INTERIM REPORT

Accession No. ______________

ORNL/CSD/INF-79/8

Contact Program or Project Title:

Review of Critical Experiments Performed for Fuel Cycle Safety Guidance

Subject of this Document: Technical Progress

Authors: G. E. Whitesides and R. M. Westfall - Computer Sciences Div.

Date of Document: July 16, 1979

Responsible NRC Individual and NRC Office or Division

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Prepared for
U.S. Nuclear Regulatory Commission
Washington, D.C. 20555
Under Interagency Agreement DOE 40-550-75
NRC FIN. No. B-0409

UNION CARBIDE CORPORATION, NUCLEAR DIVISION
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for the
DEPARTMENT OF ENERGY

OAK RIDGE NATIONAL LABORATORY
OPERATED BY
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NUCLEAR DIVISION
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ORNL/CSD/INF-79/8

DATE: July 16, 1979

SUBJECT: Quarterly Progress Report on Review of Critical Experiments Performed for Fuel Cycle Safety Guidance

TO: U.S. Nuclear Regulatory Commission

FROM: G. E. Whitesides

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NRC Research and Technical Assistance Report

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PROGRAM FOR THE REVIEW OF CRITICAL EXPERIMENTS

PERFORMED FOR FUEL CYCLE SAFETY GUIDANCE

Quarterly Summary

April 1, 1979 to June 30, 1979

Personnel Time -- 838 man hours

(a) This quarter $37,520

(b) Fiscal year-to-date 60,311

(c) Projected to End of Fiscal Year 5,930

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QUARTERLY PROGRESS REPORT ON REVIEW OF CRITICAL EXPERIMENTS

PERFORMED FOR FUEL CYCLE SAFETY GUIDANCE

The objective of this task is to provide advice and guidance for the NRC-funded critical experiments programs being conducted at the Rocky Flats Nuclear Criticality Safety Facility and at the BPNL Critical Mass Laboratory. During this quarter the activity included performing an analytical review of experimental results from each program, providing assistance in the design of upcoming experiments, and gathering information to be used in a comprehensive evaluation of the long-term objectives of NRC critical experiments programs.

The analysis of seventy critical experiments performed to simulate nuclear fuel shipping-cask and storage-pool situations has been completed. The specifications for these experiments were taken from the reports: PNL-2438, NUREG/CR-0073, and NUREG/CR-0796. The study served as a check on the completeness of the experimental specifications as well as a validating procedure for the data libraries and the analytical methods developed for the SCALE system. The CSAS2 analytical sequence (BONAMI-S, NITAWL-S, KENO-IV/S) was employed in the study along with each of the three principal neutron cross section libraries available in SCALE.

The results of the study are given in Tables 1 and 2. Each of the two-hundred and ten analyses involved the calculation of approximately thirty-thousand neutron histories. Four major conclusions can be drawn from these results.

1. For the 2.35 wt.% enriched UO_2 rod lattices, the average of the calculated multiplication factors was 0.994 for the 27 group ENDF/B-IV library, 1.002 for the 123 group GAM-THERMOS library and 1.004 for the 16 group Hansen-Roach library.

2. For the 4.29 wt.% enriched UO_2 rod lattices, the average of the calculated multiplication factors was 0.988 for the 27 group ENDF/B-IV library, 0.989 for the 123 group GAM-THERMOS library, and 0.993 for the 16 group Hansen-Roach library.

3. Each of the six sets of thirty-five analyses is sufficiently large that a normal distribution of the results can be observed. Virtually all of the values lie within three standard deviations of the average values. Furthermore, a significant number of the results differ from the average values by more than two standard deviations.

4. Each of the three libraries is adequate for performing criticality safety analyses for systems similar to the ones studied. The analytical biases to be applied in the use of these libraries is a function of both fuel enrichment and neutron moderation level.

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TABLE 1. CSAS2 ANALYSES OF 2.35 WT.% ENRICHED UO_2 THREE-CLUSTER LATTICES

Exp. No.	Plate Material	Plate Thickness (cm)	Array Size	Plate-to-Center Cluster Gap (cm)	Critical Separation Between Clusters (cm)	Calculated Multiplication Factor: 27-Group NDFB4	Calculated Multiplication Factor: 123-Group GAMTH	Calculated Multiplication Factor: HANSEN-ROACH
15	--	--	20 x 17	--	11.92	0.992 ± 0.004	1.008 ± 0.004	0.995 ± 0.004
5	--	--	20 x 16	--	8.39	0.990 ± 0.004	1.005 ± 0.004	1.000 ± 0.004
27	SS304L	0.302	20 x 16	0.645	7.42	0.999 ± 0.004	0.997 ± 0.004	1.005 ± 0.004
26	SS304L	0.302	20 x 16	4.042	7.76	1.004 ± 0.004	0.999 ± 0.004	1.011 ± 0.004
28	SS304L	0.485	20 x 16	0.645	6.68	0.991 ± 0.004	1.002 ± 0.004	1.007 ± 0.004
29	SS304L	0.485	20 x 16	4.042	7.51	0.991 ± 0.004	0.994 ± 0.004	1.002 ± 0.004
24	6061 Al	0.625	20 x 16	0.645	8.67	0.996 ± 0.005	0.998 ± 0.004	1.009 ± 0.004
48	6061 Al	0.625	20 x 16	4.042	8.78	0.992 ± 0.004	0.997 ± 0.004	1.005 ± 0.004
46	Zircalloy-4	0.652	20 x 16	0.645	8.79	0.990 ± 0.004	0.996 ± 0.004	1.003 ± 0.004
47	Zircalloy-4	0.652	20 x 16	4.042	8.78	0.994 ± 0.004	0.998 ± 0.004	0.996 ± 0.005
31	Copper	0.646	20 x 16	0.645	6.62	0.987 ± 0.004	1.001 ± 0.005	1.008 ± 0.005
12	Copper	0.646	20 x 16	4.442	7.51	0.992 ± 0.004	1.000 ± 0.004	0.999 ± 0.004
43	Copper	0.337	20 x 15	0.645	6.88	0.995 ± 0.004	1.004 ± 0.004	1.016 ± 0.004
44	Copper	0.337	20 x 15	4.042	7.00	0.986 ± 0.004	1.007 ± 0.004	1.006 ± 0.004
41	Cu(0.989 Cd)	0.357	20 x 15	0.645	5.15	0.992 ± 0.004	1.014 ± 0.004	1.015 ± 0.004
36	Cd	0.061	20 x 17	0.645	6.74	0.991 ± 0.004	1.005 ± 0.004	1.009 ± 0.004
37	Cd	0.061	20 x 17	4.042	9.37	0.996 ± 0.004	1.006 ± 0.004	1.005 ± 0.004
50	Cd	0.0291	20 x 17	1.482	7.87	0.991 ± 0.004	0.998 ± 0.004	1.012 ± 0.004
54	Cd	0.061	20 x 17	1.482	7.60	0.987 ± 0.004	1.007 ± 0.004	1.001 ± 0.004
52	Cd	0.0901	20 x 17	1.482	7.54	0.989 ± 0.004	1.009 ± 0.004	1.005 ± 0.004
20	Boral	0.713	20 x 17	0.645	6.34	0.997 ± 0.004	1.010 ± 0.004	1.006 ± 0.004
16	Boral	0.713	20 x 17	4.442	9.03	0.986 ± 0.004	1.007 ± 0.005	1.008 ± 0.004
32	SS304L (1.058)	0.298	20 x 17	0.645	7.56	0.994 ± 0.004	1.004 ± 0.004	1.003 ± 0.004
33	SS304L (1.058)	0.298	20 x 17	4.042	9.62	0.996 ± 0.004	0.999 ± 0.004	1.011 ± 0.004
38	SS304L (1.628)	0.298	20 x 17	0.685	7.36	0.992 ± 0.004	1.000 ± 0.004	0.999 ± 0.004
39	SS304L (1.628)	0.298	20 x 17	4.042	9.52	0.994 ± 0.004	1.002 ± 0.004	1.014 ± 0.004
	Reflector Material	**Reflector Thickness (cm)**		**Reflector-to-Fuel Cell Edge Gap (cm)**				
1	U (0.19) Metal	7.65	19 x 16	0	11.83	0.998 ± 0.004	1.001 ± 0.004	1.001 ± 0.004
2	U (0.19) Metal	7.65	19 x 16	1.321	13.93	0.992 ± 0.004	1.011 ± 0.004	1.005 ± 0.004
3	U (0.19) Metal	7.65	19 x 16	1.956	14.11	1.004 ± 0.004	1.000 ± 0.003	1.002 ± 0.004
4	U (0.19) Metal	7.65	19 x 16	2.616	13.70	1.000 ± 0.004	0.999 ± 0.004	1.002 ± 0.004
5	U (0.19) Metal	7.65	19 x 16	5.405	10.69	0.990 ± 0.004	0.998 ± 0.004	0.997 ± 0.003
6	U (0.19) Metal	7.65	19 x 16	10.676	8.56	0.988 ± 0.004	0.999 ± 0.004	0.995 ± 0.005
9	Pb	10.2	19 x 16	0	13.84	0.999 ± 0.004	1.008 ± 0.004	1.008 ± 0.004
11	Pb	10.2	19 x 16	2.616	11.25	0.987 ± 0.004	1.006 ± 0.004	1.006 ± 0.004
12	--	--	19 x 16	--	8.31	0.990 ± 0.004	0.992 ± 0.004	0.992 ± 0.004

TABLE 2. CSAS2 ANALYSES OF 4.29 WT.% ENRICHED UO_2, THREE-CLUSTER LATTICES

Exp. No.	Plate Material	Plate Thickness (cm)	Array Size	Plate-to-Center Cluster Gap (cm)	Critical Separation Between Clusters (cm)	Calculated Multiplication Factor		
						27-Group NDF84	123-Group GMTH	HANSEN-ROACH
32	--	--	15 x 8	--	10.60	0.989 ± 0.005	0.984 ± 0.004	0.997 ± 0.004
14	SS304L	0.485	15 x 8	0.245	8.58	0.997 ± 0.004	0.989 ± 0.006	0.993 ± 0.005
13	SS304L	0.485	15 x 8	3.277	9.65	0.989 ± 0.005	0.991 ± 0.005	0.998 ± 0.005
8	SS304L	0.302	15 x 8	0.428	9.22	0.986 ± 0.005	0.993 ± 0.005	0.988 ± 0.005
7	SS304L	0.302	15 x 8	3.277	9.76	0.989 ± 0.005	0.991 ± 0.005	0.996 ± 0.005
10R	SS304L (1.05B)	0.298	15 x 8	0.432	6.10	0.982 ± 0.004	0.987 ± 0.004	1.001 ± 0.004
9	SS204L (1.05B)	0.298	15 x 8	3.277	8.08	0.991 ± 0.004	0.986 ± 0.004	0.988 ± 0.004
12	SS304L (1.62B)	0.298	15 x 8	0.432	5.76	0.982 ± 0.004	0.985 ± 0.004	0.987 ± 0.004
11	SS304L (1.62B)	0.298	15 x 8	3.277	7.90	0.988 ± 0.004	0.992 ± 0.005	0.996 ± 0.004
6	6061 Al	0.625	15 x 8	0.105	10.72	0.990 ± 0.005	0.983 ± 0.006	1.003 ± 0.004
5	6061 Al	0.625	15 x 8	3.277	10.77	0.985 ± 0.005	0.987 ± 0.005	0.997 ± 0.005
30	Zircalloy-4	0.652	15 x 8	0.78	10.92	0.987 ± 0.005	0.984 ± 0.005	0.990 ± 0.004
29	Zircalloy-4	0.652	15 x 8	3.277	10.86	0.986 ± 0.005	0.979 ± 0.005	0.991 ± 0.004
16	Copper	0.646	15 x 8	0.084	8.15	0.989 ± 0.005	0.990 ± 0.005	0.999 ± 0.004
15	Copper	0.646	15 x 8	3.277	9.42	0.987 ± 0.005	0.992 ± 0.005	0.994 ± 0.005
18	Copper	0.337	15 x 8	−0.057[a]	8.48	0.985 ± 0.005	0.991 ± 0.004	0.983 ± 0.004
17	Copper	0.337	15 x 8	4.241	9.62	0.979 ± 0.005	0.989 ± 0.004	0.988 ± 0.005
20	Cu (0.989 Cd)	0.357	15 x 8	−0.057[a]	6.66	0.987 ± 0.004	0.986 ± 0.005	0.992 ± 0.004
19	Cu (0.989 Cd)	0.357	15 x 8	4.241	8.35	0.990 ± 0.005	0.992 ± 0.004	0.989 ± 0.004
26	Cd	0.0291	15 x 8	0.7009	5.93	0.988 ± 0.004	0.987 ± 0.005	0.994 ± 0.005
25	Cd	0.0291	15 x 8	3.277	7.42	0.986 ± 0.004	0.994 ± 0.004	1.001 ± 0.004
28	Cd	0.0610	15 x 8	0.669	5.96	0.993 ± 0.004	0.993 ± 0.004	0.991 ± 0.004
27	Cd	0.0610	15 x 8	3.277	7.42	0.984 ± 0.004	0.985 ± 0.004	0.998 ± 0.004
22	Cd	0.0901	15 x 8	0.640	5.87	0.988 ± 0.005	0.986 ± 0.004	0.991 ± 0.004
21	Cd	0.0901	15 x 8	3.277	7.38	0.992 ± 0.005	0.995 ± 0.004	0.993 ± 0.004
24	Cd	0.2006	15 x 8	0.529	5.60	0.988 ± 0.004	0.990 ± 0.005	1.000 ± 0.005
23	Cd	0.2006	15 x 8	3.277	7.28	0.990 ± 0.005	0.992 ± 0.005	0.986 ± 0.004
31	BORAL	0.713	15 x 8	3.277	6.72	0.997 ± 0.005	0.996 ± 0.005	0.989 ± 0.005
	Reflector Material	Reflector Thickness (cm)		Reflector-to-Fuel Cell Edge Gap (cm)				
14	U (0.19) Metal	7.65	13 x 8	0.0	15.38	0.983 ± 0.004	1.013 ± 0.004	0.990 ± 0.004
16	U (0.19) Metal	7.65	13 x 8	3.912	18.05	0.990 ± 0.005	0.990 ± 0.004	1.003 ± 0.004
17	U (0.19) Metal	7.65	13 x 8	5.405	13.49	0.985 ± 0.004	0.990 ± 0.004	0.992 ± 0.004
19	Pb	10.2	13 x 8	0.0	20.62	0.993 ± 0.004	1.001 ± 0.004	0.996 ± 0.005
21	Pb	10.2	13 x 8	1.321	19.04	0.993 ± 0.005	0.989 ± 0.005	1.006 ± 0.004
22	Pb	10.2	13 x 8	5.405	10.30	0.979 ± 0.006	0.977 ± 0.005	0.995 ± 0.005
23	--	--	13 x 8	--	8.24	0.974 ± 0.005	0.978 ± 0.005	0.986 ± 0.004

[a] Gap lies within lattice cell boundary.

Another interesting effect was observed during the analysis of the systems with the depleted uranium shielding walls. It was found that the small amount of U-235 (0.19 wt.%) in the depleted uranium was worth approximately 2% Δk in the calculated multiplication factor. Thus the consideration of depleted uranium as being pure U-238 could lead to a substantial error in criticality safety analyses.

The analysis of the optimum-moderated, bulk-oxide experiment performed at Rocky Flats has been refined through the use of more rigorous cross-section processing methods and additional information on the water content of the fuel. The results reported in the most-recent progress report are repeated here as Table 3. Table 4 lists results obtained in subsequent analyses.

KENO-IV/CG Analysis[a] of the Optimum-Moderated Bulk-Oxide Experiment[b]

Table 3

TRIS in Plexiglas

Case No.	Moderator	Bulk of Reflector	North End	Cavity Plates	K-eff
1	No	No	No	No	1.031 ± 0.005
2	No	Yes	Yes	Yes	0.995 ± 0.005
3	No	Yes	No	Yes	1.003 ± 0.005
4[c]	No	Yes	No	No	1.019 ± 0.005

[a] 27 Group ENDF/B-IV cross sections were applied.

[b] Experiment 1A, Table II of "Reference Critical Experiments, Progress Report, July 1, 1978 - September 30, 1978," Rockwell International, NUREG/CR-0499.

[c] Best representation of actual situation.

Table 4*

Case No.	X-Sect CODE	enrichment	wt.% H_2O in "Dry Oxide"	K-eff
4	NITAWL	4.56	0	1.019 ± 0.005
5	ROLAIDS	4.56	0	0.989 ± 0.005
6	ROLAIDS	4.46	0.00111	0.990 ± 0.005
7	ROLAIDS	4.46	0.0027	0.998 ± 0.005

*Cases 4, 5, 6, and 7 all have the same geometric description.

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A major effect on the calculated multiplication factor is seen when ROLAIDS processed cross sections are substituted for those processed with the Nordheim integral method of NITAWL. A paper on the importance of cross section processing on the analysis of moist bulk-oxide critical experiments has been submitted for presentation at the upcoming winter meeting of the American Nuclear Society. The other major effect shown in Table 4 is due to the water content of the "dry oxide." Correspondence from Rocky Flats personnel describing the sources of information is attached as appendix A. The results obtained for case 7, which is based on the Rocky Flat thermogravimetric analysis of the "dry oxide" water content, are very satisfactory. These results have been used to establish a bias for those calculated with the CSAS2 analytical sequence (NITAWL-S,KENO-IV/S) in the SCALE system. The CSAS2 sequence is being used to perform rough calculations for all the configurations reported in RFP-2868.

Analyses were performed to assist in the design of the four-fuel-bundle and flux-trap experiments. It was found t t the application of the 4.29 wt.% UO_2 rods offers considerably more flexibility in the experimental design than could be obtained with the 2.39 wt.% rods. A study was performed to determine the degree of undermoderation of each fuel at its design lattice pitch. These results were compared to those for a Westinghouse PWR fuel-pin lattice. Each study is described in the correspondence to S. R. Bierman, PNL, attached as appendix B.

An effort was initiated to compile information on potential needs for criticality-safety data applicable to the support of future license applications. Informal interviews and discussions on this subject were conducted at the ANS-8 subcommittee on criticality safety standards meeting at Jacksonville, Florida, at the Nuclear Criticality Safety Short Course and Specialists Update at Taos, New Mexico, at the ANS annual meeting in Atlanta, Georgia, and on several occasions with visitors to Oak Ridge.

APPENDIX A

ROCKY FLATS PLANT
ENERGY SYSTEMS GROUP
P. O. Box 464
Golden, Colorado 80401
(303) 497-7000
Contractor to
U. S. Department of Energy

Rockwell
International

June 8, 1979

J. A. Bucholz
Oak Ridge National Laboratory
P. O. Box X
Oak Ridge, Tennessee 37830

Dear Jim:

I'm enclosing some data from RFP-2895, the topical in progress on the driven experiments at H/U $\sim$ 0.75. Slight changes in isotopic analysis and assay will result in small changes in the value of H/U, but the large differences seem to be entirely due to different assumptions about the initial moisture in the oxide.

I calculated the amount of water to add to the "dry" oxide for an H/U of 0.75 based on National Lead's value of 0.00111 weight-fraction water in the oxide. Using the formula from page 35 of RFP-2895, this calculation is

$$H/U = \frac{\{[(15129.1)(.00111) + 273.2](.111901) + 7.765\}(237.87/1.00797)}{(15129.1)(1 - .00111)(.8449)}$$

$= 0.743$

With .00111 replaced by 0.0, H/U = 0.708, and using .0027 gives H/U = 0.794.

I think that this difference in water content will have a noticeable effect on k_{eff}. Since there is a large uncertainty in the hydrogen weight per can from water (33.61 ± 3.28 g from page 33 of RFP-2895), it might be worthwhile to run several calculations to cover the range. Tom Oh did some calculations for the metal driver and oxide and found that k_{eff} changed very little with large changes in H/U (see page 37, RFP-2895).

Sincerely,

Deanne

Deanne Pecora

DP:clf
Enc.

POOR
ORIGINAL

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analyze the weight gain; and the weight gain was found to be attributed to an absorption of oxygen from the air by oxide powder, $UO_{\sim 2.3}$, which was not completely oxidized to U_3O_8. This conclusion was further checked by a repeat of one of the earlier experiments to measure the change in reactivity over a period of time. See the section on Discussion of Uncertainties.

Determination of H/U Value

To obtain an H/U atomic ratio for the damp oxide, the water and uranium in oxide plus the hydrogen from the plastic bag, vinyl tape, and mylar tape had to be determined.

[1] Hydrogen from Moisture Initially in Oxide

Five samples of dry, uncompacted oxide from each of the two shipments from the manufacturer were analyzed. The average moisture content of these ten samples measured by thermogravimetric analysis (TGA) was 0.0027 ± 0.0013 g H_2O per g sample. From the initial water content, the hydrogen weight per can was 4.57 ± 2.20 g.

[2] Hydrogen from Water Injected in Oxide

The injected water content of the oxide was measured two ways. The first method (TGA) was used to measure total (initial and injected) water content of one sample of damp oxide from each of 26 cans selected from the entire lot of cans. Fourteen cans were sampled by digging into one of the holes which had been used to inject water. The other twelve

APPENDIX B

UNION CARBIDE

UNION CARBIDE CORPORATION
NUCLEAR DIVISION
P.O. BOX X, OAK RIDGE, TENNESSEE 37830

April 20, 1979

Mr. S. R. Bierman
Battelle-Pacific Northwest Laboratories
209 E. Building, 200 E. Area
Post Office Box 999
Richland, Washington 99352

Dear Sid:

We have recently performed additional analyses to assist in the design of the four-fuel-bundle and flux-trap simulation experiments. These calculations were performed with the 4.29 wt. % enriched rods at a lattice pitch of 0.745 in.

The results are summarized in the attached table. These results indicate that the four-bundle configuration can be expected to go critical separated by either stainless steel or Boral plates. Also demonstrated in the feasibility of the three-fuel-bundle, two-flux-trap experiment.

The additional worth of the 4.29 wt. % fuel over the 2.35 wt. % fuel provides for more flexibility in the design of these experiments. Furthermore, the different behavior of the two sets of fuel with decreasing gap size seems to indicate that the 2.35 wt. % fuel is substantially more undermoderated at this H_2O/UO_2 volume ratio. Also, the substantially smaller flux trap worth for the 4.29 wt. % fuel (5% Δk versus 13% Δk for the 2.35 wt. % fuel) is consistent with a lower reactivity worth due to moderation in the gap. We will compare the neutron spectra for these lattices with that of a PWR bundle to ascertain the relevance of the experiments to shipping cask and fuel storage pool designs.

Do not hesitate to contact us to discuss any aspects of the analyses on which you may have questions.

Sincerely,

R.M. Westfall

R. M. Westfall
Computer Sciences Division

RMW/bbf

cc: D. E. Solberg (NRC)
J. R. Knight
G. E. Whitesides
File-NoRC

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Analyses[a] to Assist in the Design of the
Four-Bundle and Flux-Trap Experiments

Assumed: 800 rods of 4.29 wt % enriched UO_2 at a lattice pitch of 0.745 in., H_2O/UO_2 = 1.6.

0.091 in Boral plates and 0.19 in. SS-304L plates

Four-Bundle Analysis Results

Subarray Size	Gap Width	Absorber Plate	k-eff ± 1 σ
14 × 14	1.5 in.	SS-304	1.136 ± 0.004
11 × 11	1.5 in.	SS-304	1.062 ± 0.006
9 × 9	1.5 in.	SS-304	0.989 ± 0.006
11 × 11	1.0 in.	SS-304	1.096 ± 0.006
9 × 9	1.0 in.	SS-304	1.020 ± 0.006
14 × 14	1.5 in.	Boral	1.053 ± 0.005
13 × 13	1.5 in.	Boral	1.031 ± 0.005
12 × 12	1.5 in.	Boral	0.994 ± 0.005
13 × 13	1.0 in.	Boral	1.050 ± 0.005
11 × 11	1.0 in.	Boral	0.994 ± 0.005

Three Subarray Flux-Trap Results

Outer Bundles	Central Bundle	Flux Trap	Gap	k-eff ± 1 σ
17 × 16	16 × 16	Open	1.5 in.	1.036 ± 0.005
17 × 16	16 × 16	Closed	1.5 in.	1.080 ± 0.005

[a] Analyses performed with KENO-IV and XSDRNPM using using 16-group Hansen-Roach cross sections. Analyses performed by J. R. Knight.

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UNION CARBIDE

UNION CARBIDE CORPORATION
NUCLEAR DIVISION
P.O. BOX X, OAK RIDGE, TENNESSEE 37830

May 22, 1979

Mr. S. R. Bierman
Battelle-Pacific Northwest Laboratories
209-E Building, 200-E Area
Post Office Box 999
Richland, Washington 99352

Dear Sid:

In my letter of April 20, 1979 I observed a difference in the reactivity worth of water gaps between bundles of 2.35 wt.% and 4.29 wt.% enriched UO_2 rods. Since that time, J. R. Knight has performed a series of infinite lattice cell calculations to provide more information on the behavior of these fuels as a function of H_2O/UO_2 volume ratio. In addition to the two types of rods to be used in the critical experiments, he analyzed a Westinghouse PWR fuel pin for comparison purposes. The results of the analyses are given in the attached table.

The median fission energy (MFE) for the design H_2O/UO_2 ratio of 1.6 was determined from the analyses.

Fuel Type	Median Fission Energy
2.35 wt.% Enriched UO_2	0.049 eV
2.8 wt.% Enriched UO_2	0.054 eV
4.29 wt.% Enriched UO_2	0.072 eV

As a spectral index, the MFE is seen to indicate a harder spectrum for the systems with higher fuel enrichment. This trend is probably due to the increased thermal absorption of the additional ^{235}U in the fuel. The variation of the neutron absorptions in the water to the total cell values (given in the table) confirm this effect.

For the 4.29 wt.% enriched UO_2 fuel, an additional spectral hardening effect is due to the heavier shielding of the ^{238}U resonance absorption. Actually, the lower ^{238}U loading and the smaller Dancoff factor (0.173 vs 0.201 and 0.234 for the other two enrichments) would tend to give a larger resonance integral. However, these factors must be offset by the larger pin diameter with its attendant smaller escape probability. The resonance integral is substantially smaller than those for the other two systems. This would give rise to a larger resonance flux and an overall harder spectrum. However, this effect is probably secondary to the increased thermal absorption discussed above.

The variation of the infinite lattice multiplication factors with lattice pitch is shown in the attached plot. For all three systems, the decrease in k-eff (for $H_2O/UO_2 \simeq 1.6$) from the optimum value is on the order of a few percent (~0.4 to 1.9% $\Delta k/k$). Again the variation generally follows the enrichment — with the degree of undermoderation for the experimental fuels bracketing the quantity for the PWR fuel.

The implication that we draw from these results is that the enrichment-dependent differences that we saw in our earlier analyses are representative of what would be seen with PWR fuel. The two enrichments of the experimental fuel span the range of interest very nicely.

Sincerely,

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CSAS1 Infinite Lattice Cell Analyses[a]

Case No.	Pitch, cm	K_∞	H_2O/UO_2	I^{28}_{eff}(bn)	Dancoff	Abs(H_2O)/ Abs(Cell)
	2.35 Wt.% Enriched UO_2[b] (Experimental Fuel)					
1a	1.40	1.210	0.71	14.69	0.430	0.0301
1b[c]	1.684	1.323	1.30	17.07	0.201	0.0812
1c	1.797	1.328	2.00	17.57	0.151	0.1042
1d	1.799	1.328	2.01	17.57	0.150	0.1046
1e	2.032	1.304	2.92	18.19	0.086	0.1547
1f	2.54	1.179	5.29	18.73	0.028	0.2680
	4.29 Wt.% Enriched UO_2[d] (Experimental Fuel)					
2a	1.60	1.318	0.79	14.08	0.366	0.0201
2b[c]	1.892	1.447	1.60	15.82	0.173	0.0508
2c	2.176	1.475	2.52	16.53	0.088	0.0882
2d	2.178	1.475	2.52	16.53	0.087	0.0885
2e	2.54	1.443	3.88	16.93	0.039	0.1437
2f	3.0	1.351	5.91	17.13	0.015	0.2202
	2.80 Wt.% Enriched UO_2[e] (Westinghouse 17 × 17 Sequoia)					
3a	1.176	1.230	0.71	14.62	0.481	0.0232
3b[c]	1.430	1.375	1.68	17.39	0.234	0.0676
3c	1.572	1.390	2.31	18.14	0.161	0.0966
3d	1.690	1.383	2.88	18.56	0.120	0.1220
3e	2.120	1.289	5.29	19.31	0.043	0.2213

[a] 27 GROUPNDFB4 Cross Sections Through NITAWL and XSDRNPM.

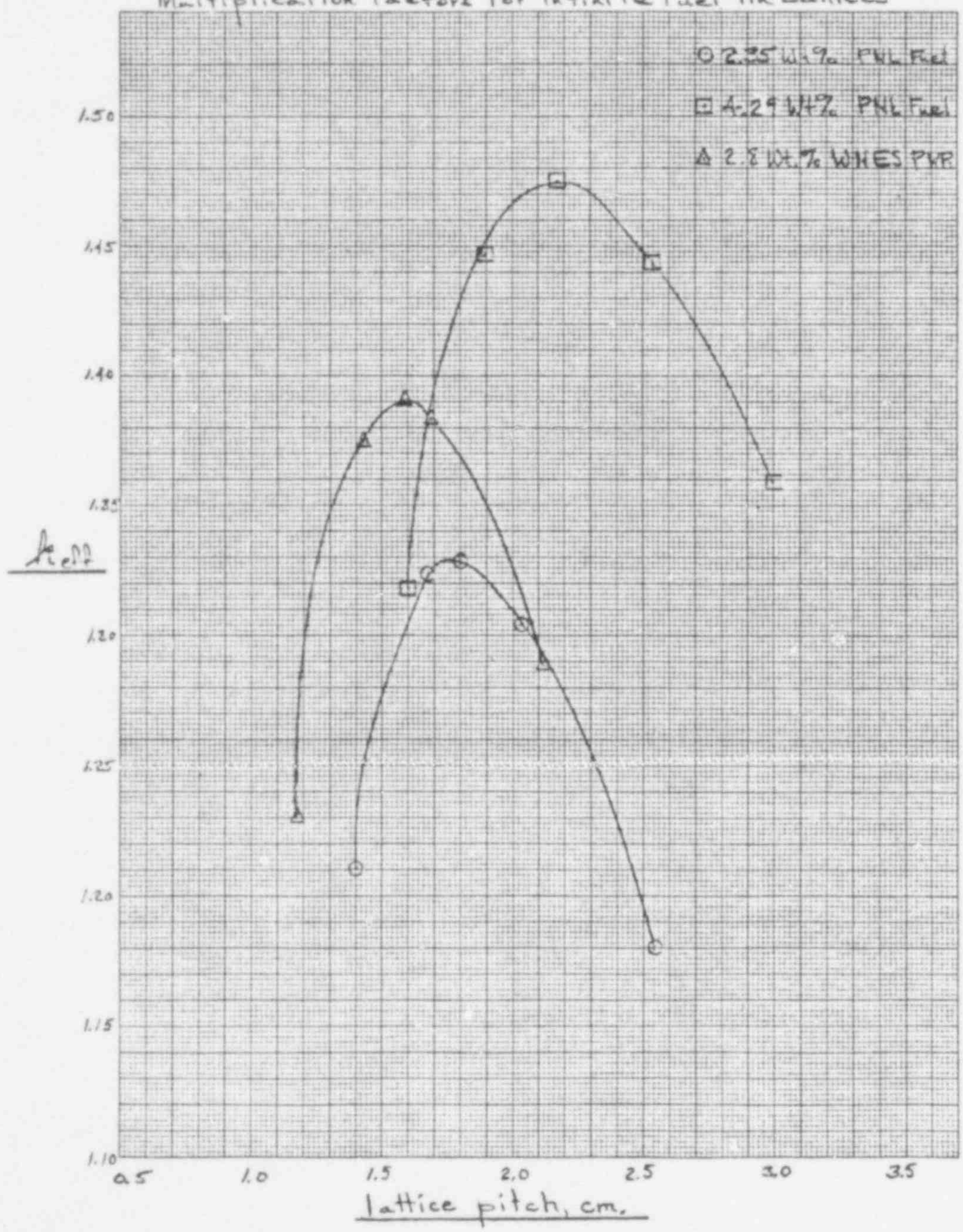
[b] Fuel OD = 1.176 cm, Clad OD = 1.27 cm.

[c] Nominal Design Configuration.

[d] Fuel OD = 1.2649 cm, Clad OD = 1.415 cm.

[e] Fuel OD = 0.9294 cm, Clad OD = 1.0719 cm.

Multiplication Factors For Infinite Fuel-Pin Lattices



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