PDR

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

April 20, 1979

50-261

Mr. Homer Lowenberg
Assistant Director for
Operating and Technology
Office of Nuclear Material Safety
and Safeguards
Nuclear Regulatory Commission
Washington, DC 20555

Dear Mr. Lowenberg:

The ORIGEN-S Code and the Shielding Analytical Sequence #2 (SAS2 Module) of the SCALE System were applied for computing quantities of heavy metal isotopes in the discharged fuel from the H. B. Robinson Reactor operated by the Carolina Power and Light Company. These results were compared with analytical measurements of the isotopes in the discharged fuel, cooled for 669 days. The fuel was dissolved and measured at ORNL in work for the LWR Fuel Reprocessing and Recycle Program.[1] The measurements were made from samples of three dissolver "runs." Only the fraction of rods which represent "fully irradiated" (31,364 MWD/MTU[2]) fuel were dissolved.[1] Two rods were used from Assembly B05. Mass analyses were determined in units of atom % of isotopes of an element for Run 2, only. Radioactivity concentrations/MTU were measured for several isotopes of all three dissolver runs.

Four tables are presented, showing the entire specifications of the computer case and the comparison between the calculated and experimental results. Table 1 contains the reactor cell pin description, the reactor history and other optional parameters of the SAS2 case. Table 2 is a list of nuclides for which cross sections were repeatedly computed for the six time-dependent libraries produced for ORIGEN-S. Table 3 compares results on an atom % bases. Table 4 compares the computed results converted to curies/metric ton uranium with measured activities of isotopes of the three runs.

Some of the main reasons for differences between the experimental and computed results for an isotope are:

(1) Input specifications not exact (i.e., burnup).

(2) ENDF/B-IV cross sections not applied for a particular isotope (or others in its chain).

(3) Less quality in the ENDF/B-IV data for the isotope.

(4) Deficiencies and approximations in the computer model (i.e., 1-D model, infinite lattice, 200 MeV/fission).

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(5) Measurements from different dissolvers indicate some experimental variance.

(6) Measurements of ^{241}Am activity was reported[1] to be subject to interference from ^{238}Pu and only a small part of ^{129}I dissolves into the solution.

(7) Omission of significant densities of fission products in the cell calculation because ENDF/B-IV data not available.

The printout from the case is being sent to you under separate cover. If you have any questions, please call O. W. Hermann (574-5256) or R. M. Westfall (574-5278). Important pages from Refs. 1, 2, and 3, giving design data and reported analyses, were copied and attached to this letter.

Sincerely,

O. W. Hermann

O. W. Hermann
Computer Sciences Division

OWH/bbf

cc w/enc: M. J. Bell (NRC)
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References

1. B. L. Vondra, *LWR Fuel Reprocessing and Recycle Program Quarterly Report for Period July 1 to September 30, 1976*, ORNL/TM-5660, 1976.

2. P. E. MacDonald, "Transmittal of CPL Assembly B05 Axial Flux Measurements," (ltr to A. P. Malinauskas, ORNL), Aerojet Nuclear Company, Idaho Falls, MacD-67-75, September 1975.

3. O. Ozer, "EPRI-CELL Test Calculations of Isotopes as a Function of Burnup," (ltr to W. B. Lowenstien and B. A. Zolotar), EPRI, April 1976.

Table 1. SAS2 Data for H. B. Robinson Fuel Case[3]

Total Burnup = 31,364 MWD/MTU
Fuel Loaded: 2.561 wt % ^{235}U, 0.023 wt % ^{234}U
Fuel Temperature = 1200°F
Zircalloy Clad Temperature = 612°F
Moderator Temperature = 572°F at 2250 psia
H_2O Vol. Frac. = 0.72832
UO_2 Vol. Frac. = 0.9073
Average Boron in H_2O = 450 wt. ppm (855 to 45, linear)
Rod Lattice = 15 x 15 (square)
Assembly Fuel Weight = 443.7 kg uranium
Number of Rods/Assembly = 204
Active Rod length = 365.76 cm
Rod Pitch = 1.43 cm
Fuel Pellet OD = 0.92939 cm
Rod Gap OD = 0.94844 cm
Clad OD = 1.07188 cm
Number of Cycles = 2
Number of ORIGEN-S Libraries per Cycle = 3
Cycle 1: 18.978 MW/Assmb., 487 burn-days, 64 down-days
Cycle 2: 14.981 MW/Assmb., 312 burn-days
Cooling Time of Discharge = 669 days
27 Neutron-Energy-Group Library
Nordhiem Integral Resonance Treatment
1-D S_n Transport Model in Computing Cross Sections
Order of Angular Quadrature = S_8
Cell Spatial Intervals = 40 (from factor SZF=0.7)
Thermal Wt Fact. (THERM): From 1/V Absorber

Table 2. Cross Sections Selected for ENDF/B-IV Update

^{234}U, ^{235}U, ^{236}U, ^{238}U

^{238}Pu ^{239}Pu ^{240}Pu ^{241}Pu ^{242}Pu

^{241}Am, ^{243}Am

^{244}Cm, ^{237}Np, ^{133}Cs, ^{135}Xe

Table 3. Comparison of Mass Analyses and ORIGEN-S Results

H. B. Robinson Reactor Fuel, Discharged May 6, '74. From Dissolver Run 2 (Assumed from "Full Burnup" Region) 31,364 MWD/MTU, Cooled 669 days (3/16/76)

Isotope	Atom % Found[1]	Atom % ORIGEN-S	Data From ENDF/B-IV
^{234}U	0.014	0.014	yes
^{235}U	0.653	0.585*	yes
^{236}U	0.347	0.347	yes
^{237}U	ND	4.2×10^{-9}	no
^{238}U	98.99	99.05	yes
^{238}Pu	1.56	1.62	yes
^{239}Pu	55.79	56.51	yes
^{240}Pu	24.91	22.91	yes
^{241}Pu	12.29	13.36	yes
^{242}Pu	5.45	5.60	yes
^{241}Am	62.4	55.8*	yes
^{242}Am	0.312	0.41	no
^{243}Am	37.29	43.8	yes
^{242}Cm	3.28	2.42	no
^{243}Cm	1.21	0.31*	no
^{244}Cm	90.66	92.51	yes
^{245}Cm	4.43	4.15	no
^{246}Cm	0.453	0.56	no
^{247}Cm	0.004	0.009	no
^{248}Cm	0.001	0.0008	no

Table 4. Comparison of Observed and ORIGEN-S Activities

H. B. Robinson Reactor Fuel, Discharged May 6, 1974,
Dissolver Runs of Fuel from "Full Burn-up" Region
31, 364 MWD/MTU, Cooled 669 days (March 6, 1976)

	Curies/MTU Computed and Measured			
Isotope	ORIGEN-S	Run 2	Run 4	Run 5
^{238}Pu	2.83×10^{3}	2.41×10^{3}	2.80×10^{3}	2.84×10^{3}
$^{239}Pu + {}^{240}Pu$	8.89×10^{2}	8.00×10^{2}	9.73×10^{2}	8.49×10^{2}
^{241}Am	5.52×10^{2}	3.41×10^{2}	1.54×10^{2}	3.04×10^{2}
^{244}Cm	2.88×10^{3}	1.97×10^{3}	2.09×10^{3}	2.22×10^{3}
^{242}Cm	3.07×10^{3}	2.67×10^{3}	2.38×10^{3}	2.49×10^{3}
^{106}Ru	1.76×10^{5}	5.57×10^{4}	8.22×10^{4}	8.14×10^{4}
^{134}Cs	9.53×10^{4}	6.58×10^{4}	6.9×10^{4}	7.17×10^{4}
^{137}Cs	1.05×10^{5}	8.52×10^{4}	9.05×10^{4}	9.48×10^{4}
^{144}Ce	2.34×10^{5}	1.75×10^{5}	1.83×10^{5}	1.86×10^{5}
^{125}Sb	6.89×10^{3}	$\leq 3.46 \times 10^{3}$	$\leq 5.02 \times 10^{3}$	$\leq 3.16 \times 10^{3}$
^{154}Eu	1.32×10^{4}	$\leq 3.62 \times 10^{3}$	NA	4.04×10^{3}
^{90}Sr	7.08×10^{4}	5.31×10^{4}	NA	6.81×10^{4}
^{95}Zr	1.33×10^{3}	$\leq 2.05 \times 10^{3}$	NA	NA
^{3}H	5.28×10^{2}	2.57×10^{2}	3.08×10^{2}	NA
^{129}I	3.49×10^{-2}	2.34×10^{-4}	5.22×10^{-5}	4.98×10^{-5}

Ref 1.

Table 9. Mass analysis of actinides from run 2[a]

H. B. Robinson Fuel
Burnup: 31,364 MWd/MTU
Reactor shutdown: May 6, 1974
Separation: March 16, 1976

Actinide	Found	ORIGEN	Actinide	Found	ORIGEN
^{234}U	0.014	0.013	^{241}Am	62.4	65.95
^{235}U	0.653	0.615	^{242}Am	0.312	0.0002
^{236}U	0.347	0.352	^{243}Am	37.29	34.02
^{237}U	[b]	3E-9			
^{238}U	98.99	99.02	^{242}Cm	3.28	1.00
			^{243}Cm	1.21	0.14
^{238}Pu	1.56	1.32	^{244}Cm	90.66	97.57
^{239}Pu	55.79	56.72	^{245}Cm	4.43	1.14
^{240}Pu	24.91	23.87	^{246}Cm	0.453	0.152
^{241}Pu	12.29	12.73	^{247}Cm	0.004	0.002
^{242}Pu	5.45	5.36	^{248}Cm	0.001	0.0002

[a]Atom % of each as of March 16, 1976.

[b]Not detected.

Table 6. Calculated and observed radioisotope concentrations in dissolver solutions (March 16, 1976)

Isotope	Conc. calculated by ORIGEN code		Experimentally determined conc. (Ci/MTU)		
	dis sec^{-1} ml^{-1}[a]	Ci/MTU	Run 2	Run 4	Run 5
^{238}Pu	2.6×10^{7}	2.11×10^{3}	2.41×10^{3}	2.80×10^{3}	2.84×10^{3}
$^{239,240}Pu$	1.04×10^{7}	8.42×10^{2}	8.00×10^{2}	9.73×10^{2}	8.49×10^{2}
^{241}Am	6.99×10^{6}	5.67×10^{2}	3.41×10^{2}	1.54×10^{2}	3.04×10^{2}
^{244}Cm	5.85×10^{7}	4.74×10^{3}	1.97×10^{3}	2.09×10^{3}	2.22×10^{3}
^{242}Cm	1.98×10^{7}	1.60×10^{3}	2.67×10^{3}	2.38×10^{3}	2.49×10^{3}
^{106}Ru	1.90×10^{9}	1.54×10^{5}	5.57×10^{4}	8.22×10^{4}	8.14×10^{4}
^{134}Cs	1.40×10^{9}	1.14×10^{5}	6.58×10^{4}	6.9×10^{4}	7.17×10^{4}
^{137}Cs	1.23×10^{9}	9.99×10^{4}	8.52×10^{4}	9.05×10^{4}	9.48×10^{4}
^{144}Ce	2.33×10^{9}	1.89×10^{5}	1.75×10^{5}	1.83×10^{5}	1.86×10^{5}
^{125}Sb	8.04×10^{7}	6.52×10^{3}	$\leq 3.46 \times 10^{3}$	$\leq 5.02 \times 10^{3}$	$\leq 3.16 \times 10^{3}$
^{154}Eu	1.70×10^{8}	1.38×10^{4}	$\leq 3.62 \times 10^{3}$	N.A.	4.04×10^{3}
^{90}Sr	8.10×10^{8}	6.57×10^{4}	5.31×10^{4}	N.A.	6.81×10^{4}
^{95}Zr	7.91×10^{6}	6.41×10^{2}	$\leq 2.05 \times 10^{3}$	N.A.	N.A.
^{3}H	5.36×10^{6}	4.35×10^{2}	2.57×10^{2}	3.08×10^{2}	N.A.
^{14}C[b]	6.59×10^{3}	5.34×10^{-1}	N.A.	N.A.	N.A.
^{129}I	4.03×10^{2}	3.27×10^{-2}	2.34×10^{-4}	5.22×10^{-5}	4.98×10^{-5}

[a] Based on 1.4 M $UO_2(NO_3)_2$ = 333 g of uranium per liter.

[b] Assuming that the UO_2 has a nitrogen content of 20 ppm.

N.A. = not available.

Ref 2.

TABLE 1

ASSEMBLY B05[(d)] POWER HISTORY

CYCLE I

DATE	Power (kW/ft)			Burnup
	Average	Peak	EFPD*	MWD/MTU
Oct. 1971	6.984	9.526	95.574	3738.414
Nov. 1971	6.968	9.659	119.979	4690.838
Dec. 1971	7.103	9.952	149.677	5872.262
Jan. 1972	7.241	9.564	177.194	6988.207
Feb. 1972	7.294	9.487	205.307	8136.586
March 1972	6.975	8.703	235.551	9318.067
April 1972	6.984	8.912	265.175	10476.822
May 1972	6.850	8.711	270.689	10688.366
June 1972	6.850	8.711	289.456	11408.360
July 1972	6.907	8.626	312.617	12304.323
Aug. 1972	6.580	8.267	341.243	13359.268
Sep. 1972	6.491	7.817	369.039	14369.771
Oct. 1972	6.544	8.384	398.627	15454.203
Nov. 1972	6.329	8.330	423.646	16341.049
Dec. 1972	6.230	8.228	443.9	17047.761
Jan. 1973	6.514	8.189	460.4	17649.731
Feb. 1973	6.659	8.503	475.7	18220.347
March 1973	6.111	8.036	487.167	18612.816

* Effective Full Power Days

Ref 2.

TABLE (continued)

CYCLE II

Date	Power (kW/ft)			Burnup
	Average	Peak	EFPD	MWD/MTU
May 1973	5.412	6.976	6.477	18809.141
June 1973	5.136	6.565	25.432	19354.386
July 1973	5.576	7.332	58.801	20396.486
Aug. 1973	5.619	7.447	87.589	21302.456
Sep. 1973	5.448	7.052	116.562	22186.500
Oct. 1973	5.263	6.922	145.215	23031.092
Nov. 1973	5.322	6.678	166.160	23655.400
Dec. 1973	5.356	6.774	192.626	24449.312
Jan. 1974	5.384	6.783	221.157	25309.643
Feb. 1974	5.365	6.736	247.853	26111.799
March 1974	5.349	6.681	278.105	27018.065
April 1974	5.349	6.68	307.254	27891.366
May 1974	5.336	6.453	311.759 (312)	28026.
		TOTAL	799 EFPD	

Total Burnup (average) - 28026 MWD/MTU

Total Burnup (peak 3 ft)* - 31363.9 MWD/MTU

Removed May 6, 1974 13 months cooling time

* 3 to 6 ft from bottom

Cool Time

F. May 6, 1974

B. March 15, 1973

31
15
30
6
61 shutdown days (730 d)

Cool Time = 730 - 61 = 669 days

DESIGN DATA

Ref 3.

I.	Fuel Assembly	
	Array	15x15
	Pitch, inches	8.466
	Weight, KgU	443.7
II.	Control Rod Guide Tube	
	Number/Assembly	8
	Material	Zr-4
	OD, inch	.546
	ID, inch	.512
III.	Instrumentation Tube	
	Number/Assembly	1
	Material	Zr-4
	OD, inch	.546
	ID, inch	.512
IV.	Burnable Poison Rod	
	Number/Assembly	12
	B_2O_3, W/O	12.5
	Dimensions	See attached figure
V.	Fuel Rod	
	Number/Assembly	204
	Active Length, inches	144
	Rod OD, inches	.422
	Rod ID, inches	.3734
	Rod Pitch, inches	.563
	Clad Material	Zr-4
	Clad Thickness, inches	.0243
VI.	Fuel Pellet	
	Enrichment, W/O U235	2.561
	Pellet OD, inches	.3659
	Dish Volume, %	1.18
VII.	Spacer Grids	
	Number in Active Fuel Region	6
	Material	Inconel
	Volume/Grid, $inch^3$	5.61
VIII.	Operating Characteristics	
	Assembly Average Power, ~~MWT~~ MW	14.01 — ~~[illegible]~~
	Core Average Power Density, Kw/ℓ	82.5
	Moderator Average Temperature, °F	572
	Operating Pressure, psia	2250

572, 2250 > VF = .72832

450 PPM Boron VF_B = .00129

Boron in [illegible]

[illegible]

[illegible]

Full [illegible]

1200°F at 2250 psia
= 648.9°C = 921.9°K
≐ 922 °K

[illegible] 39.251 MW

3 cycles [illegible] 17.417 MW/ASSM

Put in Xe-135 + Cs-133 - [illegible]

Clad Temp = Mod Temp + 40°F (22°K) assume.

Ref 3.

The average fuel temperature was assumed to be 1200°F, and a constant boron concentration of 450 ppm was assumed to be present in the moderator for the base calculation. A factor of 0.99, recommended by NAI, has been used to reduce the 3rd broad group CINDER cross sections of ^{240}Pu (P240).

The isotopic concentrations were calculated for 19 steps out to a burnup of 32000 MWD/Tonne. A critical buckling search was carried out at each step. In addition to the base run, the sensitivity of the calculations to a more accurate representation of the boron letdown curve, and to reduced capture rates in ^{240}Pu has been determined by running two additional cases. In one of the cases the capture width of the 1.056 ev ^{240}Pu resonance, which accounts for a majority of captures in this isotope, has been reduced from .033 eV to .032 eV. In the second case the boron concentration in the moderator has been assumed to decrease linearly with increasing burnup, from a value of 900 ppm at the beginning of cycle 1 down to zero at the end of that cycle. For the second cycle the boron concentration was left at 450 ppm as previously.

Results

The complete results for the base calculation and the two sensitivity runs are given in appendix B.

Table 1 gives a comparison of the EPRI-CELL results with measurements and results obtained by CP&L, VEPCO, TVA and Southern Services. The error associated with the experimental values corresponds to the calculated variation in isotopic ratios due to a 5.1% uncertainty in the burnup. The calculations contributed by the utilty groups were done using the codes NULIF (CP&L, VEPCO-I, TVA) and LEOPARD (VEPCO-III and Southern Services). The VEPCO-II results correspond to PDQ7 calculations for a Surry plant assembly with very similar specifications and burnup history to the Robinson assembly used in this test.

The EPRI-CELL calculations in general agree well with the other results and are within the experimental uncertainty due to burnup. The major exception to this agreement is a 15% discrepancy in the EPRI-CELL calculated ^{241}Pu densities.

The sensitivity of the calculation to a reduction of the ^{240}Pu capture cross section and the use of a partial "sawtooth" representation for the boron letdown curve is shown on table II as percent deviations from the base calculation.

Nuclear Power Experience

Table 1 Robinson 2 Plant Description

Owner/Operator: Carolina Power & Light Co.

Address: P.O. Box 790
Hartsville, So. Carolina 29550

R Est. Cost (millions): $80 + 24 for initial fuel

Type: Pressurized light water moderated and cooled

NSSS Supplier: Westinghouse
Arch. Engr: Ebasco

Generator Supplier: Westinghouse
Constructor: Ebasco

Design Output: Initial: 2094 MWt, 700 MWe (gross), 663 MWe (net)
Ultimate: 2300 MWt, 769 MWe (gross), 730 MWe (net)

Fuel: UO_2 pellets; 0.422 in. OD Zircaloy clad; 32,028 rods; 157 Fuel assemblies; 1.85, 2.56 and 3.1 wt % enriched (initial), 2 regions (initial) were pressurized, 144 in. active height

Control: 41 rod cluster control assemblies, 20 rods/cluster, 5% Cd - 15% In - 80% Ag, 304 SS clad, magnetic latch CRDMs

Also has boron chemical shim control

Reactor Vessel: 155.5 in. ID SA - 302 Grade B, internally clad with austenitic SS

Thermal & Hydraulic: 3 loops, 2250 psia nominal pressure, 100.6 x 10^6 lb/hr total flow, 546.5°F and 600.6°F reactor inlet and outlet, 5.3 kW/ft av thermal output

Containment: steel lined, reinforced concrete cylinder with vertical pre-stressing; reinforced concrete domed roof. Type 3a.

Turbine: Tandem-compound, 1 double flow HP element, 2 double flow LP elements, 1800 rpm

Generator: 1800 rpm, 3 phase, 60 cycle, hydrogen inner cooled.