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ARGONNE NATIONAL LABORATORY
P. O. Box 299
Lemont, Illinois

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by

J. L. Hyde, P. D. Deans, D. J. Pellarin, and G. W. McManaway

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Summary

An accurate calibration of the control rod for x below 240 cm was necessitated by the decrease in reactivity of CP-2 with age. For this purpose the regulating rod has been partially recalibrated.

The differential inhour curve of 1943 (dh/dx vs x) has been verified. The fact that the integral curve (ih vs x) is slightly in error will not affect ordinary measurements in which only inhour differences are determined.

An analytical expression covering the range $x = 160$ to 280 cm has been fitted to the 1943 curve:

$$ih = 3.9272 - 0.13405 x + 0.0012083x^2$$

This expression permits interpolation to four decimal places over this range and is convenient to use instead of a calibration table.

The barometric coefficient of reactivity has been re-determined directly and corrected by an approximate method to yield a figure of -0.260 ih/mb. This is believed to be as accurate as the previous value, -0.245 ih/mb. Since inhour measurements are not very sensitive to the value of this coefficient, the use of either figure should give satisfactory results.

Tentative values, suitable for current use, have also been determined for flux distribution, statistical weights, galvanometer drift factor, and pile sensitivity.

I. Loss of Reactivity of CP-2 and Reasons for Recalibration

After the construction of CP-2 in 1943, its original reactivity corresponded to about 160 ih (CP-641). By 1949, however, the observed reactivity was never greater than 60 ih. During one year of the writers' experience, from March 1951 to March 1952, the reactivity was somewhat lower still, being slightly over 50 ih. The reason for this decrease is not clear.

A possible, but purely speculative, explanation is that some UO_2 lumps may have become overheated with resultant partial conversion to U_3O_8 . This would cause a volume expansion, with probable disintegration of the lumps and an increase in the surface-to-mass ratio, resulting in a decrease in resonance escape probability and, hence, a loss in reactivity.

The possibility that a forgotten piece of cadmium or other absorber had been left in the pile has largely been eliminated by an inspection of all test holes and control rods.

The detailed calibration of the regulating rod made in 1943 ceases at $x = 240$ cm, the calibration points at lower values of x being 20 cm apart. This fact necessitated the development of an accurate means of interpolation between the existing calibration points below 240 cm, as well as verification of the calibration in this region if certain measurements were to be made. Only a few square centimeters of absorber can now be introduced without resulting in a position of the rod for criticality with x less than 240 cm.

In order to be certain of our experimental results, the barometric coefficient, previous rod calibration, and other pertinent figures were re-examined, since many of these had not been checked since 1943. The procedures,

experimental considerations, and related information are detailed below in the hope that these may be of some general use.

II. Inhour Corrections in Pile Measurements

In pile testing, the figures reported as "dih" (or inhour difference) represent differences between position of the control rod for criticality (in terms of "inhours controlled") resulting from changes in pile makeup from one condition to another. For example, the introduction of some absorbing material into hole T23 via the graphite stringer would bring about such a change in pile makeup, and the resulting dih could be measured relative to the inhour value of the empty stringer. It is necessary, of course, to correct for any other factors which might affect the result, so that the dih value thus obtained will depend upon the control rod calibration only.

The effect of barometric pressure on pile reactivity, due to absorption of neutrons by nitrogen, is an obvious correction. This is readily made if the barometric coefficient (the ratio $\Delta ih / \Delta p$) is known with sufficient accuracy. The experimental determination of this ratio is complicated by the drift of pile reactivity with time (cf. Section III-D). These two effects are practically inseparable by any experimental technique, and a long-term statistical study would be required to yield the most accurate value for the barometric coefficient (cf. Section III-A).

Since it is not, in general, possible to set the control rod exactly at the critical position, so that the pile power will not change with time, the rate of drift of the galvanometer is used to measure the Δih between the actual rod setting and the true critical position (cf. Section III-B). The ratio ($\Delta ih / \text{drift rate}$) is known as the drift coefficient.

If the drift coefficient and a preliminary value for the barometric coefficient are known, the control rod can be calibrated with good accuracy to give the curve of inhours controlled vs rod position. By "rod position" is meant the displacement from the all-out position, i.e., with the tip of the rod at the interface between reflector and shield.

In pile measurements which are designed to measure inhour differences, an arbitrary position of the regulating rod near the critical position is frequently chosen in preference to the all-out position, and all inhour differences are computed with respect to this arbitrary position. The only purpose in doing this is to simplify the calculations, since the result (which is the inhour difference between two critical rod positions) is independent of the reference point with respect to which these are measured. An arbitrary barometric pressure is likewise taken as a reference pressure.

It should now be clear that the critical rod position in inhours, corrected to an arbitrary time and an arbitrary barometric pressure (e.g., at the start of the testing day), may be determined by adding the following four quantities:

- Δih_{rod} = Observed rod position in inhours, relative to some convenient standard position.
- Δih_{drift} = Difference between actual rod position and the critical position, calculated from galvanometer drift rate.
- $\Delta ih_{pressure}$ = Correction for change in critical position due to change in the barometric pressure from that at the start of the testing day.
- Δih_{time} = Correction for change in critical position due to time drift since start of the testing day.

Each of these four quantities will be discussed separately in the following description of the partial recalibration of CP-2.

As an alternative to calculating the $\Delta i h_{\text{drift}}$ as described, it is possible to interpolate between two rod settings (one above and one below critical) by means of the respective galvanometer drift rates. This method requires two rod settings for one determination of the critical rod position, whereas the calculation of $\Delta i h_{\text{drift}}$ for each rod position results in two determinations of the critical position from the same number of observations, thus giving an indication of the testing error.

III. Re-Calibration of CP-2

A. Barometric Coefficient, $\Delta i h / \Delta p = -0.260 \text{ ih/mb}$ (tentative)

The difficulty of determining the change in pile reactivity with barometric pressure, when this change cannot be experimentally isolated from the drift in reactivity with time, is obvious. Two of the variables responsible for the time drift, considered more fully in Section III-D, are cooling of the pile and temperature effects on the control rod. The effects due to cooling of the pile may be eliminated if the pile temperature remains constant while the observations are being made. Temperature effects on the control rod (due to thermal expansion) can be eliminated if the necessary data are taken by means of free periods, i.e., with all rods completely withdrawn. Other effects which are a function of time can be minimized by taking the data during the shortest possible time interval.

Conditions well suited to this calibration were obtained, quite fortuitously, over the night of October 17 - 18, 1951. During 16

hours the barometer rose by 8.00 millibars (corrected), and the graphite temperature in the pile remained constant at 30.16° C. During this time the reactivity in inhours, calculated from the average of six free periods by the inhour equation (Equation IV, Section III-C) decreased from 48.257 to 46.387 ih (the latter at 749.6 mm, corrected), giving a barometric coefficient of -0.234 ih/mb. This compares with the figures -0.242 ih/mb (CP-641) and -0.245 ih/mb (CP-2902) previously used. The methods employed to obtain the previous figures are not described in the references given.

The barometric coefficient obtained directly in this way must be regarded as preliminary. It is subject to correction by means of statistical correlation in a way now to be outlined.

If the drift of pile reactivity with time is assumed to be linear over an eight-hour day, it is possible, from repeated measurements of critical rod position (dih) for a single test sample, to correlate with barometric pressure (by least squares) any remaining dih changes which are non-linear with time. Obviously, this method is fruitful only if the changes in barometric pressure are non-linear with time. Any correlation thus uncovered is actually a correction to the barometric coefficient, since if the latter were entirely correct, pile reactivity should show no correlation with barometric pressure.

Insufficient data are available for proper correlation at the present time. Most testing days do not yield fruitful results, since quite frequently the pressure varies almost linearly with time. However, the following data, taken on March days when the pressure changed fairly uniformly at nearly 1 mb/hr, permit an approximate correction to be made (Table I).

TABLE I

Revision of Barometric Coefficient

Date	Barometer	Short-Term (1-2 hrs)		Longer-Term (3-7 hrs)		
		No. of Intervals	Residual Coeff.(avg)*	No. of Intervals	Duration (hrs)	Residual Coeff.(avg)
3/10/52	Falling	5	-.033	1	7	-.020
3/11/52	Rising	7	-.048	1	6½	-.027
3/12/52	Falling	6	-.025	1	3	-.026
3/17/52	Falling	10	-.016	3	3½	-.022

4-day avg = -.031

4-day avg = -.024

Weighted average = -.026

New barometric coefficient = $-0.234 - 0.026 = -0.260$ ih/mb* Barometric coefficient in addition to -0.234 ih/mb

On the days shown, the pile was cool (graphite temperature about 23° C) and had not been operated at high power for at least 24 hours in the most recent case. Testing was done all day at 20 watts, and some samples were measured 3 to 6 times, which permitted the necessary observations to be made over time intervals ranging up to 7 hours. The preliminary barometric coefficient (-0.234 ih/mb) was used in these tests, and any remaining change in pile reactivity was calculated as a pressure coefficient. This procedure, which assumes a negligible time drift in a "cool" pile, compared to the effect produced by pressure changes of nearly 1 mb/hr, must be approximately correct, for approximately the same coefficients, over several hours, were obtained

with a rising and falling barometer. The approximate result (corrected) is -0.260 ih/mb.

It is somewhat doubtful that the measurements quoted are sufficient to distinguish between the previously used coefficient, -0.245 ih/mb, and the result just obtained, -0.260 ih/mb. The best value is probably in the range from -0.245 to -0.260 ih/mb. It is likely that the best figure for the barometric coefficient would be obtained by many statistical correlations over a considerable period of time.

Since an insufficient number of measurements has been made to obtain an accurate result by statistical analysis, the use of either -0.245 or -0.260 ih/mb will be in accord with present findings. If the barometric coefficient is in error, the effect on inhour determinations will not be serious since correction for the drift in pile reactivity with time tends to compensate for an error in the barometric coefficient (cf. Section III-D). In fact, a number of accurate measurements have been made using the uncorrected coefficient -0.234 ih/mb.

It should be noted that, if the pressure changes too rapidly, accurate results will not be obtained. On more than one occasion, when the pressure was falling rapidly, the pile reactivity (corrected for pressure) was observed to decrease rapidly. This is interpreted as a failure of the pile to follow the rapid pressure change, which nevertheless was corrected for. A lag of this type may be due to inadequate venting to the atmosphere so that the pressure inside the shield was higher than outside, or the cracks between the graphite blocks might

be the major constricting influence. (The observed barometric coefficient, -0.26 ih/mb, and pile sensitivity, 0.507 ih/cm² of absorber (Section III-G), are consistent with about 450 cc of air per cell, about 350 of which is in the cavity surrounding each metal lump, the remainder being in cracks and pores.)

Although no strict rule can be given as to the maximum tolerable rate of pressure change, it is fairly safe to say that a prolonged change at a rate much faster than 1 mb/hr may make accurate inhour measurements impossible.

B. Drift Coefficient, Δ ih/3 min drift = 0.0225 (for present galvanometer suspensions)

No measurements, except the sensitivity ratio of the two galvanometers, are required. This ratio was determined by averaging several observations of the deflection of the differential galvanometer which accompanied exactly 1.00 cm deflection of the level galvanometer resulting from a slow change in power level of the pile. During these observations the level galvanometer (sensitivity ca. 4×10^{-10} amp/mm) was set at a deflection of 20.0 cm $\pm$ 1 cm using the 0.1 shunt (by adjusting the power level to 20 watts), and its zero was checked before and after a measurement by switching the shunt to zero in order to be sure that the suspension had not "fatigued" (i.e., suffered torsion hysteresis) during the measurement. The ratio obtained was

$$\frac{\text{differential galv. deflection}}{\text{level galv. deflection}} = 44.5$$

The actual sensitivity ratio, on equivalent shunts, would therefore be 4.45.

The drift coefficient is derived as follows, for the particular case of operation at 20 cm galvanometer deflection on the 0.1 shunt (approximately 20 watts):

If the pile is rising exponentially in power, then

$$\frac{p + \Delta p}{p} = e^{\Delta t/T} = 1 + \frac{\Delta t}{T} \quad \text{if } \Delta t \ll T$$

where

p = initial power

Δp = power increase in time Δt (measured in cm)

T = pile period for the conditions used

$$\therefore \frac{\Delta p}{p} = \frac{\Delta t}{T}$$

or

$$\frac{1}{T} = \Delta ih = \frac{1}{p} \frac{\Delta p}{\Delta t}$$

where

Δih = inhours away from critical.

If

$p = 200$ cm and $\Delta t = 1/20$ hr,

then

$\Delta ih = 0.100 \quad \Delta p = 0.100 \times (3 \text{ min drift of level galv.})$.

Using the sensitivity ratio obtained above (4.45),

$\Delta ih_{\text{drift}} = 0.0225 \times (3 \text{ min drift of differential galv.})$.

If the galvanometer drift is in a positive direction, Δih_{drift} is to be added to the observed rod setting.

C. Control Rod Recalibration

1. Experimental Method

Pile periods were determined at various settings of the regulating rod on each of three galvanometer shunts (1.0, .1, and .01), by observing the time required for the galvanometer to rise from 10.0 to 27.2 cm deflection*. For each shunt the corresponding inhour value was calculated by the new "adjusted" inhour equation¹ and the three numbers averaged. The average was corrected to 740 mm barometric pressure. The results, shown in Table II, Column 4, differed slightly from the 1943 calibration table (Column 5). The differences are not important for most purposes as will be shown.

2. The Inhour Equations

$ih = \frac{54}{T} + \frac{33}{T + 0.7} + \frac{1139}{T + 6.5} + \frac{1793}{T + 34} + \frac{581}{T + 83}$	I (CP-3094) "Usual"
$ih = \frac{64}{T} + \frac{245}{T + 3.57} + \frac{688}{T + 10.1} + \frac{1938}{T + 34.5} + \frac{665}{T + 83}$	II (CP-614) "Old" (also Memo Rpt. W305-P2 ²)
$ih = \frac{54}{T} + \frac{20.7}{T+0.62} + \frac{207}{T+2.19} + \frac{543}{T+6.5} + \frac{2070}{T+31.7} + \frac{802}{T+80.3}$	III (CP-3094) "New"
$ih = \frac{54}{T} + \frac{20.3}{T+0.62} + \frac{204}{T+2.19} + \frac{535}{T+6.5} + \frac{2036}{T+31.7} + \frac{787}{T+80.3}$	IV (Ref. 1) "Adjusted"
$ih = \frac{54}{T} + \frac{20.2}{T+0.62} + \frac{202}{T+2.19} + \frac{529}{T+6.5} + \frac{2016}{T+31.7} + \frac{779}{T+80.3}$	V (Ref. 3) "Hanford"

* The three times thus obtained for the different shunts at a given rod setting did not agree perfectly due to non-linearity of the ion chamber and galvanometer. It would perhaps have been better to utilize the calibration curve to obtain power ratios more nearly equal to 2.718.

¹ Hughes, Dabbs, Cahn, and Hall, Phys. Rev. 73, 111-124 (1948).

² Anderson, Fermi, Wattenberg, Weil, and Zinn, Phys. Rev. 72, 16-23 (1947).

³ Hanford Works, General Electric Co., Technical Division, private communication.

Note: In all the foregoing equations, the pile period T is given in seconds.

The "old" inhour equation (Equation II) enjoyed use for a time but, as more accurate information on neutron delay periods and yields became available, was superseded first by the "usual" inhour equation (Equation I) and then in 1945 by the "new" inhour formula (Equation III). This was later adjusted so that $ih = 1$ when $T = 3600$, in accordance with the definition of the inhour, to give the "adjusted" inhour equation (Equation IV). Equation V, now used at the Hanford Works, is adjusted in a different way so that $ih \rightarrow \frac{3600}{T}$ as $T \rightarrow \infty$.

The inhour plot taken from CP-3094, which is reproduced in the Physical Review², is actually a plot of Equation I and III, not of II and IV as one might suspect from the text. A plot of Equation II would fall below any of the others.

3. Check of the 1943 Regulating Rod Calibration

It is a little uncertain whether Equation I or II was used in obtaining the 1943 calibration. Inhour values, calculated from observed pile periods by Equations I, II, and IV are given in Table II.

TABLE II

Re-Calibration of Regulating Rod

1	2	3	4	5	6	7	8	9
In hours Controlled, Corrected to 740 mm (986.67 mb)*								
Rod Position (cm)	Calcd. from Pile Periods			From 1943 Calibration				
	Eq.I	Eq.II	Eq.IV	From Fitted Curve	Eq.V	Eq.V	Eq.V	Eq.V
	"usual"	"old"	"adjusted"	Table	Eq.V	(+1.5cm)	(-3.5cm)	(-2.0cm)
0	0	0	0	0	---	---	---	---
50	0.62	0.62	0.62	---	---	---	---	---
100	3.76	3.41	3.47	3.55	---	---	---	---
150	11.59	10.54	10.71	---	---	---	---	---
200	25.92	24.03	24.39	25.40	25.45	25.95	24.20	24.70
205	---	---	26.54	---	27.20	---	---	26.50
210	29.61	27.78	28.17	---	29.00	29.60	27.73	28.30
215	---	---	30.31	---	30.90	---	---	30.15
220	33.52	31.45	31.89	32.84	32.85	33.42	31.45	32.05
225	---	---	34.29	---	34.90	---	---	34.05
230	37.80	35.64	36.11	---	37.00	37.62	35.50	36.15

None of these values agree exactly with the 1943 calibration, as represented by the calibration table or by a least-squares fitted parabola valid from $x = 160$ to 280 cm:

$$ih = 3.9272 - 0.13405x + 0.0012083x^2 \quad (V)$$

* The old barometric coefficient, -0.245 ih/mbar (CP-2902), was used. The absolute pressure, measured by a mercury barometer with brass scale, was reduced to 0° C.

It will be noted that substitution into Equation V of rod positions 2.0 cm less than observed (i.e., substitution of $(x-2)$ for x) leads to Column 9, which duplicates Column 4 within experimental error. Likewise, substitution of $(x+1.5)$ and $(x-3.5)$ lead to Columns 7 and 8, respectively. Thus, by a small shift of the "zero" of the rod position indicator, the 1943 calibration can be made to agree with Equation I, II, or IV, or undoubtedly also with Equations III and V. This much zero shift cannot be due to gear wear, since the present amount of backlash is only a little over 0.2 cm. One might guess that someone may have caused the shift by giving the rod a bad bang at the end of its travel, or by a faulty repair job. But this still leaves it uncertain whether Equation I or Equation II was used in the 1943 calibration.

For the measurement of inhour differences, the use of the 1943 calibration, as represented by the calibration table or by Equation V, will be valid since dih/dx for any value of x will be in agreement with any dih/dx calculated from a curve fitted to Column 4 so long as the curves are parallel, which they apparently are in their useful range. Since the pile periods used in calculating Column 4 may be subject to some error, it is felt that Equation V is better to use. If the absolute value of "inhours controlled" vs x should be desired for some purpose, it may be obtained from Equation V if $(x-2)$ is substituted for x .

4. Use of Equation V; $ih = 3.9272 - 0.13405x + 0.0012083x^2$

Differentiation of Equation V gives:

$$dih/dx = -0.13405 + 0.0024166x \quad (VI)$$

Integration between the limits x_1 and x_2 gives:

$$ih_2 - ih_1 = (x_2 - x_1) \left[-.13405 + 0.0012083 (x_2 + x_1) \right] \quad (\text{VII})$$

If any convenient reference rod position is taken for x_1 , Equation VII will give Δih_{rod} for any setting x_2 , with reference to x_1 . For example, if $x_1 = 200$ cm, then $\Delta ih_{\text{rod}} = (x_2 - 200) (0.10761 + 0.0012083x_2)$; a simple operation for a calculation.

If the range of rod settings is between 240 and 270 cm, an even simpler relation may be used. This depends on values given in the 1943 calibration table for dih/dx at the four points $x = 240, 250, 260, 270$ cm, which lead to the relations:

$$dih/dx = -.030 + 0.00200x \quad (\text{VIII})$$

or

$$ih_2 - ih_1 = (x_2 - x_1) \left[-0.030 + 0.00100 (x_2 + x_1) \right] \quad (\text{IX})$$

A comparison of values for dih/dx , calculated by Equations VI and VIII, is given in Table III.

TABLE III

Values of dih/dx

<u>Rod Setting (cm)</u>	<u>Eq. VI</u>	<u>Eq. VIII</u>	<u>1943. Calibr. Table</u>
240	.4459	.450	.450
250	.4701	.470	.470
260	.4943	.490	.490
270	.5184	.510	.510

It is highly possible that Equation VI gives the most precise results, but the use of Equation VIII is probably sufficiently precise, since the testing error in CP-2 for an average of two 3-minute drifts is ± 0.016 ih for 95% confidence, as established by a series of measurements made by the writers.

It is not known just how the dih/dx values in the 1943 calibration table were obtained. It would be possible to determine dih/dx directly by using the galvanometer drift coefficient (Section III-B) and determining the inhour difference caused by a small motion of the control rod, and this method may have been used in 1943. It is the opinion of the writers, however, that the best values for dih/dx are to be obtained by differentiating an analytical expression fitted to the integral curve, as in Equation VI.

5. Selsyn Errors

It has been observed⁴ that a periodic error is present in all Selsyn indicators. If the error is plotted against the angular rotation, a distorted sine wave results whose maximum amplitude amounts to about 0.2 degree. This is due to electrical unbalances in the stator, since it is impossible to make one of perfect uniformity.

The maximum error of ± 0.2 degree, if 360° rotation corresponds to 10 cm rod displacement and if $dih/dx = 0.5$ ih/cm, would amount to only ± 0.003 ih, which is small compared with the testing error in CP-2.

⁴ A.I.E.E. Transactions 65, 570-576 (1946).

D. The Time Drift

The correction for the drift in pile reactivity with time is a catch-all correction designed to consider all variables not otherwise corrected for. Some of the factors included in the time-drift correction are cooling of the pile, error in the barometric coefficient, and thermal expansion or contraction of the control rod. It generally happens that all these variables combine to produce a drift which is approximately linear over a period of from one to eight hours.

What happens in practice is that a given sample A, when measured at the beginning and end of time intervals Δt_1 , Δt_2 , Δt_3 , etc., shows inhour values (critical rod positions) corresponding to Δih_0 , Δih_1 , Δih_2 , Δih_3 , etc. If sample A is to be compared with another sample B at the time when B is measured (e.g., at the middle of the time interval Δt_2), the inhour value of sample A at this time may be calculated by a linear interpolation. If the interpolation is done only for the time interval Δt_2 , then Δih_A (measured at the middle of Δt_2) = $\frac{1}{2}(\Delta ih_1 + \Delta ih_2)$, and the desired number ($\Delta ih_B - \Delta ih_A$) may be obtained for the time at which B was measured.

When the time drift (e.g., for sample A) takes place at a fairly uniform rate over an entire day or half-day (which is usually the case), it is perhaps better to put a single least-squares line through the points Δih_0 , Δih_1 , Δih_2 , Δih_3 , etc., plotted as a function of time, and interpolate along this line. The disadvantage of this least-squares method is that calculation of results must wait for completion of the testing. On the other hand, in the step-wise method (interpolation in

each time interval between successive measurements of A) the calculation of results need only await the completion of each interval (commonly about one hour).

Both positive and negative time drifts have been observed in CP-2, but these showed a correlation with barometric pressure (Section III-A). With the adoption of the proper barometric coefficient, cooling of the pile should account for the major portion of the time drift, which accordingly should always be positive. A cooling rate of 0.01°C/hr would result in a positive time drift of approximately 0.01 ih/hr (cf. CP-641). Cooling rates of this magnitude are observed in a "cool" pile, but observed time drifts in either direction can exceed this rate if an improper barometric coefficient is used.

The effect of attempting inhour measurements too soon after operation of the pile at high power is inaccuracy due to (a) an accelerated and non-linear time drift due to cooling and (b) the effect of the gamma background on the ion chamber used for power measurement. This background should amount to a reading of not over 0.05 watt if good accuracy is desired at 20 watts . Below 0.05 watt the decay of the gamma background is observed merely as a negative time drift.

E. Flux Distribution

The flux (or neutron density) distribution in CP-2 has been measured with copper foils of 1'' diameter and 0.022'' thickness, counted by an end-window counter. Measurements were made in the graphite stringer and metal stringer simultaneously; in the metal stringer the copper foils, covered with aluminum foil, were taped to the tops of

the uranium lumps. Results, normalized to unity at the pile center, are given in Table IV and plotted in Figure 1. The central flux in the graphite stringer was found to be 1.43 times the flux at the surface of a central uranium lump.

A somewhat smoother curve was obtained in the graphite stringer; difficulty in locating the foils equally close to all the metal lumps may have produced some error. The normalized flux in the metal stringer appears to be generally slightly larger than in the graphite. This difference might largely disappear with a different method of normalization.

Due to the different lattices present in CP-2, a single cosine curve cannot be fitted to the flux distribution. In the first four graphite blocks (each $16\frac{1}{2}$ " long) on either side of the pile center (i.e., $|x| < 66$ ") the flux is approximately represented (particularly in the metal stringer) by:

$$\Phi/\Phi_0 = \cos 0.0140x \text{ (inches)}$$

From the fourth through the center of the seventh block ($49" < |x| < 107"$) the following relation is a fairly good fit:

$$\Phi/\Phi_0 = 0.90 \cos 0.0123x \text{ (inches)}$$

At $|x| > 107"$ the rise in flux due to the reflector becomes evident, and the flux then drops substantially to zero in the south shield. This drop to zero does not occur in the center of the north face, due to the existence of a large test hole (currently plugged) at this location.

TABLE IV

Flux Distribution and Statistical Weights in CP-2

Dist. from Center inches	blocks	ϕ/ϕ_0 Metal	ϕ/ϕ_0 Graphite	cos .0140x	.9 cos .0123x	Statistical Weights (metal)		
						$(\phi/\phi_0)^2$	cos ² (.0140x)	Cd Wire
(south)								
-169	1/8	10 1/4	---	.0004	---	---	---	---
-152	5/8	9 1/4	---	.0013	---	---	---	---
-136	1/8	8 1/4	---	.0234	---	---	---	---
-119	5/8	7 1/4	---	.171	.090	---	---	---
-103	1/8	6 1/4	---	.260	.266	---	---	---
- 86	5/8	5 1/4	---	.408	.435	---	---	---
- 70	1/8	4 1/4	---	.555	.585	---	---	---
- 61	7/8	3 3/4	.669	---	.648	.45	.420	.47
- 53	5/8	3 1/4	.742	.715	.731	.55	.535	.58
- 45	3/8	2 3/4	.783	---	.805	.61	.648	.67
- 37	1/8	2 1/4	.881	.835	.868	.78	.751	.76
- 28	7/8	1 3/4	.921	---	.920	.85	.846	.84
- 20	5/8	1 1/4	.959	.943	.959	.92	.918	.90
- 12	3/8	3/4	.987	.978	.985	.97	.970	.95
- 4	1/8	1/4	1.000	1.000	.998	1.00	0.996	1.00
+ 4	1/8	1/4	.995	.994	.998	.99	0.996	1.00
+ 12	3/8	3/4	.989	.972	.985	.98	.970	.94
+ 20	5/8	1 1/4	.959	.934	.959	.92	.918	.88
+ 28	7/8	1 3/4	.910	.908	.920	.83	.846	.81
+ 37	1/8	2 1/4	.872	---	.868	.76	.751	.73
+ 45	3/8	2 3/4	.811	.792	.805	.66	.648	.63
+ 53	5/8	3 1/4	.741	---	.731	.55	.535	.52
+ 61	7/8	3 3/4	.662	.650	.648	.44	.420	.41
+ 70	1/8	4 1/4	.568	---	---	.32	---	---
+ 78	3/8	4 3/4	---	.502	---	---	---	---
+ 94	7/8	5 3/4	---	.342	---	---	---	---
+111	3/8	6 3/4	---	.212	---	---	---	---
+127	7/8	7 3/4	---	.126	---	---	---	---
+144	3/8	8 3/4	---	.054	---	---	---	---

(north)

F. Statistical Weights

In metal testing it is necessary to know the statistical weights of the regions in the pile where the metal lumps (eggs) under test are located. Statistical weights have been determined from the squared flux distribution and also from inhour measurements. In the latter case the inhour difference, caused by a piece of 1-mm diameter cadmium wire placed successively on top of each of the 16 eggs in the standard stringer, has been measured.

Statistical weights from inhour measurements are subject to experimental errors of appreciable magnitude, and the results given in Table IV, which are the normalized and weighted averages of several determinations, are still considered to be relatively inaccurate. Although these approximately agree with the statistical weights determined from the squared flux distribution, it is felt that the flux method is more accurate.

It is likewise felt that the square of the experimental flux curve will give more accurate values than the squares of a fitted cosine curve, although the latter is also in approximate agreement. A good experimental curve is especially necessary for CP-2, where the lattice is not uniform throughout.

It is therefore felt that the best values for the statistical weights are given by the squared experimental flux distribution as given in Column 7 of Table IV.

G. Sensitivity

The sensitivity of CP-2 has been determined by use of a thin ribbon of pure iron (Westinghouse "Puron") whose self-protection should be

negligible. The thermal cross-section was taken as 2.43 barns, and the iron was assumed to be a strictly $1/V$ absorber. It was placed in the graphite stringer so as to subtend a $61\text{-}1/4''$ length at the center of the pile, and the inhour difference was measured with respect to the empty stringer. For the $61\text{-}1/4''$ length a constant of 0.480 ih/cm^2 was determined. Using the relation $w = \cos^2(0.0140x)$, where x is given in inches, integrated over the $61\text{-}1/4''$ length, an average statistical weight was calculated: $\bar{w}_{\pm 30.6''} = 0.947$. Thus for unit statistical weight, the sensitivity of CP-2 for a $1/V$ absorber is 0.507 ih/cm^2 .

In similar experiments, by poisoning with cadmium wires $0.036''$ in diameter whose cross-section was taken as $\frac{\pi d^2}{4}$, it was determined that the factor for converting square centimeters of cadmium into equivalent square centimeters of $1/V$ absorber (iron) is 1.18 for CP-2. This figure is not in agreement with the previously reported factor 1.26^2 .

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