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ANALYTICAL SUPPORT FOR THE ORR WHOLE-CORE LEU U_3SI_2-AL FUEL DEMONSTRATION

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ABSTRACT

Analytical methods used to analyze neutronic data from the whole-core LEU fuel demonstration in the Oak Ridge Research Reactor are briefly discussed. Calculated eigenvalues corresponding to measured critical control rod positions are presented for each core used in the gradual transition from an all HEU to an all LEU configuration. Some calculated and measured results, including β_{eff}/ℓ_p, are compared for HEU and LEU fresh fuel criticals. Finally, the perturbing influences of the six voided beam tubes on certain core parameters are examined. For reasons yet to be determined, differential shim rod worths are not well-calculated in partially burned cores.

INTRODUCTION

This paper deals with analytical methods and some computational results which support the Whole Core LEU Silicide Fuel Demonstration in the Oak Ridge Research Reactor (ORR). As was discussed in the previous paper,[1] this demonstration began with an all HEU equilibrium core (core 174C) which was followed by a sequence of HEU/LEU mixed cores in a gradual transition toward an all LEU U_3Si_2-Al equilibrium core. Except for two HEU shim rod followers, the 30-MW ORR reactor is currently operating with an all LEU core. During this transition phase a wealth of experimental data was obtained by the ORR staff against which computational codes and methods may be benchmarked. Some of these computational/experimental comparisons will be reported here. However, comparisons between measured and calculated cobalt wire activations will be given in the next paper.[2]

CODES AND METHODS

Figure 1 shows a map of a typical HEU/LEU transition core. The HEU and LEU 19-plate fuel elements are of identical geometry as are the 15-plate shim rod (SR) fuel followers. Fresh 19 and 15-plate elements contain 340 g and 200 g ^{235}U, respectively, for the U_3Si_2-Al dispersion fuel and 285 g and 167 g, respectively, for the U_3O_8-Al HEU case. Magnetic fusion experiments

(MFE) are located in grid positions C3 and C7 and the HFED (High uranium density Fuel Element Development) miniplate irradiation facility is in E3. Radioisotopes of europium and irridium were produced in the locations shown in Fig. 1. The pressure vesel simulator and gamma shield are part of the HSST (Heavy Section Steel Technology) experiment which is normally in a retracted position at core startup until equilibrium xenon concentrations have been achieved. The EPRI-CELL code[3] was used to generate 5-group cross sections for each region in the reactor. For computational purposes, each fuel element was represented by a fuel (meat-clad-moderator) region and a side plate (H_2O/Al) region. Burnup-dependent cross sections were calculated for both HEU and LEU fuel using EPRI-CELL. In most cases these 5-group cross sections are based on ENDF/B Version IV data.

The burnup behavior of each fuel element in each reactor cycle was analyzed using the REBUS-3 fuel cycle analyses code.[4] Each of the HEU-to-LEU transition cores was analyzed by the REBUS-3 code as a non-equilibrium problem. This code allows for the use of burnup-dependent cross sections and for control rod movement during the burn cycle. In most of these calculations the burn cycle length, determined from the total MWh's of reactor operation, was divided into three equal sub intervals. Critical control rod positions at the boundaries of each of these sub intervals were determined from the recorded control rod position history and input into the REBUS problem. At each of these boundaries, or time nodes, the code determines burnup-dependent atom densities in six axial regions of equal height for each fuel element, the eigenvalue, fuel element powers, and neutron fluxes. These calculations are based on diffusion theory for which the three-dimensional DIF3D code[5] is used. The buildup of neutron-induced ^{6}Li and ^{3}He poisons in the beryllium reflector, which begins with the fast neutron threshold reaction $^{9}Be(n,\alpha)^{6}He$, are also taken into account in the REBUS-3 calculations. From numerous REBUS calculations a library of axially-dependent atom densities for partially burned fuel elements and fuel element followers has been obtained for use in subsequent calculations. These atom densities are appropriately adjusted for the shutdown decay of ^{135}I, ^{135}Xe and ^{149}Pm in the fuel elements and for the decay of ^{3}H into ^{3}He in the beryllium reflector.

The poison section of each shim rod consists of square water-filled cadmium annulus 0.040" thick, 2.30" on a side and 30.5" long. It was shown in Ref. 6 that these cadmium control elements may be represented in a diffusion calculation by using blackness-modified diffusion parameters in which the cadmium is black to group 5 neutrons (E_n <0.625 eV). In the normal operation of the ORR, shim rods F4 and F6 are fully withdrawn while the other four (B4, B6, D4, and D6) are banked together at a position to achieve criticality.

There are six evacuated beam tubes (6-7/8" ID) which leave the east side of the aluminum core box at various angles. The perturbing effect of these beam tubes on power and flux distributions within the core was investigated, in a preliminary way, using the two-dimensional transport code, TWODANT[7]. Just recently, three-dimensional continuous-energy VIM[8] Monte Carlo calculations[9] have been performed to study the effect of the beam tubes on certain core parameters. Some results of these calculations will be presented at the end of this report.

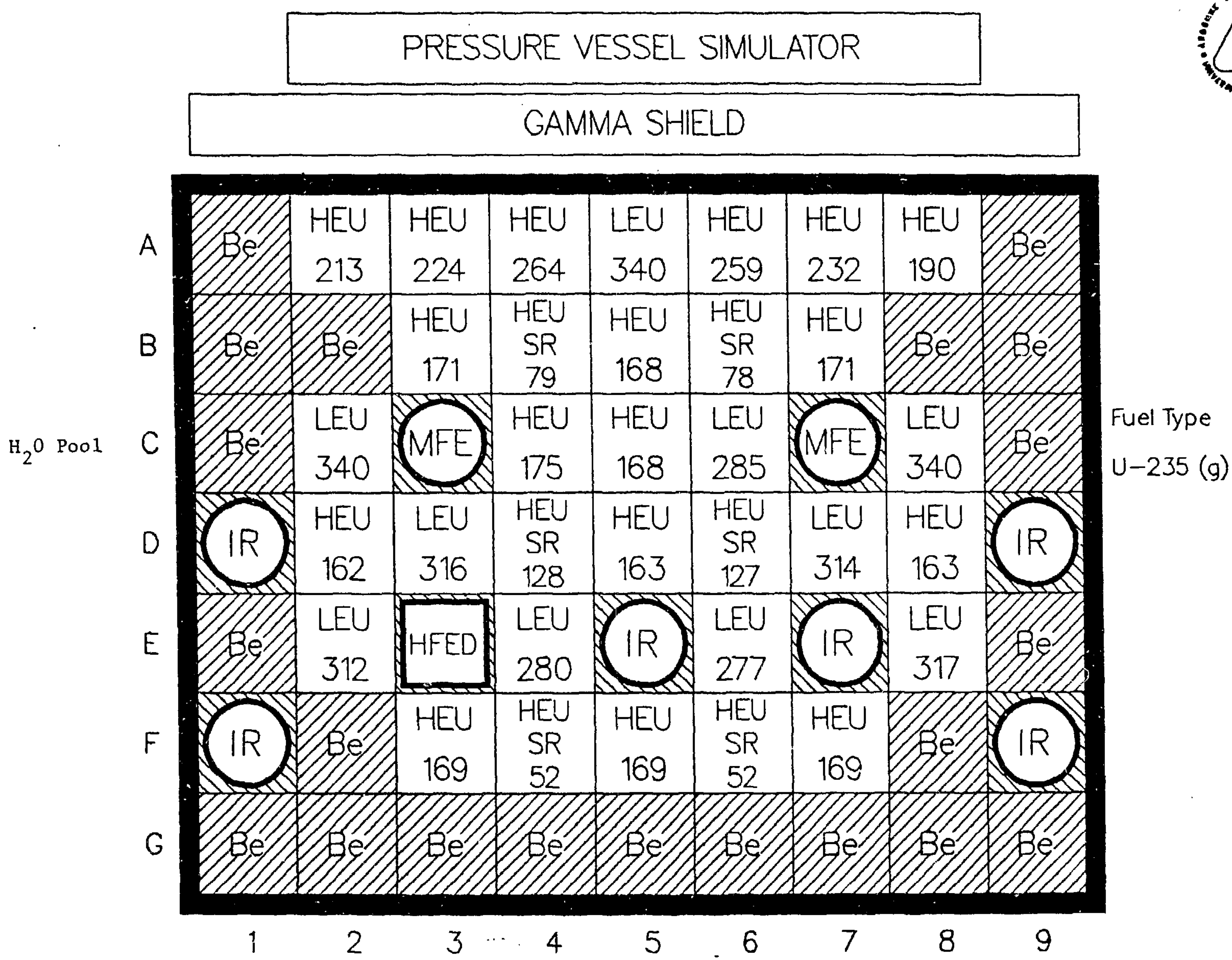

Fig. 1. ORR Cycle 175C

Calculated kinetic parameters for several ORR cores are based on ENDF/B Version V data. Beginning with REBUS-3 atom densities and flux distributions, the VARI3D code[10] was used to obtain β_{eff} and an appropriate set of (λ_i, β_i) kinetic parameters.

Numerous reactivity substitution measurements were made, relative to H_2O and/or Al, for the irradiation modules, and the MFE, HFED, and HSST experiments. The worth of beryllium reflector pieces poisoned with ^3He and ^6Li was also measured relative to unirradiated beryllium. These measurements were used to show that all these facilities are reasonably well modeled in the diffusion calculations.

CALCULATED EIGENVALUES CORRESPONDING TO MEASURED CONTROL ROD POSITIONS AT CRITICALITY

From the control rod position data recorded throughout each burn cycle, critical rod positions at the boundaries of each subinterval of the cycle length were input into all of the REBUS-3 fuel cycle burnup calculations. The code then adjusts the control rod positions throughout the burn cycle and calculates the eigenvalue at each of these "time nodes." A small adjustment of the calculated eigenvalue is needed because the average coolant temperature is different from that at which the water cross sections were generated. For this correction a calculated temperature coefficient of

$$\alpha_T = - 1.104 \times 10^{-2} \ \% \ \frac{\delta k}{k} / {}^\circ F$$

was used. Cross sections for the water coolant in the core were calculated at a temperature of 140°F which is the nearest temperature available in the cross section library to the average of the inlet and outlet coolant temperatures (~125°F). These coolant temperatures are recorded periodically throughout each operating cycle. The temperature correction to the eigenvalue amounts to a few tenths of a percent.

The eigenvalue calculations for each of the transition cores operated to date are summarized in Table I. The results in this table show that the eigenvalues are reasonably well-calculated and that the REBUS-3 code adequately accounts for the change in core reactivity due to fuel burnup. Note that no results are available for core 177C which shut down only a few days ago. The last entry in the table is also incomplete. This is the core which will be operating at the time of the ORR tour on Thursday.

It should be mentioned, however, that the results have not been corrected for the somewhat off-setting effects of neutron leakage through the six voided beam tubes and the depletion of cadmium near the bottom of the control elements. These matters are still under investigation but some preliminary findings will be presented later in this paper.

Table I. Calculated Eigenvalues Corresponding to Measured Critical Rod Positions

Core	Fuel Elements[a] HEU	LEU	CL in FPD's[b]	BOC	Calculated Eigenvalues 1/3 CL	1/2 CL	2/3 CL	EOC
174C	27+6	0+0	16.8402	1.0004	1.0018		1.0021	1.0021
174D	24+6	3+0	12.8451	1.0022		1.0023		1.0049
174E	24+6	3+0	10.6211	1.0043		1.0025		1.0027
174FX	20+6	7+0	0.0	0.9981				
174F	24+6	3+0	15.4290	1.0001	1.0008		1.0011	1.0020
175A	20+6	7+0	18.5178	1.0012	1.0018		1.0018	1.0012
175B	20+6	7+0	20.3036	0.9942	0.9949		0.9964	0.9972
175C	17+6	10+0	17.3544	0.9984	1.0015		1.0015	1.0020
176-AX1	13+4	14+2	0.0	1.0013				
176A	17+6	10+0	17.2238	1.0001	1.0001		1.0008	1.0029
176B	13+4	14+2	21.8612	1.0008	0.9992		1.0000	0.9984
176C	14+4	14+2	19.4343	1.0017	1.0012		1.0003	1.0011
176D	8+4	17+2	19.4449	1.0018	1.0003		1.0008	1.0027
177-AX1	4+2	21+4	0.0	1.0006				
177A	8+4	17+2	14.7716	0.9955	0.9963		0.9969	0.9988
177B	4+2	21+4	18.5173	1.0033	0.9996		0.9996	0.9997
177C	4+2	21+4						
177D	0+2	24+4						

[a]The notation 27+6 means there are 27 19-plate standard fuel elements in the core and 6 15-plate fuel follower elements.

[b]CL is the cycle length in full power days (FPD's).

FRESH FUEL CORES

Typical approach-to-critical measurements were made in the ORR using cores consisting of fresh HEU and LEU fuel and reflected with both water and beryllium. Figures 2 and 3 show the different core configurations and the loading steps followed in the approach-to-critical measurements. The beryllium-reflected cores consisted of a 3x3 assembly of fuel with shim rods located at each corner. Beryllium reflector pieces were added successively in the approach-to-critical studies. For these measurements all four control rods were banked together and moved as a unit. Table II gives the eigenvalue calculation corresponding to the critical banked rod position for each core configuration. For the water-reflected cores the eigenvalues are over-predicted by about 0.3% for the fresh HEU fuel and are under-predicted by about 0.7% for the fresh LEU fuel. The calculations tend to over-estimate the effect of the beryllium reflector by about 0.6%, but these results are very sensitive to the values used for the ^{6}Li and ^{3}He poison concentrations in the beryllium. These poison concentrations were estimated from incomplete records available for the irradiation history of each beryllium reflector element.

Because of the small size of these fresh cores, especially the beryllium reflected ones, the results are expected to be sensitive to core-reflector interface effects which are not properly accounted for in diffusion theory. Therefore, detailed Monte Carlo calculations are planned but no results are currently available.

Differential shim rod worths were measured in these fresh cores by the positive period technique. Table III compares measured and calculated values of the % $\frac{\delta k}{k}$/in. As can be seen, there is a wide scatter in the calculated-to-experimental (C/E) ratios. These discrepancies are still under investigation and some improvement may result from refined calculations. However, to-date no completely satisfactory explanation has been found for this spread in the C/E ratios. The repeatability of the experimental measurements appears to be of the order of 5-7%.

β_{eff} AND THE PROMPT NEUTRON LIFETIME

The ratio of the effective delayed neutron fraction to the prompt neutron lifetime, $\beta_{eff}/=\ell_p$, was measured by J. T. Mihalczo and G. E. Ragan in several ORR cores using a two-detector cross-correlation method[11] to obtain the prompt neutron decay constant. To determine the calculated ratio, β_{eff} and ℓ_p were evaluated separately. Beginning with flux distributions and burnup-dependent cross sections and atom densities from previous REBUS-3 calculations, the VARI3D code[10] was used to first calculate the adjoint flux and subsequently β_{eff}. The code also evaluates a 6-family coalesced set of the kinetic parameters (λ_i, β_i) from ENDF/B Version V delayed neutron data.

The prompt neutron lifetime was calculated by considering the change in the eigenvalue resulting from a uniform distribution of a purely 1/v absorber throughout the entire reactor volume. The fractional change in k resulting from this perturbation is given by

POOL
W

HEU-1
LEU-2

S — N

A-1	A-2	A-3	A-4	A-5	A-6	A-7	A-8	A-9
B-1	B-2	B-3	B-4	B-5	B-6	B-7	B-8	B-9
C-1	C-2	C-3 MFE-7J	C-4 8	C-5 6 8	C-6 8	C-7 MFE-6J	C-8	C-9
D-1	D-2	D-3 6 3	D-4 1 SR 1	D-5 1 1	D-6 1 SR 1	D-7 6 6	D-8	D-9
E-1	E-2	E-3 2 2	E-4 1 1	E-5 1 1	E-6 1 1	E-7 3 5	E-8	E-9
F-1	F-2	F-3 4 4	F-4 1 SR 1	F-5 1 1	F-6 1 SR 1	F-7 5 7	F-8	F-9
G-1	G-2	G-3	G-4	G-5	G-6	G-7	G-8	G-9

E

Fig. 2. Approach-to-Critical Loading Sequence for H_2O-Reflected Fresh Fuel Cores, HEU-1 and LEU-1.

POOL
W

HEU-2
LEU-2

S — N

A-1	A-2	A-3	A-4	A-5	A-6	A-7	A-8	A-9
B-1	B-2	B-3	B-4	B-5	B-6	B-7	B-8	B-9
C-1	C-2 6 Be 6	C-3 MFE-7J	C-4 6 Be 6	C-5 6 Be 6	C-6 6 Be 6	C-7 MFE-7J	C-8 6 Be 6	C-9
D-1	D-2 6 Be 6	D-3 6 Be 5	D-4 1 SR 1	D-5 1 1	D-6 1 SR 1	D-7 6 Be 6	D-8 6 Be 6	D-9
E-1	E-2 6 Be 6	E-3 4 Be 4	E-4 1 1	E-5 1 1	E-6 1 1	E-7 5 Be 3	E-8 6 Be 6	E-9
F-1	F-2 6 Be 6	F-3 2 Be 2	F-4 1 SR 1	F-5 1 1	F-6 1 SR 1	F-7 3 Be 2	F-8 6 Be 6	F-9
G-1	G-2 6 Be 6	G-3 1 Be 1	G-4 1 Be 1	G-5 1 Be 1	G-6 1 Be 1	G-7 1 Be 1	G-8 6 Be 6	G-9

E

Fig. 3. Approach-to-Critical Loading Sequence for Be-Reflected Fresh Fuel Cores, HEU-2 and LEU-2.

Table II. Calculated Eigenvalues Corresponding to the Measured Critical Rod Positions in Cores with Fresh Fuel

Core	Fuel	Reflector	Loading Step	Rod Bank* in.	k_{eff}
HEU-1	HEU	H_2O	5	24.37	1.00275
HEU-1	HEU	H_2O	6	17.21	1.00351
LEU-1	LEU	H_2O	6	25.14	0.99485
LEU-1	LEU	H_2O	7	21.33	0.99147
LEU-1	LEU	H_2O	8	15.46	0.99122
HEU-2	HEU	Be	5	24.13	1.00754
HEU-2	HEU	Be	6	17.34	1.01104
LEU-2	LEU	Be	5	25.27	0.99687
LEU-2	LEU	Be	6	18.41	1.00075

*The rod bank position is measured with respect to fully inserted rods where the 30.5 inch length of cadmium is symmetrically located about the core midplane.

Note: For loading steps not shown in this table the reactor was subcritical as shown by both experiments and calculations.

Table III. ORR Differential Rod Worths in Fresh Fuel Cores

Core	Reflector	Rod	R_i* in.	R_f* in.	Bank in.	% $\frac{\delta k}{k}$/in. Calc.	Exp.	C/E
HEU-1	H_2O	D4	12.00	12.36	20.83	0.5536	0.4936	1.122
HEU-1	H_2O	D6	16.75	17.21	17.21	0.3255	0.3290	0.989
HEU-1	H_2O	F4	12.00	12.26	20.03	0.4793	0.4579	1.047
LEU-1	H_2O	D4	12.00	12.22	17.65	0.6154	0.6265	0.982
LEU-1	H_2O	D6	14.65	15.46	15.46	0.4871	0.4991	0.976
LEU-1	H_2O	F4	12.00	12.32	16.64	0.3993	0.4025	0.992
HEU-2	Be	D4	12.00	12.19	20.97	0.6312	0.5006	1.261
HEU-2	Be	D6	12.00	12.22	20.88	0.6213	0.5418	1.147
HEU-2	Be	F4	12.00	12.19	21.20	0.6806	0.5483	1.241
HEU-2	Be	F6	12.00	12.17	21.15	0.6779	0.5676	1.194
LEU-2	Be	D4	15.00	15.27	20.33	0.5257	0.5360	0.981
LEU-2	Be	D6	15.00	15.25	20.21	0.5164	0.5236	0.986
LEU-2	Be	F4	15.01	15.23	20.55	0.5905	0.5137	1.150
LEU-2	Be	F6	15.00	15.28	20.42	0.5912	0.5653	1.046

*$R_f - R_i$ is the step change in the rod position which produced the positive asymptotic period.

$$\frac{\delta k}{k} = k \int_V [\sum_j \phi_j^* \delta\Sigma_{aj} \phi_j] \, dV/PD \tag{1}$$

where PD is the perturbation denominator. This result, when combined with the equation for the prompt neutron lifetime,

$$\ell_p = k \int_V [\Sigma_j \phi_j \phi_j^*/v_j] \, dV/PD, \tag{2}$$

yields

$$\ell_p = \frac{\delta k}{k}/N \sigma_{ao} v_o. \tag{3}$$

Here N is the concentration (atoms/b-cm) of the purely 1/v absorber whose cross section is σ_{ao} when the neutron velocity is v_o. Strictly speaking, Eq. (3) is valid only in the limit as $N \to 0$.

This 1/v insertion method was used to evaluate ℓ_p where ^{10}B was chosen as the 1/v absorber. At 2200 m/sec σ_{ao} (^{10}B) = 3837 barns. Burnup-dependent infinitely dilute ^{10}B cross sections were generated for spectra characteristic of each reactor region and calculations were performed for atom concentrations of 5.0×10^{-8} and 2.5×10^{-8} atoms/b-cm. Final results were obtained by extrapolation to zero ^{10}B concentration. Effects from elastic and inelastic scattering and from the non-1/v behavior of the ^{10}B absorption cross section above about 0.3 MeV were found to have a totally neglibible influence on ℓ_p evaluated by this ^{10}B 1/v insertion method.

Results of these β_{eff} and ℓ_p calculations are summarized in Table IV where the ratios of the two are compared with the measured values. Although measurements were made in each of the cores indicated in Table IV, experimental results[12] are available only for the water-reflected fresh cores. For these two cases the calculated β_{eff}/ℓ_p values agree remarkably well with the measurements. A strong photoneutron source term from the beryllium reflector together with a low frequency noise problem in the measurement of the frequency-dependent cross-power spectral density function so far have made it impossible to determine β_{eff}/ℓ_p in the other cores. However, the results do show that β_{eff}/ℓ_p is smaller in these cores than in the fresh cores which is in qualitative agreement with the calculations.

ON-GOING ANALYTICAL STUDIES

Perturbing Influences of Voided Beam Tubes

The REBUS-3 non-equilibrium studies described earlier (Table I) do not account for the perturbing effects of the six voided beam tubes. Preliminary studies of the influence of the evacuated beam tubes on flux and power distributions in the core were made using two-dimensional XY transport theory calculations. By comparing these results with analogus XY diffusion cal-

Table IV. β_{eff} and the Prompt Neutron Lifetime

Core	Fuel Elements* HEU	LEU	β_{eff}	ℓ_p μ-sec.	β_{eff}/ℓ_p (sec^{-1}) Calc.	Exp.	C/E
HEU-1	12+4	0+0	8.0522-3	47.8731	168.2	169.0 ± 0.9	0.9953 ± 0.0053
LEU-1	0+0	14+4	7.9796-3	41.5521	192.0	192.1 ± 0.8	0.9943 ± 0.0041
176B	13+4	14+2	7.4503-3	62.7516	118.7		
176BX2	27+6	0+0	7.4740-3	69.7233	107.2		
177AX2	4+2	21+4	7.3730-3	66.8051	110.4		

*The notation 12 + 4 means there are 12 19-plate standard fuel elements in the core and 4 15-plate fuel follower elements.

culations, it was found that the effect of the beam tubes could be represented approximately in a DIF3D calculation by filling the beam tubes with about 3% of normal water density. However, these XY studies suffer from the fact that they do not allow one to model the actual three-dimensional character of the beam tubes nor do they permit one to model the real angles at which the beam tubes leave the aluminum core box on the east side of the core. For these reasons beam tube effects were studied using the continuous energy, three-dimensional Monte Carlo Code, VIM[9]. Calculations were done for the case of voided beam tubes and for the case of the beam tubes flooded with water at normal density for core 177-AX1. Similar XYZ calculations were made with the DIF3D diffusion code where the "voided" case corresponded to water at 3% of normal density. Although comparisons between the two types of calculations are still preliminary and incomplete, some observations can be made.

1. The two types of calculations are consistent in their predictions of the amount by which the eigenvalue is lowered due to neutron leakage through the voided beam tubes relative to the flooded case.

Calculation	δk_{eff}, %
VIM - Monte Carlo	-0.73 ± 0.33
DIF3D - Diffusion	-0.493

2. Within the statistics of the Monte Carlo calculations (based on 200,000 neutron histories), the voided-to-flooded ratio of the region-integrated fission rates for VIM and DIF3D agree.

	Voided-to-Flooded Fission Rate Ratio	
Row	VIM-Monte Carlo	DIF3D
A	1.032 ± 0.015	1.025
B	1.039 ± 0.017	1.021
C	1.021 ± 0.013	1.011
D	0.983 ± 0.011	1.001
E	0.978 ± 0.014	0.982
F	0.942 ± 0.011	0.950

The statistical errors correspond to one standard deviation.

3. The eigenvalues for the Monte Carlo calculations have a standard deviation of about 0.24% and are about 1.0% larger than the corresponding diffusion calculations. Before the reason for this discrepancy is understood, a detailed analyses of the results from both sets of calculations needs to be done.

Energy, position and angular coordinates for each neutron crossing the plane of the aluminum core box on the east side of the core where the beam tubes are located have been saved on a tape from the Monte Carlo calculations. From this information we plan to construct group and position-dependent reflection coefficients (albedos) for subsequent use in diffusion calculations where the beam tubes will be accounted for by means of these boundary conditions.

Differential and Integral Rod Worths

Differential shim rod worths (% $\frac{\delta k}{k}$/in.) are measured in the ORR by the positive period technique. This data is then integrated from the lower to the upper limit of rod movement to obtain the total rod worth. Measured and calculated differential worths for the HEU and LEU fresh cores were given in Table III. Except for the beryllium-reflected HEU core, these calculated and measured differential worths are in reasonable agreement if one takes into account repeatability errors (~5-7%) associated with the measurements. Some additional refinements in these calculations remain to be done and this may improve the C/E ratios.

For reasons which are at best only partly understood, however, calculated differential worths in the partially depleted HEU/LEU mixed cores are usually substantially larger than the measured values. This is illustrated in Table V for recent measurements made in core 177-AX1. The calculations include an approximate treatment for the perturbing effects of the voided beam tubes, the depletion of ^{113}Cd in the lower sections of the cadmium poison regions (due to the irradiation of the shim rods in previous burn cycles), and the depletion of ^{235}U in the fuel followers. Kinetic parameters (λ_i,β_i) were generated for this core and used to convert measured periods to reactivities. Clearly there are effects, perhaps associated with shim rod burnups, which are not properly modeled in the calculations. In an effort to better understand this worth descrepancy we plan to do the following.

1. Investigate the effect of the cross section mis-match between those sections of the fuel followers located in the core and the lower parts in the water reflector below the core. To date, fuel follower cross sections have been generated only for a core environment.

2. At the next shutdown period in the ORR differential worth measurements will be made using sets of both burned and fresh shim rods. This data should show whether we are able to better calculate differential worths for fresh shim rods than for burned ones.

3. Some worth measurements will be made at several power levels in order to determine the importance of the inherent neutron source term from photoneutron reactions mostly on beryllium.

4. Data will be taken to better determine repeatability errors associated with rod worth measurements.

5. The die-away curve following a rod drop will be measured in order to determine an effective set of kinetic parameters (λ_i,a_i). Unfortunately, this method does not determine β_{eff}.

Table V. Differential Shim Rod Worths in Core 177-AX1

Rod	R_i in.	R_f in.	Bank in.	k_{eff}* (at R_i)	C/E Worth Ratios (λ_i,β_i) ORR	(λ_i,β_i) ANL	+ Voided B.T.'s	+ Cd Depl.
F6	12.00	12.66	16.24	0.9975	1.623	1.804	1.704	1.501
F4	12.00	12.62	16.25	0.9975			1.642	
B6	12.00	12.41	16.66	0.9975			1.475	
B4	11.99	12.39	16.69	0.9975			1.572	
D6	6.00	6.60	19.59	0.9967			0.787	
D6	12.00	12.23	17.48	0.9977			1.020	
D6	18.00	18.39	15.17	0.9977			1.265	
D4	12.00	12.26	17.66	0.9978			1.112	

*With the rod at the initial position, R_i, the reactor was critical. The rod was then withdrawn to R_f and the positive period measured.

Note: Prior to these measurements shim rods F4 and F6 had been irradiated for 7 bur cycles, B4 and B6 for 3 cycles, and D4 and D6 for 0 cycles.

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