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COMPILATION OF FAST REACTOR EXPERIMENTS

VOLUME I

PHILIP F. PALMEDO, EDITOR

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DEPARTMENT OF APPLIED SCIENCE
BROOKHAVEN NATIONAL LABORATORY
UPTON, NEW YORK 11973

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INTRODUCTION

Background

The complexity of the physics of nuclear reactors is due to three related factors: the unwieldiness of the basic equations, the nature and number of the parameters required to define such systems, and the mechanical complexities that characterize real reactors. Because of differences in their characteristic neutron spectra, the physics of fast reactors is, if anything, more complex than that of thermal systems. These are the characteristics that provide the basic scientific challenge in the attempt to develop analytical techniques and cross section sets adequate for accurate fast reactor design. Part of that challenge consists of the development and coordination of adequate amounts of the right kind of experimental data. This is an enterprise which was initiated in the late 1940's, and has rapidly accelerated in the last decade until today at least 15 major research centers are significantly involved in it.

This report is a first step toward addressing the problem of technical communication that is directly implied by the situation outlined above. It is a very modern type of problem appearing in only rudimentary form in earlier technologies.

Specifically, this report is the first part of a compilation of those fast reactor experiments which, by virtue of their accuracy, lack of ambiguity, and the small number of material components involved, are of potential use in testing analytical techniques and cross sections. (1) The specific purposes of the compilation are to provide up-dated and corrected data from experiments that may have been only partially or incorrectly reported in the literature and to provide a convenient means of access to particular types of experimental information (e.g., one may want to know what measurements of neutron life-time have been made by pulsed neutrons in systems containing hydrogen, or merely criticality information in a certain type of system).

It is not intended that every fast critical experiment ever performed be included in this compilation. Only those experiments which can conceivably be used to test cross sections or calculational methods are considered. Thus, complex assemblies or mock-up experiments are only briefly described, if included

at all. Similarly, not all existing examples of each type of individual measurement are included. The criteria rule out, for example, most measurements of control rod worth which are commonly made for operational reasons.

This first part of the compilation includes only data from three facilities operated by the Argonne National Laboratory: ZPR-3 (through Assembly 48A), ZPR-6 (through Assembly 6) and ZPR-9 (through Assembly 24A). These facilities have, of course, been the basic source of fast reactor physics information (outside of the very hard spectrum region) in this country. Furthermore, the published data from these facilities, particularly the early assemblies, have clearly been in need of critical review. Such a review was possible only through the active participation of Argonne personnel. W. A. Davey, A. L. Hess, C. E. Till and their colleagues in the ANL Reactor Physics Division were indispensable collaborators in this review.

In order to fulfill its purpose and its potential the Compilation must be an active, not a static document. This is a first draft of a document which, if successful, will not reach its ultimate form until experimental reactor physics information is no longer needed for the development of fast breeder reactors. Not only are there undoubtedly errors contained in the current version, but there are recognized deficiencies of detail in the description of some of the experiments. Hopefully, these will be corrected by the appropriate workers in the field and revised entries distributed to users of the compilation. Furthermore, as mentioned above, the current draft considers only three of the many facilities in the world producing significant experimental data in fast reactor physics. Data from other facilities have been compiled to various degrees at Brookhaven and, although the Brookhaven program has been terminated, we hope that this activity will be taken up elsewhere.

At the risk of belaboring the obvious, the secondary nature of this document must be emphasized. In many cases, the descriptions of the experiments are significantly condensed from that required for a complete understanding of the results. It is true that in some instances the compilation contains more information, or a later assessment of a particular experiment, than appears in the cited reference, but this is due to the early nature of many of the experiments included in this "first draft". Users of the Compilation are urged to refer to the references, and particularly to cite the original authors if their data are used. It is their expertise, cleverness and hard work that are reflected here, not those of the compilers.

Related Activities

During the development of the Compilation the question of an automated, computer-based system often came up. It was felt, however, that the diversity of the experiments involved and the requirement for careful individual description, as well as the need for various types of figures, precluded such an approach. Furthermore, it was felt that the document would be of greater utility if it could be readily at hand as a reference at each user's desk. Nonetheless, related computer-based compilations are being worked on. Hampel, et al. at Livermore have described a computerized "library and evaluation system for integral neutron experiments". (2) A similar system has been described by Katsuragi. (3)

Although we would strongly support such developments, one of the strong motivations of the Compilation is the feeling that analysts should take into account more fully the details of the experiments they are using. In some instances in the past this has been difficult, partly because of lack of sufficient detail in reporting experiments and partly because of an underestimation of the significance of some effects (particularly heterogeneity). Thus we feel that, before the restraints of computer storage are imposed on experimental data, the actual experimental arrangements should be understood in detail and the data critically examined. A primary intent of this Compilation is to aid in that process. We conceive of computer storage as the next step before analysis, a step which does not preclude this one, but in fact depends upon it.

Organization of the Compilation

In general, the Compilation has been arranged on the basis of type of experiment rather than facility and assembly. In this way one can readily locate all the experiments of a particular type that one may be interested in at a particular time. On the other hand, a numbering system has been used which makes it easy to locate all the experiments performed on a particular assembly. (The loose-leaf format makes it possible for someone to rearrange the entries by assembly if he so desires).

The system of numbering entries is as follows: Each facility is given a number corresponding to the part of Section 1 in which it is described; e.g. ZPR-6, described in Section 1.2, has the identifying number 2. In other sections, in which individual experiments are described, the entries are numbered according to the facility, using the identifying number just described,

and the assembly. For example, a measurement of sodium void coefficient made in ZPR-6 Assembly 7 would appear as entry number 6-2-7 where the 6 refers to Section 6 (Na Void Coefficients), 2 refers to ZPR-6 and 7 refers to Assembly 7. A cell fission distribution measured on ZPR-3 Assembly 24 would appear under 10.1-1-24. In all cases the number identifying the assembly is underlined for ease of identification.

Two points of cross reference are provided. In Section 2, along with the description of each assembly, is a list of the experiments performed on that assembly. A check-index is also provided at the end of the Introduction from which one can locate any combination of experiments.

In earlier drafts of the Compilation the introduction to each section included a discussion of the pertinent experimental techniques. Recently, however, an excellent summary of such techniques has been published by Davey and Redman⁽⁴⁾. Since their text covers experimental techniques used in the ZPR work particularly well, the general discussions of experimental techniques have been deleted from this edition.

Acknowledgements

Peter Gay, in describing the production of the first encyclopedia wrote, "Diderot found the Encyclopédie tiring but stimulating - what he had taken on as a chore became a vocation. He was compelled to negotiate with greedy publishers, appease temperamental contributors, answer ecclesiastical critics, deal with capricious government officials, and read endless pages of proofs". Although that passage struck a responsive note when read by the editors, much of the parallel pertains particularly to parts of the Compilation not included in this first edition. Furthermore, the publishers not only showed no sign of greed but were most helpful in the task of getting out a document not much smaller than the Encyclopédie.

I have already spoken of the indispensable collaboration offered by W. Davey, C. Till, A. Hess and their colleagues at Argonne National Laboratory. William Hannum of the USAEC was also of great help from the point of view of support and organization. Several people at Brookhaven made significant contributions to this document during its development. The idea of the Compilation originated with Herbert Kouts; among those who contributed to the processes of compilation, review and editing were Richard Hoeffling, James Phelps, and particularly John Conant.

As mentioned above, it has not been possible to include in this first edition the full range of available data, particularly the foreign work. Nonetheless, several reactor physicists from abroad have been most cooperative in encouraging this enterprise. Among these I would particularly like to thank P. Engelmann (GfK, Karlsruhe, Germany), E. Hellstrand (A.B. Atomenergi, Studsvik, Sweden) and A. I. Leipunskii (Obninsk, USSR) for supplying special data for the Compilation. I hope all the pertinent European data will be incorporated in the near future.

Several young ladies bravely bore the burden of repeated typing of the manuscript. The final draft was expertly produced by Virginia Kuzloski.

References:

1. P. F. Palmedo, "A Suggested Format for a Compilation of Fast Reactor Experiments", BNL Internal Report RP-491 (1968) (also EACRP-A-87).
2. V. E. Hampel, R. J. Howerton and J. A. Wade, "A Computerized Library and Evaluation System for Integral Experiments", UCRL-71584 Rev. I, Trans. Am. Nucl. Soc. 12, 1, 249 (1969).
3. S. Katsuragi, "Collection and Evaluation of Experimental Data (Cormorant Code)", PNCN 141, 69-16-(1), Tokai, Japan (1969).
4. W. G. Davey and W. C. Redman, Techniques in Fast Reactor Critical Experiments, to be published as an American Nuclear Society Monograph.

Compilation of Fast Reactor Experiments

Check Index

The following pages contain a check index of all entries in the Compilation. The general scheme of the index is clear from inspection: an "X" indicates that a given type of measurement (specified by the column) has been made on a given assembly (indicated by the row) and is reported in the appropriate section. Only two refinements to the system are used: If an assembly is listed but is not checked under the first column (Section 2), this means that that assembly has been described only partially, usually for some specific experiment. Secondly, if an experiment made on a certain assembly is reported along with similar measurements from another assembly, the number of that assembly is entered in the table. Thus, for example, central reaction rates measured on ZPR-3 Assembly 38 are reported with those from Assembly 24 in Section 5.1-1-24. Thus, a 24 is entered in the Check Index under Section 5.1.

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COMPILATION OF FAST REACT EXPERIMENTS CHECK INDEX

ZPR-3 Assembly	CRITICALITY SHAPE FACTORS		REACTIVITY WORTHS				REACTION RATES		NA VOID	DOPPLER	TEMPERATURE	OTHER ρ	ACTIVATION REACTIVITY COEFFICIENTS R. RATES WORTHS LIFETIME LEAKAGE							SPECTRA LIFETIME		CONTROL RODS IMPORTANCE		
	2	3	4.1	4.2	4.3	4.4	5.1	5.2	6	7	8	9	10.1	10.2	10.3	10.4	10.5	10.6	10.7	11	12.1	12.2	13	14
13	X						X													X				
14	X						X													X				
15	X						X													X				
16	X						X													X				
17	X						X													X				
20	X						X	X					X							X				
21																				X				
22	X						X													X				
23	X						X													X				
24	X	X					X													X				
25	X						X													X				
27																								
28																								
29	X						X													X				
30	X						X													X				
31	X	2.4					X													X				
32	X						X													X				

COMPILATION OF FAST REACTOR EXPERIMENTS CHECK INDEX

[illegible]

COMPILATION OF FAST REACTOR EXPERIMENTS CHECK INDEX

ZPR-6 Assembly	CRITICALITY SHAPE FACTORS		REACTIVITY WORTHS				REACTION RATES		NA VOID DOPPLER TEMPERATURE OTHER ρ				HETEROGENEITY							SPECTRA LIFETIME			CONTROL RODS IMPORTANCE	
	2	3	4.1	4.2	4.3	4.4	5.1	5.2	6	7	8	9	10.1	10.2	10.3	10.4	10.5	10.6	10.7	11	12.1	12.2	13	14
1	X		X	X			X							X							X			
2	X		X	X			X		X			X	X								X			
3	X					X	X	X	X			X			X						X			
4Z	X		X	X	X	X	X	X	X	X			X							X	X			X
5	X		X		X		X		X	X			X	X	X	X	X		X	X	X			X
6	X		X		X			X	X	X			X	X	X					X				

COMPILATION OF FAST REACTOR EXPERIMENTS CHECK INDEX

ZPR-9 Assembly	CRITICALITY SHAPE FACTORS		REACTIVITY WORTHS				REACTION RATES		NA VOID	DOPPLER	TEMPERATURE	OTHER ρ	ACTIVATION	REACTIVITY	COEFFICIENTS	R. RATES	WORTHS	LIFETIME	LEAKAGE	SPECTRA LIFETIME	CONTROL RODS IMPORTANCE				
	2	3	4.1	4.2	4.3	4.4	5.1	5.2													6	7	8	9	10.1
1	X		X				X	X													X				
2	X		X				X	X															X		
3	X		X		X		X	X													X				
4	X		X		X	X	X	X				X		X							X				
4A	X																								
4B	X		X		X		X	X															X		
5	X		X		X		X	X													X				
6	X		X		X		X	X				X		X							X				
7	X		X		X		X	X													X				
7A	X																								
8	X		X		X	X	X	X													X				
8A	X																								
8B	X				X	X																			
9	X		X		X				X														X		

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SECTION 1 - DESCRIPTIONS OF FACILITIES

In this section the principle facilities used for fast reactor experiments will be described. The descriptions are somewhat more detailed than those provided by Homma et al. (1) particularly with regard to the fuel and diluent compositions. They are not intended, however, as complete descriptions of all aspects of the facilities, but rather only of those aspects which are germane to the understanding of the experiments described in the compilation. Since a given set of fuel plates etc. may be used for a large number of assemblies, the fuel and diluent plates are usually described in detail in this section. These data, combined with information for particular assemblies given in Section 2, should be adequate for criticality calculations.

Reference:

H. Homma, H. Patzelt and S. Stehe, "Unterkritische Anordnungen, Kritische Anordnungen und Pulsreaktoren zum Studium Schneller Reaktoren", KFK-350 (1965).

1.1**ZPR-3****(Zero Power Reactor - 3)**

Location: National Reactor Testing Station, Idaho Falls,
Idaho, USA

Operated by: Argonne National Laboratory for the U. S. Atomic
Energy Commission.

Date of First Operation: October, 1955

Basic Description:

A photograph of the reactor is shown in Figure 1. The assembly machine is basically a platform on which two tables or carriages are mounted, one of which is movable. Half of the assembly is built up on each carriage by inserting drawers containing the reactor material into a matrix structure consisting of square cross section stainless steel or aluminum (type 3003F) tubing stacked in a square array (67 in. x 67 in.). The array is constrained in position by means of clamps which are fastened to the carriage.

Normally the steel tubes are used, making up a 31 x 31 array. The vertical and horizontal pitches are 2.1755 in. and 2.1635 in. respectively. The steel is type 304 with the following weight percentages:

TABLE I

Composition of ZPR-3 304 Stainless Steel

<u>Material</u>	<u>Weight Percent</u>
Fe	73.4
Cr	17.0
Ni	8.4
Mn	0.75
Si	0.45

In the core section the fuel and diluent plates, nominally 2 in. high, are loaded into aluminum or (usually) steel drawers that slide into the matrix tubes. The characteristics of the tubes and drawers are shown in Fig. 2 while a photograph of a loaded drawer is shown in Fig. 3. The section containing core components is shown at the bottom of the figure. Such "front" sections come in 15 in. and 21 in. lengths. The rear sections, an example of which is shown at the top of Fig. 3, which usually carry blanket materials come in 17 in. (to match the 15 in. front) or 11 in. lengths. A leaf spring (~10g mild steel) at the back of each drawer section compresses the components.

1.1 (Cont'd)

ZPR-3

(Zero Power Reactor - 3)

Usually cores are constructed in an approximation to cylindrical geometry. Figure 4 shows the arrangement of drawers (and the drawer numbering system) for a loading with a 3-zone core (assembly 43).

Fuel:

Enriched U:

(93.26 wt% U-235, 5.39 % U-238, 0.95% U-234,
0.40% U-236)

1 in. x 0.125 in. x 0.5 in.
1 in. x 0.125 in. x 1 in.
2 in. x 0.125 in. x 0.5 in.
2 in. x 0.125 in. x 1 in.
2 in. x 0.125 in. x 2 in.
2 in. x 0.125 in. x 3 in.

Coated with 0.001 in "KEL-F" Density = 18.75 g/cm^3

Other fuel and diluent materials are described in
Table II.

References:

- (1) B. C. Cerutti, et al., "The Fast Critical Assembly," AML-5513 (1956).
- (2) J. K. Long, et al., "Fast Neutron Power Reactor Studies with ZPR-III", ICPUAE, Geneva, 1958, 12, 119
- (3) B. C. Cerutti, et al., "ZPR-III, Argonne's Fast Critical Facility," Nucl. Sci. and Eng., 1, 126 (1956).
- (4) A. M. Broomfield et al. (A. L. Hess, Ed.), "The Design and Critical Mass Determinations for ZPR-3 Assemblies 48, 48A, and 48B" ZPR-TN-4 (1969).

Figure 1
Critical Assembly Machine

ALL MATERIAL IS TYPE 304 STAINLESS STEEL

ALL DIMENSIONS IN cm

MATRIX TUBES

AVERAGE WALL

DENSITY = 7.958 g/cm^3

MASS PER AXIAL LENGTH =
 17.57 g/cm

REGULAR DRAWERS (PERFORATED STEEL)

SIDES AND BOTTOM

AVERAGE DENSITY = 3.157 g/cm^3

FRONT AVERAGE

DENSITY = 4.472 g/cm^3

MASS PER AXIAL LENGTH =
 4.079 g/cm

CONTROL-AND SAFETY-ROD DRAWERS

SIDES AND BOTTOM

AVERAGE DENSITY = 7.848 g/cm^3

FRONT AVERAGE DENSITY = 7.300 g/cm^3

Fig. 2 ZPR-3 Matrix & Drawer Geometries

Figure 3 Typical ZPR-3 Drawer Loadings

1.1 (cont'd)

Fig. 4

Typical Assembly Loading Diagram, ZPR-3

Drawer designations sometimes also indicate in the first digit which half of the assembly is involved eg. 1-P-16 or 2-P-16 (the two central drawers).

TABLE II. Specifications of Material Plates Used In ZPR-3

Plate Type and Description	Specifications for Particular Plate Lengths				
	Nominal Size, in.	Core Material Contents	Core Dimensions, cm	Can Mass g	Exterior can Dimensions, cm
Plutonium (4.5% ^{240}Pu)-Al alloy core clad in 12 mil stainless steel (304). Pu = 95.01 w/o ^{239}Pu , 4.55 w/o ^{240}Pu , 0.43 w/o ^{241}Pu , 0.005 w/o ^{242}Pu . Density = 15.06 g/cm ³	1/8x2x1	32.30 g Pu 0.37 g Al	0.216 x 4.483 x 2.362	8.75	0.3175 x 5.08 x 2.54
	1/8x2x2	69.03 g Pu 0.77 g Al	0.216 x 4.483 x 4.902	16.79	0.3175 x 5.08 x 5.08
	1/8x2x3	104.30 g Pu 1.16 g Al	0.216 x 4.483 x 7.442	24.66	0.3175 x 5.08 x 7.62
Plutonium (22% ^{240}Pu)-Al alloy core clad in 12 mil stainless steel (304). Pu = 72.84 w/o ^{239}Pu , 21.94 w/o ^{240}Pu , 4.59 w/o ^{241}Pu , 0.62 w/o ^{242}Pu .	1/8x2x1	34.05 g Pu 0.39 g Al	0.216 x 4.483 x 2.362	9.07	0.3175 x 5.08 x 2.54
	1/8x2x2	71.93 g Pu 0.83 g Al	0.216 x 4.483 x 4.902	17.49	0.3175 x 5.08 x 5.08
	1/8x2x3	109.53 g Pu 1.25 g Al	0.216 x 4.483 x 7.442	26.18	0.3175 x 5.08 x 7.62
Pu-U alloy core clad in 12 mil stainless steel (304) Pu = 90.40 w/o ^{239}Pu , 8.50 w/o ^{240}Pu , 0.98 w/o ^{241}Pu , 0.05 w/o ^{242}Pu , U = 99.771 w/o ^{238}U + 0.229 w/o ^{235}U . Density = 18.28 g/cm ³	1/4x2x3	57.71 g Pu 229.76 g U 7.36 g Mo	0.533 x 4.514 x 7.061	22.07	0.610 x 5.08 x 7.645
	1/4x2x4	79.10 g Pu 314.87 g U 10.10 g Mo	0.533 x 4.514 x 9.601	28.51	0.610 x 5.08 x 10.18
	1/4x2x5	100.18 g Pu 398.70 g U 12.80 g Mo	0.533 x 4.514 x 12.141	35.54	0.610 x 5.08 x 12.725
	1/4x2x6	121.84 g Pu 485.14 g U 15.56 g Mo	0.533 x 4.514 x 14.681	42.78	0.610 x 5.08 x 15.265
	1/4x2x7	142.43 g Pu 567.12 g U 18.18 g Mo	0.533 x 4.514 x 17.221	49.05	0.610 x 5.08 x 17.805
	1/8x2x2	15.63 g Pu 62.25 g U 2.00 g Mo	0.24 x 4.514 x 4.521	14.65	0.316 x 5.08 x 5.105

TABLE II (cont.)

Plate Type and Description	Specifications for Particular Plate Lengths				
	Nominal Size in.	Core Material Contents	Core Dimensions, cm	Can Mass g	Exterior can Dimensions, cm
Depleted uranium. 0.206 w/o ^{235}U	1/8x2x1 1/8x2x2 1/8x2x3 1x1x2 1x1x5 2x2x2 2x2x5	74.62 g U 148.17 g U 223.75 g U 608.86 1529.59 2460.39 6162.14	0.3175 x 5.08 x 2.54 0.3175 x 5.08 x 5.08 0.3175 x 5.08 x 7.62 2.54 x 2.54 x 5.08 2.54 x 2.54 x 12.70 5.08 x 5.08 x 5.08 5.08 x 5.08 x 12.70		
Sodium in 1/4-in.-thick cans of stainless steel (type 304), steel-wall thickness = 15 mils	2 x 3 2 x 4 2 x 6 2 x 7 2 x 8	17.93 g Na 24.44 37.68 43.25 49.50	0.56 x 5.00 x 6.60 0.56 x 5.00 x 9.00 0.56 x 5.00 x 13.87 0.56 x 5.00 x 15.92 0.56 x 5.00 x 18.22	29.76 37.97 57.32 66.31 75.27	0.635 x 5.08 x 7.62 0.635 x 5.08 x 10.16 0.635 x 5.08 x 15.24 0.635 x 5.08 x 17.78 0.635 x 5.08 x 20.32
Graphite	1/8x2x2 1/8x2x3	12.88 g C 19.42 g C	0.3175 x 5.08 x 5.08 0.3175 x 5.08 x 7.62		
Stainless steel (type 304): 73.4 w/o Fe, 17.0 w/o Cr, 8.4 w/o Ni, 0.75 w/o Mn, 0.45 w/o Si	1/8x2x1/2 1/8x2x1 1/8x2x3 1/4x2x1 1/4x2x2	15.47 30.68 92.07 62.96 126.49	0.3175 x 5.08 x 1.27 0.3175 x 5.08 x 2.54 0.3175 x 5.08 x 7.62 0.635 x 5.08 x 2.54 0.635 x 5.08 x 5.08		
Nickel: 99.4 w/o Ni, 0.25 w/o Mn, 0.15 w/o Fe, 0.20 w/o impurities	1/4x2x1 1/4x2x2	70.45 g 141.45 g	0.635 x 5.08 x 2.54 0.635 x 5.08 x 5.08		
Aluminum - 45% density Aluminum - 100% density	1/8x2x1/2 1/8x2x3	2.30 g Al 31.92 g Al	0.3175 x 5.08 x 1.27 0.3175 x 5.08 x 7.62		
Natural B_2C : 13.68 w/o ^{10}B , 63.30 w/o ^{11}B , 22.56 w/o C, 0.46 w/o impurities	1/4x1/2x2 1/4x1/2x3	8.868 g 13.148 g	0.635 x 1.27 x 5.08 0.635 x 1.27 x 7.62		
Enriched B_2C : 62.32 w/o ^{10}B , 7.02 w/o ^{11}B , 27.68 w/o C, 2.98 w/o impurities	1/4x1/2x2 1/4x1/2x3	8.011 g 12.418 g	0.635 x 1.27 x 5.08 0.635 x 1.27 x 7.62		

1.2 ZPR-6 (Zero Power Reactor - 6)

Location: Argonne National Laboratory, Lemont, Illinois, USA

Operated by: Argonne National Laboratory for the U.S. Atomic Energy Commission

Date of First Operation: July 23, 1963

Basic Description:

ZPR-6 is a split-table assembly, very similar in construction to ZPR-3. See Section 1.1. A sketch of the facility is shown in Figure 1. Each half of the assembly consists of a 45 by 45 matrix of stainless steel (304) tubing of 5.52 cm square (outside cross section), 0.102 cm thick and 1.2 m in length. Al (6061) tubing is also available. These tubes are stacked and held in place by large clamps fastened to the assembly bed. When the assembly is in the closed position, a 2.4 m cube is formed. Uranium blanket slugs may be directly loaded into the array as may stainless steel drawers containing various reactor materials. (See Figure 3 of Section 1.1). All drawers are of 5.24 cm square (outside) and 0.081 cm thick. A sketch of a cross section of a loaded drawer is shown in Figure 2. Reactor materials such as fuel plates are constrained by means of spring clamps in the back of the drawers.

The composition of the type 304 stainless steel used in this assembly is shown in Table I.

Table I
Composition of 304 Stainless Steel in ZPR-6 and 9

<u>Material</u>	<u>Weight, %</u>	<u>Material</u>	<u>Weight, %</u>
Fe	69.8	Ag	0.6
Cr	18.4	Cu	0.3
Ni	9	C	0.1
Mn	1.5	Cb	0.1

FIG. 1
FAST CRITICAL FACILITY ZPR-3 AND -9

1.2 (cont'd)

Figure 2
Cross Section of Typical Drawer Loading in ZPR-6

1.2 (cont'd)

Fuel and Other Materials:

The inventory of fuel and other plates is shared with ZPR-3, ZPR-9 and ZPPR. The main constituents of that inventory are described in Table II of Section 1.1. In addition, plates are available of a Pu-U-Mo alloy having the composition 69.5/28/2.5 (U/Pu/Mo). The Pu isotopic composition is 87/11.5/1.5 (Pu-239/240/241). The alloy is 0.32 cm thick, clad in 12 mil stainless steel (304).

References:

1. W. Y. Kato, et al., "Design and Construction of the Argonne Fast Critical Facility (ZPR-6)", Physics of Fast and Intermediate Reactors 1, 295, IAEA, Vienna, 1961
2. L. R. Dates, "Design, Construction Details and Preoperational Testing of an Argonne Fast Critical Facility" ANL-7195 (1967)

1.3

ZPR-9 (Zero Power Reactor-9)

Location: Argonne National Laboratory, Lemont, Illinois, USA

Operated by: Argonne National Laboratory for the U. S. Atomic Energy Commission

Date of First Operation: February 10, 1964

Basic Description:

Mechanically and structurally, ZPR-9 is identical to ZPR-6 (See Figure 1 of Section 1.2) with two exceptions:

1. The matrix tubing may be 6061-T6 Al alloy rather than SS (304).
2. The drawers containing various reactor materials may be 5086-H34 Al alloy rather than SS (304).

The method of loading the reactor is as in ZPR-6. Its reflector may be of Al, low carbon steel or depleted uranium.

Dimensions of the various assemblies were determined from the dimensions of a typical matrix position as shown in Figure 1. The first row of the upper right table in the figure gives the fixed weight of aluminum (drawer plus matrix) per centimeter of core length. The second row gives the fixed weight of aluminum (in the matrix) and steel (in the 10 dual-purpose rods) for each centimeter of core length.

NOTES
BOWING CONDITION
OF MATRIX TUBE
IS EXAGGERATED
FOR THE PURPOSE
OF CLARITY.

ALL DIMENSIONS IN INCHES

	Aluminum	Iron
Full Drawer	9.92 g/cm	15.0 g/cm
B. P. Rod Drawer	3.81 g/cm	15.0 g/cm
Average cross-sectional area of matrix position = 30.75 cm ²		

"A"	"B"	"C"	CONDITION
0.007	2.191	2.199	CORE UNLOADED
0.0002	2.179	2.186	FULLY LOADED 800 LITER CORE

Fig. 1 Characteristics of ZPR-9 Matrix and Drawers

1.3 (cont'd)

Fuel and Other Materials:

The inventory of fuel and other plates is shared with ZPR-3, ZPR-6 and ZPPR. See Sections 1.1 and 1.2.

Reference:

C. E. Cohn, et al., "Safety Analysis for the ZPR-9 Facility", ANL-7166 (1966)

SECTION 2 - DESCRIPTIONS OF ASSEMBLIES AND CRITICALITY DATA

This section provides a description of each fast critical assembly that is considered useful for analytical studies. Sufficient criticality information (critical size, cell structure, isotope concentrations etc.) is given so that the input to criticality calculations is defined. A list is also given of the principal experiments performed on each assembly. In this way, this section acts as a focal point and index to the compilation, referring back to the facility descriptions and forward to individual experiments.

In order that this section can also serve as a resumé of all assemblies studied on the major facilities, an abbreviated description is also given of those assemblies which are not useful for general analytical purposes.

In general, complex multi-zoned assemblies are not described in detail; nevertheless, brief descriptions of such assemblies are provided and reference is made to any published descriptions. An exception is made when complex assemblies are significant in terms of evaluating the feasibility of using zoned experiments to investigate the properties of large systems (e.g., Assembly 42 of ZPR-3) or if the assembly has been used for measurements of interest (e.g., Doppler measurements) whose interpretation requires a knowledge of the environment.

Several comments should be made with respect to entries under specific headings in this section:

Critical Configuration

The physical structure of the various regions of the assembly is described including the geometry and cell structure. In most cases, in describing the cell, only the arrangement of the constituents is given. The detailed description of the individual cell constituents is given in Section 1 under the Facility Description. The cell defined in this way should be adequate for the calculation of the effect of heterogeneity on critical mass and on other (e.g. sample worth or fission ratio) measurements. In most cases the volume fractions of materials that would be derived from the description of the cell structure and the individual cell constituents in a region are not those that characterize the region as a whole. Structural material and slight alteration of the basic cell structure in control rods, etc. serve to perturb the over-all composition. The latter is accurately reported under the next heading.

The critical mass that is reported is that for the "as built" critical configuration described above. In the case of a pseudo-cylindrical ZPR assembly, for example, it is the critical mass for the core with its (usually) irregular boundary. Normally the "as built" system is not exactly critical; a control rod may be partially inserted, or, if all rods are fully in, the assembly may be slightly super-critical. The reported critical mass has been corrected for these effects, even when not specified. The justification for this procedure resides in the fact that such corrections can be accurately determined experimentally for example by a relative measurement of control rod worth vs. fuel worth at the core edge. By the same token, the reported critical mass may include corrections for in-core chambers, experimental channels, etc. These are clearly not the sort of corrections that even the most conscientious analyst would want to make himself.

In some cases other corrections to the measured critical mass may be specified. Some of these, such as the correction for an irregular core boundary, may rely on direct measurements and be both small and accurate, whereas others, such as that for heterogeneity, may be relatively large and purely theoretical. In cases in which heterogeneity measurements were made on the assembly in question, those measurements will be referred to and described in the appropriate section.

In general, the cylindrical core dimensions given are those for the "as built" core, and may not be corrected for the reactivity effect of edge irregularity, etc. In the case of the critical mass, however, both the "as built" critical mass and the corrected critical mass are given. Thus, the corrected critical dimensions can be derived from the corrected critical mass and the atom concentration of that material. Since it is common to derive corrections to the critical mass from measurements of the worth of fuel at the radial core boundary, it is the critical radius that should be adjusted to give consistency in the mass, volume, and concentration.

No emphasis has been placed on presenting parameters for a spherical version of the measured assembly. Such conversions incorporate too large a theoretical component to be considered original experimental data, and it is to the latter which the current compilation is primarily devoted. Nonetheless, if shape factors (and corrections for heterogeneity) are conveniently available, they may be cited (and their sources referenced) as indications of the order of magnitude of these corrections.

A further entry under this heading is the reactivity worth of fuel at the edge of the core, preferably in $\Delta k/k$ $\Delta M/M$ where M is the critical mass. Other significant reactivity conversion factors such as between inhours and $\Delta k/k$ are included when appropriate.

Composition of Core

Under this heading are given the homogenized concentrations of the constituents of the core. Particular attention has been paid to obtaining correct values for the atom concentrations. The approximate corresponding volume percentages are given primarily to aid in obtaining an appreciation of the relative concentrations of materials when making a quick scan of the section. Some arbitrariness is involved in defining volume percentages, particularly as to the disposition of void fractions. In general, however, the volume percentages given are those for the full density material. It should be emphasized, however, that it is the atom concentrations that should be used in calculations.

Composition of Blanket

The comments made above also apply to this section.

Measurements Made

The manner in which experiments are referenced in this section depends on their usefulness, accuracy and the availability of the results. If a measurement is considered significant and sufficiently accurate for analytical purposes, reference is made to the section of the Compilation in which it is described and where the results are given. If a measurement is not considered useful for analysis by virtue of its not being sufficiently accurate or well enough described, or if the assembly itself is only of minor interest, the measurement is mentioned and reference made to the original source in the literature. Some measurements are not mentioned at all, particularly those performed for operational purposes, such as control rod worths.

Related Assemblies

Under this heading other assemblies are listed which have more than one important feature in common with the assembly being described. In general, these are assemblies on the same facility having, for example, the same fuel composition of principal diluent.

References

The references given are those available in the open literature which formed the basis of the entries above. In many cases, particularly for the early experiments, the values in the literature have been corrected or up-dated on the basis of subsequent knowledge. Such corrections are always made in consultation with the originating laboratory and, wherever feasible, the bases for these corrections are specified. In many cases, however, the open literature is either inconsistent or incomplete and the information in the Compilation is more exact than that contained in the references. On the other hand, in some cases the references contain additional information or perhaps greater experimental detail than has been included in the Compilation, and can be consulted with profit.

SECTION 2.1 - ZPR-3 ASSEMBLIES

2.1-1A

ZPR-3

Assembly 1A

Type of Experiment: Critical (U-Al-Steel, U-235:U-238 $\approx$ 1:1)

Date: 1955

Critical Configuration:

Fig. 1 Assembly 1A Outline

Core: rectangular: 30.7 x 73 x 45.4cm
volume = 54.0 liters

cell structure: 4142441424641434

where 1 = enriched U, 2 = depleted U, 4 = 63% (perforated) Al,
6 = 304 stainless steel. All plates are 0.318 cm
thick and are described in Section 1.1.

Blanket: At least 23 cm thick on all sides (See Figure 1)

Critical Mass: 142.4 kg U-235 in core

Composition of Core:

<u>Material</u>	<u>Volume %</u>	<u>Atom Concentration atoms / cm³ x 10²²</u>
U-235	14	0.6778
U-238	16	0.7680
U-234		0.0075
U-236		0.0033
Al	31	1.8990
Stainless Steel (304)	12	
Fe		0.7705
Ni		0.0839
Cr		0.1917
Mn		0.0080
Si		0.0094
Void	26	

Composition of Blanket:

<u>Material</u>	<u>Volume %</u>	<u>Atom Concentration atoms / cm³ x 10²²</u>
U-235	0.2	0.00912
U-238	83	3.998
Stainless Steel (304)	7	
Fe		0.4542
Ni		0.0495
Cr		0.1130
Mn		0.0047
Si		0.0055
Al	2	0.1367
Void	7	

Related Assemblies: ZPR-3 Assemblies 1B-D, 2-5, 6A-6F
(Similar compositions)

References:

- (1) J. K. Long, et al., "Fast Neutron Power Reactor Studies with ZPR-III," ICPNAN, Geneva, 1958, 12, 119.
- (2) B. C. Cerutti, et al., "The Fast Critical Assembly," ANL-5513 (1956).

2.1-1B

EPR-3

Assembly 1B

Type of Experiment: Critical (U-Al-Steel U-235:U-238 $\approx$ 1:1)

Date: 1955

Critical Configuration:

Core: "cylindrical"

length = 30.7 cm. effective diameter = 46.6 cm.

cell structure: as in assembly 1A (2.1-1A)

Blanket:

at least 23 cm. thick on all sides

Critical Mass: 137.1 kg U-235 in core

Composition of Regions:

Identical to Assembly 1A (2.1-1A)

Measurements Made:

U-238 capture to U-235 fission at core center.

Related Assemblies:

EPR-3 Assemblies 1A, 1C, 1D, 3-5, 6A-6F
(similar compositions)

References:

- (1) J. R. Long, et.al., "Fast Neutron Power Reactor Studies with EPR-III" ICFEAS, Geneva, 1958 12, 119.

2.1-1C

EPR-3

Assembly 1C

Type of Experiment: Critical (U-Al-Steel, U-235:U-238 $\approx$ 1:1)

Date: 1955

Critical Configuration:

Core: (rectangular)
30.7 cm long x 33.2 cm x 56.2 cm

Blanket:
at least 23 cm thick on all sides

Critical Mass: 151.0 kg. U-235 in core

Composition of Regions:

Identical to Assembly 1A (2.1-1A)

Related Assemblies:

EPR-3 Assemblies 1A, 1B, 1D, 2-5, 6A-6F (similar compositions)

References:

- (1) J. K. Long, et al., "Fast Neutron Power Reactor Studies with EPR-III", ICPUAE, Geneva, 1958 12, 119.

2.1-2

ZPR-3

Assembly 2

Type of Experiment: Critical (U-Al-Steel, U-235:U-238 $\approx$ 1:1)

Date: 1955

Critical Configuration:

Core: "cylindrical"

length = 40.8 cm

effective diameter = 40.1 cm

cell structure as Assembly 1A (2.1-1A)

Blanket: at least 30 cm thick on all sides

Critical Mass: 136.0 kg U²³⁵ in core

Composition of Core:

<u>Material</u>	<u>Volume %</u>	<u>Atom Concentration atoms / cm³ x 10²²</u>
U-235	14	0.6730
U-238	16	0.7536
U-234		0.0074
U-236		0.0032
Al	32	1.899
Stainless Steel (304)	12	
Fe		0.7643
Ni		0.0832
Cr		0.1902
Mn		0.0079
Si		0.0093
Void	26	

Composition of Blanket:

as for Assembly 1A (2.1-1A)

Measurements Made:

Central fission ratios (5.1-1-2)

Reactivity effect of heterogeneity

Related Assemblies: ZPR-3 Assemblies 1A-1D, 3-5, 6A-6F (similar compositions)

Reference:

J. K. Long, et. al., "Fast Neutron Power Reactor Studies with ZPR-III", ICPUR, Geneva, 1958, 12, 119.

2.1-2A

ZPR-3

Assembly 2A

Type of Experiment: Critical (U-235, Al, Steel)Date: 1956Critical Configuration: (2)

Core: "cylindrical"

length = 40.8 cm effective diameter = 42.0 cm

cell structure: 4146441464641464

where 1 = enriched U, 2 = depleted U, 4 = 63% (perforated) Al and 6 = 30% stainless steel. All plates are 0.318 cm thick and are described in Section 1.1

Blanket: at least 30 cm thick on all sides

Critical Mass: 147.7 kg U-235 in core. The critical mass corrected for central gap, (-1.1 kg), irregular core boundary, (-0.1 kg), and heterogeneity (+3.8 kg) is 150.3 kg U-235.

Composition of Core:

<u>Material</u>	<u>Volume %</u>	<u>Atom Concentration</u> <u>atoms / cm³ x 10²²</u>
U-235	14	0.6715
U-238	1	0.0490
U-234		0.0074
U-236		0.0282
Al	31	1.896
Stainless Steel (304)	28	
Fe		1.727
Ni		0.1881
Cr		0.4298
Mn		0.0179
Si		0.0211
Void	26	

Composition of Blanket:

as for Assembly 1A (2.1-1A)

Measurements Made:Central reactivity worths (U²³⁸ and SS).

Central reaction rates (5.1-1-2A)

Reactivity effect of heterogeneity

Related Assemblies: ZPR-3 Assemblies 1A-1D, 2-5, 6A-6F had similar composition with higher U-238 and lower SS concentrations.

2.1-2A (Cont'd)

References:

- (1) W. G. Davey, "k Calculations for 22 EPR-III Fast Reactor Assemblies Using ANL Cross-Section Set 623" ANL-6570 (1962).
- (2) J. K. Long, et. al., "Fast Neutron Power Reactor Studies with EPR-III," ICFUAR, Geneva, 1958, 12, 119.

2.1-3

EPR-3

Assembly 3

Type of Experiment: Critical (U-Al-Steel, Annular core, U-235:
U-238 $\approx$ 1:1)

Date: April 1956

Critical Configuration:

Core: "Annular"

length = 40.8 cm effective inside diameter = 17.1 cm

effective outside diameter = 48.6 cm

cell structure: as for Assembly 1A (2.1-1A)

Blanket:

Inner blanket: 17.1 cm diameter. Outer blanket at least 23 cm thk

Critical Mass: 176.9 kg U²³⁵ in core.

Composition of Core:

Atom Concentration

<u>Material</u>	<u>Vol %</u>	<u>atoms / cm³ x 10²²</u>
U-235	14	0.6826
U-238	16	0.7632
U-234		0.0075
U-236		0.0029
Al	31	1.869
Stainless Steel (304)	12	
Fe		0.7429
Ni		0.0819
Cr		0.1871
Mn		0.0078
Si		0.0092
Void	27	

Composition of Blankets:

A) Central Blanket:

Atom Concentration

<u>Material</u>	<u>Volume %</u>	<u>atoms / cm³ x 10²²</u>
U-235	0.1	0.0038
U-238	40	1.906
Al	25	1.483
Stainless Steel (304)	7	
Fe		0.4542
Ni		0.0495
Cr		0.1130
Mn		0.0047
Si		0.0055
Void	28	

2.1-3

ZPR-3

Assembly 3(Cont'd)

B) Outer Blanket:
as for Assembly 1A (2.1-1A)

Measurements Made:

Central fission ratios (5.1-1-3)

Prompt neutron lifetime

Related Assemblies:

ZPR-3 Assemblies 1A-1D, 2,4,5,6A - 6F (similar compositions)

Reference:

- (1) J. K. Long, et al., "Fast Neutron Power Reactor Studies with ZPR-III," ICPUAE, Geneva, 1958, 12, 119.

2.1-4

ZPR-3

Assembly 4

Type of Experiment: Critical (U-Al-Steel, U-235: U-238 $\approx$ 1:1)

Date: April 1956

Critical Configuration:

Core: "Annular Cylinder"

length = 40.8 cm effective inner diameter = 17.23 cm

outer diameter = 51.9 cm

cell structure: 4412441244644124 where 1=Enriched U, 2=Depleted U,
4 = 63% Al and 6 = 304 stainless steel.

All plates are 0.318 cm thick and are
described in Section 1.1.

Blanket: Inner blanket diameter = 17.23 cm, two outer annular
blankets both 18.1 cm thick

Critical Mass: 201.1 kg U-235 in core.

Composition of Core:

Material	Volume %	Atom Concentration
		atoms / cm ³ x 10 ²²
U-235	14	0.6730
U-238	16	0.7632
U-234		0.0074
U-236		0.0029
Al	32	1.899
Stainless Steel (304)	12	
Fe		0.7581
Ni		0.0825
Cr		0.1886
Mn		0.0079
Si		0.0092
Void	26	

Composition of Blankets:

Central blanket: as for central blanket in Assembly 3 (2.1-3)

Inner annular blanket: as for central blanket in Assembly 3 (2.1-3)

Outer annular blanket: as for blanket of Assembly 1A (2.1-1A)

Measurements Made:

Central fission ratios (5.1-1-4)

Related Assemblies: ZPR-3 Assembly 5 (Same core composition)

References:

J. K. Long, et al., "Fast Neutron Power Reactor Studies with
ZPR-III," ICFUAR, Geneva, 1958, 12, 119

2.1-5

ZPR-3

Assembly 5

Type of Experiment: Critical (U-Al-Steel, U-235: U-238 $\approx$ 1:1)

Date: April 1956

Critical Configuration (1):

Core: "Cylindrical"

length = 40.8 cm effective diameter = 43.6 cm

cell structure: as for Assembly 4

Blanket: Two outer annular blankets as for Assembly 4

Critical Mass: 159.5 kg U-235 in core. CM corrected for heterogeneity (+4.6 kg), irregular boundary (-0.1 kg) and central gap (-1.2 kg) = 162.8 kg U-235. Estimated equivalent spherical critical mass = 156 kg U-235 (2).

Composition of Regions: (2)

Core and blanket composition as for Assembly 4 except that there is no central blanket

Measurements Made: (1)

Central fission ratios (5.1- $\frac{1}{2}$ -5)

Central reactivity worths

Related Assemblies:

ZPR-3 Assemblies 1A-1D, 2-4, 6A-6F (similar compositions)

References:

- (1) J. K. Long, et al., "Fast Neutron Power Reactor Studies with ZPR-III," ICFUAS, Geneva, 1958, 12, 119.
- (2) W. G. Davey, "k Calculations for 22 ZPR-III Fast Reactor Assemblies Using AML Cross-Sections Set 635", AML-6570 (1962).

2.1-6A

ZPR-3

Assembly 6A

Type of Experiment: Critical (U-Al-SS, U-235: U-238 ~ 1:1)

Date: 1956

Critical Configuration:

Core: "Rectangular"

length = 40.8 cm, depth = 22.17 cm, width = 81.4 cm

cell structure: as for Assembly 1A (2.1-1A)

Blanket: at least 30 cm thick on all sides

Critical Mass: 194.5 kg U-235 in core.

Composition of Core:

<u>Material</u>	<u>Volume %</u>	<u>Atom Concentration atoms / cm³ x 10²²</u>
U-235	14	0.6730
U-238	16	0.7632
U-234		0.0074
U-236		0.0029
Al	31	1.893
Stainless Steel (304)	12	
Fe		0.7643
Ni		0.0832
Cr		0.1902
Mn		0.0079
Si		0.0093
Void	26	

Composition of Blanket:

As for Assembly 1A

Related Assemblies: ZPR-3 Assemblies 1A-1D, 2-4, 6B-6F (similar compositions).

Reference:

J. K. Long, et al., "Fast Neutron Power Reactor Studies with ZPR-III," ICPUR, Geneva, 1950, 12, 119.

2.1-6B

ZPR-3

Assembly 6B

Type of Experiment: Critical (U-Al-SS U-235:U-238 $\approx$ 1:1)

Date: 1956

Critical Configuration:

Core: "Cylindrical"
length = 20.55 cm. effective diameter = 65.6 cm
cell structure: as for Assembly 1A

Blanket:
at least 30 cm. on all sides

Critical Mass: 183.0 kg U-235 in core

Composition of Regions:

As for Assembly 6A (2.1-6A)

Related Assemblies: ZPR-3 Assemblies 1A-1D, 2-4, 6A, 6C-F
(similar compositions)

Reference:

J. K. Long, et al., "Fast Neutron Power Reactor Studies
with ZPR-III, "ICRUAE" Geneva, 1958, 12, 119.

2.1-6C

EPR-3

Assembly 6C

Type of Experiment: Critical (U-Al-SS), U-235:U-239 $\approx$ 1:1)

Date: 1956

Critical Configuration:

Core: "cylindrical"

Length = 18 cm, effective diameter = 72.1 cm

Cell Structure: as for Assembly 1A

Blanket

at least 30 cm on all sides

Critical Mass:

221.0 kg U-235 in core

Composition of Regions:

As for assembly 6A (2.1-6A)

Related Assemblies: EPR-3 Assemblies 1A-1D, 2-4, 6A, B, D, E, F
(similar compositions).

Reference:

- (1) J. K. Long, et al., "Fast Neutron Power Reactor Studies with EPR-III", ICPUR, Geneva, 1958 12, 119.

2.1-6D

SFR-3

Assembly 6D

Type of Experiment: Critical (U-Al-SS, U-235:U:238 $\approx$ 1:1)

Date: 1956

Critical Configuration:

Core: "Cylindrical"

length = 56.1 cm

effective diameter = 35.7 cm

cell structure: as for Assembly 1A

Blanket: at least 30 cm on all sides

Critical Mass: 147.2 kg U-235 in core

Composition of Core:

<u>Material</u>	<u>Volume %</u>	<u>Atom Concentration atoms / cm³ $\times 10^{22}$</u>
U-235	14	0.6730
U-238	16	0.7535
U-234		0.0074
U-236		0.0029
Al	31	1.893
Stainless Steel (30%)	12	
Fe		0.7643
Ni		0.0012
Cr		0.1902
Mn		0.0079
Si		0.0093
Void	27	

Composition of Blanket:

As for Assembly 1A

Related Assemblies:

SFR-3 Assemblies 1A-1D, 2-4, 6A-C, 6E, 6F (similar compositions)

Reference:

J. K. Long, et al., "Fast Neutron Power Reactor Studies with SFR-III," ICFRAN, Geneva, 1958, 12, 119.

3.1-6E

EPR-3

Assembly 6E

Type of Experiment: Critical (U-Al-Ss, U-235:U-238 $\approx$ 1:1)

Date: 1956

Critical Configuration:

Core: "cylindrical"
length = 71.4 cm diameter = 33.55 cm
cell structure: as for Assembly 1A

Blanket:
at least 30 cm thick on all sides

Critical Mass: 164.2 kg U-235 in core

Composition of Regions:

as for Assembly 6A

Related Assemblies: EPR-3 Assemblies 1A-1D, 2-4, 6A-6D, 6F
(similar compositions)

References:

- (1) J. K. Long, et al., "Fast Neutron Power Reactor Studies with EPR-III," ICPUNE, Geneva, 1958, 12, 119.

2.1-6F

ZPR-3

Assembly 6F

Type of Experiment: Critical (U-Al-SS)

Date: January 1957

Critical Configuration: (1)

Core: "spherical"
effective radius = 22.8 cm.
cell structure; as for Assembly 1A (2.1-1A)

Blanket: at least 30 cm thick on all sides

Critical Mass: 131.1 kg U-235 in core. C.M. corrected
for heterogeneity (+3.4 kg, irregular core
boundary (-0.1 kg), and central gap (-1.1 kg)
= 133.3 kg U-235 (2)

Composition of Regions:

as for assembly 6A

Measurements Made:

Central U-238 to U-235 fission ratio (=0.069
by radiochemical method) (1)

Central Reaction Rates (5.1-1-6)

Prompt neutron lifetime (12.1-1-6F)

Related Assemblies:

ZPR-3 Assemblies 1-4, 6A-6E (similar compositions)

References:

(1) J. K. Lang, et al., "Fast Neutron Power Reactor Studies
with ZPR-III," ICFUN, Geneva, 1956, 12, 119.

(2) W. G. Snavely, "k Calculations for 22 ZPR-III Fast Reactor
Assemblies Using AEC Cross-Section Set 635" AEC-5570 (1962).

2.1-9

ZPR-3

Assembly 9

Type of Experiment: Critical (U-Al-SS, U-235:U-238 $\approx$ 1:3)**Date:** September 1956**Critical Configuration:****Core:** "cylindrical"

length = 40.8 cm

effective diameter = 46.5 cm

cell structure: 421223XY26322124

where 1 = enriched U, 2 = depleted U, 3 = Al (full density)
4 = 63% Al and 6 = 304 SS. All plates are 0.318 cm thick.The plates at locations X and Y are not constant
the length of the element. At X, front-to-back, the
plates are: depleted U (1 in. long), SS (2 in),
depleted U (2 in), SS (2 in), depleted U (1 in).At Y, the plates are: enriched U (1 in), Al (2 in),
enriched U (1 in). All plates are 0.318 cm thick
and are described in Section 1.1.**Blanket:** 35.6 cm thick on all sides**Critical Mass:** 151.9 kg U-235 in core. CM corrected
for heterogeneity (+6.1 kg) irregular boundary
(-0.1 kg) and central gap (-1.4 kg) = 156.5 kg
U-235.**Composition of Core:**

<u>Material</u>	<u>Volume %</u>	<u>Atom Concentration</u> <u>atoms / cm³ x 10²²</u>
U-235	12	0.5626
U-238	38	1.824
U-234		0.0062
U-236		0.0024
Al	22	1.302
Stainless Steel (304)	15	
Fe		0.9321
Ni		0.1015
Cr		0.2319
Mn		0.0097
Si		0.0114
Void	13	

2.1.9 (Cont'd)

ZPR-3

Assembly 9

Composition of Blanket:
as for Assembly 1A

Measurements Made:

Prompt neutron lifetime (12.1-1-9)
Central reaction rates (5.1-1-9)

Related Assemblies: ZPR-3 Assembly 9A, 9B and 15 (similar core compositions).

Reference:

J. K. Long, et al., "Fast Neutron Power Reactor Studies with ZPR-III ICPUAE, Geneva, 1958, 12, 119.

2.1-9A

ZPR-3

Assembly 9A

Type of Experiment: Critical (U-Al-SS, U-235:U-238 $\approx$ 1:3)Date: May, 1957Critical Configuration:Core: "spherical"

effective diameter = 50.4 cm

cell structure: 32124231X26232124

where 1 = enriched U, 2 = depleted U, 3 = Al (full density)

4 = 63% (perforated) Al and 6 = 304 SS. The plates are not constant the length of the element. Depleted and enriched U plates were alternated so that half the length was depleted and half enriched U. All plates are 0.318 cm thick and are described in Section 1.1.

Blanket: at least 30 cm thick on all sides.Critical Mass: 146.2 kg U-235 in core. CM corrected for heterogeneity (+5.8 kg), irregular boundary (-0.1 kg) and central gap (-1.3 kg) = 150.6 kg U-235Composition of Core:

<u>Material</u>	<u>Volume %</u>	<u>Atom Concentration atom / cm³ x 10²²</u>
U-235	12	0.5624
U-238	38	1.824
U-234		0.0062
U-236		0.0024
Al	22	1.296
Stainless Steel (304)	14	
Fe		0.8836
Ni		0.0962
Cr		0.2198
Mn		0.0092
Si		0.0108
Void	14	

2.1.9A (Cont'd)

EPR-3

Assembly 9A

Composition of Blanket:

<u>Material</u>	<u>Volume %</u>	<u>Atom Concentration atoms / cm³ x 10²²</u>
U-235	0.2	0.0091
U-238	83	3.998
SS (304)	8	
Fe		0.4542
Ni		0.0495
Cr		0.1130
Mn		0.0047
Si		0.0055
Void	9	

Measurements Made:

Central reaction rates (5.1-1-9A)

Related Assemblies: EPR-3 Assemblies 9, 9B, and 15 (similar core compositions).

Reference:

J. K. Long, et al., "Fast Neutron Power Reactor Studies with EPR-III," ICFRAN, Geneva, 1958, 12, 119.

2.1-98 ZPR-3 Assembly 98

Type of Experiment: Critical (U-Al-ss, U-235: U-238 $\approx$ 1:3)

Date: May, 1957

Critical Configuration:

Core: "cylindrical"

length = 25.6 cm. effective diameter = 66.8 cm

cell structure: as for 9A

Blanket: at least 30 cm thick on all sides

Critical Mass: 193.3 kg U-235 in core.

Composition of Core:

<u>Material</u>	<u>Volume %</u>	<u>Atom Concentration</u> <u>atoms / cm³ x 10²²</u>
U-235	12	0.5576
U-238	38	1.815
U-234		0.0061
U-236		0.0024
Al	21	1.284
Stainless Steel (304)	14	
Fe		0.8948
Ni		0.0974
Cr		0.2226
Mn		0.0093
Si		0.0109
Void	15	

Composition of Blanket:
as for Assembly 9A

Related Assemblies: ZPR-3 Assemblies 9 and 9A (similar compositions)

Reference:

J. K. Long, et al., "Fast Neutron Power Reactor Studies with ZPR-III," ICFUAR, Geneva, 1958, 12, 119.

2.1-10 ZPR-3 Assembly 10

Type of Experiment: Critical (U-235, U-235: U-238 ~ 1:5)

Date: January 1958

Critical Configuration:

Core: "cylindrical"

length = 45.9 cm effective diameter = 44.25 cm

cell structure: 222142221a2a2622122

where 1 = enriched U, 2 = depleted U, and 6 = 304 SS "1a2a"
indicates a 1 in high column of depleted U atop a 1 in
high column of enriched U. All plates are 0.318 cm thk. See 1.1.

Blanket: at least 30 cm thick on all sides

Critical Mass: 155.8 kg U-235 in core. CM corrected for
heterogeneity (+9.1 kg), irregular boundary (-0.1 kg) and
central gap (-1.7 kg) = 163.1 kg U-235.

Composition of Core:

<u>Material</u>	<u>Volume %</u>	<u>Atom Concentration</u> <u>atoms / cm³ x 10²²</u>
U-235	12	0.5696
U-238	58	2.779
U-234		0.0063
U-236		0.0026
Stainless Steel (304)	19	
Fe		1.199
Ni		0.1306
Cr		0.2984
Mn		0.0124
Si		0.0146
Void	11	

Composition of Blanket:

as for Assembly 2A

Measurements Made:

Central reaction rates (5.1-1-10)

Prompt neutron lifetime (23.1-1-10)

Reference:

W. G. Devey, "k Calculations for 22 ZPR-III Fast Reactor
Assemblies Using AML Cross Sections Set 635," AML-6570
(1962).

2.1-11

ZPR-3

Assembly 11

Type of Experiment: Critical (U-Graphite series)

Date: January 1958

Critical Configuration:

Core: "cylindrical"

length = 51.0 cm

effective diameter = 58.0cm

cell structure: 2221222222221222

where 1 = enriched U,

2 = depleted U and all plates are 0.318 cm thick.

(See Section 1.1)

Blanket: 30.5 cm thick on all sides

Critical Mass = 240.6 kg U-235 in core. CM corrected

for heterogeneity (+16.6 kg), irregular boundary

(-0.2 kg) and central gap (-3.0 kg) = 254.0 kg

U-235.

Composition of Core:

<u>Material</u>	<u>Volume %</u>	<u>Atom Concentration</u> <u>atoms / cm³ x 10²²</u>
U-235	10	0.4571
U-238	72	3.443
U-234		0.0050
U-236		0.0020
Stainless Steel (304)	9	
Fe		0.5886
Ni		0.0619
Cr		0.1415
Mn		0.0059
Si		0.0069
Void	9	

Composition of Blanket:

as for Assembly 9A

Measurements Made:

Central reaction rates (5.1-1-11)

Central sample worths

Prompt neutron lifetime (12.1-1-11)

Related Assemblies:

ZPR- Assemblies 11, 12, 14, 16, and 17 form a set with variable C/U-238 ratio.

References:

- (1) W. G. Davey, "k Calculations for 22 ZPR-III Fast Reactor Assemblies Using ANL Cross-Section Set 635," ANL-6570(1962).
- (2) J. K. Long, et al., "Fast Neutron Power Reactor Studies with ZPR-III," ICPUAE, Geneva, 1958, 12, 119.

Type of Experiment: Critical (U-Graphite series)

Date: February, 1958

Critical Configuration:

Core (2) "cylindrical"

length = 45.9 cm effective diameter = 52.75 cm

cell structure: 2727127272712727 where 1 = enriched U, 2 = depleted U and 7 = Graphite. All plates are 0.318 cm thk. See Sect. 1.1

Blanket: 30.5 cm thick on all sides

Critical Mass : 176.8 kg U-235 in core. CM corrected for heterogeneity (+5.8 kg), irregular boundary (-0.1 kg) and central gap (-1.8 kg) = 180.7 kg U-235.

Composition of Core:

<u>Material</u>	<u>Volume %</u>	<u>Atom Concentration atoms / cm³ x 10²²</u>
U-235	9	0.4509
U-238	35	1.699
U-234		0.0050
U-236		0.0019
SS (304)	9	
Fe		0.5679
Ni		0.0618
Cr		0.1413
Mn		0.0059
Si		0.0069
C	32	2.676
Void	15	

Composition of Blanket:

As for Assembly 9A

Measurements Made:

Central reaction rates (5.1-1-12)

Central sample worths

Prompt neutron lifetimes (12.1-1-12)

Related Assemblies: ZPR-3 Assemblies 11, 12, 14, 16 and 17 form a set with variable C/U-238 ratio.

References:

- (1) W. G. Davey, "k Calculations for 22 ZPR-III Fast Reactor Assemblies Using ANL Cross-Sections Set - 63" ANL-6570 (1962).
- (2) J. K. Long, et al., "Fast Neutron Power Reactor Studies with ZPR-III ICPUAE, Geneva, 1958, 12, 119.

2.1-13

ZPR-3

Assembly 13

Type of Experiment: Critical (U-SS-Al)

Date: April, 1958

Critical Configuration:

Core: "cylindrical"

length = 40.8 cm effective diameter = 40.6 cm

cell structure: 4124441246441244 where 1 = enriched U,
2 = depleted U, 4 = 63% Al, and 6 = stainless steel. All
plates are 0.318 cm thick. (See Section 1.1)

Blanket: 30.4 cm thick on all sides

Critical Mass: 138.6 kg U-235 in core

Composition of Core:

<u>Material</u>	<u>Volume %</u>	<u>Atom Concentration atom / cm³ x 10²²</u>
U-235	14	0.6729
U-238	16	0.7632
SS (304)	12	
Fe		0.7270
Ni		0.7292
Cr		0.1809
Mn		0.0075
Si		0.0089
Al	30	1.833
Void	28	

Composition of Blanket:

As for Assembly 1A

Measurements Made:

Prompt neutron lifetime (12.1-1-13)

Related Assemblies:

ZPR-3 Assemblies 1-4, 6A-6E (similar compositions)

Reference:

- (1) G. S. Brunson et al., "A Survey of Prompt-Neutron
Lifetimes in Fast Critical Systems" ANL-6681 (1963).

2.1-14

ZPR-3

Assembly 14

Type of Experiment: Critical (U-Graphite series)

Date: February, 1958

Critical Configuration:

Core: "cylindrical"

effective diameter = 46.3 cm

length = 45.9 cm

cell structure: 7777177777717777

where 1 = enriched U and 7 = Graphite

Blanket: 33 cm thick on all sides

Critical Mass: 136.0 kg U-235 in core. C.M. corrected
for heterogeneity (+2.6 kg), irregular boundary

(-0.1 kg) and central gap (-1.1 kg) = 137.4 kg U-235.

Composition of Core:

<u>Material</u>	<u>Volume %</u>	<u>Atom Concentration</u> <u>atoms/cm³ x 10²²</u>
U-235	9	0.4509
U-238	1	0.0336
U-234		0.0050
U-236		0.0019
C	64	5.353
Stainless Steel (304)	9	
Fe		0.5686
Ni		0.0619
Cr		0.1415
Mn		0.0059
Si		0.0069
Void	17	

Composition of Blanket:

As for Assembly 9A (2.1-9A)

2.1-14 (cont'd)

Measurements Made:

Central reaction rates (5.1-1-14)

Prompt neutron lifetime (12.1-1-14)

Related Assemblies:

ZPR-3 Assemblies 11, 12, 14, 16 and 17 form a series with variable C/U-238 ratio.

References:

1. W. G. Davey, "k Calculations for 22 ZPR-III Fast Reactor Assemblies Using ANL Cross-Sections Set 635" ANL-6570 (1962)
2. J. K. Long et al., "Fast Neutron Power Reactor Studies with ZPR-III", ICPUAE, Geneva, 1958, 12, 119

2.1-15

ZPR-3

Assembly 15

Type of Experiment: Critical (U-Al-SS, U-235: U-238 $\approx$ 1:3)

Date: February, 1958

Critical Configuration:

Core: "cylindrical"

length = 51.0 cm effective diameter = 57.4 cm

cell structure: 552512525a6a2512525 where 1 = enriched U, 2 = depleted U, 5 = 45% Al (perforated) and 6 = stainless steel.

"5a6a" indicates a 1 in. high column of 45% Al atop a 1 in. high column of SS. All plates are 0.318 cm thick. (See Section 1.1).

Blanket: at least 30 cm thick on all sides

Critical Mass: 220.4 kg U²³⁵ in core.

Composition of Core:

<u>Material</u>	<u>Volume %</u>	<u>Atom Concentration atoms / cm³ x 10²²</u>
U-235	9	0.4519
U-238	32	1.512
U-234		0.0050
U-236		0.0019
Al	19	1.170
Stainless steel (304)	12	
Fe		0.7270
Ni		0.0792
Cr		0.1809
Mn		0.0075
Si		0.0089
Void	28	

Related Assemblies:

ZPR-3 Assemblies 9, 9A and 9B (similar composition)

Reference:

J. K. Long, et al., "Fast Neutron Power Reactor Studies with ZPR-III," ICPUAE, Geneva, 1958, 12, 119.

2.1-16

ZPR-3

Assembly 16

Type of Experiment: Critical (U-Graphite series)

Date: February, 1958

Critical Configuration: (2)

Core: "cylindrical"

length = 51.0 cm effective diameter = 55.9 cm

cell structure = 2721272227221722 where 1 = enriched U
2 = depleted U and 7 = Graphite. All plates are 0.318
cm thick (See Section 1.1)

Blanket: at least 30 cm thick on all sides

Critical Mass = 204.8 kg U-235 in core. C.M. corrected for
heterogeneity (+10.2 kg), irregular boundary (-0.2 kg)
and central gap (-2.0 kg) = 212.8 kg U-235⁽¹⁾.

Composition of Core: (1)

<u>Material</u>	<u>Volume %</u>	<u>Atom Concentration</u> <u>atoms / cm³ x 10²²</u>
U-235	9	0.4509
U-238	50	2.405
U-234		0.0050
U-236		0.0019
C	18	1.516
Stainless Steel	9	
Fe		0.5686
Ni		0.0619
Cr		0.1415
Mn		0.0059
Si		0.0069
Void	14	

Composition of Blanket:

As for Assembly 9A

Measurements Made:

Central fission ratios (5.1.1-16)

Prompt neutron lifetime

2.1-16 (Cont'd)

ZPR-3

Assembly 16

Related Assemblies: ZPR-3 Assemblies 11, 12, 14, 16 and 17 form a set with variable C/U-238 ratio.

References:

- (1) W. G. Davey, "k Calculations for 22 ZPR-III Fast Reactor Assemblies Using ANL Cross Sections Set 635", ANL-6570 (1962).
- (2) J. K. Long et al., "Fast Neutron Power Reactor Studies with ZPR-III", ICUPAE, Geneva, 1958, 12, 119.

2.1-17

ZPR-3

Assembly 17

Type of Experiment: Critical (U-Graphite series)

Date: February, 1958

Critical Configuration: (2)

Core: "cylindrical"

length = 45.9 cm effective diameter = 49.5 cm

cell structure: 7277127772717277 where 1 = enriched U
2 = depleted U, and 7 = Graphite. All plates are 0.318
cm thick. (See Section 1.1).

Blanket: 33 cm thick on all sides

Critical Mass = 156.5 kg U-235 in core. CM corrected for
heterogeneity (+3.5 kg) irregular boundary (-0.1 kg)
and central gap (-1.4 kg) = 158.5 kg U-235. (1)

Composition of Core:

<u>Material</u>	<u>Volume %</u>	<u>Atom Concentration atoms / cm³ x 10²²</u>
U-235	9	0.4509
U-238	21	0.9888
U-234		0.0050
U-236		0.0019
C	46	3.826
Stainless steel	9	
Fe		0.5686
Ni		0.0619
Cr		0.1415
Mn		0.0059
Si		0.0069
Void	15	

Composition of Blanket:

as for Assembly 9A

2.1-17 (Cont'd)

ZPR-3

Assembly 17

Measurements Made:

Central fission ratios (5.1-1-17)

Prompt neutron lifetimes (12.1-1-17)

Related Assemblies:

ZPR-3 Assemblies 11, 12, 14, 16, and 17 form a set with variables C/U-238 ratio.

References:

- (1) W. G. Davey, "k Calculations for 22 ZPR-III Fast Reactor Assemblies Using ANL Cross-Section Set 635," ZPR-6570 (1962).
- (2) J. K. Long, et.al., "Fast Neutron Power Reactor Studies with ZPR-III," ICPUAE, Geneva, 1958, 12, 119.

2.1-20

ZPR-3

Assembly 20

Type of Experiment: Critical (Fermi A "clean core")Date: September, 1958Critical Configuration:

Fig. 1 Assembly 20 Cross-Section

Fig. 2 Transverse Section

Core: "cylindrical"

length = 76.40 cm effective diameter = 79.4 cm

cell structure: the basic cell spans 4 drawers and is made up as follows: 4842654214494244, 4824214562449424, 421428564294421, 4284424654214492 where all plates are 0.318 cm thick (see section 1.1) and 1 = enriched U, 2 = depleted U, 4 = 63% Al (perforated), 5 = 45% Al, 6 = SS (304), 8 = Zr, 9 = Mo. At some positions in the core "seeded" drawers were used in which U-235 replaces some U-238. (1)

Blanket: See Figure 2.

Critical Mass: 431.5 kg U-235 in core. CM corrected for heterogeneity (+15.2 kg), irregular boundary (-0.2 kg), and central gap (-3.0 kg) = 443.5 kg U-235. (3)

Fuel Worth at Core Edge: $\frac{\Delta M/M}{\Delta k/k} = 5.0$

Inhour Relation: 1% $\Delta k/k = 451$ Th

Composition of Core:

<u>Material</u>	<u>Volume %</u>	<u>Atom Concentration</u> <u>atoms/cm³ x 10²²</u>
U-235	6	0.2927
U-238	19	0.9065
U-234		0.0032
U-236		0.0012
Al	25	1.516
SS (304)	14	
Fe		0.8881
Ni		0.0967
Cr		0.2211
Mn		0.0092
Si		0.0108
Mo	5	0.3200
Zr	4	0.1828
Void	26	

Composition of Blanket:

<u>Material</u>	<u>Blanket 1*</u>	<u>Volume Concentration</u>			
		<u>2</u>	<u>3</u>	<u>4</u>	
U-235	0.1	0.1	0.1	0.1	
U-238	45	49	46	60	
Al	10	13	1	1	
SS (304)	19	21	17	7	
Mo	2				
Void	24	17	36	32	

- * Blanket 1 = Fine Blanket of Fig. 1
 Planket 2 = Medium Blanket (Region 1)
 Blanket 3 = Medium Blanket (Region 2)
 Blanket 4 = Coarse Blanket (Region 1 and 2)

<u>Material</u>	<u>Blanket 1</u>	<u>Atom Concentration, atoms/cm³ x 10²²</u>			
		<u>2</u>	<u>3</u>	<u>4</u>	
U-235	0.00481	0.00530	0.00530	0.00673	
U-238	2.179	2.338	2.225	2.860	
Al	0.608	0.8122	0.0519	0.0663	
Fe	1.211	1.309	1.038	0.456	
Ni	0.132	0.142	0.113	0.050	
Cr	0.310	0.326	0.258	0.113	
Mn	0.013	0.014	0.011	0.005	
Si	0.015	0.016	0.013	0.006	
Mo	0.157				

Measurements Made:

Central reactivity worths (large samples) ⁽¹⁾
Substitution (Na for Al) ⁽¹⁾
Reactivity worth of bunching ⁽¹⁾
Cell fission distribution (10.1-1-20)
Central fission ratios (5.1-1-20)
Spatial variation of reaction rates (5.2-1-20)
Temperature coefficient (8-1-20)
Prompt neutron lifetime (12.1-1-20)
Effect of counter position on Rossi- α (12.2-1-20)

Related Assemblies:

ZPR-3 Assembly 21 (2.1-21)

References:

- (1) C. E. Branyan, "Core A Critical Studies for the Enrico Fermi Atomic Power Plant on ZPR-III" ANL-6629 (October 1962).
- (2) F. W. Thalgott et al., "Fast Critical Experiments and Their Analysis", ICPUAE, Geneva 1964, 6, 124.
- (3) W. G. Davey, "k Calculations for 22 ZPR-III Fast Reactor Assemblies Using ANL Cross-Section Set 635" ANL-6570 (1962).

2.1-21

ZPR-3

Assembly 21

Type of Experiment: Critical (Fermi-A engineering mock-up)

Date: January, 1959

Description of Assembly:

This assembly duplicated, as closely as possible, the geometry and composition of the Fermi reactor (core A) including channels, end gaps, etc.

Measurements Made:

Radial worth of replacing U-238 by U-235
Worth of U-238 and Al in blanket
Central fission ratios and U-238 capture rate
Fission rate traverses
Control rod studies

Related Assemblies:

Fermi Core A, ZPR-3, Assembly 20

Reference:

C. E. Branyan, "Core A Critical Studies for the Enrico Fermi Atomic Power Plant on ZPR-III" ANL-6629 (1962).

2.1-22

ZPR-3

Assembly 22

Type of Experiment: Critical (U-SS, U-238 diluent)Date: April, 1959Critical Configuration:

Core: "cylindrical"

length = 51.0 cm effective diameter = 58.7 cm

cell structure: as for Assembly 11 (2.1-11)

Blanket: ~30.5 cm thick on all sides

Critical Mass: 243.7 kg U-235 in core. CM corrected
for heterogeneity (+14.3 kg), irregular boundary

(-0.2) and central gap (-5 kg) = 254.8 kg U-235.

Spherical CM (shape factor = .93) ⁽²⁾ = 237.0 kg
U-235Fuel Worth at Core Edge: $\frac{\Delta M/M}{\Delta k/k} = 7.0$ Composition of Core:

<u>Material</u>	<u>Volume %</u>	<u>Atom Concentration</u> <u>atoms / cm³ x 10²²</u>
U-235	9	0.4519
U-238	71	3.413
U-234		0.0050
U-236		0.0019
SS (304)	9	
Fe		5.779
Ni		0.0631
Cr		0.1442
Mn		0.0060
Si		0.0070
Void	10	

Composition of Blanket:

As for Assembly 9A (2.1-9A)

2.1-22 (Cont'd) ZPR-3

Assembly 22

Measurements Made:

Central reaction rates (5.1-1-22)

Prompt neutron lifetime (12.1-1-22)

Related Assemblies: Near duplicate of ZPR-3 Assembly 11
(2.1-11) and Zebra Assembly 1 (2.8-1)

References:

(1) D. Meneghetti and J. R. White, "Recent Calculations for Representative ZPR-III Assemblies" in ANL-7010 p. 110 (1964).

(2) W. G. Davey, "k Calculations for 22 ZPR-III Fast Reactor Assemblies Using ANL Cross Section Set 635" ANL-6570 (1962).

2.1-23

ZPR-3

Assembly 23

Type of Experiment: Critical (U-SS-Al)

Date: June, 1959

Critical Configuration:

Core: "cylindrical"

length = 51.0 cm effective diameter = 60.9

cell structure: 4441444444441444 where 1 = enriched
U and 4 = 63% (perforated) Al. All plates are
0.318 cm thick (See Section 1.1)

Blanket: Approximately 30 cm thick on all sides

Critical Mass: 258.1 kg U-235 in core. CM corrected
for heterogeneity (+9.8 kg), irregular boundary
(-0.2 kg) and central gap (-3.0 kg) = 264.7 kg
U-235⁽¹⁾. Spherical CM (shape factor = 0.944)
= 249.9 kg U-235⁽²⁾

Fuel worth at core edge: $\frac{\Delta M/M}{\Delta k/k} = 4.5$

Composition of Core:

<u>Material</u>	<u>Volume %</u>	<u>Atom Concentration</u> <u>atoms /cm³ x 10²²</u>
U-235	9.27	0.4456
U-238	0.70	0.0336
U-234		0.0049
U-236		0.0019
SS (304)	9.2	
Fe		0.5717
Ni		0.0642
Cr		0.1427
Mn		0.0060
Si		0.0070
Al	42.82	2.582
Void	38.03	

Composition of Blanket:

As for assembly 9A (2.1-9A)

Measurements Made:

Central reaction rates (5.1-1-23)

Prompt neutron lifetime (12.1-1-23)

References:

(1) W. G. Davey, "k Calculations for 22 ZPR-III Fast Reactor Assemblies Using ANL Cross Section Set 635" ANL-6570 (1962).

(2) D. Meneghetti and J. R. White, "Recent Calculations for Representative ZPR-III Fast Assemblies", p. 110 in ANL-7010 (1964).

2.1-24

ZPR-3

Assembly 24

Type of Experiment: Critical (U-SS)Date: September, 1959Critical Configuration:

Core: "cylindrical"

length = 71.27 cm effective diameter = 76.88 cm

cell structure: The unit cell spanned five drawers containing enriched and depleted plates as follows: 2(2)12(10)12(2), 2(7)12(8), 2 12(9)12(4), 2(4)12(9)12, 2(8)12(7) where 1 = enriched U and 2(7) indicates 7 thicknesses of depleted U. All plates are 0.318 cm thick. (See Section 1.1)

Blanket:

radial thickness = 33.7 cm end thickness = 30.5 cm

Critical Mass:

460.7 kg U-235 in core, CM corrected for heterogeneity (+35.7 kg), irregular boundary (-0.4 kg), and central gap (-6.0 kg) = 490.0 kg U-235. Spherical CM (shape factor = 0.92) = 450.8 kg U-235.

Fuel Worth at Core Edge: $\frac{\Delta M/M}{\Delta k/k} = 9.4$

Composition of Core:

<u>Material</u>	<u>Volume %</u>	<u>Atom Concentration</u> <u>atoms / cm³ x 10²²</u>
U-235	8	0.3639
U-238	73	3.449
U-234		0.0040
U-236		0.0015
SS (304)	9	
Fe		0.5779
Ni		0.0631
Cr		0.1442
Mn		0.0060
Si		0.0070
Void	10	

2.1-24 (Cont'd) ZPR-3

Assembly 24

Composition of Blanket:

as for Assembly 9A (2.1-9A)

Measurements Made:

Central fission ratios (5.1-1-24)

Prompt neutron lifetime (12.1-1-24)

Related Assemblies:

ZPR-3 Assembly 38 (spherical version)

Reference:

W. G. Davey, "k Calculations for 22 ZPR-III Fast Reactor Assemblies Using ANL Cross-Section Set 635" ANL-6570 (1962).

Type of Experiment: Critical (U-SS)

Date: November, 1959

Critical Configuration:

Core: "cylindrical"

length = 76.3 cm diameter = 83.2 cm

cell structure: The unit cell spanned 2 drawers as follows: 212(10) 12(3); 2(7) 12(10) where 1 = enriched U and 2 = depleted U. 2(3) indicates 3 thicknesses of depleted U. All plates are 0.318 cm thick (See Section 1.1).

Blanket: radial thickness = 40.8 cm; end thickness = 30.5 cm

Critical Mass: 581.6 kg in core. CM corrected for heterogeneity (+37.7 kg), irregular boundary (-0.4kg) and central gap (-6.0 kg) = 612.9 kg U-235.

Spherical CM (shape factor = 0.92) = 563.9 kg U-235.

Fuel Worth at Core Edge: $\frac{\Delta M/M}{\Delta k/k} = 7.2$

Composition of Core:

<u>Material</u>	<u>Volume %</u>	<u>Atom Concentration</u> <u>atoms / cm³ x 10²²</u>
U-235	7	0.3447
U-238	74	3.560
U-234		0.0038
U-236		0.0014
SS (304)	9	
Fe		0.5530
Ni		0.0604
Cr		0.1379
Mn		0.0057
Si		0.0067
Void	10	

Composition of Blanket:

As for Assembly 9A (2.1-9A)

Measurements Made:

Central reaction rates (5.1-1-25)

Prompt neutron lifetime (12.1-1-25)

Reference:

(1) W. G. Davey, "k Calculations for 22 ZPR-III, Fast Reactor Assemblies Using ANL Cross-Section Set 635", ANL-6570 (1962).

2.1-27

ZPR-3

Assembly 27

Type of Experiment: Critical - to study a configuration representative of an accidental meltdown.

Date: 1960

Critical Configuration:

An annular core of "normal" composition surrounded a dense interior core of reduced height. Above the interior core was a void region. The approximate compositions of the core regions were:

<u>Material</u>	<u>Volume Percent</u>	
	<u>Interior Core</u>	<u>Annular Core</u>
U-235	14	6
U-238	41	20
SS (304)	14	15
Al		26
Mo	15	5
Zr	5	5
Void	11	23

Measurements Made:

Spatial distributions of fission rates and U sample worths.

Related Assemblies:

ZPR-3 Assembly 28

Reference:

- (1) W. Gemmell, J.K. Long, and W. P. Keeney, "Experimental Investigations of Secondary Critical Configurations (ZPR-III Assemblies 27 and 28)" ANL-6866 (1964).

2.1-28

ZPR-3

Assembly 28

Type of Experiment: Critical - to study a configuration representative of an accidental meltdown.

Date: 1960

Critical Configuration:

A central void region is partially surrounded by an annular dense core and these are surrounded by a blanket. The composition of the dense core is the same as that in Assembly 27 (2.1-27).

Measurements Made:

Spatial variation of fission rates and uranium sample weights.

Related Assemblies:

ZPR-3 Assembly 27

Reference:

W. G. Gemmell, J. K. Long, and W. P. Keeney, "Experimental Investigations of Secondary Critical Configurations (ZPR-III Assemblies 27 and 28)" ANL-6866 (1964).

Type of Experiment: Critical (dilute UO_2 core)

Date: October, 1960

Critical Configuration:

Fig. 1 Assembly 29 Loading Pattern

Core: "cylindrical"

length = 71.27 cm effective diameter = 90.12 cm
cell structure: 6A2AA1AA2*A665555 where 1 = enriched
U, 2 = depleted U, 5 = 45% (perforated) Al, 6 = SS
(304) and A = Al_2O_3 . All plates are 0.318 cm thick
(see Section 1.1). In 56 of the total 416 core drawers
the U-238 plate indicated by an asterisk was replaced
by two half-height plates, one of U-238 and one of
U-235. These "seeded" drawers were uniformly distri-
buted throughout the core.

Blanket: axial thickness = 30.48 cm. radial thickness = 29.97 cm

Critical Mass: 420.7 kg U-235 in core. CM corrected for hetero-
geneity (+24.0 kg), irregular core boundary (-0.2 kg) and
central gap (-3.0 kg) = 441.5 kg U-235⁽²⁾. Spherical CM
(shape factor = 0.91) = 401.8 kg U-235.

Fuel Worth at Core Edge: $\frac{\Delta M/M}{\Delta k/k} = 5.4$

Composition of Core:

<u>Material</u>	<u>Volume %</u>	<u>Atom Concentration</u> <u>atoms / cm³ x 10²²</u>
U-235	5	0.2389
U-238	10	0.4790
U-234		0.0026
U-236		0.0010
SS (304)	25	
Fe		1.529
Ni		0.1669
Cr		0.3815
Mn		0.0186
Si		0.0218
Al	24	1.471
O	15	1.393
Void	21	

Composition of Blanket:

As for Assembly 9A (2.1-9A)

Measurements Made:

Prompt neutron lifetime (12.1-1-29)
 Central fission ratios (5.1-1-29)
 Spatial distribution of reaction rates (5.2-1-29)
 Effect of local bunching on U-236/U-235
 fission ratio (10.4-1-29)
 Spatial distributions of sample reactivity worths (4.2-1-29)
 Central reactivity worths

Related Assemblies:

ZPR-3 Assemblies 30 and 31 (similar composition)

References:

- (1) A. L. Hess, et al., "Critical Studies of a 450-liter Uranium Oxide Fast Reactor Core (ZPR-III Assembly 29)" ANL-6336 (1961).
- (2) W. G. Davey, "k Calculations for 22 ZPR-III Fast Reactor Assemblies Using ANL Cross Section Set 635" ANL-6570 (1962).

Type of Experiment: Critical (Simulated UO core)

Date: December, 1960

Critical Configuration:

Fig. 1 Assembly 30 Loading Pattern

Core: "cylindrical"

length = 66.19 cm effective diameter = 82.8 cm
 cell structure: a unit cell spanned 4 drawers as follows: 556A12A6555556A2, 51A65552A5665A15, 2A6555556A21A655, 5A265551A5662A55, where 1 = enriched U, 2 = depleted U, 5 = 45% density (perforated) Al, 6 = SS (304) and A = Al₂O₃. All plates are 0.318 cm thick. (See Section 1.1)

Blanket: depleted uranium 30 cm thick on all sides

Critical Mass: 394.9 kg U-235 in core. CM corrected for heterogeneity (+22.5 kg), irregular boundary (-0.2 kg), and central gap (-3.0 kg) = 414.2 kg U-235 (2) = 376.9 kg U-235.

Fuel Worth at Core Edge: $\frac{\Delta M/M}{\Delta k/k} = 5.7$

Composition of Core:

<u>Material</u>	<u>Volume %</u>	<u>Atom Concentration atoms / cm³ x 10²²</u>
U-235	6	0.2840
U-238	9	0.4338
U-234		0.0031
U-236		0.0011
SS (304)	25	
Fe		1.522
Ni		0.1662
Cr		0.3800
Mn		0.0159
Si		0.0185
Al	23	1.408
O	7	0.6970
Void	30	

Composition of Blanket:

As for Assembly 9A (2.1-9A)

Measurements Made:

Prompt neutron lifetime (12.1-1-30)
Central fission ratios (5.1-1-30)
Reactivity coefficients for distributed materials (9-1-30)
Central reactivity worths
Reactivity worth of bunching

Related Assemblies:

ZPR-3 Assemblies 29, 31 (related compositions)

References:

- (1) P. I. Amundson et al., "Critical Studies of a Dilute Oxide Fast Reactor Core (ZPR-III Assembly 30)" ANL-6337 (1961).
- (2) W. G. Davey, "k Calculations for 22 ZPR-III Fast Reactor Assemblies Using ANL Cross-Section Set 635" ANL-6570 (1962).

Type of Experiment: Critical (dilute U-Al-SS)

Date: January, 1961

Critical Configuration:

Fig. 1 Assembly 31 Loading Pattern

Core: "cylindrical"

length = 66.2 cm effective diameter = 90.4 cm

cell structure: a unit cell spanned 4 drawers as follows:
5565125655555642, 5156555255665415, 2565555565214655,
5526555155662455 where 1 = enriched U, 2 = depleted U,
4 = 63% density Al (perforated), 5 = 45% Al, 6 = SS (304).
All plates are 0.318 cm thick (see Section 1.1). (In some
core drawers, stainless steel pieces, 1/8 x 2 x 13 in. and
enriched U pieces 1 x 2 in. or 1 x 3 in. were used. This
produced an increased stainless steel mass of ~ 10% and a
0.5% to 1.65% increase in the U-235 mass for these drawers.
Such "high mass" drawers are marked x in Figure 1)

Blanket: depleted uranium, axial thickness = 33.0 cm, radial
thickness = 27.5 cm.

Critical Mass: 463.0 kg U-235 in core. CM corrected for heterogeneity (+ 25.9 kg), irregular boundary (-0.2 kg) and central gap (-3.0 kg) = 485.7 kg U-235⁽²⁾. Spherical CM: see 2.1-39

Fuel Worth at Core Edge: $\frac{\Delta M/M}{\Delta k/k} = 5.6$

Composition of Core:

<u>Material</u>	<u>Volume %</u>	<u>Atom Concentration atoms / cm³ x 10²²</u>
U-235	6	0.2793
U-238	9	0.4387
U-234		0.0030
U-236		0.0012
SS (304)	25	
Fe		1.524
Ni		0.1664
Cr		0.3805
Mn		0.0159
Si		0.0185
Al	23	1.416
Void	37	

Composition of Blanket:

As for Assembly 9A (2.1-9A)

Measurements Made:

Prompt neutron lifetime (12.1-1-31)
Central fission ratios (5.1-1-31)
Central reactivity worths (4.1-1-31)

Related Assemblies:

ZPR-3 Assemblies 29 and 30 (similar compositions), and Assembly 39 (a spherical version).

References:

- (1) J. M. Gasidlo, J. K. Long, and R. L. McVean, "Critical Studies of a Dilute Fast Reactor Core (ZPR-III Assembly 31)" ANL-6338 (1961).
- (2) W. G. Davey, "k Calculations for 22 ZPR-III Fast Reactor Assemblies Using ANL Cross-Section Set 635", ANL-6570 (1962).

Type of Experiment: Critical (U-SS)

Date: February, 1961

Critical Configuration:

Fig. 1 Assembly 32 Loading Pattern

Core: "cylindrical"

length = 61.1 cm effective diameter = 52.4 cm
cell structure: 6661666666661666 where 1 = enriched U
and 6 = SS (304). All plates are 0.318 cm thick (see
Section 1.1)

Blanket: depleted U, 45 cm thick on all sides. In the outer
blanket region the depleted U was loaded directly into
the matrix.

Critical Mass = 227.5 kg U-235 in core. CM corrected for
heterogeneity (+9.7 kg), irregular boundary (-0.2 kg)
and central gap (-3.0 kg) = 234.0 kg U-235⁽²⁾. Spheri-
cal CM (shape factor = 0.932) = 218.1 kg U-235⁽³⁾

Fuel Worth at Core Edge: $\frac{\Delta M/M}{\Delta k/k} = 4.2$

Composition of Core:

<u>Material</u>	<u>Volume %</u>	<u>Atom Concentration atoms/cm³ x 10²²</u>
U-235	9	0.4451
U-238	1	0.0317
U-234		0.0049
U-236		0.0019
SS (304)	81	
Fe		5.033
Ni		0.5496
Cr		1.256
Mn		0.0525
Si		0.0612
Void	9	

Composition of Blanket:

As for Assembly 9A (2.1-9A)

Measurements Made:

Spatial variation of reactivity worths (4.2-1-32)
 Prompt neutron lifetime (12.1-1-32)
 Central fission ratios (5.1-1-32)
 Radial fission rate traverses (5.2-1-32)
 Central sample reactivity worths (4.1-1-32)
 Reactivity effect of heterogeneity (10.2-1-32)

Related Assemblies:

ZPR-3 Assembly 33 (related composition)

References:

- (1) P. I. Amundson, et al., "Critical Studies of Uranium-Steel and Uranium-Steel-Sodium Fast Reactor Cores (ZPR-III Assemblies 32 and 33)" ANL-6690 (1963).
- (2) W. G. Davey, "k Calculations for 22 ZPR-III Fast Reactor Assemblies Using ANL Cross-Section Set 635" ANL-6570 (1962).
- (3) D. Meneghetti and J. R. White, "Recent Calculations for Representative ZPR-III Fast Assemblies" p. 110 in ANL-7010 (1964).

Type of Experiment: Critical (U-SS-Na)

Date: March, 1961

Critical Configuration:

Fig. 1 Assembly 33 Loading Pattern

Core: "cylindrical"

length = 61.1 cm effective diameter = 53.5 cm

cell structure = 66616NN66NN61666 where 1 = enriched U,
6 = SS (304) and N = Na in SS cans: All plates are 0.318
cm thick (see Section 1.1)

Blanket: depleted uranium - 45 cm thick on all sides. In the
outer blanket region (see Fig. 1) depleted U was loaded
directly into the matrix.

Critical Mass = 238.0 kg U-235 in core. CM corrected for hetero-
geneity (+9.7 kg), irregular boundary (-0.2 kg) and central
gap (-3.0 kg) = 244.5 kg U-235⁽²⁾. Spherical CM (shape
factor = 0.93) = 227.4 kg U-235⁽³⁾.

Fuel Worth at Core Edge: $\frac{\Delta M/M}{\Delta k/k} = 4.4$

2.1-33 (Cont'd)

Composition of Core:

<u>Material</u>	<u>Volume %</u>	<u>Atom Concentration</u> <u>atoms/cm³ x 10²²</u>
U-235	9	0.4451
U-238	1	0.0317
U-234		0.0049
U-236		0.0019
SS (304)	64	
Fe		3.950
Ni		0.4313
Cr		0.9858
Mn		0.0412
Si		0.0481
Na	18	0.4005
Void	8	

Composition of Blanket:

As for Assembly 9A (2.1-9A)

Measurements Made:

Prompt neutron lifetime (12.1-1-33)
Central reactivity worths (4.1-1-33)
Spatial variation of reactivity worths (4.2-1-33)
Central fission rates (5.1-1-33).
Spatial variation of reaction rates (5.2-1-33)

References:

- (1) P. I. Amundson et al., "Critical Studies of Uranium-Steel and Uranium-Steel Sodium Fast Reactor Cores (ZPR-III Assemblies 32 and 33)", ANL-6690 (1963).
- (2) W. G. Davey, "k Calculations for 22 ZPR-III Fast Reactor Assemblies Using ANL Cross Section Set 635", ANL-6570 (1962).
- (3) D. Meneghetti and J. R. White, "Recent Calculations for Representative ZPR-III Fast Assemblies", p. 110 in ANL-7010 (1964).

Type of Experiment: Critical (simulated dilute UC core)

Date: May, 1961

Critical Configuration:

Fig. 1 Assembly 34 Loading Pattern

Core: "cylindrical"

length = 86.36 cm effective diameter = 92.04 cm

cell structure: 6554327172345566 where 1 = enriched U
2 = depleted U, 3 = Al, 4 = 63% (perforated) Al, 5 = 45%
Al, 6 = SS (304) and 7 = Graphite. All plates are 0.318
cm thick (see Section 1.1).

Blanket: depleted U; radial thickness = 30.5 cm, axial thick-
ness = 20.3 cm. After the critical experiment, the thick-
ness of the radial blanket was reduced to 20 cm. (See
Figure 1).

Critical Mass = 503.0 kg U-235 in core. CM corrected for hetero-
geneity (+24.9 kg), irregular boundary (-0.4 kg) and central
gap (-6.0 kg) = 521.5 kg U-235⁽²⁾. Spherical CM (shape factor
= 0.92)⁽³⁾ = 479.8 kg U-235.

Fuel Worth at Core Edge: $\frac{\Delta M/M}{\Delta k/k} = 5.0$

Composition of Core:

<u>Material</u>	<u>Volume %</u>	<u>Atom Concentration</u> <u>atoms/cm³ x 10²²</u>
U-235	5	0.2245
U-238	10	0.4968
U-234		0.0025
U-236		0.0009
SS (304)	25	
Fe		1.531
Ni		0.1672
Cr		0.3822
Mn		0.0160
Si		0.0186
Al	25	1.535
C	9	0.7633
Void	26	

Composition of Blanket:

As for Assembly 9A (2.1-9A)

Measurements Made:

Central reaction rates (5.1-1-34)
 Spatial variation of fission rates (5.2-1-134)
 Central reactivity worths
 Reactivity worth of bunching
 Prompt neutron lifetime (12.1-1-34)
 Reactivity worths of distributed materials (9-1-34).

References:

- (1) R. J. Huber et al., "Critical Studies of a Dilute Carbide Fast Reactor Core-ZPR-III Assembly 34", ANL-6401 (1961).
- (2) W. G. Davey, "k Calculations for 22 ZPR-III Fast Reactor Assemblies Using ANL Cross-Section Set 635", ANL-6570 (1962).
- (3) D. Meneghetti and J. R. White, "Recent Calculations for Representative ZPR-III Fast Assemblies", p. 110 in ANL-7010 (1964).

Type of Experiment: Critical (Fermi Core B Mockup)

Date: August, 1961 - February, 1962

Critical Configuration:

An eight-drawer module including plates of U-235, Fe_2O_3 , Na, and SS was used in the core. Several blanket regions were required. An inner Ni reflector was studied.

Measurements Made:

- Temperature coefficient
- Prompt neutron lifetime
- Reactivity effect of axial core expansion
- Reactivity worth of oscillator
- Reactivity worth of heterogeneity (bunching)
- Distributed material worths
- Variation of sodium reactivity coefficient with sodium density
- Spatial variation of sample reactivity worths
- Central fission ratios

Reference:

T. A. Doyle and A. L. Hess, "Critical Studies of Core B for the Enrico Fermi Atomic Power Plant (ZPR-III Assembly No. 35)" ANL-6669 (1963).

Type of Experiment: Critical (U-Na-SS)

Date: June, 1961

Critical Configuration:

Fig. 1 Assembly 36 Loading Pattern

Core: "cylindrical"

length = 71.3 cm effective diameter = 49.6 cm

cell structure: 22212N22N21222 where 1 = enriched U and 2 = depleted U. These plates are 0.318 cm thick (see Section 1.1) N = Na plates 0.635 cm thick (x5.08 cm x 17.78 cm deep).

Blanket: depleted uranium; radial thickness = 35 cm, axial thickness = 35.5 cm

Critical Mass = 242.7 kg U-235 in core. CM corrected for heterogeneity (+10.4 kg), irregular boundary (-0.2 kg) and central gap (-3.0 kg) = 249.9 kg U-235(2). Spherical CM (shape factor = .87) = 217.4 kg U-235

Fuel Worth at Core Edge: $\frac{\Delta M/M}{\Delta k/k} = 4.3$

2.1-36 (Cont'd)

Composition of Core:

<u>Material</u>	<u>Volume %</u>	<u>Atom Concentration</u> <u>atoms/cm³ x 10²²</u>
U-235	9	0.4505
U-238	50	2.376
U-234		0.0050
U-236		0.0019
SS (304)	13	
Fe		0.7879
Ni		0.0860
Cr		0.1967
Mn		0.0082
Si		0.0096
Na	18	0.4011
Void	10	

Composition of Blanket:

As for Assembly 9A

Measurements Made:

Central reaction rates (5.1-1-36)
Spatial variation of fission rates (5.2-1-36)
Central sample reactivity worths (4.1-1-36)
Prompt neutron lifetime (12.1-1-36)

Related Assemblies:

Assembly 36 was derived from ZPR-3 Assembly 22 by replacing part of the U-238 diluent by Na.

References:

- (1) J. M. Gasidlo, J. K. Long, and R. L. McVean, "Critical Studies of a Fast Reactor Core Containing Depleted Uranium and Sodium as Diluents (ZPR-III Assembly 36)", ANL-6494 (1962).
- (2) W. G. Davey, "k Calculations for 22 ZPR-III Fast Reactor Assemblies Using ANL Cross-Section Set 635", ANL-6570 (1962).

2.1-37 ZPR-3 Assembly 37

Type of Experiment: Subcritical

Date: July, 1961

Description of Assembly:

This assembly was constructed to measure the gamma dose rate, neutron flux, and core temperature buildup as a function of time for a subcritical assembly fueled with plutonium. It was loaded to a k_{eff} of approximately 0.4. For a description of the assembly, volume ratios, and results, see reference 1.

Related Assemblies:

ZPR-3, Assembly 2.

Reference:

- (1) P. I. Amundson, et al., "A Subcritical Plutonium-Fueled Fast Reactor Core (ZPR-III Assembly 37)", ANL-6595 (1962).

Type of Experiment: Critical (spherical, U-SS)

Date: March, 1962

Critical Configuration:

Fig. 1 Assembly 38 Loading Pattern

Core: "spherical", effective radius = 41.5 cm
cell structure: as for Assembly 24

Blanket: depleted uranium, 31 cm thick

Critical Mass: (of a pure spherical version) = 424 ± 1.5 kg
U-235 in the core. The uncertainty derives from the
correction for the somewhat flattened shape. CM corrected
for heterogeneity (+ 32.9 kg), irregular boundary (-0.4 kg)
and central gap (-5.5 kg) = 451 ± 2 kg U-235 (based on
values for Assembly 24) (2)

Fuel Worth at Core Edge = 13.8 lh/kg U-235.

Composition of Regions:

as for Assembly 24

2.1-38 (Cont'd)

Measurements Made:

Central and core edge sample reactivity worths
Central fission ratios (5.1-1-24)

Related Assemblies:

ZPR-3 Assembly 24 (cylindrical equivalent)

References:

- (1) J. C. Bates, et al., "Two Spherical Fast Critical Experiments (ZPR-III Assemblies 38 and 39)", ANL-6582 (1962).
- (2) W. G. Davey, "k Calculations for 22 ZPR-III Fast Reactor Assemblies Using ANL Cross-Section Set 635", ANL-6570 (1962).

Type of Experiment: Critical (spherical U-SS-Al)

Date: April, 1962

Critical Configuration:

Fig. 1 Assembly 39 Loading Pattern

Core: "spherical", effective radius = 45.4 cm
cell structure: as for Assembly 31 (2.1-31)

Blanket: depleted uranium, 30 cm thick

Critical Mass = 426.5 kg U-235 in core. CM corrected for heterogeneity (+23.9 kg), irregular boundary (-0.2 kg) and central gap (-2.7 kg) = 447.5 kg U-235 (based on values for Assembly 31) (2)

Fuel Worth at Core Edge = 25.4 ± 2.0 Ih/kg

Composition of Regions:

As for Assembly 31 (2.1-31)

Measurements Made:

Sample reactivity worths at core center (4.1-1-39)

Central fission ratios: the values of Assembly 31 were verified (see 5.1-1-31)

Spatial variation of fission rates (5.2-1-39)

Shape factor (3-1-24)

Related Assemblies:

ZPR-3 Assembly 31 (cylindrical equivalent)

References:

- (1) J. C. Bates, et al., "Two Spherical Fast Critical Experiments (ZPR-III Assemblies 38 and 39)", ANL-6582 (1962).
- (2) W. G. Davey, "k Calculations for 22 ZPR-III Fast Reactor Assemblies Using ANL Cross-Section Set 635", ANL-6570 (1962).

Type of Experiment: Critical (dilute U-235, U-238, Al, SS)

Date: September - December, 1962.

Critical Configuration:

Core: "cylindrical"

length = 81.43 cm effective diameter = 93.10 cm

cell structure: the unit cell spanned four drawers as follows:

5252515652525252, 5152525652525251, 5252525652515252,
5252525615252525 where 1 = enriched U, 2 = depleted U, 5 =
45% Al (perforated) and 6 = stainless steel. All plates
are 0.318 cm thick. (see Section 1.1)

Critical mass: 493.75 kg of U-235 in core.

Fuel Worth at Core Edge: $\frac{\Delta M/M}{\Delta k/k} = 5.8$

Composition of Core:

<u>Material</u>	<u>Volume %</u>	<u>Atom Concentration</u> <u>atoms/cm³ x 10²²</u>
U-235	6	0.2864
U-238	29	1.3964
U-234		0.0029
U-236		0.0012
SS (304)	14	
Fe		0.8774
Ni		0.0955
Cr		0.2183
Mn		0.0091
Si		0.0107
Al	18	1.0785
Void	33	

Composition of Blanket:

as for Assembly 9A (2.1-9A)

Measurements Made:

Central sample reactivity worths, including sample size effects (4.3-1-41)

Central fission ratios (5.1-1-41)

Prompt neutron lifetime (12.1-1-41)

Reactivity effect of fuel bunching

2.1-41 (Cont'd)

Reference:

A. L. Hess et al, "Critical Studies of a 440 liter Fast Reactor Core Fueled with 35 v/o Uranium Enriched to 17 a/o (Assembly 41)", ANL-6732 (to be published).

Type of Experiment: Critical (dilute carbide core-zoned) to test feasibility of zoned critical experiments.

Date: January - March, 1963

Critical Configuration:

The cylindrical core consists of two fuel zones separated by a filter of depleted uranium. These are blanketed by depleted uranium.

Fig. 1 Assembly 42 Loading Pattern

Core: "cylindrical"

length = 86.5 cm effective diameter = 23.4 cm
cell structure: as for Assembly 34 (2.1-34)

Filter: length = 86.5 cm effective thickness = 1.8 cm

Driver: outer effective radius = 33.8 cm

Blanket: outer effective radius = 70.2 cm

Critical Mass = 379.4 kg U-235 in core (does not include
0.7 kg U-235 in filter)

Fuel Worth at Edge of Driver = 25 lh/kg U-235

Inhour Conversion: $1\% \Delta k/k = 409 \text{ lh}$

2.1-42 (Cont'd)

Composition of Core Regions:

Approximate Volume %			
<u>Material</u>	<u>Central Zone</u>	<u>Filter</u>	<u>Driver</u>
U-235	5	0.2	9
U-238	11	80	7
SS (304)	23	7	29
Graphite	13		44
Al	26		
Void	23	13	11

Atom Concentration, atoms/cm ³ x 10 ²²			
<u>Material</u>	<u>Central Zone</u>	<u>Filter</u>	<u>Driver</u>
U-235	0.2422	0.0082	0.4466
U-238	0.5280	3.845	0.3139
U-234	0.0026	0.0001	0.0048
U-236	0.0010		0.0019
Fe	1.404	0.4288	1.777
Ni	0.1533	0.0468	0.1941
Cr	0.3505	0.1070	0.4436
Mn	0.0146	0.0045	0.0185
Si	0.0171	0.0052	0.0216
C	0.8968		3.680
Al	1.544		

Compositions of Blanket Regions:

<u>Material</u>	Volume %		
	<u>Radial Inner</u>	<u>Radial Outer</u>	<u>Axial</u>
U-235	.2	.2	.2
U-238	84	83	82
SS (304)	9	7	9
Al			
Void	7	9	8

Atom Concentration, atoms/cm ³ x 10 ²²			
<u>Material</u>	<u>Radial Inner</u>	<u>Radial Outer</u>	<u>Axial</u>
U-235	0.0082	0.0082	0.0082
U-238	4.008	3.989	3.950
Fe	0.5655	0.4536	0.5779
Ni	0.0617	0.0495	0.0631
Cr	0.1411	0.1132	0.1441
Mn	0.0059	0.0047	0.0060
Si	0.0069	0.0055	0.0070
Al			0.0012

Measurements Made:

Plate orientation effects (10.2-1-42a)
Fuel bunching effects (10.2-1-42b)
Central reactivity worths (4.1-1-42)
Spatial variation of reactivity worths (4.2-1-42)
Spatial variation of reaction rates (5.2-1-42)
Central reaction rates (5.1-1-42)
Neutron lifetimes (12.1-1-42)
Effect of counter position on lifetimes (12.2-1-42)

Related Assemblies:

ZPR-3 Assembly 34 (one zone version)

Reference:

P. I. Amundson, et al., "A Two-Zone Fast Critical Experiment",
ANL-6733 (1964).

2.1-43

ZPR-3

Assembly 43

Type of Experiment: Critical (Simulated dilute UC-Na core) zoned.

Date: February - August, 1963

Critical Configuration:

The cylindrical core consists of two fuel zones separated by a buffer of depleted uranium and graphite. See Figure 1 and 2.

Figure 1
Assembly 43 Interface View

2.1-43 (cont'd)

Figure 2
Critical Configuration

Central Zone:

length = 86.51 cm effective diameter = 48.80 cm
cell structure: NN27N126N72N where 1 = enriched U (0.159 cm thick), 2 = depleted U (0.318 cm), 6 = stainless steel (0.159 cm), 7 = graphite (0.318 cm) and N = Na (0.635 cm). See 1.1 for description of plates.

Buffer:

length = 86.51 cm effective outer radius = 31.39 cm
cell structure: 2727272272727272 (as defined above).

Driver:

length = 86.51 cm effective outer radius = 45.26 cm
cell structure: 7671766767717667 as defined above except that here all plates are 0.318 cm thick.

Axial Blanket: (low density)

length = 38.1 cm (each end) effective radius = 24.40 cm
cell structure: NN27N26N72N where all plates are 0.318 cm thick except N which are 0.635 cm.

2.1-43 (cont'd)

Outer Blanket: (depleted uranium)

length = 142.3 cm (see figure 2) effective radius = 75.7 cm

Critical Mass = 588.1 kg U-235 (72.06 kg in central zone,
1.88 kg in buffer and 514.16 kg in the driver).

Fuel Worth at Edge of Driver = 29.2 lh/kg U-235

Inhour Conversion: $1\% \Delta k/k = 444.4 \text{ lh}$

Composition of Core Regions:

<u>Material</u>	Volume %		
	<u>Central Zone</u>	<u>Buffer</u>	<u>Driver</u>
U-235	2	0.1	10
U-238	15	45	0.7
Graphite	10	35	39
SS (304)	20	9	40
Na	48		
Void	5	11	10

<u>Material</u>	Atom Concentration, atoms/cm ³ x 10 ²²		
	<u>Central Zone</u>	<u>Buffer</u>	<u>Driver</u>
U-235	0.1141	0.0045	0.4566
U-238	0.7318	2.171	0.0326
U-234	0.0013		0.0050
U-236	0.0005		0.0020
C	0.8321	2.912	3.295
Na	1.061		
Fe	1.215	0.5696	2.506
Ni	0.1326	0.0622	0.2736
Cr	0.3032	0.1422	0.6255
Mn	0.0127	0.0059	0.0261
Si	0.0148	0.0069	0.0305

2.1-43 (cont'd)

Composition of Blanket Regions:

<u>Material</u>	<u>Volume %</u>	
	<u>Axial Blanket</u>	<u>Radial Blanket</u>
U-235	0.03	0.2
U-238	15	83
Graphite	10	
Na	48	
SS (304)	22	7
Void	5	9

<u>Material</u>	<u>Atom Concentration, atoms/cm³ x 10²²</u>	
	<u>Axial Blanket</u>	<u>Radial Blanket</u>
U-235	0.00153	0.00912
U-238	0.7207	3.998
C	0.8298	
Na	1.055	
Fe	1.361	0.4542
Ni	0.1487	0.0496
Cr	0.3398	0.1134
Mn	0.0142	0.0047
Si	0.0166	0.0055

Measurements Made:

Effect of counter position on lifetimes (12.2-1-43)
Central reaction rates (5.1-1-43)
Spatial variation of reaction rates (5.2-1-43), (5.2-1-43a)
Prompt neutron lifetime (12.1-1-43)
Central reactivity worths (4.1-1-43)
Na void coefficient (6-1-43)
Doppler coefficient (7-1-43), (7-1-43A)

Related Assemblies: ZPR-3 Assembly 43A

Reference:

J. M. Gasidlo, J. K. Long and W. P. Keeney, "Doppler Effect Measurements, Sodium Void Coefficients, and Critical Studies of a 5,000-Liter Fast Power Breeder Reactor by the Two-Zone Method" ANL-6838 (1964)

2.1-43A

ZPR-3

Assembly 43A

Type of Experiment: Critical (zoned, U-Na-C)

Date: August, 1963

Critical Configuration:

Figure 1
Assembly 43A Loading Pattern

This assembly was geometrically identical to Assembly 43 (See figures 1 and 2 of Section 2.1-43) with the exception of a slight decrease in the thickness of the driver region (see figure 1) and with the following changes in cell structure:

Core: N727N71267N727 where 1 = enriched U (0.159 cm thick), 2 = depleted U (0.318 cm), 6 = Stainless steel (0.159 cm), 7 Graphite (0.318 cm) N= Na (0.635 cm).

Buffer: 7277272727272727

Axial Blanket (first 10.2 cm): N727N7267N727 where here the stainless steel plate (6) is 0.318 cm thick.

Critical Mass: 550.7 kg U-235 in the 3 central zones.

2.1-43A (cont'd)

Composition of Core Regions:

<u>Material</u>	<u>Volume %</u>		
	<u>Central Zone</u>	<u>Buffer</u>	<u>Driver</u>
U-235	2	0.06	10
U-238	15	30	0.7
Graphite	30	48	39
Na	29		
SS (304)	16	9	40
Void	7	12	10

<u>Material</u>	<u>Atom Concentration, atoms / cm³ x 10²²</u>		
	<u>Central Zone</u>	<u>Buffer</u>	<u>Driver</u>
U-235	0.1141	0.0030	0.4566
U-238	0.7318	0.01447	0.0326
U-234	0.0013		0.0050
U-236	0.0005		0.0014
C	2.496	4.060	3.295
Na	0.6364		
Fe	1.020	0.5696	2.506
Ni	0.1114	0.0622	0.2736
Cr	0.2547	0.1422	0.6255
Mn	0.0106	0.0059	0.0261
Si	0.0124	0.0069	0.0305

Composition of Blanket:

As for Assembly 43 except for the inner 10.2 cm of the axial blanket which has the following composition:

<u>Material</u>	<u>Volume %</u>	<u>Atom Concentration (atoms/cm³ x 10²²)</u>
U-235	0.03	0.0015
U-238	15	0.7207
C	30	2.489
SS (304)	19	
Fe		1.168
Ni		0.1276
Cr		0.2916
Mn		0.0122
Si		0.0142
Na	29	0.633
Void	8	

2.1-43A (cont'd)

Measurements Made:

Doppler coefficient (7-1-43A)

Related Assemblies:

ZPR-3 Assembly 43 (similar composition)

Reference:

J. M. Gasidlo, J. K. Long and W. P. Keeney, "Doppler Effect Measurements, Sodium Void Coefficients, and Critical Studies of a 5,000-liter Fast Power Breeder Reactor by the Two-Zone Method", ANL-6838 (1964)

2.1-44

ZPR-3 Assembly 44

Type of Experiment: Critical (mock-up of Rapsodie)

Date: October 1963 - May 1964

Description of Assembly:

This was a four zone assembly, the single core zone containing Pu and U. During the experimentation the enrichment of the core was increased to allow the introduction of gaps, channels, etc. characteristic of the "Engineering Core".

Measurements Made:

Central fission ratios
Spatial variation of reaction rates
Central sample reactivity worths
Spatial variation of Na worth

Reference:

A. L. Hess, et al., "Critical Studies for the French Fast Reactor, 'RAPSDIE' (ZPR-3 Assembly 44)", ANL-7044 (1966)

2.1-45

ZPR-3

Assembly 45

Type of Experiment: Critical (zoned core designed for Doppler and Na void experiments)

Date: June - October 1964

Critical Configuration:

This assembly will be described in abbreviated form; its significance lies in the Doppler measurements made in it. A cross section of the assembly is shown in Figure 1(1).

Figure 1
Assembly 45 Loading Pattern

The effective radii (outer) of the various regions are as follows:

Radius, cm

Central Zone	20.93
Axial Blanket	20.93
Buffer	24.185
Driver	32.1
Radial Reflector	43.19
Blanket	62.6
Critical Mass = 56.18 kg Pu and 0.75 kg U-235 in central zone, 245 kg U-235 in driver.	

2.1-45 (cont'd)

Composition of Regions ⁽²⁾

Atom Concentration, atoms/cm ³ x 10 ²²						
<u>Material</u>	<u>Central Zone</u>	<u>Axial Blanket</u>	<u>Buffer</u>	<u>Driver</u>	<u>Reflector</u>	<u>Blanket</u>
U-235	0.0015	0.0020		0.4483		0.0091
U-238	0.7239	0.968		0.0252		4.00
Pu-239	0.1067					
Pu-240	0.0051					
Fe	0.9105	0.8195	0.7345	0.5587	0.6232	0.4493
Ni	0.1258	0.1132	3.8251	1.9378	1.9502	0.0562
Cr	0.2457	0.2211	0.1982	0.1474	0.1632	0.1186
Na	0.6365	0.643	0.4243		0.2122	
C	2.4994	2.50	1.6662	4.1563	4.1656	
Al	0.0111					

Measurements Made:

Doppler effect (7-1-45)
Central reaction rates

Related Assemblies:

ZFR-3 Assembly 45A (similar composition)

References:

1. Reactor Development Program Progress Report July 1964, ANL-6923
2. G. J. Fischer, et al., "Measurement and Analysis of Doppler Effect in Plutonium-fueled Fast Reactor Assemblies", p. 603 ANL-7120 (1965)

2.1-45A

ZPR-3

Assembly 45A

Type of Experiment: Critical (Zoned core with central region representing a large U-Pu-C-Na reactor; for Doppler measurement).

Date: November - December, 1964

Critical Configuration:

The configuration is similar to Assembly 45 with the radial reflector removed. (See figure 1 of Section 2.1-45). The dimensions of the zones are as follows:

	<u>Radius, cm</u>	<u>length, cm</u>
Central Zone	20.93	91.6
Buffer	24.185	91.6
Driver	32.1	91.6
Blanket	62.6	
Axial Blanket	20.93	

Critical Mass = 56.18 kg Pu, 0.75 kg U-235 in the central zone, 315 kg U-235 in the driver.

Composition of Regions (2)

<u>Material</u>	<u>Atom Concentration, atoms/cm³ x 10²²</u>				
	<u>Central Zone</u>	<u>Axial Blanket</u>	<u>Buffer</u>	<u>Driver</u>	<u>Blanket</u>
U-235	0.0015	0.0020	0.0010	0.4483	0.0091
U-238	0.7239	0.968	0.4826	0.0252	4.00
Pu-239	0.1067				
Pu-240	0.0051				
Fe	1.0989	0.9880	2.7366	0.5587	0.4493
Ni	0.1519	0.1366	0.3781	1.9378	0.0562
Cr	0.2966	0.2666	0.7389	0.1474	0.1186
Na	1.0608	1.072	0.8486	4.1563	
C	0.8331	0.833			
Al	0.0111				

2.1-45A (cont'd)

Measurements Made:

Doppler effect (7-1-45)
Central reaction rates (5.1-1-45A)
Spatial variation of reaction rates (5.2-1-45A)
Central sample reactivity worths (3)

References:

1. Reactor Development Program Progress Report November 1964, ANL-6977
2. G. J. Fischer, et al., "Measurement and Analysis of Doppler Effect in Plutonium-fueled Fast Reactor Assemblies", p. 603 in ANL-7120 (1965)
3. Reactor Development Program Progress Report - January 1965 ANL-7003

2.1-46

ZPR-3 Assembly 46 (A-G)

Type of Experiment: Critical (Mock-up of first core loading of FARET).

Date: January - October, 1965

Description of Assemblies:

46A: Simulated PuC-UC core + 38.5% Na
46B: as 46A with increased U enrichment
46C: simulated PuO₂-UO₂ core
46D: 3 zone core; oxide, carbide and metal
46E: not taken critical
46F: 3 zone core
46G: 3 zone core

Measurements Made:

In some cases central fission ratios, neutron lifetime, spatial distribution of reaction rates and reactivity worths and control rod worths were measured.

Reference:

A. L. Hess, et al., "Experiments with a Series of Small Pu-Plus-U Fueled Fast Criticals (Faret Mockups - ZPR-3 Assembly 46)" ANL-7215

2.1-47

ZPR-3

Assembly 47, 47A

Type of Experiment: Critical (SEFOR Mock-up)

Date: October, 1965 - May, 1966

Description of Assemblies:

The first of two cores was made up of two regions, the center containing Pu-U-Mo alloy fuel, and the outer containing Pu metal fuel. The core also contained U, BeO and Na₂CO₃. A sodium, stainless steel, and void region surrounded the core. The reflector was Ni. The second core (Assembly 47A) was similar but contained gaps to study fuel expansion effects.

Measurements Made:

Central Fission ratios
Spatial distribution of reaction rates
Central sample reactivity worths
Reactivity worth of fuel expansion
Doppler effect (7-1-47)
Spatial variation of reactivity worths
Sodium void coefficient

Reference:

R. L. McVean, et al., "Critical Studies of the Southwest Experimental Fast Oxide Reactor (SEFOR) in ZPR-3 (Assembly 47)" ANL-7248 (1967)

2.1-48

ZPR-3

Assembly 48

Type of Experiment: Critical (Pu-U-C-Na)

Date: October - December 1966

Critical Configuration:

Core: "Cylindrical"

length = 76.35 cm effective radius = 41.71 cm

cell structure(1): 7M2P27M77QM7 where 2 = depleted U, 7 = graphite, M = Na, P = Pu-239, and Q = Pu-239-U alloy. All plates are 0.318 cm thick except M and Q which are 0.635 cm thick (see Section 1.1).

Blanket: depleted U, average thickness = 30.5 cm

2.1-48 (cont'd)

Critical Mass: 261.31 kg Pu-239 in the core. At this loading the core contained several control rods with fuel spikes. The correction to the critical mass for this and the partial insertion of one rod was + 12.85 kg Pu-239. The CM corrected also for the irregular core boundary (-2.58 kg) and the central gap (-0.64 kg) = 270.94 kg Pu-239. The core also contained 1.84 kg Pu-241.

Fuel Worth at Core Edge: $\Delta M/M = 6.35$

$\Delta k/k$

Inhour Conversion: $1\% \Delta k/k = 1002.5$ Ih.

Core Composition:

<u>Material</u>	<u>Approximate Volume %</u>	<u>Atom Concentration atoms / cm³ x 10²²</u>
Pu-239	3	0.1645
Pu-240		0.0106
Pu-241		0.0011
Pu-242		0.00004
U-235		0.0016
U-238	15	0.7405
C	25	2.0770
Na	25	0.6231
Stainless Steel(304)	16	
Fe		1.0180
Ni		0.1119
Cr		0.2531
Mn		0.0106
Si		0.0124
Mo		0.0206
Al		0.0109
Void	16	

2.1-48 (cont'd)

Blanket Composition:*

<u>Material</u>	<u>Approximate Volume %</u>	<u>Atom Concentration atoms/cm³ x 10²²</u>
U-235		0.0083
U-238	83	3.969
Stainless Steel (304)	8	
Fe		0.4925
Ni		0.536
Cr		0.1225
Mn		0.0051
Si		0.0060
Void	9	

*The axial and radial blankets had slightly different compositions⁽¹⁾. These are averages weighted according to core-blanket interface areas.

Measurements Made:

Central reaction rates (5.1-1-48)
Spatial distribution of fission rates (5.2-1-48)
Central sample reactivity worths (4.1-1-48)
Spatial variation of reactivity worths (4.2-1-48)
Effect of sample size on reactivity worths (4.3-1-48)
Doppler effect (7-1-48)
Neutron spectrum (11-1-48)
Reactivity effect of heterogeneity (10.2-1-48)

Sodium void coefficient (6-1-48)
Central gap worth⁽³⁾

Related Assemblies:

ZPR-3 Assemblies 48A, 48B, 49, 50 (related compositions)

References:

1. A. M. Broomfield, et al., "ZPR-3 Assembly 48: Studies of a Dilute Plutonium Fueled Assembly", Proc. Int. Conf. on Fast Critical Experiments and Their Analysis, p. 205, ANL-7320 (1966)

2.1-48 (cont'd)

- 2. A. M. Broomfield, et al., "The Design and Critical Mass Determinations for ZPR-3 Assemblies 48, 48A and 48B" ZPR-TM-4 (1969)**
- 3. ANL Reactor Development Program Progress Report March 1967, p. 37 ANL-7317**

2.1-48A

ZPR-3

Assembly 48A

Type of Experiment: Critical (Pu-U-SS, Studies for the Fast Flux Test Facility, FFTF).

Date: December 1966-January 1967

Description of Experiment:

This was an initial set of experiments related to the design of the FFTF, particularly with respect to control rods. The experiments were performed on modifications of Assembly 48.

Measurements Made:

Reactivity worths of control rod mock-ups including interaction effects. (13-1-48A)
Spatial variation of sample reactivity worths
Studies on partial reflectors of nickel, stainless steel and sodium.
Spatial variation of reaction rates.

References:

ANL Reactor Development Program Progress Reports:

December, 1966	ANL-7286, p. 14
January, 1967	ANL-7302, p. 24
February, 1967	ANL-7308, p. 12
March, 1967	ANL-7317, p. 34
April, 1967	ANL-7329, p. 21

SECTION 2.2 - ZPR-6 ASSEMBLIES

2.2-1

ZPR-6 Assembly 1 (Loading No. 8)

Type of Experiment: Critical (U-Steel, U-238/U-235 $\approx$ 7)

Date: July, 1963

Critical Configuration:

Figure 1
Assembly 1 Loading Pattern

Core: "cylindrical"

length = 50.95 cm., effective diameter = 57.4 cm.,
cell structure: 2222122222221222, where 1 = U-235,
and 2 = U-238 and all plates are 0.318 cm thick
(See Section 1.2)

Blanket: At least 30-cm thick depleted uranium both
axially and radially.

Critical Mass: 234.8 kg U-235 in core.

Fuel Worth at Core Edge = 261h/kg U-235

Inhour Conversion: 1% $\Delta k/k$ = 480 1h

2.2-1 (cont'd)

Composition of Core:

<u>Material</u>	<u>Approximate Volume %</u>	<u>Atom Concentration (atoms/cm³ x 10²²)</u>
U-235	10	0.463
U-238	71	3.42
U-234		0.0045
U-236		0.0022
SS (304)	11	
Fe		0.665
Cr		0.188
Ni		0.0815
Mn		0.0144
Void	8	

Composition of Blanket:

<u>Material</u>	<u>Volume %</u>	<u>Atoms Concentration (atoms/cm³ x 10²²)</u>
U-235	0.2	0.00828
U-238	83	4.00
U-234		0.00008
U-236		0.00004
SS (304)	11	
Fe		0.661
Cr		0.187
Ni		0.0810
Mn		0.0143
Void	6	

Measurements Made:

Central fission ratios (5.1-2-1)
Prompt neutron lifetime (12.1-2-1)
Central reactivity coefficients of various samples (4.1-2-1)
Reactivity effects of heterogeneity (10.2-2-1)
Radial edge worths of various samples (4.2-2-1)

2.2-1 (cont'd)

Related Assemblies:

ZPR-3 Assemblies 11 and 22 (Core compositions similar)

References:

1. ANL Reactor Development Program Progress Report - September 1963, ANL-6784, p. 10 (1963)
2. F. W. Thalgott, et al., "Fast Critical Experiments and Their Analysis," ICPUAE, Geneva 6, 124-136 (1965)
3. ANL Reactor Development Program Progress Report - January 1964, ANL-6840, p. 19 (1964)

2.2-2

ZPR-6 Assembly 2

Type of Experiment: Critical (U-Steel-C-Na)

Date: January, 1964

Critical Configuration:

Figure 1
Assembly 2 Loading Pattern

Core: "cylindrical"

length = 91.4 cm, effective diameter = 92.18 cm.,
volume = 610.2 liters

cell structure: 2N712N72N172N where 1 = U-235,
2 = U-238, 7 = graphite, N = sodium. U-235 plates
are 0.159 cm thick, U-238 and graphite plates are
0.317 cm thick, sodium plates are 0.635 cm thick.
(See Section 1.2)

Blanket: At least 30 cm thick depleted uranium both
axially and radially.

Critical Mass: 544 kg of U-235 in core.

Fuel Worth at Core Edge: 17.6 lh/drawer

Inhour Conversion: $1\% \Delta k/k = 451 \text{ lh}$

2.2-2 (cont'd)

Composition of Core:

<u>Material</u>	<u>Volume %</u>	<u>Atoms Concentration (atoms/cm³ x 10²²)</u>
U-235	5	0.2285
U-238	21	0.9820
U-234		0.0022
U-236		0.0011
SS (304)	17	
Fe		1.038
Cr		0.2934
Ni		0.1272
Mn		0.0225
C	18	1.290
Na	36	0.7910
Void	3	

Composition of Blanket:*

<u>Material</u>	<u>Volume %</u>	<u>Atoms Concentration (atoms/cm³ x 10²²)</u>
U-235	0.2	0.008104
U-238	83	3.993
U-234		
U-236		
SS (304)	11	
Fe		0.6782 (0.4223)
Cr		0.1950 (0.1214)
Ni		0.0909 (0.0566)
Void	6	

*The atom concentrations given in parenthesis are for an outer region of the blanket where no stainless steel drawers were used.

Measurements Made:

Central fission ratios (5.1-2-2)
 Fine structure of fission rates (10.1-2-2)
 Neutron lifetime (12.1-2-2)
 Reactivity worth distributions (4.2-2-2)

2.2-2 (cont'd)

Sodium-void coefficient studies (6-2-2)
Central reactivity coefficients (4.1-2-2)
Axial flux traverses (ANL-6936, p. 18)
Reactivity coefficient of expansion (3-2-2)

Related Assembly:

ZPR-6 Assembly 3 (Identical core composition)

References:

1. G. K. Rusch, et al., "Investigations of a 600-liter Uranium Carbide Core (ZPR-VI Assembly No. 2)" Reactor Physics Division Annual Report - July 1, 1963 to June 30, 1964, ANL-7010, 91 (1965)
2. F. W. Thalgott, et al., "Fast Critical Experiments and Their Analysis," ICPUAE, Geneva 6, 124-136 (1965)

2.2-3

ZPR-6 Assembly 3

Type of Experiment: Critical (U-Steel-C-Na, H/D $\approx$ 1/3)

Date: September, 1964

Critical Configuration:

Figure 1
Loading Pattern ZPR-6 Assembly 3

Core: "cylindrical pancake"
length = 50.8 cm, effective diameter = 154.6 cm,
volume = 953.4 liters
cell structure: Same as for ZPR-6, Assembly 2 (2.2-2)

Blanket: At least 30 cm thick depleted uranium both
axially and radially.

Critical Mass: 850 kg of U-235 in core

Fuel Worth at Core Edge: See Ref. 3.

Inhour Conversion: $1\% \Delta k/k = 451$ Ih

Composition of Core:

As for Assembly 2 (2.2-2) with the exception that perforated aluminum ($\sim$ 45% of natural density) was used near the axial blankets in about 870 of the 1250 core drawers.

2.2-3 (cont'd)

Composition of Blanket:

As for Assembly 2 (2.2-2)

Measurements Made:

Sodium void coefficients (6-2-3)
Fission ratio traverses (5.2-2-3)
Cell fine structures (10.1-2-2)
Effect of Na voiding on central reactivity worths (4.4-2-3)
Prompt neutron lifetimes (12.1-2-3)
Effect of heterogeneity on sodium void coefficients (10.3-2-3)
Streaming effects on sodium void coefficients (10.7-2-3)
Central reaction rates (5.1-2-3)

Related Assembly:

ZPR-6 Assembly 2 (Identical core composition)

References:

1. F. H. Helm, et al., "Physics Parameters and Sodium Void Coefficients in a 950-Liter Pancake Core", Reactor Physics Division Annual Report - July 1, 1964 to June 30, 1965, ANL-7110, (1965)
2. Reactor Development Program Progress Report - October 1964, ANL-6965 (1964)
3. ANL Reactor Development Program Progress Report - September 1964, ANL-6944, 22 (1964)

2.2-4Z

ZPR-6 Assembly 4Z

Type of Experiment: Critical (U-Steel-C-Na, Zoned)

Date: May 1965

Critical Configuration:

Figure 1
Plane View of Midsection of ZPR-6 Assembly 4Z

Core: "Cylindrical"

The core is composed of a central zone, a buffer zone, and a driver zone.

length = 121.9 cm for all zones

effective diameter: central zone = 83.06 cm

buffer zone = 94.89 cm

driver zone = 108.35 cm

volume = 1123.8 liters

cell structure: central zone: basic cell spans 3 drawers and is made as follows - 2N217272aN27, 27172aN2N2172a, 272N272172aN.

buffer zone: 2727272272727272

driver zone: 2a71a2aN2a1a72aN1a7

2.2-4Z (cont'd)

where 1 = U-235 (0.159 cm thick), 1a = U-235 (0.318 cm)
2 = U-238 (0.159 cm), 2a = U-238 (0.0795 cm), 7 =
graphite (0.159 cm), and N = sodium (1.27 cm).

Blanket: At least 30 cm thick depleted uranium both
axially and radially.

Critical Mass: CM = 1101 kg of U-235 in core (after
correction for irregular core boundary).

Fuel Worth at Core Edge: $(\Delta M/M) / (\Delta k/k) = 2.99$

Inhour Conversion to $\Delta k/k$: 468 Ih = 1% $\Delta k/k$

Composition of Central Zone:

<u>Material</u>	<u>Volume %</u>	<u>Atom Concentration</u> <u>(atoms/cm³ x 10²²)</u>
U-235	3	0.153
U-238	22	1.056
SS (304)	15	
Fe		0.904
Cr		0.2386
Ni		0.113
C	14	1.293
Na	36	0.920
Void	9	

Composition of Buffer Zone:

<u>Material</u>	<u>Volume %</u>	<u>Atom Concentration</u> <u>(atoms/cm³ x 10²²)</u>
U-235	0.1	0.004546
U-238	46	2.172
SS (304)	11	
Fe		0.697
Cr		0.1384
Ni		0.087
C	36	3.0163
Void	10	

2.2-4Z (cont'd)

Composition of Driver Zone:

<u>Material</u>	<u>Volume %</u>	<u>Atom Concentration (atoms/cm³ x 10²²)</u>
U-235	14	0.6564
U-238	11	0.5243
SS (304)	15	
Fe		0.904
Cr		0.2386
Ni		0.113
C	14	1.293
Na	36	0.920
Void	10	

Composition of Blanket:

<u>Material</u>	<u>Volume %</u>	<u>Atom Concentration (atoms/cm³ x 10²²)</u>
U-235	0.2	0.0081
U-238	84	3.993
SS (304)	7.08	
Fe		0.4322
Cr		0.114
Ni		0.054
Void	8	

Measurements Made:

Heterogeneity effects on critical mass
Spectrum measurements (11-2-4Z)
Central fission ratios (5.1-2-4Z)
Fission rate traverses (5.2-2-4Z)
Fission rate fine structure (10.1-2-4Z)
Importance of fission neutrons (14-2-4Z)
Sodium Void Coefficients (6-2-4Z)
Radial worths (4.2-2-4Z)
Central worths (4.1-2-4Z)
Prompt neutron lifetime (12.1-2-4Z)
Effect of sample size on worth (4.3-2-4Z)
Effect of Na void on central worths (4.4-2-4Z)
Doppler coefficient (7-2-4Z)

2.2-4Z (cont'd)

Related Assemblies:

ZPR-6 Assembly 4Z (2.2-4Z), ZPR-9 Assembly 12 (2.3-12) and APR-9 Assembly 11 (2.3-11) (in order of decreasing core size) are zoned assemblies whose central zones have the same core position as ZPR-6 Assembly 5 (2.2-5).

References:

1. R. A. Karam, et al., "Measured Physics Parameters in a Zones Fast Uranium Carbide Core, Assembly 4Z", ANL-7281 (December 1966)
2. R. A. Karam, et al., "Zoned Core Simulating a 2600 Liter Carbide Fast Reactor", Reactor Physics Division Annual Report - July 1, 1964 to June 20, 1965, ANL-7110, p. 114-115 (December 1965).

2.2-5

ZPR-6 Assembly 5

Type of Experiment: Critical (U, Steel, C, Na)

Date: July 8, 1966

Critical Configuration:

Figure 1
Cross Sectional View of Assembly 5 of ZPR-6

Core: "cylindrical"

The core is in two regions. The only difference between the regions is that in region 1 the U-235 is in the form of one 0.159 cm thick plate, whereas in region 2 it is in the form of two 0.079 cm thick plates.

length: Region 1 = 142.24 cm
Region 2 = 142.24 cm

effective diameter: Region 1 = 125.46 cm
Region 2 = 155.72 cm

2.2-5 (cont'd)

volume = 2709 liters

cell structure: The basic cell spans 3 drawers and is made up as follows: N2a71272N272, 712N2N27172, 72N2a72712N2.

where 1 = U-235 (0.159 cm thick in region 1, 2 x 0.079 cm in region 2), 2 = U-238 (0.317 cm), 2a = U-238 (0.159 cm), 7 = graphite (0.317 cm) and N = sodium (1.27 cm).

Blanket: Depleted uranium 30 cm thick on both ends and 29.79 cm thick radially.

Critical Mass: 1583 kg of U-235 in core.

Inhour Conversion: 1% $\Delta k/k$ = 476 Th.

Composition of Core Region 1:

<u>Material</u>	<u>Volume %</u>	<u>Atom Concentration (atoms/cm³ x 10²²)</u>
U-235	3	0.1540
U-238	22	1.0633
SS (304)	15	
Fe		0.9040
Cr		0.2386
Ni		0.1130
C	14	1.293
Na	36	0.920
Void	9	

Composition of Core Region 2:

<u>Material</u>	<u>Volume %</u>	<u>Atom Concentration (atoms/cm³ x 10²²)</u>
U-235	3	0.1442
U-238	22	1.056
SS (304)	15	
Fe		0.904
Cr		0.2386
Ni		0.113
C	14	1.293
Na	36	0.920
Void	9	

2.2-5 (cont'd)

Composition of Blanket:

<u>Material</u>	<u>Volume %</u>	<u>Atom concentration</u> <u>(atoms/cm³ x 10²²)</u>
U-235	0.2	0.0081
U-238	84	3.993
SS (304)	7	
Fe		0.4322
Cr		0.114
Ni		0.054
Void	8	

Measurements Made:

Streaming (leakage) effects (10.7-2-5)
Central sample worths (4.1-2-5) and size effects (4.3-2-5)
Sodium void coefficients (6-2-5)
Central fission ratios (5.1-2-5)
Reaction rate traverses (5.2-2-5)
Neutron spectrum (11-2-5)
Pulsed experiments
Doppler Measurements (7-2-5)
Bunching experiments (10.2,3,4,5-2-5)
Heterogeneity effects on sodium void coefficients (10.3-2-5)
Importance distributions (14-2-5)
Cell fine structures (10.1-2-5)
Effect of heterogeneity on Reaction Rates (10.4-2-5)

Related Assemblies:

ZPR-6 Assembly 4Z
ZPR-9 Assembly 11 and 12

References:

1. Reactor Development Program Progress Report - July 1966, ANL-7245 pp. 15-17, (August 26, 1966)
2. Reactor Development Program Progress Report - August 1967, ANL-7371 pp. 62-63 (September 28, 1967)
3. R. A. Karam, et al. "Measured Physics Parameters in a Large Uranium Carbide Fast Core, Assembly 5 ZPR-6", Reactor Physics Division Annual Report July 1, 1966 to June 30, 1967, ANL-7310 pp. 167-189 (1968)

2.2-6

ZPR-6 Assembly 6

Type of Experiment: Critical (U-Steel-O-Na)

Date: December 27, 1967

Critical Configuration:

Figure 1
Regions in Assembly 6 of ZPR-6

Core: "cylindrical"

The core is in three regions due to slight differences in the weight per unit length of the various enriched uranium plates used.

length = 152.4 cm for all regions

effective diameter: Region 1 = 154.34 cm

Region 2 = 171.06 cm

Region 3 = 181.74 cm

volume = 3953.5 liters

cell structure: UNF612FNU

where 1 = U-235 (0.159 cm thick), 2 = U-238 (0.635 cm),
N = Sodium (1.27 cm), F = Fe₂O₃ (0.317 cm), 6 = 304
Stainless Steel (0.159 cm), and U = U₃Og (0.635 cm).

2.2-6 (cont'd)

Blanket: at least 30 cm depleted uranium (0.2% enrichment) both axially and radially.

Critical Mass: CM = 1817 kg of U-235 in core.

Fuel Worth at Core Edge: $(\Delta M/M) / (\Delta k/k) = 9.06$

Inhour Conversion to $\Delta k/k$: 1% $\Delta k/k = 458$ Th

Composition of Core Region 1:

<u>Material</u>	<u>Volume %</u>	<u>Atoms Concentration (atoms/cm³ x 10²²)</u>
U-235	2	0.1150
U-238	12	0.5796
SS (304)	22	
Fe		1.410
Cr		0.2788
Ni		0.1365
Na	36	0.9142
O	23*	1.465
Void	5	

Composition of Core Region 2:

<u>Material</u>	<u>Volume %</u>	<u>Atoms Concentration (atoms /cm³ x 10²²)</u>
U-235	2	0.107
U-238	12	0.5790
SS (304)	24	
Fe		1.572
Cr		0.3254
Ni		0.1582
Na	31	0.7790
O	23*	1.465
Void	8	

*Assuming oxygen in U₃O₈ and Fe₂O₃ completely fills the space occupied by these plates.

2.2-6 (cont'd)

Composition of Core Region 3:

<u>Material</u>	<u>Volume %</u>	<u>Atoms Concentration</u> <u>(atoms/cm³ x 10²²)</u>
U-235	3	0.156
U-238	12	0.5780
SS (304)	23	
Fe		1.524
Cr		0.3115
Ni		0.1518
Na	33	0.8310
O	23	1.465
Void	5	

Composition of Blanket:

<u>Material</u>	<u>Volume %</u>	<u>Atoms Concentration</u> <u>(atoms/cm x 10²²)</u>
U-235	0.2	0.0827
U-238	85	4.008
SS (304)	7	
Fe		0.42282
Cr		0.1215
Ni		0.05665
Void	8	

Measurements Made:

Neutron spectrum (11-2-6)
 Sodium-void coefficients (6-2-6, 6a)
 Flux fine structures (10.1-2-6)
 Central worths (4.1-2-6)
 Plutonium- α experiments
 Heterogeneity effects (10.2-2-6 a,b)
 Central reaction rates (5.2-2-6)
 Spatial variation of reaction rates (5.2-2-6)
 Effect of heterogeneity on sodium void coefficient
 (10.3-2-6 a,b)
 Effect of sample size on reactivity worths (4.3-2-6)
 Doppler measurements (7-2-6)

2.2-6 (cont'd)

References:

1. "Reactor Development Program Progress Report - January 1969"
ANL-7419, p. 14-15 (1968)
2. R. A. Karam, L. R. Dates, W. Y. Kato, J. E. Marshall,
T. Nakamura, and G. K. Rusch, "A 4000-Liter Uranium
Oxide Fast Core, Assembly 6 of ZPR-6", Reactor Physics
Division Annual Report - July 1, 1967 to June 30 1968,
ANL-7410 p. 75-80 (1969).

SECTION 2.3 - ZPR-9 ASSEMBLIES

Type of Experiment: Critical (U-235, Al, U-238)

Date: February, 1964

Critical Configuration:

Fig. 1 Geometric Outline of ZPR-9
Assembly No. 1

Core: "cylindrical"

length = 51.04 cm*, effective diameter = 63.16 cm

*includes 1.68 mm aluminum drawer fronts plus 0.75-mm air gap in core midplane.

cell structure: 2221222222212222

where 1 = enriched U, 2 = depleted U.

All plates are 0.318 cm thick (See 1.3)

Blanket: outer effective diameter = 133.28 cm.
axial thickness = 30 cm.

Critical Mass: 279.2 kg U-235 in core. CM corrected for heterogeneity (+15.60 kg), central gap (-0.59 kg) and irregular boundary (-0.38 kg) = 294 kg U-235. Spherical CM (shape factor = 0.938) = 276 kg U-235.

Fuel Worth at Core Edge: $\Delta M/M / \Delta k/k = 6.09 \pm (5-10\%)$.

Inhour Conversion: $1\% \Delta k/k = 469$ Ih

Composition of Core:

<u>Material</u>	<u>Volume %</u>	<u>Atom Concentration</u> <u>atoms/cm³ x 10²²</u>
U-235	10	0.454
U-238	73	3.38
Al	11	0.665
Fe	0.6	0.0526
Void	6	

Composition of Blanket:

<u>Material</u>	<u>Volume %</u>	<u>Atom Concentration</u> <u>atoms/cm³ x 10²²</u>
Al	94	5.639
Void	6	

Measurements Made:

Gap worth
Central worths (4.1-3-1)
Spatially dependent reaction rates (5.2-3-1)
Prompt neutron lifetime (12.1-3-1)
Central worths of separated tungsten isotopes (4.1-3-1)
U-238/U-235 central fission ratio (5.1-3-1)

Related Assemblies:

ZPR-3 assemblies 11 and 22 and ZPR-6 assembly 1.
ZPR-9 assemblies 1-9 from a series related to the design of
a nuclear rocket.

References:

- (1) R. C. Doerner, W. G. Knapp, K. K. Almenas, and R. A. Karam, "Physics Measurements in Tungsten-Based, Aluminum-Reflected Fast Reactors," ANL-7007 (March 1967).

Type of Experiment: Critical (U-235, Al, W, U-238; W/U-238 $\approx 1/4$)

Date: March, 1964

Critical Configuration:

Fig. 1 Assembly 2 Loading Pattern

Core: "cylindrical"

length = 61.20 cm (includes 1.68 mm aluminum drawer fronts plus 0.75 mm air gap in the core midplane.) Effective diameter = 68.22 cm.

cell structure: 2W212W222W212W22 where 1 = enriched U
2 = depleted U, W = tungsten. All plates are 0.318 cm thick (See 1.3)

Blanket: outer effective diameter = 140.56 cm
axial thickness = 30 cm

Critical Mass: 385.3 kg U-235 in core. Corrected for heterogeneity (+20.94 kg), central gap (-0.76 kg), and irregular boundary (-0.48 kg) = 405 kg U-235. Spherical CM (shape factor = 0.936) = 379 kg U-235.

Fuel Worth at Core Edge: $(\Delta M/M) / (\Delta k/k) = 720 \pm (5-10\%)$

Inhour conversion: $1\% \Delta k/k = 457 \text{ Ih}$

Composition of Core:

<u>Material</u>	<u>Volume %</u>	<u>Atom Concentration</u> <u>(atoms/cm³ x 10²²)</u>
U-235	10	0.452
U-238	53	2.43
Al	11	0.666
Fe	0.5	0.0412
W	21	1.22
Void	4	

Composition of Blanket:

as for Assembly 1 (2.3-1)

Measurements Made:

Gap worth

Central worths (4.1-3-2)

Spatially dependent reaction rates (5.2-3-2)

Prompt neutron lifetime (12.2-3-2)

U-238/U-235 central fission ratio (5.1-3-2)

Related Assemblies:

ZPR-9 Assemblies 1-4 form a series with variable W/U-238 ratio

Reference:

- (1) R. C. Doerner, W. G. Knapp, K. K. Almenas and R. A. Karam, "Physics Measurements in Tungsten-Based, Aluminum-Reflected Fast Reactors," ANL-7007 (March 1967).

Type of Experiment: Critical (U-235, Al, W, U-238, W/U-238 $\approx 1/2$)

Date: April, 1964

Critical Configuration:

Fig. 1 Assembly 3 Loading Pattern

Core: "cylindrical"

length = 71.36 cm effective diameter = 71.58 cm
 cell structure: 2W21W2W2W2W12W2W where 1 = enriched U,
 2 = depleted U, W = tungsten, All plates are 0.318 cm
 thick (See 1.3)

Blanket: Outer effective diameter = 140.56 cm.
 axial thickness = 30 cm.

Critical Mass: 492.9 kg U-235 in core. CM corrected for hetero-
 geneity (+33.51 kg), central gap (-1.14 kg), and irregular
 boundary (-0.74 kg) = 525 kg U-235. Spherical CM (shape factor =
 0.916) = 481 kg U-235.

Fuel Worth at Core Edge: $(\Delta M/M) / (\Delta k/k) = 7.01 \pm (5-10\%)$.

Inhour Conversion: $1\% \Delta k/k = 446. \text{ Ih}$

Composition of Core:

<u>Material</u>	<u>Volume %</u>	<u>Atom Concentration</u> <u>atoms / cm³ x 10²²</u>
U-235	10	0.448
U-238	37	1.70
Al	11	0.667
Fe	0.5	0.0411
W	37	2.14
Void	5	

Composition of Blanket:

as for Assembly 1 (2.3-1)

Measurements Made:

Central worths (4.1-3-3)
Spatially dependent reaction rates (5.2-3-3)
Prompt neutron lifetime (12.1-3-3)
Central worth as function of sample size (4.3-3-3)
U-238/U-235 central fission ratio (5.1-3-3)

Related Assemblies:

ZPR-9 Assemblies 1-4 form a series with a variable W/U-238 ratio.

Reference:

R. C. Doerner, W. G. Knapp, K. K. Almenas, and R. A. Karam,
"Physics Measurements in Tungsten-Based, Aluminum-Reflected
Fast Reactors," ANL-7007 (March 1967).

Type of Experiment: Critical (U-235, Al, W)

Date: June, 1964

Critical Configuration:

Fig. 1 Assembly 4 Loading Pattern

Core: "cylindrical"

length = 56.12 cm effective diameter = 50.42 cm

cell structure: WlWWlWWlWWlWWlWWlWW where l = enriched U
and W = tungsten; U-235 plates were 0.159 cm. thick and W
plates were 0.318 cm. thick. (See 1.3)

Blanket: outer effective diameter = 130.74 cm.

axial thickness = 30 cm

Critical Mass: 285.2 kg U-235 in core. CM corrected for hetero-
geneity (+4.05 kg), central gap (-0.42 kg), and irregular
boundary (-0.27 kg) = 288.6 kg U-235. Spherical CM (shape
factor = 0.931) = 269. kg U-235

Fuel Worth at Core Edge: $(\Delta M/M)/(\Delta K/K) = 467 \pm (5-10\%)$.

Inhour Conversion: 1% $\Delta k/k = 430$ Ih

Composition of Core:

<u>Material</u>	<u>Volume %</u>	<u>Atom Concentration</u> <u>atoms / cm³ x 10²²</u>
U-235	15	0.677
U-238	1	0.0483
Al	11	0.665
Fe	1	0.0837
W	59	3.41
Void	14	

Composition of Blanket:

as for Assembly 1 (2.3-1)

Measurements Made:

Fuel bunching (10.2-3-4)
Gap worth
Central worths (4.1-3-4)
Spatially dependent reaction rates (5.2-3-4)
Reflector replacement worths (9-3-4)
Prompt neutron lifetime (12.1-3-4)
Central worth as function of sample sizes (4.3-3-4)
Central worth of hydrogen-boron mixtures (4.4-3-4)
Central worths of separated tungsten isotopes (4.1-3-4)
U-238/U-235 central fission ratio (5.1-3-4)

Related Assemblies:

ZPR-9 Assemblies 1-4 form a series with a variable W/U-238 ratio.

Reference:

R. C. Doerner, W. G. Knapp, K. K. Almenas, and R. A. Karam,
"Physics Measurements in Tungsten-Based, Aluminum-Reflected
Fast Reactors", ANL-7007 (March 1967).

2.3-4A

ZPR-9

Assembly 4A

Type of Experiment: Subcritical (U-235, Al, W, Re)

Date: September, 1964

Description of Experiment:

Insufficient rhenium was available to attain criticality at the intended rhenium concentration of 5 volume %. Extrapolation of subcritical multiplication experiments indicated a critical mass of 364 kg U-235, 26.6 kg U-238, 1541.9 kg tungsten, and 143.5 kg rhenium. The critical length and effective radius would have been 56.18 cm. and 27.99 cm. respectively.

Reference:

W. G. Knapp and R. C. Doerner, "Physics Measurements with Modified Diluent Compositions in Tungsten-Based, Aluminum-Reflected Fast Reactors", ANL-7207 (1967).

Type of Experiment: Critical (U-235, Al, W, Re)

Date: October, 1964

Critical Configuration:

Fig. 1 Assembly 4B Loading Pattern

Core: "cylindrical"

length = 56.16 cm. effective diameter = 54.04 cm.,
volume = 128.8 liters. (experimental, not corrected for
heterogeneity, gap, or irregular edge)

cell structure: 3W1WW1WW1WRW1WW1WW1W, W1WRW1WW1WW1WW1WRW1W
where 1 = enriched U, 3 = Al (100% density) W = tungsten,
R = rhenium. W plates were 0.318 cm. thick. U-235, Al,
and Re plates were 0.159 cm. thick.

Blanket: outer effective diameter = 130.74 cm. axial thickness = 30. cm

Critical Mass: 339.6 kg U-235 in core. Corrected for hetero-
geneity (+7.23 kg), central gap (-.31 kg), and irregular
boundary (-0.36 kg) = 346.2 kg U-235. Spherical CM
(shape factor = 0.94) = 325.4 kg U-235

Fuel Worth at Core Edge: $(\Delta M/M)/(\Delta k/k) = 5.5$

Inhour Conversion: 1% $\Delta k/k = 432.3$ Ih

2.3-4B (Cont'd)

ZPR-9

Assembly 4B

Composition of Core:

<u>Material</u>	<u>Volume %</u>	<u>Atom Concentration</u> <u>atoms / cm³ x 10²²</u>
U-235	14	0.674
U-238	1	0.049
Al	13	0.749
W	56	3.64
Re	4	0.247
Fe	0.4	0.035
Void	12	

Composition of Blanket:

as for Assembly 1 (2.3-1)

Measurements Made:

Central worths (4.1-3-4B)
Effect of size on hydrogen worth (4.3-3-4B)
Central worths of hydrogen-boron mixtures
Prompt neutron lifetime (12.2-3-4B)
Spatially dependent reaction rates (5.2-3-4B)
U-238/U-235 central fission ratio (5.1-3-4B)

Related Assemblies:

ZPR-9 Assemblies 3, 4, 5, and 6. (related compositions)

Reference:

W. G. Knapp and R. C. Doerner, "Physics Measurements with Modified Diluent Compositions in Tungsten-Based Aluminum-Reflected Fast Reactors", ANL 7207 (1967).

Type of Experiment: Critical (U-235, Al, W, C)

Date: November, 1964

Critical Configuration:

Fig. 1 Assembly 5 Loading Pattern

Core: "cylindrical"

length = 55.9 cm effective diameter = 34.06 cm

volume = 204.7 liters.

cell structure: W71W7W71W7W1W7W71W where 1 = enriched U, 7 = graphite, W = tungsten, C and W plates were 0.318 cm. thick and U-235 plates were 0.159 cm. thick. (See 1.3).

Blanket: outer effective diameter = 141.66 cm.

axial thickness = 30 cm.

Critical Mass: 357.0 kg of U-235 in core. Corrected for heterogeneity (+8.89 kg), central gap (-2.2 kg), and irregular boundary (-0.45 kg) = 363.21 kg U-235. Spherical CM (shape factor = 0.934) = 339.2 kg U-235).

Fuel Worth at Core Edge: $(\Delta M/M) / (\Delta k/k) = 6.2$

Inhour Conversion: 1% $\Delta k/k = 424.8$ Ih

2.3-5 (Cont'd)

ZPR-9

Assembly 5

Composition of Core:

<u>Material</u>	<u>Volume %</u>	<u>Atom Concentration</u> <u>atomx/cm³ x 10²²</u>
U-235	9	0.451
U-238	1	0.033
Al	11	0.681
W	34	2.13
C	35	2.951
Void	10	

Composition of Blanket:

As for Assembly 1 (2.3-1)

Measurements Made:

Central worths (4.1-3-5)
Effect of sample size on hydrogen worth (4.3-3-5)
Central worths of hydrogen-boron mixtures (4.1-3-5)
Prompt neutron lifetime (12.1-3-5)
Spatially dependent reaction rates (5.2-3-5)
U-238/U-235 central fission ratio (5.1-3-5)

Related Assemblies

ZPR-9 Assemblies 3, 4, 4B, and 6 (related compositions).

Reference:

W. R. Knapp and R. C. Doerner, "Physics Measurements with Modified Diluent Compositions in Tungsten-Based, Aluminum-Reflected Fast Reactor", ANL-7207 (1967).

Type of Experiment: Critical (U-235, Al, W)

Date: December, 1964

Critical Configuration:

Fig. 1 Assembly 6 Loading Pattern

Core: "cylindrical"

length = 61.26 cm, effective diameter = 73.2 cm. volume = 258.1 liters. (Experimental; not corrected for heterogeneity, gap, or edge irregularity.)

cell structure = W51W5W51W5W15W5W15 where 1 = enriched U, 5 = Al. (45% density), and W = tungsten. Al and W plates were 0.318 cm. thick. U-235 plates were 0.159 cm. thick. (See 1.3).

Blanket: outer effective diameter = 154.6 cm. axial thickness = 38.1 cm.

Critical Mass: 453.5 kg U-235 in core. Corrected for heterogeneity (+9.81 kg), central gap (-2.45 kg) and irregular boundary (-0.49 kg) = 460.3 kg U-235. Spherical CM (shape factor = 0.939) = 429.5 U-235.

Fuel Worth at Core Edge: $(\Delta M/M) / (\Delta k/k) = 5.4$

Input Conversion: 1% $\Delta k/k = 430.6$ Ih

2.3-6 (Cont'd)

ZPR-9

Assembly 6

Composition of Core:

<u>Material</u>	<u>Volume %</u>	<u>Atom Concentration</u> <u>atoms/cm³ x 10²²</u>
U-235	9	0.450
U-238	0.7	0.033
Al	27	1.597
W	34	2.13
Void	30	

Composition of Blanket:

As for Assembly 1 (2.3-1)

Measurements Made:

Central worths (4.1-3-6)

Effect of sample size on hydrogen worth (4.3-3-6)

Central worths of hydrogen-boron mixtures (4.1-3-6)

Prompt neutron lifetime (12.1-3-6)

Spatially dependent reaction rates (5.2-3-6)

Central gap worth

"Bunching" and "unbunching" experiments (10. 2-3-6)

B-10 poisoning of reflector (9-3-6)

U-238/U-235 central fission ratio (5.1-3-6)

Related Assemblies:

ZPR-9 Assemblies 3, 4, 4B, and 5 (related composition)

Reference:

W. G. Knapp and R. C. Doerner, "Physics Measurements with Modified Diluent Compositions in Tungsten-Based, Aluminum-Reflected Fast Reactors", ANL-7207 (February 1967).

2.3-7

ZPR-9

Assembly 7 Loading 13

Type of Experiment: Critical (U-235, Al, W; Al_2O_3 reflected)

Date: August, 1965

Critical Configuration: See figure 1. This has also been referred to as Loading 18 of Assembly 7.

Fig. 1 Assembly 7 Loading Pattern

Core: "cylindrical"

length = 51.1 cm, effective diameter = 55.2 cm, volume = 124.8L
cell structure: W51W5W51W5W15W5W15 where 1 = enriched U,
5 = Al (45% density), and W = tungsten; Al and W plates were
0.318 cm. thick and U-235 plates were 0.159 cm. thick. (See 1.3)

Blanket: (Al_2O_3) outer effective diameter = 130.1 cm. axial
thickness = 35.56 cm

Critical Mass: 213.5 kg U-235 in core.

Fuel Worth at Core Edge: 30.1 lh/kg U-235

Inhour Conversion: $1\% \Delta k/k = 433.1 \text{ lh}$

Composition of Core:

<u>Material</u>	<u>Volume %</u>	<u>Atom Concentration</u> <u>atoms/cm³ x 10²²</u>
U-235	9	0.450
U-238	0.7	0.033
Al	26	1.59
W	33	2.11
Fe	0.4	0.03
Void	30	

Composition of Blanket:

<u>Material</u>	<u>Volume %</u>	<u>Atom Concentration</u> <u>atoms/cm³ x 10²²</u>
Al ₂ O ₃	78	
Al	12 (Matrix drawers)	4.32
O		5.45
Void	10	

Measurements Made:

Central worths (4.1-3-7)
Central worths of boron-Lucite mixtures (4.1-3-7)
Prompt neutron lifetimes (12.1-3-7)
Spatial variations of reaction rates (5.2-3-7)
U-238/U-235 central fission ratio (5.1-3-7)
Spatial variation of reactivity worths (4.2-3-7)

Related Assemblies:

ZPR-9, Assemblies 6, 7a, 8 and 9 (related compositions)

Reference:

R. C. Doerner, W. G. Knapp, R. A. Karam, and D. K. Butler,
"ZPR-9 Assemblies No. 6-9 Critical Experiments", ANL-7208
(1967).

Type of Experiment: Critical (U-235, Al, W; Al₂O₃ Al reflected)

Date: October, 1965

Critical Configuration:

Fig. 1 Assembly 7A Loading Pattern

Core: "cylindrical"

length = 51.1 cm., effective diameter = 53.96 cm.

cell structure: Same as for Assembly 7

Blanket: Inner reflector of Al₂O₃ plus outer, Al isolation blanket. Al₂O₃ outer effective diameter = 154.35 cm, Al outer effective diameter = 180.08 cm. Axial Al₂O₃ blanket thickness = 35.56 cm. Al isolation blanket thickness = 11.04 cm.

Critical Mass: 204.04 kg U-235 in core.

Fuel Worth at Edge of Core: 17.43 lh/kg of U-235

Inhour Conversion: 1% $\Delta k/k$ = 433.1 lh

2.3-7A (Cont'd)

ZPR-9

Assembly 7A Loading 71

Composition of Core:

<u>Material</u>	<u>Volume %</u>	<u>Atom Concentration</u> <u>atoms/cm³ x 10²²</u>
U-235	9.4	0.450
U-238	0.7	0.033
Al	26.4	1.59
W	33.4	2.11
Fe	0.4	0.03
Void	29.7	

Composition of Blanket:

<u>Material</u>	<u>Volume %</u>	<u>Atom Concentration</u> <u>atoms/cm³ x 10²²</u>
Al ₂ O ₃	78	
Al	12	4.23
O		5.47
Void	10	

Composition of Isolation Blanket:

<u>Material</u>	<u>Volume %</u>	<u>Atom Concentration</u> <u>atom/cm³ x 10²²</u>
Al	94	5.66
Void	6	

Related Assemblies:

ZPR-9 Assemblies 6, 7, 8, and 9 (related compositions)

Reference:

R. C. Doerner, W. G. Knapp, R. A. Karam, and D. K. Butler,
"ZPR-9 Assemblies No. 6-9 Critical Experiments", ANL-7208
(March 1967).

Type of Experiment: Critical (U-235, Al, W, Al_2O_3 ; BeO, Al reflected)

Date: January, 1966

Critical Configuration:

Fig. 1 Assembly 8 Loading Pattern

Core: "cylindrical"

length = 51.1 cm (including 0.3 cm for the central gap and Al drawer fronts) effective diameter = 63.42 cm

cell structure: WA1W5WA1W5W1AW5W1A where 1 = enriched U, 5 = Al (45% density), W = tungsten, and A = Al_2O_3 . Al, W, and Al_2O_3 plates were 0.318 cm. thick, and U-235 plates were 0.159 cm thick. (See 1.3).

Blanket: Inner radial reflector of BeO plus outer, Al isolation blanket. BeO outer effective diameter = 85.30 cm. Al outer effective diameter = 180.08 cm. Axial blanket thickness = 35.36 cm.

Critical Mass: 283.304 kg U-235 in core.

Fuel Worth at Core Edge: 20.8 lh/kg U-235. Because of the size of the core and the high worth of the BeO reflector, this quantity is quite uncertain and introduces a considerable uncertainty into the correction for k_{ex} in the critical mass.

Inhour Conversion: 1% $\Delta k/k$ = 431.4 lh

2.3-8 (Cont'd)

ZPR-9

Assembly 8

Composition of Core:

<u>Material</u>	<u>Volume %</u>	<u>Atom Concentration</u> <u>atoms/cm³ x 10²²</u>
U-235	9	0.451
U-238	0.7	0.033
Al	32	1.66
W	34	2.14
Fe	0.4	0.026
O	10	0.89
Void	14	

Composition of Blanket:

<u>Material</u>	<u>Volume %</u>	<u>Atom Concentration</u> <u>atoms/cm³ x 10²²</u>
Al	11	0.69
BeO	84	
Be		5.81
O		5.81
Void	5	

Composition of Isolation Blanket:

<u>Material</u>	<u>Volume %</u>	<u>Atom Concentration</u> <u>atoms/cm³ x 10²²</u>
Al	94	5.66
Void	6	

Measurements Made:

Central worths (4.1-3-8)
Central worths of boron-lucite mixtures (4.1-3-8)
Effect of sample size on central hydrogen worths (4.3-3-8)
Prompt neutron lifetime (12.1-3-8)
Spatial variations of worths of fuel materials (4.2-3-8)
Central gap worths
Reflector studies
Spatial variation of reaction rates (5.2-3-8)
U-238/U-235 central fission ratio (5.1-3-8)
Microscopic fission rate traverse in core edge fuel (5.2-3-8)
Worth of boron in reflector
Reflector removal worths
Spatial variation of sample worths (4.2-3-8)

Related Assemblies:

ZPR-9 Assemblies 6, 7, and 8A (2.3-8A), 8B(2.3-8B) and 9
(related compositions)

Reference:

R. C. Doerner, W. G. Knapp, R. A. Karam, and D. K. Butler,
"ZPR-9 Assemblies No. 6-9 Critical Experiments", ANL-7208
(March 1967).

2.3-8A

ZPR-9

Assembly 8A

Type of Experiment: Critical (Hydrogen added to Assembly 8)

Date: January, 1966

Critical Configuration: See Figure 1 of 2.3-8

Core: "cylindrical"

length = 51.1 cm. effective diameter = 62.02 cm.

cell structure: Same as for assembly 8 (2.3-8).

Polyethylene sheets, 20 mils thick, were added to the bottom of each core drawer throughout the core, excepting in the dual-purpose control rods. The effective diameter of the loaded region was 62.86 cm. Total H content was 172.55 g and total C content was 1034.09 g. No correction was made for the effect of C.

Blanket: Inner reflector of BeO plus outer, Al isolation blanket. BeO outer effective diameter = 85.54 cm. Axial blanket thickness = 35.56 cm of Al.

Critical Mass: 266.093 kg U-235 in core.

Fuel Worth at Core Edge: 20.8 lh/kg U-235

Inhour Conversion: $1\% \Delta k/k = 431.0 \text{ lh}$

Composition of Core:

<u>Material</u>	<u>Volume %</u>	<u>Atom Concentration atoms/cm³ x 10²²</u>
U-235	9	0.451
U-238	0.7	0.033
Al	32	1.66
W	34	2.14
Fe	0.4	0.026
O	10	0.89
H	1(poly)	0.066
C		0.033

Composition of Inner Blanket:

<u>Material</u>	<u>Volume %</u>	<u>Atom Concentration atoms/cm³ x 10²²</u>
Al	11	0.69
Be	84 (BeO)	5.81
O		5.81
Void	5	

Composition of Outer Blanket:

<u>Material</u>	<u>Volume %</u>	<u>Atom concentration atoms/cm³ x 10²²</u>
Al	94	5.66
Void	6	

Related Assemblies:

ZPR-9, assemblies 6, 7, 8(2.3-8), 8B (2.3-8B), 8C and 9
(related composition)

Reference:

R. C. Doerner, W. G. Knapp, R. A. Karam, and D. K. Butler,
"ZPR-9 Assemblies No. 6-9 Critical Experiments", ANL-7208
(March 1967).

2.3-8B

ZPR-9

Assembly 8B

Type of Experiment: Critical (Hydrogen added to blanket of Assembly 8A)

Date: January, 1966

Critical Configuration: See Figure 1 of 2.3-8

Core: "cylindrical"

length = 51.1 cm., effective diameter = 61.76 cm.

cell structure: Same as for Assembly 8 (2.3-8). Hydrogen in core as described in (2.3-8A), excepting that the effective diameter of the loaded region was 75.30 cm. and the total H and C content in the assembly was 251.64 g. and 1508.05 g., respectively.

Blanket: Inner reflector of BeO plus outer, Al isolation blanket.

BeO outer effective diameter = 85.54 cm.

Al outer effective diameter = 180.084 cm.

Axial blanket thickness = 35.36 cm. Al.

Critical Mass: 263.798 kg U-235 in core.

Fuel Worth at Core Edge: 20.833 kg U-235

Inhour Conversion: $1\% \Delta k/k = 431.0$ Ih

Composition of Core:

as for Assembly 8A

Composition of Inner Blanket:

<u>Material</u>	<u>Volume %</u>	<u>Atom Concentration</u> <u>(atoms/cm³ x 10²²)</u>
Al	11	0.69
Be	84 (BeO)	5.81
O		5.81
H		0.066
C		0.033

Composition of Outer Blanket:

as for Assembly 8A

2.3-8B (Cont'd)

ZPR-9

Assembly 8B

Measurements Made:

Spatial variation of sample worths (4.2-3-8B)

Effect of sample size on reactivity distributions (4.3-3-8B)

Related Assemblies:

ZPR-9, Assemblies 6, 7, 8, (2.3-8) and 9 (related compositions)

Reference:

**R. C. Doerner, W. G. Knapp, R. A. Karam, and D. K. Butler,
"ZPR-9 Assemblies No. 6-9 Critical Experiments", ANL-7208 (1967).**

Type of Experiment: Critical (U-235, Al, W; Al_2O_3 , Al reflected)

Date: December, 1965

Critical Configuration:

Fig. 1 Assembly 9

Core: "cylindrical"

length = 51.1 cm, effective diameter = 52.26 cm

cell structure: WAlW5WAlW5WAlW5WAl where l = U-235, 5 = Al (45% density) W = tungsten, A = Al_2O_3 ; Al, W, and Al_2O_3 plates were 0.125 in. thick and U-235 plates were 0.0625 in. thick. (See 1.3).

Blanket: inner reflector of Al_2O_3 plus outer, Al isolation blanket.

Al_2O_3 outer effective diameter = 154.35 cm.

Al outer effective diameter = 180.08 cm.

Axial blanket was 35.56 cm. thick, Al_2O_3 for inner reflector plus 11.04 cm. thick Al isolation blanket.

Critical Mass: 192.40 kg U-235 in core.

Fuel Worth at Core Edge: 32.20 lh/kg U-235.

Inhour Conversion: $1\% \Delta k/k = 431.3 \text{ lh}$

2.3-9

(Cont'd)

ZPR-9

Assembly 9

Composition of Core:

<u>Material</u>	<u>Volume %</u>	<u>Atom Concentration (atoms/cm³ x 10²²)</u>
U-235	9.4	.450
U-238	0.7	.033
Al		1.77
W		2.13
Fe		0.037
O		0.89
Void		

Composition of Blanket:

<u>Material</u>	<u>Volume %</u>	<u>Atom Concentration (atoms/cm³ x 10²²)</u>
Al		4.33
O		5.45
Void		

Composition of Isolation Blanket:

as for Assembly 8A

Measurements Made:

Central worths (4.1-3-9)
 Central worths of boron-lucite mixtures (4.1-3-9)
 Prompt neutron lifetime (12.1-3-9)
 Spatial variations of worths (4.2-3-9)
 Reflector worth studies
 Spatial variation of reaction rates (5.2-3-9)

Related Assemblies:

ZPR-9 Assemblies 6, 7, and 8

Reference:

R. E. Doerner, W. G. Knapp, R. A. Karam, and D. K. Bultor. "ZPR-9 Assemblies No. 6-9 Critical Experiments," ANL-7208 (March 1967).

2.3-11

ZPR-9

Assembly 11A

(Loading No. 15)

Type of Experiment: Critical (Zoned; U, C, Na, SS)

Date: May - October, 1966

Critical Configuration:

Fig. 1 Assembly Loading Pattern ZPR-9, Assembly 11

The stainless steel matrix was used in this and subsequent assemblies

Core: "cylindrical"

length = 91.4 cm effective diameter = 41.78 cm

volume = 125 liters

cell structure: the cell includes 3 drawer types:

1) 2M217272'M27

2) 27172'M2M2172'

3) 272M272172'M

where 1 = U-235 (0.159 cm thick), 2 = U-238 (0.317 cm),
2' = U-238 (0.159 cm), 7 = graphite (0.317 cm), M = sodium
(1.27 cm). See Section 1.2.

2.3-11 (Cont'd)

Buffer:

length = 91.4 cm outer effective diameter = 56.06 cm
 cell structure: 27N22'B2'2N72 where B = B₄C (natural boron),
 0.317 cm thick.

Driver:

length = 91.4 cm outer effective diameter = 79.88 cm
 cell structure: 771K71777717K177 where K = nickel (.634 cm
 thick)

Reflector: Type C1018 steel

axial thickness = 33 cm outer effective diameter = 160.04 cm

Critical Mass: 76 kg U-235 in central core, 1.0 kg in buffer
 and 403 kg in driver; 480.1 kg total U-235

Inhour Conversion: $1\% \Delta k/k = 428.2 \text{ Ih}$

Composition of Regions:

Approximate Volume Percent Composition

<u>Material</u>	<u>Core</u>	<u>Buffer</u>	<u>Driver</u>	<u>Reflector</u>
U-235	3		9	
U-238	22	25	1	
Stainless				
Steel (304)	15	15	11	11
			Type C1018 Steel	85
Na	36	36		
Graphite	16	11	52	
B ₄ C		5		
Ni			20	
Void	8	8	7	4

2.3-11 (Cont'd)

Atom Concentration, Atoms/cm³ x 10²²

<u>Material</u>	<u>Core</u>	<u>Buffer</u>	<u>Driver</u>	<u>Reflector</u>
U-235	0.1548	0.0026	0.4443	
U-238	1.061	1.214	0.0319	
U-234	0.0015		0.0044	
U-236	0.0007	0.0021		
Fe	0.8904	0.8904	0.6839	7.777
Ni	0.1125	0.1125	0.1854	0.0891
Cr	0.2541	0.2541	0.1952	0.2036
Na	0.9001	0.9001		
C	1.273	0.9354	4.187	
B(nat.)		0.2984		

Measurements Made:

Neutron spectrum (11-3-11)
Central sample reactivity worths (4.1-3-11)
Doppler effect
Central fission ratios (5.1-3-11)
Spatial distribution of fission rates (5.2-3-11)
Spatial distribution of fission neutron importance (14-3-11)
Cell fission distributions (10.1-3-11)
Doppler coefficient (7-3-11)

Related Assemblies:

ZPR-6 (Assembly 4Z (2.2-4Z). ZPR-9 Assembly 12 (2.3-12) and ZPR-9 Assembly 11 (2.3-11) (in order of decreasing core size) are zoned assemblies whose cores have the same core composition as ZPR-6 Assembly 5 (2.2-5).

Reference:

R. A. Lewis, L. G. LeSage, and R. A. Karam, "ZPR-9 Assemblies 11 and 12 - Two Small Zoned Versions of the 2600-Liter Assembly 5 ZPR-6", ANL Reactor Physics Division Annual Report, July 1, 1966 to June 30, 1967, ANL-7310 p. 190 (1968).

2.3-12

ZPR-9

Assembly 12

(Loading No. 10)

Type of Experiment: Critical (Zoned; U, C, Na, SS)

Date: November 1966 - January 1967

Critical Configuration:

CORE: 1 2 3 (DRAWER TYPES)
CONTROL ROD: 4
SAFETY ROD: 5

Fig. 1 Assembly Loading Pattern ZPR-9, Assembly 12

Core: "cylindrical"

length = 91.4 cm effective diameter = 51.76 cm

volume = 192 liters

cell structure: as for Assembly 11 (2.3-11)

Buffer:

length = 91.4 cm outer effective diameter = 65.04 cm.

cell structure: 727N727727N727

where 2 = U-238 (0.317 cm thick), 7 = graphite (0.317 cm)
and N = sodium (0.635 cm) See section 1.3

Driver:

length = 91.4 cm outer effective diameter = 81.70 cm

cell structure: 2N17N12N71N7 where 1 = U-235 (0.317 cm thick) and others as defined above.

2.3-12 (Cont'd)

Depleted U Reflector:

Axial thickness = 12.7 cm. Outer effective diameter = 109.04 cm

Steel Reflector:

Axial thickness = 20.3 cm. Outer effective diameter = 161.5 cm

Critical Mass: 579 total kg U-235, including 116 kg U-235 in central core. Volume of central core = 192 liters

Worth of Driver Drawer at Outer Edge of Driver = 0.248 % $\Delta k/k$

Inhour Conversion: 1% $\Delta k/k$ = 451.2 Ih

Composition of Regions:

Approximate Volume Percent					
<u>Material</u>	<u>Core</u>	<u>Buffer</u>	<u>Driver</u>	<u>Depleted Reflector</u>	<u>Steel Reflector</u>
U-235	3		14	0.2	
U-238	22	20	11	83	
Stainless	15	15	18	7	11
Steel (304)				Type C1018 Steel :	85
Na	36	15	31		
Graphite	16	41	16		
Void	8	9	10	10	4

Atom Concentration, atoms/cm ³ x 10 ²²					
<u>Material</u>	<u>Core</u>	<u>Buffer</u>	<u>Driver</u>	<u>Reflector</u>	<u>Reflector</u>
U-235	0.153	0.0021	0.6653	0.0081	
U-238	1.063	0.9710	0.4999	3.993	
U-234	0.0015		0.0065		
U-236	0.0007		0.0031		
Fe	0.8901	0.8726	1.052	0.4322	7.777
Ni	0.1125	0.1103	0.1329	0.054	0.0891
Cr	0.2541	0.2491	0.3082	0.114	2.036
Na	0.8996	0.387	0.7565		
C	1.285	3.430	1.278		

2.3-12 (Cont'd)

Measurements Made:

Neutron spectrum (11-3-12)
Central sample reactivity worths (4.1-3-12)
Doppler coefficients (7-3-12)
Distribution of fission neutron importance (14-3-12)
Central fission ratio (5.1-3-18)
Spatial distribution of reaction rates (5.2-3-12)

Related Assemblies:

ZPR-9, Assembly 18 (identical assembly)

References:

1. R. A. Lewis, L. G. LeSage, and R. A. Karam, "ZPR-9 Assemblies 11 and 12 - Two Small Zoned Versions of the 2600 - Liter Assembly 5 ZPR-6", ANL Reactor Physics Division Annual Report, July 1, 1966 to June 30, 1967, ANL-7310, p. 190 (1968).
2. L. G. LeSage, et. al., "A Review of Data Pertaining to Spectral Equilibration and Spectral Matching in Zoned Cores", ANL Reactor Physics Division Annual Report July 1, 1966 to June 30, 1967, ANL-7310, p. 199 (1968).

Type of Experiment: Critical (zoned; U, Na, C, H)

Date: January, 1967

Critical Configuration:

The core and buffer regions are as shown in Figure 1 of 2.3-12.

Core: "cylindrical"

length = 91.4 cm effective diameter = 51.74 cm

volume = 192 liters

cell structure: the cell includes three drawer types:

1) hNh7h1H7h2hNh2h7h2

2) I7h1I2hNE2HNh7h1I2

3) h7h2hNh7h2h7H1hNh2

where 1 = U-235 (0.159 cm thick), 2 = U-238 (0.317 cm),

7 = graphite (0.317 cm), h = polyethylene (0.0508 cm),

H = polyethylene (0.0635 cm), I = polyethylene (0.1016 cm),

N = sodium (0.635 cm). See section 1.3.

Buffer:

length = 91.4 cm outer effective diameter = 65.02 cm

cell structure: see 2.3-12

Driver:

length = 91.4 cm outer effective diameter = 75.70 cm

cell structure: see 2.3-12

Blanket and Reflector:

as for Assembly 12 (2.3-12)

Critical Mass: Total U-235 in 3 central regions = 402.8 kg.
(approximately 115 kg in core)

Inhour Conversion: $1\% \Delta k/k = 437.85 \text{ Ih}$

2.3-13 (Cont'd)

Composition of Core:

<u>Material</u>	<u>Approximate Volume %</u>	<u>Atom Concentration atoms/cm³ x 10²²</u>
U-235	3.2	0.1541
U-238	15	0.7389
U-234		
U-236		
Stainless		
Steel (304)	15	
Fe		0.9086
Ni		0.1148
Cr		0.2593
Mn		
Si		
Na	36	0.9028
Polyethylene	8.7	
H		0.6754
C		0.3377
C (as graphite)	14	1.154
Void	8	

Compositions of Other Regions:

As for Assembly 12 (2.3-12)

Measurements Made:

Doppler coefficient (7-3-13)

Central sample reactivity worths (4.1-3-12)

Related Assemblies:

ZPR-9 Assembly 13 was a modification of Assembly 12. Assemblies 14-17 were modifications of Assembly 13 in which graphite was systematically substituted for depleted uranium in the central core.

Reference:

R. Pond and C. E. Till, "Doppler Effect Measurements in CH₂-Softened Spectra; ZPR-9 Assemblies 13 - 17", ANL Reactor Physics Division Annual Report July 1, 1966 to June 30, 1967, p. 159 ANL-7310 (1968).

Type of Experiment: Critical (Zoned; U, Na, C, H)

Date: February, 1967

Critical Configuration:

See Figure 1, Section 2.3-12

Core: "cylindrical"

length = 91.4 cm effective diameter = 51.74 cm

volume = 192 liters

cell structure: identical to that for Assembly 13 (2.3-13)
except that the last depleted plate in drawer type 2 is re-
placed by a graphite plate.

Buffer:

length = 91.4 cm outer effective diameter = 65.02 cm

cell structure: as for Assembly 11 (2.3-11)

Driver:

length = 91.4 cm outer effective diameter = 74.70 cm

cell structure: as for Assembly 12 (2.3-12)

Blanket and Reflector: as for Assembly 12 (2.3-12)

Critical Mass: total U-235 = 374.1 kg, approximately 115 kg of
which is in central core.

Inhour Conversion: 1% Ak/k = 435.7 Ih

Composition of Core:

<u>Material</u>	<u>Volume %</u>	<u>Atom Concentration</u> <u>atoms/cm³ x 10²²</u>
U-235	3.2	0.1539
U-238	13.7	0.6580
U-234		
U-236		
Stainless Steel (304)	15	
Fe		0.9086
Ni		0.1148
Cr		0.2593
Mn		
Si		
Na	36	0.9028
Polyethylene	8.7	
H		0.6754
C		0.3377
C (as graphite)	16	1.299
Void	7	

2.3-14 (Cont'd)

Composition of Other Regions:

as for Assembly 12 (2.3-12)

Measurements Made:

Doppler coefficient (7-3-13)

Central sample reactivity worths (4.1-3-12)

Related Assemblies:

ZPR-9 Assembly 13 was a modification of Assembly 12. Assemblies 14-17 were modifications of Assembly 13 in which graphite was systematically substituted for depleted uranium in the central core.

Reference:

E. Pond and C. E. Till, "Doppler Effect Measurements in CH₂-Softened Spectra; ZPR-9 Assemblies 13-17", ANL Reactor Physics Division Annual Report July 1, 1966 to June 30, 1967, p. 159 ANL-7310 (1968).

2.3-15

ZPR-9

Assembly 15

Type of Experiment: Critical (zoned; U, Na, C, H)Date: March, 1967Critical Configuration: See Figure 1, Section 2.3-12Core: "cylindrical"

length = 91.4 cm effective diameter = 51.74 cm

volume = 192 liters

cell structure: identical to that for Assembly 13 (2.3-13)
except that the last depleted plates in drawer types 1 and 2 are replaced by graphite plates.Buffer:

length = 91.4 cm outer effective diameter = 63.02

cell structure: as for Assembly 11 (2.3-11)

Driver:

length = 91.4 cm outer effective diameter = 73.94 cm

cell structure: as for Assembly 12 (2.3-12)

Blanket and Reflector: as for Assembly 12 (2.3-12)Critical Mass: Total U-235 = 352.9 kg (approximately 115 kg in central core)Composition of Core:

<u>Material</u>	<u>Volume %</u>	<u>Atom Concentration</u> <u>atoms/cm³ x 10¹²</u>
U-235	3.2	0.1537
U-238	12	0.5771
U-234		
U-236		
Stainless Steel (304)	15	
Fe		0.9086
Ni		0.1148
Cr		0.2593
Mn		
Si		
Na	36	0.9028
Polyethylene	8.7	
H		0.6754
C		0.3377
C (as graphite)	17	1.443
Void	8	

2.3-15 (Cont'd)

Composition of Other Regions:

as for Assembly 12 (2.3-12)

Measurements Made:

none

Related Assemblies:

ZPR-9 Assembly 13 was a modification of Assembly 12. Assemblies 14-17 were modifications of Assembly 13 in which graphite was systematically substituted for depleted uranium in the central core.

Reference:

R. Pond and C. E. Till, "Doppler Effect Measurements in CH_2 -Softened Spectra; ZPR-9 Assemblies 13 - 17" ANL Reactor Physics Division Annual Report July 1, 1966 to June 30, 1967, p. 159 ANL-7310 (1968).

2.3-16

ZPR-9

Assembly 16

Type of Experiment: Critical (zoned; U, Na, C, H)

Date: March, 1967

Critical Configuration: See Figure 1 of Section 2.3-12

Core: "cylindrical"

length = 91.4 cm effective diameter = 51.74 cm

volume = 192 liters

cell structure: identical to that for Assembly 13 (2.3-13)
except that the last depleted plates in all drawers are re-
placed by graphite plates.

Buffer:

length = 91.4 cm outer effective diameter = 65.02 cm

cell structure: as for Assembly 11 (2.3-11)

Driver:

length = 91.4 cm outer effective diameter = 73.24 cm

cell structure: as for Assembly 12 (2.3-12)

Blanket and Reflector: as for Assembly 12 (2.3-12)

Critical Mass: Total U-235 = 333.1 kg (approximately 115 kg in
central core).

Inhour Conversion: 1% $\Delta k/k$ = 428.1 Ih

Composition of Core:

<u>Material</u>	<u>Volume %</u>	<u>Atom Concentration</u> <u>atoms/cm³ x 10²²</u>
U-235	3.2	0.1536
U-238	10	0.4963
U-234		
U-236		
Stainless steel (304)	15	
Fe		0.9086
Ni		0.1148
Cr		0.2593
Mn		
Si		
Na	36	0.9028
Polyethylene	8.7	
H		0.6754
C		0.3377
C (as graphite)	19	1.587
Void	8	

2.3-16 (Cont'd)

Composition of Other Regions:

as for Assembly 12 (2.3-12)

Measurements Made:

Doppler coefficient (7-3-13)

Central sample reactivity worths (4.1-3-12)

Related Assemblies:

ZPR-9 Assembly 13 was a modification of Assembly 12. Assemblies 14-17 were modifications of Assembly 13 in which graphite was systematically substituted for depleted uranium in the central core.

Reference:

R. Pond and C. E. Till, "Doppler Effect Measurements in CH₂-Softened Spectra; ZPR-9 Assemblies 13-17", ANL Reactor Physics Division Annual Report July 1, 1966 to June 30, 1967, p. 159 ANL-7310 (1968).

2.3-17

ZPR-9

Assembly 17

Type of Experiment: Critical (U, Na, C, H)Date: April, 1967Critical Configuration: 3 regions (as for Assembly 12, see 2.3-12)Core: "cylindrical"

length = 91.4 cm effective diameter = 54.92 cm

cell structure: the cell includes three drawer types:

1) hNh7h1h7h7hNh7h7h7

2) I7h1I7hN171Nh7h1I7

3) h7h7hNh7h7h7H1hNh7

where the symbols are defined in section 2.3-13.

Blanket and Reflector: as for Assembly 12 (2.3-12)Critical Mass: total U-235 = 126.7 kgInhour Conversion: $1\% \Delta k/k = 391.8$ IhComposition of Core:

<u>Material</u>	<u>Volume %</u>	<u>Atom Concentration</u> <u>atoms/cm³ x 10²²</u>
U-235	3.2	0.1525
U-238	0.2	0.0110
U-234		
U-236		
Stainless Steel (304)	15	
Fe		0.9086
Ni		0.1148
Cr		0.2593
Mn		
Si		
Na	36	0.9028
Polyethylene	8.7	
H		0.6754
C		0.3377
C (as graphite)	29	2.4529
Void	8	

Composition of Other Regions:

as for Assembly 12 (2.3-12)

2.3-17 (Cont'd)

Measurements Made:

Doppler coefficient (7-3-13)

Central sample reactivity worths (4.1-3-12)

Related Assemblies:

ZPR -9 Assembly 13 was a modification of Assembly 12. Assemblies 14-17 were modifications of Assembly 13 in which graphite was systematically substituted for depleted uranium in the central core.

Reference:

R. Pond and C. E. Till, "Doppler Effects Measurements in CH₂ Softened Spectra; ZPR-9 Assemblies 13-17" ANL Reactor Physics Division Annual Report July 1, 1966 to June 30, 1967, P. 159 ANL-7310 (1968).

2.3-18

ZPR-9

Assembly 18

Type of Experiment: Critical (zoned, for Doppler studies; U, Na, SS, C)

Date: June, 1967

Critical Configuration:

Identical to Assembly 12 (2.3-12)

Measurements Made:

Central fission ratio (5.1-3-18)

Effect of environment on Doppler - effect measurements (7-3-18)

Reference:

R. A. Lewis and T. W. Johnson, "Sensitivity of Small - Sample Doppler - Effect Measurements to Environment", ANL Reactor Physics Division Annual Report July 1, 1967 to June 30, 1968 ANL-7410, p. 96 (1968).

2.3-19 ZPR-9 Assembly 19 (Loading No. 12)

Type of Experiment: Critical (zoned, U oxide core)

Date: February, 1968

Critical Configuration:

Fig. 1 Assembly Loading Pattern ZPR-9, Assembly 19

Core (Test Zone): "cylindrical"

length = 91.4 cm effective diameter = 51.74 cm

volume = 192 liters

cell structure: UNF612FNU where 1 = U-235 (0.159 cm thick),
2 = U-238 (0.318 cm), 6 = type 304 stainless steel (0.159 cm),
U = U_3O_8 (0.635 cm), N = Na (1.27 cm) and F = Fe_2O_3 (0.318 cm).

The plates are described in Section 1.3

Buffer:

length = 91.4 cm outer effective diameter = 65.02 cm

cell structure: U3U3'U3'U3U where 3 = Al (0.635 cm thick),
3' = Al (0.318 cm) and U = U_3O_8 (0.635 cm)

2.3-19 (Cont'd)

Driver:

length = 91.4 cm outer effective diameter = 85.84 cm
cell structure: 76716766'76'6761767 where 1 = U-235 (0.318 cm thick), 6 = type 304 SS (0.318 cm), 6' = SS (0.159 cm) and 7 = graphite (0.318 cm).

Steel Reflector: Type C1018 steel:

axial thickness = 15.2 cm
outer effective diameter = 125.96

Depleted U Reflector:

axial thickness = 15.2 cm
outer effective diameter = 154.70

Critical Mass = 481.16 kg total U-235; 87 kg in central core,
393 kg in driver, 1 kg in buffer

Inhour Conversion: $1\% \Delta k/k = 435.5 \text{ Ih}$

Composition of Core:

<u>Material</u>	<u>Volume %</u>	<u>Atom Concentration</u> <u>atoms/cm³ x 10²²</u>
U ₃ O ₈	19	
U-235	2	0.1156 (total)
U-238	5	0.5789 (total)
U-234		0.0011
U-236		0.0005
Stainless		
Steel	18	
Fe ₂ O ₃	10	
Fe		1.4360
Ni		0.1319
Cr		0.2979
Na	38	0.9333
O		1.468
Void	8	

2.3-19 (Cont'd)

Composition of Other Regions:

Approximate Volume Percent in

<u>Material</u>	<u>Buffer</u>	<u>Driver</u>	<u>Reflector 1</u>	<u>Reflector 2</u>
U ₃ O ₈	48			
U-235		10		
U-238		1		83
Stainless				
Steel	11	46	11	7
Al	31	(Cl018 steel :	85	
C		36		
Void	10	7	4	10

<u>Material</u>	<u>Buffer</u>	<u>Driver</u>	<u>Reflector 1</u>	<u>Reflector 2</u>
Atom Concentration (atoms/cm ³ x 10 ²²)				
U-235	0.0017	0.4471		0.0081
U-238	0.8242	0.0255		3.993
U-234		0.0044		
U-236		0.0021		
Fe	0.6839	2.833	7.777	0.4332
Ni	0.0864	0.3579	0.0891	0.0540
Cr	0.1952	0.8083	0.2036	0.1140
C		2.976		
O	2.2027			
Al	1.8738			

Measurements Made:

Central sample reactivity worths (4.1-3-19)
 Spatial variation of worths (4.2-3-19)
 Spatial variation of reaction rates (5.2-3-19)
 Doppler coefficients (7.3-19)
 Effect of streaming on reactivity worths (4.4-3-19)

Related Assemblies:

ZPR-9 Assembly 23 was identical. Assemblies 21 and 22 had identical core compositions and Assembly 24 was similar.

Assembly 20 was planned but never constructed.

Reference:

L. G. Le Sage and W. R. Robinson, "ZPR-9 Assemblies 19, 21, 22 and 24", ANL Reactor Physics Division Annual Report July 1, 1967 June 30, 1968, ANL-7410, p. 80 (1969).

2.3-21

ZPR-9

Assembly 21 (Loading No. 13)

Type of Experiment: Critical (zoned, U oxide core)

Date: February, 1968

Critical Configuration:

☒ CONTROL ROD

NOTE: STATIONARY HALF SHOWN ABOVE, MOVABLE
HALF HAS FIVE CONTROL RODS.

Fig. 1 Assembly Loading Pattern ZPR-9, Assembly 21

Core (test zone): "cylindrical"

length = 91.4 cm effective diameter = 28.54 cm

volume = 58 liters

cell structure: as for Assembly 19 (2.3-19)

Buffer:

length = 91.4 cm outer effective diameter = 41.78 cm

cell structure: as for Assembly 19 (2.3-19)

Driver:

length = 91.4 cm outer effective diameter = 65.17 cm

cell structure: as for Assembly 19 (2.3-19)

Reflectors: as for Assembly 19 (2.3-19)

2.3-21 (Cont'd)

Critical Mass = 338.50 kg U-235 total; 26 kg in central core,
1 kg in buffer, 311 kg in driver

Inhour Conversion: $1\% \Delta k/k = 429.5 \text{ Ih}$

Composition of Regions:

The compositions were very close to those of Assembly 19 (2.3-19) so that the same approximate volume percentages hold. The atom concentrations of the reflectors were identical. The other atom concentrations are as follows:

Atom Concentration (atoms/cm³ x 10²²)

<u>Material</u>	<u>Core</u>	<u>Buffer</u>	<u>Driver</u>
U-235	0.1152	0.0017	0.4443
U-238	0.5770	0.8232	0.0254
U-234	0.0011		0.0043
U-236	0.0005		0.0021
Fe	1.4335	0.6839	2.8129
Ni	0.1310	0.0864	0.3554
Cr	0.2959	0.1952	0.8027
C			2.9605
Na	0.9202		
O	1.4632	2.2000	
Al		1.8718	0.0065

Measurements Made:

Spatial variation of reactivity worths (4.2-3-19)
Effect of streaming on reactivity worths (4.4-3-19)
Spatial variation of reaction rates (5.2-3-19)
Doppler coefficients (7-3-21)

Related Assemblies:

ZPR-9 Assemblies 19, 22, 23 and 24.

Reference:

L. G. Le Sage and W. R. Robinson, "ZPR-9 Assemblies 19, 21, 22 and 24", ANL Reactor Physics Division Annual Report July 1, 1967 to June 30, 1968, ANL-7410, p. 80 (1969).

2.3-22

ZPR-9

Assembly 22 (Loading No. 10)

Type of Experiment: Critical (Zoned, U oxide core)

Date: February, 1968

Critical Configuration:

Fig. 1 Assembly Loading Pattern ZPR-9, Assembly 22

Core (test zone): "cylindrical"

length = 91.4 cm effective diameter = 51.74 cm

volume = 192 liters

cell structure: as for Assembly 19 (2.3-19)

Buffer:

length = 91.4 cm

outer effective diameter = 65.02 cm

cell structure: 2 pieces of 1.27 cm thick Al

Driver:

length = 91.4 cm

outer effective diameter = 84.25 cm

cell structure: as for Assembly 19 (2.3-19)

2.3-22 (Cont'd)

Reflectors: as for Assembly 19 (2.3-19)

Critical Mass = 443.58 kg U-235 total; 85 kg in central core
359 kg in driver

Inhour Conversion: $1\% \Delta k/k = 435.2$ Ih

Composition of Regions:

The compositions were very close to those of Assembly 19 (2.3-19) so that the same approximate volume percentages apply. The atom concentrations of the reflectors were identical. The others are as follows:

Atom Concentration (atoms/cm³ x 10²²)

<u>Material</u>	<u>Core</u>	<u>Buffer</u>	<u>Driver</u>
U-235	0.1129		0.4462
U-238	0.5654		0.0255
U-234	0.0011		0.0044
U-236	0.0005		0.0021
Fe	1.4128	0.6839	2.8325
Ni	0.1298	0.0864	0.3579
Cr	0.2930	0.1952	0.8082
C			2.9604
Na	0.9017		
O	1.4338		
Al		5.0759	

Measurements Made:

Spatial variation of reactivity worths (4.2-3-19)

Spatial variation of reaction rates (5.2-3-19)

Effect of streaming on reactivity worths (4.4-3-19)

Reference:

L. G. Le Sage and W. R. Robinson, "ZPR-9 Assemblies 19, 21, 22, and 24," ANL Reactor Physics Division Annual Report July 1, 1967 to June 30, 1968, ANL-7410, p. 80 (1969).

Type of Experiment: Critical (zoned; U, C, SS; central zone adjusted to $k_{\infty} = 1$)

Date: April, 1968

Critical Configuration:

Fig. 1 Assembly Loading Pattern ZPR-9, Assembly 24

Core (test zone): "cylindrical"

length = 91.4 cm effective diameter = 51.74 cm

volume = 192 liters

cell structure: 7'2727"172'727' where

1 = U-235 (0.159 cm thick), 2 = U-238 (0.318 cm)

2' = U-238 (0.476 cm), 7 = graphite (0.635 cm)

7' = graphite (0.318 cm) and 7" = graphite (0.953 cm)

These plates are described in Section 1.3.

2.3-24 (Cont'd)

Buffer:

length = 91.4 cm outer effective diameter = 61.34 cm
cell structure: 27272727272 where 2 = U-238 (0.318 cm thick) and 7 = graphite (0.635 cm).

Driver:

length = 91.4 cm outer effective diameter = 102.80
cell structure: 7'67676'16'76767' where 6 = 304 stainless steel (0.318 cm thick), 6' = SS (0.635 cm) 7 = graphite (0.635 cm). 7' = graphite (0.318 cm).

Steel Reflector: Type C1018 steel

axial thickness = 15.2 cm outer effective diameter = 128.76 cm

Depleted U Reflector:

axial thickness = 15.2 cm outer effective diameter = 161.90

Critical Mass = 505 kg U-235 total; 85 kg in test zone
1 kg in buffer, 416 kg in driver

Inhour Conversion: $1\% \Delta k/k = 422.4 \text{ Ih}$

Composition of Regions:

The null-zone compositions were designed to emphasize the 0.1 to 25 keV energy range, and approximately one-half the total (calculated) fissile-isotope fissions were in this range. Two-inch cubic samples of the test zone material were used for determination of the test-zone reactivity. The ratio of graphite to depleted uranium was varied until the reactivity of the sample, as measured by an oscillation technique, was zero with respect to void. At this point, the total test zone was reloaded to the experimentally determined null composition, and the null was rechecked by further reactivity measurements.

Approximate Volume Percent

<u>Material</u>	<u>Core</u>	<u>Buffer</u>	<u>Driver</u>
U-235	2.4		4.7
U-238	26	30	
Stainless			
Steel (304)	11	11	36
Graphite	53	52	52
Void	8	7	7

2.3-24 (Cont'd)

Atom Concentration (atoms/cm³ x 10²²)

<u>Material</u>	<u>Core</u>	<u>Buffer</u>	<u>Driver</u>
U-235	0.1135	0.00311	0.2179
U-238	1.223	1.456	0.0126
U-234	0.0011		0.0021
U-236	0.0005		0.0010
Fe	0.6755	0.6838	2.2211
Ni	0.0854	0.0864	0.2807
Cr	0.1928	0.1952	0.6339
C	4.338	4.287	4.276

Measurements Made:

Spatial variation of reactivity worths (4.2-3-19)
Central reaction rates, including α (U-235)
and α (Pu-239). (5.1-3-24a and 24b)
Central reactivity worths

Related Assemblies:

ZPR-9 Assemblies 19, 21, and 22
ZPR-3 Assemblies 55 and 55A

References

- 1.) L. G. Le Sage and W. R. Robinson, "ZPR-9 Assemblies 19, 21, 22 and 24", ANL Reactor Physics Division Annual Report July 1, 1967 to June 30, 1969, ANL-7410, p. 80 (1969).
- 2.) M. M. Bretcher and W. C. Redman, "Low-Flux Measurements of ²³⁹Pu and ²³⁵U Capture-to-Fission Ratios in a Fast Reactor Spectrum" ZPR-TM-2, ANL (1969).

Type of Experiment: Critical (Zoned; small central Pu zone for α measurement).

Date: April, 1968

Critical Configuration:

A small plutonium zone of equivalent spherical radius 8.4 cm was substituted at the center of the U-235 null zone of Assembly 24 (see Section 2.3-24). Its composition was adjusted so that $k_{\infty} = 1$.

Composition of Central Zone:

<u>Material</u>	<u>Volume %</u>	<u>Atom Concentration</u> <u>atoms/cm³ x 10²²</u>
Pu-239	1.8	0.09161
Pu-240		0.00093
U-235		0.00272
U-238	27	1.272
Stainless		
Steel (304)	10	0.8119
C	43	3.647
Al		0.00993
Void*	19	

* Additional void was introduced (with SS spacers) to achieve null reactivity.

Measurements Made:

Capture-to-fission ratio in Pu-239 (4.1-3-24a)

Related Assemblies:

ZPR-9 Assembly 24 (2.3-24)

ZPR-3 Assembly 55A (2.1-55A)

Reference:

C. E. Till, et al., "Null-Reactivity Measurements of Capture Fission Ratio in ^{235}U and ^{239}Pu ", Nucl. Sci. Eng. 40, 132 (1970).

SECTION 3 - SHAPE FACTORS

The geometry of fast reactor critical experiments rarely corresponds to the simple configurations that can be readily calculated. Thus it is useful to establish relationships that allow one to derive a simple geometry critical mass (spherical, say) from one measured in a complex geometry (an imperfect cylinder, for example). Such relationships, often of a semi-empirical nature are termed "shape factors".

Loewenstein and Main have defined the shape factor as "the ratio of the spherical critical mass of a system to the critical mass of a given assembly" (1). Other definitions have been used, however, so that in the results given in this section the definition being used will be specified.

This section differs from most others in the compilation in that a given entry involves several assemblies. In general, these will be assemblies having the same constituents, differing only in the overall geometrical arrangement. In some instances the assemblies considered will have been described in Section 2. Otherwise, they will be described in this section.

Reference:

W. B. Loewenstein and G. W. Main, 'Fast Reactor Shape Factors and Shape-Dependent Variables', ANL-6403 (1961).

Facility: ZPR-3 (1.1)

Description of Assemblies: See table of results; the assemblies are described in appropriate subsections of Section 2. All cores contain U^{235} (~14 vol. %), U^{238} (15.7-16%), Al (31.4-31.5%) and 304 stainless steel (12.3-12.4%) and are reflected principally by depleted U.

Results:

<u>ZPR-3 Assembly No.</u>	<u>$N(U^{238})/N(U^{235})$</u>	<u>L/D^a</u>	<u>Experimental Critical Mass (kg U^{235})</u>
6C	1	0.23	221.0
6B	1	0.31	183.0
1B	1	0.66	137.1
2	1	1.02	136.0
6D	1	1.57	147.4
6E	1	2.13	164.1
6F	1	Sphere	131.1
9B	3	0.38	193.3
9	3	0.88	151.9
9A	3	Sphere	146.2

^a Ratio of actual core height to diameter.

Reference:

J. K. Long et al., "Fast Neutron Power Reactor Studies with ZPR-III", 1958 Geneva Conference 12, 119 (1959).

3-1-24 Shape Factors

Facility: ZPR-3 (1.1)

Description of Assemblies:

<u>Assembly</u>	<u>Geometry</u>	<u>Core Description</u>	<u>Section Reference</u>
24	cylinder (L/D=0.972)	High density U-235,U-238	2. <u>1</u> -24
38	sphere	same as 24	2. <u>1</u> -38
31	cylinder (L/D=0.732)	Low density U-235,U-238,A1	2. <u>1</u> -31
39	sphere	same as 31	2. <u>1</u> -39

In all cases the blanket was high density depleted uranium.

Results:

<u>Assemblies</u>	<u>Shape Factor</u>
24/38	0.920 ± 0.0003
31/39	0.921 ± 0.002

Reference:

J. C. Bates, et al., "Two Spherical Fast Critical Experiments (ZPR-III Assemblies 38 and 39)" ANL-6582 (1962).

SECTION 4 - SAMPLE REACTIVITY WORTHS

The measurement of the reactivity worths of samples of various materials are useful as additional data with which to check cross sections. They also serve to extend the usefulness of a particular assembly to isotopes not included as constituents of the assembly.

The techniques of sample worth measurements have been discussed by Davey and Redman (1). Although the experimental accuracy of this type of experiment is important in determining its usefulness to analysis, perhaps more important is the degree to which the analytical procedure can reproduce the details of the experiment. Such details as sample geometry and the immediate environment of the sample are often not given in the literature, but every effort has been made to include them here.

The Section is divided into four parts:

- 4.1 Central Reactivity Worths
- 4.2 Spatial Variations of Worths
- 4.3 Effect of Sample Size on Reactivity Worths
- 4.4 Other Effects on Reactivity Worths

Reference:

W. G. Davey and W. C. Redman, Techniques in Fast Reactor Critical Experiments, to be published as an American Nuclear Society Monograph.

SECTION 4.1 - CENTRAL REACTIVITY WORTHS

Facility: ZPR-3 (1.1)Assembly: 31 (2.1-31)Method of Measurement:

The fissionable samples were loaded across the first 1/4 in. of the central drawer in each half of the core, The normal core loading having been recessed by this amount. The reference was run with two 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 1/8 x 2 x 2 in. plate sandwiched between two 1/16 x 2 x 2 in. plate 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 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.

<u>Results:</u> Material	Sample Mass (kg)	Sample Worth (1h $\pm$ 0.5) ^c	Reactivity Coefficient	
			(1h/kg)	(1h/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	-

Isotopic Values

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} .

(c) $\text{Ih} = 3.15 \times 10^{-5} \text{ Ak/k}$

Reference:

J. M. Gasidlo, J. K. Long, and R. L. McVean, "Critical Studies of a Dilute Fast Reactor Core (ZPR-III Assembly 31)" ANL-6338 (1961).

4.1-1-32 Central Reactivity Worths

Facility: ZPR-3 (1.1)

Assembly: 32 (2.1-32)

Method of Measurement:

The samples were approximately 2 x 2 x 1/4 in. in size. A 2 x 2 x 1/4 in. void was created at the core center by effectively removing the first 1/4 in. of core material in the central drawer. The reference case contained one 45% Al (perforated) plate (2 x 2 x 1/8 in.) and one 63% Al plate in the sample position. Since the samples were either clad in or sandwiched between Al, the net change in Al was zero. Reactivity was measured with a calibrated control rod.

Results:

<u>Material</u>	<u>Weight (kg)</u>	<u>Reactivity Worth (Δk / kg)</u>
U-235	0.268	212 $\pm$ 2
U-233	0.221	403 $\pm$ 3
Pu metal (95% Pu-239)	0.186	374 $\pm$ 3

other large sample, reactivity worths are reported in the reference.

Reference:

P. I. Amundson, et al., "Critical Studies of Uranium-Steel and Uranium-Steel-Sodium Fast Reactor Cores (ZPR-III Assemblies 32 and 33)" ANL-6690 (1963).

4.1-1-33

Central Reactivity Worths

Facility: ZPR-3 (1.1)

Assembly: 33 (2.1-33)

Method of Measurement:

See Section 4.1-1-32

Results:

<u>Material</u>	<u>Weight (kg)</u>	<u>Reactivity Worth ($\Delta k/k$)</u>
U-235	0.268	197 $\pm$ 2
U-233	0.221	367 $\pm$ 3
Pu metal (95% Pu-239)	0.186	349 $\pm$ 3

Other, large sample, reactivity worths are reported in the reference.

Reference:

P. I. Amundson, et al., "Critical Studies of Uranium-Steel and Uranium-Steel-Sodium Fast Reactor Cores (ZPR-III Assemblies 32 and 33)", ANL-6690 (1963).

Facility: ZPR-3 (1.1) Assembly: 36 (2.1-36)

Method of Measurement:

See Section 4.1-1-32.

Results:

A.	Sample	Mass (kg)	Worth ^(c) (1h $\pm$ 0.5)	Reactivity Coefficient	
				(1h/kg)	(1h/g-mole)
	93.1% Enriched	0.2878	60.5	210 $\pm$ 2	
	99.8% Depleted	2.378	-21.9	-9.2 $\pm$.2	
	U ²³³ Mixture(a)	0.2266	94.6	418 $\pm$ 2	
	Pu ²³⁹ Mixture(b)	0.1860	71.5	384 $\pm$ 3	
B. Isotopic Values					
	U ²³⁵	0.2684		225 $\pm$ 2	52.9 $\pm$.5
	U ²³⁸	2.373		-9.7 $\pm$.2	-2.78 $\pm$.05
	U ²³³	0.2212		428 $\pm$ 2	99.8 $\pm$.5
	Pu ²³⁹	0.1758		402 $\pm$ 3	96.1 $\pm$.7

(a) The isotopic concentrations were 97.40% U²³³ and 2.60% U²³⁸. The isotopic value was calculated assuming that all of the reactivity effect was due to the U²³³.

(b) The isotopic concentrations were 94.51% Pu²³⁹, 5.11% Pu²⁴⁰, and 0.38% Pu²⁴¹. The isotopic value was calculated assuming that Pu²⁴⁰ has approximately $\frac{1}{5}$ the worth of Pu²³⁹.

(c) $\text{Ih} = 2.26 \times 10^{-5} \Delta k/k$

Reference:

J. M. Gasidlo, J. K. Long, and R. L. McVean, "Critical Studies of a Fast Reactor Core Containing Depleted Uranium and Sodium as Diluents (ZPR-III Assembly 36)" ANL-6494 (1962).

4.1-1-39

Central Reactivity Worths

Facility: ZPR-3 (1.1)

Assembly: 39 (2.1-39)

Method of Measurement:

as for Assembly 31 (See Section 4.1-1-31)

Results:

The values given below are relative to void.

<u>Material</u>	<u>Sample mass (kg)</u>	<u>Sample Worth (Ih)</u>	<u>Isotope Worth)Ih/kg)</u>
U-235 (93.1%)	0.2878	29.0 $\pm$ 0.5	108 $\pm$ 1.9
Pu-239(a)	0.1860	35.0 $\pm$ 0.5	197 $\pm$ 2.8

(a) 94.51 % Pu-239, 5.11 % Pu-240, 0.38 % Pu-241
Isotope worth based on assuming Pu-240 has 1/5 the worth
of Pu-239.

Reference:

J. C. Bates, et al., "Two Spherical Fast Critical Experiments
(ZPR-III Assemblies 38 and 39)" ANL-6582 (1962).

Facility: ZPR-3 (1.1)

Assembly: 42 (2.1-42)

Method of Measurement:

Fissile Materials: See Section 4.1-1-31

Non-Fissile Materials: The samples were 2 x 2 x 1 in. except for boron carbide (1 x 2 x 1/4 in.). The core-center void for these samples was created by recessing the perforated front sections of opposing drawers by 1 in.

Reactivity change was measured with a calibrated control rod.

Precision:

Reactivity changes measured to $\pm .5$ lh (gap closing uncertainty).

Results and Corrections

Corrections applied to specific samples indicated in Table I.

References:

- (1) P. I. Amundson, "A Two-Zone Fast Critical Experiment", ANL-6733 (1964).
- (2) J. K. Long, et al., "Fast Neutron Power Reactor Studies with ZPR-III" Geneva Conf. 1958, 12, 119.

Table I
Central Reactivity Worths*

<u>Material</u>	<u>Worths</u> <u>(Ih/kg)</u>		
U-235 (b)	117	±	2.0
Pu-239 (b)	197	±	2.5
U-233 (b)	223	±	2.5
U-238 (b)	-8.0	±	0.3
Thorium	-13.0	±	0.3
Zirconium	-1.3	±	0.5
Sodium (a)	10.3	±	5.0
Lead	-0.3	±	0.3
Carbon	35.5	±	2.5
Bismuth	-0.07	±	0.4
Aluminum	0.2	±	0.5
Ph-I Oxide (a,d)	-15.3	±	2.5
Ph-II Oxide (a,d)	-14.5	±	2.5
Niobium (a)	-16.6	±	1.0
Molybdenum	-10.3	±	0.5
Mercury (a)	-5.4	±	0.5
Al ₂ O ₃	8.3	±	1.5
Oxygen (e)			
Lithium (a)	-97.6	±	10.0
Beryllium	83.1	±	2.0
B-10 (c)	-2290	±	50.0
Tantalum (a)	-30.2	±	0.5
SS	-1.7	±	0.5
Silver	-50.4	±	0.8
Nickel	-2.5	±	0.5
Chromium (a)	-0.7	±	1.0
SS	-1.7	±	0.5

(a) Corrected for reactivity effects of stainless steel canning material.

(b) Corrected for effects of all other isotopes in samples.

(c) Corrected for effects of B¹¹ and carbon in enriched B₄C sample.

(d) Physicum samples fully described in reference 2.

(e) Oxygen worth calculated from Al₂O₃ measurement.

*Ih = $2.45 \times 10^{-5} \Delta k/k$

Facility: ZPR-3 (1.1)Assembly: 43 (2.1-43)Method of Measurement:

Fissionable samples 2 in. x 2 in. x 0.5 in. were introduced at the core center as described in Section 4.1-1-31

Results:

Material	Mass (kg)	Worth (lh $\pm$ 0.5)	Reactivity Coefficients (lh/kg)
93.1% Enriched U	0.2684	15.2	56.6 $\pm$ 1.8
99.8% Depleted U	2.439	-9.7	-4.0 $\pm$ 0.2
U ²³³ Mixture (a)	0.221	22.4	101.1 $\pm$ 2.3
Pu ²³⁹ Mixture (b)	0.186	14.7	79.3 $\pm$ 2.7
Isotopic Values			
	lh/kg	lh/gm-mole	$R = \frac{[(\nu - 1)\sigma_f - \sigma_c]}{\text{lh/gm-mole}}$
U ²³³	104 $\pm$ 2.4	24.2 $\pm$ 0.6	0.164 $\pm$ 0.004
U ²³⁵	60.5 $\pm$ 1.9	14.2 $\pm$ 0.4	0.151 $\pm$ 0.004
U ²³⁸	-4.1 $\pm$ 0.2	-0.976 $\pm$ 0.048	0.170 $\pm$ 0.008
Pu ²³⁹	82.6 $\pm$ 2.8	19.7 $\pm$ 0.7	0.172 $\pm$ 0.006

(a) The mixture consisted of 97.40% U²³³ and 2.60% U²³⁸.

(b) The mixture consisted of 94.51% Pu²³⁹, 5.11% Pu²⁴⁰, and 0.38% Pu²⁴¹.

The isotopic value was calculated by assuming that Pu²⁴¹ had the same worth as Pu²³⁹, and Pu²⁴⁰ had one-fifth the worth of Pu²³⁹.

Reference:

J. M. Gasidlo, J. K. Long, and W. P. Keeney, "Doppler Effect Measurements, Sodium Void Coefficients, and Critical Studies of a 5,000-liter Fast Power Breeder Reactor by the Two Zone Method" ANL-6938 (1964).

Facility: ZPR-3 (1.1)

Assemblies: 48 and 48B
(2.1-48, 2.1-48B)

Method of Measurement:

Two methods were used to insert samples to the core center:

A) A 2 x 2 x 2 in. void was created at the front of the central drawer (see Section 4.1-1-31). The drawer was fully withdrawn to remove or change samples. The plates in one drawer on either side of the cavity were loaded horizontally so that the samples "viewed" ends of plates in all directions.

B) A 1/2 in. radial traverse tube, passing close to the interface plane was used to insert samples attached to a 0.45 in. diameter steel rod. The rod contained two carrier sections, with sample spaces 2 in. long and 0.42 in. in diameter, one of which was used for the sample and the other for a reference. Reactivity changes in both cases were determined with a calibrated autorod(2).

Precision:

- A) $2 \times 10^{-6} \Delta k/k$ due to temperature changes during the sample changes.
- B) $\leq 10^{-7} \Delta k/k$.

Results:

The results of size-dependent worths are reported in Section 4.3-1-48. The results below are generally for the smallest samples(1).

Note $1\% \Delta k/k = 1002.5 \text{ Ih.}$

References:

1. A. L. Hess, Q. L. Baird and A. M. Broomfield, "Material Worth Measurements in ZPR-3 Assemblies 48, 48A, and 48B" ZPR-TM-7 (1969)
2. A. M. Broomfield, et al., "The Design and Critical Mass Determinations for ZPR-3 Assemblies 48, 48A and 48B", ZPR-TM-4 (1969)

Table I

Summary of Selected Central Worth Measurements in Assemblies 48 and 48B

Material or Isotope	Reactivity Coefficient, ρ/k		Sample Size Used to Derive Worth Value
	Assembly 48	Assembly 48B	
^{235}U	$+ 339 \pm 4$	$+ 334 \pm 5$	Isotopic value derived from 0.0034 in. enriched U and 0.022 in. depleted U annular samples
^{238}U	-24.8 ± 0.5	-23.6 ± 0.7	Isotopic value derived from 0.0034 in. enriched U and 0.022 in. depleted U annular samples
^{239}Pu	$+ 445 \pm 4$	$+ 441 \pm 5$	Values derived from worths of 0.007-in. annulus of Pu (4.5% ^{240}Pu) and 0.006-in. annulus of Pu (22% ^{240}Pu) ^a
^{240}Pu	$+ 81 \pm 20$	$+ 66 \pm 30$	
^{10}B	-8926 ± 60	$+8589 \pm 50$	0.010 in. annular
SS (304)	-14.1 ± 0.2	-13.1 ± 0.2	0.42 in. cylinder
Fe	-12.3 ± 0.4	-13.2 ± 0.6	0.42 in. cylinder
Cr	-12.3 ± 1.5	-12.1 ± 1.5	0.42 in. cylinder
Ni	-18.2 ± 0.2	-17.4 ± 0.4	0.42 in. cylinder
Mn	-22.9 ± 1.0	-	0.42 in. cylinder
Al	-15.7 ± 0.8	-	0.42 in. cylinder
Na	$- 6.3 \pm 0.3$	$- 8.5 \pm 0.6$	2-in. cube
C	$- 4.5 \pm 1.2$	$- 7.4 \pm 1.8$	0.42 in. cylinder
O	$- 7.2 \pm 2.8$	-	Derived from values for 0.42-in. cylinders of Al and Al_2O_3
Ta	$- 164 \pm 5$	$- 153 \pm 6$	0.005 in. annular (48), .010 in. annular (48B)
Mo	$- 43.4 \pm 0.4$	-	0.42 in. cylinder
CH_2	$+1676 \pm 7$	-	0.42 in. cylinder

a. For derivation, ^{241}Pu was assumed equivalent to ^{239}Pu , and ^{242}Pu was equated to ^{240}Pu .

4.1-2-1 Central Reactivity Worths

Facility: ZPR-6 (1.2) Assembly: 1 (2.2-1)

Method of Measurement:

Samples were placed in a 1-inch deep void at the front of a central drawer in the stationary half of the assembly. Samples were changed either manually or by means of a remotely controlled sample changer. Control rod calibration curves were used to obtain the worth of a sample.

Precision:

- + 0.6 lh for manually changed samples
- + 0.1 lh for sample changer when linear portion of control rod worth curve was used
- + 0.3 lh for sample changer when nonlinear portion of control rod worth curve was used.

Results:

See Table I. $1\% \Delta k/k = 480 \text{ lh.}$

Reference:

Reactor Development Program Progress Report - December 1963
ANL-6810, P. 7 (1964)

4.1-2-1 (cont'd)

Table I
Central Reactivity Coefficients

Sample	Number of Pieces and Size, in.	Weight, gm	Reactivity Change, β ^(a) lh	lh/kg
Pu ²³⁹	1 - 1/4 x 2 x 2	87.87	38.1 ± 0.6 ^(b)	433.5 ± 6.8
U ²³⁵	2 - 1/16 x 2 x 2	136.58	34.6 ± 0.6	253.3 ± 4.4
U ²³⁵	4 - 1/16 x 2 x 2	272.95	74.0 ± 0.6	271.1 ± 2.2
U ²³⁸	4 - 1/8 x 2 x 2	600.97	-7.7 ± 0.6	-12.7 ± 1.0
U ²³⁸	8 - 1/8 x 2 x 2	1201.12	-15.0 ± 0.6	-12.5 ± 0.5
Stainless Steel	4 - 1/4 x 2 x 2	510.06	-7.5 ± 0.6	-14.7 ± 1.2
B ₄ C	8 - 1/4 x 1/2 x 2 ^(d)	63.5	-121.6 ± 2.0 ^(c)	-1915 ± 32
B ₄ C + Lucite	8 - 1/4 x 1/2 x 2 ^(e)	63.5	-153.3 ± 2.3 ^(c)	-2414 ± 36
B ₄ C + Lucite	8 - 1/4 x 1/2 x 2 ^(f)	63.5	-172.2 ± 2.2 ^(c)	-2712 ± 35
Aluminum	2 - 1/4 x 2 x 2	86.77	-1.7 ± 0.6	-19.6 ± 6.9
Aluminum	4 - 1/4 x 2 x 2	173.44	-3.1 ± 0.6	-17.9 ± 3.5
Al ₂ O ₃	4 - 1/8 x 2 x 2	78.9	-1.9 ± 0.6	-24.1 ± 7.6
Al ₂ O ₃	8 - 1/8 x 2 x 2	157.44	-2.9 ± 0.6	-18.4 ± 3.8
Tungsten	4 - 1/8 x 2 x 2	580.23	-13.9 ± 0.6	-24.0 ± 1.0
Tungsten	8 - 1/8 x 2 x 2	1163.7	-28.7 ± 2.8	-24.6 ± 2.4
Rhenium	1 - 1/2 x 2 x 2	633.1	-41.6 ± 0.6	-65.7 ± 0.9
Rhenium	2 - 1/2 x 2 x 2	1270.3	-82.2 ± 2.0 ^(b)	-64.7 ± 1.6
B ₁₀	2 x 2 x 1	29.20	-84.9 ± 0.3	-2908 ± 10
B ₄ C	2 x 2 x 1	66.96	-21.7 ± 0.3	324.1 ± 4.4
Beryllium	2 x 2 x 1	120	-3.06 ± 0.10	-25.5 ± 0.8
Bismuth	2 x 2 x 1	555.5	-1.68 ± 0.10	-3.38 ± 0.20
Carbon	2 x 2 x 1	103	-2.86 ± 0.10	-27.8 ± 0.9
Copper	2 x 2 x 1	552.43	-10.7 ± 0.10	-19.4 ± 0.17
Chromium	2 x 2 x 1	220.73	-3.35 ± 0.10	-15.2 ± 0.5
Hafnium	2 x 2 x 1	805.3	-38.9 ± 0.3	-68.3 ± 0.4
Inconel	2 x 2 x 1	519	-9.4 ± 0.3	-18.1 ± 0.6
Lithium	2 x 2 x 1	28.6	-3.68 ± 0.10	-128.7 ± 3.5
Manganese	2 x 2 x 1	209.6	-3.28 ± 0.10	-15.6 ± 0.5
Molybdenum	2 x 2 x 1	599	-14.7 ± 0.3	-24.5 ± 0.5
Nickel	2 x 2 x 1	545.93	-10.34 ± 0.10	-18.94 ± 0.18
Niobium	2 x 2 x 1	481.2	-14.9 ± 0.10	-31.0 ± 0.2
Palladium	2 x 2 x 1	643.2	-29.7 ± 0.2	-46.2 ± 0.3
Potassium	2 x 2 x 1	44.55	-0.92 ± 0.10	-20.7 ± 2.2
Sodium	2 x 2 x 1	51.38	-0.73 ± 0.10	-14.2 ± 2.0
Sulfur	2 x 2 x 1	63.10	-2.13 ± 0.1	-33.8 ± 1.6
Silver	2 x 2 x 1	642	-50.7 ± 0.1	-79.0 ± 0.2
Tantalum	2 x 2 x 1	924.7	-41.3 ± 0.1	-44.7 ± 0.1
Vanadium	2 x 2 x 1	183.67	-3.08 ± 0.10	-16.8 ± 0.54
Zirconium	2 x 2 x 1	406	-4.7 ± 0.3	-11.6 ± 0.7

(a) An error of ±0.6 lh was assigned as a best estimate of the reproducibility of the measurements made after the tables had been separated and closed and the control rods scrambled. When the sample changer was used, an error estimated at ±0.1 lh was given to each of those measurements which were made through use of the linear portion of the control rod worth calibration curve. An error estimate of ±0.3 lh was given each of those measurements which were made by use of the nonlinear sections of the control rod calibration. These estimates assume that the differential worth of the control rod is 6.0 lh/cm.

(b) The plutonium sample consisted of 94.51% Pu²³⁹, 5.11% Pu²⁴⁰, and 0.38% Pu²⁴¹. No correction was made for the effects of Pu²⁴⁰ and Pu²⁴¹.

(c) Error includes uncertainty of total worth of calibrated rod No. 2 (±1.2%) plus the uncertainty in differential worth of rod No. 9 (±2.5%).

(d) Total volume of B₄C pieces was 2 in.³.

(e) B₄C sandwiched between eight Lucite pieces which formed two 1/4 x 2 x 2-in. layers. Total volume of B₄C and Lucite was 4 in.³.

(f) Eight B₄C pieces (each 1/4 x 1/2 x 2 in.) and eight Lucite pieces (each 1/4 x 1/2 x 2 in.) homogeneously mixed. Total volume of B₄C and Lucite was 4 in.³.

4.1-2-2 Central Reactivity Worths

Facility: ZPR-6 (1.2) Assembly: 2 (2.2-2)

Method of Measurement:

See Section 4.1-2-1

Precision:

± 0.5 for manually changed samples
 ± 0.05 for samples changed by mechanical sample changer.

Corrections:

See Table I

Results:

(1% $\Delta k/k = 451$ Ih)

Reference:

G. K. Rusch, et al., "Investigation of a 600-Liter Uranium Carbide Core (ZPR-VI Assembly No. 2)," Reactor Physics Division Annual Report - July 1, 1963 to June 30, 1964, ANL-7010 pp. 91-110 (1965)

Table I
Central Sample Worths

Can Wt, g	Material Wt, g	Material	Inhours	Can Correction, In.	Net Inhours	lb/kg
—	272.95	U ²³⁵	28.5 ± 0.5	—	+28.5 ± 0.5	+104.4 ± 1.8
20.0 (SS)	123.46	Pu	19.5 ± 0.5	-0.069	+19.6 ± 0.5	+168.7 ± 4.1
26.8 (Al)	92.97	Pu	14.7 ± 0.5	0.045	+14.7 ± 0.5	+158.1 ± 5.4
19.2 (Al)	177.08	WO ₃ (#0)	-0.515 ± 0.05	-0.033 ± 0.006	-0.482 ± 0.056	-2.72 ± 0.32
19.4 (Al)	224.47	W (#5)	-2.595 ± 0.05	-0.033 ± 0.006	-2.562 ± 0.056	-11.4 ± 0.32
—	1052	W	-11.51 ± 0.05	—	-11.5 ± 0.05	-10.9 ± 0.05
19.5 (Al)	257.85	W (#1)	-3.18 ± 0.05	-0.033 ± 0.003	-3.15 ± 0.056	-12.2 ± 0.25
19.2 (Al)	173.74	W (#2)	-1.943 ± 0.05	-0.033 ± 0.006	-1.91 ± 0.056	-11.0 ± 0.32
4 (Al)	227.14	W (#3)	-2.430 ± 0.05	-0.033 ± 0.006	-2.397 ± 0.056	-10.1 ± 0.24
19.4 (Al)	211.44	W (#4)	-1.778 ± 0.05	-0.033 ± 0.006	-1.745 ± 0.056	-8.26 ± 0.27
19.4 (Al)	209.37	W ¹⁸⁰ (#6)	-1.489 ± 0.05	-0.033 ± 0.006	-1.457 ± 0.056	-6.96 ± 0.34
19.2 (Al)	163.59	W ¹⁸⁰ O ₃ (#7)	-1.000 ± 0.05	-0.033 ± 0.006	-0.967 ± 0.056	-5.91 ± 0.34
—	1154	D, U.	-7.198 ± 0.05	—	-7.198 ± 0.05	-6.24 ± 0.04
—	166.9	Al	-0.285 ± 0.05	—	-0.285 ± 0.05	-1.71 ± 0.44
4.3 (SS)	155.2	Al ₂ O ₃	+0.375 ± 0.05	-0.015 ± 0.001	+0.389 ± 0.051	+2.50 ± 0.32
—	499.6	SS-304	-1.723 ± 0.05	—	-1.723 ± 0.05	-3.45 ± 0.1
—	1183.6	Au	-21.8 ± 0.05	—	-21.8 ± 0.05	-18.4 ± 0.04
—	103	C	+1.74 ± 0.05	—	+1.74 ± 0.05	+16.9 ± 0.5
—	488	Fe	-1.400 ± 0.05	—	-1.400 ± 0.05	-2.87 ± 0.10
49.4 (SS)	137.3	Fe ₂ O ₃	-0.188 ± 0.05	-0.170 ± 0.005	-0.018 ± 0.055	-0.13 ± 0.40
49.7 (SS)	152.3	UO ₂	-0.820 ± 0.05	-0.171 ± 0.005	-0.649 ± 0.055	-4.26 ± 0.36
8 (SS)	220.73	Cr	-0.833 ± 0.05	-0.193 ± 0.006	-0.690 ± 0.056	-3.13 ± 0.25
30.3 (SS)	481.20	Nb	-8.235 ± 0.05	-0.104 ± 0.003	-8.131 ± 0.053	-16.9 ± 0.11
55.8 (SS)	33.30	B ¹⁰	-53.8 ± 0.2	-0.193 ± 0.006	-53.6 ± 0.2	-1943.0 ± 7.0
—	29.07 (B ¹⁰)					

4.1-2-4Z Central Reactivity Worths

Facility: ZPR-6 (1.2) Assembly: 4Z (2.2-4Z)

Experimental Method:

An automatic sample changer was used to position samples near the core center. Reactivity was determined by period measurements analyzed by an on-line computer. Worths were measured relative to void and were corrected only for canning material.

Results:

See Table I.

Reference:

R. A. Karam, et al., "Measured Physics Parameters in a Zoned Fast Uranium Carbide Core, Assembly 4Z", ANL-7281 (1966)

4.1-2-4Z (cont'd)

Table I

Central Worths of Various
Materials in ZPR-6 Assembly 4Z

Sample	Weight, g	Weight (and Composition) of Can, g	Measurements, lh ^b		
			Gross Worth	Net Worth	Worth/kg
Cd	499.50	26.97 (SS)	-4.598	-4.553 ± 0.010	-9.115
W	1108.0	-	-5.742	-5.742 ± 0.010	-5.182
Na	51.38	56.42 (SS)	-0.144 ± 0.002	-0.049 ± 0.005	-0.954
Be	114.308	-	+1.107	+1.107 ± 0.010	+9.689
C	103.0	-	+1.194	+0.194 ± 0.010	+1.883
SS (304)	499.60	-	-0.849	-0.849 ± 0.010	-1.699
U ²³³	1153.80	-	-3.857	-3.857 ± 0.010	-3.343
Li	28.30	57.03 (SS)	-0.691	-0.595 ± 0.010	-21.024
SS Can	72.610	-	-0.122	-0.122 ± 0.002	-1.680
Al	166.90	-	-0.297	-0.297 ± 0.013	-1.779
B ₄ C	59.62	64.70 (SS)	-6.520	-6.410 ± 0.025	-107.511
UO ₂	106.5	20.1 (Al)	-0.370	-0.334 ± 0.015	-3.136
EuO	34.2	20.6 (Al)	-2.472	-2.436 ± 0.025	-7.225
GdO	59.2	20.2 (Al)	-1.164	-1.128 ± 0.025	-19.054
NaCl	58.175	26.1 (Al)	-0.150	-0.114 ± 0.015	-1.959
DyO	104.70	20.1 (Al)	-2.062	-2.026 ± 0.015	-19.350
Ni	546.0	-	-1.148	-1.148 ± 0.010	-2.102
Fe	488.0	-	-0.739	-0.739 ± 0.007	-1.510
Nb	481.2	30.10 (SS)	-3.842	-3.791 ± 0.010	-7.878
Zr	406.0	-	-0.650	-0.650 ± 0.005	-1.601
U ²³⁸	37.073	48.97 (SS)	-0.228	-0.141 ± 0.022	-3.800
U ²³⁵	{ 17.95 (total) 16.73 (25)	72.61 (SS)	+0.674	+0.803 ± 0.022	+44.735
Polyethylene	59.15	-	+19.751	+19.751 ± 0.010	+333.913
Mo	599.0	-	-3.415	-3.415 ± 0.010	-5.701
V	183.67	55.30 (SS)	-0.231	-0.133 ± 0.010	-0.72
Ta	924.70	27.54 (SS)	-11.956	-11.937 ± 0.200	-12.87
B ¹⁰	29.29	55.73 (SS)	-23.438	-23.331 ± 0.200	-796.552
Y	81.50	20.1 (Al)	+0.030	+0.066 ± 0.010	-0.810
Pu ²³⁹	117.157	7.053 (Al)	+8.400	+8.446 ± 0.200	+72.091
Pu ²⁴⁰	5.52	20.06 (SS)			
U ²³³	{ 146.708 (97.15% U ²³³)	{ 5.286 (Al) 19.977 (SS)	+11.60	11.643 ± 0.200	+79.362

^aSome but not all samples were enclosed in cans of various materials.^bMeasurements are relative to void. 1% Δk/k = 468 lh.

Facility: ZPR-6 (1.2)Assembly: 5 (2.2-5)Experimental Method:

Worths of samples were measured relative to void (2 x 2 x 1 in.) at the center of the assembly. The void was created by recessing the normal fuel loading by 1 in. at the front of the central drawer.

1. Criticality was achieved with control rods and automatic sample changer "in".

2. Sample changer was withdrawn (worth ~30 Ih), and ~10 Ih added with control rod.

3. Sample changer was returned to "in", and the reactor period measured "on line" by feeding data directly to a computer.

The above procedure was repeated several times with and without a sample.

Results:

Note 1% $\Delta k/k = 476$ Ih

Table I
Central Worth Measurements in Assembly 5 of ZPR-6

Sample	Sample Wt., g	Can Wt., g	Gross Worth, Ih	Net Worth, Ih	Worth, Ih/kg
Be	114.308	Bare	+1.143 $\pm$ 0.048	+1.143 $\pm$ 0.048	+9.956 $\pm$ 0.420
C	103.0	Bare	+0.183 $\pm$ 0.022	+0.183 $\pm$ 0.022	+1.777 $\pm$ 0.214
Ni	546.0	Bare	-1.134 $\pm$ 0.015	-1.134 $\pm$ 0.015	-2.077 $\pm$ 0.027
V	183.67	55.30 (SS)	-0.246 $\pm$ 0.010	-0.136 $\pm$ 0.014	-0.740 $\pm$ 0.076
Li	28.30	57.03 (SS)	-0.790 $\pm$ 0.010	-0.677 $\pm$ 0.015	-33.922 $\pm$ 0.530
Zr	406.0	Bare	-0.671 $\pm$ 0.020	-0.671 $\pm$ 0.020	-1.653 $\pm$ 0.049
Mo	599.0	Bare	-3.416 $\pm$ 0.015	-3.416 $\pm$ 0.015	-5.703 $\pm$ 0.025
Al	166.90	Bare	-0.300 $\pm$ 0.017	-0.300 $\pm$ 0.017	-1.797 $\pm$ 0.102
B-10	29.29	55.73 (SS)	-23.298 $\pm$ 0.030	-23.196 $\pm$ 0.033	-791.94 $\pm$ 1.13
B ₂ C	59.62	64.70 (SS)	-6.258 $\pm$ 0.010	-6.137 $\pm$ 0.015	-102.94 $\pm$ 0.262
POLY	58.98	Bare	+19.122 $\pm$ 0.010	+19.122 $\pm$ 0.010	+324.21 $\pm$ 0.170
Nb	481.2	30.10 (SS)	-3.888 $\pm$ 0.010	-3.837 $\pm$ 0.015	-7.974 $\pm$ 0.081
W	1106.2	Bare	-5.792 $\pm$ 0.020	-5.792 $\pm$ 0.020	-5.227 $\pm$ 0.018
Ta	924.70	27.54 (SS)	-11.955 $\pm$ 0.010	-11.909 $\pm$ 0.015	-12.870 $\pm$ 0.016
Na	51.38	56.42 (SS)	-0.144 $\pm$ 0.008	-0.041 $\pm$ 0.010	-6.799 $\pm$ 0.195
SS-304	499.6	Bare	-0.851 $\pm$ 0.020	-0.851 $\pm$ 0.020	-1.708 $\pm$ 0.040
Fe	488.0	Bare	-0.737 $\pm$ 0.005	-0.737 $\pm$ 0.005	-1.510 $\pm$ 0.010
Fe ₂ O ₃	296.4	Bare	-0.356 $\pm$ 0.010	-0.356 $\pm$ 0.010	-1.201 $\pm$ 0.034
Re	1266.9	Bare	-20.977 $\pm$ 0.020	-20.977 $\pm$ 0.020	-16.568 $\pm$ 0.016
ZrH	93.7	20.30 (Al)	+3.700 $\pm$ 0.010	+3.736 $\pm$ 0.012	+39.872 $\pm$ 0.128
Cr	220.73	56.30 (SS)	-0.440 $\pm$ 0.020	-0.339 $\pm$ 0.022	-1.536 $\pm$ 0.100
Ti	90.42	56.88 (SS)	-0.117 $\pm$ 0.020	-0.018 $\pm$ 0.022	-0.177 $\pm$ 0.243
Hf	806.0	Bare	-9.079 $\pm$ 0.020	-9.079 $\pm$ 0.020	-11.264 $\pm$ 0.028
Eu	100.92	Bare	-7.249 $\pm$ 0.200	-7.249 $\pm$ 0.200	-71.839 $\pm$ 1.983
U-233	146.708	5.286 (Al)	+12.188 $\pm$ 0.200	+12.217 $\pm$ 0.200	+83.274 $\pm$ 1.370
	97.15% U-233	19.977 (SS)			
Pu	122.67	7.093 (Al)	+8.539 $\pm$ 0.200	+8.575 $\pm$ 0.200	+69.899 $\pm$ 1.630
	4.50% Pu-240	20.06 (SS)			
	95.50% Pu-239				

References:

- (1) R. A. Karam, et al., "Measured Physics Parameters in a Large Uranium Carbide Fast Core, Assembly 5 ZPR-6", Reactor Physics Division Annual Report - July 1, 1966 to June 30, 1967, ANL-7310, 167 (1968)
- (2) R. A. Karam, et al., "Experimental Verification of Reactor Physics Parameters of Zoned Cores", Proc. Int. Conf. Fast Critical Experiments and Their Analysis October 10-13, 1966, ANL-7320, 403 (1966)

Facility: ZPR-6 (1.2)Assembly: 6 (2.2-6)Experimental Method:

The central reactivity worths of various 2 x 2 x 1 in. samples were measured. These samples were measured by the period method relative to void. A reference run (void) was made before and after each measurement of the sample worth. See Section 4.1-2-5.

Results:Note: 1% $\Delta k/k$ = 458 Ih

Table I
Central Reactivity Worths in Assembly 6 of ZPR-6

Sample	Wt of Sample (g)	Can ^a Type	Can Wt (g)	Gross Sample Worth (Ih)	Net Sample Worth (Ih)	Specific Sample Worth (Ih/kg)
Inconel X	507.0	Bare	-	-0.785 ± 0.018	-0.785 ± 0.013	-1.548 ± 0.026
Ti	90.42	SS	56.88	-0.040 ± 0.012	+0.026 ± 0.013	+0.288 ± 0.181
SS Can	72.607	Bare	-	-0.084 ± 0.005	-0.084 ± 0.005	-1.157 ± 0.069
UO ₂	106.5	Al	20.1	-0.337 ± 0.013	-0.317 ± 0.014	-2.977 ± 0.131
C	103.0	Bare	-	+0.366 ± 0.001	+0.366 ± 0.001	+3.553 ± 0.010
Be	114.308	Bare	-	+1.304 ± 0.003	+1.304 ± 0.003	+11.408 ± 0.026
Cr	220.73	SS	56.30	-0.287 ± 0.006	-0.222 ± 0.008	-1.006 ± 0.036
B ₄ C	59.62	SS	64.73	-6.443 ± 0.010	-6.368 ± 0.011	-106.810 ± 0.185
Nb	481.2	SS	30.15	-3.560 ± 0.008	-3.525 ± 0.009	-7.325 ± 0.019
(CH ₂) _n	58.986	Bare	-	+12.324 ± 0.003	+12.324 ± 0.003	+208.927 ± 0.051
Mo	599.0	Bare	-	-3.115 ± 0.021	-3.115 ± 0.021	-5.200 ± 0.035
Depleted U	1153.58	Bare	-	-3.764 ± 0.003	-3.764 ± 0.003	-3.263 ± 0.003
Zn	414.2	SS	26.3	-1.040 ± 0.006	-1.010 ± 0.008	-2.438 ± 0.019
Zr	496.0	Bare	-	-0.443 ± 0.007	-0.443 ± 0.007	-1.091 ± 0.017
Ni	546.0	Bare	-	-0.132 ± 0.008	-0.132 ± 0.008	-1.524 ± 0.015
Na	51.38	SS	56.42	-0.052 ± 0.006	+0.013 ± 0.008	+0.253 ± 0.156
W	1052.0	Bare	-	-5.095 ± 0.001	-5.095 ± 0.001	-4.843 ± 0.001
V	183.57	SS	55.30	-0.161 ± 0.003	-0.097 ± 0.005	-0.528 ± 0.033
Mn	209.58	SS	55.92	-0.545 ± 0.003	-0.481 ± 0.006	-2.295 ± 0.029
Fe	488.0	Bare	-	-0.450 ± 0.004	-0.450 ± 0.004	-0.922 ± 0.008
TaO	101.144	SS	71.645	-1.689 ± 0.013	-1.607 ± 0.014	-15.889 ± 0.139
Al Block	165.33	Bare	-	-0.122 ± 0.010	-0.122 ± 0.010	-0.738 ± 0.061
Fe ₂ O ₃	296.4	Bare	-	-0.106 ± 0.003	-0.106 ± 0.003	-0.358 ± 0.010
SS Block	480.9	Bare	-	-0.530 ± 0.003	-0.530 ± 0.003	-1.102 ± 0.006
ZrH	107.01	Al	26.874	+2.638 ± 0.004	+2.664 ± 0.006	+24.874 ± 0.056
Li	28.60	SS	56.72	-0.582 ± 0.007	-0.517 ± 0.009	-18.077 ± 0.315
Al Can	26.2093	Bare	-	-0.026 ± 0.004	-0.026 ± 0.006	-0.992 ± 0.229
IOB	29.29	SS	55.73	-23.272 ± 0.011	-23.208 ± 0.012	-792.352 ± 0.410
Eu Oxide	34.0	Al	20.4	-2.673 ± 0.013	-2.653 ± 0.014	-78.029 ± 0.412
Hf	806.0	Bare	-	-8.931 ± 0.017	-8.931 ± 0.017	-11.081 ± 0.021

^aSome samples were canned in either stainless steel or aluminum cans.

Reference:

Reactor Development Program Progress Report - March 1968,

ANL-7438 (1968)

Facility: ZPR-9 (1.3)Assembly: 1 (2.3-1)Experimental Method:

Nominal outside dimensions of all samples were 2 x 2 x 1 in. Worths were measured relative to void by means of a calibrated control rod. Samples were manually inserted in a void space at the core center. Additional experiments were carried out using a number of samples containing enriched isotopes of tungsten. The effective environment of the sample is shown in figure 1 where $d = 1$ in. and the cell structure is shown in 2.3-1.

Precision:

The uncertainty was generally about ± 0.5 Ih. due to reproducibility of cart closure.

Results:

Table I

<u>Material</u>	<u>Central Worth (Ih/kg)*</u>
U-235	250
U-238	-10.7
W	-21.8
WO ₂	-23.4
Re	-57.9
C	-34.8
B-10	-2722
Au	-32.7
O**	-19.1

* $1\% \Delta k/k = 469$ Ih.

** Determined from difference W and WO₂.

Fig. 1 Effective environment for central worth measurements

Table II

Central Worths of Separated Tungsten Isotopes

Sample Identification Number:	Normal WO ₂	Separated Metals				Normal Metal	W ¹⁸⁶	W ¹⁸⁴ O ₃
	0	1	2	3	4	5	6	7
Isotopic composition								
W ¹⁸²	26.4	36.9	24.1	12.5	5.8	26.4	1.6	1.91
W ¹⁸³	14.4	17.7	14.7	9.8	5.7	14.4	2.1	1.85
W ¹⁸⁴	30.6	31.5	34.2	30.8	23.3	30.6	11.6	94.3
W ¹⁸⁶	28.4	13.9	26.9	46.8	65.1	28.4	84.7	1.91
Weight, g	177.08	257.85	173.74	237.14	211.44	224.47	209.37	163.59
Central worths, Th/kg*	-24.1	-26.7	-24.5	-23.9	-21.7	-24.4	-20.7	-22.9

* 1% $\Delta k/k = 469$ lh

Reference:

R. C. Doerner, et al, "Physics Measurements in Tungsten-Based, Aluminum-Reflected Fast Reactors", ANL-7007 (1967).

4.1-3-2

Central Reactivity Worths

Facility: ZPR-9 (1.3) Assembly : 2 (2.3-2)

Experimental Method and Precision:

See section 4.1-3-1

Results:

Table I

<u>Material</u>	<u>Central Worths</u> <u>($\Delta k/k$)*</u>
U-235	219
U-238	-9.2
W	-16.7
Re	-49.9
B-10	-2382
Au	-27.3

* $\Delta k/k$ = 457.

Reference:

R.C. Doerner, W.G., Knapp, K.K. Almenas, and R.A. Karam
"Physics Measurements in Tungsten-Based, Aluminum-Reflected
Fast Reactors," ANL-7007 (March 1967)

4.1-3-3

Central Reactivity Worths

Facility: ZPR-9 (1.3)

Assembly: 3 (2.3-3)

Experimental Method and Precision:

See Section 4.1-3-1.

Results:

Table I

<u>Material</u>	<u>Central Worth</u> <u>($\Delta k/k$)*</u>
U-235	+162
U-238	-6.3
W	-14.8
Re	-44.3
C	-21.1
E-10	-2110
H	-350
Au	-23.4

*1% $\Delta k/k$ = 446 Δk

Related Experiment:

Worth of hydrogen as function of sample size. (See Section 4.3-3-3).

Reference:

R. C. Doerner, W. G. Knapp, K. K. Almenas and R. A. Karam, "Physics Measurements in Tungsten Based, Aluminum-Reflected Fast Reactors", ANL-7007 (March 1967)

4.1-3-4 Central Reactivity Worths

Facility: ZPR-9 (1.3) Assembly: 4 (2.3-4)

Experimental Method:

Samples were placed in a central void as shown in Fig. 1 of 4.1-3-1 except that in this case an automatic sample changer was used. The sample changer employed a drawer containing normal core and reflector materials (except for the void in the front 1 in.) attached to a drive motor. The drawer could be remotely removed and inserted axially into the core and a series of samples inserted. The sample reactivities were measured by a calibrated control rod and/or periods in comparison to void or, in the case of canned samples, a dummy can.

In an additional experiment, central worths of hydrogen-boron mixtures were measured. Homogeneous mixtures of Lucite powder and amorphous boron were sealed in aluminum cans, and their central worths were determined as a function of H:B weight ratios.

Precision:

Reproducibility generally about 0.07 Ih.

Results:

Note: $1\% \Delta k/k = 430 \text{ Ih.}$

4.1-3-4 (cont'd)

Table I

<u>Material</u>	<u>Central Worths (Ih/kg)</u>
U-235	270
U-238	-5.5
W	-19.6
WO ₂	-12.6
Re	-71.7
C	-2.5
B-10	-3664
B ₄ C	-399.2
H	+3350
Al	-6.6
Al ₂ O ₃	-5.3
Zr	-5.0
ZrH ₄	+60
Au	-39.3
O*	+26.6

*Determined from difference between W and WO₂.

Table II

Central Worths of Separated Tungsten Isotopes

Sample Identification Number:	Normal WO ₂	Separated Metals				Normal Metal	W ¹⁸⁶	W ¹⁸⁴ O ₂
	0	1	2	3	4	5	6	7
Isotopic composition								
W ¹⁸²	26.4	36.9	24.1	12.5	5.8	26.4	1.6	1.91
W ¹⁸³	14.4	17.7	14.7	9.8	5.7	14.4	2.1	1.87
W ¹⁸⁴	30.6	31.5	34.2	30.8	23.3	30.6	11.6	94.3
W ¹⁸⁶	28.4	13.9	26.9	46.8	65.1	28.4	84.7	1.91
Weight, g	177.08	257.85	173.74	237.14	211.44	224.47	209.37	163.59

4.1-3-4 (cont'd)

The worths of B-Lucite mixtures are shown in Fig. 1. See also Section 4.4-3-4.

Figure 1
Central Worth of Boron-Lucite Mixtures in Assembly No. 4

Related Experiment:

Worth of Hydrogen as function of sample size (4.3-3-4).

Reference:

R. C. Doerner, W. G. Knapp, K. K. Almenas, and R. A. Karam,
"Physics Measurements in Tungsten-Based, Aluminum-Reflected
Fast Reactors", ANL-7007 (1967)

Facility: ZPR-9 (1.3)Assembly: 4B (2.3-4B)Experimental Method:

Nominal outside dimensions of all samples were 2 x 2 x 1 in. Worths were measured relative to void by means of a calibrated control rod, using an automatic sample changer. See Section 4.1-3-4.

In an additional experiment central worths of hydrogen-boron mixtures were measured.

Precision:

Reproducibility generally about ± 0.07 Ih.

Results:

Table I

<u>Material</u>	<u>Sample Weight(g)</u>	<u>Central Worth (Ih / kg) *</u>
U-235		218.7
U-238		-5.2
B-10		-3064.0
W		-17.0
Re		-60.8
Al		-6.0
C		-18.0
H		-2910.0
Au		-31.9
Li	28.6	-917.5
WO ₂	78.37	-12.4

$$1\% \Delta k/k = 432.3 \text{ Ih}$$

Related Experiment:

Worth of hydrogen as function of sample size, (4.3-3-4B)
Effect of hydrogen on 3 worths (4.4-3-4)

Reference:

W. G. Knapp and R. C. Doerner, "Physics Measurements with Modified Diluent Compositions in Tungsten-Based Aluminum-Reflected Fast Reactors", ANL-7207 (1967)

4.1-3-5

Central Reactivity Worths

Facility: ZPR-9 (1.3)

Assembly: 5 (2.3-5)

Experimental Method:

See Section 4.1-3-4.

Precision:

Reproducibility generally about ± 0.07 β .

Results:

Table I

<u>Material</u>	<u>Sample Weight (g)</u>	<u>Central Worth (β / kg)*</u>
U-235		197.1
U-238		-8.2
B-10		-3333.0
W		-16.3
Re		-65.6
Al		0.3
C		20.6
H		-3880.0
Au		-31.6
U-233	110.33	363.3
WO ₂	51.7	-17.0
Al ₂ O ₃	237.9	4.15

1% $\Delta k/k = 424.8$ β

Reference:

W. G. Knapp and R. C. Doerner, "Physics Measurements with Modified Diluent Compositions in Tungsten-Based, Aluminum-Reflected Fast Reactors", ANL-7207 (1967)

4.1-3-6 Central Reactivity Worths

Facility: ZPR-9 (1.3) Assembly: 6 (2.3-6)

Experimental Method:

See Section 4.1-3-4

Precision:

Reproducibility generally about ± 0.07 Ih.

Results:

Table I

<u>Material</u>	<u>Sample Weight (g)</u>	<u>Central Worth (Ih/kg)*</u>
U-235		148.2
U-238		-3.4
B-10		-2065.0
W		-10.6
Re		-39.1
Al		-3.0
C		8.6
H		-3510.0
Au		-20.1
Pu-239	121.55	252
U-233	143.42	266
Gd	12.814	-43

*Ih ($\% \Delta k/k$) = 430.6

Related Experiments:

Worth of hydrogen as function of sample size (4.3-3-6).
Effect of hydrogen on B worths (4.4-3-4).

Reference:

W. G. Knapp and R. C. Doerner, "Physics Measurements with Modified Diluent Compositions in Tungsten-Based, Aluminum-Reflected Fast Reactors", ANL-7207 (1967)

4.1-3-7

Central Reactivity Worths

Facility: ZPR-9 (1.3)

Assembly: 7 (2.3-7)

Experimental Method:

See Section 4.1-3-4. Polyethylene samples were made by laying 1x2x0.020-in-thick strips in 2x2x1-in. Al cans. Central worths of varying mixtures of boron and lucite were measured. Samples were made by filling 2x2x1-in. Al cans with fine powders of crystalline boron and Lucite. Samples were also made by compressing powder mixtures under high temperature and high pressure, to form small pellets, approximately 1 in. diameter by $\frac{1}{4}$ in. thick.

Precision:

The maximum error per sample is considered to be 0.3 Ih, and includes rod calibration error, analytical errors and reactor operator judgment in determining critical rod position.

Results:

Note $1\% \Delta k/k \approx 433.1 \text{ Ih}$.

Table I
Central Worths of Nonhydrogenous
Materials in Assembly No. 7

Material(a)	Sample Weight, g	$\Delta\rho$, lb	$\Delta\rho/\Delta M$, lb/kg
Rhenium	1266.9	-58.0 $\pm$ 0.2 -59.5 $\pm$ 0.2	-45.8 -46.9 } 46.4 $\pm$ 0.2
Be(b)	114.309	-0.265	-2.3 $\pm$ 2.6
Tungsten	1052.0	-11.6	-11.0 $\pm$ 0.3
Carbon	103.0	2.67	25 $\pm$ 3
WO ₂ (b)	78.370	-0.659	-8.4 $\pm$ 3.8
B ¹⁰ (c)	29.29	-72.0	-2460 $\pm$ 10
B ₄ C(d)	59.62	-13.9	-234 $\pm$ 5
Gold	1183.6	-23.7	-20.0 $\pm$ 0.3
U ²³⁸ (b)	507.555	-1.35	-2.7 $\pm$ 0.6
U ²³⁵ (b)	134.980	23.8	176 $\pm$ 2
UO ₂ (b)	106.500	0.515	4.8 $\pm$ 2.8
Crystalline B(b)	75.200	-37.5 $\pm$ 0.2 -37.7 $\pm$ 0.2	-498 -502 } -500 $\pm$ 4
Eu ₂ O ₃ (b)	34.2	-2.41	-70 $\pm$ 9
Gd ₂ O ₃	59.20	0.458 $\pm$ 0.05 0.350 $\pm$ 0.05	7.74 5.91 } 6.8 $\pm$ 5.1
Y ₂ O ₃ (b)	81.5	2.95	36 $\pm$ 4
Dy ₂ O ₃ (b)	104.7	1.96	19 $\pm$ 3
U ²³³ (e)	283.60 + 8.32 g U ²³⁸	85.0 $\pm$ 0.5	300 $\pm$ 2
Gadolinium	397.930	-16.5	-41.4 $\pm$ 0.7
Europium	324.93	-52.4	-161 $\pm$ 1
Lucite	59.153	25.8	435 $\pm$ 5

(a) All samples occupy a 5 x 5 x 2.5-cm³ volume at the center of the core and are unclad unless otherwise noted.

(b) Clad in 0.032-in.-thick Type 1100 aluminum.

(c) Clad in 0.064-in.-thick Type 304 stainless steel. Samples also contained 2.23 g of B¹¹ plus 1.78 g of impurities, mostly Ni, Ca, Al, Fe, Mg, Mn, and Si.

(d) Unclad hot pressure plates of B₄C containing 0.78 g of impurity. Boron is 19.57 w/o B¹⁰ and 80.43 w/o B¹¹.

(e) U²³³ plates have an inner cladding of 0.015-in. aluminum and a center cladding of 0.015-in. Type 304 stainless steel.

4.1-3-7 (cont'd)

Table II
Central Worths of Polyethylene in Assembly No. 7

Sample		Constituent Weights, g		Correction for Carbon, lh	Hydrogen Worth, ^(b) lh/g
Weight, g	Worth, ^(a) lh	Hydrogen	Carbon		
59.153	32.96	8.458	50.695	1.28	3.73 ± 0.03
53.918	30.07	7.710	45.992	1.16	3.75 ± 0.03
49.116	27.70	7.023	42.092	1.05	3.69 ± 0.03
5.020	2.75	0.718	4.282	0.11	3.68 ± 0.29
					avg: 3.71

(a) All measurements were made during the same reactor run and have an estimated error of ±0.20 lh.

(b) Assumes an error of ±11% in carbon.

Table III
Central Worths of Boron-Lucite Mixtures

Sample			Constituent			Apparent Boron Worth, lh/g ^(d)
% Boron	Weight, g	Measured Worth, lh	Weights, g		Worth of Lucite, ^(a) lh	
			Boron	Lucite		
20	27.232	-1.15 ± 0.05	5.446	21.785	9.476 ± 0.653	1.95 ± 0.12
40	31.307	-6.023 ± 0.05	12.522	18.784	8.171 ± 0.375	1.133 ± 0.03
50	28.893	-4.007 ± 0.05	14.447	14.447	6.264 ± 0.433	0.712 ± 0.03
70	33.578	-10.66 ± 0.05	23.505	10.073	4.381 ± 0.302	0.641 ± 0.01
25 P ^(b)	19.939	-2.79 ± 0.05	4.985	14.954	6.504 ± 0.448	1.864 ± 0.09
50 P ^(b)	19.854	-5.88 ± 0.05	9.927	9.927	10.198 ± 0.297	1.027 ± 0.03
75 P ^(b)	19.275	-7.96 ± 0.05	14.591	4.818	2.095 ± 0.144	0.685 ± 0.01
100 P ^(c)	75.200	-37.55 ± 0.10	75.200	0	0	0.500 ± 0.004

(^a) Based on measured worth of Lucite (0.435 ± 0.005) being constant with size and density. Error associated with Lucite is ±0.03 lh/g.

(^b) P = pellet.

(^c) Crystalline boron, taken from Table I.

Reference:

R. C. Doerner, W. G. Knapp, R. A. Karam, and D. K. Butler, "ZPR-9 Assemblies No. 6-9 Critical Experiments", ANL-7208 (1967)

4.1-3-8

Central Reactivity Worths

Facility: ZPR-9 (1.3)Assembly: 8 (2.3-8)Experimental Method and Precision:

See Section 4.1-3-7

Results:Note $1\% \Delta k/k = 431.4 \text{ Ih}$

Table I
Central Worths of Nonhydrogenous Material
in Assembly No. 8

Sample	Weight, g	Measured Worth, Ih	Sample Worth, Ih/kg
Carbon	103	$+0.893 \pm 0.160$	$+8.7 \pm 1.6$
Boron	75.2	-39.8	-529 ± 4
Beryllium	114.309	+5.77	$+50.5 \pm 2.7$
Lithium	28.6	-1.29	-45 ± 10
B ¹⁰	29.2	-72.5	-2480 ± 10
B ₄ C	59.62	-15.4	-257.7 ± 5.0
Al (1100)	166.9	-0.46 ± 0.13	-2.77 ± 0.76
U ²³³	134.98	+22.8	$+169 \pm 2$
U ²³⁸	506.956	-7.49	-14.8 ± 0.6
Niobium	481.20	8.84	-18.4 ± 0.8
Dy ₂ O ₃	104.7	-2.97	-28.3 ± 2.9
WO ₂	78.37	-0.202	-2.57 ± 3.8
Silver	642.02	-38.9	-60.6 ± 0.5
Y ₂ O ₃	81.5	+1.03	$+12.7 \pm 3.7$
Eu ₂ O ₃	34.2	-3.92	-115 ± 9
Gd ₂ O ₃	59.2	-16.8	-284 ± 5
Tungsten	1108.0	-12.8	-11.6 ± 0.3
Gold	1183.6	-27.2	-23.0 ± 0.3
Gadolinium	433.6	-20.7	-47.8 ± 0.7
Dysprosium	557.3	-18.6	-33.4 ± 0.5
Europium	304.86	-52.2	-171.3 ± 9.8
Rhenium	1266.9	-59.9	-47.2 ± 0.2

Table II
Central Worths of Hydrogen in Assembly No. 8

Sample		Constituent Weights, g		Carbon Correction, lb	Hydrogen Worth, lb/g
Weight, g	Worth, lb	Hydrogen	Carbon		
1.9900	1.7 ± 0.2	0.2845	1.7054	0.015	5.9 ± 0.7
4.0423	2.8 ± 0.2	0.5780	3.4642	0.030	4.7 ± 0.3
8.0300	5.6 ± 0.2	1.1482	6.8817	0.060	4.85 ± 0.17
12.0097	8.2 ± 0.2	1.7173	10.2923	0.090	4.69 ± 0.12
16.0079	10.7 ± 0.2	2.2891	13.7187	0.12	4.62 ± 0.09
20.0039	13.2 ± 0.2	2.8605	17.1433	0.15	4.56 ± 0.07
23.973	15.98 ± 0.17	3.4281	20.5448	0.18	4.609 ± 0.049
29.075	19.01 ± 0.16	4.1577	24.9172	0.22	4.519 ± 0.038
34.029	21.90 ± 0.17	4.8661	29.1628	0.25	4.449 ± 0.035
39.051	24.65 ± 0.16	5.5842	33.4667	0.29	4.362 ± 0.028
43.857	27.15 ± 0.20	6.2715	37.5854	0.33	4.276 ± 0.031
49.116	29.08 ± 0.24	7.0235	42.0924	0.37	4.088 ± 0.034
53.918	31.05 ± 0.06	7.7102	46.2077	0.40	3.975 ± 0.008
58.9865	33.30 ± 0.23	8.4350	50.5514	0.44	3.896 ± 0.027

Table III
Central Worths of Boron-Lucite Mixtures

Identification	Weight, g				Corrections, lb				Sample Worth, lb/g	Apparent Boron Worth, ^f lb/g
	Boron	Carbon	Hydrogen	Oxygen	Measured Worth	Hydrogen ^c	Carbon ^d	Oxygen ^e		
100% B powder ^a	75.2	-	-	-	-32.81	-	-	-	-0.529	-0.529
90% B powder	54.1485	3.6099	0.4813	1.9252	-42.374	2.325	0.031	0.034	-0.704	-0.784
75.7% B pellet	34.5913	2.8100	0.3746	1.4986	-11.641	1.813	0.024	0.027	-0.603	-0.926
60% B powder	33.8220	13.5238	1.8038	7.2153	-27.773	8.550	0.118	0.128	-0.492	-1.081
50% B pellet	9.9274	5.9543	0.7941	3.1767	-5.760	3.819	0.052	0.056	-0.290	-0.976
40% B pellet	12.5228	11.2705	1.5027	6.0109	-7.576	7.153	0.098	0.106	-0.241	-0.678
35% B powder	16.4465	18.3297	2.4439	9.7758	-7.788	11.533	0.159	1.173	-0.165	-1.195
20% B pellet	5.4462	13.0709	1.7427	6.9711	-2.465	8.278	0.114	0.123	-0.089	-1.606
15% B powder	6.2556	21.2690	2.8358	11.3434	-2.735	13.680	0.185	0.201	-0.065	-2.686
0% B ^b									+4.85	

^aCrystalline boron taken from Table XIII.

^bInfinite dilute hydrogen.

^cTaken from Table XIV.

^dFrom Table XIII, C = 0.0087 lb/g.

^eUsed calculated value for O = 0.0177 lb/g.

^fDefined as $\frac{P_S - P_C - P_H - P_O}{\text{weight of boron}}$

Reference:

R. C. Doerner, W. G. Knapp, R. A. Karam, and D. K. Butler, "ZPR-9 Assemblies No. 6-9 Critical Experiments", ANL-7208 (1967)

Facility: ZPR-9 (1.3)Assembly: 9 (2.3-9)Experimental Method and Precision:

Same as for Assembly 7. (See Section 4.1-3-7). An exception is that the worths in Table I were determined from the change in reactor period associated with the sample in and sample out. Periods were determined by on-line computer least-squares fit of the d.c. signal from one of the reactor monitoring channels to a single exponential.

Results:Note $1K \Delta k/k = 433.1\text{lh}$

Table I
Central Worths of Nonhydrogenous Materials
in Assembly No. 9

Material	Sample Weight, g	Measured Worth, lh	Sample Worth, lh/kg
Lucite	72.970	27.3 ± 0.1	376 ± 2
Carbon	103	1.16 ± 0.11	12.1 ± 2.9
Al_2O_3	226.4	-0.232 ± 0.038	-0.63 ± 0.17
U^{235}	134.980	28.1 ± 0.1	206.7 ± 0.6
U^{238}	507.555	-2.91 ± 0.12	-5.7 ± 0.2
Gadolinium	12.8144	-0.73 ± 0.10	-57 ± 8
Gd_2O_3	59.2	-2.77 ± 0.10	-46.8 ± 1.7
WO_3	78.3702	-0.95 ± 0.10	-12.1 ± 1.3
Natural Boron	75.2	-49.1 ± 0.2	-653 ± 3
Y_2O_3	81.5	0.36 ± 0.09	4.4 ± 1.1
Dy_2O_3	104.7	-4.28 ± 0.09	-40.9 ± 0.9
Eu_2O_3	34.2	-6.13 ± 0.13	-179 ± 4
B_4C	83.509	-45.4 ± 0.3	-543 ± 3
Tungsten	1108	-17.7 ± 0.2	-15.9 ± 0.2
BeO	177.7	3.79 ± 0.09	21.3 ± 0.5
Beryllium	114.3087	6.37 ± 0.09	55.7 ± 0.8
1100 Aluminum	166.9	-0.58 ± 0.12	-3.5 ± 7
B^{10}	29.2	-89.7 ± 0.2	-3704 ± 7
Rhenium	1266.9	-74.5 ± 0.3	-58.8 ± 0.2
Rhenium	39.581		-70.7 ± 7.5
Gadolinium	29.841		-71 ± 10
Gadolinium	448.432		-56.9 ± 0.7
Dysprosium	32.262		-62.2 ± 9.4
Dysprosium	484.471		-51.2 ± 0.6
Europium	20.59		-237 ± 14
Europium	304.34		-220 ± 1
B^{10}	0.775	-2.923 ± 0.052	-3770 ± 67
U^{235}	142.53	31.2	359 ± 2

4.1-3-9 (cont'd)

Table II
Central Worths of Hydrogenous Material
in Assembly No. 9

Material	Sample Weight, g	Measured Worth, lh	Hydrogen Weight, g	Correction for Carbon ^a	Hydrogen Worth, lh/g
Poly-ethylene	1.999	1.45 ± 0.03	0.285	0.021	4.94 ± 0.11
	4.042	3.03 ± 0.08	0.578	0.042	5.17 ± 0.14
	8.03	5.63 ± 0.10	1.148	0.083	4.83 ± 0.09
	12.01	8.40 ± 0.15	1.717	0.124	4.82 ± 0.09
	16.01	10.97 ± 0.14	2.239	0.165	4.72 ± 0.06
	20.004	13.83 ± 0.12	2.860	0.206	4.76 ± 0.04
	23.973	16.67 ± 0.12	3.428	0.247	4.85 ± 0.04
	29.075	19.95 ± 0.11	4.157	0.299	4.73 ± 0.03
	34.029	23.45 ± 0.10	4.866	0.350	4.75 ± 0.02
	39.051	26.37 ± 0.10	5.584	0.402	4.65 ± 0.02
	43.827	29.72 ± 0.07	6.267	0.451	4.67 ± 0.01
	49.116	32.43 ± 0.07	7.023	0.506	4.55 ± 0.01
	53.918	35.72 ± 0.07	7.710	0.555	4.56 ± 0.01
	58.987	38.05 ± 0.06	8.435	0.608	4.44 ± 0.01
Lucite	72.970	27.34 ± 0.11	5.837		

^aCarbon worth assumed constant with sample size with a value of (0.0121 ± 0.0029) lh/g.

Table III
Central Worths of Boron-Lucite Mixtures
in Assembly No. 9

Percent Boron	Weight, g	Measured Worth, lh	Constituent Weights, g			Self-shielding Factor ^b	Lucite Correction ^c lh	Apparent Boron Worth, (lh/g)
			Boron	Lucite	Hydrogen			
20	25.231	-1.35 ± 0.09	5.046	21.765	1.342	0.979	2.500 ± 0.077	-2.19 ± 0.04
40	26.705	-0.91 ± 0.12	12.592	18.764	1.592	0.981	7.079 ± 0.145	-1.32 ± 0.01
50	28.044	-2.45 ± 0.09	5.632	5.102	0.495	0.990	2.855 ± 0.045	-0.25 ± 0.02
70	33.977	-15.09 ± 0.14	23.960	10.073	0.880	0.990	4.939 ± 0.090	-0.22 ± 0.01
90	27.219	-15.70 ± 0.10	24.007	2.722	0.257	0.997	1.891 ± 0.022	-0.09 ± 0.01
25 (d)	15.940	-1.22 ± 0.10	4.105	14.005	1.795	0.985	5.982 ± 0.115	-1.83 ± 0.03
50 (e)	15.654	-7.32 ± 0.11	0.303	0.375	0.776	0.995	5.982 ± 0.079	-1.15 ± 0.01
75 (e)	14.235	-6.75 ± 0.13	14.591	4.664	0.194	0.995	1.856 ± 0.037	-0.23 ± 0.02
100 ^f	73.2	-48.80 ± 0.22	73.2	0	0	-	-	-4.002 ± 0.002

^dup - pellet.

^edefined as the ratio of estimated Lucite worth in the sample to its infinitely dilute value.

^fCrystalline boron, from Table V.

^gRelative errors in the Lucite correction are assumed to be ±2% from the estimated relative error in infinitely dilute hydrogen.

Reference:

R. C. Doerner, W. G. Knapp, R. A. Karam, and D. K. Butler,
"ZPR-9 Assemblies No. 6-9 Critical Experiments", ANL-7208
(1967)

Facility: ZPR-9 (1.3)Assembly: 11 (2.3-11)Experimental Method:

The samples were inserted into the core using an axial oscillator device installed in the center position of the moveable half of the core. The oscillator consisted of an external sample changer and drive mechanism and a stainless steel drawer loaded similarly to a regular core drawer except for a 1-inch space for the sample at the front. The drawer is withdrawn from the core to insert or remove the samples. The reactivity of the sample was determined from repetitive positive period measurements. Alternating sample-in and sample-out measurements were made, and the reactivity of the sample was determined from the difference in the sample-in and sample-out reactivities. The measured worth of stainless steel was used to correct for the stainless steel in the samples which were canned. The samples were surrounded by the normal core material, and there was no void space around the samples. Each of the 2 x 1 inch sides of the sample was adjacent to a stainless steel matrix tube wall and the 2 x 2 inch sides faced toward the ends of the normally loaded ZPR plates.

The samples were nominally 2 x 2 x 1 inches in size except as indicated below.

<u>Material</u>	<u>Weight</u>	<u>Size (inches)</u>
Enriched U	~ 18 gm.	1/16 x 1/2 x 2
Enriched U	~27.2 gm	1 3/4 x 1 3/4 x 0.030
Enriched U	~64.2 gm	1 3/4 x 1 3/4 x 0.070
Plutonium	~120 gm	1/4 x 2 x 2
CH ₂	<58.98	2 x 2 x 1 with small holes drilled to reduce mass

4.1-3-11 (cont'd)

Results:

Table I
Central Worth Measurements in ZPR-9 Assembly 11

Sample	Weight of Sample, g	Weight of Can, g	Gross Worth, lh	Net Worth, lh
Be	114.808	Bare	+0.671 ± 0.057	+0.671 ± 0.057
C	103.0	Bare	-0.220 ± 0.057	-0.220 ± 0.057
Ni	546.0	Bare	-1.973 ± 0.057	-1.973 ± 0.057
V	183.67	55.30 (SS)	-0.498 ± 0.057	-0.324 ± 0.090
Li	28.30	57.03 (SS)	-1.378 ± 0.023	-1.27 ± 0.320
Zr	406.0	Bare	-1.136 ± 0.023	-1.136 ± 0.023
Mo	590.0	Bare	-5.293 ± 0.023	-5.243 ± 0.023
Al	186.90	Bare	-0.518 ± 0.023	-0.518 ± 0.023
B-10	39.29	55.73 (SS)	-35.678 ± 0.030	-35.830 ± 0.035
D ₂ C	59.62	64.70 (SS)	-9.878 ± 0.028	-9.684 ± 0.034
Polyethylene	58.98	Bare	+28.682 ± 0.028	+28.682 ± 0.028
Nb	481.2	30.10 (SS)	-5.900 ± 0.045	-5.811 ± 0.051
W	1106.0	Bare	-8.928 ± 0.080	-8.928 ± 0.080
Ta	924.70	27.64 (SS)	-18.30 ± 0.10	-18.22 ± 0.10
U-235	1153.60	Bare	-5.908 ± 0.010	-5.908 ± 0.010
U-235	27.710	47.30 (SS)	+1.946 ± 0.028	1.833 ± 0.038
U-235	64.183	47.30 (SS)	+4.627 ± 0.080	+4.714 ± 0.083
Na	51.38	56.42 (SS)	-0.283 ± 0.015	-0.114 ± 0.035
SS-304	469.6	Bare	-1.401 ± 0.040	-1.401 ± 0.040
Pu	117.157	7.093 (Al)	+13.714 ± 0.080	+13.796 ± 0.055
		20.06 (SS)		
U-233 (97.18% U-233)	146.708	5.286 (Al)	+20.967 ± 0.200	+21.057 ± 0.200
		19.977 (SS)		

* 1% at/k = 429.3 lh.

Reference:

R. A. Lewis, L. G. LeSage, and R. A. Karam, "ZPR-9 Assemblies 11 and 12 - Two Small Zoned Versions of the 2600-Liter Assembly 5 ZPR-6" ANL Reactor Physics Division Annual Report July 1, 1966 to June 30, 1967. ANL-7310 p. 190 (1968)

Facility: ZPR-9 (1.3)Assemblies: 12-17 (2.3-12--2.3-17)Experimental Method:

As described in Section 4.1-3-11

Results:

Table I
Reactivity Worth Measurements

Sample ^a	Weight, g	Can Weight, g	Assembly 12, ^b Net lh/kg	Assembly 13, ^c Net lh/kg	Assembly 14, ^d Net lh/kg	Assembly 16, ^e Net lh/kg	Assembly 17, ^f Net lh/kg
Mo	538.8	—	-8.059 ± 0.017	-19.41 ± 0.05	-20.28 ± 0.00	-21.43 ± 0.01	-24.87 ± 0.12
Ni	546.1	—	-2.992 ± 0.018	-11.60 ± 0.03	-11.99 ± 0.02	-12.79 ± 0.00	-14.44 ± 0.01
Fe	484.3	—	-2.110 ± 0.021	-6.186 ± 0.03	-6.084 ± 0.015	-6.040 ± 0.002	-3.494 ± 0.008
Be	114.3	—	+12.20 ± 0.09	+39.20 ± 0.06	+46.13 ± 0.11	+56.89 ± 0.03	+128.69 ± 0.03
C	102.0	—	+1.578 ± 0.109	+10.52 ± 0.04	+13.56 ± 0.08	+17.74 ± 0.01	+48.81 ± 0.31
Al	167.1	—	-2.561 ± 0.060	-1.143 ± 0.150	-0.325 ± 0.006	+0.993 ± 0.006	+10.64 ± 0.04
Na	51.39	56.42 (SS)	-1.376 ± 0.200	-1.323 ± 0.720	+0.108 ± 0.049	+1.603 ± 0.078	+13.90 ± 0.33
W	1108.	—	-7.340 ± 0.009	-23.07 ± 0.32	-27.53 ± 0.32	-30.01 ± 0.32	-42.19 ± 0.32
Ta	924.7	27.54 (SS)	-17.982 ± 0.016	-49.04 ± 0.38	-57.58 ± 0.38	-62.16 ± 0.38	-89.23 ± 0.38
B	75.2	20.6 (SS)	—	-824. ± 6.	-975. ± 3.	-1090 ± 5	-1660 ± 5
Poly (CH ₂) 1	58.988	—	+443.40 ± 0.25	+436.65 ± 0.06	+487.39 ± 5.93	+488.2 ± 3.9	+707.8 ± 4.2
Poly (CH ₂) 2	13.70	72.32 (SS)	—	+469.0 ± 3.1	+512.2 ± 3.1	+550.1 ± 0.9	+905.7 ± 1.3
SS-304	481.0	—	-2.304 ± 0.021	-7.958 ± 0.029	-8.059 ± 0.004	-8.281 ± 0.019	-7.029 ± 0.023
SS can	72.38	—	-2.542 ± 0.138	-8.994 ± 0.041	-9.600 ± 0.034	-9.837 ± 0.111	-8.635 ± 0.290
B ₂ C	59.02	64.70 (SS)	—	-713.2 ± 5.9	-757.0 ± 5.9	-837.1 ± 5.9	-1295. ± 6.
Depleted uranium	1155.	—	-4.674 ± 0.009	-8.510 ± 0.005	-8.911 ± 0.012	-9.191 ± 0.001	-11.88 ± 0.04
Al can	26.36	—	—	—	—	+1.328 ± 0.076	+10.85 ± 0.27
Enriched uranium	18.11 ^g	72.38 (SS)	+70.12 ± 0.88 ^h	—	—	—	—
Enriched uranium	18.24 ^g	72.34 (SS)	—	+134.5 ± 0.5 ^h	—	—	—
Enriched uranium	18.17 ^g	72.34 (SS)	—	—	+137.4 ± 0.3 ^h	+143.6 ± 0.0 ^h	+135.0 ± 0.7 ^h
Pu	119.24 ⁱ	22.27 (SS) 6.85 (Al)	+93.05 ± 1.68 ^j	—	—	—	—
Pu	121.55 ⁱ	19.77 (SS) 7.05 (Al)	—	—	—	+199.0 ± 2.0 ^j	+228.1 ± 2.2 ^j

^a All samples are nominal 1 x 2 x 2 in. except the enriched uranium $\frac{1}{16}$ x $\frac{1}{2}$ x 2 in. and the plutonium $\frac{1}{4}$ x 2 x 2 in.^b Assembly 12: 1% $\Delta k/k$ = 451.2 lh.^c Assembly 13: 1% $\Delta k/k$ = 438.86 lh.^d Assembly 14: 1% $\Delta k/k$ = 435.00 lh.^e Assembly 16: 1% $\Delta k/k$ = 428.07 lh.^f Assembly 17: 1% $\Delta k/k$ = 391.78 lh.^g 93.2 wt% U-235.^h U mixture.ⁱ 0.01 wt% Pu-238; 95.65 wt% Pu-239; 4.48 wt% Pu-240; 0.45 wt% Pu-241; 0.01 wt% Pu-242.^j Pu mixture.Reference:

R. Pond and C. E. Till, "Analysis of Doppler Effect Measurements in CH₂-Softened Spectra, ZPR-9 Assemblies 13-17" ANL Reactor Physics Division Annual Report July 1, 1967 to June 30, 1968, ANL-7310 p. 87 (1969).

Facility: ZPR-9 (1.3)Assembly: 19 (2.3-19)Experimental Method:

As described in Section 4.1-3-11. All samples were nominally 1 x 2 x 2 in. except the enriched uranium which was 1/16 x 1/2 x 2 in.

Results:

The results are compared with those from ZPR-6 Assembly 6 in Table 1.

Table I
Central Reactivity Worths in Assembly 19;
Comparison with Assembly 6

Sample Material	Weight of Sample, g	Can Type	Can Weights, g	Gross Sample Worth, lh	Net Sample Worth, lh	Specific Sample Worth, lh/kg	Worth Assy 19, ZPR-9 Worth Assy 6, ZPR6
(CH ₂) _n	58.986	bare	—	17.513 ± 0.009	17.513 ± 0.009	296.9 ± 0.2	1.421
Be	114.308	bare	—	1.801 ± 0.007	1.801 ± 0.007	15.76 ± 0.06	1.381
B ₂ O ₃	29.29	SS	55.73	-39.312 ± 0.070	-39.185 ± 0.071	-1338.2 ± 2.4	1.689
C	102.0	bare	—	0.459 ± 0.007	0.459 ± 0.007	4.50 ± 0.07	1.254
Na	51.38	SS	56.42	-0.095 ± 0.005	0.020 ± 0.007	0.39 ± 0.14	1.538
Al	165.33	bare	—	-0.091 ± 0.007	-0.091 ± 0.007	-1.15 ± 0.04	1.566
Fe	488.0	bare	—	-0.720 ± 0.007	-0.720 ± 0.007	-1.475 ± 0.014	1.600
SS Can	72.39	bare	—	-0.153 ± 0.005	-0.153 ± 0.005	-2.11 ± 0.07	—
SS Block	480.9	bare	—	-0.871 ± 0.007	-0.871 ± 0.007	-1.81 ± 0.02	1.643
Ni	546.0	bare	—	-1.435 ± 0.007	-1.435 ± 0.007	-2.63 ± 0.02	1.725
Zr	406.0	bare	—	-0.748 ± 0.007	-0.748 ± 0.007	-1.84 ± 0.02	1.888
Nb	481.2	SS	30.10	-5.983 ± 0.007	-5.920 ± 0.009	-12.30 ± 0.02	1.679
Mo	599.0	bare	—	-5.115 ± 0.075	-5.115 ± 0.075	-8.539 ± 0.125	1.642
Ta	924.7	bare	—	-19.724 ± 0.007	-19.724 ± 0.007	-21.289 ± 0.008	—
W	1108.0	bare	—	-8.945 ± 0.007	-8.945 ± 0.007	-8.074 ± 0.007	1.756
Enriched	18.17 U	SS	72.603	1.100 ± 0.007	1.254 ± 0.009	69.01 ± 0.50	—
	16.93 U-235						
Depleted	1153.8	bare	—	-6.317 ± 0.007	-6.317 ± 0.007	-5.475 ± 0.006	1.678

Reference:

L. G. Le Sage and W. R. Robinson, "ZPR-9 Assemblies 19, 21, 22, and 24," ANL Reactor Physics Division Annual Report July 1, 1967 to June 30, 1968, ANL-7410 p. 80 (1969).

SECTION 4.2 - SPATIAL VARIATION OF REACTIVITY WORTHS

4.2-1-29

Spatial Variation of Reactivity Worths

Facility: ZPR-3 (1.1) Assembly: 29 (2.1-29)Method of Measurement:

Small samples of U-235, U-238, Pu-239 and B-10 were moved along the axis of the assembly and the reactivity was determined by control rod positions. The center drawers were modified to allow insertion of a guide tube through which the samples were moved remotely. Traverses were also made of the drive rod with and without an empty sample can (for the Pu and B canning material).

TABLE ISPECIFICATIONS OF TRAVERSE REACTIVITY SAMPLES

<u>Reactive Material</u>	<u>Mass, (g)</u>	<u>Composition</u>	<u>Length, (in.)</u>	<u>Diameter, (in.)</u>
Enriched Uranium	22.93	93.1% U ²³⁵ , 6.9% U ²³⁸	$\frac{1}{2}$	$\frac{7}{16}$
Natural Uranium	64.39	99.3% U ²³⁸ , 0.7% U ²³⁵	2	$\frac{3}{8}$
Plutonium*	24.09	94.9% Pu ²³⁹ , 0.3% Pu ²⁴¹ , 4.8% Pu ²⁴⁰	$\frac{1}{2}$	$\frac{1}{2}$
Enriched B*	3.25	97.5% B, B = 84.6 a/o B ¹⁰	2	$\frac{1}{2}$

* In stainless steel can

Results:AXIAL REACTIVITY COEFFICIENTS

Distance from Interface (in.)	Isotope Worth, ($\Delta k/\text{mole} \times 10^5$) ^(a)			
	U^{235} (± 3.0)*	U^{238} (± 1.0)*	Pu^{239} (± 2.9)*	B^{10} (± 1.0)*
-26	8.6**	3.6**		
-21			0.2	-1.03
-20	10.4	3.2		
-14	26.3	3.1	31.8	-16.6
-12	34.2	0.8		
-10	44.9	-0.3		
-8	51.9	-1.5		
-7			83.6	-54.7
-6	56.6	-2.2		
-4	64.1	-1.9		
-2	67.3	-3.0		
0	67.3	-2.7	111.2	-77.0
2	67.3	-1.6		
4	65.6	-1.4		
6	58.2	-1.8		
7			87.9	-55.1
8	49.1	-0.5		
10	44.5	+0.5		
14			32.4	-19.8
20.45			2.8	-1.2

* Accuracy

** Doubtful values.

(a) $1 \text{ Ih} = 2.33 \times 10^{-5} \Delta k/k$ Reference:

A. L. Hess, et al., "Critical Studies of a 450 liter Uranium Oxide Fast Reactor Core (ZPR-III Assembly 29)" ANL-6336 (1961).

Facility: ZPR-3 (1.1)Assembly: 32 (2.1-32)Method of Measurement:

A core drawer was modified for this measurement by removing the front 0.5 in. of material. The 2 x 2 x 1/2 in. cavity thus produced could accommodate 21.9 gm of Na. By using two opposing drawers and four symmetric drawer locations at each measurement, a total of 175.2 gm of Na could be used. The Na was introduced one position at a time and the reactivity measured by a calibrated rod.

Precision: ± 0.4 Δk due to reproducibility of cart closure.Results:

Reactivity Worth of Sodium (Δk)			
Radius (in.)	Mass (gm) <u>87.6</u>	<u>131.4</u>	<u>175.2</u>
3.08	6.2	8.0	11.3
6.53	7.3	9.8	12.1
7.85	6.4	8.9	10.9

Reference:

P. I. Amundson, et al., "Critical Studies of Uranium-Steel and Uranium-Steel-Sodium Fast Reactor Cores (ZPR-III Assemblies 32 and 33)", ARL-6690 (1963).

4.2-1-33 Spatial Variation of Reactivity Worths

Facility: ZPR-3 (1.1) Assembly: 33 (2.1-33)

Method of Measurement:

See Section 4.2-1-32.

Results:

<u>Radius, (cm)</u>	Reactivity Worth of Sodium (1h) Mass (gm)	
	<u>175.2</u>	<u>350.4</u>
5.54	7.87	16.0
16.59	9.27	18.9
27.64 (Inner edge of blanket)	6.9	13.1

Reference:

P. I. Amundson, et al., "Critical Studies of Uranium-Steel and Uranium-Steel-Sodium Fast Reactor Cores (ZPR-III Assemblies 32 and 33)" ANL-6690 (1963).

Facility: ZPR-3 (1.1)

Assembly: 42 (2.1-42)

Method of Measurement:

Full axial columns of various materials were substituted at different radii in the core and reflector. For materials other than enriched U, two 1/8 in. thick columns were included in a drawer as shown in Fig. 1a and b. The reference core contained void in those sample positions. The reactivity of the void case was determined by extrapolating the case with 100% Al and that with 45% Al in the sample position to the void situation.

The column worth of enriched U was determined by replacing a column of Al with a 1/16 in. column of U-235 and a 1/16 in. column of Al. See Figure 1c and d. A correction was made for the presence of the Al in calculating the worth of the enriched column.

The measurement positions are shown in Figure 2.

Precision:

± 0.5 lh due to reproducibility of cart closure

Corrections:

U samples were corrected for isotopic content (linearly) to get U-235 and U-238 worths. No correction was made for the effective position of the sample due to flux gradients.

Results: See Table I

Reference:

Amundson, P.I. et al., "A Two-zone Fast Critical Experiment," ANL-6733 (1964).

4.2-1-42 (cont'd)

(a) Drawer configuration for column worth, gamma, stress level, and control worth in the core

(b) Drawer configuration for column worth, gamma, stress level, and control worth in the driver

(c) Enriched column worth for core

(d) Enriched column worth for driver

Fig. 1 Drawer Arrangement for Column Worth Measurement

Fig. 2 Positions for Column Worth Measurements

Table I Column Worth (Ih/kg)

Material	Radius			
	0 in. Core	4.98 in. (12.4 cm) Core	6.9 in. (17.5 cm) Core	11.75 in. (29.8 cm) Driver
Enriched Uranium	73.5 ± 0.9	72.5 ± 0.9	67.0 ± 0.9	36.9 ± 0.9
Depleted Uranium	-2.53 ± 0.09	-2.35 ± 0.05	-2.05 ± 0.05	0.40 ± 0.02
Stainless Steel	0.12 ± 0.12	0.45 ± 0.03	0.43 ± 0.03	2.69 ± 0.06
Aluminum	3.9 ± 0.3	3.7 ± 0.2	3.7 ± 0.2	6.6 ± 0.3
Graphite	29.4 ± 1.1	27.4 ± 0.3	23.8 ± 0.6	23.1 ± 0.6
U^{235}	79.0 ± 0.9	78.0 ± 0.9	72.0 ± 0.9	39.7 ± 0.9
U^{238}	-2.68 ± 0.09	-2.49 ± 0.05	-2.20 ± 0.05	-0.42 ± 0.02

Facility: ZPR-3 (1.1)Assembly: 48 (2.1-48)Method of Measurement:

Small annular or cylindrical samples, described in Table I were traversed through channels placed axially or radially in the assembly and reactivity was determined with a calibrated rod.

Table I
Specifications of Reactivity Samples Used
In Assembly 48 Traverses

Sample Material	Geometry	Radial Dimensions (in.)			Material Weight (g.)	Core Weight (g.)	Radial Composition (in.)
		Length	OD	Thickness			
Plutonium	Annulus	1.0	0.31	0.010	1.107	0.0	0.00 Pu ²³⁹ , 0.00 Pu ²⁴⁰ , 0.00 Pu ²⁴¹
Enriched Uranium	Annulus	1.0	0.31	0.010	7.100	1.70	0.25 U ²³⁵ , 0.00 U ²³⁸
Enriched Uranium	Cylinder	2.0	0.19	-	10.00	-	0.25 U ²³⁵ , 0.00 U ²³⁸
Enriched Uranium	Annulus	1.0	0.31	0.010	0.75	0.0	0.00 U ²³⁵ , 7.20 U ²³⁸ , 7.20 Thorium ²³²
Neptunium	Annulus	1.0	0.31	0.010	0.37	1.77	>99% Np
Polycrystalline Steel	Cylinder	2.0	0.42	-	30.00	-	99.99% Fe, approx 0.01% C, 0.01% Si
Polyethylene	Cylinder	2.0	0.42	-	4.072	-	CH ₂

*Plutonium: 90% Pu²³⁹, 10% Pu²⁴⁰.

*Data composition: Fe core, giving confirmation of additional analysis.

In addition, a polyethylene sample, 2 in. long, 0.42 in. in diameter and weighing 4.072 g. was used.

The axial traverse channel passing through drawers 1-P-16 and 2-P-16 is shown in Figure 1. The radial traverse channel ran through the P-row drawers of Half No. 1 about 1 in. back from the interface.

Fig. 1 Material Arrangements around Axial Traverse Channel in Assembly 48

Precision:

The uncertainties indicated in the tables of results refer to measured reproducibilities and do not include a 3% uncertainty due to the uncertainty of the calibration of the auto rod⁽²⁾.

Results:

Table II
Results of Axial Traverses of Reactivity Samples
Through 1- and 2-P-16 in Assembly 48

Position in. from Midplane ^a	Reactivity Coefficient (M/kg) ^b					
	Plutonium (12)	Enriched U (13)	Depleted U (10.0)	Enriched B (19)	Tantalum (12)	104 Stainless (10.9)
-24	1	-	+1.1	12	-	0
-21	11	10	+0.9	-39	+1	+0.4
-18	34	27	+2.0	-318	+2	+2.5
-16	90	-	+3.1	-635	-	+8.8
-15	122	93	+2.6	-1192	-15	+9.6
-14	152	-	0	-1826	-	+6.1
-12	213	-	-4.6	-3141	-	+2.9
-11	-	180	-	-	-70	-
-9	311	-	-11.0	-5046	-	-4.7
-6	393	248	-16.9	-6889	-129	-10.6
-4	448	-	-18.4	-7425	-	-14.7
-2	472	339	-17.7	-7906	-153	-16.1
-1	476	-	-21.6	-8036	-	-16.9
0	469	340	-21.0	-8063	-156	-16.5
1	474	-	-21.6	-8036	-	-16.0
2	464	336	-21.7	-7901	-153	-15.9
4	-	-	-20.1	-	-	-
6	359	281	-15.2	-6506	-124	-
9	299	-	-10.1	-4937	-	-4.3
11	-	174	-	-	-67	-
12	-	-	-3.7	-2954	-	-
14	-	-	-0.6	-	-	-
15	132	88	+2.4	-1126	-16	+9.7

^aNegative in Half No. 2; positive in Half No. 1.

^bFor sample material as specified in Table IX, after accounting for mass and worth of casing, if any.

A number of anomalies appear in the asymmetries of the axial worth profiles about the midplane. It is suspected that the axial fuelplate arrangements are responsible for these asymmetries.

4.2-1-48 (cont'd)

The continuity of the Pu-U alloy fuel columns is broken, by about 3/8 in., at the midplane, at 3 and 8 in. in Half No. 1, and at 7 and 12 in. in Half No. 2. Also, the coefficients at the core center are generally different, by up to 9% from the results obtained previously with the samples measured in a 2 x 2 x 2 in. void at the center of the core. (See Section 4.1-1-48) These differences are probably due to changes in the local environment.

The results of the radial measurements are given in Table III. Negative radii refer to positions in matrix column members less than 16.

Table III
Radial Traverses of Reactivity Samples in Assembly 48

Radius (in)	Reactivity Coefficients (1/k)					
	Plutonium 239 Pu al	Enriched Uranium al	Enriched Uranium al	Enriched Uranium al	Enriched Uranium al	Enriched Uranium al
-77.00	.	.	.	.	.	.
-66.00	1	-1	0.4	-3	0.9	0.5
-55.00	.	.	.	.	.	.
-44.00	6	8	0.5	2	1.0	0.6
-33.00	20	21	0.0	-10	-0.1	2.4
-22.00	40	40	1.0	-20	-0.4	1.5
-11.00	70	60	2.0	-70	-7	0.2
0.00	100	80	0.0	-100	-10	7.0
11.00	.	.	-1.0	.	.	.
22.00	200	200	-1.7	-200	-6	0.4
33.00	220	220	-1.7	-220	-10	-0.5
44.00	420	420	-1.0	-420	-70	-0.5
55.00	440	440	-0.7	-440	-10	-0.4
66.00	460	460	-0.7	-460	-10	-0.7
77.00	500	500	-1.4	-500	-10	-7.0
88.00	520	520	-2.1	-520	-10	-1.0
99.00	.	.	-1.0	.	.	.
110.00	100	70	-1.5	-100	-10	7.0
121.00	70	30	2.0	-70	-14	7.0
132.00	40	30	1.7	-40	-13	4.0
143.00	20	20	0.5	-20	-10	2.0
154.00	0	0	0.5	-7	-10	0.0
165.00	.	.	.	.	.	.

The asymmetry of the worth profiles reflect the asymmetry of the Pu loading in the core drawer.

Reference:

A. L. Hess, Q. L. Baird, and A. M. Broomfield, "Material Worth Measurements in ZPR-3 Assemblies 48, 48A and 48B", ZPR-TM-7 (1969)

4.2-2-1

Spatial Variation of Reactivity Worths

Facility: ZPR-6 (1.2)Assembly: 1 (2.2-1)Method of Measurement:

Samples were located in the front 1-inch of a core edge drawer. The radial distance to the sample center was 27.62 cm.

Results:

Note: $1\% \Delta k/k = 480 \text{ Ih}$

Table I
Relative Worth Measurements of Samples
to Void Volume in a Core Edge Drawer

<u>Sample</u>	<u>Number of Pieces and Size, in.</u>	<u>Weight, gm</u>	<u>Ih</u>	<u>Ih/kg*</u>
Rhenium	2 - $\frac{1}{2} \times 2 \times 2$	1270.3	7.7 ± 0.6	6.1 ± 0.5
Rhenium	1 - $\frac{1}{2} \times 2 \times 2$	635.4	3.7 ± 0.6	5.8 ± 0.9
Tungsten	8 - $\frac{1}{8} \times 2 \times 2$	1163.71	1.1 ± 0.6	1.0 ± 0.5
Tungsten	4 - $\frac{1}{8} \times 2 \times 2$	580.22	0.8 ± 0.6	1.4 ± 1.0

Reference:

ANL Reactor Development Program Progress Report - December 1963
ANL-6810, (1964)

4.2-2-2 Spatial Variation of Reactivity Worths

Facility: ZPR-6 (1.2)

Assembly: 2 (2.2-2)

Method of Measurement:

The worth of type 304 stainless steel was measured as a function of radial and axial position within the core. A set of four radial positions were used. At each radial position the steel worth was determined at three axial positions. See Figure 1.

a - 10 in. (25.7 cm)

e - BACK 4 in. (10.2 cm)

■ D.P. CONTROL ROD

b - FRONT 3 in. (7.6 cm)

f - 6 in. (15.2 cm) BLANKET

⊠ INSERTION SAFETY ROD

c - 2 in. (5.1 cm)

g - AXIAL CENTER OF REACTOR

d - MIDDLE 3 in. (7.6 cm) h - 7 in. (17.8 cm)

Figure 1

Location of SS Worth Measurements in Core

4.2-2-2 (cont'd)

Figure 2
Radial Position - Drawers from Center
Radial Worth of Type 304 Stainless Steel

Results:

Note: $1\% \Delta k/k = 451$ In

Reference:

G. K. Rusch, et al., "Investigations of a 600-Liter Uranium Carbide Core (ZPR-VI Assembly No. 2)", Reactor Physics Division Annual Report - July 1, 1963 to June 30, 1964, ANL-7010, 91 (1965)

4.2-2-4Z

Spatial Variations of Reactivity Worths

Facility: ZPR-6 (1.2)Assembly: 4Z (2.2-4Z)Experimental Method:

The radial variation of worth was measured for U-235, U-238 and Graphite by removing quantities of these materials from drawers in the assembly.

Results:Note: $1\% \Delta k/k = 468 \text{ lh}$

A. U-235:

Table 1

Worth of U-235 as a Function of Radius

Matrix Position* of Sample Removed	Weight of Sample, g	Effective Radius, cm	Measurements, lh	
			Worth of Sample	Worth/kg
23-23	209.52	1.74	10.50 ± 0.10	50.11
23-19, 23-27	209.52	22.72	9.30 ± 0.10	44.38
23-16, 23-30	209.52	39.29	7.65 ± 0.10	36.51
23-14, 23-32	137.04	48.09	3.90 ± 0.10	28.38
23-14, 23-32	137.04	49.68	3.50 ± 0.10	25.53
23-13, 23-33	86.24	55.20	2.30 ± 0.10	26.66

*First number is row, second number is column of matrix. (See Fig. 1 of 2.2-4Z)

B. U-238:

Table 2

Measured Worth of Depleted Uranium as a Function of Radius

Matrix Position of Sample Removed	Weight of Sample, g	Effective Radius, cm	Measurements, lh	
			Worth of Sample	Worth/kg
23-23	2676.0	1.59	-5.40 ± 0.20	-2.02
23-20	2676.0	16.56	-5.40 ± 0.20	-2.02
23-17	2676.0	33.12	-4.10 ± 0.20	-1.53
23-13	3558.0	44.16	-4.00 ± 0.20	-1.35
23-14	1813.4	51.72	-1.00 ± 0.20	-0.55
23-12	88308.0	60.72	+19.00	+0.215
07-23	88308.0	88.32	$+0.00 \pm 0.20$	0.00

4.2-2-4Z (cont'd)

C. Graphite:

Table 3
Measured Worth of Graphite as a Function of Radius

Matrix Position ^a of Sample Removed	Weight of Sample, g	Effective Radius, cm	Measurements, Δh^b	
			Worth of Sample	Worth/kg
22-22, 23-22, 24-22 22-24, 23-24, 24-24	991	5.52	-0.10 ± 0.20	-0.10
22-19, 23-19, 24-19 22-27, 23-27, 24-27	991	22.08	-0.14 ± 0.2	-0.14
21-30, 22-30, 23-30, 24-30 21-16, 22-16, 23-16, 24-16	1651	39.33	$+0.03 \pm 0.20$	+0.018
21-15, 22-15, 23-15, 24-15 21-31, 22-31, 23-31, 24-31	1651	46.16	$+2.71 \pm 0.2$	+1.65
21-15, 22-15, 23-15, 24-15 21-31, 22-31, 23-31, 24-31	1651	45.89	$+2.32 \pm 0.20$	+1.40
21-14, 22-14, 23-14, 24-14 21-32, 22-32, 23-32, 24-32	1651	47.95	$+0.40 \pm 0.20$	+0.24
21-14, 22-14, 23-14, 24-14 21-32, 22-32, 23-32, 24-32	1651	52.44	-10.23 ± 0.20	-6.19

Reference:

R. A. Karam, et al., "Measured Physics Parameters in a Zoned Fast Uranium Carbide Core, Assembly 4Z", AML 7281 (1966)

Facility: ZPR-9 (1.3)Assembly: 7 (2.3-7)Experimental Method:

A sample of interest was attached to the midsection of a long aluminum bead chain, which passed through the entire diameter of the assembly. The use of the bead chain kept the background reactivity correction to a minimum. A "slo-syn" stepping motor and gear train were used to move the sample along its traverse in an Al void tube.

Reactivities were determined by the on-line computer technique discussed in section 4.1-3-9. See also reference (2).

Table I describes the samples used.

TABLE I

<u>Sample Identification</u>	<u>Sample Weight (g)</u>	<u>Cladding</u>	<u>Description</u>
U-235	6.396	Al	Stack of 0.005 in. foils 0.9 cm. diam. x 1.2 cm. long
Polyethylene	1.888 (H=0.272g)	-	1.2 cm. diam. x 2.5 cm. with 0.6 cm. axial hole part way
B-10	0.775	Al	Enriched B-10 powder 0.9 cm. diam. x 14 cm. long.
Borated Polyethylene	2.168 (B-10=0.095 g)	-	Stack of eight 1/8 in. thick, 1.2 cm. diam., discs.

Results:

refer to Figures 1 - 4.

References:

1. R. C. Doerner, W. G. Knapp, R. A. Karam, and D. K. Butler, "ZPR-9 Assemblies No. 6-9 Critical Experiments", ANL-7208 (1967).
2. W. G. Knapp, "Measurement of Space-Dependent Material Worths in Several ZPR-9 Assemblies", ANL Reactor Physics Division Annual Report July 1, 1965 to June 30, 1966, p. 199 (1966).

4.2-3-7 (Cont'd)

4.2-3-7 (Cont'd)

Fig. 3
B¹⁰ Reactivity Traverse
in Assembly No. 7

Fig. 4
Borated Polyethylene Reactivity
Traverse in Assembly No. 7

Facility: ZPR-9 (1.3)Assembly: 8 (2.3-8)Experimental Method:

Same as for ZPR-9, Assembly 7. Refer to (4.2-3-7). In addition the worth of a single can of B-10 (4.2 g of B-10) was mapped through the BeO reflector. In all cases, a small correction (~ 2% for the inner two points and ~ 10% for the two outer points) was made for the effect of the displaced BeO. Table 1 describes the samples used.

Table 1

<u>Sample Identification</u>	<u>Sample Weight (g)</u>	<u>Cladding</u>	<u>Description</u>
U-235	6.396	Al	Stack of 0.005- in. foils 0.9 cm. diam. x 1.2 cm. long.
U-234 cyl. foil	0.742	Al	0.005-in. thick sleeve inside capsule 1.2 cm. long
Polyethylene	2.014 (H=0.288 g)	-	1.2-cm. x 2.5 cm. with 0.3-cm. axial hole.
B-10	0.133	Al	0.9 cm. diam. x 1.2 cm. long.
Tungsten	49.750	-	Eight 0.3-cm.-thick disks, 1.2 cm. diam.
Rhenium	54.871	-	Stack of sixteen 1/16 in. thick, 1.2 cm. diam. disks.

In addition, the spatially dependent worths of columns of U^{233} and Pu^{239} were made and compared to the worth of U^{235} . In these measurements, two of the 1/16-in. columns of U^{235} were removed from one of the drawers and replaced by a single, 1/8-in. thick column of U^{233} (or Pu^{239}) of roughly equivalent mass. The worth of the drawer was then mapped out starting at the core center and going out to the core edge. To provide an absolute scale to these measurements, the worth of a 1/8-in.-thick void column was mapped out in the same way.

Results:

Refer to Figures 1 - 5 and Table 2

Fig. 1 U^{235} Reactivity Traverse in Assembly No. 8

Fig. 2 Polyethylene Reactivity Traverse in Assembly No. 8

4.2-3-8 (Cont'd)

- 4.2 g B-10 in Al can

Fig. 3 B^{10} Reactivity Traverses in Assembly No. 8

Fig. 4 Tungsten Reactivity Traverse in Assembly No. 8

Fig. 5 Rhenium Reactivity Traverse in Assembly No. 8

Table 2

Results of Spatially Dependent Fuel-worth Measurements

	Ratio of Fuel Worth to U ²³⁵ Worth				
	U ²³³	U ²³⁵	Pu ²³⁹	U ²³³	Pu ²³⁹
	<u>Fuel Worths, lh/kg</u>				
<u>Position, cm</u>					
0	209.6	112.6	188.2	1.86	1.67
16.61	167.6	89.1	147.0	1.88	1.65
22.14	134.3	71.1	116.7	1.89	1.64
27.68	108.3	57.4	88.0	1.89	1.53
			Average:	1.88	1.62
	<u>Isotopic Weights, g</u>				
<u>Isotope</u>					
U ²³²	Trace				
U ²³³	711.96				
U ²³⁴	17.07	7.17			
U ²³⁵	1.46	689.12			
U ²³⁶	0.15	1.77			
U ²³⁸	2.64	41.41			
Pu ²³⁸			9.06		
Pu ²³⁹			601.65		
Pu ²⁴⁰			28.36		
Pu ²⁴¹			2.85		
Pu ²⁴²			0.06		
<u>Cladding</u>					
Aluminum	26.5		33.9		
304 SS	99.6		99.6		

Reference:

R. C. Doerner, W. G. Knapp, R. A. Karam, and D. K. Butler,
 "ZPR-9 Assemblies No. 6 - 9 Critical Experiments", ANL-7208
 (March 1967).

Facility: ZPR-9 (1.3)Assembly: 8B (2.3-8B)Experimental Method:

Same as for ZPR-9, Assembly 7. Refer to (4.2-3-7). In addition, measurements were made with the samples encapsuled in long lead rods which extended completely through the assembly to study the effect of streaming in the void tube. Comparisons of these results to those in which no lead rod filled the voided region showed no significant differences. The drive mechanism for the lead rod was a large d.c. motor.

Table 1 describes the samples used.

Table 1

<u>Sample Identification</u>	<u>Sample Weight (g)</u>	<u>Cladding</u>	<u>Description</u>
B ¹⁰	0.775	Aluminum	Enriched B ¹⁰ Powder 0.9-cm diam x 1.4 cm long
B ¹⁰	0.113	Aluminum	0.9-cm diam x 1.2 cm long
B ¹⁰	0.045	Aluminum	Natural Boron mixed with lead powder 0.9-cm diam x 1.4 cm long
B ¹⁰	0.009	Aluminum	0.9-cm diam x 1.4 cm long
U ²³⁵	6.396	Aluminum	Stack of 0.005-in. foils 0.9-cm diam x 1.2 cm long
U ²³⁵ cyl. foil	0.742	Aluminum	0.005-in.-thick sleeve inside capsule 1.2 cm long
U ²³⁵ disc	0.790	Aluminum	0.9-cm diam x 0.13 cm high
Polyethylene	2.014 (Hydrogen=0.288 g)	-	1.2-cm x 2.5 cm with 0.3-cm axial hole
Borated Polyethylene	2.168 (B ¹⁰ =0.095)	-	Stack of eight 1/8-in.thick 1.2-cm-diam discs
Rhenium	54.871	-	Stack of sixteen 1/16 in.- thick, 1.2-cm-diam discs

Table 1 (Continued)

<u>Sample Identification</u>	<u>Sample Weight (g)</u>	<u>Cladding</u>	<u>Description</u>
Rhenium	3.420	-	Single disc, as above
Tungsten	49.750	-	Eight 0.3-cm-thick discs, as above
Gadolinium	20.317	-	Fourteen 0.16-cm-thick discs, as above
Dysprosium	22.140	-	As above
Europium	16.552	-	As above
Aluminum	9.665	Aluminum	Empty capsule
Lead	3.037	Aluminum	0.9-cm diam x 1.4 cm long

Results:

Refer to Figures 1 - 12.

Reference:

R. C. Doerner, W. G. Knapp, R. A. Karam, and D. K. Butler,
 "ZPR-9 Assemblies No. 6 - 9 Critical Experiments", ANL-7208
 (March 1967).

4.2-3-8B (Cont'd)

Fig. 1 U^{235} Reactivity Traverse in Assembly No. 8B

Fig. 2 B¹⁰ Reactivity Traverse in Assembly No. 8B

Fig. 3 Polyethylene Reactivity Traverse in Assembly No. 8B

Fig. 4 Borated Polyethylene Reactivity Traverse in Assembly No. 8B

Fig. 5 Tungsten Reactivity Traverse in Assembly No. 8B

4.2-3-8B (Cont'd)

Fig. 6 Rhenium Reactivity Traverse in Assembly No. 8B

Fig. 7 Gadolinium Reactivity Traverse in Assembly No. 8B

Fig. 8 Europium Reactivity Traverse in Assembly No. 8B

Fig. 9 Dysprosium Reactivity Traverse in Assembly No. 8B

Fig. 10 Aluminum Reactivity Traverse in Assembly No. 8B

Fig. 11 U^{235} Reactivity Traverse in Assembly No. 8B (with lead rod)

Fig. 12 B^{10} Reactivity Traverse in Assembly No. 8B (with lead rod)

Facility: ZPR-9 (1.3)Assembly: 9 (2.3-9)Experimental Method:

Same as for ZPR-9 Assembly 7. Refer to (4.2-3-7). In addition, measurements were made with the samples encapsulated in long lead rods which extended completely through the assembly to study the effect of streaming in the void tube. Comparisons of these results to those in which no lead rod filled the voided region showed no significant differences. The drive mechanism for the lead rod was a large d.c. motor.

Table 1 describes the samples used.

Table 1

<u>Sample Identification</u>	<u>Sample Weight (g)</u>	<u>Cladding</u>	<u>Description</u>
B ¹⁰	0.775	Aluminum	Enriched B ¹⁰ Powder 0.9-cm diam x 1.4 cm long
U ²³⁵	6.396	Aluminum	Stack of 0.005-in. foils 0.9-cm diam x 1.2 cm long
Polyethylene	2.014 (Hydrogen=0.288 g)	-	1.2-cm x 2.5 cm with 0.3-cm axial hole
Borated Polyethylene	2.168 (B ¹⁰ =0.095)	-	Stack of eight 1/8-in.-thick 1.2-cm-diam discs
Rhenium	54.871	-	Stack of sixteen 1/16 in.-thick, 1.2-cm-diam discs
Tungsten	49.750	-	Eight 0.3-cm-thick discs, as above
Gadolinium	20.317	-	Fourteen 0.16-cm-thick discs, as above
Dysprosium	22.140	-	As above
Europium	10.552	-	As above

4.2-3-9 (Cont'd)

In addition, the reactivity worth of a single column of material extending the axial length of a core drawer in each half of the assembly was determined at various radial positions. Each column consisted of five 2 x 2 in. square, 1/16 in. thick plates, loaded end to end and parallel to the fuel columns and was located on the axial centerline of the core drawer in each half of the assembly. The reactivity effect of changing this drawer was then determined at four different radial positions in the core.

Results:

refer to Figures 1 - 11 and Table 2

Table 2

Spatial Dependence of Columns of Metal in Assembly No. 9

Sample (Weight, g)	Mean Radius, cm				Central Worth, Ih/kg*	
	0.0	11.07	22.14	27.68	Light Sample	Heavy Sample
	Worth of 20-in. Axial Column, Ih/kg*					
Re (817.2)	-59.8	-51.4	-41.6	-66.6	-70.7	-58.8
Eu (202.9)	-197.1	-169.5	-146.4	-303.6	-237	-220
Gd (299.02)	-51.2	-43.1	-37.1	-108.7	-70.7	-56.9
Dy (322.91)	-45.5	-38.7	-38.1	-114.3	-62.2	-51.2

$$* \text{Ih}/(\% \Delta k/k) = 431.4$$

Reference:

R. C. Doerner, W. G. Knapp, R. A. Karam, and D. K. Butler,
"ZPR-9 Assemblies No. 6 - 9 Critical Experiments", ANL-7208
(March 1967).

4.2-3-9 (Cont'd)

4.2-3-9 (Cont'd)

Fig. 3 B^{10} Reactivity Traverse in Assembly No. 9

4.2-3-9 (Cont'd)

Fig. 4 Borated Polyethylene Reactivity Traverse in Assembly No. 9

Fig. 5 Tungsten Reactivity Traverse in Assembly No. 9

Fig. 6 Rhenium Reactivity Traverse in Assembly No. 9

Fig. 7 Gadolinium Reactivity Traverse in Assembly No. 9

Fig. 8 Rhenium Reactivity Traverse in Assembly No. 9

Fig. 9 Dysprosium Reactivity Traverse in Assembly No. 9

Fig. 10 U^{235} Reactivity Traverse in Assembly No. 9 (with lead rod)

Fig. 11 Polyethylene Reactivity Traverse in Assembly No. 9
(with lead rod)

Facility: ZPR-9 (1.3)Assemblies: 19, 21, 22, 24 (2.3-19+2.3-24)Experimental Method:

A pneumatic sample changer, shown in Figure 1, was used for these measurements. Cylindrical samples approximately $7/8$ in. in diameter and 2 in. long were oscillated into and out of the assembly, and the reactivity was determined by a calibrated autorod, which held the flux level constant. The autorod was calibrated from period measurements. The entire sample changer could be moved horizontally so that the samples could be oscillated to any point along the radius. The samples are enclosed in stainless steel sample holders, and the double wall tube which extends into the matrix is also made of stainless steel. A drawing of a sample and sample holder is shown in Figure 2. The transit times for the samples were slightly over 1 sec. End caps for the sample holders with thicknesses of $1/32$, 2 and 4 in. were provided in order to stop neutron streaming in the sample changer tube. This effect is discussed in section 4.4-3-19. In addition, an alternate inner sample changer tube was provided which contained a 4 in. stainless steel plug to stop neutron streaming in the inward direction.

The U-235, U-238, sodium and boron reactivity samples were sealed inside thin wall (0.010 in.) stainless steel cans for safety. The geometry of the samples was either a hollow or solid cylinder, 0.87 in. in outer diameter, depending upon the amount of material required. The one exception was the natural boron powder sample which was contained in a stainless steel tube approximately $1/8$ in. in diameter and 2 in. long. The samples were sized to give reactivity signals ranging from 0.050-0.250 Ih in Assembly 19, and the accuracy of the measurements was about ± 0.002 Ih.

Fig. 1 Sketch Showing Important Features of Radial Sample Changer

Fig. 2 Reactivity Sample and Sample Holder

Table 1Reactivity Worths, $\Delta k/k$

Assembly	Sample Material	Sample Weight, g	Radial Position, cm							Average Uncertainty
			0	5.52	10.04	15.56	22.08	27.60	30.36	
19	Enriched U	3.084	68.26	69.55	68.06	66.44	65.86	65.01	59.40	0.75
	Depleted U	25.988	-6.503	-6.364	-6.505	—	-6.399	-5.991	—	0.080
	B (Nat.)	0.553	-421.5	-415.0	-414.5	-413.9	-427.1	-409.6	-415.6	—
	Al	53.014	-1.185	-1.168	-1.147	-1.028	-0.866	-0.232	-0.232	0.040
	C	33.441	3.788	—	3.765	—	4.542	6.046	—	0.070
	Na	16.564	-0.097	—	0.115	—	-0.054	1.539	—	0.130
	SS 304	34.511	—	—	—	—	—	—	—	—
21	Enriched U	3.084	101.82	101.30	100.16	93.71	—	—	—	0.50
	B (Nat.)	0.553	-622.6	-626.2	-629.8	-609.6	-592.6	—	—	3.5
	Al	53.014	-0.621	-0.262	0.315	0.272	—	—	—	0.030
	C	33.441	6.043	—	7.578	—	—	—	—	0.035
22	Enriched U	3.084	73.74	—	72.31	—	61.96	53.92	—	0.70
	B (Nat.)	0.553	-475.6	—	-452.1	—	-452.1	-472.3	—	4.2
	Al	53.014	-0.672	-0.506	-0.121	—	1.111	1.422	—	0.035
	C	33.441	5.499	—	6.854	—	13.67	21.22	—	0.065
24	Enriched U	3.084	60.18	—	61.28	—	68.48	—	—	1.50
	Al	53.014	-2.346	—	-2.246	—	-2.327	—	—	0.115

Reference:

L. G. Le Sage, E. F. Groh, and W. R. Robinson, "An Investigation of the Properties of Zoned Systems", ANL Reactor Physics Division Annual Report July 1, 1967 to June 30, 1968, ANL-7410, p. 145 (1969).

SECTION 4.3 - EFFECT OF SAMPLE SIZE ON REACTIVITY WORTHS

4.3-1-41 Effect of Sample Size on Reactivity Worths

Facility: ZPR-3 (1.1)

Assembly: 41 (2.1-41)

Method of Measurement:

Sample volumes of 2 x 2 x 2 in. and 2 x 2 x 1/2 in. were created at the core center by recessing the core plates in the central elements. Sample worths were measured with a calibrated control rod. In those cases in which the material measured occupied less than the volume of sample space, the remainder of the space was filled with empty steel cans, perforated aluminum, or was left void. The particular procedure in each case was adapted to the sample geometry. The worth of steel or aluminum in each case and the values reported in the table are corrected to represent only the material being measured. The results indicate that capture self-shielding effects are prominent for B¹⁰ and are also present to a lesser degree for tantalum. With the polyethylene samples, the principal concern is with the effects of fuel proximity.

Precision: ± 0.5 Ih due to reproducibility of cart closure.

Results: See Table I (next page)

Reference:

A. L. Hess et al., "Critical Studies of a 440 Liter Fast Reactor Core Fueled with 35 v/o Uranium Enriched to 17 a/o (Assembly 41)", ANL-6732

4.3-1-41 (cont'd)

Table I

Reactivity Works in ZPR-3 Assembly 41*

Material	Sample Space (in.)	Volume % Material	Sample Worth ^(a) (inhours)	Reactivity Coefficient ^(a) (inhours/kg)
Steel-clad Plates of Enriched B	$\frac{1}{2} \times 2 \times 2$	21	-22	-1460
Mixture (94 w/o B, B = 92 a/o B ¹⁰)	$2 \times 2 \times 2$	5.2	-23	-1450
	$2 \times 2 \times 2$	12.7	-29.5	-1088
Tantalum	$\frac{1}{2} \times 2 \times 2$	100	-12.1	-23.0
	$2 \times 2 \times 2$	25	-12.8	-24.3
	$2 \times 2 \times 2$	48	-23.7	-23.6
	$2 \times 2 \times 2$	100	-44.4	-21.1
Thorium	$\frac{1}{2} \times 2 \times 2$	100	-4.50	-12.1
	$2 \times 2 \times 2$	100	-17.8	-11.8
Enriched B ₄ C (B = 94 a/o B ¹⁰)	$\frac{1}{2} \times 2 \times 2$	100	-62	-961
	$2 \times 2 \times 2$	100 in a $\frac{3}{4} \times 2 \times 2$ piece	-66	-684
Depleted Uranium	$\frac{1}{2} \times 2 \times 2$	100	-2.94	-5.3
	$2 \times 2 \times 2$	100	-12.3	-5.1
Polyethylene (CH ₂)	$\frac{1}{2} \times 2 \times 2$	100	23.8	+817
	$2 \times 2 \times 2$	25	22.2	+731
	$2 \times 2 \times 2$	50	50.7	+845
	$2 \times 2 \times 2$	75	78.6	+879
	$2 \times 2 \times 2$	100	99.5	+838

(a) Values reported here have been corrected for canning and spacing materials.

$$* 1\% \frac{\Delta k}{k} = 440 \text{ Ih}$$

4.3-1-48 Effect of Sample Size on Reactivity Worths

Facility: ZPR-3 (1.1)

Assemblies: 48 and 48B
 (2.1-48, 2.1-48B)

Method of Measurement:

See Section 4.1-1-48

Results:

See Tables I - IV. Note: $1\% \Delta k/k = 1002.5 \text{ Ih.}$

Reference:

A. L. Hess, Q. L. Baird and A. M. Broomfield, "Material Worth Measurements in ZPR-3 Assemblies 48, 48A, and 48B", ZPR-TM-7 (1969)

Table I

Measurements of Enriched and Depleted Uranium Worths at Center
of Assemblies 48 and 48B

Sample Type ^a	Thickness, Diameter, or Cube Size, in.	Reactivity Coefficients _{th/kg}		
		Assembly 48	Assembly 48B	
<u>Enriched uranium</u> (93.1-93.3% ²³⁵ U)				
Folts	Annulus	0.0014	315 $\pm$ 14	-
	Annulus	0.0034	314 $\pm$ 4	309 $\pm$ 5
	Annulus	0.0052	310 $\pm$ 4	-
	Plate	0.0052	292 $\pm$ 38	-
	Annulus	0.0106	312 $\pm$ 3	310 $\pm$ 4
	Plate	0.0106	321 $\pm$ 10	-
	Plate	0.021	316 $\pm$ 9	-
	Plate	0.042	319 $\pm$ 5	-
	Plate	0.062	322 $\pm$ 2	-
Cylinders	0.061	312 $\pm$ 5	-	
	0.10	310 $\pm$ 2	-	
	0.20	310 $\pm$ 3	-	
<u>Depleted uranium</u> (0.21% ²³⁵ U)				
Folts	Annulus	0.022 ^b	-23.3 $\pm$ 0.5	-22.2 $\pm$ 0.7
	Plate	0.125	-21.4 $\pm$ 1.6	-
Cylinders	0.20	-22.2 $\pm$ 0.5	-	
	0.42	-20.8 $\pm$ 0.2	-	
Cube	2.0	-19.2 $\pm$ 0.1	-	

a. Plates and cubes measured in 2-in. cubical sample changer,
cylinders and annuli measured in cylindrical-sample changer.

b. 0.40% ²³⁵U

4.3-1-48 (cont'd)

Table II

Measurements of Plutonium Worth at Center
of Assemblies 48 and 48B

Sample ^a	Thickness or Diameter, in.	Reactivity Coefficient, $\Delta k/k$		
		Assembly 48	Assembly 48B	
<u>Plutonium (4.5% ²⁴⁰Pu)</u>				
Foils	Annulus	0.007	422 $\pm$ 3	418 $\pm$ 5
	Annulus	0.010	427 $\pm$ 3	423 $\pm$ 5
	Annulus	0.020	430 $\pm$ 3	428 $\pm$ 5
	Plate*	0.086	462 $\pm$ 3	-
Cylinders		0.100	434 $\pm$ 5	-
		0.200	443 $\pm$ 4	-
<u>Plutonium (22% ²⁴⁰Pu)</u>				
Foils	Annulus	0.006	356 $\pm$ 3	350 $\pm$ 5
	Annulus	0.010	366 $\pm$ 3	356 $\pm$ 5
	Annulus	0.020	367 $\pm$ 3	365 $\pm$ 5
Cylinders		0.062	356 $\pm$ 11	-
		0.100	371 $\pm$ 4	-
		0.200	381 $\pm$ 3	-

a. Annuli measured in cylindrical-sample changer, plate measurement in 2-in.-cube changer.

Table III

Measurements of Boron and Tantalum Worths at Center
of Assemblies 48 and 48B

Sample ^a	Thickness or Diameter, in.	Reactivity Coefficient, $\Delta k/k$		
		Assembly 48	Assembly 48B	
<u>Boron (enriched in ¹⁰B)^b</u>				
Annular	0.010	-7632 $\pm$ 60	-7341 $\pm$ 50	
	0.020	-7523 $\pm$ 110	-7145 $\pm$ 50	
	0.040	-7045 $\pm$ 110	-6651 $\pm$ 50	
Cylinders	0.060	-7418 $\pm$ 80	-	
	0.100	-7303 $\pm$ 50	-	
	0.200	-6698 $\pm$ 50	-	
<u>Tantalum</u>				
Pells	Annular	0.0053	-164 $\pm$ 5	-152 $\pm$ 10
	Annular	0.0106	-156 $\pm$ 3	-153 $\pm$ 6
	Annular	0.0153	-149 $\pm$ 2	-147 $\pm$ 6
	Plate	0.005	-169 $\pm$ 42	-
	Plate	0.010	-182 $\pm$ 21	-
	Plate	0.015	-167 $\pm$ 14	-
Cylinders	0.061	-142 $\pm$ 5	-	
	0.100	-137 $\pm$ 2	-	
	0.200	-125 $\pm$ 1	-	
	0.200	-131 $\pm$ 14 ^c	-	

a. Annuli and cylinders measured in cylindrical-sample changer, plates in cube changer.

b. 92.8 w/o B, 7.2 w/o impurities.

Boron = 92.1 w/o ^{10}B , 7.9 w/o ^{11}B .

c. Measured in 2-in.-cube changer.

4.3-1-48 (cont'd)

Table IV

Measurements of Nonfissile-Material Worths at Center
of Assemblies 48 and 48B

Sample Type ^a		Thickness, Diameter, or Cube Size, in.	Reactivity Coefficient, $\Delta k/k$	
			Assembly 48	Assembly 48B
Fe	Cylinder	0.42	-12.3 ± 0.4	-13.2 ± 0.6
	Plate	0.25	-11.5 ± 2.0	-
	Cube	2.0	-11.3 ± 0.2	-
Cr	Cylinder	0.42	-12.3 ± 1.5	-12.1 ± 1.5
	Cube	2.0	-10.8 ± 0.6	-
Ni	Cylinder	0.42	-18.2 ± 0.2	-17.4 ± 0.4
	Plate	0.25	-18.7 ± 1.6	-
	Cube	2.0	-15.9 ± 0.2	-
SS 304	Cylinder	0.42	-14.1 ± 0.2	-13.1 ± 0.2
	Cube	2.0	-12.7 ± 0.2	-
Na	Cylinder	0.42	-7.0 ± 4.5	-6.3 ± 3.0
	Cube	2.0	-6.3 ± 0.3	-8.5 ± 0.6
C	Cylinder	0.42	-4.5 ± 1.2	-7.4 ± 1.8
	Cube	2.0	$+1.3 \pm 1.2$	-
Al ₂ O ₃	Cylinder	0.42	-11.7 ± 1.2	-
	Cube	2.0	-9.5 ± 0.1	-
Mo	Cylinder	0.42	-43.4 ± 0.4	-
		0.42	-45.4 ± 5.1^b	-
	Plate	0.25	-46.6 ± 2.9	-
	Cube	2.0	-39.0 ± 0.3	-
Al	Cylinder	0.42	-15.7 ± 0.8	-
	Cube	2.0	-14.5 ± 0.6	-
Mn	Cylinder	0.42	-22.9 ± 1.0	-
	Cube	2.0	-19.0 ± 0.4	-
Polyethylene Cylinder		0.42	$+1676 \pm 7.0$	-

a. Cylinders measured in cylindrical-sample changer, plates and cubes in 2-in.-cube changer.

b. Measured in the 2-in.-cube sample changer.

4.3-2-4Z Effect of Sample Size on Reactivity Worths

Facility: ZPR-6 (1.2) Assembly: 4Z (2.2-4Z)

Experimental Method:

Same as for 4.1-2-4Z

Results:

Worth of U^{235} as Function
of Thickness at Center of Core

No. of Samples of Size 2 x 2 x 0.005 in.	<u>Measurements, I_h^a</u>		
	<u>Weight, g</u>	<u>Net Worth</u>	<u>Worth/kg</u>
1	4.511	+0.226±0.020	50.10±4.40
2	9.358	+0.401±0.020	42.85±2.14
3	13.759	+0.611±0.020	44.41±1.45
5	27.628	+1.246±0.030	45.10±1.10
12	55.365	+2.493±0.030	45.03±0.54
23	105.77	+4.855±0.010	45.90±0.10

a 1% $\Delta k/k = 468 I_h$

Reference:

R. A. Karam, et al., "Measured Physics Parameters in a Zoned Fast Uranium Carbide Core, Assembly 4Z", ANL-7281 (1966)

Facility: ZPR-6 (1.2)Assembly: 5 (2.2-5)Experimental Method:

Same as for 4.1-2-5

Results:(1% $\Delta k/k = 476$ lh)

Table I

Worth of U-235, U-238 and Pu as
Function of Thickness at Core Center

Material	Material Size, in.	No. in Sample	Total Material, g	Sample ^a , g	Gross Worth ^b , lh	Net Worth, lh	Material Worth, lh/kg	Isotopic ^c Worth, lh/kg
U-235 (83.1% enrichment)	2 x 2 x 0.005	1	4.511	20.907	0.2067 ± 0.0021	0.2067 ± 0.0021	45.821 ± 0.466	49.571 ± 0.500
	2 x 2 x 0.005	3	13.894	39.200	0.6546 ± 0.0023	0.6546 ± 0.0023	47.114 ± 0.186	50.877 ± 0.190
	2 x 2 x 0.005	9	41.443	87.852	1.886 ± 0.0030	1.924 ± 0.0037	46.425 ± 0.088	50.127 ± 0.086
	2 x 2 x 0.005	14	64.184	111.483	2.951 ± 0.010	3.058 ± 0.012	47.596 ± 0.187	51.393 ± 0.201
	2 x 2 x 0.005	23	105.711	105.711	4.943 ± 0.010	4.943 ± 0.010	46.760 ± 0.095	50.484 ± 0.102
	2 x 2 x 1/8	2	288.03	288.03	14.595 ± 0.100	14.595 ± 0.100	50.672 ± 0.347	54.686 ± 0.373
U-238 (0.2% enrichment)	2 x 2 x 0.005	1	5.356	21.810	-0.0258 ± 0.0019	-0.0258 ± 0.0019	-4.617 ± 0.355	-4.827 ± 0.0019
	2 x 2 x 0.005	3	15.949	32.255	-0.0802 ± 0.0022	-0.0802 ± 0.0022	-3.774 ± 0.138	-3.876 ± 0.138
	2 x 2 x 0.005	12	64.086	80.482	-0.2349 ± 0.0021	-0.2349 ± 0.0021	-3.622 ± 0.033	-3.774 ± 0.033
	2 x 2 x 1/8	1	140.643	140.643	-0.505 ± 0.004	-0.505 ± 0.004	-3.501 ± 0.028	-3.698 ± 0.028
	2 x 2 x 1	1	1153.6	1153.6	-3.869 ± 0.010	-3.869 ± 0.010	-3.353 ± 0.009	-3.481 ± 0.009
Pu 72.2 w/o 238	1.83 x 1.68 x 0.05	1	36.40	55.486	2.066 ± 0.0116	2.102 ± 0.0117	57.755 ± 0.321	
Pu 22.3 w/o 238	1.83 x 1.83 x 0.08	1	57.57	58.276	3.340 ± 0.0095	3.376 ± 0.0096	58.643 ± 0.167	

^a Foils in 2 x 2 x 1/8 in. SS cans.^b Some measurements were made relative to a SS can; thus the net worth is measured directly.^c For ENR U samples, this column is lh/kg U-235 using a U-238 worth/kg commensurate with the U-238 weight in the sample. For DEP U samples, this column is lh/kg U-238 using a constant U-235 worth/kg of +50.0.Reference:

R. A. Karam, et al., "Measured Physics Parameters in a Large Uranium Carbide Fast Core, Assembly 5 ZPR-6", Reactor Physics Division Annual Report - July 1, 1966 to June 30, 1967, ANL-7310, pp. 167-189 (1968)

Facility: ZPR-6 (1.2)Assembly: 6 (2.2-6)Experimental Method:

The calibrated autorod was used in the measurement of the reactivity worth of U-235 and U-238 as a function of sample thickness. The samples comprised 0.005 in. thick foils with nominal area of 4 in.² stacked together, and placed in a 2 x 2 x 2 in. stainless steel can on a 1/32 in. wire rack that supported the samples at 1 in. from the bottom of the can. The samples were oscillated relative to an empty SS can with wire racks. In the case of U-235, the reactivity worth as a function of sample thickness was also measured in the exact environment of the normal core loading pattern. (see Figure 1 of 6-2-6). This particular measurement comprised the oscillation of 2 x 2 x 2 in. stainless steel cans, relative to each other, loaded in the same materials except for U-235 which was present in one can only.

Results:

Table I
Reactivity Worth of U-235, U-238, Iron and Nickel
As a Function of Sample Thickness

Material and Environment	No. of Foils	Total Foil Wt, g	Worth, Ih	Specific Worth, Ih/kg Material
93% enriched uranium foils suspended in a 2- x 2- x 2-in. empty stainless steel can	1	4.638	+0.1857 ± 0.0019	+40.04 ± 0.41
	2	9.002	+0.3619 ± 0.0018	+40.20 ± 0.20
	5	23.069	+0.9206 ± 0.0016	+40.18 ± 0.07
	16	73.634	+3.039 ± 0.010	+41.14 ± 0.14
93% enriched uranium foils in plate-type heterogeneous cans identical to core-loading pattern	1	4.511	+0.2110 ± 0.002	+46.66 ± 0.44
	2	9.221	+0.406 ± 0.002	+44.06 ± 0.22
	5	22.950	+0.909 ± 0.020	+42.22 ± 0.87
	8	36.851	+1.544 ± 0.020	+42.17 ± 0.54
	14	64.349	+2.962 ± 0.020	+41.68 ± 0.31
1/16-in. plate Depleted uranium foils suspended in a 2- x 2- x 2-in. empty stainless steel can	1	61.491	+2.567 ± 0.020	+41.75 ± 0.31
	1	5.913	-0.0263 ± 0.0017	-4.262 ± 0.268
	2	11.739	-0.0420 ± 0.0021	-3.654 ± 0.179
	5	28.977	-0.1084 ± 0.0016	-3.566 ± 0.066
	10	60.227	-0.2202 ± 0.0015	-3.646 ± 0.035
2- x 2- x 1-in. block	25	147.123	-0.5136 ± 0.0018	-3.491 ± 0.009
		1163.56	-3.764 ± 0.01	-3.263 ± 0.009

* 453 Ih = 1% Δk/k.

Reference:

R. A. Karam, L. R. Dates, W. Y. Kato, J. E. Marshall, T. Nakamura, and G. K. Rusch, "Heterogeneity Effects in a Large UO₂ Core, Assembly 6 of ZPR-6," Reactor Physics Division Annual Report - July 1, 1967 to June 30, 1968, ANL-7410, pp. 133-144 (Jan. 1969).

4.3-3-3

Effect of Sample Size on Reactivity Worth

Facility: ZPR-9 (1.3)

Assembly: 3 (2.3-3)

Experimental Method:

Same as for (4.1-3-1) except that sample sizes were varied. Hydrogenous samples used were both powdered and solid Lucite, as well as solid polyethylene.

Precision:

Reproducibility generally about 0.5 lh.

Corrections:

Oxygen and carbon effects were corrected for.

Results:

Note: $1\% \Delta k/k = 446 \text{ lh}$

Figure 1
Central Hydrogen Worth in Assembly No. 3

Reference:

R. C. Doerner, W. G. Knapp, K. K. Almenas, and R. A. Karam, "Physics Measurements in Tungsten-Based Aluminum-Reflected Fast Reactors", ANL-7007 (March 1967)

4.3-3-4

Effect of Sample Size on Reactivity Worths

Facility: ZPR-9 (1.3)

Assembly: 4 (2.3-4)

Experimental Method:

Same as for (4.1-3-1) except that sample sizes were varied and an automatic sample changer was used. Hydrogenous samples used were both powdered and solid Lucite, as well as solid polyethylene.

Precision:

Reproducibility generally about 0.07 lh.

Corrections:

Oxygen and carbon effects were corrected for.

Results:

Figure 1
Central Hydrogen Worth in Assembly No. 4

Reference:

R. C. Doerner, W. G. Knapp K. K. Almenas, and R. A. Karam,
"Physics Measurements in Tungsten-Based, Aluminum-Reflected
Fast Reactors" ANL-7007 (March 1967)

4.3-3-4B Effect of Sample Size on Reactivity Worth

Facility : ZPR-9 (1.3) Assembly : 4B (2.3-4B)

Experimental Method:

Same as for (4.1-3-1), except that sample size were varied.

Precision:

Reproducibility generally about 0.07 Ih.

Corrections:

The entire non-hydrogen content of samples was treated as carbon and correspondingly corrected for.

Results:

TABLE I

Sample No.	Material	Container	Sample Weight g	Hydro- gen Weight g	Carbon(& Oxygen) Weights g	Sample Worth Ih	Carbon Worth Ih	Apparent Hydrogen Worth Ih / kg *
3	Poly	Al	4.042	0.578	3.46	-1.69	-0.06	-2820
6	Poly	Al	8.030	1.148	6.88	-3.54	-0.12	-2980
7	Poly	Al	12.010	1.717	10.29	-5.08	-0.19	-2850
10	Poly	Bare	16.008	2.289	13.72	-7.08	-0.25	-2980
12	Poly	Bare	20.004	2.861	17.14	-8.80	-0.31	-2970

* Ih/ (%Δ k/k) = 432.3

Reference:

W.G. Knapp and R.C. Doerner, "Physics Measurements with Modified Diluent Compositions in Tungsten-Based, Aluminum-Reflected Fast Reactors," ANL-7207 (Feb. 1967)

4.3-3-5

Effect of Sample Size on Reactivity Worth

Facility: ZPR-9 (1.3)

Assembly: 5 (2.3-5)

Experimental Method:

Same as for (4.1-3-1), except that sample sizes were varied.

Precision:

Reproducibility generally about 0.07 Ih.

Corrections:

The entire non-hydrogen content of samples was treated as carbon and correspondingly corrected for.

Results:

Table I

Sample No.	Material	Container	Sample Weight g	H Weight g	Sample Worth, Ih	C & O ^a Worth Ih	Apparent Hydrogen Worth* Ih/kg
2	Lucite	Al	3.75	0.300	1.53	0.07	4870
3	Poly	Al	4.042	0.578	2.88	0.07	4860
4	Poly	Al	5.020	0.718	3.35	0.09	4540
7	Poly	Al	12.010	1.717	8.01	0.21	4540
8	Lucite	Al	12.5	1.00	5.18	0.24	4940
9	Poly	Al	13.021	1.862	8.35	0.23	4360
11	Poly	Al	18.009	2.575	10.84	0.32	4090
13	Poly	Bare	22.944	3.281	13.86	0.40	4100
16	Lucite	Al	29.9	2.39	11.24	0.57	4460
18	Lucite	Al	37.3	2.98	14.40	0.71	4590
22	Poly	Bare	53.763	7.688	31.99	0.95	4040
23	Poly	Bare	53.916	7.710	32.62	0.95	4110
24	Poly	Bare	56.640	8.100	33.53	1.00	4020
26	Lucite	Bare	72.905	5.832	24.89	1.38	4030

^aSince oxygen worth was neither measured nor calculated for Assembly No.5 and since the effect is believed to be small and of the same order as carbon, carbon worth only has been used here.

*1% $\Delta k/k$ = 424.8 Ih

4.3-3-5 (cont'd)

Reference:

W. G. Knapp and R. C. Doerner, "Physics Measurements with Modified Diluent Compositions in Tungsten-Based, Aluminum-Reflected Fast Reactors", ANL-7207 (Feb. 1967)

4.3-3-6

Effect of Sample Size on Reactivity Worth

Facility: ZPR-9 (1.3)

Assembly: 6 (2.3-6)

Experimental Method:

Same as for (4.1-3-1), except that sample sizes were varied.

Precision:

Reproducibility generally about 0.07 lh

Corrections:

The entire non-hydrogen content of samples was treated as carbon and correspondingly corrected for.

Results:

Sample No.	Material	Container	Sample Weight, g	Hydrogen Weight, g	Carbon (and Oxygen) Weights, g	Sample Worth, lh	Carbon Worth, lh	Apparent Hydrogen Worth, lh/kg
1	Poly	Al	1.999	0.286	1.71	0.78	0.01	2690
3	Poly	Al	4.042	0.578	3.46	1.94	0.03	3300
4	Poly	Al	5.020	0.718	4.30	2.19	0.04	2990
5	Poly	Al	8.017	1.146	6.87	4.00	0.06	3440
7	Poly	Al	12.010	1.717	10.29	6.10	0.09	3500
10	Poly	Bare	16.008	2.289	13.72	8.22	0.12	3540
11	Poly	Al	18.009	2.575	15.43	9.09	0.13	3480
12	Poly	Bare	20.004	2.861	17.14	10.23	0.15	3520
13	Poly	Bare	22.944	3.281	19.66	11.62	0.17	3490
14	Poly	Bare	23.971	3.428	20.54	12.65	0.18	3640
15	Poly	Bare	29.086	4.159	24.93	15.35	0.21	3640
17	Poly	Bare	34.035	4.867	29.17	18.06	0.24	3660
19	Poly	Bare	39.062	5.586	33.48	20.73	0.29	3660
20	Poly	Bare	43.834	6.268	37.57	22.80	0.32	3590
21	Poly	Bare	49.122	7.024	42.10	25.30	0.36	3550
22	Poly	Bare	53.763	7.688	46.08	27.34	0.40	3510
25	Poly	Bare	59.155	8.459	50.70	29.43	0.44	3430

$$*1 \% \Delta k/k = 430.6 \text{ lh}$$

Reference:

W. G. Knapp and R. C. Doerner, "Physics Measurements with Modified Diluent Compositions in Tungsten-Based, Aluminum-Reflected Fast Reactors," ANL-7207 (Feb. 1967).

4.3-3-8

Effect of Sample Size on Reactivity Worth

Facility: ZPR-9 (1.3) Assembly: 8(2.3-8)

Experimental Method:

Same as for ZPR-9, Assembly 7 (4.1-3-7) excepting that worths were determined by the on-line computer technique described in (4.1-3-9)

Results:

Refer to Table 1 of 4.1-3-8

Linear extrapolation to zero sample size gives the infinitely dilute hydrogen worth of 4.85 Ih/g. $I_h/(\% \Delta k/k) = 431.4$

Reference:

R. C. Doerner, W. G. Knapp, R. A. Karam, and D. K. Butler, "ZPR-9 Assemblies No. 6-9 Critical Experiments," ANL-7208 (March 1967).

4.3-3-8B

Effect of Sample Size on Reactivity Worths

Facility: ZPR-9 (1.3)

Assembly: 8B (2.3-8B)

The results of reactivity distributions as a function of sample size and shape are reported in 4.2-3-8B.

SECTION 4.4 - OTHER EFFECTS ON REACTIVITY WORTHS

4.4-2-3

Effects on Reactivity Worths

Effect Studied: Effect of Na voiding on Central Sample Worths

Facility: ZPR-6 (1.2)

Assembly: 3 (2.2-3)

Method of Measurement:

Using an automatic sample changer, the central worth of 5 x 5 x 2.5 cm samples of various materials was measured with and without sodium voided in a central region 50 cm long and 50 cm diameter.

Results:

Table I

Central Reactivity Worths
($\Delta k/k$)*

<u>Element</u>	<u>With Na</u>	<u>Without Na</u>
U-235	+75.1	+64.5
Pu-239	+119.9	+105.9
U-233	+142.2	+116.8
U-238	-4.12	-3.95
SS	-2.24	-2.24
C	+10.4	+7.84
Fe	-2.27	-2.12
Al	-0.43	-1.47
Be	+29.1	+24.4
Zr	-1.98	-2.01
W	-6.89	-5.92

*1% $\Delta k/k$ = 451 Δk .

Reference:

F. H. Helm, et al., "Physics Parameters and Sodium Void Coefficients in a 950-Liter Pancakes Core", Reactor Physics Division Annual Report July 1, 1964 to June 30 1965, ANL-7110, pp. 101-113 (1965)

4.4-2-42 Effects on Reactivity Worths

Effect Studied: Effect of Na voiding on central sample worths.

Facility: ZPR-6 (1.2)

Assembly: 4Z (2.2-42)

Method of Measurement:

Sample worths measured with the normal Na content of the central zone are reported in Section 4.1-2-42. Using the same technique, some of the samples were remeasured with all of the Na removed from the central zone.

Results:

Sample (Weight, g)	Measurements, lh ^a		
	Gross Worth ^b	Net Worth	Worth/kg
Na (51.38)	-0.125 ± 0.002	-0.035 ± 0.008	-9.681
SS (72.18)	-0.115 ± 0.006	-0.115 ± 0.006	-1.593
C (103.0)	+0.042 ± 0.008	+0.042 ± 0.008	+0.407
Be (114.31)	+0.788 ± 0.008	+0.788 ± 0.008	+6.893
Polyethylene (13.902)	+3.583 ± 0.006	+3.583 ± 0.006	+263.487
U ²³⁵ (27.719)	+1.032 ± 0.004	+1.126 ± 0.005	+40.620
U ²³⁸ (1133.80)	-3.191 ± 0.004	-3.191 ± 0.004	-2.766
B ¹⁰ (29.29)	-19.172 ± 0.010	-19.252 ± 0.010	-657.138

^a1% $\Delta k/k$ = 468 lh.

^bSome samples were encased in stainless-steel cans.

Reference:

R. A. Karam, et al., "Measured Physics Parameters in a Zoned Fast Uranium Carbide Core, Assembly 4Z", ANL-7281 (1966)

4.4-3-4

Effects on Reactivity Worths

Effect Studied: Effect of hydrogen on boron central worth

Facility: ZPR-9 (1.3)

Assemblies: 4, 4E, 5 and 6

Experimental Method:

See Section 4.1-3-4. The hydrogen-boron samples were homogeneously mixed.

Results:

See Table I - next page. The hydrogen worths were taken from measured values as shown in Fig. 1 (See Section 4.3-3-5).

Reference:

W. G. Knapp and R. C. Doerner, "Physics Measurements with Modified Diluent Compositions in Tungsten-Based, Aluminum-Reflected Fast Reactors", ANL-7207 (Feb. 1967)

Table I Effect of H on Central B Worths

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4.4-3-19 Other Effects on Reactivity Worths

Effect Measured:

Streaming in sample insertion tube.

Facility: ZPR-9 (1.3)

Assembly: 19, 21, 22, (2.3-19 - 2.3-22)

Method of Measurement:

The basic experimental set-up is described in Section 4.2-3-19. Samples were oscillated with and without a 4 in. long stainless steel end plug. In a separate measurement on Assembly 24 it was found that, except for its effect on streaming, the end plug had no appreciable reactivity effect of its own. (1)

Results:

TABLE I COMPARISON OF REACTIVITY WORTHS WITH AND WITHOUT STAINLESS STEEL STREAMING PLUG

Assembly	Material	Reactivity Worth, Δk			
		Center of Zone		Radius 22.1 cm	
		Sample with Thin End Closure	Sample with 4 in. SS Plug	Sample with Thin End Closure	Sample with 4 in. SS Plug
19	U-235	0.2005	0.2105	---	---
	B	-0.2206	-0.2231	---	---
	Al	-0.0060	-0.0019	-0.0100	-0.0123
	C	0.1204	0.1206	0.1003	0.1019
21	Al	-0.0030	-0.0030	---	---
22	Al	-0.0003	-0.0006	---	---

* Approximate uncertainty $\pm 0.002 \Delta k$.

Reference:

1. L. G. Le Sage, E. F. Groh, and W. R. Robinson, "An Investigation of the Properties of Zoned Systems," ANL Reactor Physics Division Annual Report July 1, 1967 to June 30, 1968, ANL-7410 p. 145 (1969).