.21	0.507	8.3_1	0.73_0	0.045_8
4.05	1.851	0.0756	24.5	2.54	0.039_8
6.17	0.882	0.01830	48.2	5.5_1	0.040_7
8.11	0.434	0.00642	$67._8$	7.9_7	0.040_2
irradiation of 11/25/53:					
0.09	6.64	1.000[1]	6.6_4	0.52_9	0.047_2
2.16	4.06	0.476	8.5_4	0.77_8	0.046_1
3.99	1.853	0.0740	25.0	2.71	--
6.08	0.877	0.01785	49.1	--	--
7.97	0.441	0.00601	$73._3$	--	0.044_1
10.24	0.1482	0.001694	$87._6$	--	0.031_0

[1] Normalization for 25, 28.

TABLE V. - (continued)

central values:							
date:	9/7/51	11/2/53	11/18/53	11/23/53	11/25/53	1/4/54	Average
$\sigma_f(25)/\sigma_f(28)$:	6.68	6.67	6.56	6.52	6.64	6.70	6.628 ± 0.044
$\sigma_f(37)/\sigma_f(28)$:						4.56	

independent of radius:

$\sigma_f(02)/\sigma_f(28) = 0.234 \pm 0.005$, $\sigma_{n,2n}(02)/\sigma_f(02) = 0.206 \pm 0.006$

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TABLE VI.

Godiva, Oy (94%) untamped (radius 3.44")

Radiochemical analysis

radius (in.)	$\frac{\sigma_f(25)}{\sigma_f(28)}$	$\frac{\sigma_f(49)}{\sigma_f(25)}$	$\frac{\sigma_{n,\gamma}(28)}{\sigma_f(28)}$	$\frac{\sigma_{n,2n}(28)}{\sigma_f(28)}$
irradiation of 2/1/54:				
0.03	5.9_9	1.54_2	0.458	0.045_2
1.91	6.1_9	1.42_6	0.469	0.044_6
3.03	5.5_9	1.46_5	0.464	0.039_5

At center:

date:	6/10/52	5/19/53	7/22/53	2/1/54	2/1/54	2/1/54	Average
$\frac{\sigma_f(25)}{\sigma_f(28)}$:	6.25	6.25	5.97	5.99	6.47[1]	6.10[1]	6.177 ± 0.116

[1] Values at 1.91" and 3.03" corrected to center by Figure 2.

At any radius:

$\sigma_f(02)/\sigma_f(28) = 0.234 \pm 0.005$

$\sigma_{n,2n}(02)/\sigma_f(02) = 0.206 \pm 0.006$