NUREG/CR-0297 R
RFP-2829

REFERENCE CRITICAL EXPERIMENTS

Progress Report
April 1 - June 30, 1978

B.B. Ernst
I. Oh
G. Tuck

Rockwell International

Prepared for
U.S. Nuclear Regulatory Commission

Available from
National Technical Information Service
Springfield, Virginia 22161
Price: Printed Copy $4.50 ; Microfiche $3.00

The price of this document for requesters outside of the North American Continent can be obtained from the National Technical Information Service.

NUREG/CR-0297
RFP-2829
DIST. CODE RC

REFERENCE CRITICAL EXPERIMENTS

Progress Report
April 1 - June 30, 1978

B.B. Ernst
I. Oh
G. Tuck

Manuscript Completed: August 1978
Date Published: September 1978

Rockwell International
Rocky Flats Plant
P.O. Box 464
Golden, Colorado 80401

Division of Safeguards, Fuel Cycle, & Environmental Research
Office of Nuclear Regulatory Research
U.S. Nuclear Regulatory Commission
Under Contract No. EY-76-C-04-3533
FIN No. A1036

TABLE OF CONTENTS

SUMMARY

This is the eleventh in a series of quarterly reports describing reference critical experiments being performed at Rocky Flats for the U. S. Nuclear Regulatory Commission (NRC). This series of experiments is to provide accurate critical data on low-enriched uranium oxide (U_3O_8) systems with three different moisture contents and under several conditions of reflection. These data will provide checkpoints against which computer accuracy may be determined.

The core currently being studied consists of $\sim$ 1900 kg of low-enriched (4.5% U-235) uranium oxide with an H/U of $\sim$ 0.75. The oxide alone is not critical; hence, a high-enriched (93% U-235) uranium driver section near the core center is required.

During this quarter, nine critical data points were obtained for concrete-, plastic-, and minimally-reflected cores with three different drivers.

Thirteen experiments were added to the program to determine the effect of various moderator materials interspersed between the core units. For these experiments, all material has been obtained and fabricated, and other preparations are nearly completed.

The uranium oxide is gaining weight with time. Four oxide cans have been isolated in controlled atmospheres to determine the cause of the weight gain.

LOW-ENRICHED OXIDE EXPERIMENTS

WITH H/U ~ 0.75

Experimental Procedure

All experimental work was conducted on the horizontal split table. This table consists of two halves which move toward one another. During an experimental run, the north table is first closed, and then the south table is closed by increments toward the mating face of the north table. Both tables are capable of opening upon receipt of a scram signal. For a more detailed description, see NUREG/CR-0096.

Once a given reflector was installed and approximately aligned, the next step was to load the ~ 1900 kg of oxide, with approximately 40% on the north table and approximately 60% on the south table. This was done following the usual manual assembly procedures. This involves plotting the inverse multiplication as a function of the number of cans. With the completion of the oxide loading, a final alignment of the core and reflector was required as the weight of nearly nine tons on the table slightly shifted the first alignment.

The next step was to assemble the driver manually to approximately half the calculated critical value. An experimental run was then made by remotely closing the tables and plotting the appropriate inverse multiplication curves along with other data. At the completion of the run, the next driver mass addition was made and the run sequence repeated.

The data from several critical experiments were used to generate a master curve of the inverse multiplication extent when the table was closed versus the driver mass. This curve aided the selection of the correct driver mass for the assembly to be critical with the table nearly closed. In the case of the metal drivers, the choice was limited to the available driver parts, resulting in a maximum table separation of 1.45 cm at the critical data point. Positive and negative period data were obtained for each critical point.

During the several runs leading up to each critical data point, the continued movement of the table shifted the oxide cans very slightly from their original positions. Hence, small balls of a putty-like substance (Duxseal) were placed at points around the closing face of the reflector, oxide cans, and, when used, the solution driver cans for what was expected to be the last subcritical run. As the table closed, these small balls were flattened to the distance between the halves of core and reflector. In addition, the final 15 cm of table closure was monitored by a differential transformer system. Comparing the measurements of the flattened balls with the differential transformer reading produced data for the average core separation at the critical point on the following run.

After the critical run, the reflector back was removed and all exposed sides of the core measured. After obtaining one critical data point for each of three drivers, the oxide core was unloaded to change reflectors. During the unloading, measurements for the core dimensions were made for each layer of oxide cans.

The only major difficulty encountered during this series of experiments was with the neutron source and instrumentation location for the plastic reflector. For the concrete-reflected experiments, the source was on the top of the driver and the instrumentation beneath the reflector. This arrangement yielded a minimum core perturbation yet provided adequate data for an experimental run. The same arrangement tried on the plastic reflector with a known subcritical load produced data representative of a neutron source being shielded by the closing halves of the reflector, rather than indicating the reactivity increase from table closure. Several arrangements were tried, and the one used for the three plastic-reflected measurements was to raise the north reflector back panel up 26 cm. This method provided plane surfaces, which can be more easily used for computer input.

The critical parameters, including the core dimensions, are provided in the data section (see page 9).

Material Description

The measured composition data for uranium oxide, aluminum (type 1100) cans, aluminum (type 6061-T6) plates between layers of cans, and concrete and plastic reflectors used in the NRC oxide experiments (Task 5) will be described in the next quarterly report.

Some samples of these materials have been sent to a commercial analytical laboratory for complete elementary analysis. Chemical analyses for the plastic bags which wrapped the oxide blocks and for the two types of tape which sealed the cover and holes of the aluminum cans were reported in RFP-NUREG-2746.

A pair of samples of the solution driver were taken in almost every experiment, and they were assumed to be representative of the solutions used in the just-completed critical experiments. The laboratory analysis for the high and low concentration solution drivers are given in Table I.

The masses used for the metal driver parts are the weights as reported in NUREG/CR-0096.

The uranium oxide cans were weighed approximately every month to monitor a continuing weight gain that has been apparent for the last few months. Table II shows the average weight gains of the regular and special oxide cans (see NUREG/CR-0096) as a function of time, i.e. over approximately four, five, six, and seven month periods from the time the oxides were packed into aluminum cans. The NRC oxide

TABLE I

Properties of Uranyl Nitrate Solutions Used as Drivers for the Low-Enriched Oxide Experiments with H/U ~ 0.75

Uranium Concentration (g U/ℓ)	Solution Density (g/cm^3)	Excess Nitric Acid (molar)	Total Impurity (ppm)
86.42 ± 0.20	1.1201 ± 0.0002	0.149 ± 0.003	1340
351.18 ± 0.57	1.4885 ± 0.0014	0.549 ± 0.015	1340

All uncertainties represent one standard deviation about the mean for multiple samples. For the uranium isotopic enrichment, see RFP-NUREG-2690.

TABLE II

Average Properties of Experimental Cans

Description of Can	Number of Cans	Average Weight (in grams) at the Time the Oxide was Packed			Average Weight Gain (in grams) as a Function of Time (in months)			
					Months			
		Oxide	Water	Can	Four	Five	Six	Seven
Regular Oxide Can	126	15129	273	526	5	10	14	25
Special Oxide Can	4	12253	211	621	5	13	15	17

experiments at H/U ~ 0.75 (Task 5) were performed between five and seven months after the oxide was packed. Four oxide cans have been isolated in controlled atmospheres to determine whether the weight gain is due to water or oxygen from the air. Once this is determined, laboratory analysis will begin to quantify the elements involved.

Core Dimensions and Critical Data

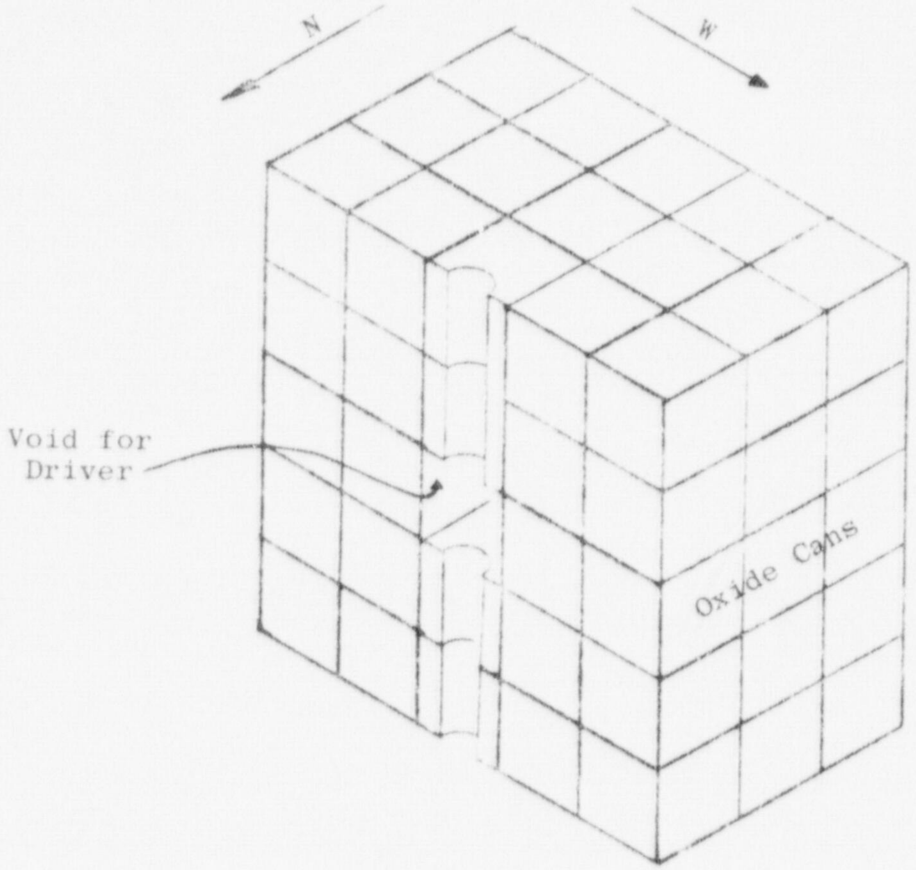
As stated in the experimental procedure section, the core was measured to determine the critical dimensions. Figures 1 through 4 show the core configurations for the different drivers. On the south part of the core, the center two oxide cans in the two top layers were slotted to allow the removal of the source. In addition, the bottom two cans for the metal driver measurements also were slotted to accomodate the support rod for the driver. Each core was a 5 x 5 x 5 array of oxide cans which were described in RFP-NUREG-2746. An aluminum (type 6061-T6) plate was used between each horizontal layer of oxide cans (eight total on both sections of the core). This plate was necessary to stabilize the oxide cans. The aluminum plate was 0.16-cm-thick and the size of 3 x 5 or 2 x 5 array of cans. This plate is not shown on the figures. Table III presents the critical parameters and core sizes of 5 x 5 x 5 arrays for the different reflectors. Figure 5 is the key to Table III. Figures 6 through 11 show the dimensions for the reflectors used in the experiments.

FIGURE 1

METAL DRIVER
NORTH CORE

See Table III and Figure 5 for dimensions.

FIGURE 2

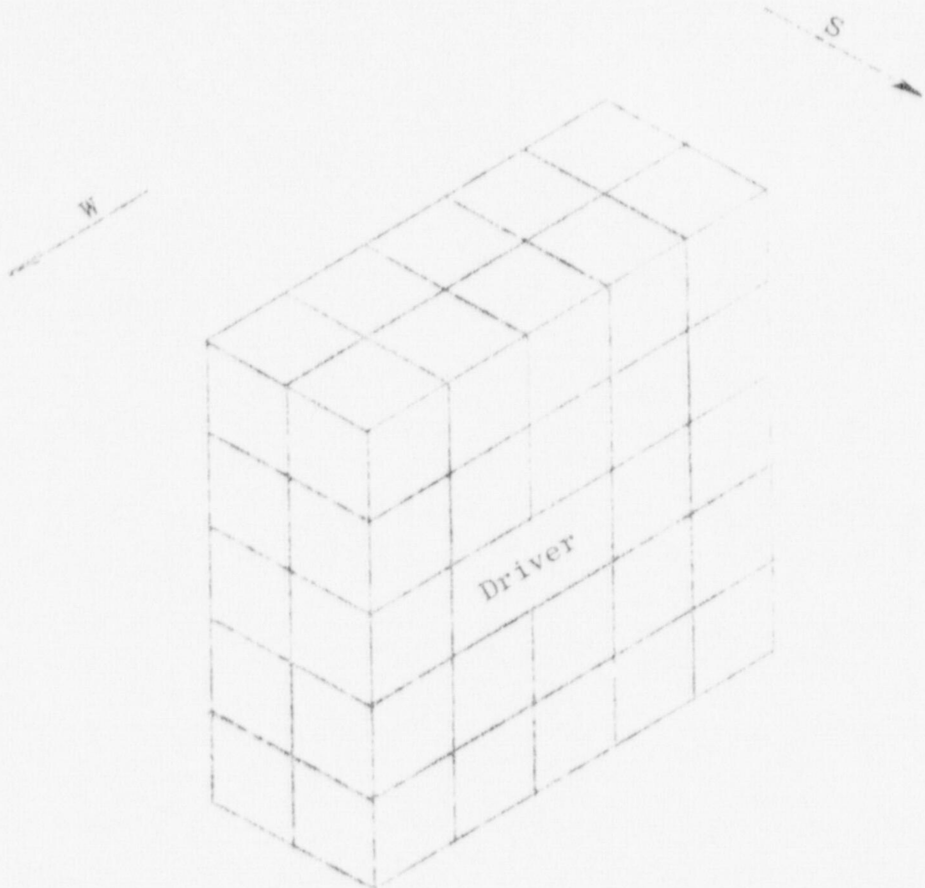


METAL DRIVER

SOUTH CORE

See Table III and Figure 5 for dimensions.

FIGURE 3

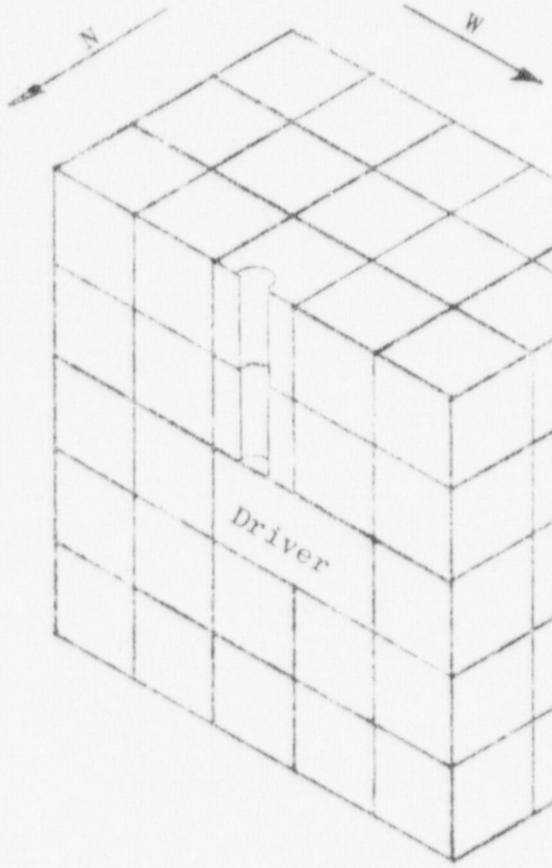


SOLUTION DRIVER

NORTH CORE

See Table III and Figure 5 for core dimensions; see NUREG/CR-0096 for description of driver cans.

FIGURE 4



SOLUTION DRIVER

SOUTH CORE

See Table III and Figure 5 for core dimensions;
see NUREG/CR-0096 for description of driver cans.

TABLE III

Core Dimensions and Critical Parameters for the Minimally-Reflected, Concrete-Reflected, and Plastic-Reflected Arrays of Uranium Oxide

	Steel Reflector (Minimally-Reflected)				Concrete Reflector			Plastic Reflector			
Driver Material	High Concentration Solution		Low Concentration Solution	Oy Metal Sphere	High Concentration Solution	Low Concentration Solution	Oy Metal Sphere	High Concentration Solution	Low Concentration Solution		Oy Metal Sphere
Total Driver Mass (kg)	16.143	15.687	13.999	33.543	14.966	12.446	29.870	14.844	13.001	12.875	29.870
Core Mass (kg U)	1543.158	1543.158	1543.158	1576.709	1543.158	1543.158	1576.709	1543.158	1543.158	1543.158	1576.709
Separation Between Two Core Parts (cm)	0.88	0.35	0.62	1.45	0.60	0.84	1.25	0.97	1.09	0.89	0.78
Core Dimension* (cm)											
A	46.50±0.12	46.50±0.12	46.26±0.16	46.54±0.11	46.60±0.12	46.33±0.23	46.53±0.10	46.23±0.11	46.23±0.11	46.23±0.11	46.23±0.11
B	0.396±0.14	0.396±0.14	0.677±0.17	0.265±0.15	0.841±0.21	1.073±0.28	0.997±0.19	0.507±0.17	0.724±0.13	0.724±0.13	0.592±0.14
D	0.693±0.06	0.165±0.06	0.512±0.06	1.081±0.04	0.465±0.12	0.624±0.12	1.219±0.15	0.461±0.10	1.031±0.10	0.835±0.10	0.414±0.12
E	0.882±0.12	0.354±0.12	0.619±0.12	1.451±0.20	0.604±0.14	0.839±0.08	1.246±0.06	0.967±0.24	1.103±0.09	0.907±0.09	0.781±0.12
F	30.98±0.08	30.98±0.08	30.85±0.42	31.26±0.21	31.10±0.16	31.13±0.23	31.05±0.26	30.72±0.36	30.72±0.36	30.72±0.36	30.72±0.36
G	---	---	---	---	0.402±0.22	0.402±0.22	0.402±0.22	0.516±0.22	0.516±0.22	0.516±0.22	0.516±0.22
H	76.95±0.23	76.95±0.23	76.89±0.17	76.82±0.08	76.98±0.11	76.89±0.11	76.95±0.15	76.78±0.12	76.78±0.12	76.78±0.12	76.78±0.12
I	6.26±0.23	6.26±0.23	6.26±0.14	6.17±0.13	6.19±0.20	6.29±0.22	6.27±0.28	6.95±0.19	6.95±0.19	6.95±0.19	6.95±0.19
J	76.82±0.25	76.82±0.25	76.83±0.17	76.80±0.14	76.98±0.07	[illegible]	76.91±0.09	76.78±0.12	76.78±0.12	76.78±0.12	76.78±0.12
K	6.58±0.22	6.58±0.22	6.51±0.14	6.57±0.11	6.05±0.13	6.11±0.12	6.08±0.08	6.66±0.29	6.66±0.29	6.66±0.29	6.66±0.29
L	76.52±0.14	76.52±0.14	76.65±0.17	76.73±0.14	77.50±0.07	77.50±0.07	77.50±0.07	76.88±0.37	76.88±0.37	76.88±0.37	76.88±0.37
M	76.86±0.24	76.86±0.24	76.71±0.24	76.84±0.14	76.93±0.36	76.93±0.36	76.93±0.36	76.98±0.25	76.98±0.25	76.98±0.25	76.98±0.25
N	0.994±0.11	0.994±0.11	1.165±0.43	0.623±0.23	1.101±0.24	1.033±0.29	1.077±0.24	0.618±0.38	0.835±0.37	0.835±0.37	0.703±0.37
O	---	---	---	---	0.428±0.29	0.428±0.29	0.428±0.29	0.897±0.11	0.897±0.11	0.897±0.11	0.897±0.11

*Refer to Figure 5 for identification of dimensions.

FIGURE 5

CORE DIMENSIONS

Dashed lines indicate core boundaries, and solid lines represent reflector boundaries.

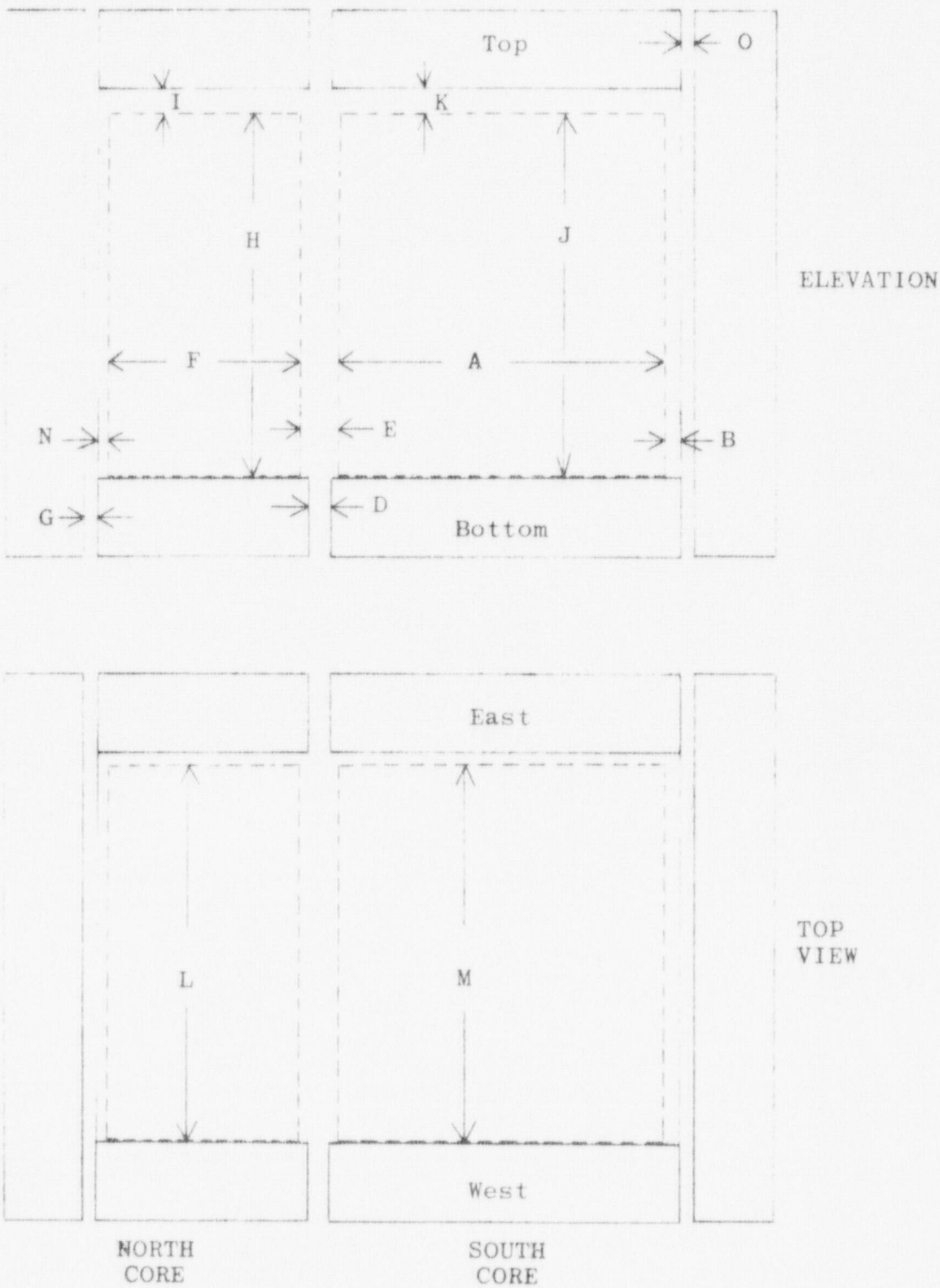
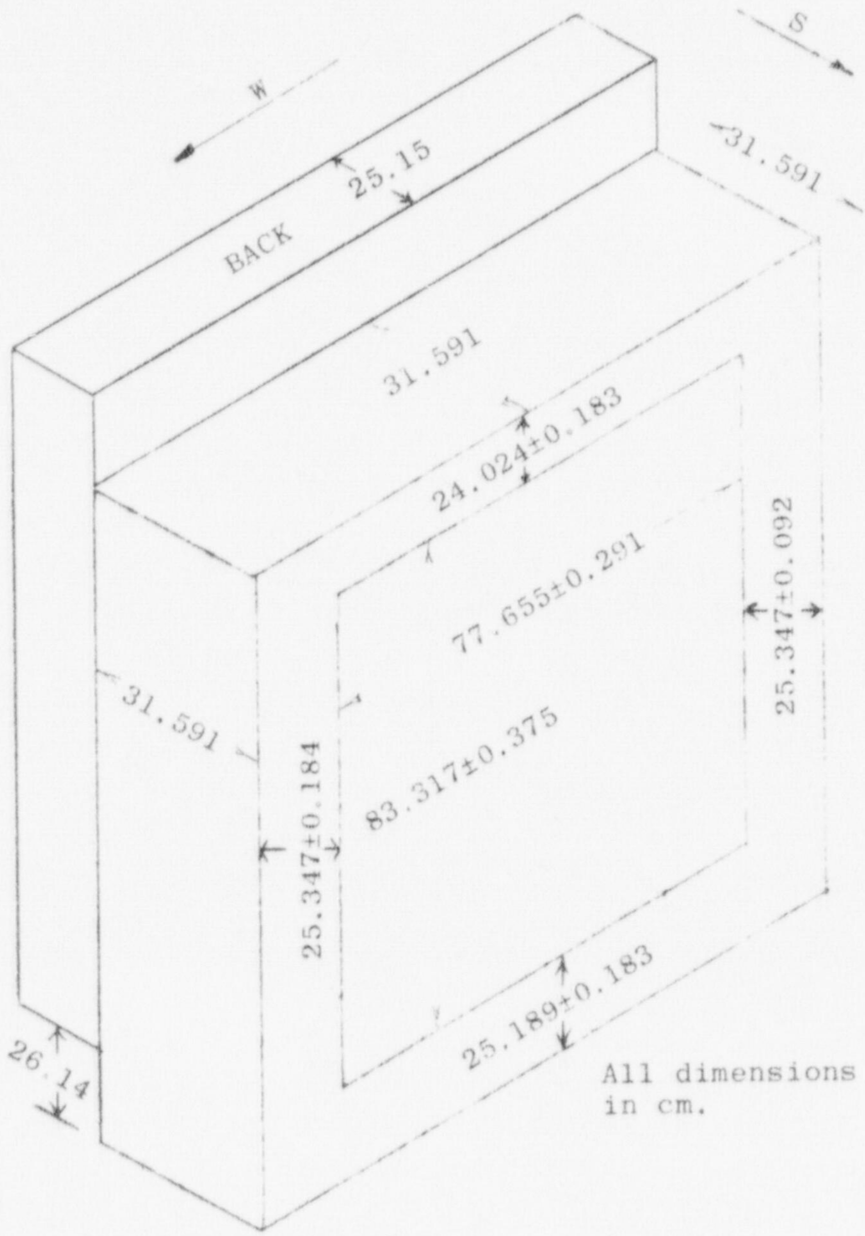


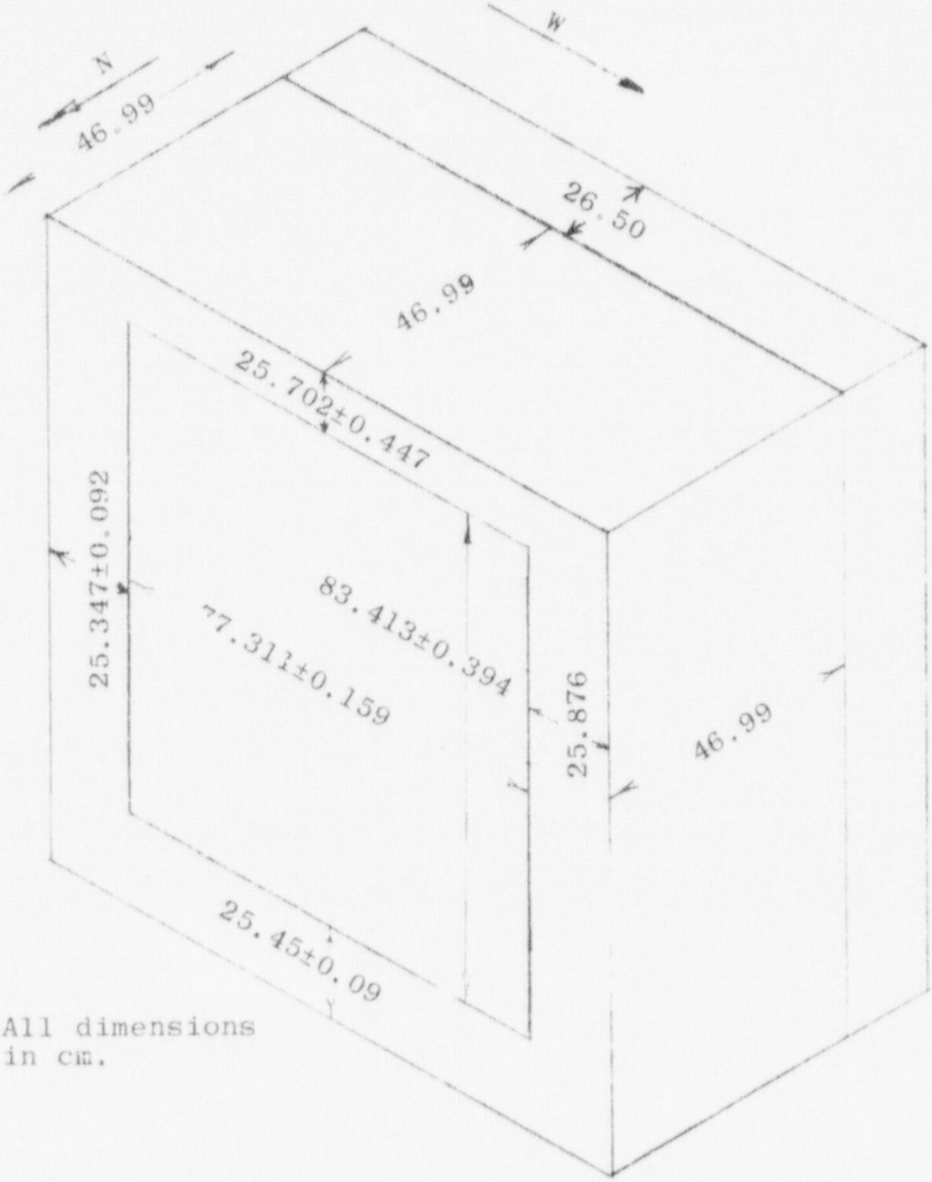
FIGURE 6



NORTH REFLECTOR

PLASTIC

FIGURE 7

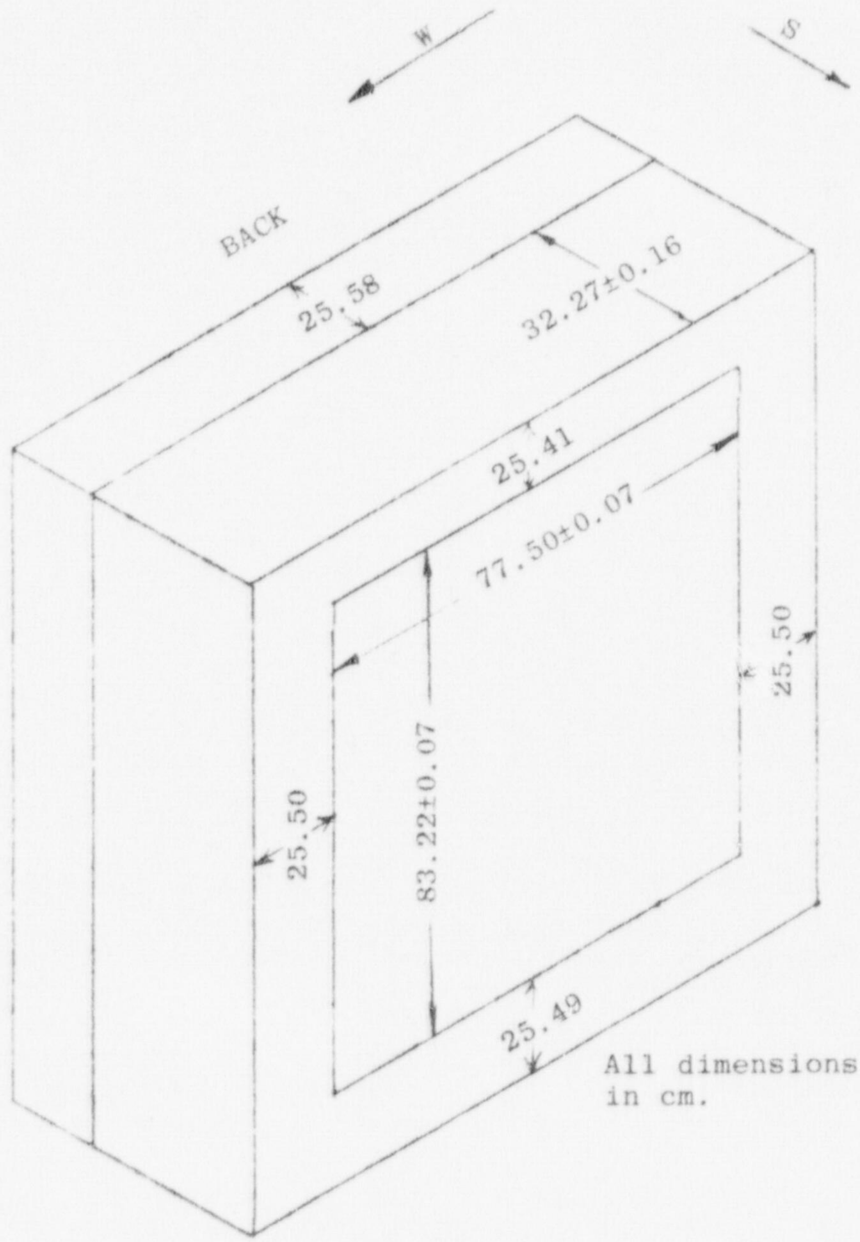


All dimensions in cm.

SOUTH REFLECTOR

PLASTIC

FIGURE 8

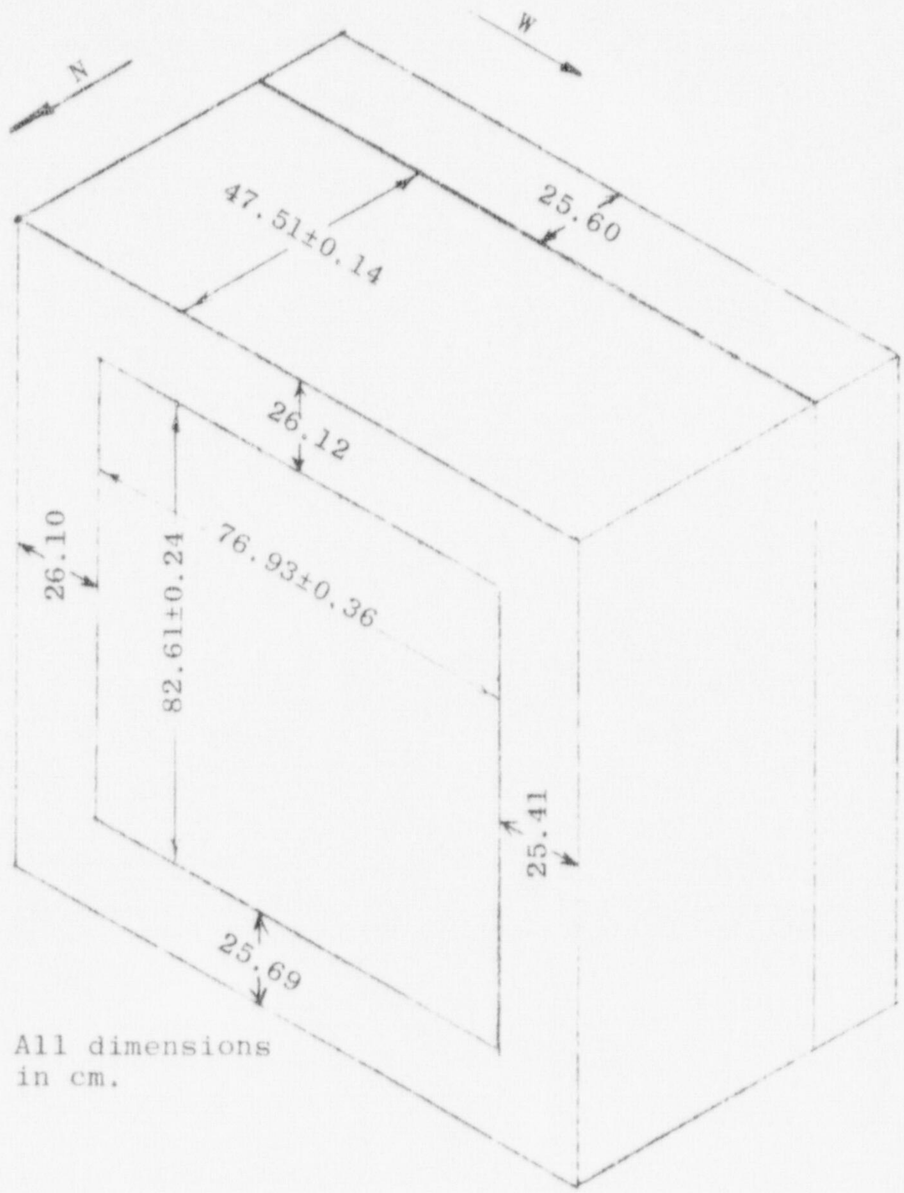


All dimensions in cm.

NORTH REFLECTOR

CONCRETE

FIGURE 9

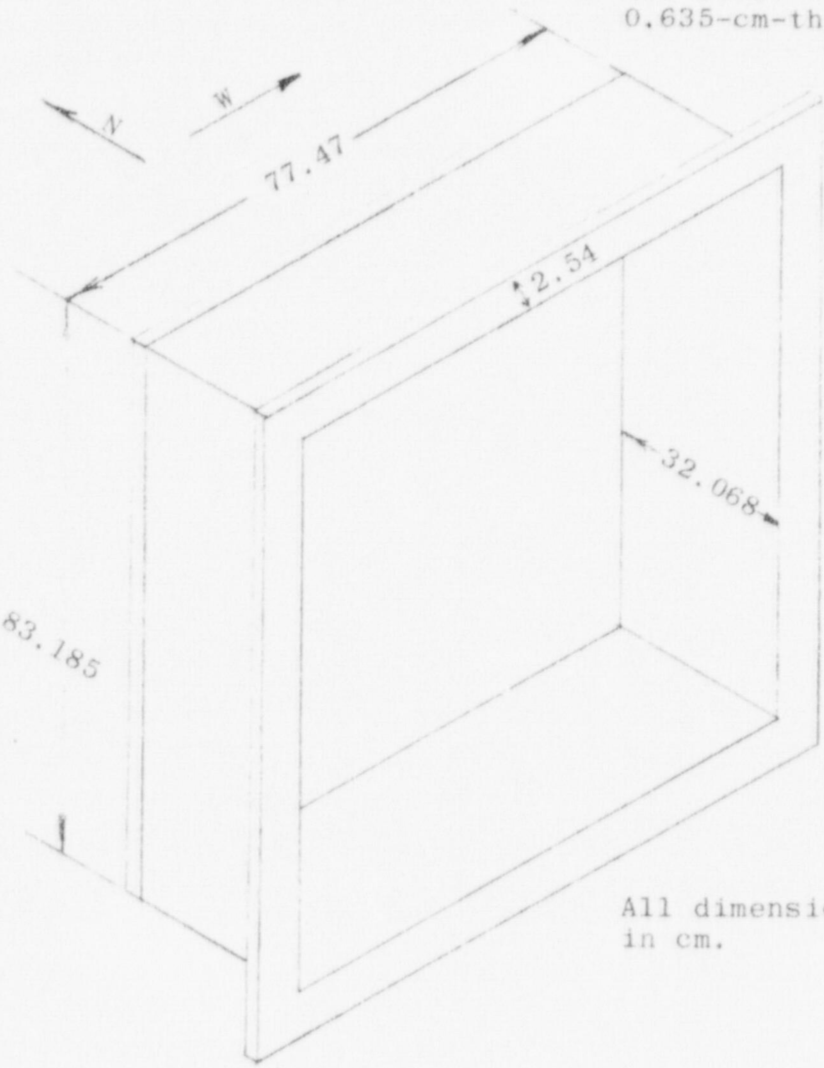


SOUTH REFLECTOR

CONCRETE

FIGURE 10

All steel
0.635-cm-thick

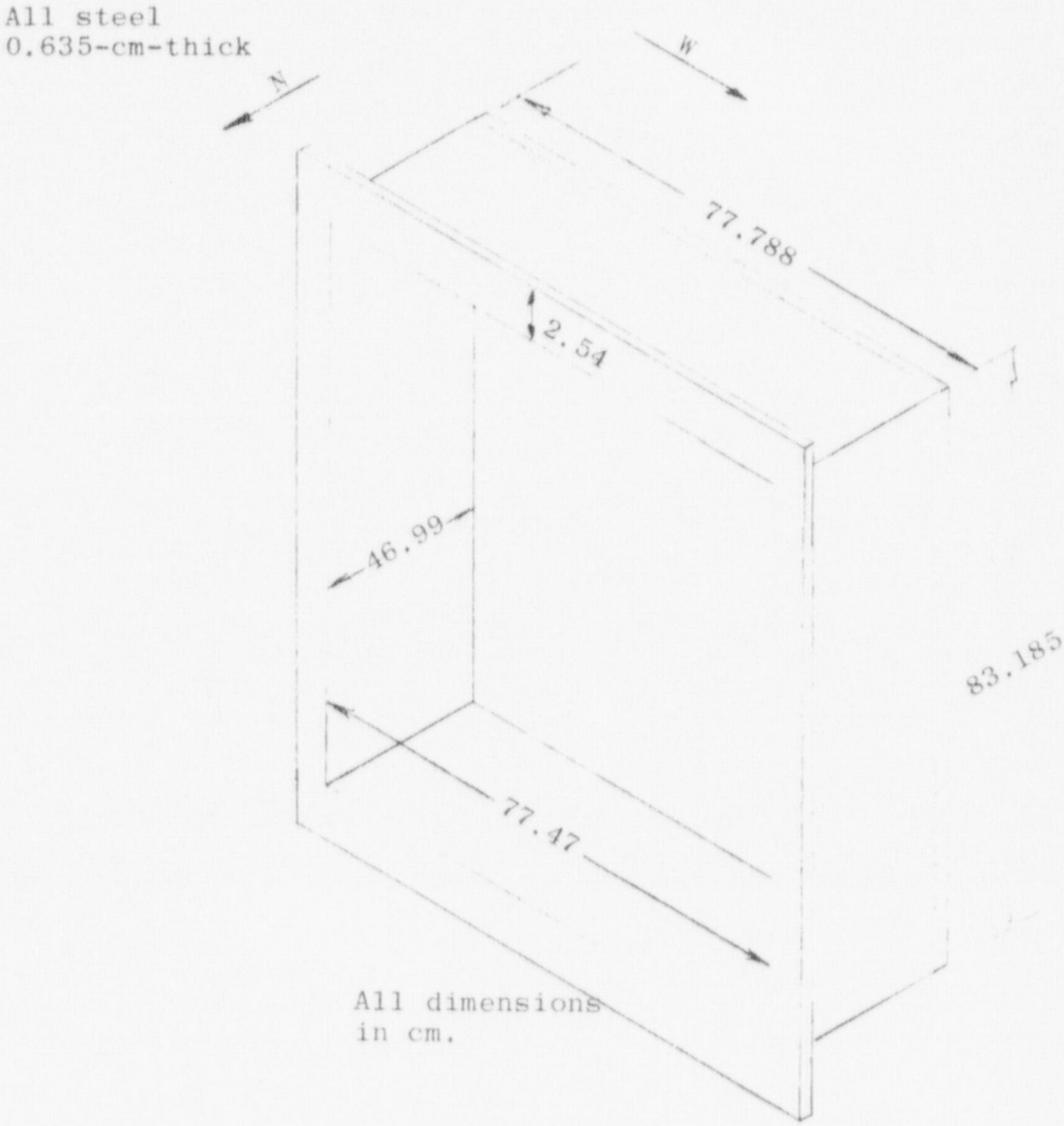


All dimensions
in cm.

NORTH REFLECTOR

STEEL

FIGURE 11



SOUTH REFLECTOR

STEEL

INTERSPERSED MODERATOR EXPERIMENTS

Material Preparation

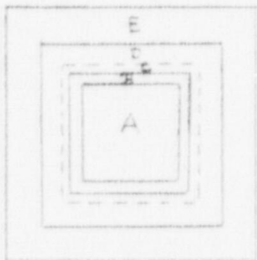
Thirteen additional experiments were added to the Reference Critical Experiments Program, at the request of the NRC, to determine the effect of various moderator and packaging materials (plastic, steel, and PVC) interspersed between the core units. For these experiments, all materials have been obtained and fabricated, and other preparations are nearly completed. In addition, the concrete to be used for these additional experiments has been poured.

Calculated Critical Thickness of PVC

A series of KENO-IV calculations was done to determine the reactivity of a plastic-reflected 4 x 4 x 4 array of oxide cans with plastic and PVC interspersed between the cans. These calculations were done to determine what thickness of PVC should be used in the experiments. The fuel units used in the calculations are shown in Figure 12. For one series of calculations, the PVC thickness plus a void remained constant at 0.95 cm. The PVC thickness was then varied to determine the thickness needed for a k_{eff} = 1.0.

The following data were used in the calculations:

FIGURE 12



Region A represents fuel; region B, aluminum can; region C, void; region D, PVC; and region E, plastic reflector.

1. Oxide Cans (Cubes)

   Inner Dimension = 7.4549 cm

   Outer Dimension = 7.62 cm

2. Fuel

   $U(4.5)_3O_8 + H_2O$

   H:U = 0.739

   $\rho(U_3O_8) = 4.688\ g/cm^3$

3. PVC

   $\rho = 1.65\ g/cm^3$

   38.44 wt-% : C

   4.84 wt-% : H

   56.72 wt-% : Cl

In all of these calculations, region A was a cube having 14.91 cm on a side; region B was 0.1651-cm-thick aluminum; region E was 1.27-cm-thick plastic; and region C plus region D was 0.9525 cm (see Figure 12). The thickness of region D (PVC) was varied to determine the critical thickness of PVC in this array. Results are given in Table IV.

To determine the effect of the 0.893 cm void of item 5 in the table, a calculation was done which removed the void but retained the PVC thickness of 0.0595 cm. Calculated k_{eff} of this system was 1.0744 ± 0.0065.

The smallest thickness of PVC that is commonly manufactured is 0.054 cm, and this was chosen for the experiment since previous KENO calculations have calculated k_{eff} values that are slightly higher than the experimental values.

TABLE IV

Calculated k_{eff} Values for
Plastic-Reflected Array of Uranium Oxide
With Six Different PVC Thicknesses

Calculation Number	PVC Thickness (cm)	Void Thickness (cm)	k_{eff}
1	0.0	0.9525	1.1784 ± 0.0074
2	0.3175	0.6350	0.7017 ± 0.0050
3	0.6350	0.3175	0.5332 ± 0.0045
4	0.9525	0.0	0.5672 ± 0.0045
5	0.0595	0.893	0.9569 ± 0.0068
6	0.0595	0.0	1.0744 ± 0.0065

ACKNOWLEDGMENTS

This work was performed for the U. S. Nuclear Regulatory Commission, FIN NO A1036, under U. S. Department of Energy Contract EY-76-C-04-3533.

The following personnel performed the work reported in this quarterly progress report:

B. B. Ernst
I. Oh
D. E. Payne
D. Pecora
R. E. Rothe
W. R. Sheets
G. Tuck

NRC FORM 335
(7-77)

U.S. NUCLEAR REGULATORY COMMISSION

BIBLIOGRAPHIC DATA SHEET

1. REPORT NUMBER (Assigned by DDC)
NUREG/CR-0297
RFP-2829

4. TITLE AND SUBTITLE (Add Volume No., if appropriate)
REFERENCE CRITICAL EXPERIMENTS - Progress Report for Period April 1, 1978, through June 30, 1978

2. (Leave blank)

3. RECIPIENT'S ACCESSION NO.

7. AUTHOR(S)
B. B. Ernst, I. Oh, G. Tuck

5. DATE REPORT COMPLETED
MONTH August YEAR 1978

9. PERFORMING ORGANIZATION NAME AND MAILING ADDRESS (Include Zip Code)
Rockwell International
Energy Systems Group
Rocky Flats Plant

DATE REPORT ISSUED
MONTH September YEAR 1978

6. (Leave blank)

8. (Leave blank)

12. SPONSORING ORGANIZATION NAME AND MAILING ADDRESS (Include Zip Code)
Systems Performance Branch
Division of Safeguards, Fuel Cycle & Environmental Research
Office of Nuclear Regulatory Research
Nuclear Regulatory Commission
Washington, D. C. 20555

10. PROJECT/TASK/WORK UNIT NO.

11. CONTRACT NO.
FIN # A-1036

13. TYPE OF REPORT
Progress

PERIOD COVERED (Inclusive dates)
4/1/78 - 6/30/78

15. SUPPLEMENTARY NOTES

14. (Leave blank)

16. ABSTRACT (200 words or less)

This is the eleventh in a series of quarterly reports describing reference critical experiments being performed at Rocky Flats for the U.S. Nuclear Regulatory Commission (NRC). This series of experiments is to provide accurate critical data on low-enriched uranium oxide (U_3O_8) systems with three different moisture contents and under several conditions of reflection. These data will provide check points against which computer accuracy may be determined.

The core currently being studied consists of ~ 1900 kg of low-enriched (4.5% U-235) uranium oxide with an H/U of ~ 0.75. The oxide alone is not critical; hence, a high enriched (93% U-235) uranium driver section near the core center is required.

This report provides details on nine critical experiments performed in the reporting period, for concrete, plastic, and minimally-reflected cores with three different drivers. It is also reported that all necessary materials have been acquired and fabricated for the current series of experiments.

17. KEY WORDS AND DOCUMENT ANALYSIS

17a. DESCRIPTORS

Nuclear Criticality
Critical Experiments
Nuclear Fuel

17b. IDENTIFIERS/OPEN-ENDED TERMS

18. AVAILABILITY STATEMENT
No restriction

19. SECURITY CLASS (This report)
Unclassified

21. NO. OF PAGES
29

20. SECURITY CLASS (This page)
Unclassified

22. PRICE
$

NRC FORM 335 (7-77)

UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D. C. 20555

OFFICIAL BUSINESS
PENALTY FOR PRIVATE USE, $300

POSTAGE AND FEES PAID
U.S. NUCLEAR REGULATORY
COMMISSION

U.S. MAIL

120555003927 1 ANRC
US NRC
SECY PUBLIC DOCUMENT ROOM
BRANCH CHIEF
HST LOBBY
WASHINGTON DC 20555