PHYSICS MEASUREMENTS ON THE SNAP

EXPERIMENTAL REACTOR (SER)

By

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ABSTRACT

Prior to operation of the SER at temperature and power and with NaK coolant present, a series of measurements were performed in the neighborhood of room temperature and at powers of 1 watt or less. These measurements were designed to establish the characteristics of the system under controlled conditions and to determine safe operating procedures. This report is a description of these measurements.

In particular, measurements were made to determine critical mass in various reflector configurations, control drum and safety element worth, flux mappings in the reactor and importance mappings external to the reactor, reactivity coefficients of various materials, and kinetic parameters.

The most important conclusion drawn is that the system as designed has the necessary reactivity and control for its anticipated operation. Full feasibility determinations must necessarily wait upon the outcome of experiments at power and temperature.

I. INTRODUCTION

The SNAP Experimental Reactor (SER) designed and fabricated for power operation has initially been run in the SNAP critical facility at powers below 1/2 watt. The purpose of this low power operation has been to check the preliminary calculations, to measure desired physical quantities, and to calibrate the system prior to its installation in the power test facility.

The results of many of the experimental measurements, reported here, were forecast by calculations, with varying degrees of success. For a complete review of the system, the report describing its characteristics as calculated should be consulted.[1] The initial low power operation covered a period of approximately a month and included the following measurements:

a) Critical mass

b) Control drum calibration

c) Evaluation of safety elements

d) Worth of reflector materials

e) Temperature coefficients

f) U^{235} foil activations

g) Reactivity mapping external to reflector

h) Feasibility of pile oscillator experiment in SER

i) Reactivity worth of material distribution in core

j) Noise measurements

The results of these measurements are presented here.

II. SYSTEM DESCRIPTION

The critical experiments with the SER core and reflector system were performed in the SNAP critical facility. For the purpose of the experiments, the SNAP critical assembly was removed and the equipment shown in Figure 1 was installed in the test cell.
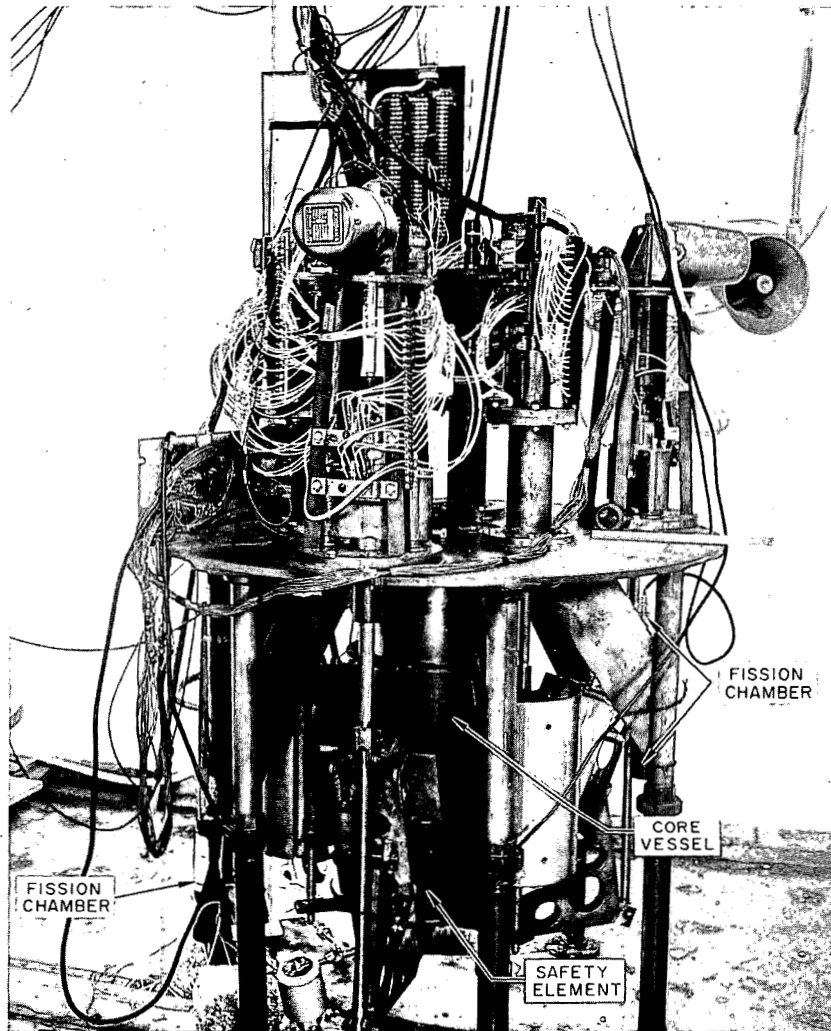
Figure 1. SER Critical Assembly

The core vessel and two of the fission chambers are identified in the photograph. Two more fission chambers are located out of view and in positions approximately diametrically opposed to the visible chambers. The reactor and

the fission chambers are the only features in the photograph which bear directly on the experimental program. The fission chambers are the fundamental detecting agencies in the experimental program.

There are, as indicated, four U^{235} fission chambers equipped with Westinghouse No. 6376 chambers, Atomic Instruments No. 218 linear amplifiers and associated pre-amplifiers, and Atomic Instruments No. 131 scalars. In addition, the output of each of two of the amplifiers is used to operate a Hewlett-Packard No.523B Electronic Counter in conjunction with a 560-A digital (printing) recorder.

The reactor is shown in a schematic cross section, Figure 2. A nominal detailed description of the design reactor system follows (taken from Reference 1).
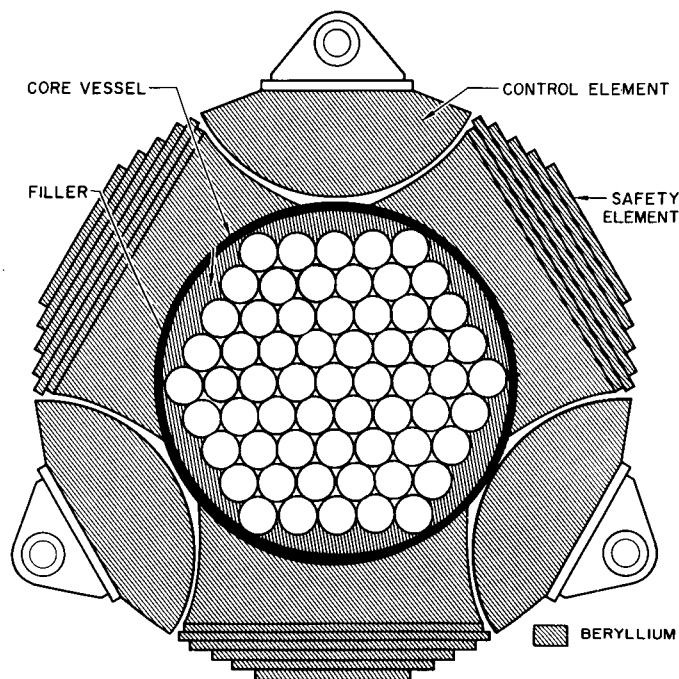
Figure 2. Axial View of the SER Core
and Radial Reflector Configuration

A. REACTOR RADIAL DIMENSIONS

Hexagonal fuel element array	9.135 in. diameter across corners
	7.911 in. diameter across flats
	8.308 in. diameter of equal area circle
Internal Be reflector	6 pieces between hexagonal fuel element array and cylindrical core vessel

Core vessel, 347 SS	9.368 in. OD
	9.180 in. ID
External Be reflector	3.0 in. thick (variable)

B. REACTOR AXIAL DIMENSIONS

Active core length	10.0 in.
End Be reflector	1.5 in. at each end
End 347 SS weld plugs	0.5 in. at each end
Grid plate thickness	0.25 in. at top
	0.31 in. at bottom
Coolant plenum	1.25 in. at top
	1.5 in. at bottom

C. FUEL ELEMENTS

Number of fuel elements	61
Length	10 in. of active fuel
	15.2 in. overall length
Diameter	1.00 in. OD
Stainless steel cladding	0.01 in. thick
Ceramic coating	0.0025 in. thick (nominal)
Fuel material	0.975 in. diameter
Fuel alloy composition	93 w/o Zr
	7 w/o U
Uranium enrichment	93% U^{235}
U^{235} loading per fuel element	47.5 gm U^{235}
Fuel alloy hydrided to	6×10^{22} hydrogen atoms/cc

D. CORE COMPOSITION

Volume fractions	0.845 fuel material alloy
	0.120 NaK coolant
	0.035 347 SS cladding

Effective atomic densities:

H	0.0507×10^{24} atoms/cc of core
Zr	0.0299×10^{24} atoms/cc of core
U^{235}	0.00084×10^{24} atoms/cc of core
U^{238}	0.000062×10^{24} atoms/cc of core
Na	0.00059×10^{24} atoms/cc of core
K	0.00125×10^{24} atoms/cc of core

Moderator to fuel atomic ratio H/U^{235} 60

Fuel loading   2.9 kg U^{235}

In the critical facility, the coolant and coolant plena were omitted. Many of the above specifications are only nominal. Fuel elements, for example, showed marked individual variations. Further, the system was deliberately modified in many of the experiments which were performed. The modifications are indicated in the text. A fuller description of the SER system will be found in Reference 1.

III. TECHNIQUES FOR DETERMINATION OF REACTIVITY

Since a very large part of the experimental program consisted of observations of the reactivity state of the system, or the difference in reactivity for two states of the system; it appears useful to indicate briefly the different means employed to assess reactivity values. There were four such methods and they will be designated; supercritical, rod drop, sub-critical multiplication, and control drum comparison. In each instance, the method is based originally on instantaneous neutron flux level information sensed at, and by, the fission chambers. The first two methods depend on the time rate of change of the flux level, the third on its magnitude at steady state, and the fourth is based simply on finding the neutron level at a steady state at a magnitude very substantially above source level.

The reactivity of a slightly supercritical system can be determined by observing the rate of change of the system's power level and deducing an exponential period; subsequently, consulting the inhour equation to find the corresponding excess reactivity. Rod drop reactivity determinations are made by abruptly changing a system from critical to subcritical and observing the "instantaneous" power drop. Both these procedures lead to evaluation of the reactivity worth of a change in the system in dollar units. The relative importance of delayed neutrons must be determined to permit reduction to absolute reactivity units. A discussion of the theoretical basis for these techniques is found in Reference 2, Chapter XVII.

In the approach to criticality and in subsequent subcritical measurements, the subcritical source multiplication method has been used, and the steady state power level of a subcritical multipulication system is observed. This method permits the identification of the critical point of the system. Further, if due care is taken to separate the fundamental mode from higher modes of the data, one can make relative determinations of reactivity for system states, e.g., one can determine the relative value of various control drum settings. Provided one knew independently an equation which adequately described the system, the natural geometric modes for the solution of this equation, and the expansion coefficients of the external source, one could make absolute reactivity determinations. To some order of approximation, one need only know the source's fundamental mode coefficient at some configuration point in order to make an absolute determination.

These provisions are, however, beyond what might reasonably and practicably be attained with good accuracy, in the critical system under consideration. The calibration is therefore relative and requires some external bit of data to normalize the results to a definite prescribed unit of reactivity. The basis for this technique also is discussed in Chapter XVII, Reference 2.

If we assume that the control drums have by some means been calibrated; then, the reactivity of a change in the system can be measured by observing the change in control drum position required to maintain the system in the same reactivity state with and without the change in the system.

A. CRITICAL MASS

1. Initial Approach With Full Reflector

For the initial loading to critical, the reflector was provided the full safety available thickness of beryllium. This beryllium includes the control drums, the fixed safety pieces, and six removable plates of varying sizes attached to each safety.

The beryllium safeties were constituted as in Table I below and the plates are numbered from innermost to outermost, see Figure 2. These are typical average dimensions which can vary slightly from one safety to another.

TABLE I

DIMENSIONS OF SHIM PLATES

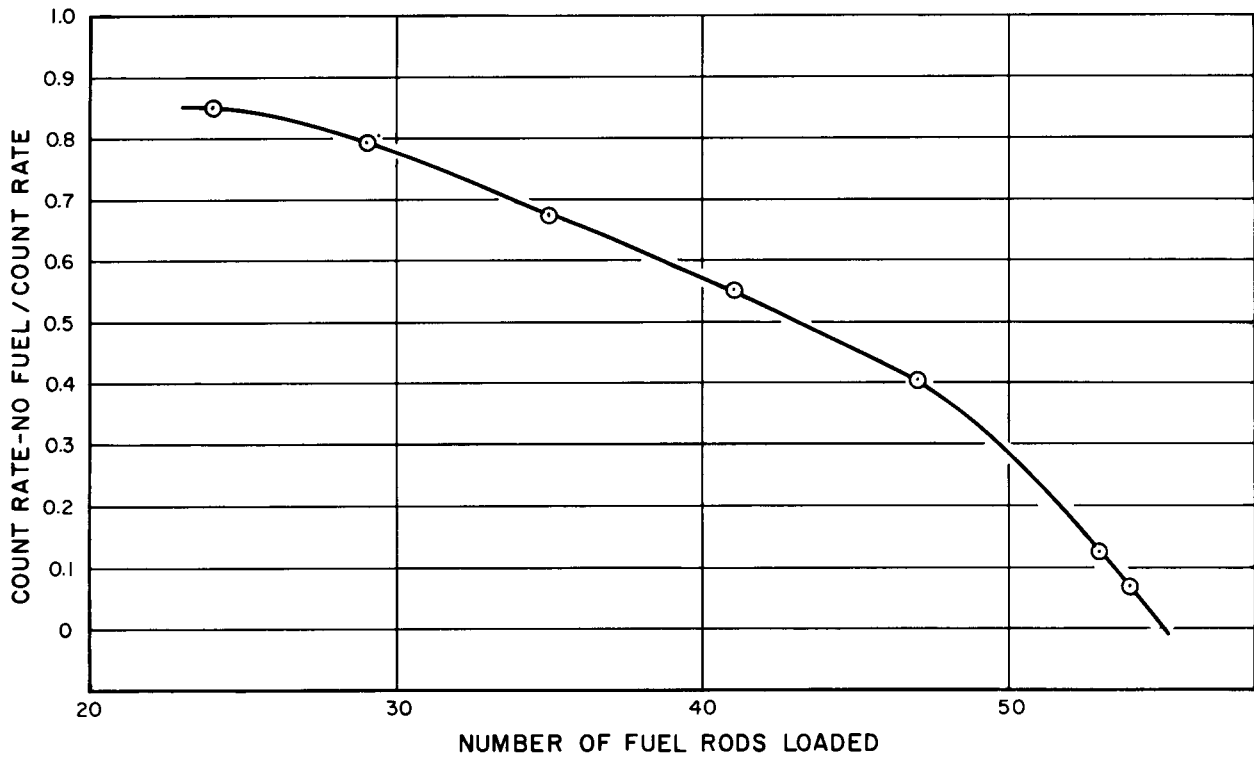| Safety	Mass (gms)	Nominal Dimension (Inches)		
		Length	Width	Thickness
Fixed Plate	5820			
Plate No. 1	795	12-15/16	7-7/8	1/4
No. 2	832	12-15/16	8-3/16	1/4
No. 3	761	12-15/16	7-1/2	1/4
No. 4	624	12-1/2	6-3/8	1/4
No. 5	510	12-1/2	5-1/4	1/4
No. 6	437	12-1/2	4-1/2	1/4

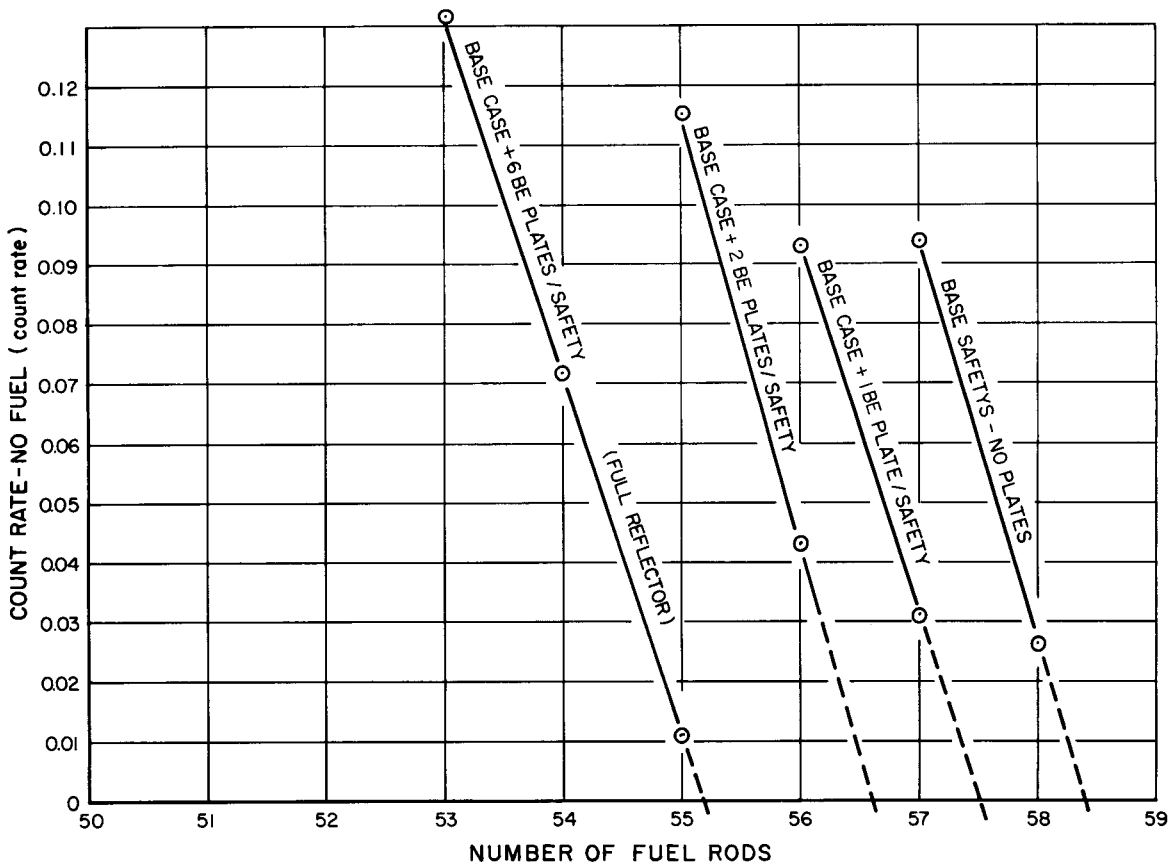Figure 3. Initial Approach to Critical, Reciprocal Count Rate

Figure 4. Reciprocal Count Rates, Approaches to Critical

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With the control drums out and the safeties down, a portion of the fuel was loaded into the center of the core. The neutron count rate was carefully and continuously monitored. The safeties were brought up slowly and individually, and then the control drums were moved in separately. With the full reflector in, a subcritical count rate was determined. An additional loading of fuel was positioned around the initial center load and the procedure repeated. In this fashion, a reciprocal count rate curve was generated which extrapolated to apparent zero (criticality), at 55.2 rods with full reflector.

2. Later Loadings

Subsequently, approaches to critical were made with the reflector at reduced thickness:

      a) Fixed safety with two plates, 7,447 gms Be/safety

      b) fixed safety with one plate, 6,615 gms Be/safety

      c) Fixed safety, no plates, 5,820 gms Be/safety

Since each of these cases was evidently less reactive (with the same fuel loading) than the preceding one, the system was unloaded only sufficiently to ensure that there would be a least two points on the reciprocal count rate curve.

Results of the latter part of the initial approach to critical are presented in Figure 3. Figure 4 summarizes the reciprocal count rate curve in the neighborhood of critical for this and subsequent loadings

B. CONTROL DRUM CALCULATION

The control drums were calibrated over approximately 28¢ worth of their range by use of the supercritical period method and by sub-critical multiplication over the remainder of their range.

Since safe practice limited the total available excess at any time to about 28¢ (corresponding to a 20 second period), only a small portion of a control drum could be calibrated by the supercritical technique. The remainder of the drum traverse was calibrated by the subcritical multiplication method. The data obtained by subcritical count were interpreted by the rule:

$$M = \frac{kS}{1 - k}$$

with

M = measured multiplication rate,

S = source strength,

and k = system reactivity.

S is not determinable from the data available. However, if a small portion of the drum is calibrated both by the supercritical method and by the subcritical multiplication method, and if the supercritical results are converted from dollar units to absolute units by use of a computed value of the effective delay fraction, then a value of S can be imputed (in a limited range at least).

Some criticism can be made of this interpretative procedure:

a) The above relation of M, k, and S implies a complete description by the fundamental mode only,

b) Further implied is, that the value of S does not change with the configuration.

The supercritical calibrations were considered inherently more reliable. They do suffer in that the inhour equation used in their interpretation is not adequately corrected to account for photoneutrons. It is believed that this correction will not prove great. In relating the calibrations determined by subcritical multiplication to those determined supercritically, a calculated value of the effective delay fraction, 0.0085, was used. This value had an accuracy of probably no better than 5-10%.

Figure 5 presents the drum calibration as determined by these methods. Subsequent supercritical calibrations made in the SER facility without the extreme restriction on excess reactivity have indicated these interpretations were indeed defective and that the imputed calibration curve should be increased by 40% approximately uniformly.

Hence, the total value of each control drum represented in Figure 6 as about $2.50 appears from later measurements actually to be $3.50.

The rod drop technique was inapplicable to the drum calibration because it requires a change in the system reactivity more rapid than permitted by the drum drives.
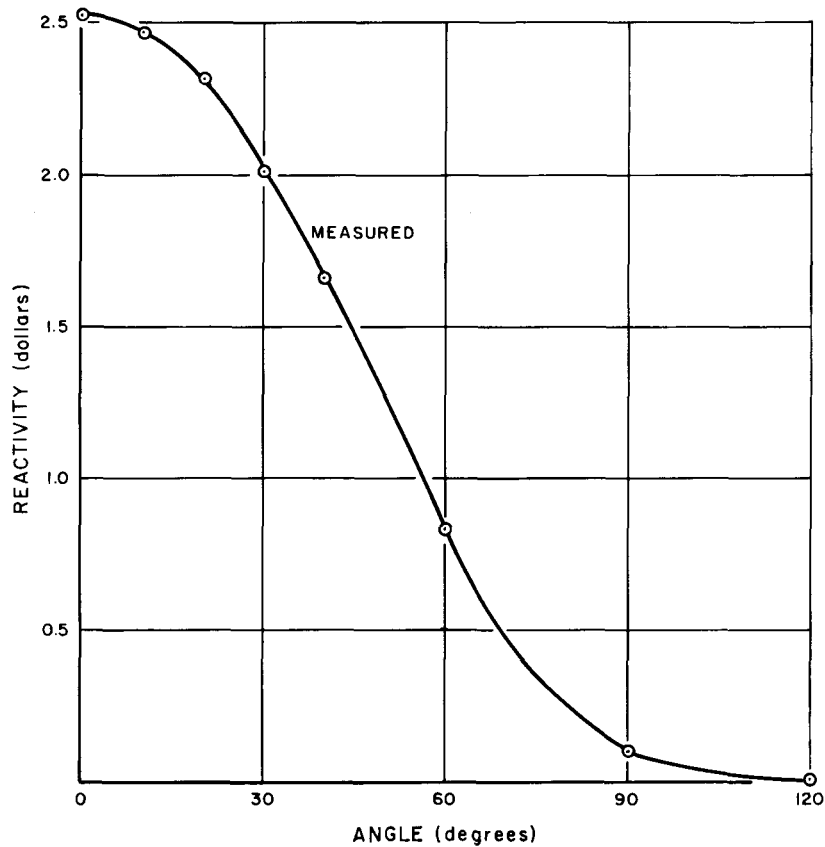
Figure 5. SER Drum Calibration

A program is now in effect to improve experimental and analytical techniques applied in control calibration.

The results of these measurements and those described in the preceding section lead to the following conclusions:

1) In the cold, clean condition, with safeties up, six plates on each safety, and with control drums all the way in (most reactive), the excess reactivity of the system would be about 7%.

2) In the same condition but with control drums all the way out (least reactive) the system excess reactivity should be about -1.9%.

No account here is taken of the reflective value of the vault in which the SER will be operated. It has been estimated that this effect will add about 1% of reactivity in all conditions.

C. EVALUATION OF SAFETY ELEMENTS

The reactivity value of one safety element was determined in a rod drop experiment. It was assumed the other safeties would have substatially the same value.

A single safety (with no plates attached) was found to have a value of $3.50. (Sub-critical determinations led to an apparent value of $3.00, but this is not considered a good measurement).

We are led then to an apparent value of the three safeties of $10.5.

The total reactivity available in safeties and drums combined is, from literal addition, $21.0. This number should be regarded as no more than a rough magnitude since additivity can hardly be expected to be justified to such an extent.

D. WORTH OF REFLECTOR MATERIAL

The approaches to criticality with different numbers of plates on the safeties-described in a preceding section - were further analyzed to determine the reactivity values of the plates. The analysis was based on the same simplified and normalized M, k, S relation.

Results of that analysis are presented in Figure 6.

A 1-in. thick aluminum disk, diameter approximately equal to core vessel inner diameter, was placed against each grid plate. A supercritical determination was made of the reactivity value of these two plates, and they were found together to be worth about 30¢.

The purpose of the measurement was to estimate the value of NaK in the plena of the operating system. The aluminum plates are very coarse representatives of NaK at best. Since the total transport and absorption cross sections associated with the aluminum plates are respectively move and less than those associated with NaK in the plena, we may reasonably expect the NaK in the end plena to be worth no more than 30¢. A more definitive statement is not justified.

E. TEMPERATURE COEFFICIENTS

In order to heat the system for the purpose of measuring temperature coefficients, strip resistance heaters were fixed to the outer surfaces of the safeties and drums, and ring heaters were attached to the grid plates.
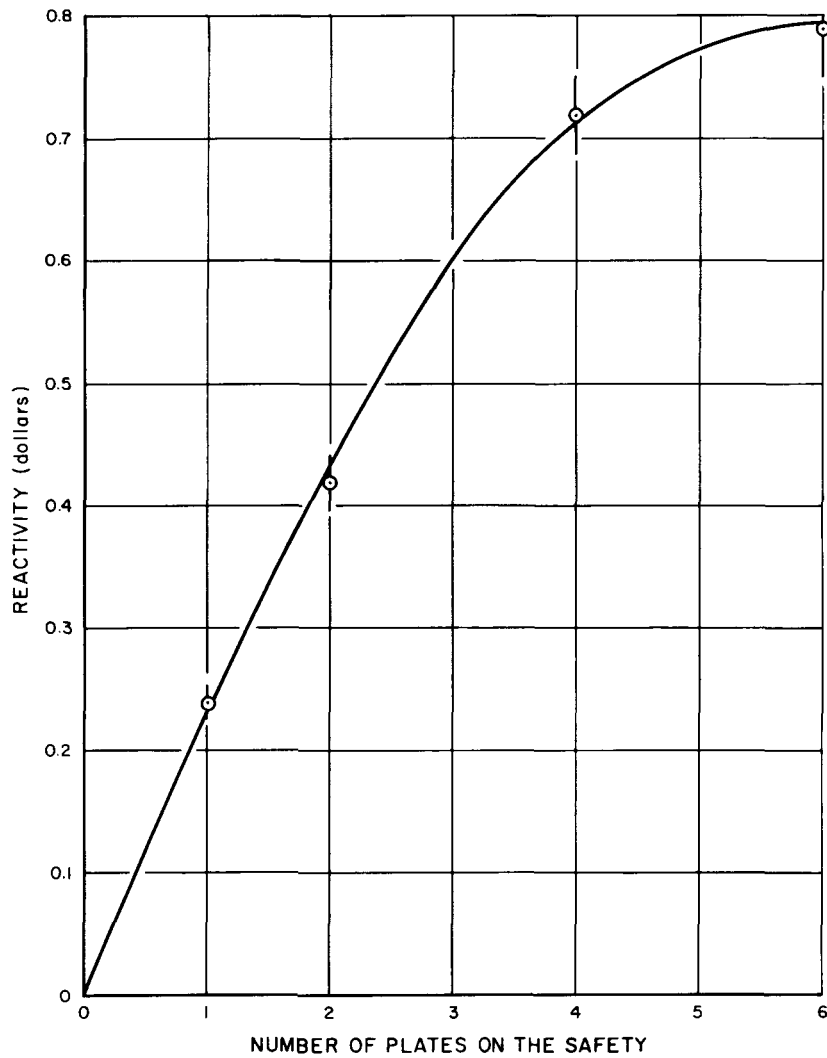
Figure 6. Beryllium Reflector Worth

Two classes of experiments were performed; in one, the heaters on the grid plate or the reflector were driven at high current so that the element to which they were attached heated rapidly while the other parts of the system remain substantially at their initial temperatures on account of the rather long thermal relaxation times.

The system was placed on a supercritical period, with grid plates (or reflector) unheated, and control settings were noted. The system was then brought to the neighborhood of critical and the grid plate (or reflector) was rapidly heated. When thermocouples indicated a suitable temperature distribution had been attained, the controls were returned to their former (supercritical) setting, and a supercritical determination of the system reactivity with grid plates
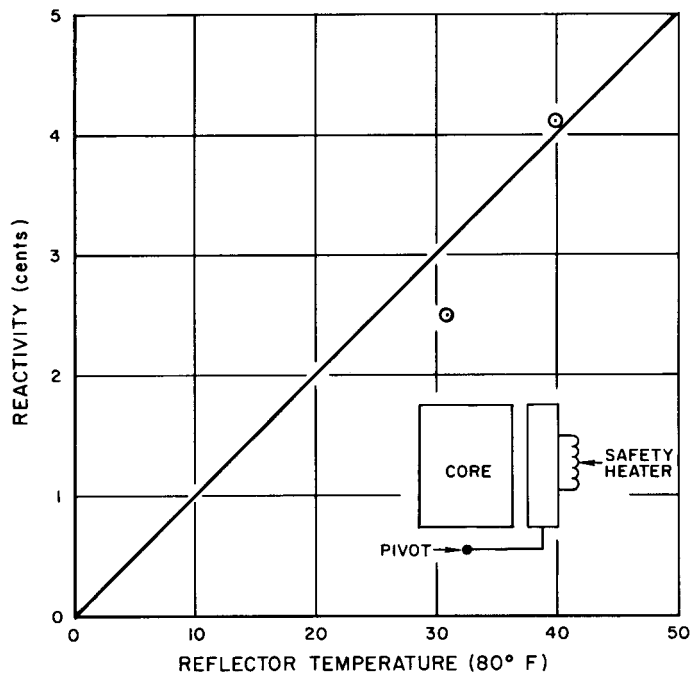
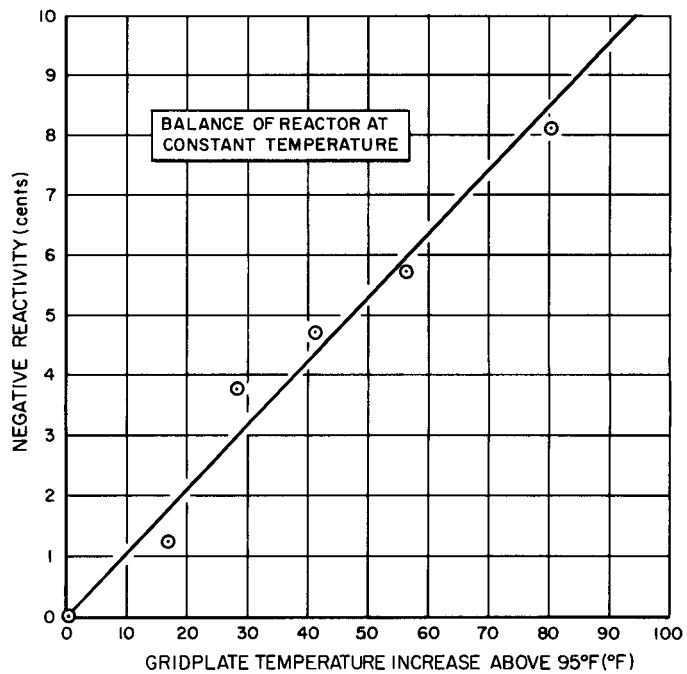Figure 7. Change in Radial Reflector with Temperature

Figure 8. Change in Grid Plate Worth with Temperature

(or reflector) hot, was made. In this manner, determinations of grid plate and radial reflector temperature coefficients were made separately. While the grid plate coefficient so measured appears reasonable over the range of measurement, the reflector coefficients is highly suspect or difficult to interpret. An inset sketch of the reflector safety heating geometry appears in Figure 7. Note that any outward translation of the safety would be governed by expansion of the strut connecting it to the pivot. In the experimental geometry, that strut remained cold and presumably did not expand. The safety piece in expanding, therefore, pushed its outer surface outward and its inner surface inward toward the core. This latter effect led to the positive temperature coefficient associated with the reflector, see Figure 7. This situation may, in some degree, be approximated in some conditions of operation but would not be in some others. The data were taken only in the range of 80-120°F. The measured temperature coefficient for the radial reflector, in this range of temperatures and in this condition of heating, is + 0.1¢/°F. It may be quite different in other conditions.

The grid plate temperature coefficients are also strictly limited in the temperature range over which they were measured. The range of measurement was approximately 95-170°F. Further, the grid plates, top and bottom, were held at the same temperature; not a representative operating condition. In these conditions, the grid plate temperature coefficient was found to be - 0.1¢/°F, see Figure 8.

The temperature range over which these measurements were made was limited, because at higher temperatures the increased temperature gradient shortened thermal relaxation times to the point where there was not sufficient time to make measurements following these techniques.

In the other set of temperature coefficient experiments, the entire system was heated and cooled slowly so that fairly stable temperature distributions were maintained throughout.

The system was made slightly supercritical and a period reactivity determination made; temperatures in various parts of the system were noted. The control settings during this observation were taken as reference settings. The controls were adjusted to hold the system approximately critical, and the system was slowly heated. After a time, observations of temperatures were again made, the controls were returned to reference position, and a second reactivity determi-
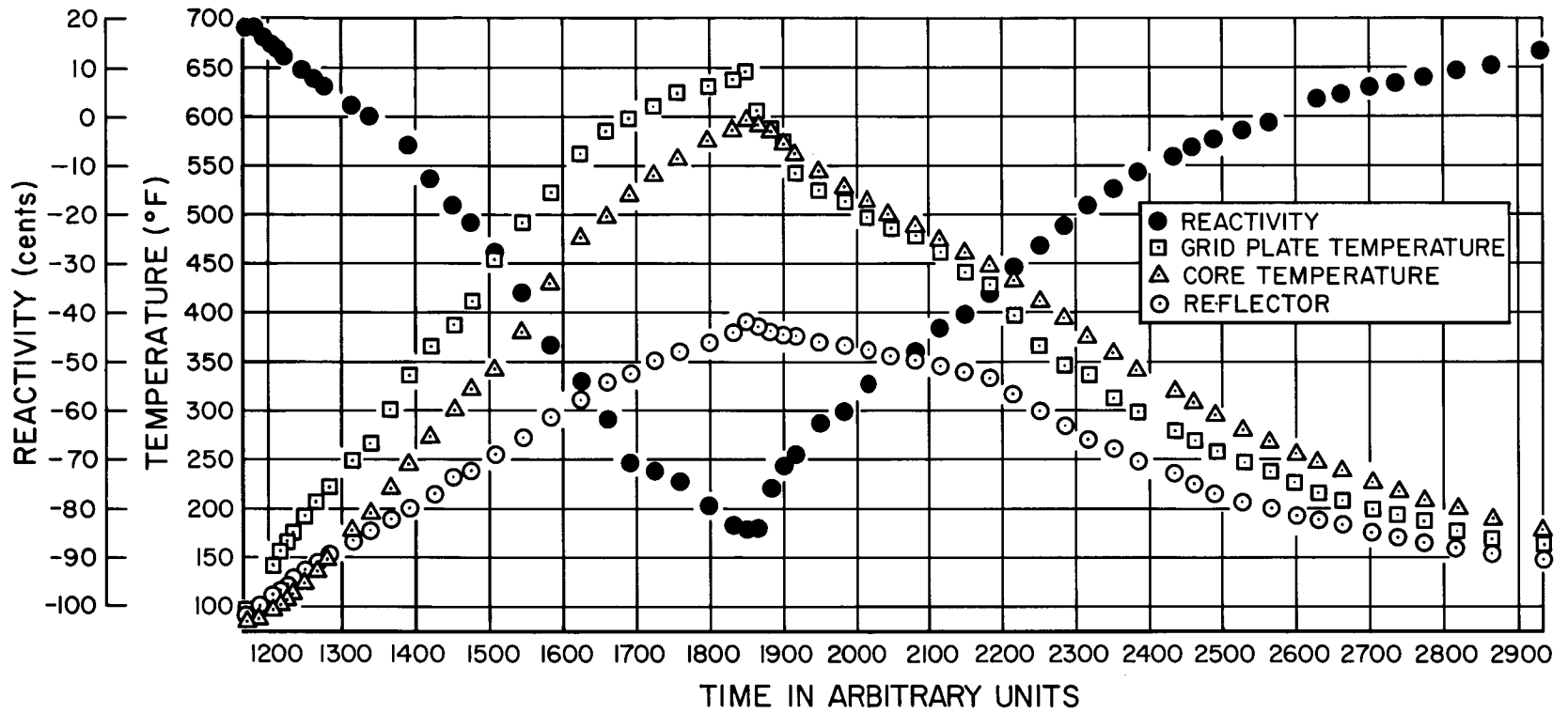
Figure 9. Reactivity Changes with Changes in Temperature Distribution

nation made. This procedure was continued until the system was subcritical when the controls were in the reference position. Thereafter the controls remained in the reference position and reactivity was measured by the subcritical multiplication method. The heating was continued until the core average temperature was about 600°F. The system was then allowed to cool slowly and the same kinds of measurements were made periodically during the cooling time. The results of these measurements are presented in Figure 9.

In Figure 10 a plot is made of the core reactivity coefficient as obtained by extrapolating and literally accepting the grid plate and reflector coefficients (Figures 7 and 8) and combining them with the data in Figure 9.

The system temperature coefficient as measured appears to be fit by the relation:

$$\frac{1}{k}\frac{dk}{dT} = -(1.12 + \frac{T}{100}) \times 10^{-5}$$

where

T = temperature (°C)

k = reactivity (absolute units),

and

k(absolute) = 0.85 k (dollars).

F. U^{235} FOIL ACTIVATIONS

A set of 93% U^{235} uranium foils was used to monitor fluxes. It has been verified that these foils are identical, except for small weight differences for which corrections are easily made. The foils were distributed in the reactor in three distinct patterns and activated; the patterns used were as follows:

1) Radial traverse - distributed from the center outward radially in the reactor midplane,

2) Axial traverse - distributed from top to bottom along the reactor centerline,

3) Circumferential traverse - distributed at corners and mid flat positions around half the core reflector interface in the reactor midplane (illustrated in Figure 13).
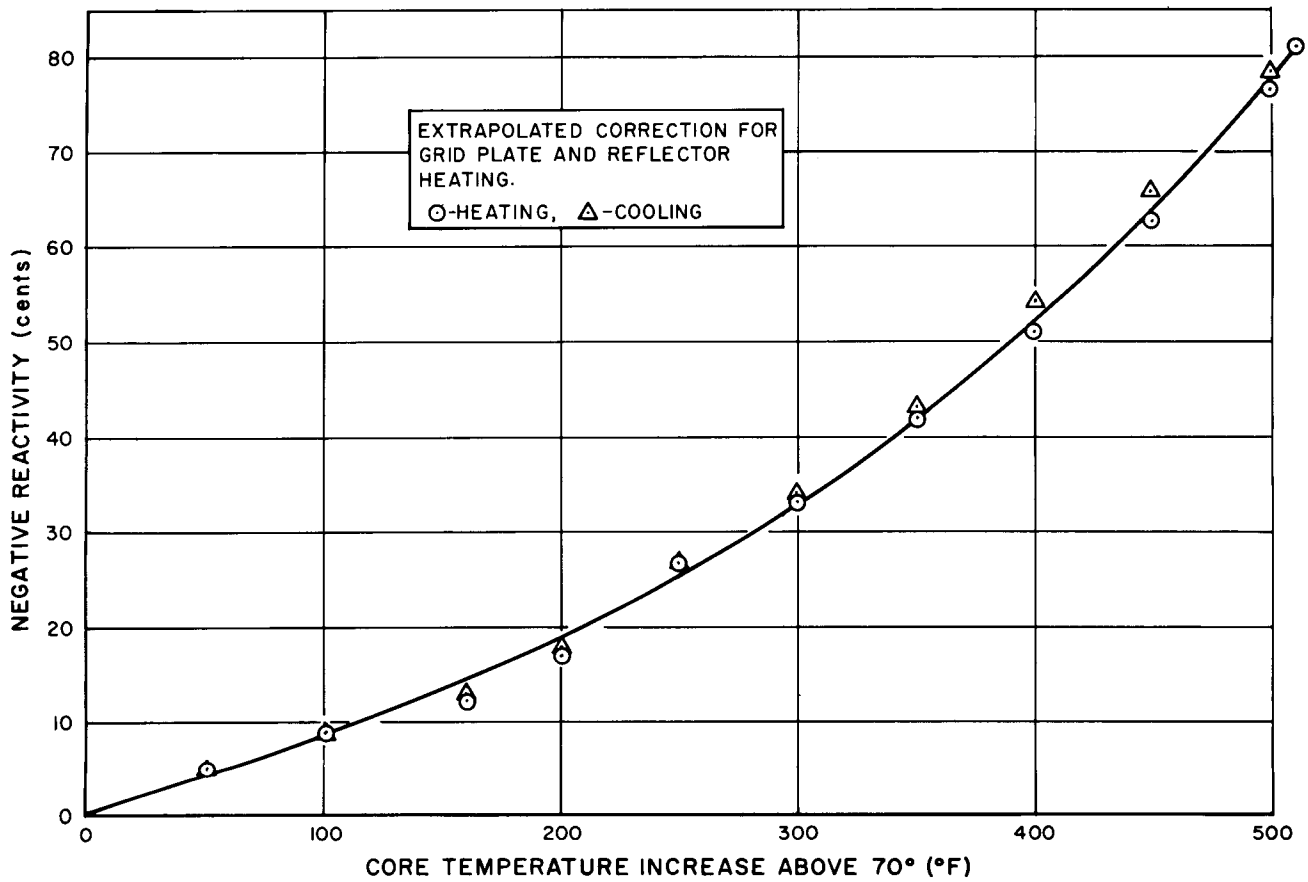
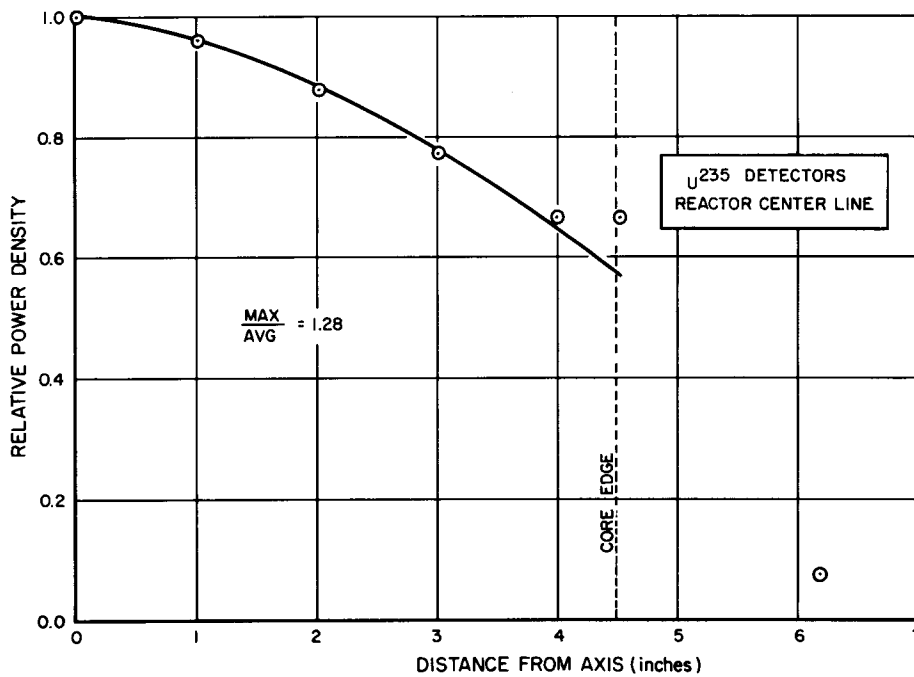Figure 10. Reactivity Change with Temperature, Core
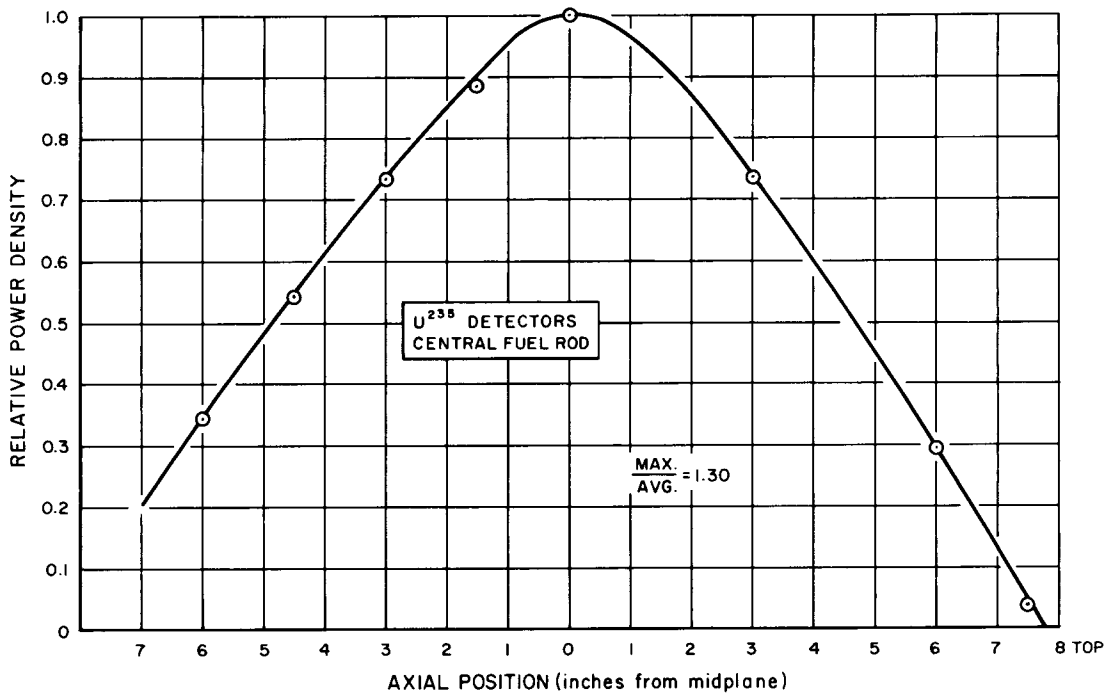

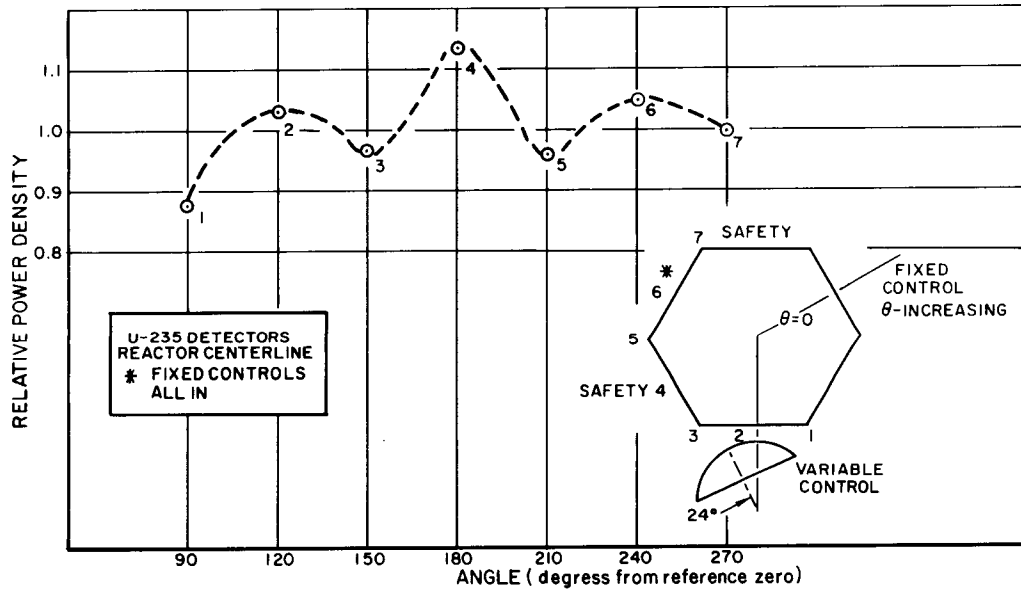Figure 11. Radial Flux Traverse

Figure 12. Axial Flux Traverse

Figure 13. Circumferential Flux Traverse

In each pattern, the foils were activated by maintaining the reactor critical for a reasonable time. After removal from the assembly, each foil was counted a number of times, in a gamma responsive beta shielded scintillation detector. A decay curve was thus constructed for each foil. Readings were taken from each such curve at the same value of time after shutdown, corrected for weight differences among the foils, and normalized to the value of one of their number. These normalized values are presented in Figures 11, 12, and 13 corresponding respectively to patterns 1, 2, and 3 above.

The plotted values are therefore substantially;

$$C \int_0^\infty \Sigma_f(E)\phi(E, r)\, dE$$

where

$\Sigma_f(E)$ = macroscopic fission cross section of foil at energy E,

$\phi(E, r)$ = flux at energy E, location r,

and   C = normalization factor.

In the fueled region of the reactor, this expression - apart from disturbances introduced by the presence of the foil - in proportional to the power density. In the non-fueled region of the reactor, it is proportional to an average value of the flux over all energies weighted by the fission cross section.

Since a very substantial number of the fissions occur in the thermal region, no very great error is made in considering this quantity to approximate the thermal flux shape.

Figure 11 (axial traverse) gives a distribution rather more sharply peaked than a cosine function, though not especially remarkable. Figure 12 is a quite typical radial power distribution. Further, if one fits a curve smoothly through the points, ignoring reflector peaking, it is closely a Bessel function. The fluctuation measured in foil activity about the core circumference, Figure 13, is evidently due to a combination of geometric effects. The inset in the figure shows the foil orientations relative to the various components. The fluctuations are evidently caused by : (1) relative distance from core center, (2) relative neighboring reflector thickness, and (3) orientation of nearby control drums. The experiment is not sufficiently definitive to pinpoint these effects further.
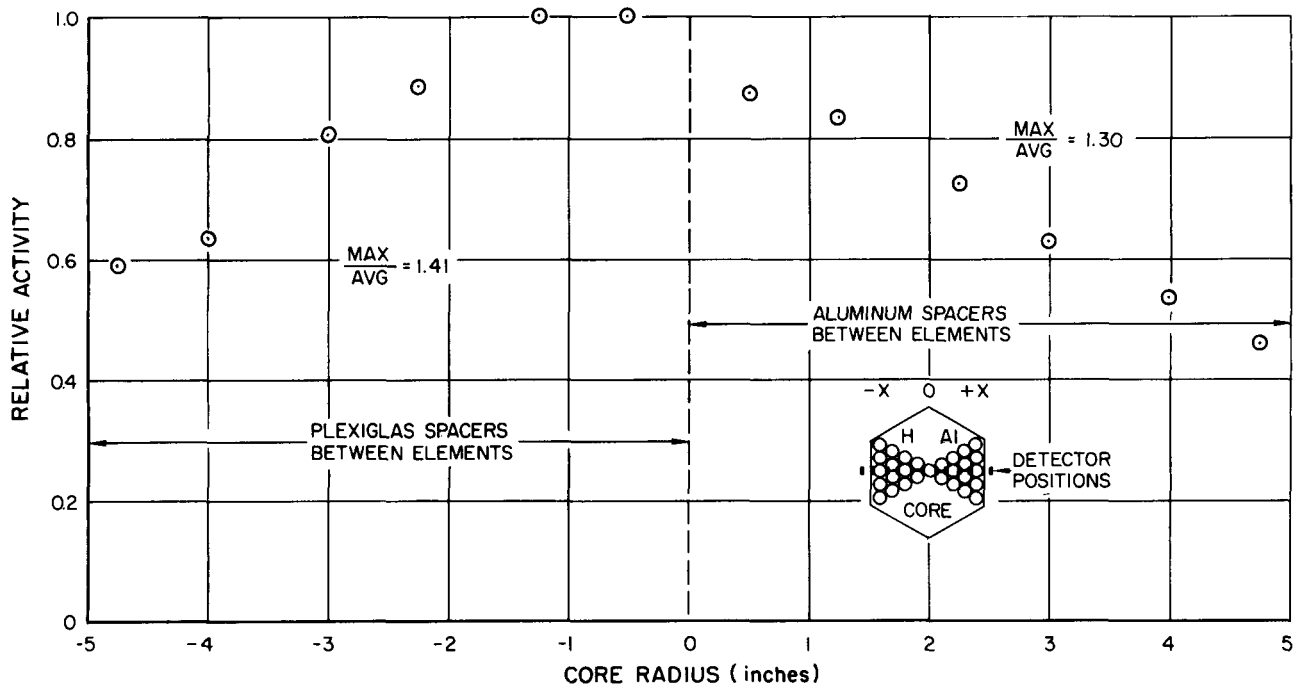
Figure 14. Flux Traverse in Hydrogen and Aluminum Loaded Core Regions

In order to demonstrate the effect of hydrogenous moderator on power distribution, two further traverses were run. A radial traverse was run across opposed hextants; in one, plexiglas strips were in the interstitial positions; in the other, aluminum strips were so located. The results, with a sketch of the arrangements, appear in Figure 14. In the hydrogenous region, the maximum to average power ratio is apparently 1.41; in the aluminum region it is 1.3.

A core circumferential traverse was made with one hextant plexiglas loaded and the remaining five, aluminum loaded. Results are shown in Figure 15. Figure 15-A displays the general experimental arrangement for the hydrogen loaded core.

G. REACTIVITY MAPPING EXTERNAL TO THE REFLECTOR

A cylindrical sample of nickel; length 1.54 in. and diameter 1.75 in., was centered in each of three transverse planes and used to map an external importance field. A rough sketch is inset in Figure 16. The system was put on supercritical period for each position of the sample, and the system reactivity was noted. That part of the reactivity, attributed to the presence of the nickel sample, is plotted in Figure 16.
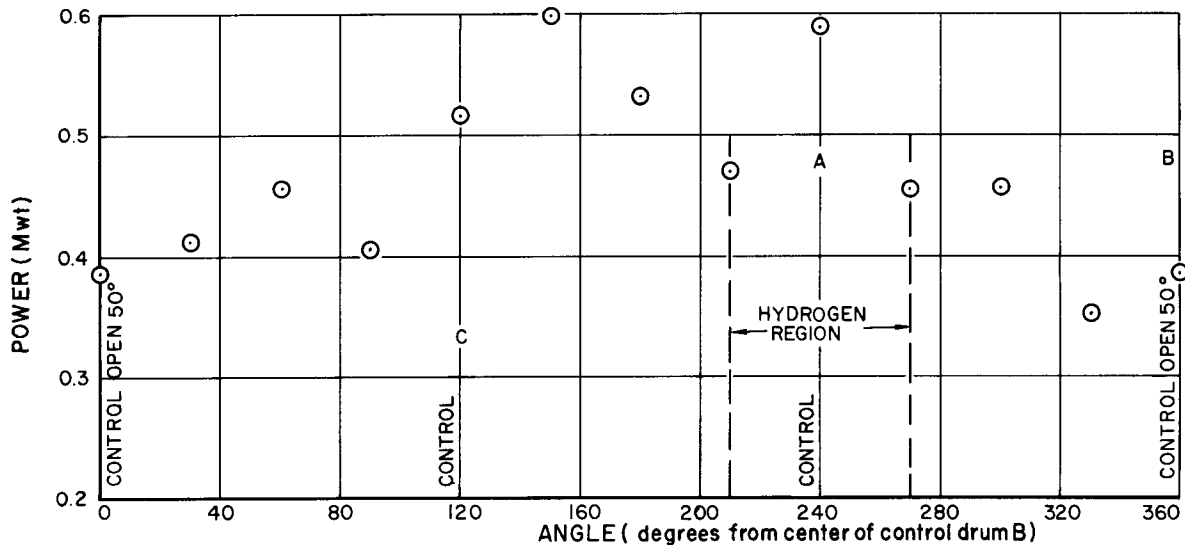
Figure 15a. Circumferential Flux Traverse with Partial Hydrogen Loading

Figure 16 may therefore be regarded as a nickel reactivity value curve outside the reflector. More strictly, since the sample was rather large, it is an average value of nickel over the volumes occupied by the sample.

Though the meaning of the curve in Figure 16 is quite specific, we may crudely assume that it is fairly typical of reflector materials. As such, the curve can be regarded as a reflector material importance weighting curve with no significance attached to its normalization. This assumption is well taken provided the reflector materials:

1) Scatter fairly isotropically in the laboratory system.

2) Do not significantly thermalize neutrons and are used in a system where reflection of thermal neutrons is not especially significant.

Though the beryllium reflectors in the SNAP system do not fully meet the second condition, the function mapped in Figure 16 has proved quite useful in evaluation of safety and drum traverses.
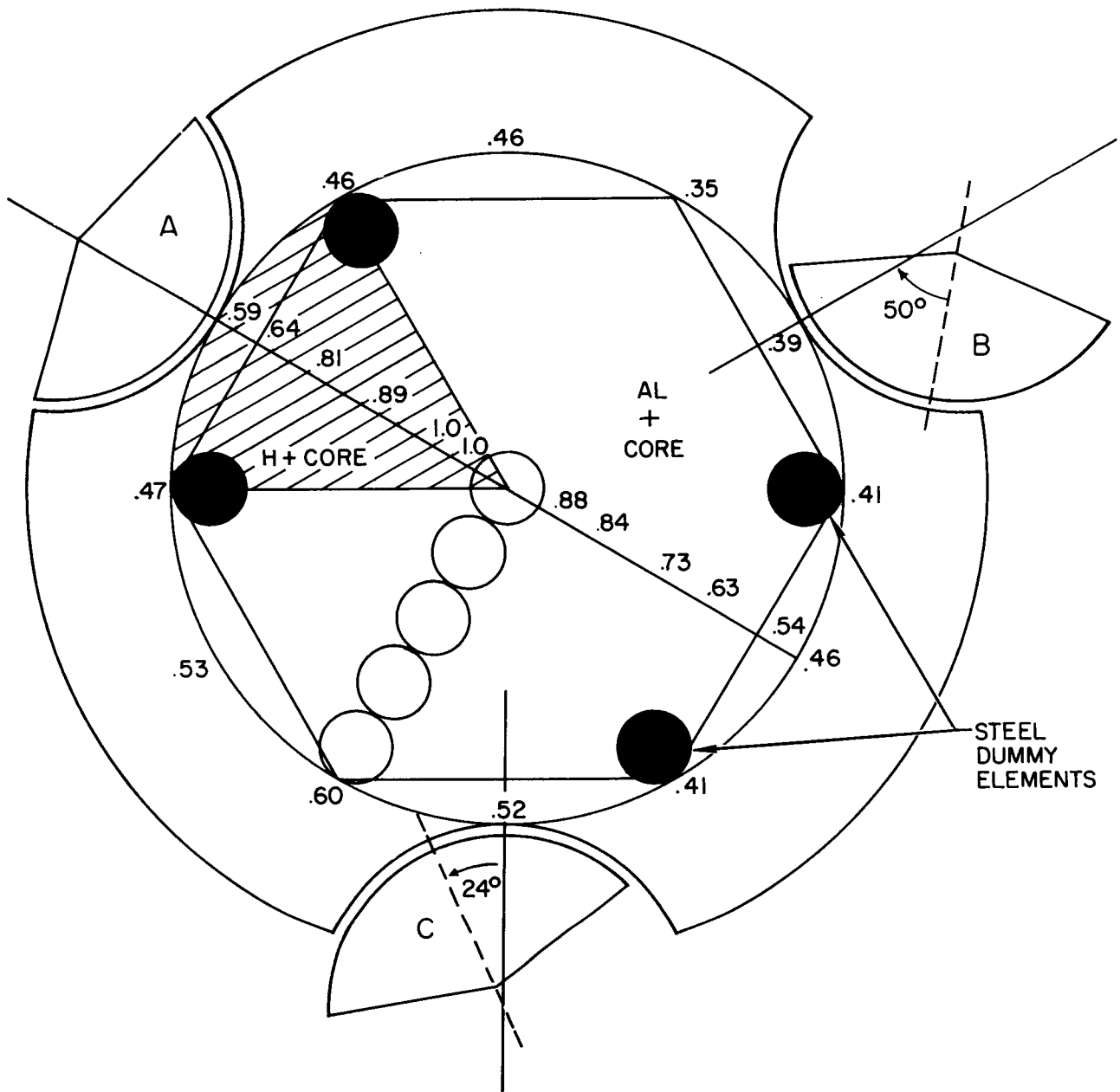
THE INSERTED NUMBERS ARE PROPORTIONAL TO THE FOIL ACTIVATIONS
MEASURED AT THOSE POINTS.

Figure 15b. Arrangement for Foil Activation in Hydrogen Loaded Core
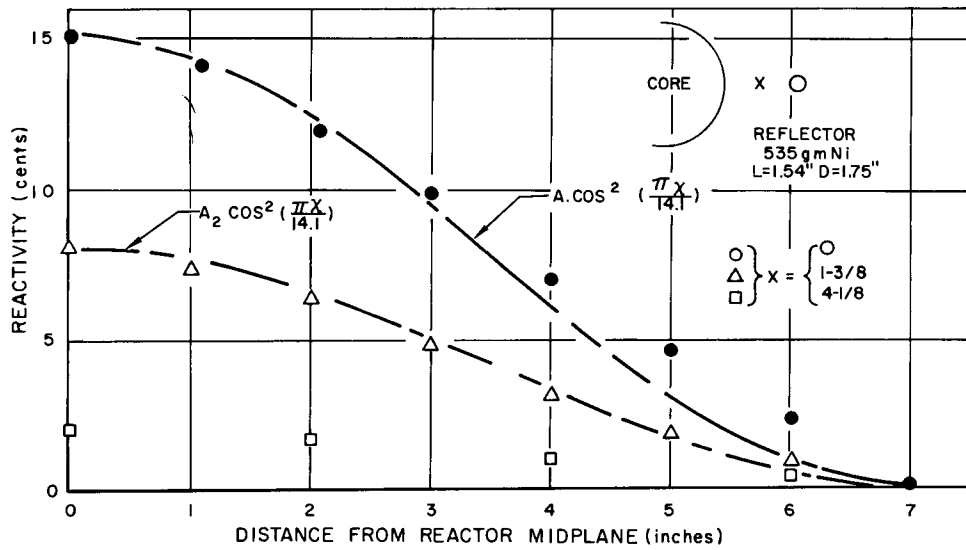
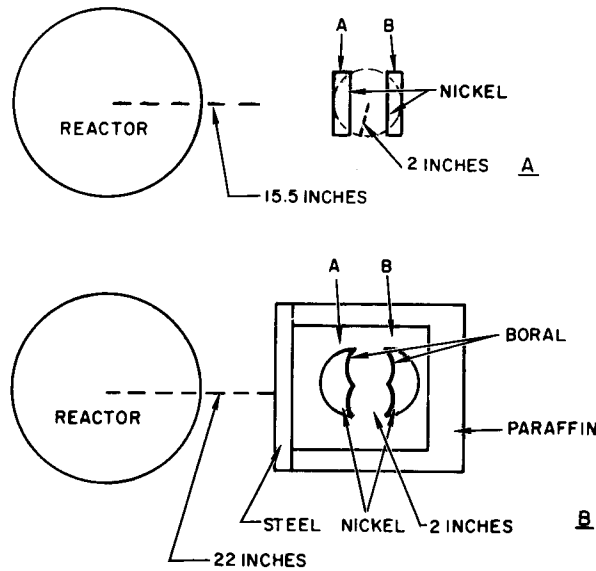Figure 16. Importance Mapping (Nickel Sample)

Figure 17a, b. Layout for External
Drum Rotation

H. FEASIBILITY OF PILE OSCILLATOR EXPERIMENT IN SER

Since useful information can be gleaned from oscillating a power reactor system, a measurement was performed to determine how conveniently the system could be oscillated. The SER at power is quite inflexible and it is convenient to be able to oscillate the system reactivity with a device external to the reflector. The purpose of the measurement, therefore, was to determine the swing in reactivity available from rotating a suitable device external to, and near the reflector.

The device chosen was a 400 gm nickel plate. Figure 17-A is a cross section sketch of the experimental arrangement. The system was approximately 0.8¢ more reactive with the nickel in position A than with it in position B.

In order to mock up the effects of steel and concrete barriers which would be present in the SER power operation, the experiment was redone in the geometry sketched in Figure 17-B. In this, the nickel sample was backed with boral, the whole enclosed in a paraffin box with 4 in. wall thickness, and the box separated from the reactor by a steel plate 3/8 in. thick. Again, the system reactivity with the sample in position A was approximately 0.8¢ greater than with the sample in position B.

Since the 0.8¢ reactivity swing is more than adequate for an oscillator experiment, and since the sample and situation were chosen to be representative of what might reasonably be achieved with an oscillator device, one can conclude that the SER at power can be conveniently and successfully oscillated.

Reactivity determinations in these measurements were made by the super-critical period method.

I. REACTIVITY WORTH OF MATERIAL DISTRIBUTED IN CORE

1. Aluminum

The triangular interstices among the fuel rods were filled with aluminum strips, in stages, from the center out. A reactivity determination was made, by supercritical technique, at each stage. After the core had been partially loaded with strips, the aluminum end plates were removed to prevent the system from exceeding the 28¢ limit on excess reactivity. Table II contains the results of the measurement. Each successive stage is loaded around, and radially outward, from its predecessor. Figure 2 defines the loading steps more precisely.

TABLE II

REACTIVITY WORTH OF ALUMINUM

Stage	No. of Strips	Reactivity Increase (¢) over preceding stage
1	10	8.1
2	12	9.2
3	10	7.9
4	15	11.5
5	13	9.8
6	24	17.5
7	12	8.6
Total All Strips	96	72.6

The strips were so shaped as to occupy 66% of the interstitial volume.

A comparison of scattering and absorption cross sections of 0.66 normal density aluminum on the one hand and NaK on the other yields

	Σ_s	Σ_a
Al (0.66 normal density)	0.056	0.0092
NaK	0.037	0.025

The differences between the two materials are such that the aluminum measurements can only very roughly approximate NaK, but can be expected to bound the NaK reactivity effects from above.

2. Plexiglas

Sixteen of the aluminum strips comprising a complete sextant of the reactor were replaced a few at a time by strips of plexiglas. Within machining errors, the strips were of identical shape and size as the aluminum ones. The reactivity worth of the plexiglas was measured supercritically to be 87.6¢. The purpose of this measurement was to estimate the reactivity worth of water in the interstices. We may make this estimate if we assume:

a) the ratio of the value of water to plexiglas is in the ratio of their hydrogen densities - 67/63,

b) the whole core loading value of plexiglas is six times the sextant loading.

The value of a full core plexiglas loading with respect to aluminum is then:

$$6 \times 87.6¢ = \$5.26.$$

With respect to a void it is

$$\$5.26 + 0.73 = \$5.99.$$

Adjusted by the volume factor of 66% and the hydrogen density ratio, the plexiglas value becomes an apparent water value of

$$\$5.99 \times \frac{67}{63} \times \frac{100}{66} = \$9.57.$$

3. Trichlorethylene

The reactor vessel was filled with trichlorethylene. Figure 20, which deals with a similar experiment on light and heavy water, indicates the extent to which the region around the core was flooded. With the core interstitial regions and the available void end regions filled with trichlorethylene, the system was so subcritical that no significant count rate was observable.

This measurement was performed to determine the nuclear suitability of trichlorethylene for flushing the SER coolant loop after operation with NaK.

4. Borated Water

The reactor vessel was filled, as in the trichlorethylene measurement, with borated water. This experiment was performed three times with different borations:

a) Saturated with H_3BO_3 or approximately 6 gms of boric acid per 100 milliliters. Since the solution of boric acid in water involves the evolution of heat, temperature change, and change in solubility, the precise boric acid concentration was not well known,

b) 4.59 gms H_3BO_3 per 100 milliliters of water

c) 4.0 gms H_3BO_3 per 100 milliliters of water.
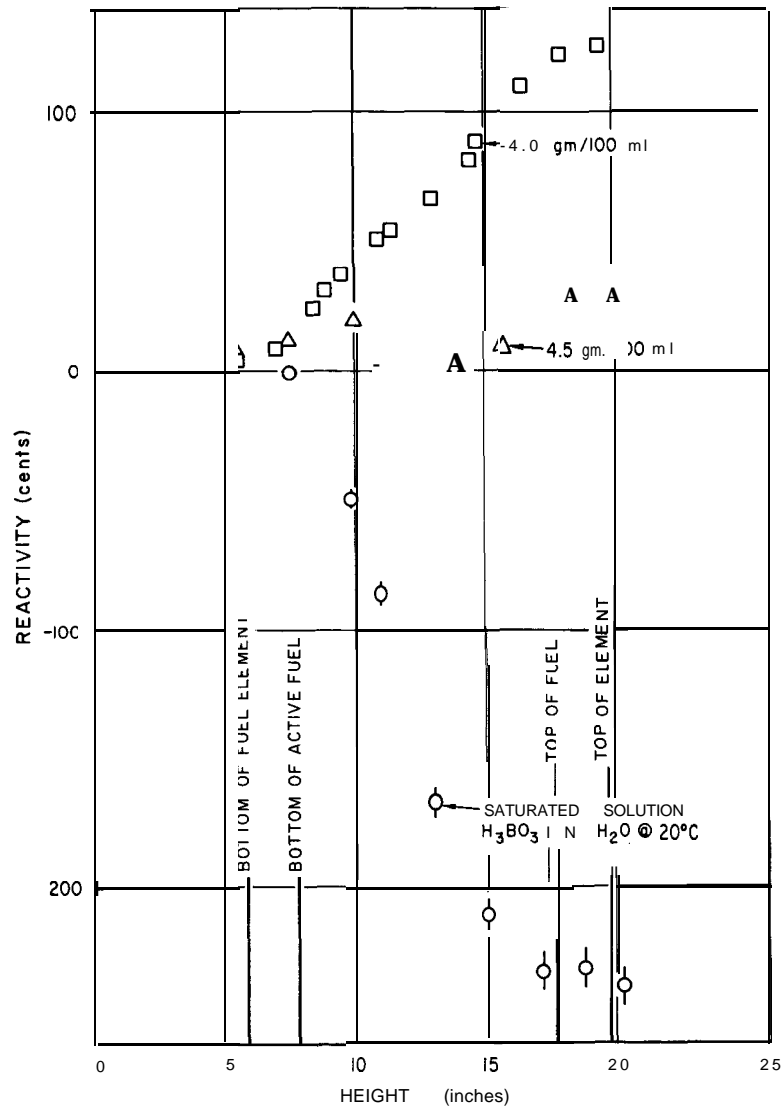
Figure 18. System Reactivity Changes vs Partial Loadings of Boric Acid Solutions
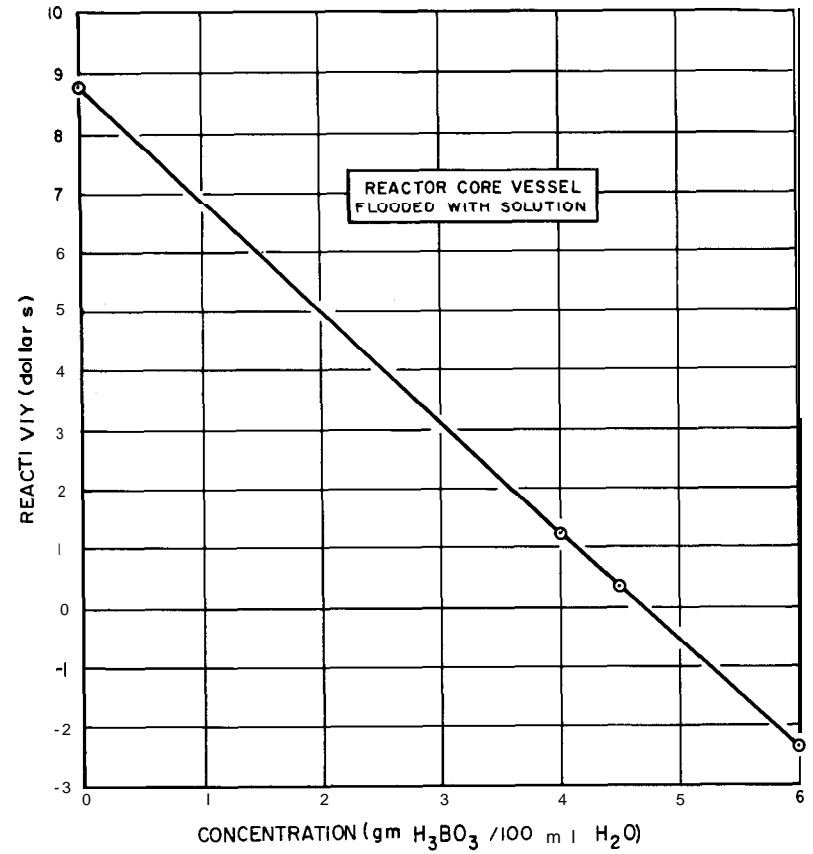
Figure 19. Reactivity of Water Flooded System with Various Amounts of Boric Acid Solute

The solutions were added to the vessel in 300 milliliter increments. Reactivity determinations were made at each stage of the loading. The techniques used were supercritical-period and subcritical-multiplication, dependent on the total reactivity available in the configuration. Results of these measurements are presented in Figure 18. In Figure 19 the results were replotted in terms of excess reactivity of the water flooded core for various boric acid concentrations.

5. Water

The plexiglas measurements provided sufficient information to establish a safe procedure for measuring the effects of water itself in the core.

Aluminum strips were placed in all interstices (occupying 66% of the interstitial volumes). The fixed control rods were set so that, with no water in the system and with the safeties and variable control drums all the way in, the system reactivity would be about 16¢. A water reservoir was located near, and at a greater height than, the reactor. This reservoir fed into the bottom of the core vessel and was emptied remotely from the control room. A strictly limited amount of water was placed in the reservoir at each stage. The amount of water in the reservoir was such that, by best estimate, all of it added to the system would lead to a system reactivity no greater than 28¢ above critical.

The first water loading was to a depth 3-7/8 in. above the bottom of the vessel - about 4 in. from the fueled region. The supercritically determined value was about 2¢. A fixed drum was then moved to a new position to compensate for the reactivity increment, a supercritical period run was made to determine the effect of this drum movement, and the second water loading was made. This procedure was continued until the water level had penetrated the fueled region by about 1.2 in. Thereafter, loadings were made with the fixed control drums set in positions to maintain the system well subcritical. At each water increment, an observation was made of count rate to make a subcritical estimate of system reactivity. The system was so far subcritical, however, that the estimates were very rough and had real value as a safety gauge only; no data value per se. With the system filled with water, controls were adjusted to bring the system to the neighborhood of critical. One aluminum strip was removed, the volume it occupied allowed to fill with water, and a supercritical determination of reactivity value of the water replacement in this location, which was central, was found to be 8.6¢. A total of 16 aluminum strips in one hextant were so replaced in stages
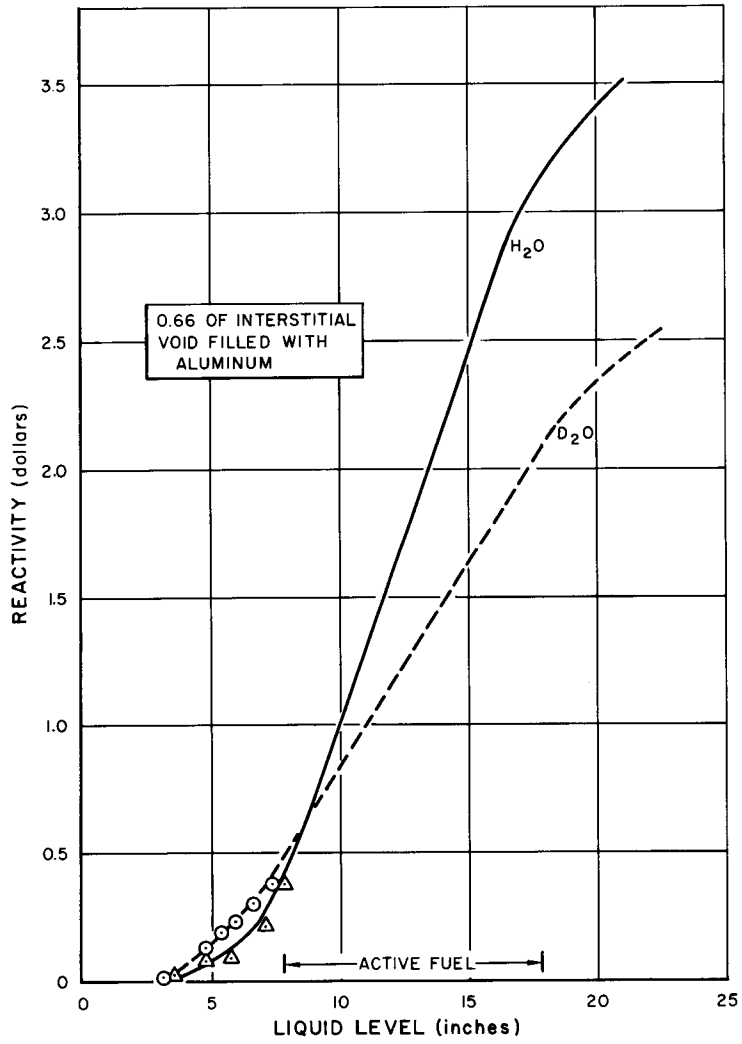
Figure 20. System Reactivity vs Height of Water
(Heavy Water)

and the reactivity value of the change found to be 85¢. If this value is scaled by a factor of 6 to determine the effect of replacement of all the aluminum in the core, we find the water is worth $5.10 more than the aluminum. Since the aluminum has already been measured as $0.73, the apparent value of this amount of water with respect to a void is $5.83. This accounts for the value of water in 66% of the core interstitial volume. Scaled up by the factor 1/0.66 the apparent value of water in the entire interstitial volume is $8.75 which is in reasonably good agreement with the $9.57 value imputed from plexiglas measurements. The value of the water in the tank to the bottom surface of the fuel is measured as 33¢. If we associate the same value with the water above the fuel, then complete flooding of the tank with water, we are led to an apparent reactivity increase of $9.41; Figure 20 displays these results.

6. Heavy Water

Heavy water was measured in a manner similar to light water (above). The results are shown in Figure 20.

J. NOISE MEASUREMENTS

With the system maintained at criticality, observations were made of fluctuations in the neutron level. This noise, suitably analyzed as to frequency distribution, permitted an evaluation of the quantity β/ℓ (delayed neutron fraction importance divided by prompt neutron lifetime).

In this determination it was found that

$$\beta/\ell = 74.6 \text{ sec}^{-1}$$

or, with β taken as 0.0085,

$$\ell = 11.4 \times 10^{-6} \text{ seconds.}$$

A description of the noise analysis is reserved for another report.[3]

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