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OAK RIDGE NATIONAL LABORATORY
Operated By
CARBIDE AND CARBON CHEMICALS COMPANY

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POST OFFICE BOX P
OAK RIDGE, TENNESSEE

DATE: May 18, 1955

SUBJECT: APPR Critical Experiment

FROM: J. G. Gallagher
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INTRODUCTION

A critical mock-up is to be made of the ORNL Designed Army Package Reactor. The principal objectives of the experiment are to determine the critical masses of the clean and boron poisoned assemblies, to evaluate the control rods, and to determine power and flux distributions.

This memo gives a general description of the critical mock-up and the suggested measurements on the various configurations.

DESCRIPTION OF MOCK-UP

A description of and reactor physics calculations for the ORNL Army Package Reactor are given in Ref. (1) and (2).

The mock-up approximates the macroscopic and microscopic properties of the water-moderated, stainless steel fuel element reactor design outlined in Ref. (1) and (2). The chief macroscopic properties, the cell dimensions (2.900 x 2.952 in.), volume fraction of metal (0.2043) and outside dimensions (a 7 x 7 array of cells with corners missing and core height of 22 in.) will be reproduced in the mock-up.

A general view of the mock-up is shown in ORNL Dwg. No. D-2-02-015-39. It consists of 45 fuel element boxes positioned at top and bottom by a light grid. The details of the fuel element boxes are in ORNL Dwg. No. D-2-02-015-38 and the Appendix. The side plates of the boxes have slots

- (1) A Conceptual Design of a Pressurized-Water Package Power Reactor, A. L. Boch, et al, ORNL-1613.
- (2) A Conceptual Design of a Pressurized-Water Package Power Reactor, Supplement 1, R. R. Bate and A. M. Perry, ORNL-1613, Suppl. 1.

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to receive 18 plates. The absorber section of each of the control rods is detachable from its respective fuel element box. The fuel element end box mock-ups which approximate the steel distribution in the reflector of the APPR, are removable so that certain measurements can be made on an essentially water reflected core.

The microscopic properties of the planned reactor are more difficult to reproduce. The Army Package Reactor is estimated⁽²⁾ to have a cold clean critical mass of 7.4 kg and a hot poisoned critical mass of 17.8 kg. The designed reactor has the 17.8 kg of U-235 and 34.9 gm of B-10 (185.6 gm of boron) distributed through 45 fuel elements each with 18 plates.

The fact that the mock-up is to be used to determine both the critical mass of the clean and the boron poisoned assembly is incompatible with a single set of fuel plates each with the same loading of uranium and boron. As a compromise the uranium and boron will be introduced in separate plates. The fuel plates will consist of an 0.002 in. uranium foil encased in a stainless steel sandwich. The boron plates will be fabricated by the same technique used for the APPR fuel plates. In addition steel plates (see Appendix) will be available so that each of the 18 slots of the fuel element boxes will always be occupied. Separate fuel, boron, and steel plates have the disadvantage of a certain amount of inhomogeneity but will insure that the mock-up always has the same metal-to-water ratio.

The details of the fuel plates and the special catcher foil plates are given in ORNL Dwg. No. D-2-02-015-37 and in the Appendix. The fuel

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plates will contain either a 2.5 in. or 1.25 in. wide by 22 in. x 0.002 in. uranium foil. A total of 585 fuel foils and 46 half foil fuel plates will be available. Insertion of all the fuel plates (13 full and 1 half foil plate per box) introduces 18.9 kg of U-235 into the core.

The amount of B-10 necessary to make critical, at 68° F, the core containing 18.9 kg of U-235 is estimated to be 63.9 gm (340 gm of boron) which will be divided among 180 plates (4 per box).

Details of the boron plate are given in ORNL Dwg. No. C-2-02-015-36 and the Appendix. In addition 50 boron plates containing 0.944 gm per plate will be fabricated.

An estimate of the number of fuel, boron and steel plates in each fuel element box for two typical configurations is:

Clean Critical Experiment

- 5 full foil fuel plates
- 1 half foil fuel plate
- 14 steel plates (includes 2 fixed end plates)

Poisoned Critical Experiment

- 13 full foil fuel plates
- 1 half foil fuel plate
- 4 boron steel plates
- 2 steel plates (includes 2 fixed end plates)

The detailed design of the absorber section of the control rods is not settled because of an uncertainty in how the boron will be introduced. Two methods are presently under consideration. The method which is indicated in the ORNL APPR Design⁽¹⁾ is to use a sandwich of boron carbide in copper (16.3 wt % B₄C) clad with stainless steel. This method was used

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to fabricate the Homogeneous Reactor Experiment control plates⁽³⁾ and is under further development by ORNL Metallurgy⁽⁴⁾. The alternate is to construct a double walled square tube into which powdered B₄C and copper would be introduced and pressed to obtain the desired loading of boron per cm².

I. CLEAN CRITICAL MASS

Purpose

Determine the clean critical mass of the APPR mock-up and make a series of measurements on this configuration.

Description of Mock-up

Initially the absorber section of the control rods will not be attached to the fuel element boxes and end box mock-ups will not be in place. In subsequent measurement the absorber section of the control rods and end box mock-ups will be in place.

General Discussion

In determining the cold clean critical mass an attempt will be made to keep the loading of fuel elements and steel plates as uniform as possible. It should be noted that the addition of one full foil fuel plate (or one half foil fuel plate) per element adds 1405 grams (or 703 grams) of U-235 to the core. The addition of the one half foil fuel plate to each element corresponds to about 3% $\Delta k/k$; therefore, it is to be expected that some non-uniformity of loading is to be encountered.

(3) Method of Fabrication of Control and Safety Element Components for the Aircraft and Homogeneous Reactor Experiments, J. H. Coobs and E. S. Bomar, ORNL-1463.

(4) Personal Communication, R. J. Beaver to J. G. Gallagher, April 28, 1955.

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Measurements to be made on this Configuration:

- a. Determine the reactivity effects of various fuel plate and steel plate arrangements.
- b. Determine flux distribution using gold foils within a cell at the center of the mock-up.
- c. Measure flux distribution using bare and cadmium covered gold foils and power distribution using special fuel plates with provision for catcher foils. Measurements are to be made radially at the midplane, along the vertical axis, from center of the core to one corner and in detail at potential hot spots.
- d. Determine the effect on criticality of attaching the absorber section of the control rods.
- e. Determine the reactivity effects of end box mock-ups at top and bottom of fuel element boxes. The distribution of steel within the top and bottom reflector is shown in Fig. 1 for the ORNL Design⁽¹⁾.
- f. Determine the flux distribution in core and reflector using bare and cadmium covered gold foils with end structures in place and absorber section of control rods attached.
- g. Determine the power distribution by means of catcher foils in the special fuel plates with end structures in place and absorber section of control rods attached.

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II. POISONED CRITICAL MASS

Purpose

Determine the critical mass of the APPR mock-up with various uniform boron loadings and make a series of measurements on the configuration with maximum boron.

Description of Mock-up

Initially the absorber section of the APPR control rods will not be attached to the fuel element boxes and the end box mockups will be removed.

General Discussion

The expected variation of the critical core loading vs. boron loading for the clean critical mass of 7.4 kg is shown in Fig. 2. If the critical mass is other than 7.4 kg of U-235 Fig. 2 can be used to estimate the variation of critical core loading vs. boron loading. Fig. 2 gives the envelope of possible combinations of the available boron and fuel plates which can be inserted in the 18 slots of the fuel element boxes. The addition of a half loaded boron plate to each cell adds 42.5 gm of boron or 7.99 gm of B-10 to the core and is worth about $-4\% \Delta k/k$ for a core with the clean critical mass of 7.4 kg.

Measurements to be made on this Configuration (maximum boron loading)

- a. Determine flux distribution using gold foils within a cell at the center of the mock-up.
- b. Determine the reactivity effects of various fuel, boron, and steel plate arrangements.

- c. Measure flux and power distributions axially and radially.
- d. Repeat flux and power distributions with absorber section of control rods attached and end box mock-up in place.

III. CONTROL ROD FULLY INSERTED

Purpose

Determine the worth or shutdown capacity of the central rod and one eccentric rod and to make a series of measurements on this configuration.

Description of Mock-up

The absorber section of all control rods will be attached. End box mock-ups are in place. A fine regulating rod and safety rods will be located in the reflector.

General Discussion

The worth of the central control rod and one eccentric rod is to be found by finding the critical core loading for central control rod fully inserted into the clean assembly. This measurement will be repeated for a boron poisoned assembly (2 boron plates per box). The central rod alone is worth 6.7%; one eccentric rod along 3.1%; and the combination is worth 11.1%.

Some measurements are to be made with the control rods fully inserted into the boron poisoned core so that the worth or shutdown capacity of the rods can be estimated at the midlife time of the APPR.

Measurements to be made on this Configuration

1. Determine flux and power distribution at the midplane for the central rod completely inserted.
2. Repeat 1 for the central rod and one eccentric rod.
3. Repeat 1 for the central rod in the boron poisoned core.

IV. CONTROL RODS PARTIALLY INSERTED

Purpose

Determine the power distribution when the control rods are partially inserted.

Description of Mock-up

All five absorber sections of the control rods are attached to their respective fuel element boxes. End box mock-ups are in place.

General Discussion

The power distribution that will exist in the APPR at midlife time is of particular interest. The position of the control rods at midlife in the APPR can be estimated from the calculated worth of all five rods fully inserted ($\frac{K_{eff}-1}{K_{eff}} = 0.224$) and the maximum $\frac{K_{eff}-1}{K_{eff}}$ to be balanced at temperature which is⁽¹⁾ 0.067. The worth of the five rods will be re-evaluated from the results of Section III. Using the calculated worth, the rods must be inserted to 30% of their integrated worth. From a curve of worth vs. insertion for a boron rod in a similar critical experiment⁽⁵⁾ the rods must be inserted to 37% of the active core or 8.1 in. from the top of the uranium foils.

(5) Critical Studies with G.E. Type Fuel Elements by ZPR-1 Group, T. H. Martin and G. T. Helfrich, ANL-5108.

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Measurements to be made on this Configuration

1. Enough measurements are to be made in order to accurately estimate the position of maximum power. This measurement will be repeated for two other control rod positions.

V. SPECIAL EXPERIMENTS

Purpose

Determine the change in reactivity of the mock-up as a function of water temperature for the clean and poisoned critical condition.

Description of Mock-up

The mock-up is loaded for clean critical condition (and later to poisoned critical condition). Thermocouples are located at several points in the core in order to get a good estimate of the average temperature.

General Discussion

The mock-up temperature is raised slowly to approximately 70° C by means of heaters located in the tank outside the reflector. Careful attention will be given to the problem of thermal expansions and attaining uniform temperature.

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APPENDIX

FUEL ELEMENT BOX SPECIFICATIONS

Design Data

Dimensional specifications	Box Type I, ORNL Dwg No. D-2-02-015-38
Side plate dimensions, in.	2.786 x 31 x 0.078
Slot dimensions, in.	0.056 wide x 0.050 deep on 0.148 centers
Number of slots	18
End plate dimensions, in.	2.800 x 31 x 0.031
Metal area in box, in. ²	0.5088
Metal area in 18 plates, in. ² (fuel, boron or steel plates)	1.2254
Area of cell, in. ²	8.5608
Volume fraction of metal in cell	0.2026

Material Specifications

Side and end plates

Wrought stainless steel type 304L or 304 commercial sheet

Material Identification

Side and end plates

Established by chemical analysis

FUEL ELEMENT SPECIFICATIONS

Fuel Element

Dimensional specifications	Test Plates Type D, E, F, and G, ORNL Dwg. No. D-2-02-015-37
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Dimensions of full foils, in.	2.500 x 22 x 0.002
half foils, in.	1.250 x 22 x 0.002
Mass of full foils, gm	33.40 ± 0.20
half foils, gm	16.70 ± 0.10
Outside dimensions of stainless steel cladding (thickness is at ϕ), in.	2.723 x 23 x 0.024
Clad-core-clad thickness, mils	11.1-2-11.1
Mass of finished foils	20.0 kg U-235 (21.46 kg U)
Type of plates, Item No. of Ref. ORNL Dwg.	1 2 3 4
Number of plates	590 46 12 12

Material Specifications

Uranium Foil

Uranium enriched to 93.2% in U-235

Stainless Steel Cladding

Wrought stainless steel type 304 commercial sheet

Glue

Minnesota Mining Company, Type EC-776

Material Identification

Uranium - Mass spectrographic analysis

Stainless Steel - Spectrographic Analysis

Glue - Chemical analysis

BORON PLATE SPECIFICATIONS⁽⁶⁾

Design Data

Dimensional specifications

Test Plates Type "B" and "C"
ORNL Dwg. No. C-2-02-015-36

(6) Boron Plate Specifications for APPR Critical Experiment, J. G. Gallagher and R. R. Bate, ORNL CF 55-5-32.

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Core dimensions (nominal), in.	2.5 x 22 x 0.015	
Outside dimensions (nominal), in.	2.723 x 23 x 0.025	
Clad-core-clad thickness, mils	5-15-5	
Type of plate	"B"	"C"
Number of plates	190	50
Natural boron content per plate, gm	1.889 ^{+0.000} _{-0.004}	0.944 ^{+0.000} _{-0.002}
Core mixture composition, wt % (Based on B ₄ C with 78.3% B)	2.33 B ₄ C 97.67 SS	1.67 B ₄ C 98.33 SS
B ₄ C content per plate, gm (Based on B ₄ C with 78.3% B)	2.411	1.206
Stainless steel content per plate, gm	198.28	202.16
Identification - number of saw cuts on ends	2	3

Material Specification

Core Material

Prealloyed steel powder

Stainless steel type 304 (-100) mesh size and irregular particle shape

Boron carbide powder

Ground and screened to (-325) mesh size

Frame material

Wrought stainless steel type 304L or 304 commercial sheet

Cover Material

Wrought stainless steel type 304L or 304 commercial sheet

Material Identification

B ₄ C	Established by chemical analysis
Prealloyed steel powder	Established by chemical analysis
Frame and clad stainless steel	Established by chemical analysis

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Inspection

Chemical analysis of the boron content and distribution in one plate out of each blending batch.

A further check on distribution will be the radiograph that will probably be necessary to locate the core for trimming the plate to size.

STEEL PLATE SPECIFICATIONS

Design Data

Dimensional specifications	Plate Type A, ORNL Dwg. No. C-2-02-015-34
Outside dimensions (nominal), in.	2.723 x 23 x 0.025
Type of plate	"A"
Number of plates	700
Identification - number of saw cuts on ends	1
Wt of plate, gm	206.03

Material Specifications

Plate Material

Wrought stainless steel type 304L or 304 commercial sheet

Material Identification

Plate material - established by chemical analysis

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AXIAL VARIATION OF STAINLESS STEEL IN APPR

Fig. 1

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6954

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BORON LOADING VS CORE LOADING OF U-235 FOR SEVERAL CLEAN CRITICAL MASSES

Fig. 2

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GRAPH IN-ONE-6935

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MATERIALS LIST					
ITEM NO.	DWG. NO.	QTY.	NAME	SIZE	MATERIAL
1		80	JIDE PLATE	#14 GAGE (07B)	STAIN STL. 304LOR 304
2		80	END PLATE	#22 GAGE (03125)	" "

DETAIL A-A
SCALE 4" = 1"

A diagram illustrating the relationship between the radius of the cutter and the distance to be determined from the cutter diameter. It shows a curved line representing the profile of the workpiece, with a vertical line indicating the distance to be determined from the cutter diameter. The radius of the cutter is labeled as R. OF CUTTER.

ITEM - 2

NO.	REVISIONS				DATE	APPR.	APPR.
DRAWING NO. D-2-02-015-38							
DRAWN MANA	DATE 4-27	CHECKED SS RD	DATE 5/10/55	APPROVED	DATE		
DESIGNED	DATE	SUBMITTED	DATE	APPROVED	DATE		
HEALTH PHYSICS		MEDICAL		OPERATIONS		SAFETY	
FIRE PROTECTION		RESEARCH SHOP		MAINTENANCE			

BOX ASSEMBLY
40 ASSEMBLIES REQ'D

ITEM 1

THIS DRAWING
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ASG
PER
SCALE: FULL

REFERENCE DRAWINGS	DWG. NO.
TEST #1	
BOX TYPE 1	
OAK RIDGE NATIONAL LABORATORY OPERATED BY CARBIDE AND CARBON CHEMICALS COMPANY A DIVISION OF UNION CARBIDE AND CARBON CORPORATION OAK RIDGE, TENNESSEE	
SUBMITTED	ACCEPTED 5-2-58 <i>[Signature]</i> 200-5-455
APPROVED	2-08-015 D-38 REV

MATERIALS LIST					
ITEM NO.	DWG. NO.	QTY.	NAME	SIZE	MATERIAL
1			TEST PLATE - TYPE "D"		
2			TEST PLATE - TYPE "E"		
3			TEST PLATE - TYPE "F"		
4			TEST PLATE - TYPE "G"		
5			INSERTS FOR ITEMS 3 & 4

ITEM 5
SCALE - FULL

NOTE:
ITEM 1 - A = 2.500
ITEM 2 - A = 1.25 ± 0.005
FABRICATE WITH FOILS CENTERED 1.05

ITEM 3
NOTE:
FOIL DIM. SAME AS ITEM 1

NOTE:
FOIL DIM. SAME AS ITEM 1

NO.	REVISIONS	DATE	APPR.	APPR.
DRAWING NO. D-2-02-015-37				
DRAWN	DATE	CHECKED	DATE	APPROVED
DESIGNED	DATE	SUBMITTED	DATE	APPROVED
HEALTH PHYSICS	MEDICAL	OPERATIONS	SAFETY	
FIRE PROTECTION	RESEARCH SHOP	MAINTENANCE		

THIS DRAWING
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REFERENCE DRAWINGS		DWG. NO.
TEST #1		
TEST PLATES		
TYPES "D", "E", "F" & "G"		
OAK RIDGE NATIONAL LABORATORY		
OPERATED BY		
CARBIDE AND CARBON CHEMICALS COMPANY		
A DIVISION OF UNION CARBIDE AND CARBON CORPORATION		
OAK RIDGE, TENNESSEE		
SUBMITTED	ACCEPTED	APPROVED
5-3	5-3	5-3
2-02-015	2-02-015	2-02-015
D-37	D-37	D-37

MATERIALS LIST					
ITEM NO.	DWG. NO.	QTY.	NAME	SIZE	MATERIAL

NO.	REVISIONS			DATE	APPR.	APPR.
DRAWING NO. D-						
DRAWN	DATE	CHECKED	DATE	APPROVED	DATE	
MANNN	5-17-55					
DESIGNED	DATE	SUBMITTED	DATE	APPROVED	DATE	
HEALTH PHYSICS		MEDICAL		OPERATIONS		SAFETY
FIRE PROTECTION		RESEARCH SHOP		MAINTENANCE		

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PER _____

SCALE: $\frac{1}{8}'' = 1'$

2-02-05

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REFERENCE DRAWINGS	DWG. NO.
TEST #1	
GENERAL ASSEMBLY	
OAK RIDGE NATIONAL LABORATORY OPERATED BY CARBIDE AND CARBON CHEMICALS COMPANY A DIVISION OF UNION CARBIDE AND CARBON CORPORATION OAK RIDGE, TENNESSEE	
SUBMITTED	ACCEPTED
	APPROVED
	REV