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CRITICAL STUDIES OF A DILUTE FAST REACTOR CORE
(ZPR-III Assembly 31)

by

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TABLE OF CONTENTS

	<u>Page</u>
ABSTRACT	5
I. INTRODUCTION.	5
II. DESCRIPTION OF ASSEMBLY 31	6
A. The ZPR-III Facility	6
B. The Unit Cell of Assembly 31	7
III. THE CRITICAL EXPERIMENT	9
A. Estimate of the Critical Mass	9
B. Approach to Critical	10
C. Comparison of the Calculated and Experimental Values of the Critical Mass	12
D. Control Rod Calibration	13
E. Worth of Edge Core Material.	14
IV. CENTRAL FISSION RATIOS	15
V. CENTRAL REACTIVITY COEFFICIENTS	16
VI. RADIAL WORTH EXPERIMENTS	18
VII. PROMPT NEUTRON LIFETIME	23
VIII. DISCUSSION	23
ACKNOWLEDGMENTS	24
REFERENCES	25

LIST OF FIGURES

<u>No.</u>	<u>Title</u>	<u>Page</u>
1	The ZPR-III Critical Facility	6
2	Loading Master - Core Drawer Type 1	7
3	Loading Master - Core Drawer Type 2	8
4	Loading Master - Core Drawer Type 3	8
5	Loading Master - Core Drawer Type 4	8
6	Front View of the Unit Cell	9
7	Inverse Subcritical Count Rate vs Total Mass of U^{235}	11
8	Outline of the Critical Core - Half #1	11
9	The Inhour Curve	14
10	The Control Rod Calibration Curve	14
11	Outline of the Radial Substitutions of Aluminum and Aluminum Oxide	19
12	Outline of the Sodium Substitutions in Regions I and II	20
13	Outline of the Sodium Substitution in Region III	20
14	Typical Sodium Substitution Drawer Loading Master - Core Drawer Type 1H	21
15	Typical Ambient Sodium Drawer Loading Master - Core Drawer Type 1J	21

LIST OF TABLES

No.	Title	Page
I	VOLUME PER CENT FRACTIONS OF ASSEMBLY 31	9
II	DISTRIBUTED ALUMINUM FOR ALUMINUM OXIDE SUBSTITUTIONS IN A ONE-SIXTEENTH SEGMENT OF ASSEMBLY 30	10
III	PARAMETERS OF THE CRITICAL CORE (Assembly 31).	12
IV	COMPARISON OF THE CALCULATED AND EXPERIMENTAL CRITICAL MASS (Assembly 31)	13
V	THE CALCULATED CENTRAL NEUTRON SPECTRA (Assembly 31)	15
VI	COMPARISON OF CALCULATED AND EXPERIMENTAL CENTRAL FISSION RATIOS (Assembly 31).	16
VII	CENTRAL REACTIVITY COEFFICIENTS OF FISSIONABLE MATERIALS (Assembly 31)	17
VIII	CENTRAL REACTIVITY COEFFICIENTS OF NONFISSIONABLE MATERIALS (Assembly 31)	18
IX	TOTAL MASS CHANGES IN THE REFERENCE LOADINGS FOR THE SODIUM SUBSTITUTIONS EXPERIMENTS (Assembly 31)	22
X	RADIAL SUBSTITUTION REACTIVITY WORTHS (Assembly 31)	22
XI	COMPARISON OF CALCULATED AND EXPERIMENTAL CRITICAL PROPERTIES OF ASSEMBLIES 29, 30, AND 31 . . .	23

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ABSTRACT

Critical studies were performed on a dilute, metallic, fast reactor core. The fuel was 38.6% enriched uranium and reduced-density aluminum was used to simulate sodium coolant. The measured critical mass was 463 kg of U^{235} in a 425-liter core. The main part of the experimental program consisted of measurements of the standard fission ratios, a number of central reactivity coefficients, and the prompt neutron lifetime. An additional series of experiments was performed to obtain the worths of aluminum, aluminum oxide, and sodium at various radial positions in the core.

I. INTRODUCTION

Assembly 31 was the last of a series of three cores designed to study the properties of dilute oxide reactors. Assembly 29, the first oxide core simulated in the ZPR-III, was a dilute, engineering-proportioned, UO_2 core. The calculated critical mass was 25 to 40% lower than the experimental value, depending on the cross-section set used in the calculations and the assumptions made as to heterogeneity and shape factor.⁽¹⁾ This large discrepancy prompted the construction of Assemblies 30 and 31 to investigate further the effects of large percentages of oxygen in dilute fast cores.

The material compositions of all three cores were similar and typical of dilute, fast power reactors. The principal difference between the three cores was the reduction of the oxygen content of Assemblies 30 and 31 to 50% and 0%, respectively, of that of Assembly 29. Thus, the primary function of Assembly 31 was to serve as a reference core of zero oxygen content for comparison with Assemblies 29 and 30 to determine whether the discrepancy was due principally to errors in the oxygen data, or to general errors in the cross-section data.

The experiments on Assembly 31 took place from January 3 to February 2, 1961.

II. DESCRIPTION OF ASSEMBLY 31

A. The ZPR-III Facility

The ZPR-III assembly is a machine which is divided into two halves, one fixed and the other movable. The principal feature of each half is a matrix consisting of a 31×31 array of stainless steel tubes, each 2.177 in. square and 33.5 in. in depth. The neutron and gamma detectors which drive the reactor instrumentation are located on the top of each matrix, and five control rods enter each matrix from the rear. Figure 1 is a photograph of the machine. A complete description of the ZPR-III Facility has been given by Cerutti *et al.*⁽²⁾

Fig. 1. The ZPR-III Critical Facility

Reactor cores are simulated in the ZPR-III by loading drawers, containing core and blanket materials, into both matrices. Each core drawer is loaded with $\frac{1}{8}$ -in.-thick columns of various materials in the

desired proportions, to a length of half the core. Then, the core drawers are inserted into the matrices in a repetitive pattern called the unit cell. Each matrix contains half the core, usually in the form of half of a horizontal cylinder, and the two halves are brought together to form the complete core assembly.

B. The Unit Cell of Assembly 31

To facilitate the comparison of results, the unit cell of Assembly 31 was copied directly from Assembly 30. The only change was the substitution of two columns of 45%-density aluminum and one column of 63%-density aluminum for the three columns of aluminum oxide per drawer in Assembly 30.⁽³⁾ This substitution effected an almost exact replacement of the aluminum in the oxide. The only change was the elimination of the oxygen contained in Assembly 30.

The unit cell consisted of five columns of enriched uranium and seven columns of depleted uranium uniformly distributed across a horizontal sequence of four drawers. Thus, the fuel plates were located in a different position in each drawer and one drawer contained two columns of fuel. Because of this uneven distribution of the fuel plates, the drawers were loaded into the matrix so that any given column of the matrix always contained the same type of drawer. Thus, the columns of fuel within the drawers lined up to form large columns of fuel throughout the matrix. This is the usual arrangement of the fuel plates in ZPR-III assemblies.

The other core materials in the unit cell were the same for each drawer and consisted of 3 columns of stainless steel, 9 columns of 45%-density aluminum, and 1 column of 63%-density aluminum. The arrangement of the materials in the four-drawer sequence is shown in Figs. 2-5, the front view of the unit cell in Fig. 6, and the volume fractions are given in Table I.

Fig. 2. Loading Master - Core Drawer Type 1

Fig. 3. Loading Master - Core Drawer Type 2

Fig. 4. Loading Master - Core Drawer Type 3

Fig. 5. Loading Master - Core Drawer Type 4

Fig. 6. Front View of the Unit Cell

Table I

VOLUME PER CENT FRACTIONS OF ASSEMBLY 31

Material	Assumed Density, gm/cm ³	Volume Per Cent	
		Core (Unit Cell)	Blanket
U ²³⁵	18.75	5.812	0.19
U ²³⁸	19.0	9.139	83.30
Stainless Steel	7.85	24.47	7.31
Aluminum	2.7	23.33	-

III. THE CRITICAL EXPERIMENT

A. Estimate of the Critical Mass

The critical mass of Assembly 31 was estimated directly from distributed aluminum for aluminum oxide substitution experiments in Assembly 30.⁽³⁾ In these experiments, first 100%-density aluminum and then 45%-density aluminum was substituted for all of the aluminum oxide in a one-eighth wedge of half the core. The results are shown in Table II.

Thus, the substitution of 2 columns of 45%-density aluminum and 1 column of 63%-density aluminum for all the oxide in the wedge-shaped region is worth

$$-48.7 \text{ Ih} - (36.8 \text{ Ih}) \left(\frac{100 - 51}{100 - 45} \right) = -81.5 \text{ Ih} \quad .$$

Then, the worth of the above substitution for the entire core is

$$\frac{395 \text{ kg}}{24.75 \text{ kg}} (-81.5 \text{ Ih}) = -1,300 \text{ Ih} \quad .$$

The additional mass of U^{235} needed at the edge of the core to compensate for the substitution is

$$\frac{(+1,300 \text{ Ih})}{20.0 \text{ Ih/kg}} = 64.9 \text{ kg} \quad .$$

Hence, the estimated critical mass of Assembly 31 is $395 + 65 = 460 \text{ kg } \text{U}^{235}$.

Table II

DISTRIBUTED ALUMINUM FOR ALUMINUM OXIDE
SUBSTITUTIONS IN A ONE-SIXTEENTH SEGMENT
OF ASSEMBLY 30

Substitution	Worth
9.524 kg 100% Al for 9.183 kg Al_2O_3	-48.7 Ih
4.222 kg 45% Al for 9.524 kg 100% Al	-36.8 Ih
where	
Experimental critical mass	= ~395 kg
Mass of U^{235} in region of substitution	= 24.75 kg
Worth of edge core material	= 20.0 Ih/kg U^{235}

B. Approach to Critical

The inventory of $\frac{1}{8} \times 2 \times 2$ -in. U^{235} and $\frac{1}{8}$ -in. stainless steel pieces was insufficient to build the core to the estimated critical size. A number of core drawers were loaded with 2×13 -in. stainless steel pieces (machined from available $\frac{1}{8}$ -in. stock) and one 1-in. and four 3-in.-long pieces of U^{235} . The mass in these drawers was greater by ~10% for the stainless steel, and 0.5% to 1.65% for the U^{235} ; they were therefore distributed throughout the core to average the effects due to the greater masses. The higher-mass drawers in half No. 1 are marked "A" in Fig. 8.

With sufficient materials available, Assembly 31 was constructed while Assembly 30 was still loaded in the ZPR-III. First, a number of edge core drawers were removed to reduce the mass of U^{235} to ~355 kg for the first loading. Then, each of the remaining core drawers was removed for the substitution of the aluminum for the aluminum oxide, as previously noted, and was reinserted into the same position in the matrix. The normal core drawers in the designated locations were converted to higher-mass drawers at this time.

Then, the approach to critical was performed in the usual manner of adding drawers at the radial edge of the core. The graph of the approach to critical is shown in Fig. 7, and the cross-sectional outline of half No. 1 for the just-critical core is shown in Fig. 8.

Fig. 7
Inverse Subcritical Count Rate
Versus Total Mass of U²³⁵.

Fig. 8. Outline of the Critical Core Half No. 1.

C. Comparison of the Calculated and Experimental Values of the Critical Mass

1. The Experimental Critical Mass

Assembly 31 went critical with a total loading of 463.1 kg U^{235} and control rod No. 10 withdrawn 0.415 in. Using the rod calibration and the worth of an edge core drawer (see Sections D and E), the reactor was 2.2 lh or 0.12 kg U^{235} supercritical. Hence, the corrected experimental value of the critical mass is 463.0 kg. This is in good agreement with the value of 460 kg estimated from the substitution experiments in Assembly 30. Various parameters of the just-critical core are shown below in Table III.

Table III

PARAMETERS OF THE CRITICAL CORE (Assembly 31)

Material	Total Mass (kg)	Assumed Density, gm/cm ³	Volume Fractions	
			Unit Cell	Critical Core
U^{235}	463.1	18.75	0.05812	0.0581
U^{238}	738.4	19.00	0.09139	0.0914
Stainless Steel	818.4	7.85	0.2447	0.2453
Aluminum	269.6	2.70	0.2333	0.2349
Core Dimensions:				
Height	66.2 cm			
Radius	45.2 cm			
Volume	425.0 liters			
Axial Blanket	33.0 cm			
Radial Blanket	27.5 cm			

The differences between the volume fractions of the just-critical core and the unit cell, shown here for comparison, are caused by the "high-mass" drawers and the unequal utilization of each of the four drawers in the unit cell.

2. The Calculated Critical Mass

The critical mass was calculated for a homogeneous sphere using the 11-group cross-section set 58,⁽⁴⁾ the SNG code⁽⁵⁾ in the S4 approximation, and the volume fractions of the unit cell. After criticality had been attained, a second calculation was performed with the 16-group cross-section set of Yiftah, Okrent, and Moldauer,^{(6)*} and the DSN code⁽⁷⁾

*Hereafter referred to as the "YOM" cross-section set.

in the S8 approximation to determine a calculated "k" value for the just-critical core. Extrapolation back to criticality indicates a calculated critical mass ~1 kg lower than provided by the SNG calculation. The differences between the volume fractions of the unit cell and the critical core are small enough to have little effect on the calculation.

For the heterogeneity correction, previous calculations for typical ZPR-III cores indicated a correction of about 5% in mass with only small variations. Since Assembly 31 was so similar to Assembly 30 in size, composition, and material arrangement, the heterogeneity correction factor was taken as -5.7%, the experimental value determined in Assembly 30.⁽³⁾ There were no bunching experiments in Assembly 31 to determine an experimental value, and there was no apparent need to calculate a theoretical value.

The conversion from a sphere to a cylinder was taken from a method utilized by Loewenstein and Okrent.⁽⁸⁾ The calculated and corrected calculated values of critical mass are shown in Table IV.

Table IV

COMPARISON OF THE CALCULATED AND
EXPERIMENTAL CRITICAL MASS
(Assembly 31)

Conditions of the Calculation	Calculated Value	Experimental Value
Homogeneous Sphere	370	-
Corrected for Heterogeneity and Cylinder with $L/D = 0.95$	364.6	-
Corrected to $L/D = 0.73$ (Value of the critical core)	376.4	463.0

D. Control Rod Calibration

The control rod was calibrated in the usual manner of determining the period corresponding to an incremental change in the rod position. Core drawers were added at the radial edge to allow calibration over the central and outer portions of rod travel.

Values of period were converted to inhours by means of the inhour curve of Fig. 9. The values of $\beta_i/\beta_{\text{eff}}$ and the total value, $\beta_{\text{eff}} = 0.0073$, were estimated from the data of Keepin *et al.*,⁽⁹⁾ by assuming that 10% of the fissions occurred in the U^{238} . The inhour curve was calculated for a prompt neutron lifetime of 8×10^{-8} sec. For the period range of the rod calibration measurements ($T > 60$ sec), the inhour curve is highly dependent

on the values of $\beta_i/\beta_{\text{eff}}$ and varies slowly with changes in the lifetime. Hence, there was no need to recalculate the inhour curve for the measured value of the prompt neutron lifetime. The results of the rod calibration are shown in Fig. 10.

Fig. 9. The Inhour Curve

Fig. 10. The Control Rod Calibration Curve

E. Worth of Edge Core Material

The worth of the edge core material is often expressed in terms of a factor defined by

$$\frac{\Delta k}{k} = q \frac{\Delta M}{M} ,$$

where $\Delta k/k$ is the reactivity change associated with an incremental change ΔM in the mass of U^{235} . This factor was calculated by performing an additional SNG problem to determine k for a core with a slightly higher mass. The resulting values of Δk and ΔM , 0.00585 and 10.37 kg, respectively, yielded a value for q of 0.21.

Experimentally, three core drawers (2.688 kg U^{235}) added at the radial edge were worth 47.5 lh. Thus, the worth of edge core material is 15.8 lh/drawer or 17.7 lh/kg U^{235} , and $q = 0.18$. The experimental and calculated values of "q" are in reasonable agreement, considering the discrepancy between the calculated and experimental values of critical mass.

IV. CENTRAL FISSION RATIOS

The central fission ratios were calculated from the central neutron spectra of the SNG and DSN calculations (see Section III-C). The central neutron spectra are given in Table V for reference.

Table V

THE CALCULATED CENTRAL NEUTRON SPECTRA (Assembly 31)

Set 58, SNG - S4			YOM Set, DSN - S8		
Energy Group	Lower Energy Limit (Mev)	Normalized Flux	Energy Group	Lower Energy Limit (Mev)	Normalized Flux
			1	3.668	0.021
1	2.25	0.058	2	2.225	0.044
2	1.35	0.076	3	1.35	0.078
3	0.825	0.113	4	0.825	0.123
4	0.500	0.157	5	0.500	0.180
5	0.300	0.164	6	0.300	0.167
6	0.180	0.130	7	0.180	0.136
7	0.110	0.097	8	0.110	0.093
8	0.067	0.086	9	0.067	0.061
			10	0.0407	0.055
9	0.025	0.075	11	0.025	0.016
			12	0.015	0.018
10	0.0091	0.037	13	0.0091	0.005
			14	0.0055	0.001
			15	0.0021	0.000
11	0	0.007	16	0.0005	0.000

The experimental fission ratios were determined from absolute fission counters⁽¹⁰⁾ (2 in. in dia. x 1 in. long) loaded into the first inch of the central drawer in each half. The same U^{235} fission counter was

maintained in one half, while counters containing various fissionable materials were alternately loaded into the other half. The measurements were made at power levels of 0.5 to 10 w, and the data were reported as the ratio of the total counts of any given counter to the standard U^{235} counter. The data were then reduced by a set of simultaneous linear equations involving the isotopic concentrations of the counters. Experimental central fission ratios are compared with calculated values in Table VI.

Table VI
COMPARISON OF CALCULATED AND EXPERIMENTAL
CENTRAL FISSION RATIOS
(Assembly 31)

Fissionable Isotope (i)	Calculated Fission Ratio (σ_{fi}/σ_{f25})		Experimental Fission Ratio ^(b) (σ_{fi}/σ_{f25})
	YOM Set ^(a)	Set 58	
U^{233}	1.56	1.50	$1.52 \pm 1.4\%$
U^{234}	0.391	0.339	$0.334 \pm 1.3\%$
U^{236}	0.134	0.106	$0.112 \pm 1.6\%$
U^{238}	0.0504	0.0445	$0.044 \pm 1.5\%$
Pu^{239}	1.22	1.17	$1.18 \pm 0.9\%$
Pu^{240}	0.389	0.324	$0.313 \pm 1.2\%$

(a) The YOM set was supplemented by values taken from BNL-325 for U^{234} and U^{236} .

(b) The limits quoted with the experimental fission ratios represent 90% statistical confidence in the ratio of the total counts of the associated fission counters. These limits do not contain the uncertainties in the isotopic concentrations of the fission counters.

V. CENTRAL REACTIVITY COEFFICIENTS

The central reactivity measurements in ZPR-III normally fall into two groups, one of small-volume (2 in.³) fissionable materials, and the other of larger-volume (8 in.³) nonfissile materials. Larger samples are required for the nonfissile materials due to their generally low worths in fast cores.

The fissionable samples were loaded across the first $\frac{1}{4}$ in. of the central drawer in each half of the core. The reference was run with two $\frac{1}{8}$ x 2 x 2-in. plates of aluminum loaded across the front of each

central drawer, one of 63% density and the other of 45% density. The enriched uranium sample in each central drawer consisted of one $\frac{1}{8}$ x 2 x 2-in. plate sandwiched between two $\frac{1}{16}$ x 2 x 2-in. plates of 100%-density aluminum. This sandwich contained almost the same total mass of aluminum used in the reference run. The Pu^{239} and U^{233} samples were contained in $\frac{1}{4}$ x 2 x 2-in. aluminum cans. Again, the total mass of the aluminum cans was almost equal to the mass of the aluminum used in the reference. The measured values are shown in Table VII.

Table VII

CENTRAL REACTIVITY COEFFICIENTS OF
FISSIONABLE MATERIALS
(Assembly 31)

Material	Sample Mass (kg)	Sample Worth (Ih $\pm$ 0.5)	Reactivity Coefficient	
			(Ih/kg)	(Ih/g-mole)
Enriched U(93.1%)	0.2878	29.0	102 $\pm$ 1.7	-
Depleted U(99.8%)	2.46	-6.3	-2.6 $\pm$ 0.2	-
U^{233} Mixture(a)	0.2266	44.0	194 $\pm$ 2.2	-
Pu^{239} Mixture(b)	0.1860	34.0	183 $\pm$ 1.9	-
<u>Isotopic Values</u>				
U^{235}			109 $\pm$ 1.9	25.6 $\pm$ 0.5
U^{238}			-2.8 $\pm$ 0.2	-0.67 $\pm$ 0.05
U^{233} (a)			198 $\pm$ 2.3	46.2 $\pm$ 0.5
Pu^{239} (b)			192 $\pm$ 2.8	46.0 $\pm$ 0.5

(a) The isotopic concentrations are 97.40% U^{233} and 2.60% U^{238} . The isotopic value was calculated assuming that all of the reactivity worth was due to the U^{233} .

(b) The isotopic concentrations are 94.51% Pu^{239} , 5.11% Pu^{240} , and 0.38% Pu^{241} . The isotopic value was calculated assuming the Pu^{240} has $\frac{1}{5}$ the worth of Pu^{239} .

The nonfissile samples were loaded into the first inch of the central drawer in each half. The reference was run with the sample volume void, and all of the values reported are relative to void. A large volume sample of depleted uranium was included in this series of measurements due to the large uncertainty in the worth of a small sample.

The reactivity measurements were determined from the difference in the critical position of the control rod for the sample and reference runs. In ZPR-III, the control rods must be removed and the halves of the reactor

must be pulled apart to insert the sample. Reproducibility in the control rod position is better than ± 0.005 in., whereas the uncertainty in closure of the halves is ± 0.5 lh. The stated uncertainties in the reactivity coefficients are based on the above value. The results are shown in Table VIII.

Table VIII
CENTRAL REACTIVITY COEFFICIENTS OF
NONFISSILE MATERIALS
(Assembly 31)

Material	Sample Mass (kg)	Sample Worth (lh $\pm$ 0.5)	Reactivity Coefficient	
			(lh/kg)	(lh/g-mole)
Al	0.3506	0.54	1.5 ± 1.4	0.041 ± 0.038
Al(a)	1.909	1.7	0.9 ± 0.5	0.024 ± 0.014
Al ₂ O ₃	0.355	3.5	9.9 ± 1.4	1.01 ± 0.14
Al ₂ O ₃ (a)	3.263	28.7	8.8 ± 0.3	0.90 ± 0.03
SS (Type 304)	1.019	-1.4	-1.4 ± 0.5	-0.08 ± 0.03
Fe	1.028	-1.6	-1.6 ± 0.5	-0.09 ± 0.03
C	0.1964	6.9	35 ± 2.5	0.42 ± 0.03
Na(b)	0.0912	1.2	13 ± 5.5	0.30 ± 0.13
Ph I(b)	0.232	-1.6	-6.9 ± 2.2	-0.98 ± 0.31
Ph II(b)	0.210	-1.2	-5.7 ± 2.4	-0.78 ± 0.33
O(c)			17.8 ± 1.2	0.28 ± 0.02

(a) These values are taken from the substitutions described in Section VI.

(b) These samples are canned in stainless steel. The sample mass is that of the named material only. The sample worth has been corrected for the effect of the stainless steel, and the reactivity coefficient is for the named material only. The Ph I and Ph II are mixtures of fission product metals and oxides with average compositions of $\text{Ph}_{0.6585}\text{O}$ and $\text{Ph}_{0.8724}\text{O}$, and average metal ion atomic weights of 117.9 and 117.8, respectively. The samples are completely described by Long *et al.*⁽¹¹⁾

(c) This value was calculated from the large mass substitutions (a) as being more reliable.

VI. RADIAL WORTH EXPERIMENTS

Measurements were made of the reactivity worths of aluminum, aluminum oxide, and sodium at various radial positions in the axial mid-plane of the core. Substitutions were made in the first 2 in. of each drawer

in both reactor halves at the core center, along an arc at an intermediate position, and along the edge of the core. The cross-sectional outline of the aluminum and aluminum oxide substitutions in half No. 1 are shown in Fig. 11. The simultaneous substitutions in half No. 2 were made in the mirror image.

Fig. 11. Outline of the Radial Substitutions of Aluminum and Aluminum Oxide

In the aluminum substitutions, all of the 45%-density aluminum in each substitution volume was replaced with 100%-density aluminum individually for each radial position. Similarly, all of the 45%-density aluminum was replaced with aluminum oxide for the measurements in Regions I and III. However, aluminum oxide was substituted for only one-third of the 45%-density aluminum in Region II.

Sodium-filled stainless steel cans were substituted in the same three regions for the sodium measurements. In addition, the aluminum in the volume immediately surrounding each sodium substitution was also replaced with sodium to provide an effective sodium environment (see Figs. 12 and 13).

Fig. 12
Outline of the Sodium
Substitutions in Regions I
and II

Fig. 13
Outline of the Sodium
Substitution in Region III

For the reference runs, the substitution drawers were loaded with six empty, $\frac{1}{4}$ -in.-thick by 2-in.-long stainless steel cans backed up by six 4-in.-long sodium-filled cans (see Fig. 14).

Fig. 14. Typical Sodium Substitution Drawer
Loading Master - Core Drawer
Type 1H

The first 6 in. also contained one column of stainless steel and the normal content of enriched and depleted uranium. The first 7 in. of the ambient drawers were loaded with six $\frac{1}{4}$ -in.-thick by 7-in.-long sodium-filled cans. A typical ambient drawer loading is shown in Fig. 15. The total mass changes involved in the reference loadings are given in Table IX for the entire substitution and ambient volumes.

Fig. 15. Typical Ambient Sodium Drawer Loading
Master - Core Drawer Type 1J

The reactivity worths of sodium were then measured by replacing the empty 2-in. stainless steel cans with sodium-filled cans throughout each substitution volume. The results of all of the substitutions are given in Table X. As described in the preceding section, opening and closing the reactor halves introduces an uncertainty of ± 0.5 lh in reactivity measurements. In addition, the removal of core drawers with subsequent changes in the drawer loadings introduces additional uncertainties. The uncertainty involved in removing a single core drawer for changes not involving fissionable materials is estimated as ± 0.1 lh. Since a large number of drawers were changed in each substitution, it seems reasonable to estimate a total uncertainty of ± 1 lh for each reactivity measurement with respect to the reference run. The stated uncertainties in the reactivity coefficients are based on this value.

Table IX

TOTAL MASS CHANGES IN THE REFERENCE LOADINGS FOR THE
SODIUM SUBSTITUTIONS EXPERIMENTS
(Assembly 31)

	Mass Change (kg)		
	Aluminum	Stainless Steel	Sodium
<u>Region I</u>			
Substitution drawers	- 5.312	-0.450	+ 2.640
Ambient drawers	-10.976	-1.494	+ 8.026
<u>Region II</u>			
Substitution drawers	- 4.721	-0.409	+ 2.346
Ambient drawers	-19.214	-2.551	+14.045
<u>Region III</u>			
Substitution drawers	- 3.542	-0.300	+ 1.760
Ambient drawers	- 7.549	-1.034	+ 5.518

Table X

RADIAL SUBSTITUTION REACTIVITY WORTHS (Assembly 31)

	Region I	Region II	Region III
Average Radius (cm)	6.61	28.35	43.71
<u>Aluminum Substitution</u>			
Mass (kg)	1.909	1.697	1.272
Worth (Ih $\pm$ 1)	1.7	7.5	9.2
Reactivity Coefficient (Ih/kg)	0.9 $\pm$ 0.5	4.4 $\pm$ 0.6	7.2 $\pm$ 0.8
(Ih/g-mole)	0.024 $\pm$ 0.014	0.12 $\pm$ 0.016	0.19 $\pm$ 0.02
<u>Al₂O₃ Substitution</u>			
Mass (kg)	3.263	0.967	2.175
Worth (Ih $\pm$ 1)	28.9	8.5	7.7
Reactivity Coefficient (Ih/kg)	8.9 $\pm$ 0.3	8.8 $\pm$ 1.0	3.5 $\pm$ 0.5
(Ih/g-mole)	0.93 $\pm$ 0.03	0.92 $\pm$ 0.10	0.36 $\pm$ 0.05
<u>Oxygen^(a)</u>			
(Ih/kg)	17.8 $\pm$ 1.2	13.8 $\pm$ 2.2	-0.6 $\pm$ 1.4
(Ih/g-mole)	0.28 $\pm$ 0.02	0.22 $\pm$ 0.04	-0.0096 $\pm$ 0.0224
<u>Sodium Substitution</u>			
Mass (kg)	1.183	1.051	0.788
Worth (Ih $\pm$ 1)	11.6	13.6	9.5
Reactivity Coefficient (Ih/kg)	9.8 $\pm$ 0.8	12.9 $\pm$ 1	12.1 $\pm$ 1.3
(Ih/g-mole)	0.23 $\pm$ 0.02	0.30 $\pm$ 0.02	0.28 $\pm$ 0.02

^aThere is an apparent anomaly in the negative worth of oxygen at the edge of the core. Due to the uncertainties in the data, the reasonable conclusion is only that the value is small.

VII. PROMPT NEUTRON LIFETIME

The average prompt neutron lifetime was determined by the Rossi- α method. Equipment and the experimental technique have been described by Brunson *et al.*⁽¹²⁾ The Rossi- α at delayed critical was measured as $(4.45 \pm 0.10) \times 10^4 \text{ sec}^{-1}$. If the estimated value $\beta = 0.0073 \pm 0.04$ is used, the average prompt neutron lifetime is $(16.4 \pm 0.7) \times 10^{-8} \text{ sec}$.

VIII. DISCUSSION

The critical mass of Assembly 31 was $\sim 25\%$ greater than the calculated value, just as it was for Assemblies 29 and 30. Some of the basic critical properties are tabulated in Table XI; a more complete comparison is given in ANL-6392.⁽¹³⁾

Table XI

COMPARISON OF CALCULATED AND EXPERIMENTAL CRITICAL PROPERTIES OF ASSEMBLIES 29, 30, AND 31

	Assembly		
	29	30	31
Volume Fractions			
U ²³⁵	4.97	5.92	5.81
U ²³⁸	9.97	9.06	9.14
Stainless Steel	24.75	24.60	24.49
Aluminum	24.38	23.60	23.49
Oxygen	14.46	7.28	0
Length (cm)	71.3	62.2	62.2
Critical Radius (cm)	45.0	41.4	45.2
Critical Volume (liters)	452	356	425
Critical Mass (kg)	421	395	463
Calculated Critical Mass (Set 58)	332	292	376
Calculated k of the Critical Configuration(a)			
Set 58	1.058	1.065	1.047
YOM Set	1.050	1.053	1.050

- (a) The calculations were performed for a homogeneous sphere with the volume and volume fractions of the critical core. The "k" values are not corrected for either the heterogeneity or shape factor

The similarity of the discrepancies in the k values calculated for the three cores is a strong indication that the discrepancy cannot be attributed to oxygen, but that the cross-section sets used are inaccurate in the calculation of the basic critical properties of large, dilute reactors.

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