REFERENCE 45

G. A. LINENBERGER, J. D. ORNDOFF, AND H. C. PAXTON, "ENRICHED-URANIUM HYDRIDE CRITICAL ASSEMBLIES," NUCL. SCI. ENG. 7:44-57 (1960).

NUCLEAR SCIENCE and ENGINEERING

THE JOURNAL OF THE AMERICAN NUCLEAR SOCIETY

EDITOR

EVERITT P. BLIZARD, *Oak Ridge National Laboratory, Oak Ridge, Tennessee*

Volume 7, 1960

ACADEMIC PRESS

New York and London

NUCLEAR SCIENCE AND ENGINEERING: 7, 44–57 (1960)

Enriched-Uranium Hydride Critical Assemblies*

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Received September 25, 1959

Critical assemblies reported here consist of approximate spheres of enriched-uranium hydride composition (approximating UH_3) in 8-in. thick normal uranium and nickel reflectors and in a uranium reflector with nickel liner. Data are of the following types: (1) critical sizes, (2) values of Rossi alpha in the neighborhood of delayed critical, (3) activation rates of various internal neutron detectors, and (4) reactivity coefficients of a variety of elements. From the reactivity coefficients at various radial positions, changes in critical mass corresponding to small changes in composition and density are computed.

CRITICAL SIZES IN THICK U AND NI REFLECTORS

The measurements to be considered are on critical assemblies with cores approximating $U^{235}H_3$ and reflectors of ~8 in.-thick normal uranium or ~8 in.-thick nickel. The hydride, a mixture of $Oy(93.15)H_3$ powder, Oy(93.15)[1] powder, and polyethylene, was prepared in the desired shapes by the Plastics Section of LASL Group CMB-6. Examples of the shapes used are shown in Fig. 1. The average empirical formula of the hydride composition is $UH_{2.93}C_{1.08}O_{0.26}$ with small deviations from part to part, and the mean piece density is 7.5 gm/cm^3. Pseudospheres of hydride, assembled out of blocks that were multiples of half-inch cubic units, were surrounded intimately by approximately 8 in.-thick reflector. A constant external reflector surface geometry was maintained for all measurements. The U reflector is effectively nearly infinite.

ASSEMBLY SYSTEM

The hydride assemblies were set up on Topsy (*1*), the Pajarito universal machine for operation at delayed critical. Briefly, the hydride (or a portion of it) is cradled in a block of reflector material on a hydraulic lift. By remote control, this subassembly is raised into a close-fitting cavity within the principal body of reflector. In the course of inital critical determinations, all of the hydride was supported on the lift (integral assumbly as in Fig. 2 of Ref. *1*). For measurements requiring internal detectors however, the upper half of the hydride, consisting of "stove lid" (Fig. 1) and additional pieces on it, was suspended within the reflector cavity. With this arrangement (split-assembly, Fig. 2), only the lower portion of the hydride, nested in reflector material, was carried on the lift. A radial hole with fillers (the "glory hole"), through reflector and into the stove lid permits the use of internal measuring equipment that will not be disturbed by motion of the lift.

As usual with Topsy, the control rods of reflector material travel within the reflector body, almost tangential to the core. The lift drops as one automatic safety, and a block of reflector withdraws from the main body as the other.

CRITICAL SIZE OF HYDRIDE IN NORMAL U REFLECTOR

In the case of pseudospheres of hydride imbedded in U metal on the lift, the critical quantity with both Topsy control rods "in" (reflector unperturbed) is equivalent to 967 half-inch cubes of hydride, or about 14.7 kg. As an indication of the influence of shape variation on reactivity, the critical mass of an approximate hydride cube in the thick U reflector was measured. The form was a 5-in. cube with $\frac{1}{2} \times \frac{1}{2}$ in. columns lacking along 4 parallel edges (a limitation imposed by Topsy design). To build up the required size, 35 additional half-inch cubes were placed in three groups on different faces. The critical

* Performed under the auspices of the U. S. Atomic Energy Commission. Though this work was completed in 1950, it has been reported only in classified documents.

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[1] Oy(93.15) = uranium in which the U^{235} concentration is 93.15 w/o. (Oy = "oralloy.")

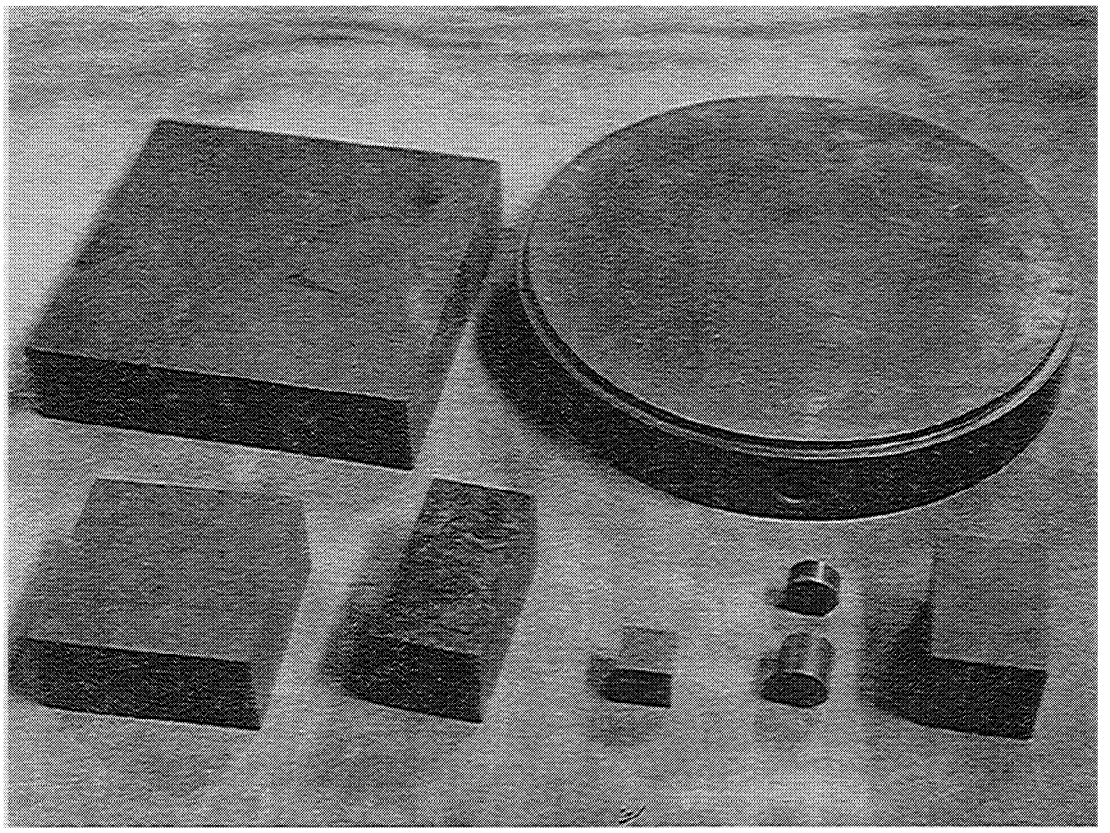

FIG. 1. Oralloy-Hydride Shapes—the disk is the "stove lid" for split assemblies

quantity was equivalent to 995 half-inch cubes as compared with 967 for the pseudosphere. The critical volume of the split pseudospherical geometry, equivalent to 972 half-inch cubes (the critical mass again is 14.7 kg), is slightly greater than with all hydride in the lift because the stove-lid density and H to U ratio were somewhat below the average for other pieces. The effect of each control rod is roughly that of 9 hydride cubes (134 gm hydride) in the outer portion of the pseudosphere. Initial delayed-critical data for these assemblies are summarized in Table I. About four months after the original stacking, the critical mass of the U-reflected hydride apparently had increased by the order of 1%. It is possible that a shift of reflector blocks in this interval may be responsible for at least part of the effect. The hydride was set up in Topsy for five and one-half months. During this time, weights and dimensions of six $\frac{1}{2}$-in. cubes and one $1 \times 1 \times 2$ in. piece of hydride were checked periodically. The weight gain during this period averaged 0.085% for the half-inch cubes and was 0.04% for the $1 \times 1 \times 2$ in. block, and the average increase in linear dimensions was 0.2% for the cubes and 0.07% for the larger piece.

It may be noted that earlier, unpublished results of Holloway and Baker correspond to a critical volume of 4020 cm^3 for $Oy(73.8)H_{10}C_4$ of density 3.05 gm/cm^3 in a $6\frac{1}{2}$-in.-thick U-metal reflector, and 4850 cm^3 in a $6\frac{1}{2}$-in.-thick Fe reflector. The critical volume of the Topsy Oy(94) metal core is 925 cm^3 in 9-in.-thick U reflector and 1130 cm^3 in a Ni reflector of about the same thickness (*1*).

CRITICAL SIZE OF HYDRIDE IN Ni REFLECTOR

With Ni reflector, the critical quantities of hydride for internal and split geometries, 970 cubes (14.7 kg) and 976 equivalent cubes, respectively, are nearly identical with values for the U reflector. The effect per control rod is the equivalent of about 7 surface cubes (104 gm hydride). Table II is a summary of data for these critical configurations.

COMPOSITE REFLECTOR

Reactivity-contribution measurements (to be discussed later) showed that substitution of Ni for

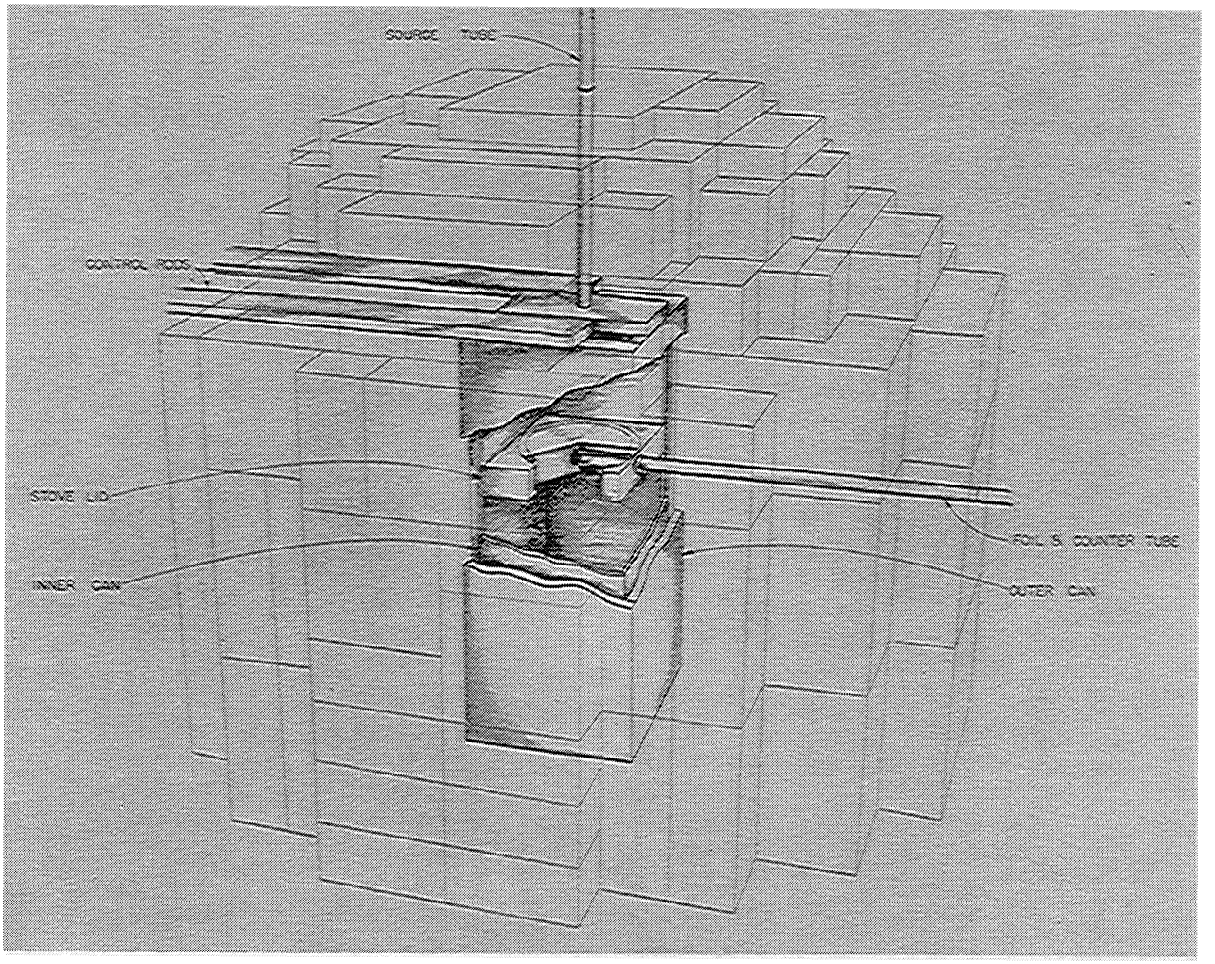

FIG. 2. Topsy Split Assembly—the stovelid and hydride supported by it form the upper, stationary half of the active core. The inner can, mounted on the lift, contains the lower half.

normal U adjoining the hydride core increases the reactivity of the system, whether in U or Ni reflector. As critical masses in thick U and Ni reflectors were essentially equal, this suggests that a composite reflector consisting of a relatively thin Ni layer about the hydride, surrounded in turn by thick U, should lead to a reduction in critical mass. According to a computation based on the reactivity contribution data, this decrease in critical mass should be 10% for a uniform $\frac{1}{2}$-in. thick Ni liner.

Accordingly, final hydride tests consisted of critical-mass determinations with 1 in. and with $\frac{1}{2}$-in. thick Ni liners (roughly approximated) in the U reflector. The liners were imperfect because of Topsy design limitation; the approximately 1-in. Ni layer thinned to $\frac{1}{4}$ in. at a few locations about the equator of the pseudosphere, and there were a few gaps and $\frac{1}{4}$-in. thick regions in the approximately half-inch layer.

With the 1-in. Ni-lined U reflector the critical quantity of hydride was equivalent to 905 half-inch cubes as compared with about 980 cubes for the final critical condition in unlined U. This amounts to a $7\frac{1}{2}$% decrease in critical mass. The assembly with the half-inch Ni liner was critical at the equivalent of 918 cubes or about $6\frac{1}{2}$% below the value for thick U alone. The latter difference might be expected to increase to about 8% or 9% if deficiencies in the $\frac{1}{2}$-in. Ni layer were removed. Although it is apparent that the observed magnitudes are open to question because of geometric compromises, the expected effect appears to have been established.

TIME-SCALE MEASUREMENTS ON HYDRIDE ASSEMBLIES

The general procedures for measurements of α by the Rossi method on near-critical assemblies have been described by Orndoff (*2*). The apparatus used consisted of detector, amplifier-discriminator, and time analyzer. The neutron detectors employed were U^{235} spiral fission chambers, which were approximately $\frac{7}{8}$ in. in diameter and fit snugly into the

TABLE I

CRITICAL CONDITIONS OF HYDRIDE CORE IN U REFLECTOR

Hydride in U(normal)	Integral Core	Split Core
Avg. empirical formula	$UH_{2.97}C_{1.11}O_{0.25}$	$UH_{2.92}C_{1.08}O_{0.26}$
Critical mass	14.68 kg	14.68 kg
Oy content of critical mass	13.54 kg	13.55 kg
Concentration of U^{235} in Oy	93.15 %	93.15 %
Effective hydride density	7.40 gm/cm^3	7.35 gm/cm^3
Critical volume	120.9 in.^{3} 1980 cm^3	121.5 in.^{3} 1990 cm^3
Radius of sphere of critical volume	3.06 in.	3.07 in.
Normal-U reflector		
U thickness at glory hole	8 in.	
U mass	2550 kg	
U density	19 gm/cm^3	

TABLE II

CRITICAL CONDITIONS OF HYDRIDE CORE IN NI REFLECTOR

Hydride in Ni	Integral core	Split core
Avg. empirical formula	$UH_{2.97}C_{1.11}O_{0.25}$	$UH_{2.92}C_{1.08}O_{0.26}$
Critical mass	14.72 kg	14.74 kg
Oy content of critical mass	13.56 kg	13.60 kg
Concentration of U^{235} in Oy	93.15 %	93.15 %
Effective hydride density	7.40 gm/cm^3	7.35 gm/cm^3
Critical volume	121.2 in.^{3} 1990 cm^3	122.0 in.^{3} 2000 cm^3
Radius of sphere of critical volume	3.07 in.	3.08 in.
Ni reflector		
Ni thickness at glory hole	8 in.	
Ni mass	1180 kg	
Ni density	8.8 gm/cm^3	

$\frac{7}{8}$-in. "glory hole" in the reflector. Since the glory hole in the hydride core was only $\frac{1}{2}$ in. in diameter, the detectors were inserted up to the reflector-hydride interface; this resulted in a minimum perturbation of the assembly consistent with reasonable sensitivity. The foils in the spiral chambers contained 2 mgm of U^{235} per cm^2 ($\sim$0.45 gm total). These thick foils did not give a pulse-height plateau, but did give a high efficiency. In operation, the discriminators were set low enough that a few alpha background pulses were recorded.

Output pulses from LASL model 502 amplifiers were about 0.5 μsec in total width. The final pulse input to the time scale apparatus consisted of square, equal-height pulses 0.3 μsec wide and 18 volts high. There was very little straggling of pulse heights, and the over-all counting system was quite stable. Three-microsecond-wide channels proved to be optimum for all the hydride measurements.

Alpha was determined at critical and at various subcritical points obtained by stacking to critical, then removing cubes in the required steps. The steps used were -4, -8, -12, and -16 one-half-inch hydride cubes removed from the outside of the hydride pseudosphere in such a fashion that they were representative of an outside layer of material. The mass increments removed, Δm, presumably produced equal increments of change in the reactivity, Δk.

Figure 3 shows a plot of the α determinations on the U-reflected hydride assembly. The ordinate, P_c, is the probability after receiving a count, of receiving a second count originating from the same chain after a time t, and within the interval of time Δt equal to a channel width. It has been shown that these coincidences have the time dependence $e^{\alpha t}$ so that alpha is determined from the slopes of the

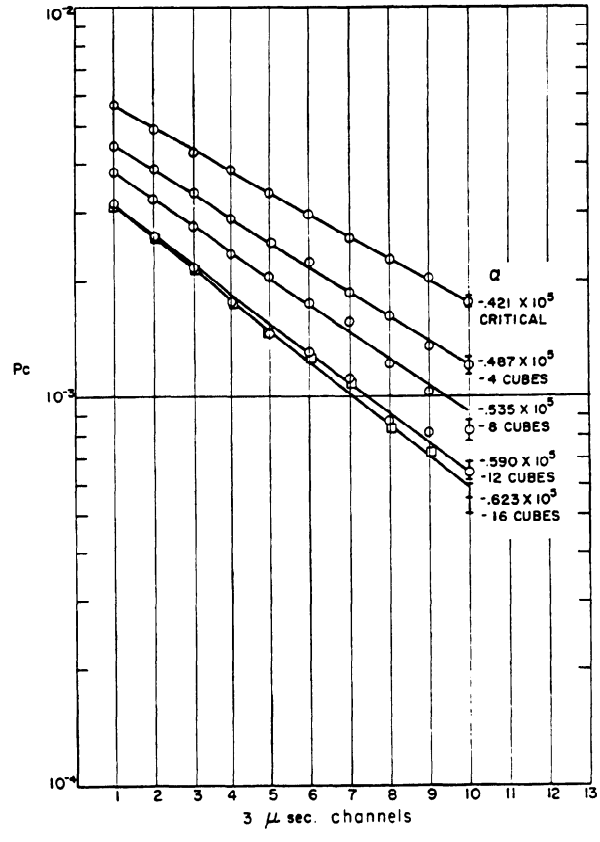

FIG. 3. Averaged Rossi-alpha data for uranium-reflected hydride.

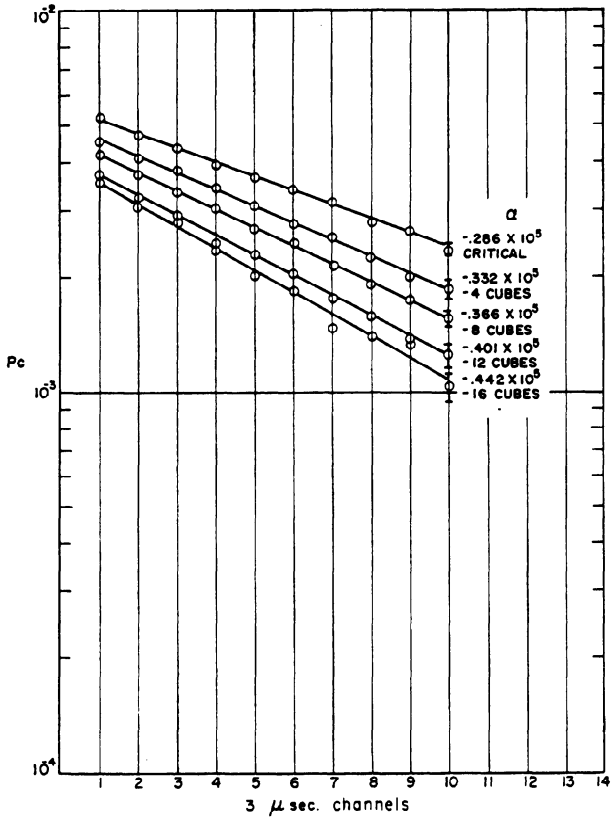

FIG. 4. Averaged Rossi-alpha data for nickel-reflected hydride.

curves. The mean errors indicated on the last points are the maximum encountered, as statistics are much better for the earlier channels. Similar data for the Ni-reflected assembly are collected in Fig. 4. The series of experiments with the two different reflectors were identical in all respects. A summary of all the data is given in Table III.

The value of τ_0, the mean life of a neutron in the assembly, was obtained from the relation

$$\alpha = (k_p - 1)/\tau_0$$

where k_p is the average number of prompt daughter neutrons per neutron. At delayed critical, the value of $k_p - 1$ was taken to be -0.0068 which is equal to (minus) the fraction of neutrons that are delayed. This will be true only if the effectiveness of delayed neutrons for producing fissions is the same as that for prompt neutrons. If delayed neutrons are more effective for producing fissions than prompt neutrons, the values of τ_0 quoted will be too low.

To compare the values of α measured for the present hydride assembly with values for other assemblies, the results of some previous measurements are listed in Table IV.

The variation of α with hydride mass is plotted in Fig. 5 for both reflectors. These curves give values of $d\alpha/dm$ equal to 0.93×10^2 $\text{sec}^{-1}\text{gm}^{-1}$ for the U-reflected assembly, and 0.66×10^2 $\text{sec}^{-1}\text{gm}^{-1}$ for the Ni-reflected system. The differences observed in α and in $d\alpha/dm$ can be interpreted as being due to reflector alone as the cores in the two cases were identical.

For the uranium-reflected assembly, a progressive increase of α amounting to $\sim$15% over a period of 4 months was too large to be accounted for on the basis of experimental uncertainties. This change appears to be inconsistent with the $\sim$1% critical mass increase during the same period (which is estimated to be consistent with $\sim$3% decrease in hydrogen content of the core). The alpha measurements reported for the U-reflected and Ni-reflected assemblies were made within about one month of each other, and the "age" effect might have changed α by a few percent during this interval of time.

TABLE III

VALUES OF ROSSI ALPHA AND PROMPT-NEUTRON MEAN LIFE FOR HYDRIDE ASSEMBLIES

Uranium Reflector		
δm (gm hydride)	$-\alpha$ (sec^{-1})	τ_0 (sec)
0	0.421×10^5	1.6×10^{-7}
−59.6	0.487×10^5	
−119	0.535×10^5	
−179	0.590×10^5	
−238	0.623×10^5	
Nickel Reflector		
δm (gm)	$-\alpha$ (sec^{-1})	τ_0 (sec)
0	0.286×10^5	2.4×10^{-7}
−59.6	0.332×10^5	
−119	0.366×10^5	
−179	0.401×10^5	
−238	0.442×10^5	

TABLE IV

ROSSI ALPHA FOR ASSEMBLIES WITH OY-METAL CORE AND WITH OTHER HYDRIDE CORES

Active material	Reflector	Reactivity level	$-\alpha$ (sec^{-1})
Oy(94) (*1*)	9 in. Normal U	Critical	0.37×10^6
$Oy(75.2)H_{10}$ (Holloway, Baker)	12 in. BeO	Approx. crit.	0.18×10^4
$Oy(\sim75)H_{10}$ (Holloway, Baker)	4½ in. WC	Approx. crit.	0.79×10^4

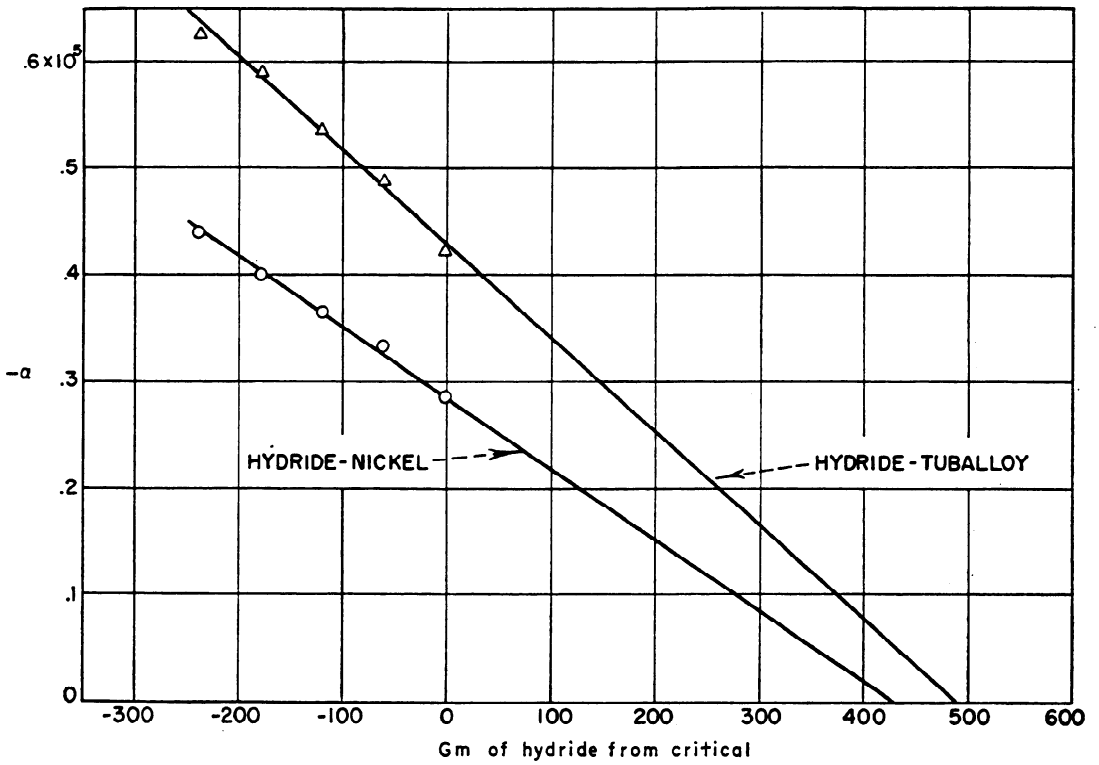

FIG. 5. Rossi-alpha *vs* core mass for the U-reflected and Ni-reflected hydride assemblies

NEUTRON DISTRIBUTION STUDIES

Detectors of gold, sulfur, Oy(94), and U^{238} (~0.02 w/o U^{235}) were used for neutron distribution measurements, the reactions of interest being (n, γ) for the gold, (n, p) for the sulfur (effective threshold ~2.7 Mev), and fission for U^{235} and U^{238}. Both the gold and the sulfur were in the form of 0.49-in. diameter foils, the gold being 0.005 in. thick and the sulfur about 0.12 in. thick (0.60 gm pressed into a pellet). The U^{238} and Oy were in the form of 0.001-in. thick foils 0.44 in. diameter, and were irradiated in contact with 0.010-in. celluloid fission-fragment catcher foils of the same diameter. These detectors were distributed at various radii throughout the hydride and reflector, and were irradiated by running the reactor at delayed critical. Beta-activity measurements were made with methane-flow proportional counters calibrated for each type of detector used.

The results are presented graphically in Figs. 6 through 9, for which the total number of disintegrations per atom of detector (for standard irradiation conditions) is plotted against position of detector in the assembly. Irradiations were standardized by monitoring with a sulfur pellet placed at the center of the reactor during each irradiation. Figure 10 gives the ratio of the effective fission cross section of U^{235} to that of U^{238} as a function of radius. Central values, about 20, compare with 6.5 for the Topsy Oy(94) metal assembly with normal-U reflector.

Two qualitative features of these curves are perhaps worth comment. The anomalously sharp fall-off of the U^{238} fission rate within the U-reflected core, may be spurious, as the U^{238} fission-fragment catchers were the least satisfactory detectors from the point of view of intensity and of consistency. The more reliable sulfur detectors show no such effect. Both U^{235} catchers and gold detectors show activities which fall off more sharply in the uranium reflector than in the nickel. Such a response is consistent with the expectation that the low-energy portion of the spectrum of neutrons emerging from the core has a longer capture mean free path in nickel than in uranium.

REACTIVITY COEFFICIENTS OF VARIOUS ELEMENTS WITHIN THE HYDRIDE ASSEMBLIES

METHOD OF MEASUREMENT

A survey of the effects on reactivity of various materials within the hydride assemblies extended over a 5-month period. Most samples were elements or simple compounds (usually oxides) in the form of pressed or machined 0.5-in. cubes. Pressed specimens were prepared by the Powder Metallurgy Section of LASL Group CMB-6. A few, in powder form,

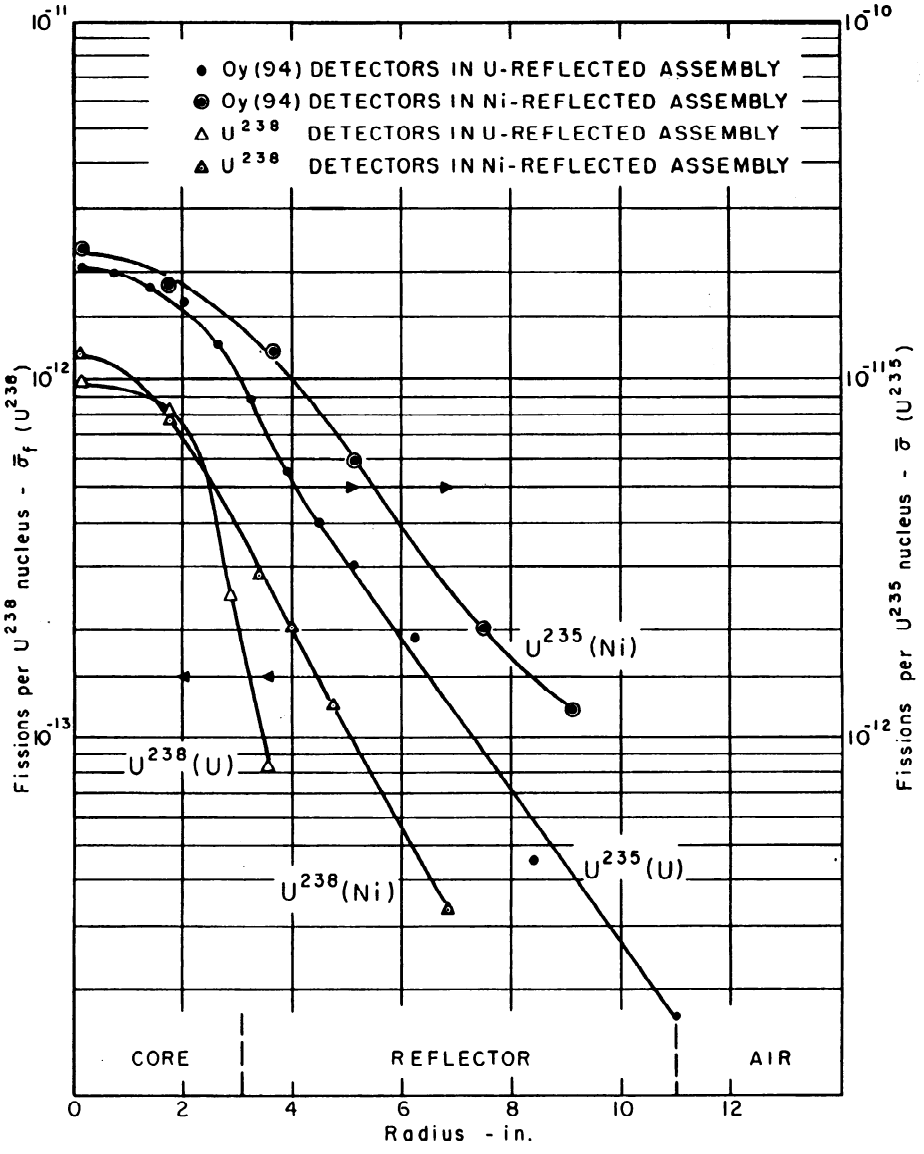

FIG. 6. Fission rates of U^{235} and U^{238} detectors within the hydride assemblies

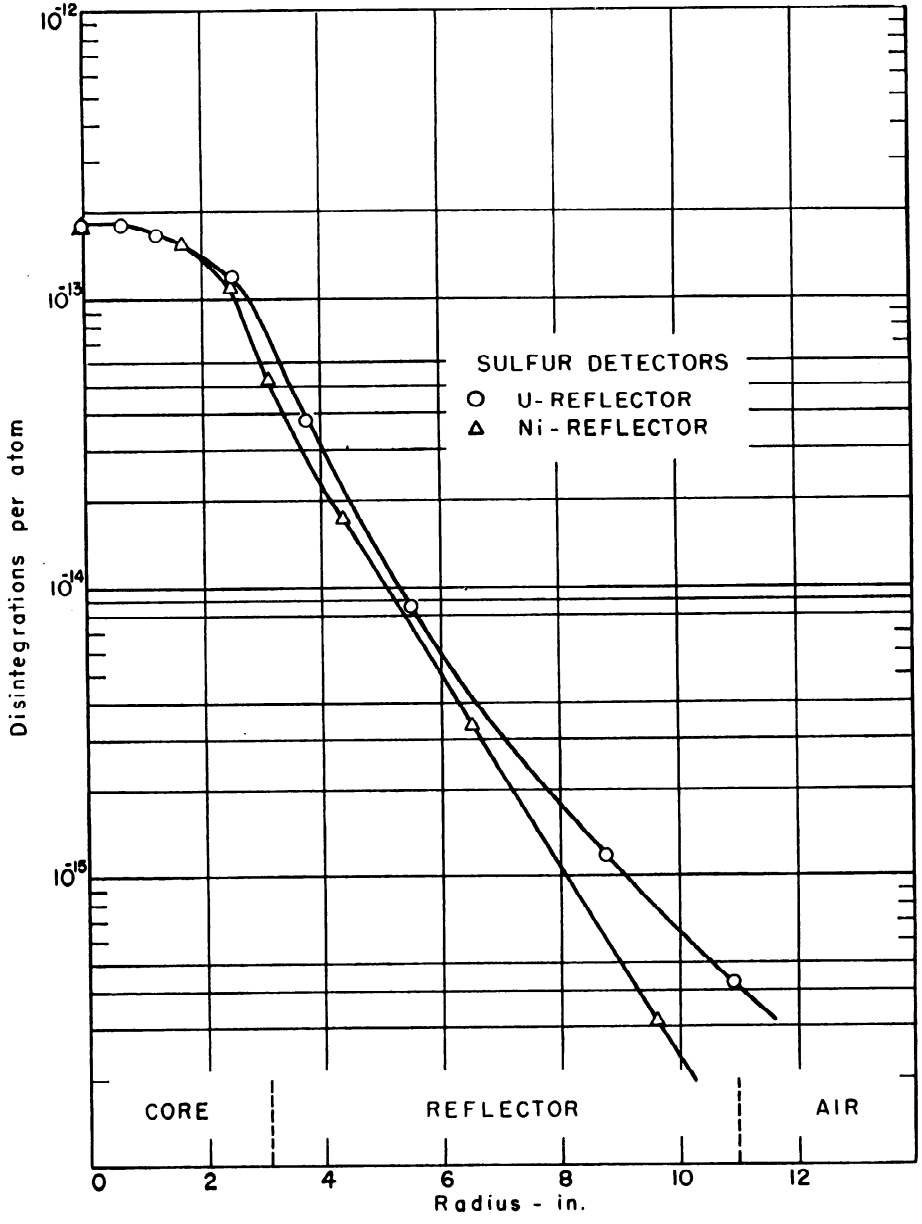

FIG. 7. Activation rates of sulfur detectors within the hydride assemblies

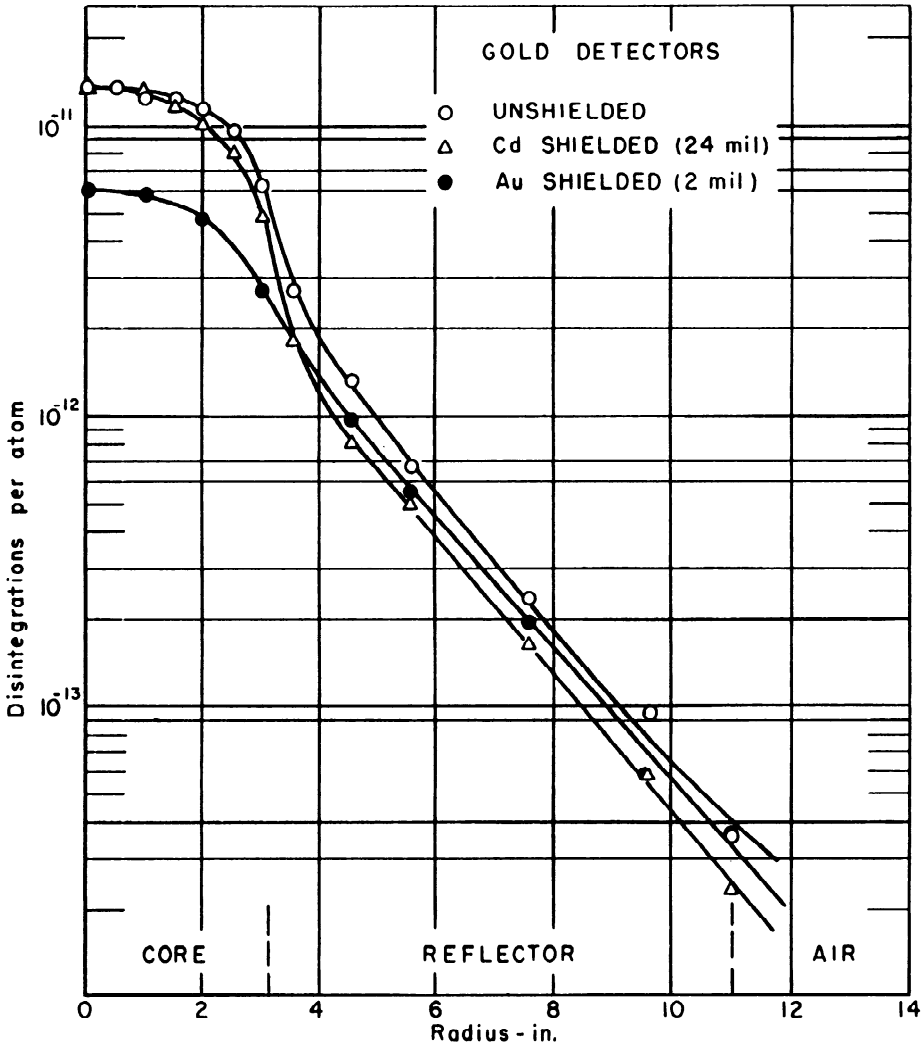

FIG. 8. Activation rates of gold detectors (bare, Cd-shielded and Au-shielded) within the U-reflected hydride assembly.

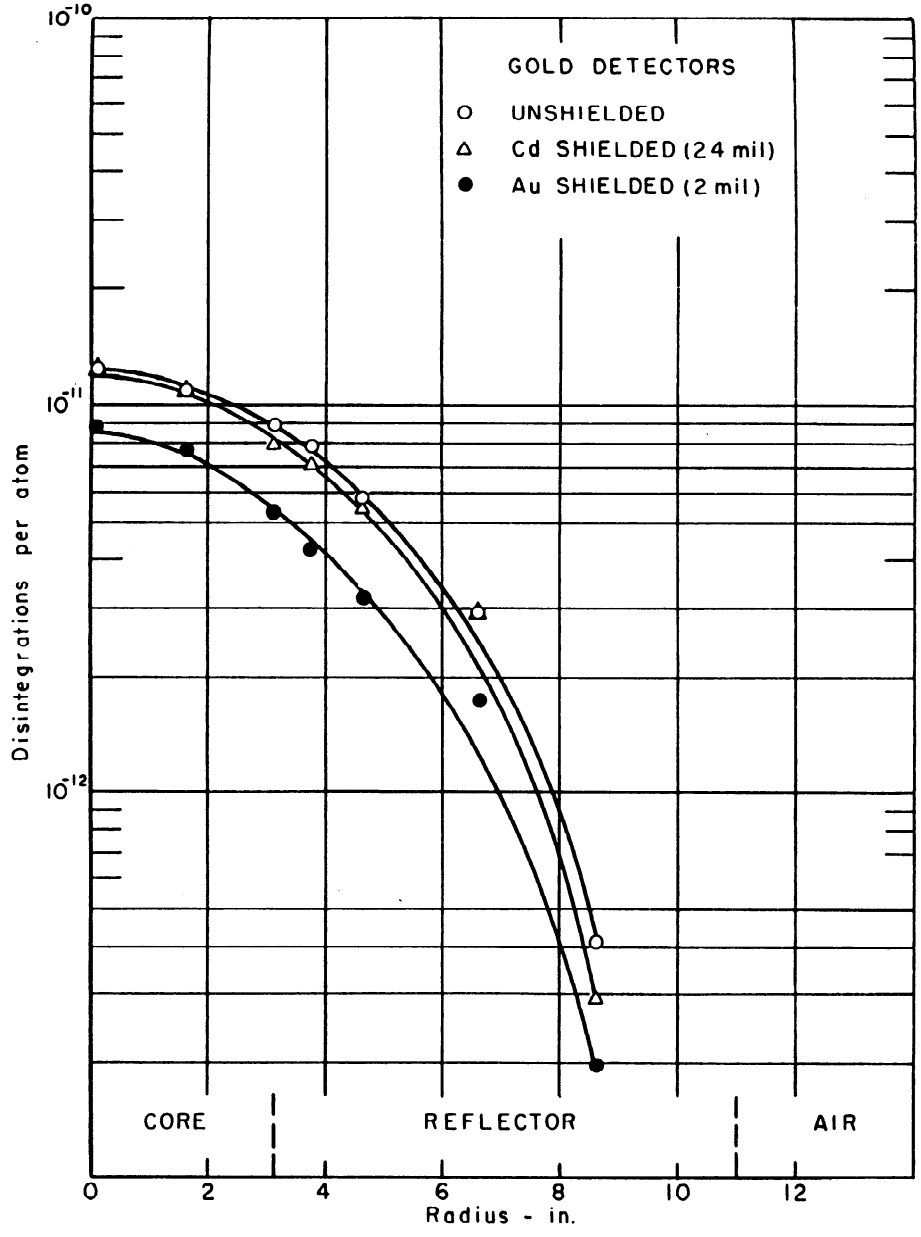

FIG. 9. Activation rates of gold detectors (bare, Cd-shielded and Au-shielded) within the Ni-reflected hydride assembly.

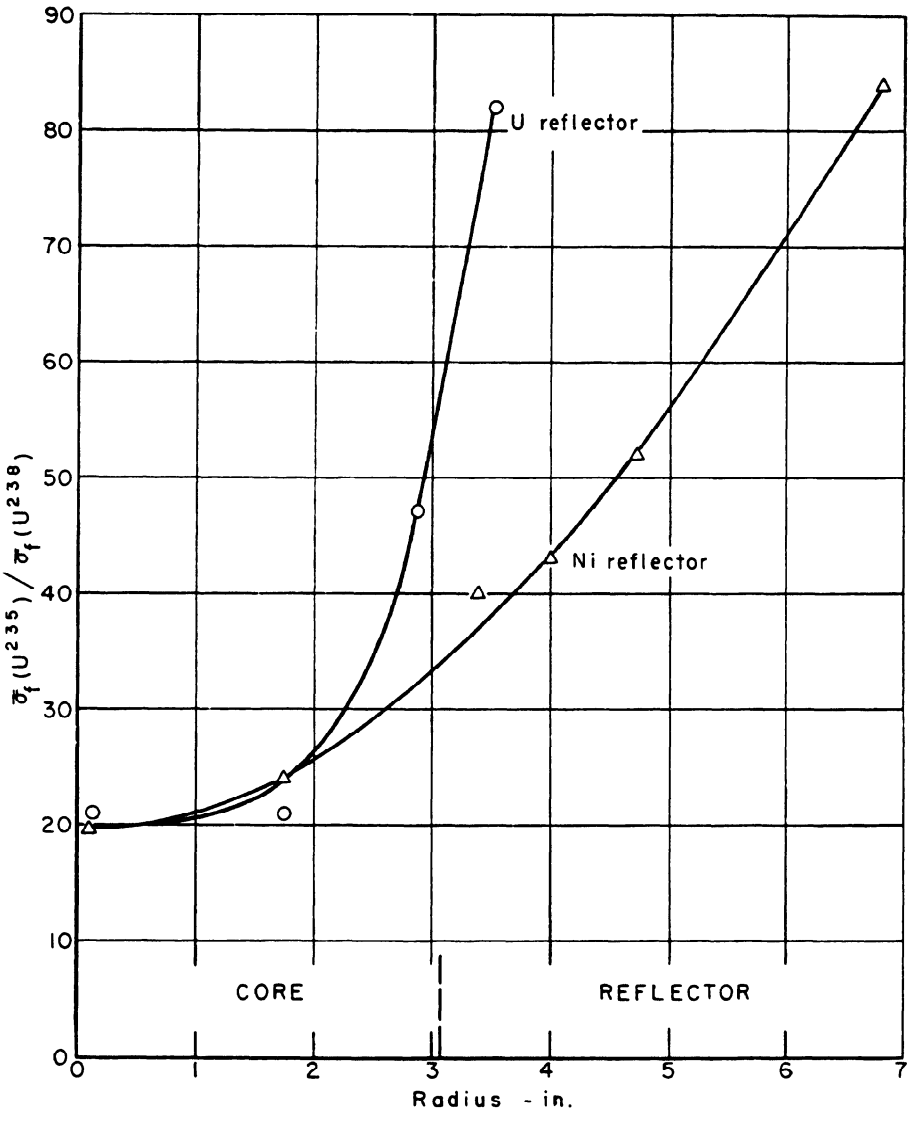

FIG. 10. Ratio of the effective fission cross section of U^{235} to that of U^{238} within the hydride assemblies

were in 0.5-gm Al containers, $\frac{1}{2}$ in. diam. $\times$ $\frac{1}{2}$ in. long. The materials came from a wide variety of sources and in most cases contaminants were not checked. The samples were introduced as near the hydride center as possible (r = 0.8 in.), in the reflector adjoining the hydride (r = 3.35 in., interface at r = 3.08 in.) and in some cases at intermediate positions.

Measurements were made in terms of control rod change required to restore the system to delayed critical when a sample was placed in a $\frac{1}{2}$-in. cu. space. By means of control-rod calibration curves, data were converted to reactivity change in cents per gm-atom (or mole) of perturbing material. The cents scale was established by measurement of positive periods corresponding to shifts from delayed critical by known increments of control rod position, and use of delayed-neutron periods and abundance ratios from Keepin, Wimett, and Zeigler (*3*).

EXPERIMENTAL RESULTS

Results of measurements in the three radial positions most generally used are given in Table V for the U-reflected and the Ni-reflected assemblies. The errors discussed in the notes which follow this table leave much to be desired; this is a consequence of the decision to devote necessarily limited efforts to a general survey instead of a careful study of a few materials. Several changes in technique in the course of this work improved reliability of results but did not eliminate occasional inconsistencies.

VARIATION WITH Z

Central reactivity coefficients as functions of Z show a downward trend from Z = 1 to Z = 50 and grouping of even-Z elements above odd-Z, which agrees (though not in magnitude) with observations on other assemblies (*4*). The rare-earth region ap-

pears to be one of extremes, and above $Z = 73$, the trend is upward.

Values for odd-proton, even-neutron nuclei form groups within which trends are preserved. Discontinuities between these groups seem to occur near the magic atomic numbers 20, 28, and 50, and another break appears between $Z = 33$ and 39 (*5*).

TABLE V

EFFECTS OF FOREIGN MATERIALS IN HYDRIDE ASSEMBLIES

Distance from center: (hydride radius 3.08 in.)	Reactivity coefficient in cents per gm-atom or mole					
	0.8 in.		2.4 in.		3.35 in.	
Z Material	U reflector	Ni reflector	U reflector	Ni reflector	U reflector	Ni reflector
1 H[a]	29.5	34	17.5	20.5	4	7
4 Be	7.5*	9	6.5	9.5	4*	5
5 B	−46	−52.5	−23.5	−26.5	−4*	−9
6 C	3.5	3.5	5	6.5	4	4.5
8 O[b]	4	3	4*		4*	4
12 Mg	7.5	9	9	10.5	4*	6
13 Al	2	3.5	5.5	6.5	2.5*	4
14 Si	2.5	2.5			3.5	2.5
16 S	−1	−0.5			1	1
21 Sc[c,d]	7.5*					
22 Ti	2.5*	5.5			6*	5.5
23 V	2.5	3.5	7.5	8	8*	6.5
24 Cr	2.5*				4*	
25 Mn	−1.5	−1.5	4	7.5	6.5*	4.5
26 Fe	2	3.5			4.5	4
27 Co	−7.5	−6.5	1	2.5	4*	3
28 Ni	−0.5	1	5.5	6	6*	4.5
29 Cu	1.5	2.5			4	5
30 Zn	3	2.5			5	5
32 Ge[d]	2.5		2.5			
33 As	−10	−7.5			4	3
39 Y[c,d]	−1*					
40 Zr[c,d]	11					
41 Nb	−4	−2.5			5	4
42 Mo	−2	−0.5			6	7
45 Rh	−30.5				1*	
46 Pd	−15.5	−13.5			3	1.5
47 Ag	−38	−39			−0.5	−4.5
48 Cd	−14.5	−13	−2.5	1	2.5*	2.5
49 In	−41	−43.5			−1	−7
50 Sn	−0.5*	1.5			4	6
51 Sb	−24.5	−24.5			−0.5	−2.5
52 Te	−4	−3.5			3	2
53 I	−41				1*	
58 Ce[c]	25.5*				12*	
60 Nd[c,d]	2.5*					
64 Gd[c,d]	−140*				−1*	
73 Ta	−53	−53	−22.5	−21.5	−1.5*	−7
74 W	−17	−17.5	−3.5	−3.5	4*	2.5
76 Os[d]	−41*		−14.5		6*	
78 Pt	−19	−16			4	2.5
79 Au	−31.5	−31	−11	−7.5	1.5*	−1
81 Tl	−1	3.5			6	5
82 Pb	3	5.5			8	9
83 Bi	5.5	6	12.5	14	7.5	9
92 U (normal)	9	13.5	9.5*	15	7.5*	7.5
92 Oy	91.5*	103.5	59.5	63	39*	33
94 Pu	169.5*	187	102.5	109	63*	53
WC	−19	−17			7.5	5
$OyH_{2.97}C_{1.11}O_{0.25}$[d]	165.5	195.5	102.5	128	58.5	
$UH_{3.23}C_{0.89}O_{0.18}$[d]	84		56			
$C_9H_8O_2$[d]	252		140		57	

[a] From measurements on polyethylene and C.

[b] From measurements on Al_2O_3 and Al.

[c] From measurements on the oxide.

[d] Samples small, so errors per gm-atom relatively large.

* Operation more stable for measurements giving these values than for others.

Errors: A number of values were from repetitions of earliest measurements. For 21 normal samples, differences ranged from 0.0 to 0.6 unit, corresponding to a probable error of ±0.2 unit (in relative values for a given reflector). In addition, there were 4 wild cases with differences of 1.1 to 2.2 units. Absolute values (for comparison between U and Ni reflectors) have an added uncertainty which should be within ±5%. Systematic differences (between U and Ni reflectors) may suggest a larger calibration error.

VARIATION WITH RADIUS

Figures 11, 12, and 13 indicate for some of the more interesting materials, reactivity changes per gm-atom (or mole) as a function of radial position within the assembly. In Fig. 11 are grouped curves typical of pronounced neutron absorbers. B, Au, and Cd, of course, are known to have large absorption cross section for low-energy neutrons. Ta, similarly effective, may be of interest because of potentially good mechanical properties. Mn, in the U-reflected assembly, is included as typical of a transition case in which a good reflector has measurable absorption near the center of the core. A striking difference between curves for Ni-reflected and for U-reflected assemblies is that the latter rise more abruptly in the outer part of the hydride core. This and a similar difference between ratios of U^{235} to U^{238} fission catcher activities for the two assemblies (Fig. 10) are consistent with greater degradation of energy of neutrons returning to the core from the U reflector than from the Ni reflector.

Figure 12 gives reactivity change results for elements of interest as reflectors. The general difference

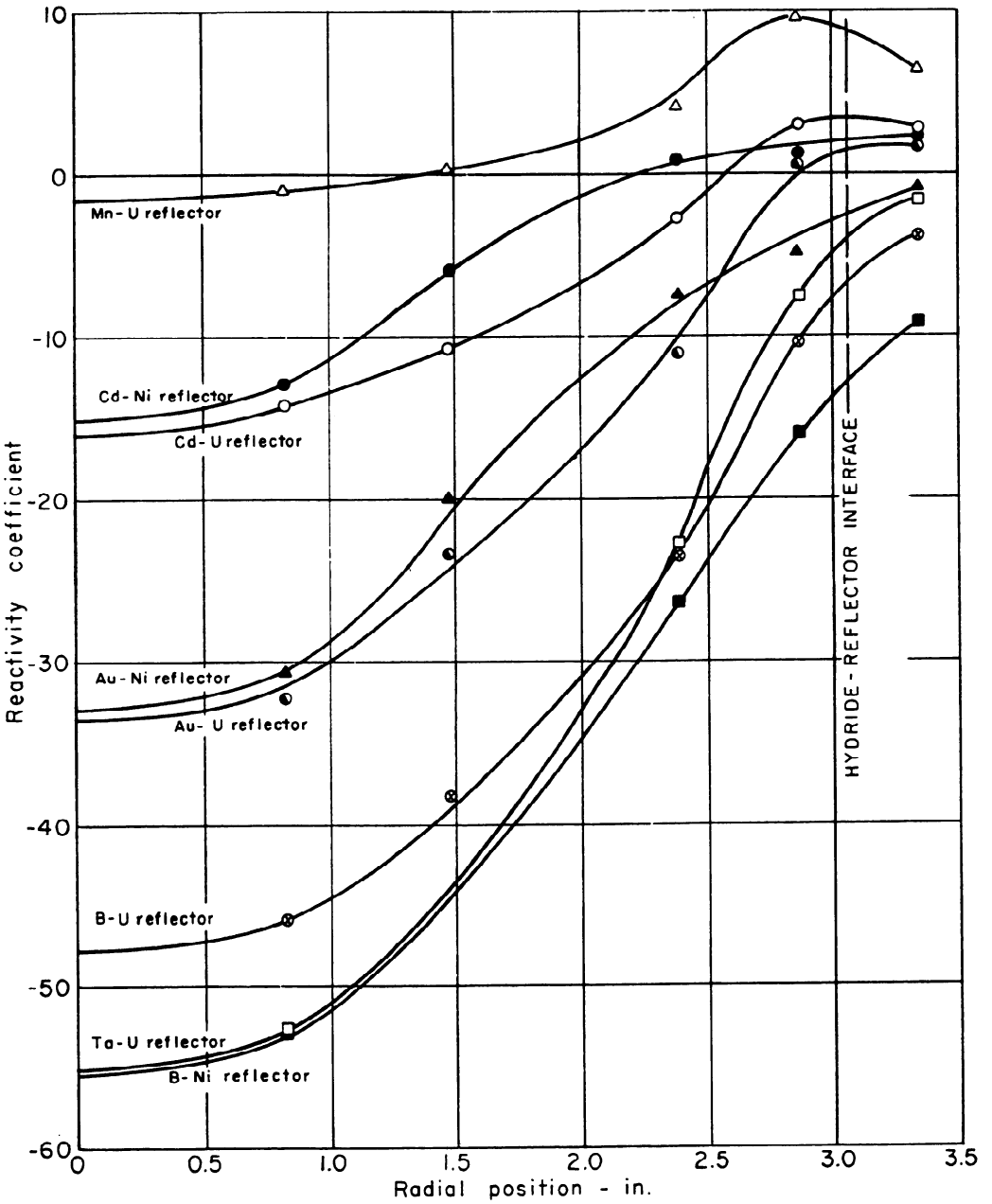

FIG. 11. Reactivity coefficients of elements that are effective neutron absorbers (Mn is added for contrast)

in shape of curves for U and for Ni reflectors, which was noted for the absorbers, seems to be maintained. The W curves, typical of absorbers, appear to be out of place in the reflector family. Although reactivity changes per gm-atom are greater for U than for Ni at the position outside the hydride (3.35 in. radius), Ni is 1.4 times as effective per unit volume as U for the U reflector and 1.1 times as effective for the Ni reflector. This consideration led to the critical mass measurements on Ni-lined U reflectors, which were described earlier.

Reactivity change-radius curves for materials which show a large positive contribution near the core center are given in Fig. 13. A U curve is repeated to emphasize the scale. Degradation of neutron energy by single-step elastic scattering can account for the large central effect of H.

CRITICAL MASS OF OyH_3 AT $\rho = 7.0$ gm/cm^3

As shown by Engle, Hansen and Paxton, (*6*) material-replacement data provide a means of computing the effect on critical mass of small changes in core composition and density.[2] As an illustration,

[2] Strictly, replacement data should be corrected to zero sample size for this application. For metal assemblies, at least, the net effect of such correction is minor.

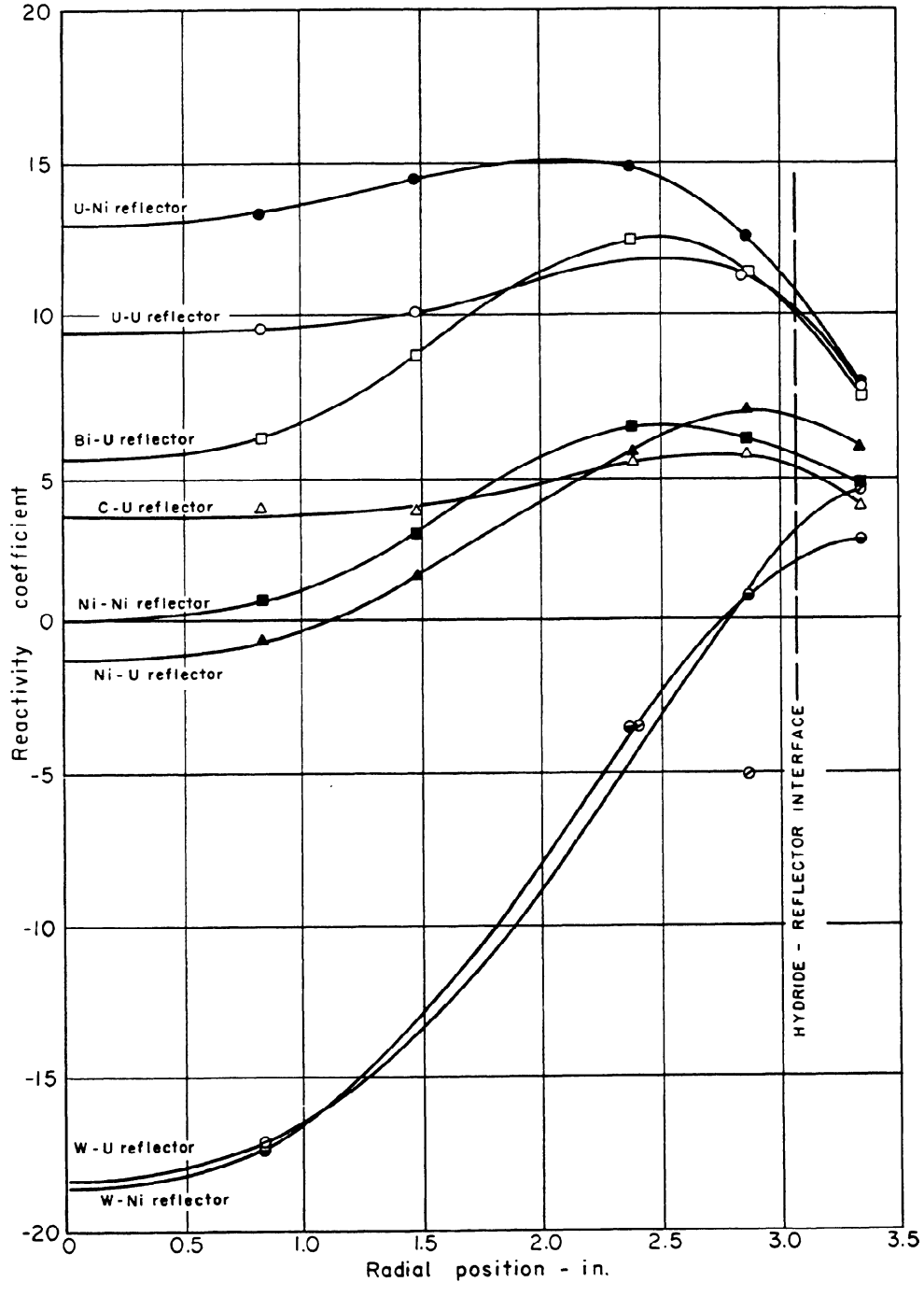

FIG. 12. Reactivity coefficients of elements that are effective neutron reflectors (W is added for contrast)

the critical mass in U of OyH_3 at a density of 7.0 gm/cm^3 will be determined.

Reactivity changes per mole at various radii for $OyH_{2.97}C_{1.11}O_{0.25}$ (the estimated composition of the hydride sample inserted for measurement) may be converted by means of data for H, C, and O to corresponding values for $OyH_{2.93}C_{1.08}O_{0.26}$ (the mean composition of the hydride core) and for OyH_3. The reactivity change per mole of $OyH_{2.93}C_{1.08}O_{0.26}$ at density ρ_0 and molecular weight M_0 is $R_0(r)$, the reactivity change per unit volume is $R_0\rho_0/M_0$. Similarly, for OyH_3 of density ρ, molecular weight M and reactivity change per mole $R(r)$, the contribution per unit volume is R/M. Then the reactivity decrease which results when $OyH_{2.93}C_{1.08}O_{0.26}$ (density ρ_0) is replaced by OyH_3 (density ρ) throughout the original core of radius r_0 is

$$\Delta R = 4\int_0^{r_0}\left(R_0\frac{\rho_0}{M_0} - R\frac{\rho}{M}\right)r^2\,dr$$

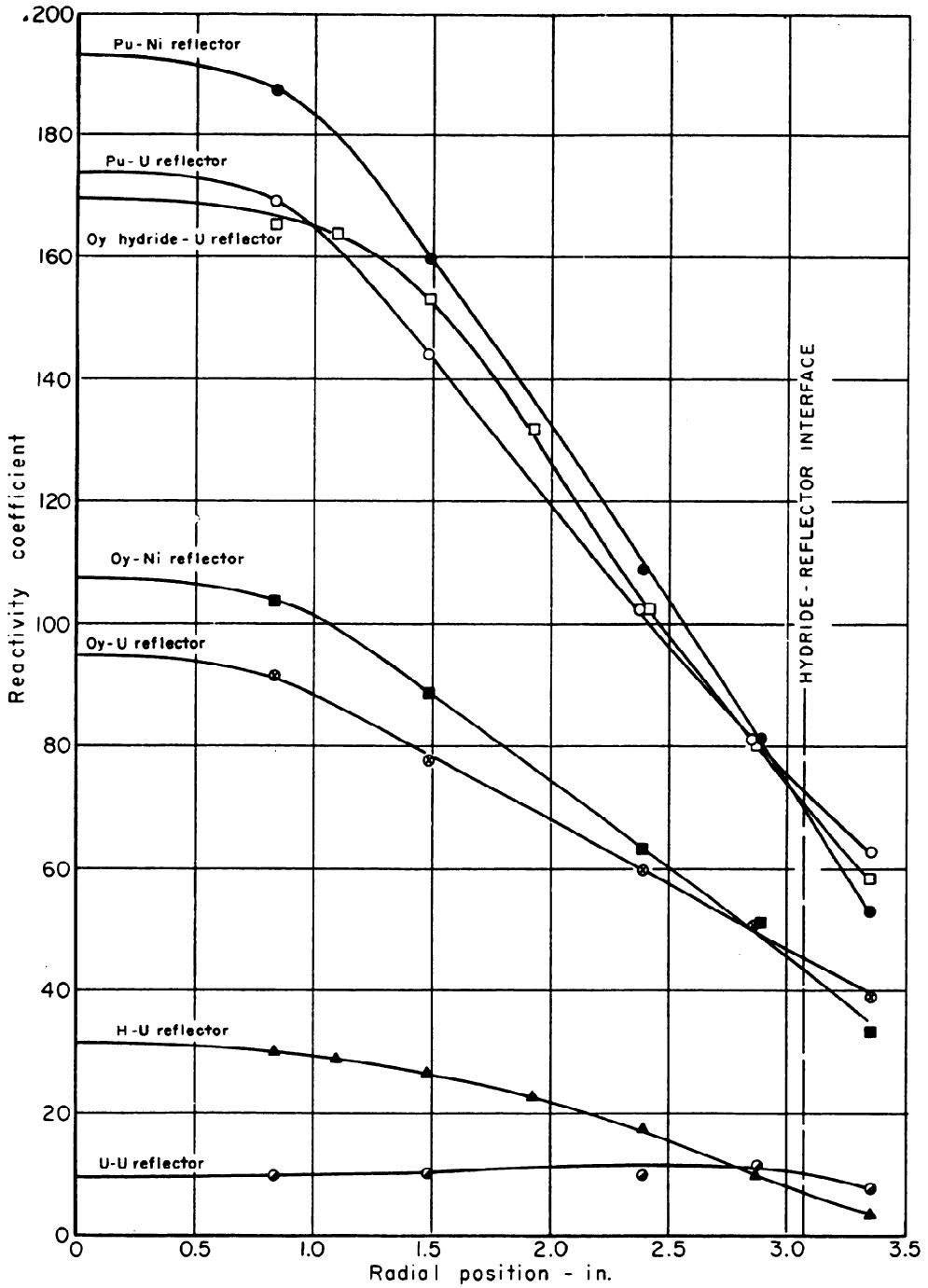

FIG. 13. Reactivity coefficients of fissionable materials and hydrogen

To maintain the reactivity of the original configuration, the core volume must be increased by a volume ΔV_c such that the reactivity increase in replacing normal U (ρ_U, M_U, $\bar{R}_U$ averaged for ΔV_c) by OyH_3 (ρ, M, $\bar{R}$ averaged for ΔV_c) equals ΔR. This reactivity contribution may be expressed

$$\Delta R = \Delta V_c \left(\bar{R} \frac{\rho}{M} - \bar{R}_U \frac{\rho_U}{M_U} \right)$$

Graphical integration of $4\pi[R_0(\rho_0/M_0) - R(\rho/M)]r^2$ to $r_0 = 7.8$ cm, where

$$\rho_0 = 7.35 \text{ gm/cm}^3, \qquad M_0 = 255$$

$$\rho = 7.00 \text{ gm/cm}^3, \qquad M = 238$$

gives $\Delta R = 171$ cents. Then the change in critical volume,

$$\Delta V_c = 171/[\bar{R}(\rho/M) - \bar{R}_U(\rho_U/M_U)]$$
$$\rho_U = 19.0 \text{ gm/cm}^3, \qquad M_U = 238$$

may be evaluated (by successive approximation, $\bar{R} = 63$ cents/mole and $\bar{R}_U = 9.7$ cents/gm-atom) as

$$\Delta V_c = 158 \text{ cm}^3$$

Thus, for OyH_3 ($\rho = 7.0$) in a thick U reflector, the critical volume would be 2160 cm^3, the critical mass 15.1 kg and the critical radius 8.02 cm (3.15 in.).

Deduced Relation between Critical Mass and Density

From the reactivity changes per mole of hydride and normal U, a relation between critical mass and hydride density may be approximated. By reasoning similar to that of the last section, the following relation holds if the density of $OyH_{2.93}C_{1.08}O_{0.26}$ (R, M) is changed from ρ_0 to $\rho = \rho_0 + \Delta\rho$:

$$4\pi \int_0^{r_0} R(r) \frac{\rho_0}{M} \frac{\Delta\rho}{\rho_0} r^2 \, dr \simeq \Delta V_c \cdot \left[R_U(r_0) \frac{\rho_U}{M_U} - R_0(r_0) \frac{\rho}{M} \right]$$

Again R_U, ρ_U and M_U apply to normal U, r_0 is the initial core radius, and ΔV_c is the change in critical volume V_c. This may be combined with

$$\frac{\Delta m_c}{m_c} = \frac{\Delta V_c}{V_c} + \frac{\Delta\rho}{\rho}$$

the fractional change of critical mass, to give

$$\frac{\Delta m_c}{m_c} \simeq \frac{\Delta\rho}{\rho} \left[1 + \frac{3 \int_0^{r_0} R(r) r^2 \, dr}{r_0^3 \{ [R_U(r_0) \rho_U M / \rho_0 M_U] - R(r_0) \}} \right]$$

$$\Delta\rho \ll \rho_0$$

Inserting $R(r_0) = 70.5$ cents/mole, $\rho_0 = 7.35$ gm/cm^3, $M = 255$, $R_U(r_0) = 10.1$ cents/mole, $\rho_U = 19.0$ gm/cm^3, $M_U = 238$ and $r_0 = 7.8$ cm, graphical integration gives

$$\Delta m_c/m_c \simeq -1.57(\Delta\rho/\rho)$$

or $m_c \simeq \text{const.} \ \rho^{-1.57}$.

This indicates a more rapid variation with density than the exponent -1.2 observed for Oy metal in thick U reflector. Although data for the Ni-reflected hydride are too sketchy for a similar computation, more extreme variations with radius indicate an exponent even greater in absolute value than that given by the preceding computation.

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