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DESCRIPTION OF REACTOR AND EXPERIMENTAL FACILITIES AND INFORMATION FOR EXPERIMENTERS

OPERATED BY UNIVERSITY OF PUERTO RICO UNDER CONTRACT
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DESCRIPTION OF REACTOR AND EXPERIMENTAL FACILITIES AND INFORMATION FOR EXPERIMENTERS

Prepared by the Reactor Division of the Puerto Rico
Nuclear Center,Mayaguez, P. R. Operated by University
of Puerto Rico under Contract No. AT (40-1)-1833 for
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INTRODUCTION

This manual has been prepared to provide experimenters and other scientific personnel with information regarding the reactor and its facilities. Practical information regarding facility size and shape, gamma or neutron flux, etc. has been compiled in ready reference form for those who use, or who wish to use, the reactor facilities.

The information regarding neutron fluxes and gamma dose rates is representative and is intended to serve only as a guide in planning an experiment.

A section containing regulations and procedures for obtaining irradiation services and for performing gross activity determinations has also been included.

DESCRIPTION OF REACTOR AND EXPERIMENTAL FACILITIES

1. REACTOR DESCRIPTION. (1)

The 1 megawatt pool-type research reactor is a light-water moderated, heterogeneous, solid fuel reactor in which water is used for cooling and shielding. The reactor core is immersed in either section of a two-section concrete pool filled with water. One of the sections of the pool contains an experimental stall in which beam tubes and other experimental facilities converge. The other section is an open area permitting bulk irradiation. The reactor can be operated in either section.

The pool is spanned by a manually-operated bridge from which an aluminum tower supporting the reactor core is suspended. Control over the reactor core is exerted by inserting or withdrawing neutron-absorbing control rods suspended from control drives mounted on the reactor core bridge. Additional control is provided by the temperature coefficient of reactivity. The aluminum tower and movable bridge are shown in Figure 1.

Heat created by the nuclear reaction is dissipated by a forced circulation cooling system. Externally located pumps, a water-to-water heat exchanger, a cooling tower, a demineralizer plant, and a filter complete the water handling system for the reactor pool.

REACTOR SPECIFICATIONS

Fuel	20% enriched U-235 in U_3O_8 and Al dispersion MTR type, Al clad fuel assemblies (18 plates)
Power	One megawatt (heat)
Lattice	54 holes on 6 x 9 rectangular pattern
Moderator	H_2O
Reflector	H_2O and graphite
Shielding	H_2O, lead, barytes concrete, and regular concrete
Cooling	Primary loop - heat exchanger Secondary loop - cooling tower

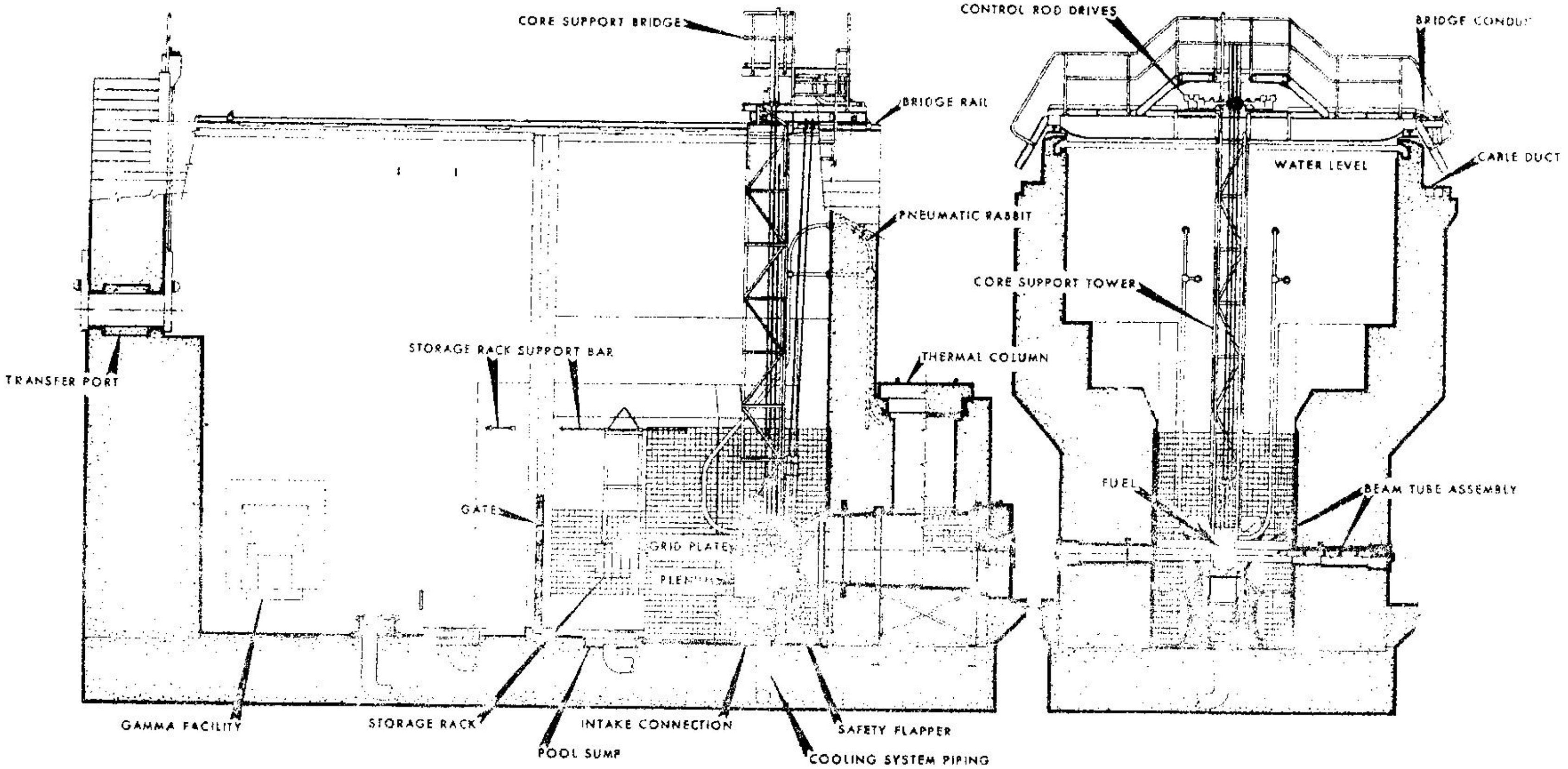


FIGURE 1 PUERTO RICO REACTOR – FRONT AND SIDE ELEVATIONS

Water Purification	Continuous demineralization of a portion of the primary flow
Control	4 Boron-carbide shim-safety rods 1 stainless steel regulating rod
Irradiation Facilities	4 - 6" beam tubes 2 - 8" beam tubes 2 - Pneumatic rabbits 1 - Thermal column 1 - Dry gamma facility
Operating Conditions:	
Maximum fuel plate sheath temperature	170°F
Primary water flow rate	900 GPM
Coolant inlet temperature	100°F
Coolant outlet temperature	107.6°F
Core pressure drop	1 psi
Secondary water flow rate	700 GPM
Secondary coolant inlet temperature	86°F
Secondary coolant outlet temperature	95.8°F
Demineralizer flow rate	20 GPM

2. EXPERIMENTAL FACILITIES.

The experimental facilities described below furnish means for the irradiation of materials while affording protection to personnel through proper shielding.

Embedded in the concrete walls of the stall area at core level are the beam tubes and a 4 by 9 foot thermal column. The respective locations are shown in Figure 2. At the outer pool surface, shielding doors and plugs afford access to the experimental units. In addition, two pneumatic rabbit loops are provided.

(a) Beam Tubes.

Two 8-inch diameter and four 6-inch diameter beam tubes radiate in horizontal planes outward from the reactor core. The basic tube

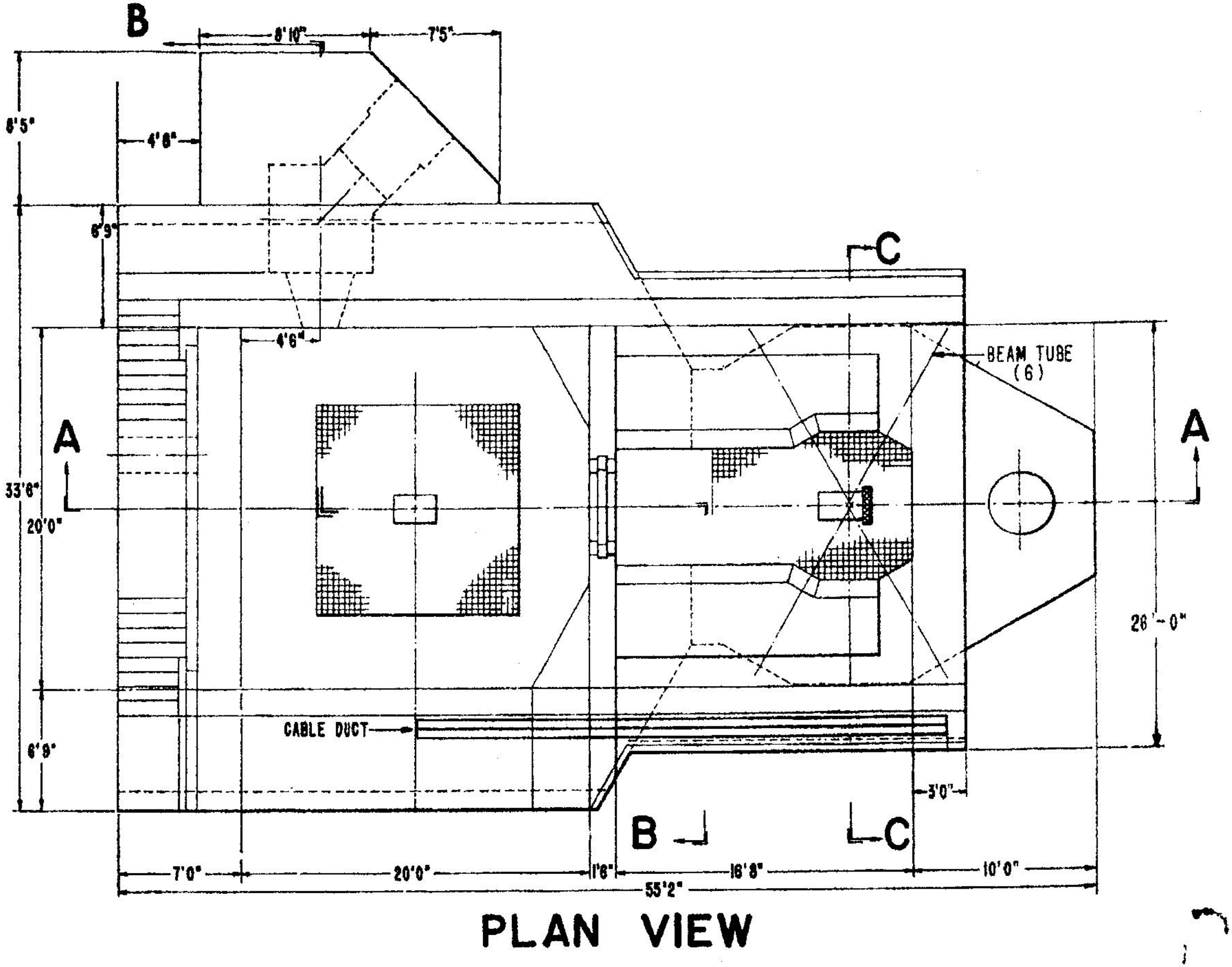


FIGURE 2 REACTOR POOL - PLAN VIEW

assembly consists of an embedded stainless steel sleeve, retractable aluminum liner, and a set of interior shielding plugs of canned barytes concrete and lead. Provisions are made for flooding the beam tubes with demineralized water.

(b) Pneumatic Rabbits.

This facility is a constant-exhaust system of concentric aluminum air lines which carry a sample carrier or rabbit into the high neutron flux areas at the core.

Automatic timing controls the period of irradiation and reversal of the air valving. The exhaust air is filtered and monitored before discharge to the atmosphere through a stack.

(c) Thermal Column.

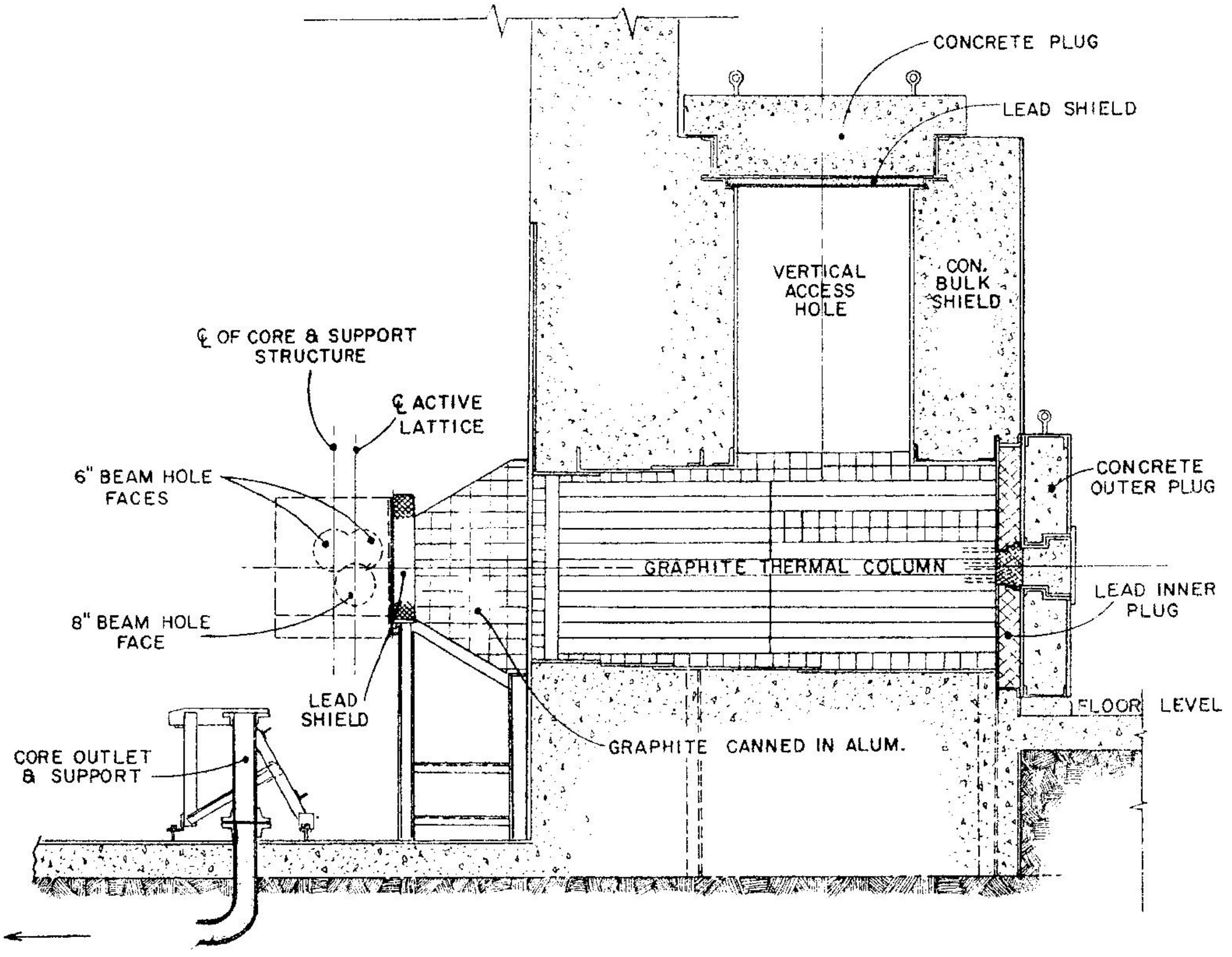
The Thermal Column (Figure 3) is a stacked graphite and lead assembly for irradiation experiments with highly thermalized neutrons.

A steel and aluminum chamber is cast integrally with the stall wall and the barytes shield at core level. This chamber is square and extends horizontally from the inside wall of the stall to the outer surface of the barytes shield. Forming a part of the embedment is a circular vertical access chamber extending from the top of the shield downward to the horizontal chamber.

The inner surfaces of the chamber are lined with boral sheet which reduces activation of the embedment and the adjacent concrete. Stacked within the boral liner for the length of the horizontal chamber is a closely packed arrangement of graphite blocks.

Fastened over the outer face of the graphite stacking is a boral plate backed up by a lead block shield. A square opening in the shield is provided for the insertion of a lead plug. A 14-inch thick, 5'-6" square barytes concrete door covers the entire exposed area of the horizontal column at the face of the barytes shield. Access to the thermal column vertical face is provided by means of the overhead crane system, which opens the barytes concrete door. The door is pinned against the vertical face by a safety lock bar at the top of the door. A central square opening allows for the introduction of a shielding plug. The smaller plug in the door and in the inner lead shield permits the insertion of small specimens for irradiation experiments while the door is kept shut.

The vertical portion of the thermal column is an air chamber with the opening at the top of the barytes shield closed by a lead plug and a concrete access cover. Both the cover and plug have lifting lugs to permit removal by the overhead service crane.



VERTICAL SECTION THRU THERMAL COLUMN

FIGURE 3 - THERMAL COLUMN.

A lead and graphite assembly forms the portion of the thermal column between the rear face of the reactor core and the inner wall of the stall. This assembly consists of an aluminum support frame bolted to the stall floor mounting pads. A lead shield is bolted to the front of the frame immediately adjacent to the reactor core, and a graphite and lead can assembly is fastened directly behind the lead shield.

(d) Gamma Room. (2)

The Gamma Irradiation Room is an integral part of the reactor pool structure and is adjacent to it at the first level on the east side of the building. The room is a cube approximately six feet square. It has a tapering side that terminates in a four foot square aluminum window (Figure 4). This window is the only partition between the room and the reactor pool and it is located at a depth of approximately twenty-seven feet.

Access to the irradiation facility is through a five foot thick high-density concrete door mounted on a railroad-type dolly which can be rolled back.

Samples to be irradiated are placed inside the room, a monitoring device is set up and the door is shut. Irradiation is performed by placing highly radioactive fuel elements in a rack adjacent to the aluminum window. Any number of fuel elements up to eight are placed in this rack, which can be moved by means of an overhead crane. Removing the fuel elements to a distance of approximately eighteen feet from the window will bring radiation exposure inside the gamma facility below the permissible operational level of 7.5 mr/hr.

A factory-calibrated ionization chamber type detector connected to a micro-microammeter and recorder is being used at present. Since flux intensity varies according to the distance and because the chamber volume is fairly large (diameter 3", height 12") it is impossible to obtain an accurate measurement of the irradiation dose at a given point.

Where greater accuracy on simultaneously irradiated samples is desired, individual monitors must be used. Gamma ray dose rates from six fuel elements after one day decay period are of the order of 15 kilo-roentgen per hour at zero distance.

3. REACTOR DESIGN DATA.

(a) Introduction.

The core described in this report is a 30 element unit in a 6 x 5 array which contains 20 standard (18-plate) fuel elements, 5 partial (18-plate) fuel elements, and 5 control (9-plate) fuel elements. This assortment permits adjustment of core excess reactivity by rearrangement of the standard and partial fuel elements to compensate for U-235 burn-up and for low cross section fission

REACTOR ROOM BASEMENT FLOOR LAYOUT

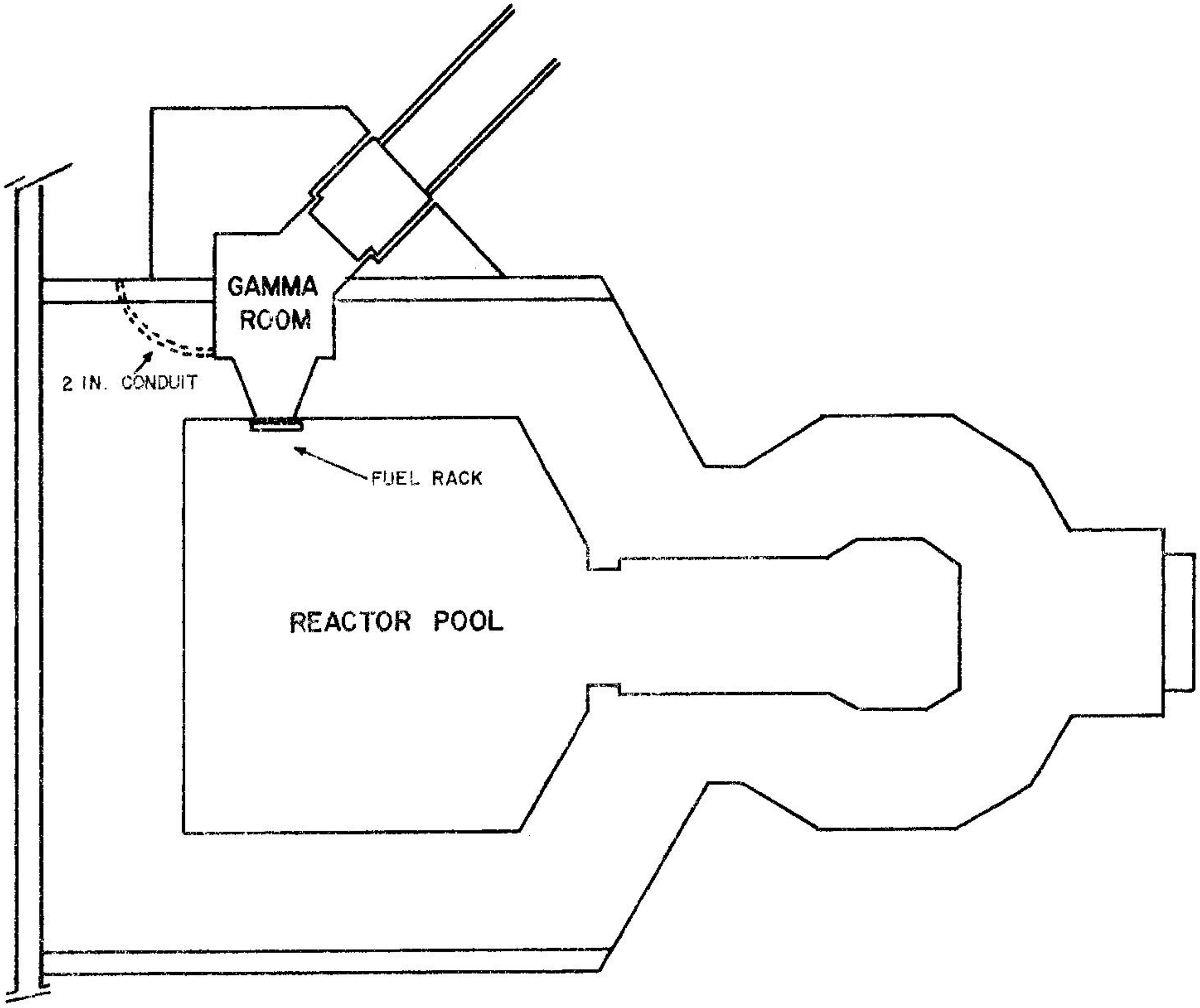


FIGURE 4

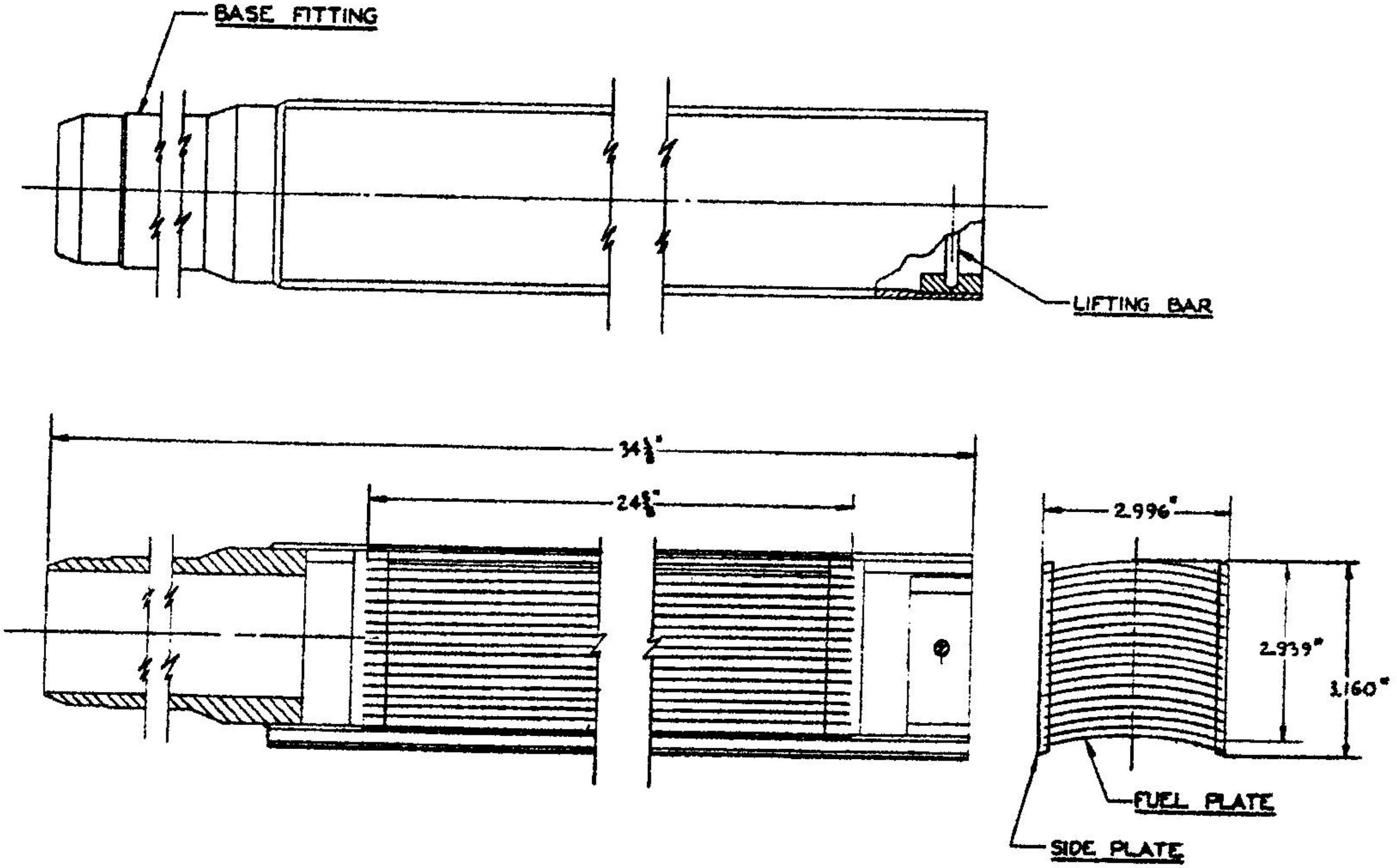
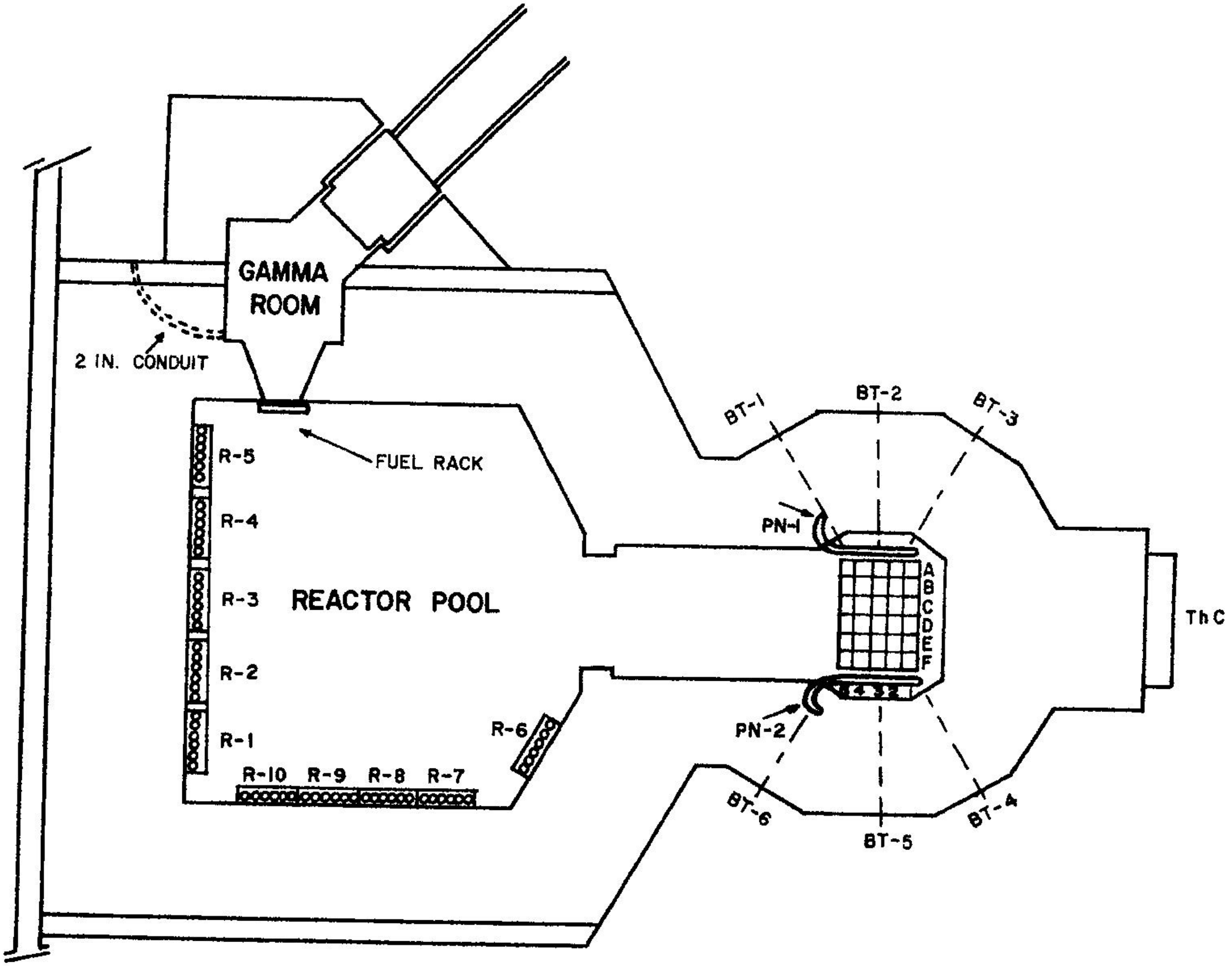


FIGURE 5 STANDARD FUEL ELEMENT

FIGURE 6 IDENTIFICATION CODING FOR STORAGE RACK AND IRRADIATION FACILITIES



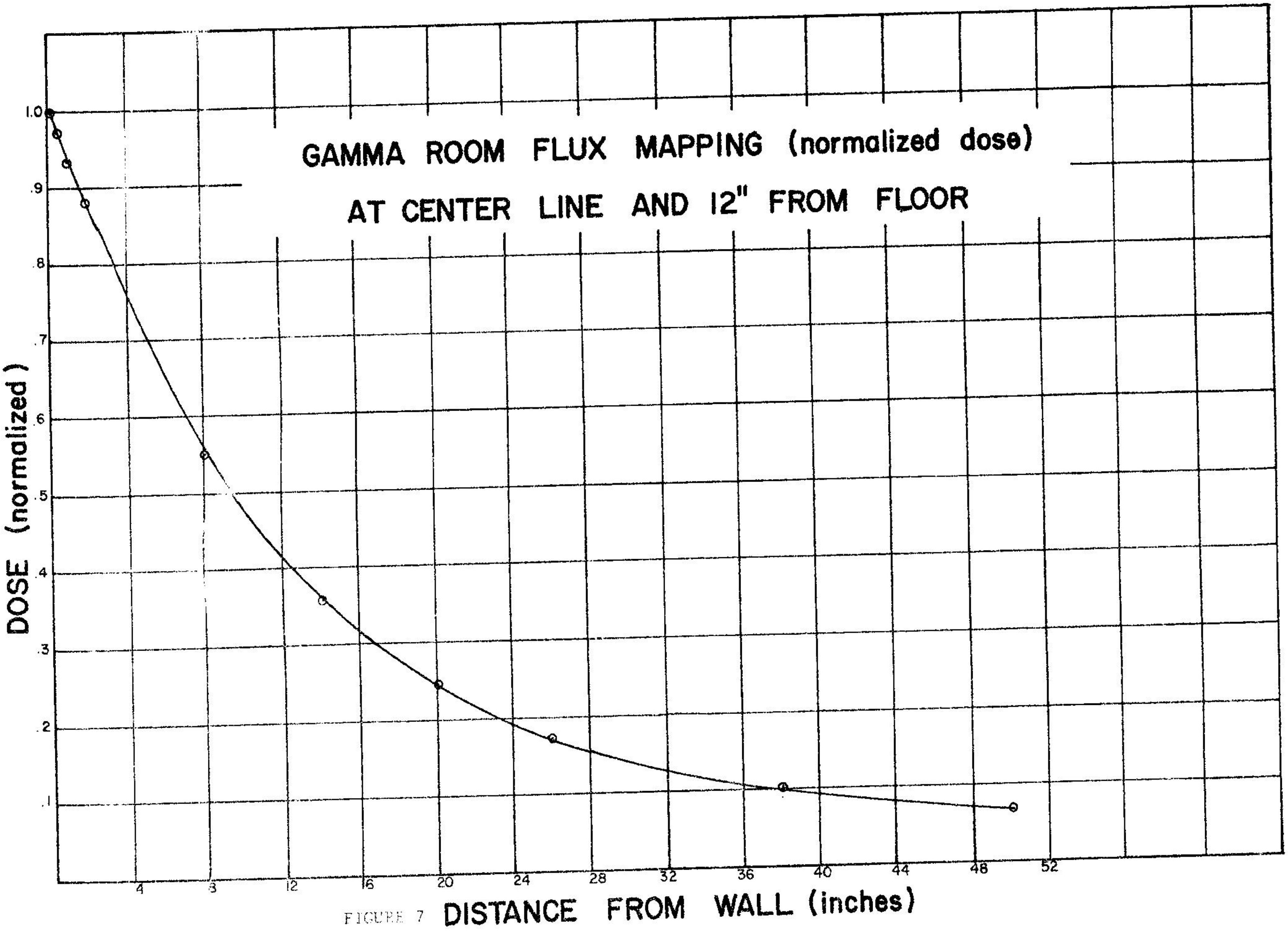

GAMMA ROOM FLUX MAPPING (normalized dose)
AT CENTER LINE AND 12" FROM FLOOR
DOSE (normalized)
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
4
8
12
16
20
24
28
32
36
40
44
48
52
DISTANCE FROM WALL (inches)

FIGURE 7

product poisoning. The core has been designated as core number 11, with core 11 A representing the stall end configuration and core 11 B the open pool configuration.

The fuel elements for the PRNC reactor consist of 20% enriched U_3O_8 compound dispersed in powdered aluminum. The U-235 mass per standard fuel element is 192 grams, the partial and control fuel elements contain 96 grams.

(b) Summary of Reactor Parameters.

TABLE 1

CORE CHARACTERISTICS

Type	Heterogeneous thermal
Power Level (initial)	1,000 Kilowatts
Power Density	208 kw/kg U-235
Moderator	H_2O
Coolant	H_2O
Reflector	
Open Pool Position	H_2O
Stall Position	H_2O, Lead and Graphite
Coolant Flow	900 GPM
Avg. Δt Across Element	7.6°F
Cold Clean Critical Mass (Core 11 A)	4223.5 gr.
Operating U-235 Mass	4799.5 gr.
Effective Prompt Neutron Lifetime* (avg.)	6.0×10^{-5} sec.
Temperature Coefficient (avg.)	-5.5×10^{-5} $\Delta K/K/^{\circ}F$
Mass Coefficient (avg.)	5.25×10^{-5} $\frac{\Delta K}{K}$ / gram U-235
Avg. Thermal Neutron Flux in Fuel	5.2×10^{12} n/cm^2 sec

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* In the power excursion calculations of the hazards analysis the neutron lifetime is quoted as 6.1×10^{-5} sec., a value which is applicable for the U-shaped core underlying the hazards analysis.

Fuel Elements

Number of Fuel Plates	
Standard Element	18 fuel plates
Partial Element	18 fuel plates
Control Element	9 fuel plates
Mass U-235 per Element	
Standard Element	192 grams
Partial Element	96 grams
Control Element	96 grams
Number of Fuel Elements in Core	
Standard Elements	20
Partial Elements	5
Control Elements	5

Control Rods

Number	4 shim-safety rods plus 1 regulating rod
Type	vertical, gravity fall
Absorbing Material	
Shim-Safety Rod	B_4C + Cd. liner
Regulating Rod	stainless steel

Reactivity Worth

	Core 11 A	Core 11 B
4 Shim-Safety Rods	$-8.75\% \frac{\Delta K}{K}$	$-8.91\% \frac{\Delta K}{K}$
1 Regulating Rod	$-.63\% \frac{\Delta K}{K}$	$-.69\% \frac{\Delta K}{K}$
Total Worth	$-9.38\% \frac{\Delta K}{K}$	$-9.60\% \frac{\Delta K}{K}$

Core K_{eff} (all rods fully inserted cold clean condition)

Core 11 A	0.91
Core 11 B	0.95

Experimental Facilities	Reactivity Effect (Beam Tubes, air-filled vs water-filled)
4 six-inch diameter beam tubes	$-0.58\% \frac{\Delta K}{K}$
2 eight-inch diameter beam tubes	$-0.72\% \frac{\Delta K}{K}$
2 two-inch diameter rabbit facilities	negligible
1 graphite thermal column	$+0.856\% \frac{\Delta K}{K}$

Reactivity Allowances for 1 MW Operation

	$\% \frac{\Delta K}{K}$
Equilibrium Xenon-135	1.40
Equilibrium Samarium-149	.90
Temperature Effect	.04
Experiments (other than Beam Tubes)	1.00
Control	.30
U-235 Burn-Up and Low Cross Section Fission Product Accumulation for 75 MWD	.50
Total	*$4.14\% \frac{\Delta K}{K}$

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* This value (4.14%) is less than 50% of Shim Rod value for Core 11 A.

TABLE II

4. CORE II A PARAMETERS.

(a) RATIO OF ϕ_i / ϕ_c (AVERAGE NEUTRON FLUX IN i^{th} ELEMENT TO AVERAGE NEUTRON FLUX IN CORE) FOR DIFFERENT CORE POSITIONS.

Position #	ϕ_i/ϕ_c	Position #	ϕ_i/ϕ_o
A-1	.652	D-1	.977
-2	.785	-2	1.687
-3	.818	-3	1.310
-4	.590	-4	1.151
-5	.460	-5	.882
B-1	.873	E-1	.890
-2	1.000	-2	1.063
-3	1.496	-3	1.523
-4	.922	-4	.902
-5	.856	-5	.740
C-1	.996	F-1	.740
-2	1.554	-2	.902
-3	1.805	-3	.830
-4	1.411	-4	.834
-5	.808	-5	.552

TABLE III

(b) THERMAL NEUTRON FLUX AT VARIOUS DISTANCES FROM CORE MID PLANE EXTENDING OUTWARD IN A NORTH DIRECTION

D (cm)	ϕ (n/cm^2/sec.)
0	5.016×10^{12}
1	6.857
3	6.440
4	5.810
10	1.866
15	7.058×10^{11}
20	2.722
25	1.111
30	4.257×10^{10}
35	1.732
38	1.119

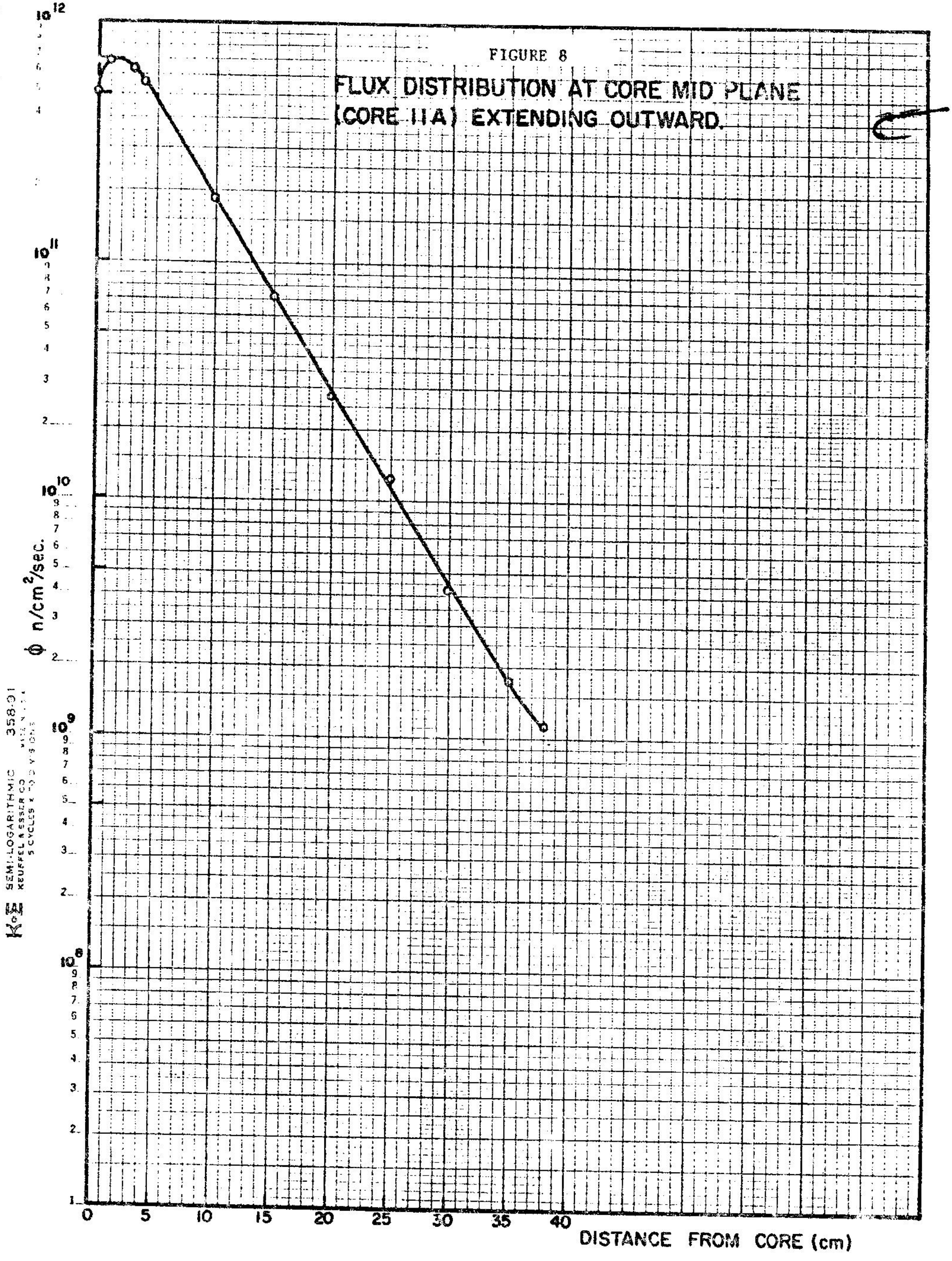


FIGURE 8

FLUX DISTRIBUTION AT CORE MID PLANE (CORE IIA) EXTENDING OUTWARD.

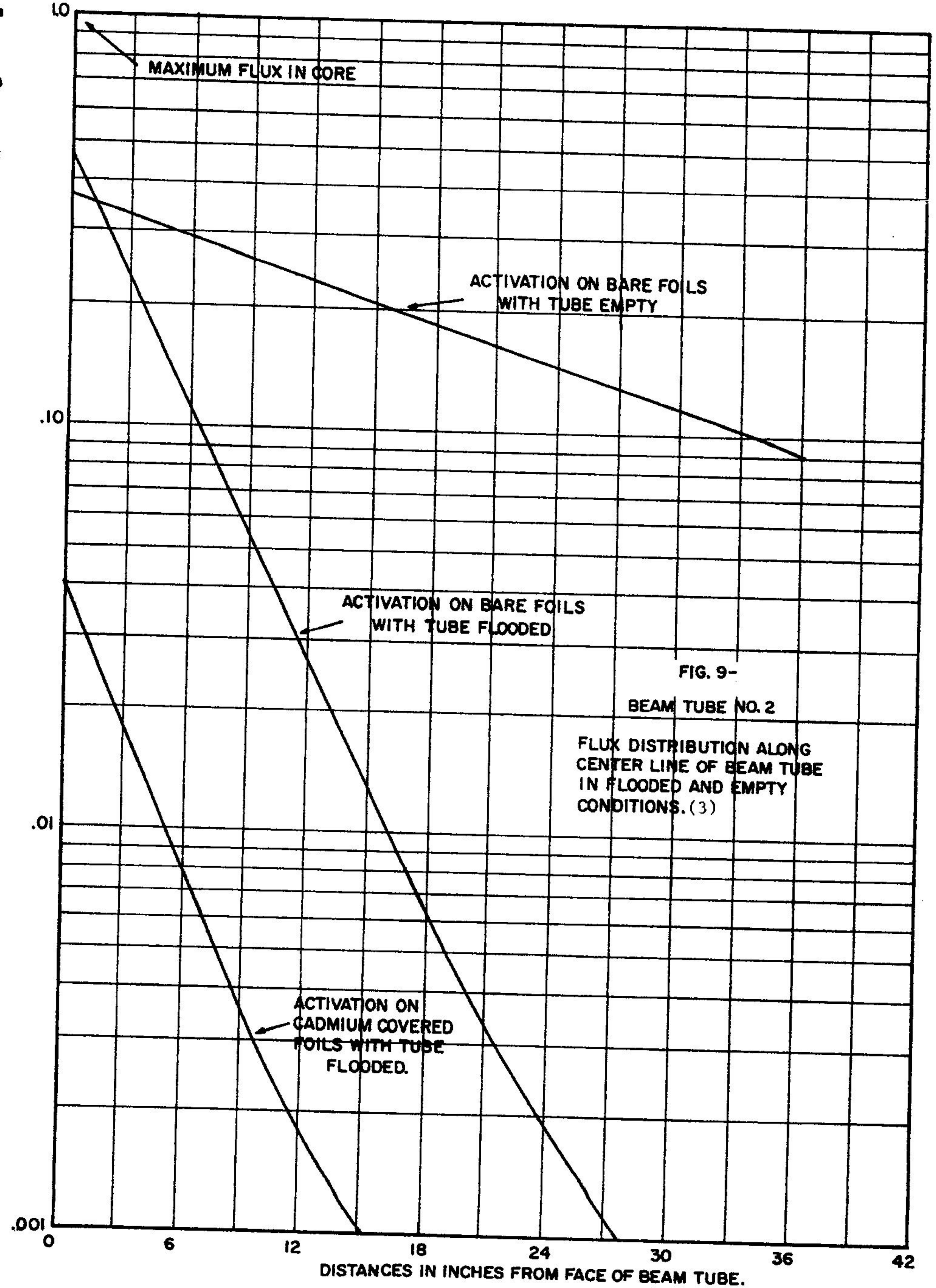
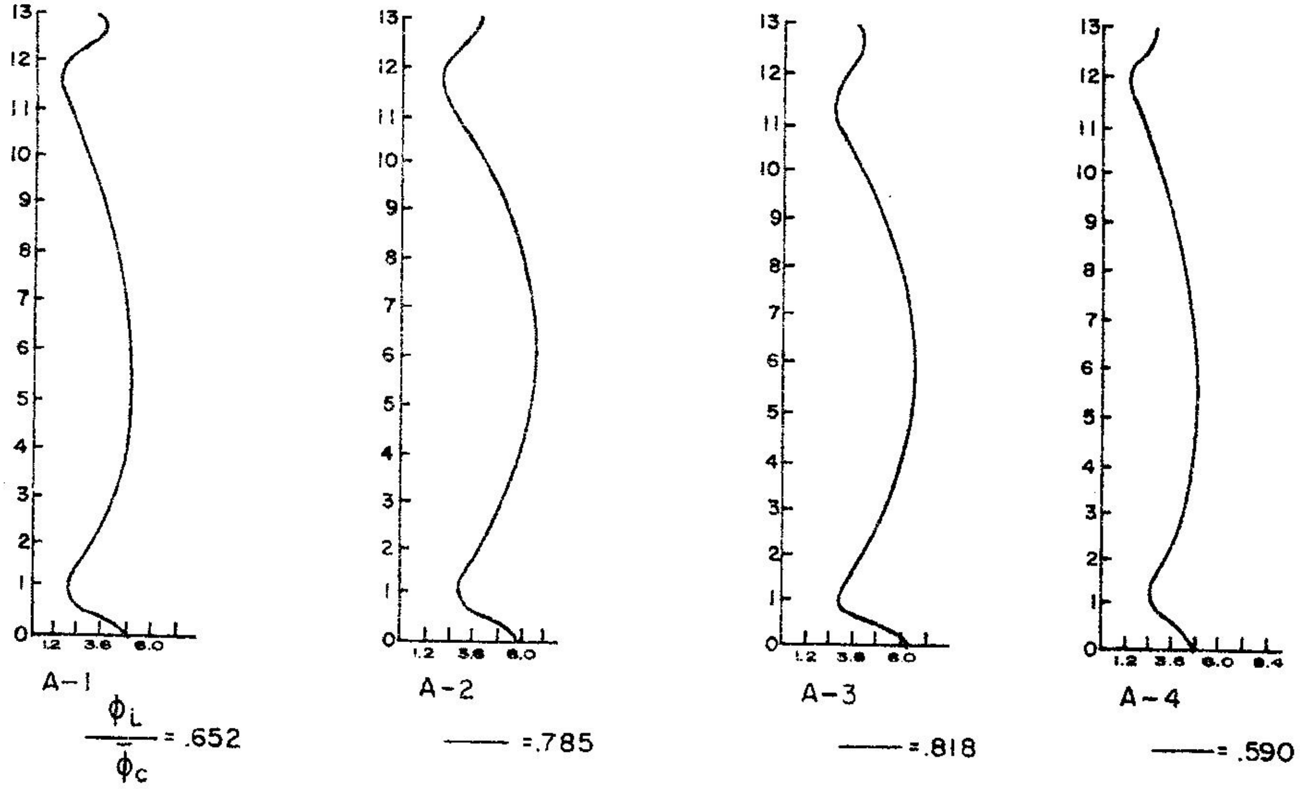


FIG. 9-

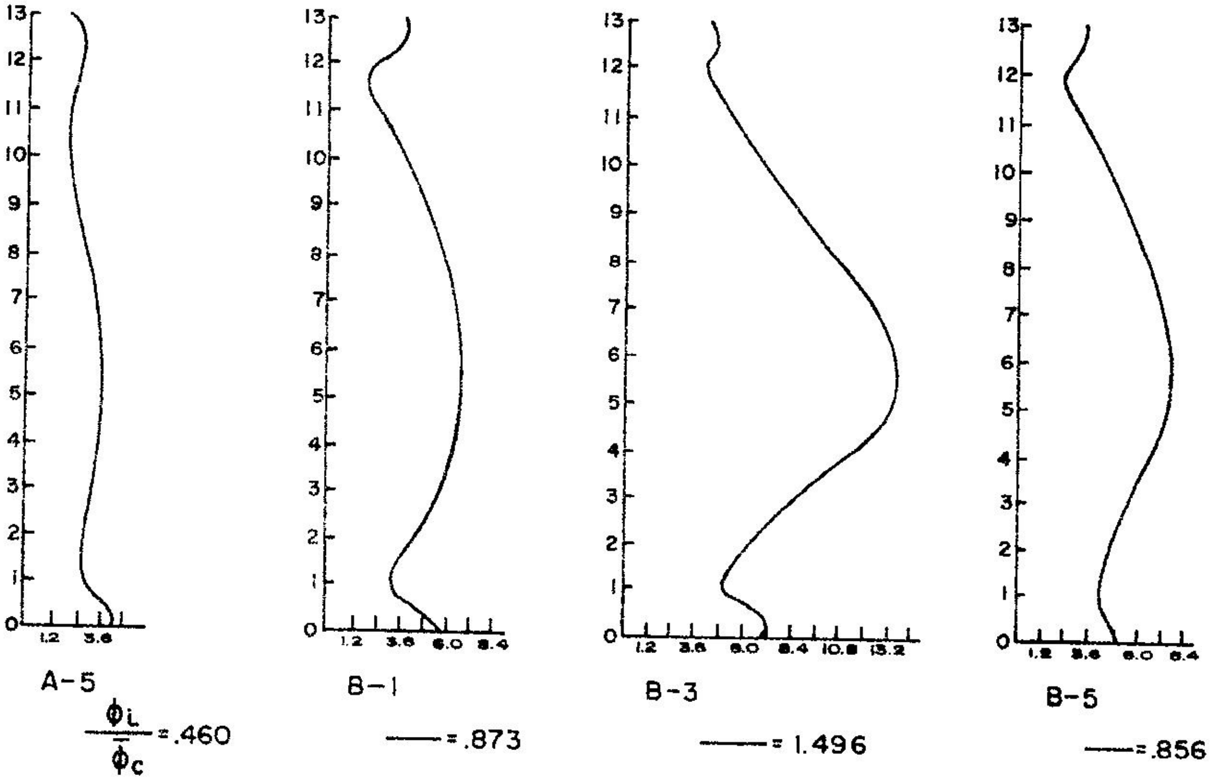
BEAM TUBE NO. 2

FLUX DISTRIBUTION ALONG CENTER LINE OF BEAM TUBE IN FLOODED AND EMPTY CONDITIONS. (3)

FIGURE 10 **FLUX DISTRIBUTION CURVES FOR CORE IIA.**

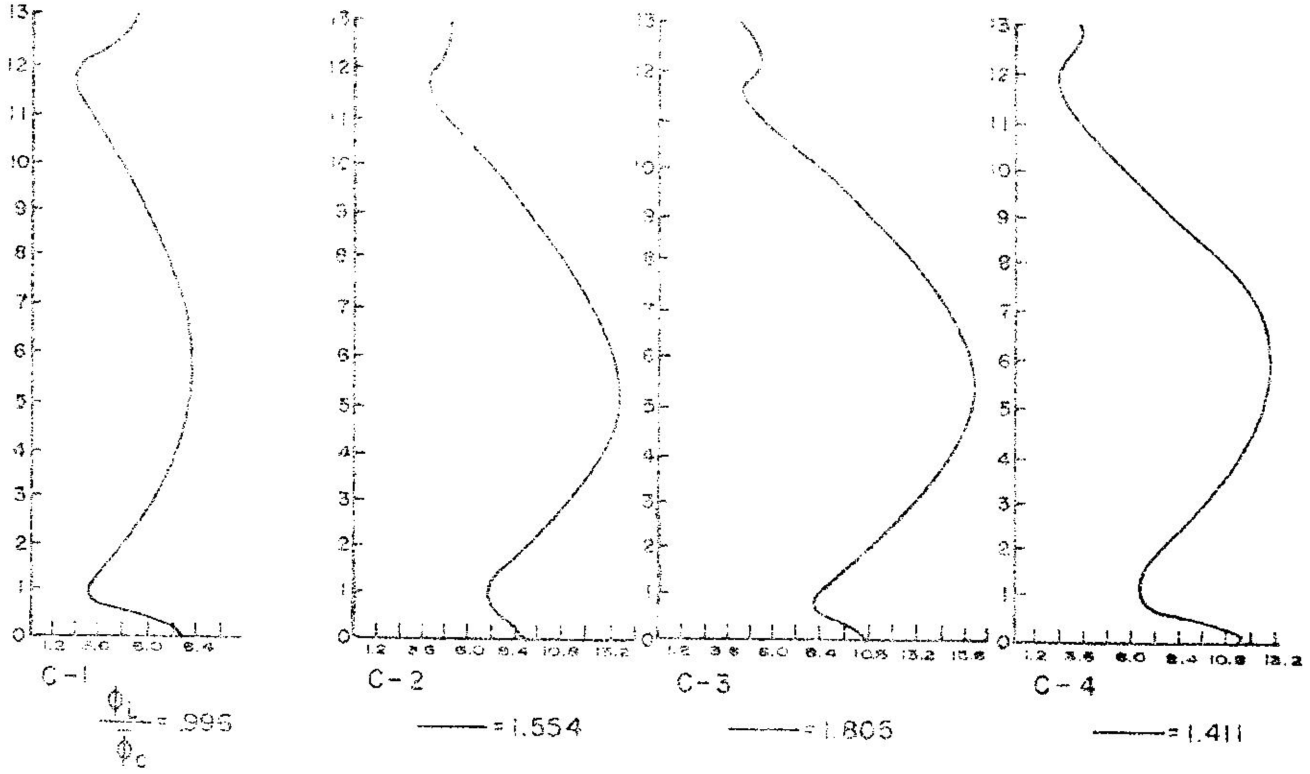


VERTICAL SCALE, 1 UNIT = 2 IN.; HORIZONTAL UNITS; ARBITRARY.



[illegible]
(Continued)

FLUX DISTRIBUTION CURVES FOR CORE IIA.



VERTICAL SCALE, 1 UNIT = 2 IN.; HORIZONTAL UNITS; ARBITRARY

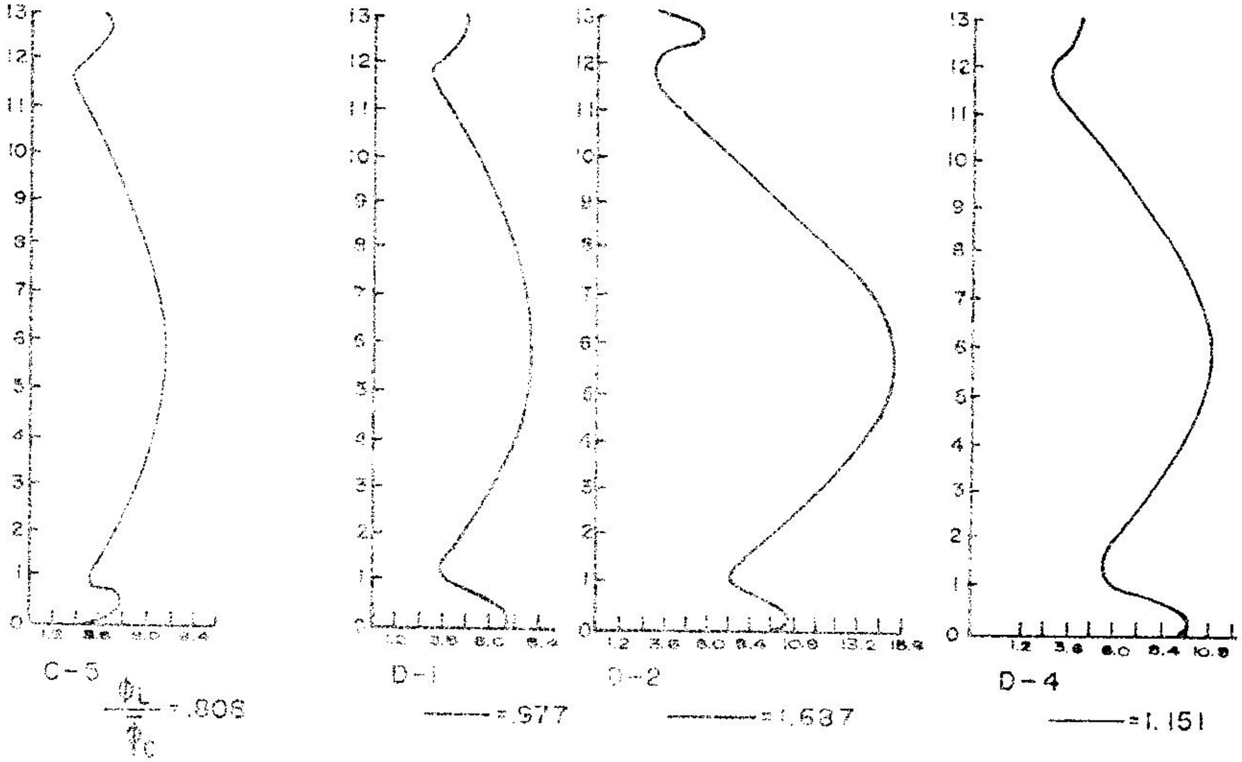
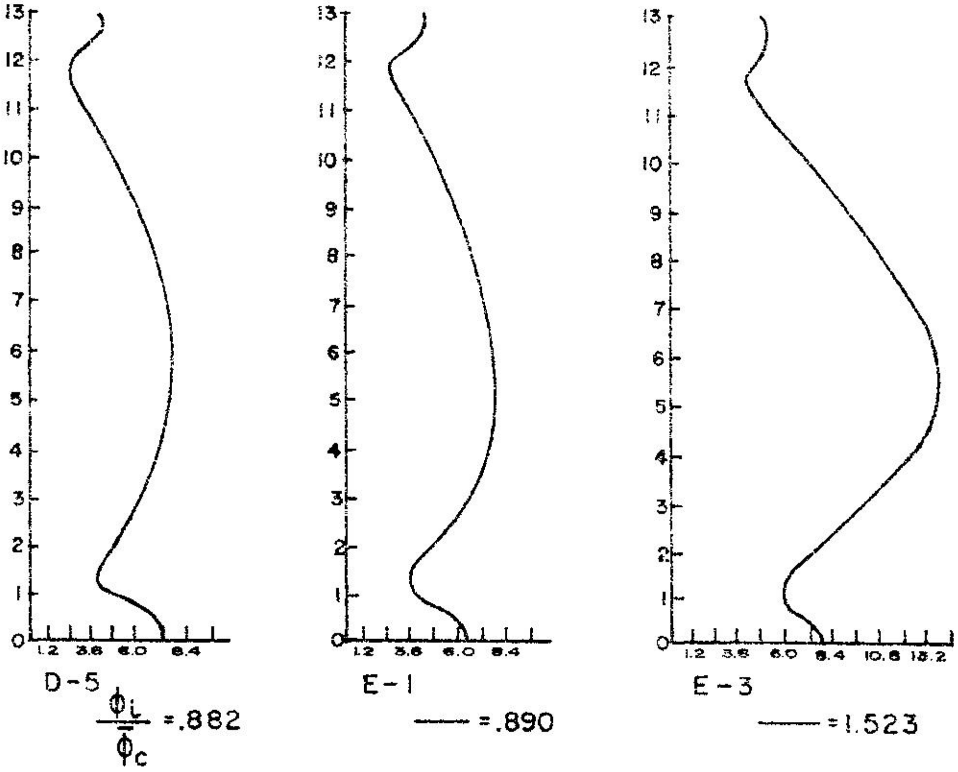


FIGURE 10
(Continued)

FLUX DISTRIBUTION CURVES FOR CORE II A.

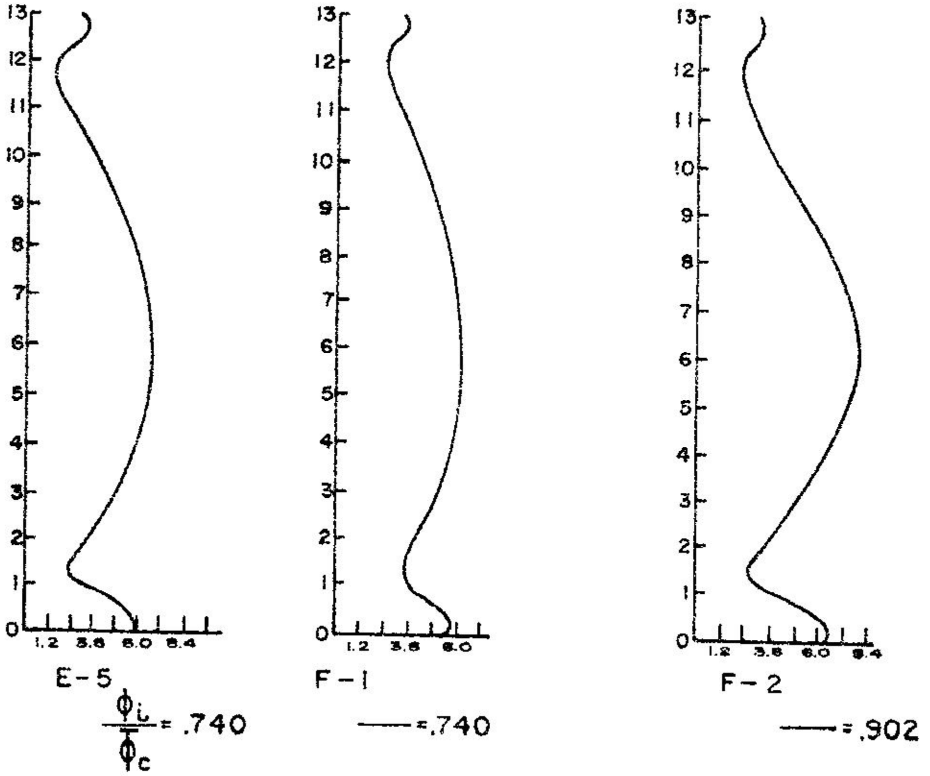


D-5 $\frac{\phi_i}{\phi_c} = .882$

E-1 —— = .890

E-3 —— = 1.523

VERTICAL SCALE, 1 UNIT = 2 IN.; HORIZONTAL UNITS; ARBITRARY.



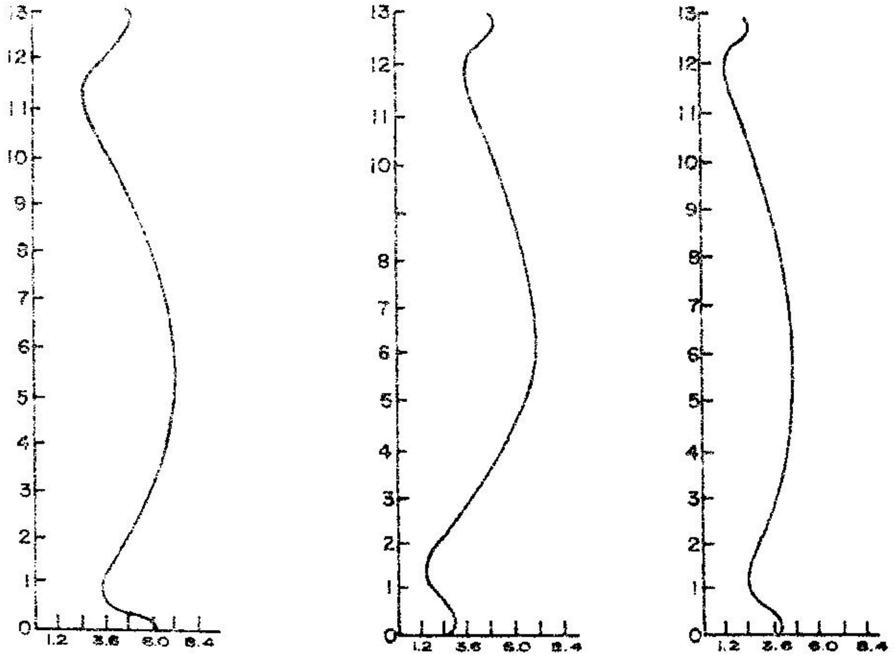
E-5 $\frac{\phi_i}{\phi_c} = .740$

F-1 —— = .740

F-2 —— = .902

FIGURE 10
(Continued)

FLUX DISTRIBUTION CURVES FOR CORE II A.



F-3 $\frac{\phi_L}{\bar{\phi}_c} = .830$

F-4 —— = .834

F-5 —— = .552

VERTICAL SCALE, 1 UNIT = 2 IN; HORIZONTAL UNITS; ARBITRARY.

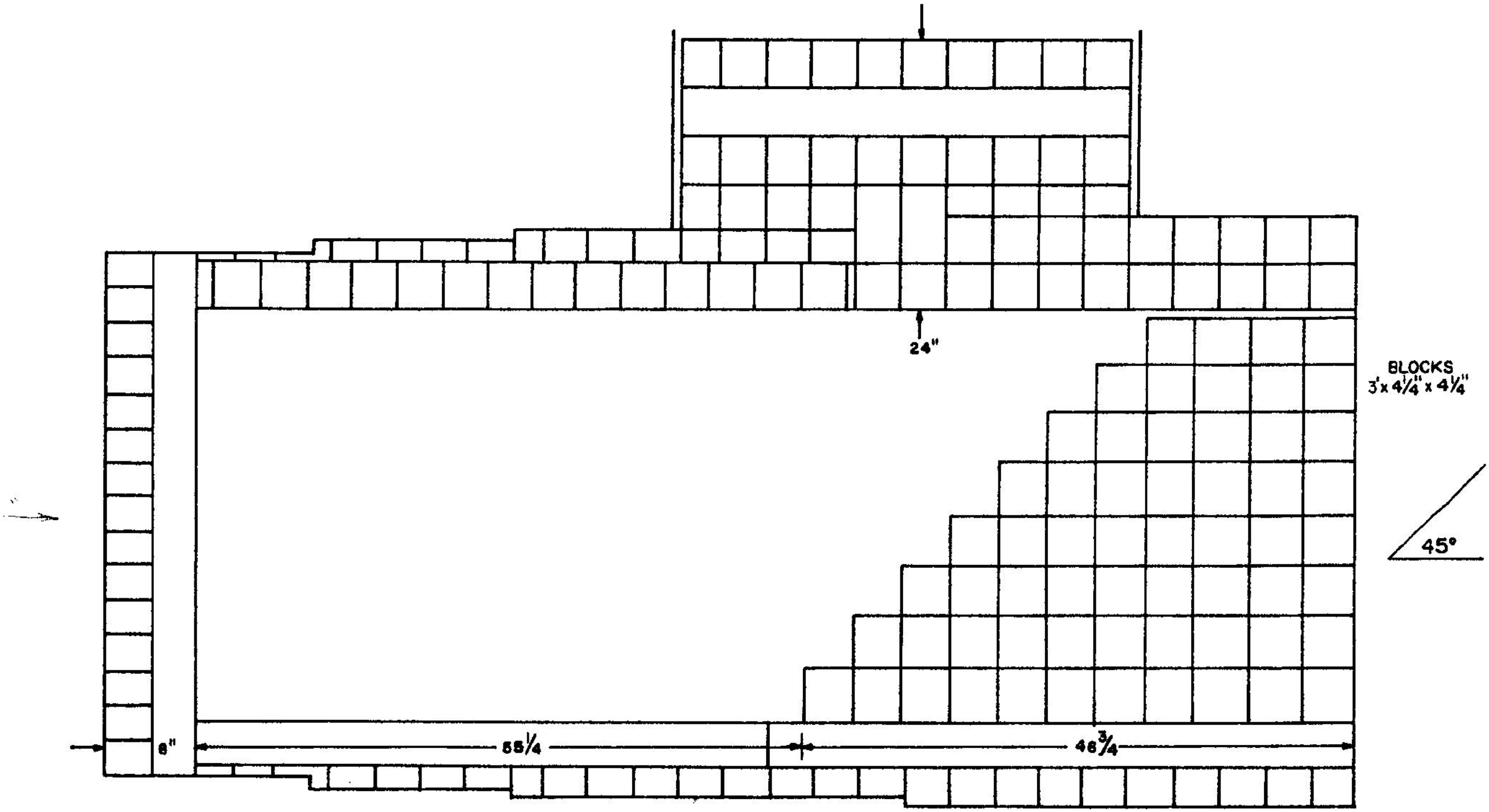


FIG. 11 - FINAL CONFIGURATION OF GRAPHITE IN THE THERMAL COLUMN. (4)

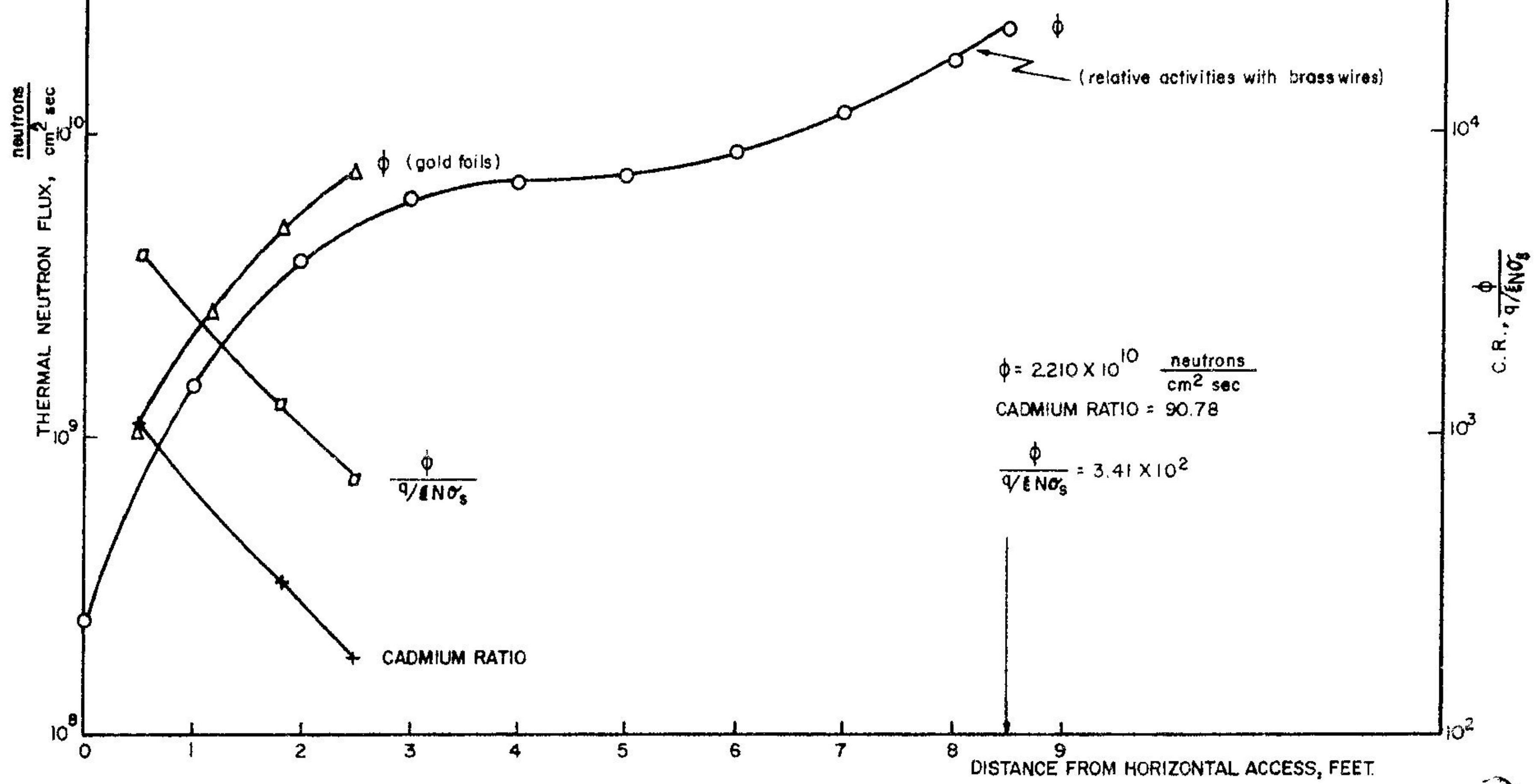


FIG 12 - NEUTRON PHYSICS PARAMETERS, HORIZONTAL CENTER-LINE, LARGE VOID IN COLUMN, FORTY-FIVE DEGREE REFLECTOR. (4)

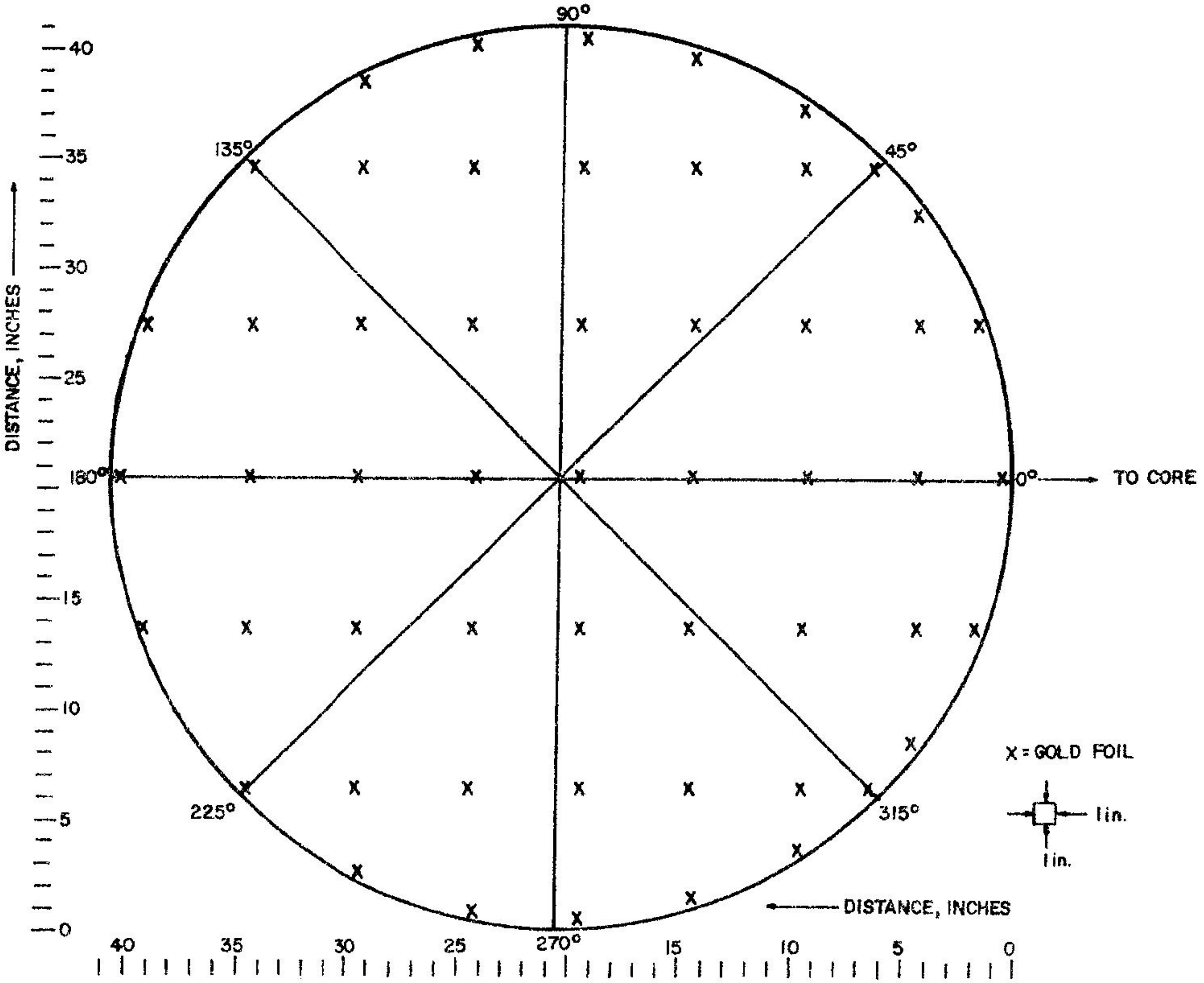


FIG. 13 – LOCATION OF GOLD FOILS USED WITH FINAL GRAPHITE CONFIGURATION. (4)

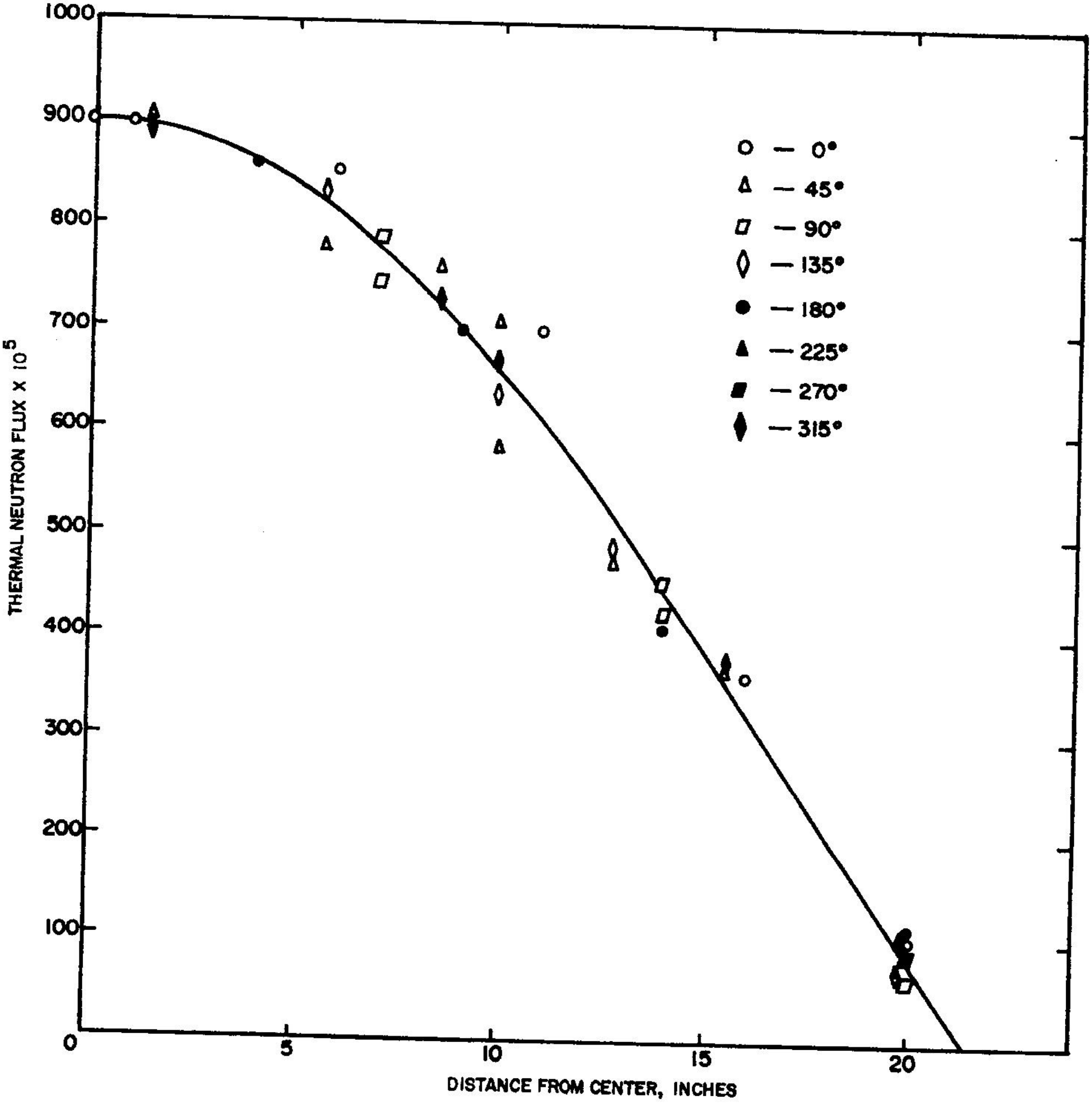


Fig. 14-FINAL FLUX DISTRIBUTION AT THE SURFACE OF THE VERTICAL ACCESS POSITION, VOID IN GRAPHITE. (4)

5. REACTOR SERVICE REQUESTS.

Persons requesting neutron irradiation service from the Reactor Division must:

(a) Fill out one Radioisotope Production card for each set of samples to be irradiated. (A set is understood to be a group of identical samples irradiated simultaneously.) A "Questionnaire for Reactor Experiment" must be filled out and submitted to Health Physics Division (5) for each new irradiation. Use brief form for short irradiations.

(b) Deliver card and sample to Reactor Supervisor's office. Note special instructions on reverse side of card.

Please use the following instructions when filling out the card.

(1) Sample number - Identification number or code of your sample.

(2) Date - Date when sample is submitted.

(3) Flux of irradiations - neutron flux desired.

(4) Time in and time out - to be filled in by Reactor Division.

(5) Total time - desired irradiation time.

(6) Material and weight - specify composition and weight of each sample to be irradiated.

(7) Activation cross section - cross section of material to produce desired radioisotope.

(8) Half life - half life of desired radioisotope.

(9) Calculated activity - activity of desired radioisotope. In cases of activation analysis or when impossible to make calculations please specify so and make a reasonable estimate.

(10) Expected activity - activity to be expected from all materials irradiated. (This includes sample container, carrier materials or undesirable materials which must be irradiated with sample.)

(11) Originator - signature of Division Head or Program Director requesting irradiation, or his designated representative.

(12) Delivered to - signature of person to whom sample is delivered. This signature will be requested by a reactor supervisor at the time sample is delivered.

(c) Except in cases in which the neutron irradiation is a repetition of a previous one a "Questionnaire for Reactor Experiment" must be filled out and submitted to the Health Physics Division at the same time the Radioisotope Production card is submitted.

(d) When the service desired is other than a neutron irradiation, the "Questionnaire for Use of Irradiation Facilities (Other than Reactor)" must be filled out and submitted to the Health Physics Division.

6. RADIATION SAFETY RULES.

The Reactor Division has adopted six radiation safety rules concerning monitoring and shielding. These rules should be taken into consideration when planning an experiment.

(a) Monitoring.

(1) All experiments installed around the reactor facilities in the basement at the present time should be reviewed to determine the need for constant or intermittent neutron monitoring. All future experiments are to be reviewed for the possible need of constant neutron monitoring.

(2) Gamma monitors suitable for wear at or near the hands shall be used when handling unshielded radioactive substances of the near-curie order.

(3) Audible signal gamma monitors shall be used near operating areas where samples are loaded or unloaded during an irradiation service. These monitors should produce a signal which is easily related to radiation intensity (eg., increase in signal rate or signal intensity).

(b) Shielding.

(1) All samples whose activity is 5 r/hr or more shall be transfered to a lead container under at least two feet of water. Enough shielding shall be provided for use during the transportation operation so that radiation intensity does not exceed 200 mr/hr. at contact.

(2) Samples whose radiation intensity is of the order of 1-5 r/hr shall be handled with a remote handling tool (tongs 3 feet long) during a transfer operation.

(3) Samples whose radiation intensity is below 1 r/hr. shall be handled with tongs at least 18" long.

A health physicist will monitor the transportation operation at any time the radiation intensity outside the lead shield (at contact) is greater than 50 mr/hr. Written permission shall be obtained from H.P.D. when it is desired to remove a sample from the reactor building whose expected radiation intensity is over 200 mr/hr. outside the lead shield. The unloading, transfer and transportation operation shall be performed under the direct supervision of a health physicist.

NUCLEONICS DATA SHEET

No. 46—Induced Radioactivity

7.

Specific Activity after Intermittent Irradiation

(6)

by JUAN FLEGENHEIMER, *Comisión Nacional de Energía Atómica, Buenos Aires, Argentina*
and YIZHAK MARCUS, *Israel Atomic Energy Commission, Rehovoth, Israel*

TO SIMPLIFY CALCULATION of the final specific activity obtained when samples are activated by intermittent irradiation in a research reactor, we have developed a graphical method that uses "normalized" growth and decay curves. These curves coupled with a sheet of transparent graph paper and a bit of arithmetic are all the tools one needs. If flux is constant for all irradiation periods (and constant throughout each irradiation period) the theory allows a direct graphical solution, but when irradiations are made at several flux levels, one must find from the graph a component of the total activity for each irradiation and then sum the components to get the total normalized specific activity.

Theory

Specific activity in curies per gram is given by the formula

$$A_\infty = 0.163\sigma\phi a/M \qquad (1)$$

where σ is activation cross section in barns, ϕ is neutron flux in multiples of 10^{12} n/cm²/sec, a is isotopic abundance in per cent and M is atomic weight.

To develop a generalized case one can normalize activities and times:

normalized activity = $\alpha = A/A_\infty$
normalized time = $\theta = t/T_{1/2}$

where A is activity, A_∞ is saturation activity, $T_{1/2}$ is half-life and t is any irradiation or cooling time. From these factors come the normalized growth curve $G = \ln \alpha(\theta_i)$ and normalized decay curve $D = \ln \alpha(\theta_c)$ (see figure).

If flux is constant the normalized activity after a sequence of irradiation for a period θ_{i1}, cooling for a period θ_{c1} and irradiation for a period θ_{i2} will be given by:

$$\alpha_{(\theta_{i1}+\theta_{c1}+\theta_{i2})} = (1 - e^{-0.693\theta_{i1}})e^{-0.693(\theta_{c1}+\theta_{i2})} + (1 - e^{-0.693\theta_{i2}}) \qquad (2)$$

This equation can be transformed into

$$\alpha_{(\theta_{i1}+\theta_{c1}+\theta_{i2})} = 1 - e^{-0.693\theta_{i2}}[1 - (1 - e^{-0.693\theta_{i1}})e^{-0.693\theta_{c1}}] \qquad (3)$$

The second term in the brackets in Eq. 3 equals the normalized activity $\alpha(\theta_{i1} + \theta_{c1})$ obtained before the second irradiation. An equivalent amount of normalized activity could be obtained after irradiation for a period θ_{ix} without cooling

$$\alpha_{(\theta_{ix})} = \alpha_{(\theta_{i1}+\theta_{c1})} = 1 - e^{-0.693\theta_{ix}} \qquad (4)$$

If this quantity replaces the second term in the brackets of Eq. 3 one gets

$$\alpha_{(\theta_{i1}+\theta_{c1}+\theta_{i2})} = 1 - e^{-0.693\theta_{i2}}[1 - (1 e^{-0.693\theta_{ix}})] = 1 - e^{0.693(\theta_{ix}+\theta_{i2})} = \alpha_{(\theta_{ix}+\theta_{i2})} \qquad (5)$$

Thus the normalized activity after the sequence $\theta_{i1} + \theta_{c1} + \theta_{i2}$ is equal to the normalized activity obtained from an irradiation period θ_{i2} that follows an irradiation period θ_{ix} chosen to give the equivalent of the first irradiation and cooling. This equivalent, and in fact the whole solution, can be best obtained graphically in a manner that we shall presently explain.

Flux factors. If the flux ϕ is not the same for all irradiation periods θ_{i1}, θ_{i2}, . . . but is constant throughout each irradiation, the general equation is

$$A = 0.163\sigma \frac{a}{M} [\phi_1(1 - e^{-0.693\theta_{i1}}) e^{-0.693(\theta_{c1}+\theta_{i2}+\theta_{c2}+\cdots)} + \phi_2(1 - e^{-0.693\theta_{i2}}) e^{-0.693(\theta_{c2}+\theta_{i3}+\cdots)} + \cdots] \qquad (6)$$

The fluxes ϕ_1, ϕ_2, . . . are now expressed as multiples of one of them, for example ϕ_1, so that Eq. 6 becomes:

$$A = 0.163\sigma\phi \frac{a}{M} [(1 - e^{-0.693\theta_{i1}})e^{-0.693\theta_{c1}+\theta_{i2}+\theta_{c2}+\cdots)} + \frac{\phi_2}{\phi_1}(1 - e^{-0.693\theta_{i2}})e^{-0.693(\theta_{c2}+\theta_{i3}+\cdots)} + \cdots] \qquad (7)$$

The factor ϕ_x/ϕ_1 is equivalent to a period $\theta(\phi_x)$ on the decay curve D given by

$$\frac{\phi_x}{\phi_1} = e^{-0.693\theta_{(\phi x)}} \qquad (8)$$

To account for this factor, the point obtained on the G curve for $(1 - e^{-0.693\theta_{ix}})$ is displaced on the D curve $\theta(\phi_x)$ units to the left or to the right, depending on whether ϕ_x/ϕ_1 is larger or smaller than one. The flux factors in Eq. 7 are thus converted to a factor to be added (or subtracted) to the decay factors, and the expression for normalized activity becomes

$$\alpha = (1 - e^{-0.693\theta_{i1}}) e^{-0.693(\theta_{c1}+\theta_{i2}+\theta_{c2}+\cdots)} + (1 - e^{-0.693\theta_{i2}})e^{-0.693(\theta_{\phi 2}+\theta_{c2}+\theta_{i3}+\cdots)} + (1 - e^{-0.693\theta_{i3}})e^{-0.693(\theta_{\phi 3}+\theta_{c3}+\cdots)} + \cdots \qquad (9)$$

The different terms of Eq. 9 must be obtained separately from the graph and then added.

How to Apply the Theory

Consider two representative problems:

I At a constant flux of 10^{13} n/cm²/sec irradiate a sodium sample for 4 hr 30 min, allow it to cool for 6 hr, irradiate at the same flux for 4 hr 12 min and cool 6 hr. Find specific activity.

II When second irradiation is done

at a different flux, 1.5×10^{13} n/cm²/sec, (no other conditions changed) what is final specific activity? (For Na^{24}, $T_{1/2} = 15$ hr; for Na^{23} $\sigma = 0.56$ barns, $a = 100\%$).

The solution to Problem I (constant flux) is almost wholly graphical and is obtained as follows:

Graphical Procedures (constant ϕ)

1. Express irradiation periods as $\theta_{i1}, \theta_{i2}, \ldots$ and cooling periods as θ_{c1}, θ_{c2}, (in both problems $\theta_{i1} = 0.30$, $\theta_{c1} = 0.40$, $\theta_{i2} = 0.28$ and $\theta_{c2} = 0.40$).
2. Superimpose a sheet of transparent graph paper on the chart and draw coordinates.
3. Mark on the transport sheet the ordinate of the G curve for θ_{i1} (mark x_1).
4. Move the transparent sheet vertically or horizontally until mark x_1 coincides with D curve.
5. Mark the ordinate of the D curve for $\theta_{i1} + \theta_{c1}$ (mark x_2).
6. Adjust the origins of the two sheets to coincide, then move the transparent sheet horizontally, until mark x_2 coincides with G curve. This produces the operation shown in Eq. 4; the abscissa corresponding to x_2 is θ_{ix}.
7. Mark the ordinate of the G curve for $\theta_{ix} + \theta_{i2}$ (mark x_3).
8. Repeat step 4.
9. Mark the ordinate of the D curve for $\theta_{ix} + \theta_{i2} + \theta_{c2}$ (mark x_4).
10. Do likewise for all irradiation periods θ_i and cooling periods θ_c.
11. Read on the ordinate the normalized activity for the last mark made. For problem I this value is $\alpha = 0.22$.
12. Calculate A_∞ from the known flux, cross-section, abundance and atomic weight, and multiply by the normalized activity to get the desired specific activity. So, $A_\infty = 0.163\sigma\phi a/M = 0.163 \times 0.56 \times 10 \times {}^{100}/_{23} = 3.99$ c/gm and $A = 0.22A_\infty = 0.881$ c/gm.

With several flux values (Problem II) terms that make up the normalized specific activity in the equation must be obtained separately and then summed. Use the following procedure:

A. Compute the flux factors. In Problem II this is $\phi_2/\phi_1 = 1.5$.

B. Determine the $\theta_{\phi 2}$ (on the θ axis) that is equivalent to the flux factor on the ϕ_x/ϕ_1 scale. In this problem the length involved is from 1 to 1.5 on the ϕ_x/ϕ_1 axis and $\theta_{\phi 2}$ equals -0.585 (minus since ratio is >1).

C. Substitute values in Eq. 9. The normalized activity becomes

$$\alpha = (1 - e^{-0.693 \times 0.30})e^{-0.693(0.40+0.28+0.40)} + (1 - e^{-0.693 \times 0.28})e^{-0.693(0.40-0.585)}$$

D. Find the value of the first term by locating $\theta_{i1}(0.30)$ on the G curve and correcting for all subsequent decay $(1.08 = \theta_{c1} + \theta_{i2} + \theta_{c2})$ on the D curve. Read the value on the ordinate—it is 0.089.

E. Find the value of the second term by locating θ_{i2} on the G curve and correcting for both flux factor and decay $(-0.185 = \theta_{\phi 2} + \theta_{c2})$ along the D curve. Again read the α value on the ordinate (0.200).

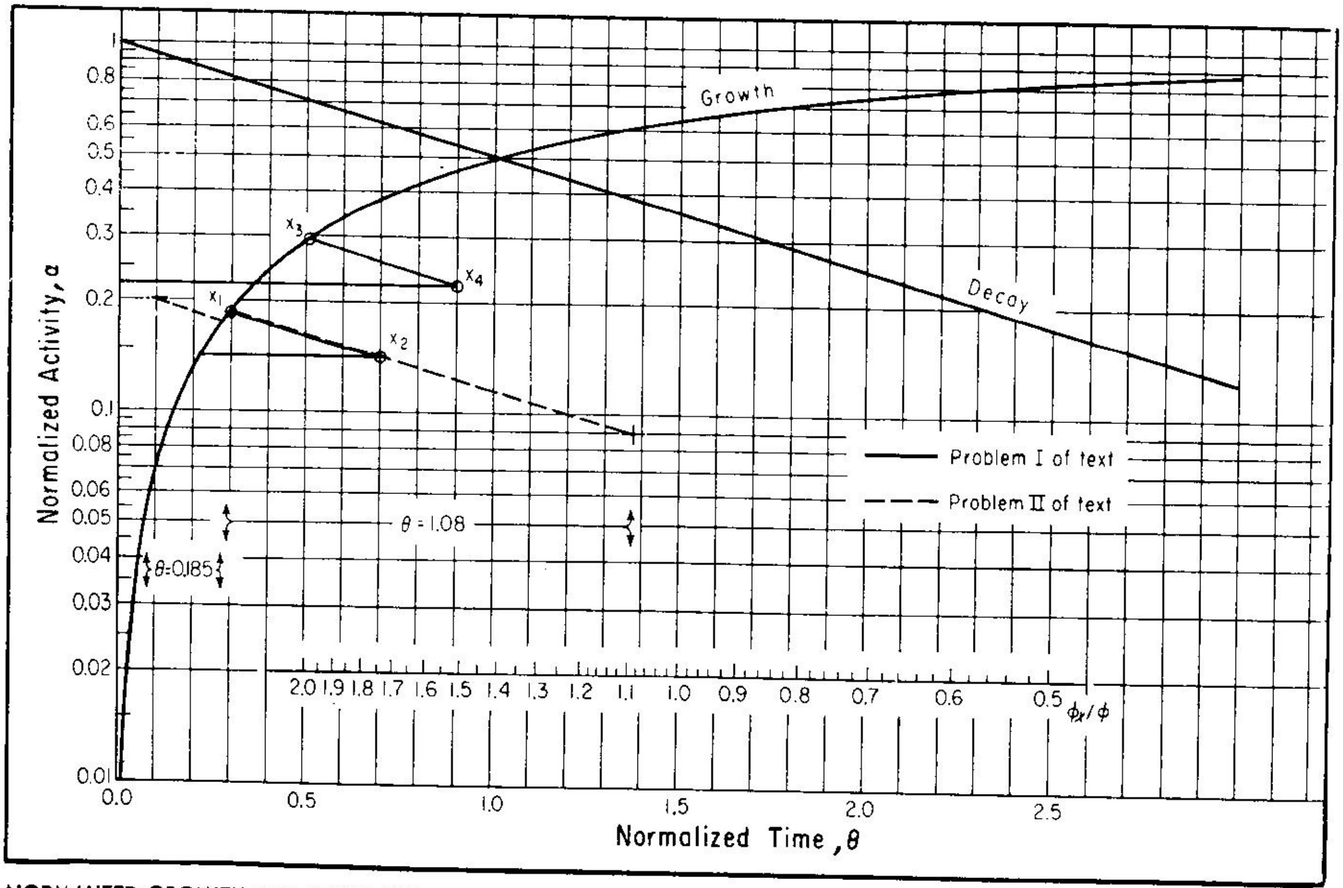
F. Follow the same procedure with additional irradiations.

G. Sum the terms (0.289).

H. Compute specific activity from total normalized activity. For the second problem this is $0.289 \times 3.97 = 1.15$ c/gm.

* * *

Helpful discussions with M. Givon and Y. Pais are acknowledged.



NORMALIZED GROWTH AND DECAY CURVES offer a quick method for calculating induced activity in neutron-irradiated samples

DATE ________ NAME ________

SUPPORTING QUESTIONAIRE

REACTOR DIVISION

RADIOISOTOPE PRODUCTION

SAMPLE NUMBER ____________________ DATE ____________________

FLUX OF IRRADIATION ____________________

TIME IN ____________ TIME OUT ____________ TOTAL TIME ____________

MATERIAL ____________________ WEIGHT ____________

ACTIVATION CROSS SECTION ____________________

HALF LIFE ____________________

CALCULATED ACTIVITY ____________________

EXPECTED ACTIVITY ____________________

ORIGINATOR ____________________

DELIVERED TO ____________________

QUESTIONNAIRE FOR REACTOR EXPERIMENTS

1. What is the purpose of the experiment?
2. What division and department is sponsoring the experiment?
3. What neutron flux and/or gamma flux is desired?
4. What will be the duration of the experiment program?
5. What will be the desired operating time for each irradiation?
6. What are the amounts and kinds of materials which will be within the reactor? List both the physical materials and their elemental breakdown.
7. What is the expected gross activity of the sample?
8. What are the recognized hazards associated with the experiment?
9. What will be the final disposition of the radioactive portions of the experiment?

Date	Signature of Person Completing Questionnaire

(Please use additional pages for answering the above questions, but sign <u>this</u> sheet and fill in the date. Return to Héctor Barceló, Head, Reactor Division)

QUESTIONNAIRE FOR USE OF IRRADIATION FACILITIES (Other than Reactors)

1. Facility requested (underline those needed):
   hot cells, gamma pool, fuel element gamma room, gamma field,
   gamma irradiation, special set up.
2. Material to be irradiated ______________________________
3. Radiation dose (s) to be used: ______________________________

4. Approximate total exposure time ______________________________
5. To be used from ______________ to ______________ (dates)

Signature Supervisor ______________
Date ______________

6. Person in charge of the experiment:*
   Name: ______________ Division: ______________ Phone: __________

*The term experiment is used here in a broad sense to imply the insertion of any kind of material whatsoever.

IMPORTANT NOTICE

1. All experiments inserted and removed from an irradiation facility shall be monitored by a Radiation Monitor, or other person authorized by the H. P. D.
2. Fill this form in triplicate and send it to the Health Physics Division for its approval. The division will return one copy with its approval or comments to the originator and one copy to the person in charge of the facility.

For Use of H. P. D. Only

Approved: Yes ______________ No. ______________
Date ______________ Signature ______________

Form PRNC-HPD (RM) 663

9. REFERENCES

(1) Hazards Summary Report for the Pool-type Research Reactor. PRNC-37 (December, 1964)

(2) Brown, R. Gamma Ray Dosimetry Using Cobalt Glass Detectors. University of Puerto Rico master's thesis. (May, 1962)

(3) Annual Report of the Reactor Division 1960-1961. (November, 1961)

(4) Angleró, O. and J.A. Wethington. Modification of the Neutron Flux Distribution in the Thermal Column of the PRNC Reactor. (March, 1963)

(5) Health Physics Guide and Regulations. PRNC-2 (January, 1963)

(6) Flegenheimer, Juan and Yizhak Marcus. Specific Activity after Intermittent Irradiation. Nucleonics 20,5 page 75f. (May, 1962)