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Analyses of the TSF First-Fission Stored-Fuel and Ex-Vessel Low-Level Flux Monitor Experiments for the Clinch River Breeder Reactor

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ANALYSES OF THE TSF FIRST-FISSION STORED-FUEL AND EX-VESSEL LOW-LEVEL FLUX MONITOR EXPERIMENTS FOR THE CLINCH RIVER BREEDER REACTOR

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ABSTRACT

One of the first experiments performed at the ORNL Tower Shielding Facility in support of the design of the Clinch River Breeder Reactor (CRBR) was a radial shield mockup in which the first-fission reaction at the stored-fuel position and the response of the ex-vessel detector were studied In the first part identified as the CRBR "first-fission" experiment, the radial region of the CRBR from the core to a stored-fuel module was mocked up in slab geometry and fission chamber responses at the stored-fuel location were interpreted as first fissions in the stored fuel In the second part, identified as the CRBR "ex-vessel" experiment the configuration was extended to mock up the entire region from the CRBR core to a low-level flux monitor (fission chamber surrounded by graphite) located in the cavity outside the reactor vessel This report describes the analyses of the experiments which were performed with the discrete ordinates transport method

For both experiments the ratios of the calculated-to-measured fission chamber responses (C/E) were less than unity, the ratios for bare counters being smaller than those for cadmium-covered counters In the first-fission experiment the C/E ratio for the bare ^{235}U fission chamber was about 0 47, whereas for the cadmium-covered chamber it was about 0 63 When the bare chamber was surrounded by graphite in the ex-vessel experiment the ratio improved to 0 65 The ratios for points inside the configuration were better -- 0 72 and 0 83 for the bare chamber in the inconel region and in the outermost steel region respectively Corresponding ratios for the cadmium-covered counters were 0 82 and 0 94 These results indicate that in the calculations the thermal and near-thermal neutron fluxes are underpredicted and that the trend worsens with deeper penetration in the shield and then improves slightly in the presence of a moderator

1 INTRODUCTION

In late 1973 and early 1974 two separate experiments were performed at the ORNL Tower Shielding Facility to provide data bases for testing some of the calculational techniques being applied by ORNL in their shielding analyses for the Clinch River Breeder Reactor (CRBR) The first experiment was called the CRBR "first-fission" experiment and was similar to the first-fission experiment performed for the Fast Test Reactor [1] The second was identified as the CRBR "ex-vessel" experiment for reasons explained below

At the time the CRBR first-fission experiment was performed plans were being made to include in the CRBR design in-vessel stored-fuel modules similar to those in the FTR vessel and, as was the case for the FTR, a question arose as to whether we could accurately calculate the enhancement of the neutron fluxes in the cavity surrounding the reactor vessel by neutrons produced by fissions in the stored fuel In order to test the calculational method the first-fission experiment was devised and the method was used to analyze it The experiment, which has been described in detail elsewhere,[2,3] consisted in mocking up, in slab geometry, the radial regions from the reactor core out to a stored-fuel location, and then interpreting responses of fission chambers at the stored-fuel location as "first" fissions that would occur in the stored fuel (that is, fissions induced solely by neutrons produced outside the stored fuel) The experiment also included measurements by other types of neutron detectors The analysis which is described in this report, consisted in calculations of the same detector responses The results of the analysis and comparisons with pertinent experimental data are presented in Section 2

The CRBR ex-vessel experiment mocked up the region from the CRBR core out to a low-level flux monitor (LLFM) external to the vessel -- that is, within the reactor cavity surrounding the pressure and guard vessels The CRBR will use three monitors positioned equidistant around the guard vessel at the core midplane Since these detectors are primarily sensitive to thermal neutrons and the neutron spectrum leaving the vessel is 1/E

from slightly above thermal to several hundred keV, each flux-monitor unit was designed to include a graphite moderator around the detector The ex-vessel experiment, described elsewhere,[2] was performed to investigate the effectiveness of the graphite in increasing the count rate of the detectors, as well as to test our capability for calculating the steady-state count rate at the ex-vessel LLFM position The analysis of the experiment, described in Section 3 of this report, was very similar to that for the first-fission experiment except that it was extended through to the ex-vessel assembly

Following completion of both of the above series of measurements, additional measurements[4] were made for a slightly modified CRBR configuration, the purpose of which was to test the ex-vessel detector reaction rate without the complication of a moderator The measurements were made in a minimum-sized gap between the vessel and an iron reflector (background shield) A comparison of the calculated and measured detector responses for this configuration is given in Section 4

(NOTE The count rates that could be expected from the graphite-surrounded detectors in the CRBR reactor cavity were predicted by Engle and Williams[5] on the basis of DOT calculations in which the radial regions of the system, including the graphite detector box were mocked up in r θ geometry On the basis of these results, it was determined that stored-fuel neutrons would overpower the monitors and the decision was made not to store fuel within the pressure vessel as a routine procedure Instead, provisions will be made for temporarily placing a maximum of five elements in the outer region of the vessel as it becomes necessary and feasible but not during power operation)

2 ANALYSIS OF CRBR FIRST-FISSION EXPERIMENT

The CRBR first-fission experiment has been described in detail in two progress reports [2,3] As mentioned previously, the experimental configurations consisted of mockups in slab geometry of the various CRBR regions from the reactor core to the stored-fuel modules, with fission chamber

measurements made at the location of the stored fuel Additional measurements with hydrogen counters and BF_3 detectors yielded information on energy spectra of the neutron fluxes at the same position

The experimental configurations selected for analysis, identified as Configurations 2 and 4 in the experiment, are shown in Figs 1 and 2 In both configurations the region extending out to the blanket (4 in of stainless steel, 6 in of sodium, and 1 in of boral) consists of a spectrum modifier designed by WARD* to filter the TSR-II neutrons so that the emergent spectrum simulated that from the CRBR core The next region mocks up the CRBR blanket and consists of depleted uranium The blanket is followed by a 5-in -thick stainless steel region mocking up the radial reflector and a 5-in -thick inconel region mocking up the radial restraint The additional layers of iron and stainless steel in Configuration 2 represent the steel shield and core barrel and the outside layer of sodium mocks up a small region of the pool sodium Configuration 2 therefore simulates the placement of the stored fuel in the sodium pool just beyond the core barrel Configuration 4 was included to provide data to test the calculations for a thinner system to see if potential disagreements were related to deep penetration in the radial shield The compositions of the materials used in both configurations are given in Tables 1 and 2

The analysis consisted of calculations of the detector responses behind both configurations The energy spectrum of the bare beam used as the source, which had been determined earlier,[6] is shown in Table 3 in the 50-group structure that had been developed for most of ORNL's LMFBR calculations

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*Westinghouse Electric Corporation's Advanced Reactors Division which has the lead design responsibility for the CRBR

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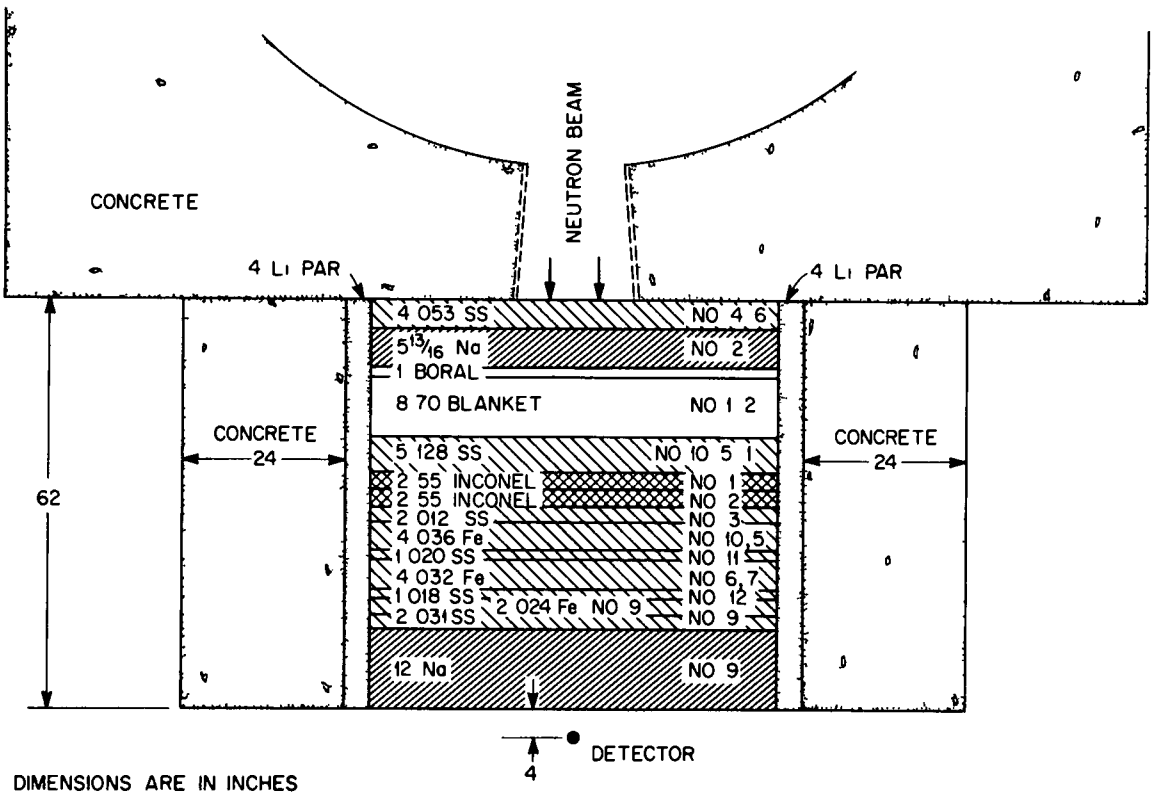

Fig 1 CRBR First-Fission Experiment Configuration 2

The calculations were performed in two-dimensional cylindrical geometry with the discrete ordinates code DOT[7] in conjunction with the analytic first-collision program GRTUNCL [8] The small air interval between the outer surface of the configuration and the detector was treated in DOT as an extra spatial region in the cylindrical geometry, with no reflections from surrounding media considered Thus the neutron fluxes in the various energy groups were obtained for the detector position directly from DOT An S_8 quadrature and P_3 scattering were applied throughout

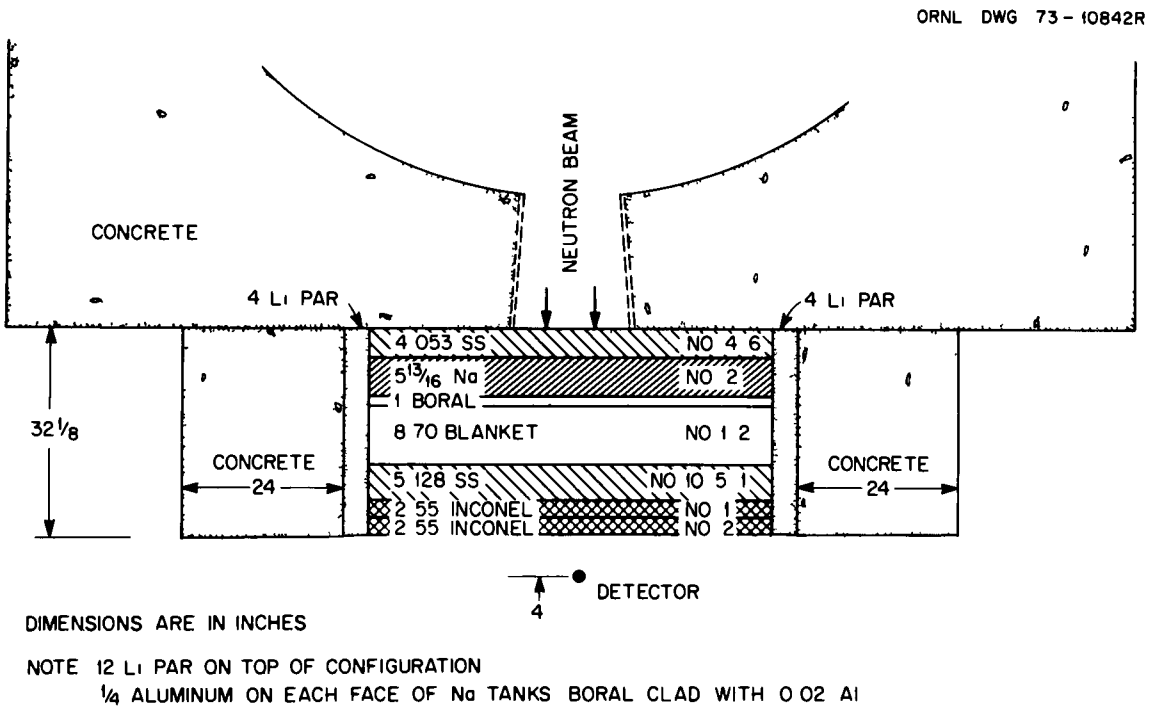

Fig 2 CRBR First-Fission Experiment Configuration 4

The number densities assumed for the various materials used in the calculations are listed in Table 4 The corresponding cross sections were largely from ENDF/B-II Revised and ENDF/B-III data For the important elements sodium, nickel, and chromium, ENDF/B-III data were used For iron the cross sections were from ENDF MAT 4180 MOD 1, which was similar to ENDF/B-IV The cross sections were employed in the 50-group energy structure that had been developed from ORNL FFTF analyses In the multigrouping process, the cross sections for the iron and stainless steel zones were weighted $1/E\Sigma_T$

Table 1 Composition of Materials Used in TSF-CRBR First-Fission Experiment

Material	Density (g/cc)	Element	wt/	
Aluminum Alloy 6061-T6	2 767	Al	98	
		Mg, Fe, Si	2	
Sodium	0 945	Na	99 7	
		Ca Zn	0 3	
Boral		B	27 5	
		Al	65 0	
		C	7 5	
Stainless Steel Type 304	7 88	Fe	69 871	
		Cr	18 46	
		Ni	9 725	
		Mn	1 394	
		Si, C, O	0 55	
			Slab No 1	Slab No 2
Inconel	8 51	Ni	74 54	74 76
		Cr	15 21	15 72
		Fe	8 63	8 46
		Cu	0 40	0 40
		C	0 098	0 094
		Mn	0 20	0 20
		Co	0 1	0 1
		Mo	0 03	0 03
		Ti	0 09	0 09
		Al	0 10	0 10
		Nb	<0 05	<0 05
			~99 75	99 31

Table 2 Composition of Radial Blanket

Constituent	Vol/	Density (g/cc)
UO_2	64 6	10 28
Al	11 2	2 80
Na	23 2	0 92
Void	1 0	

Table 3 Energy Spectrum of TSR-II 15-in -diam Bare Beam in 50-Group FTR Cross-Section Structure

Group No	Upper Energy (eV)	Intensity (neutrons cm^{-2} min^{-1} W^{-1})	Group No	Upper Energy (eV)	Intensity (neutrons cm^{-2} min^{-1} W^{-1})
1	1 49(7)[a]	4 6(1)	26	8 65(4)	3 520(3)
2	1 22(7)	2 72(2)	27	5 25(4)	1 650(3)
3	1 00(7)	8 57(2)	28	4 09(4)	1 590(3)
4	8 19(6)	2 221(3)	29	3 18(4)	1 530(3)
5	6 70(6)	4 655(3)	30	2 48(4)	1 490(3)
6	5 49(6)	6 845(3)	31	1 93(4)	1 440(3)
7	4 49(6)	9 300(3)	32	1 50(4)	4 020(3)
8	3 68(6)	1 014(4)	33	7 10(3)	2 480(3)
9	3 01(6)	1 3645(4)	34	4 31(3)	1 180(3)
10	2 47(6)	1 3145(4)	35	3 35(3)	1 150(3)
11	2 02(6)	1 0745(4)	36	2 61(3)	1 120(3)
12	1 65(6)	8 20(3)	37	2 03(3)	1 100(3)
13	1 35(6)	5 655(3)	38	1 58(3)	1 03(3)
14	1 11(6)	4 485(3)	39	1 23(3)	1 02(3)
15	9 07(5)	4 560(3)	40	9 61(2)	3 020(3)
16	7 43(5)	4 310(3)	41	4 54(2)	2 870(3)
17	6 08(5)	3 125(3)	42	2 14(2)	2 720(3)
18	4 98(5)	2 340(3)	43	1 01(2)	2 700(3)
19	4 08(5)	2 345(3)	44	4 79(1)	2 700(3)
20	2 34(5)	2 185(3)	45	2 26(1)	2 730(3)
21	2 73(5)	1 792(3)	46	1 07(1)	2 985(3)
22	2 24(5)	1 703(3)	47	5 04(0)	3 105(3)
23	1 83(5)	1 672(3)	48	2 38(0)	3 330(3)
24	1 50(5)	1 583(3)	49	1 13(0)	6 065(3)
25	1 23(5)	2 669(3)	50	4 14(-1)	9 50(4)
				Total	2 702(5)

[a]Read $1\ 49 \times 10^7$

Table 4 Nuclear Densities Used in Calculations for Various TSF Materials

Material	Element	Density (atoms barn^{-1} cm^{-2})
Aluminum Alloy	Fe	6 0(-4)[a]
	Al	6 05(-2)
Sodium	Na	2 48(-2)
Boral	Fe	7 7(-4)
	Al	3 65(-2)
	B[b]	2 59(-2)
	C	6 45(-3)
Blanket	Al	7 05(-3)
	Na	5 19(-3)
	O	2 95(-2)
	U[c]	1 48(-2)
Stainless Steel Type 304	Fe	5 94(-2)
	Cr	1 69(-2)
	Ni	7 9(-3)
	Mn	1 2(-3)
	C	2 2(-3)
Inconel	Fe	7 9(-3)
	Cr	1 53(-2)
	Ni	6 52(-2)
	Mn	5 6(-4)
	Al	7 6(-4)
	C	8 5(-4)
Iron	Fe	8 37(-2)
	Mn	5 15(-4)
	C	9 815(-4)
Concrete	H	7 3(-3)
	O	4 47(-2)
	C	1 07(-2)
	Si	3 8(-3)
	Ca	1 22(-2)
Lithiated Parrafin	^{6}Li	5 565(-4)
	^{7}Li	6 94(-3)
	C	2 68(-2)
	O	1 125(-2)
	H	4 6(-2)

[a]Read 6 0 x 10^{-4}

[b]Natural boron (19 8/ ^{10}B, 80 2/ ^{11}B)

[c]Natural uranium (99 27/ ^{238}U, 0 73/ ^{235}U)

To obtain the fission counter response, the calculated neutron fluxes at the detector position were multiplied by the fission cross section for ^{239}Pu or ^{235}U and the respective counter efficiencies (100/ for ^{239}Pu and 70/ for ^{235}U) For the BF_3 counter, the boron (n,α) reaction rate was calculated and multiplied by the detector efficiency For the hydrogen counter the calculated group fluxes were compared directly with the unfolded fluxes for the counter

The resulting calculated fission counter responses are compared with the experimental responses in Table 5 As was the case with the analysis for the FTR stored-fuel experiment,[1] the calculated values are lower than the measured values In this case, however, the calculations are not quite so low For the cadmium-covered detectors the calculated-to-measured ratios are 0 655 and 0 476 for the ^{235}U and ^{239}Pu counters respectively The same ratios for the FTR experiment and analysis were 0 45 and 0 30 As pointed out in the FTR analysis, the reason for the ^{239}Pu ratios being lower than the ^{235}U ratios is that resonance self-shielded ^{239}Pu fission

Table 5 Comparison of Calculated and Measured Fission Counter Responses in CRBR First-Fission Experiment

Configuration[a]	Detector Responses (cpm/MW)			Ratio	Ratio
	$^{235}U_{Cd}$	$^{235}U_{Bare}$	$^{239}Pu_{Cd}$	$^{235}U_{Cd}/^{235}U_{Bare}$	$^{235}U_{Cd}/^{239}Pu_{Cd}$
Conf 2 Calc	3 86(3)[b]	4 29(3)	6 94(2)	0 9011	5 57
Conf 2 Meas	5 89(3)	9 97(3)	1 46(3)	0 5905	4 04
Ratio Calc /Meas	0 655	0 430	0 476		
Conf 4 Calc	7 96(4)	8 29(4)	1 51(4)	0 960	5 26
Conf 4 Meas	1 28(5)	1 67(5)	3 52(4)	0 7675	3 63
Ratio Calc /Meas	0 622	0 497	0 430		

[a]See Figs 1 and 2

[b]Read 3 86 x 10^3

cross sections were mistakenly used in the calculations instead of infinitely dilute cross sections Correcting for the self-shielding would make the ^{239}Pu ratios approximately the same as the ^{235}U ratios In both analyses the ratios for the bare ^{235}U detector were 0 4 This poor agreement indicates trouble in calculating the thermal group, since when this group is removed by the cadmium covers the agreement improves Because of the likelihood of thermal background the thermal comparisons are deemphasized compared to the cadmium-covered results

The comparisons for the cadmium-covered BF_3 counter are given in Table 6 and those for the hydrogen counter in Table 7 For both counters the agreement is better than for the fission detectors although the calculated values are still low The best agreement was obtained for the hydrogen counter between 0 123 and 0 608 MeV, the calculated-to-measured ratios varying in this region from 0 76 to 0 98 and the integral C/E being 0 86

Since in this analysis the same 50-group cross sections were used as in the analysis for the FTR stored-fuel experiment and the materials used in the two experiments were very similar, the conclusions reached from

Table 6 Comparison of Calculated and Measured Cadmium-Covered BF_3 Counter Responses in CRBR First-Fission Experiment

Configuration[a]	Detector Response (cpm/MW)
Conf 2, Calc	9 81(4)[b]
Conf 2, Meas	1 46(5)
Ratio Calc /Meas	0 674
Conf 4, Calc	1 96(6)
Conf 4, Meas	2 86(6)
Ratio Calc /Meas	0 687

[a]See Figs 1 and 2

[b]Read 9 81 x 10^4

Table 7 Comparison of Calculated (50-Group) and Measured Hydrogen Counter Responses Behind Configuration 2 in CRBR First-Fission Experiment

Group	Energy Interval (MeV)	Fluxes (neutrons cm^{-2} min^{-1} W^{-1}) Calculated	Measured	Ratio Calc /Meas
13	1 35 -1 11	4 522(-4)[a]	1 301(-3)	0 348
14	1 11 -0 907	1 581(-3)	3 134(-3)	0 505
15	0 907 -0 743	2 333(-3)	4 829(-3)	0 483
16	0 743 -0 608	6 196(-3)	1 138(-2)	0 544
17	0 608 -0 497	3 432(-2)	3 495(-2)	0 982
18	0 497 -0 408	4 481(-2)	5 129(-2)	0 874
19	0 408 -0 334	7 177(-2)	8 592(-2)	0 835
20	0 334 -0 273	1 347(-1)	1 540(-1)	0 874
21	0 273 -0 224	1 184(-1)	1 553(-1)	0 763
22	0 224 -0 183	1 303(-1)	1 582(-1)	0 824
23	0 183 -0 150	1 779(-1)	2 002(-1)	0 889
24	0 150 -0 123	2 470(-1)	2 730(-1)	0 905
25	0 123 -0 0865	3 375(-1)	4 832(-1)	0 698
26	0 0865-0 0525	4 540(-1)	1 074(+0)	0 423

[a]Read 4 522 x 10^{-4}

the study of cross-section group structures reported in the FTR analysis[1] should apply here also That is, the difference between the calculations and the measurements would be reduced by a finer group structure but it would not resolve the problem, and the reasons for the discrepancy are still not known In this case the two configurations show that the discrepancy is the same before and after the shield and is therefore not related to underprediction of the transport through the radial shield which, in this case, was not as thick as was the FFTF shield Note in the next section that measurements made in the inconel region with cadmium-covered ^{235}U and BF_3 detectors show much improved agreement This indicates that for these "short" experiments much of the discrepancy is related to end effects

3 ANALYSIS OF CRBR EX-VESSEL EXPERIMENT

The CRBR ex-vessel experiment was performed in conjunction with the first-fission experiment and is described in the same progress report [2] The experimental configuration used is shown in Fig 3 Basically it is the configuration used in the first-fission experiment with the thickness of the outer sodium layer considerably increased and mockups of the steel reactor vessel, steel guard vessel concrete-wall reactor cavity, and graphite detector block added The compositions of the materials are the same as those given in Tables 1 and 2

A vertical cut through the simulated cavity and the graphite block is shown in Fig 4 The detector was positioned within a 6 in by 6 in void penetrating horizontally through the block The front of the block, nearest the reactor, was covered with an additional 4-in or 6-in thickness of graphite, the 6-in thickness constructed from a 2-in -thick slab plus a 4-in -thick slab The density of the 4-in slab was 1 832 g/cm^3 and the density of the 2-in slab was 1 945 g/cm^3 A graphite plug was inserted in the block behind the detector (see Fig 5) Measurements were made for both graphite configurations and also for the empty cavity (no graphite)

Three different detectors were used Two were ^{235}U fission detectors one identified as the TSF detector No 16 and the other identified as the I and C detector They have efficiencies of 70/ and 50/ respectively The third detector was a ^{3}He detector, which is sensitive to thermal neutrons The measurements with the various detectors showed that when the graphite was around the detectors the count rates were higher by factors of 7 to 8 than those measured when no graphite was present Thus, the graphite is indeed effective in increasing the count rates This confirmation of the graphite enhancement of the count rate was an important contribution of the experiment

In the analysis only the neutron fluxes inside the graphite with the 4-in cover were calculated The calculational technique was essentially the same as that used for the analyses of the first-fission experiment

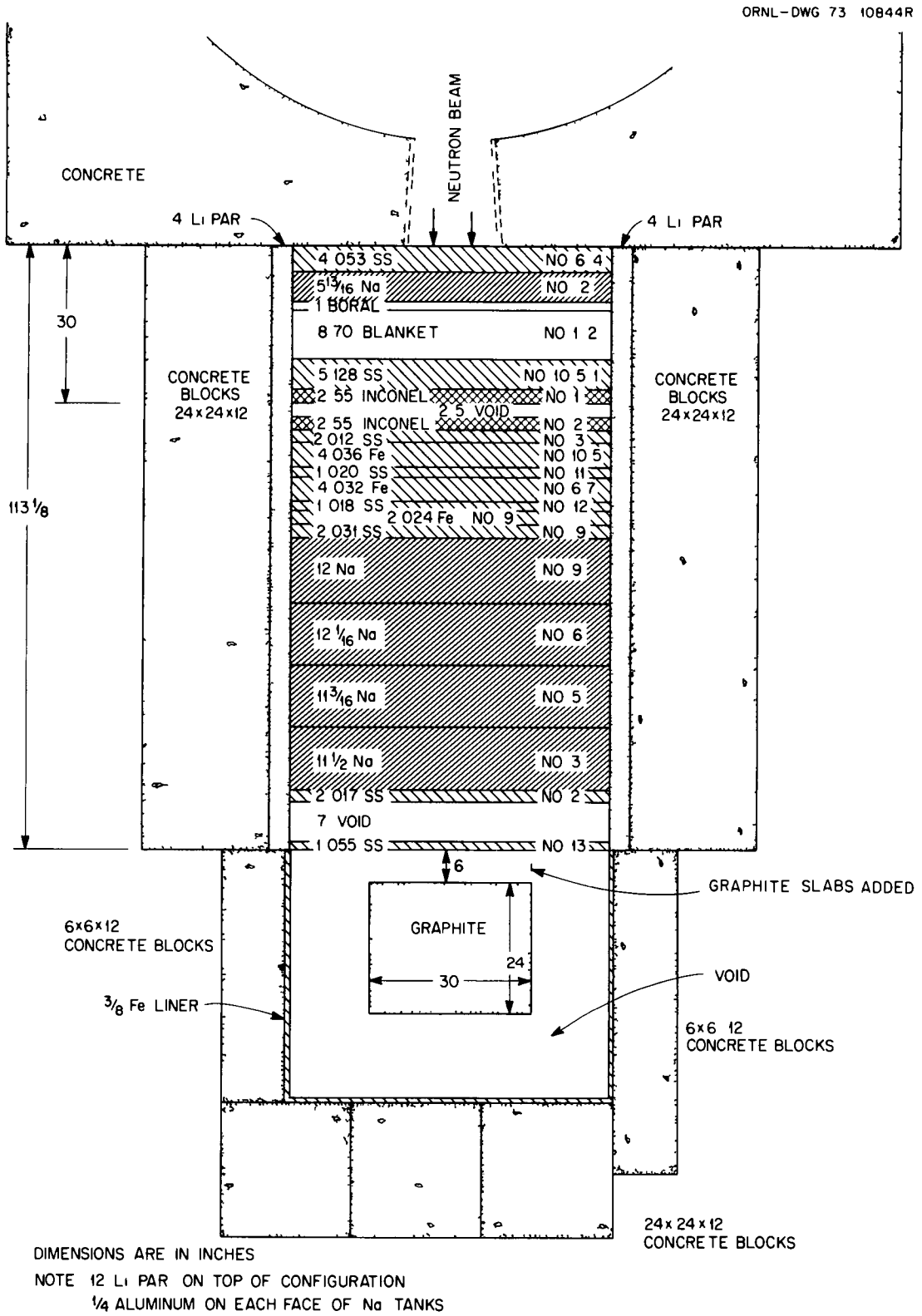

Fig 3 Configuration for CRBR Ex-Vessel Experiment The graphite slabs added in front of the graphite box were 4 or 6 in thick

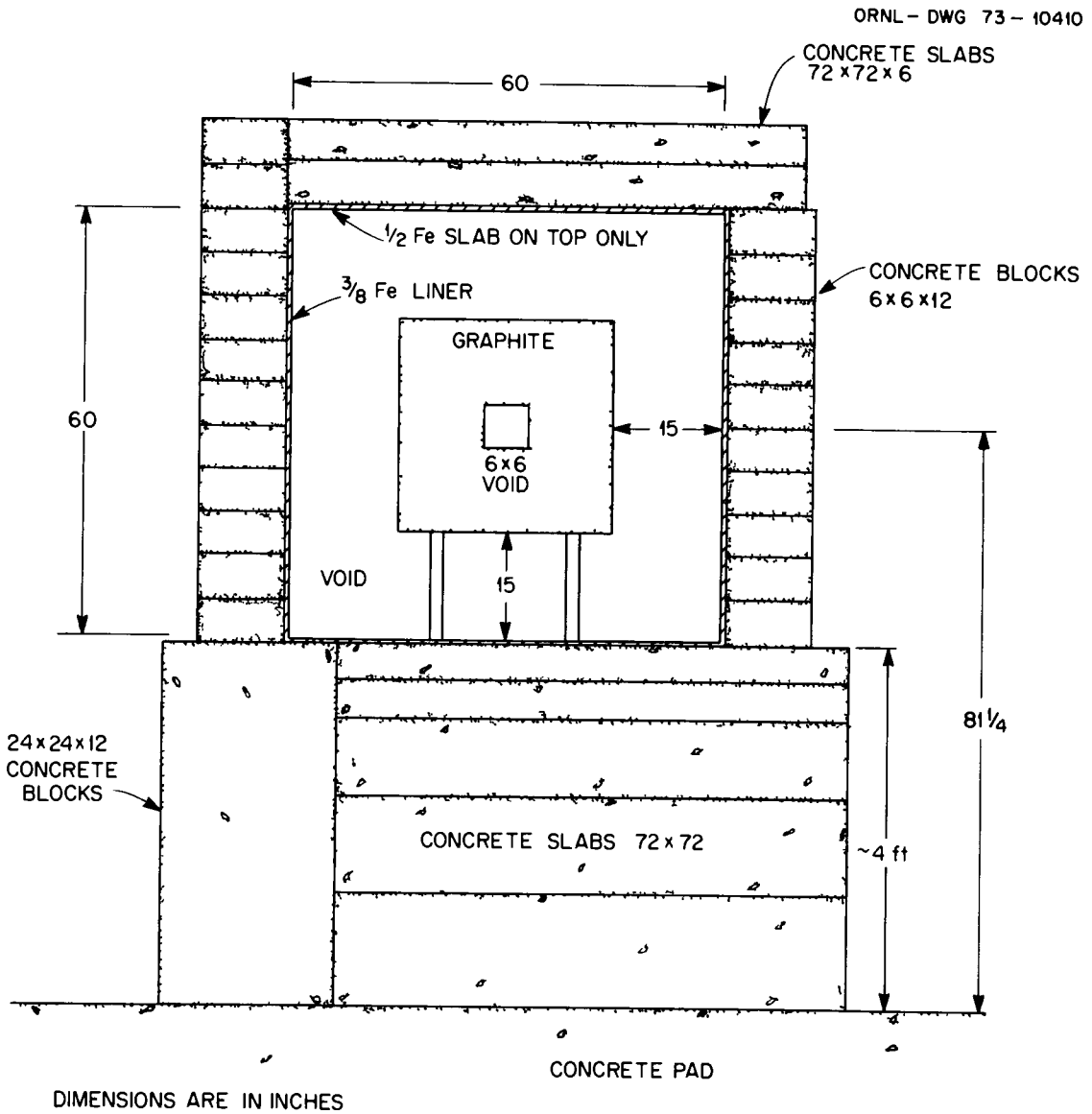

Fig 4 Vertical Cut Through Simulated Reactor Cavity and Graphite Box in CRBR Ex-Vessel Experiment

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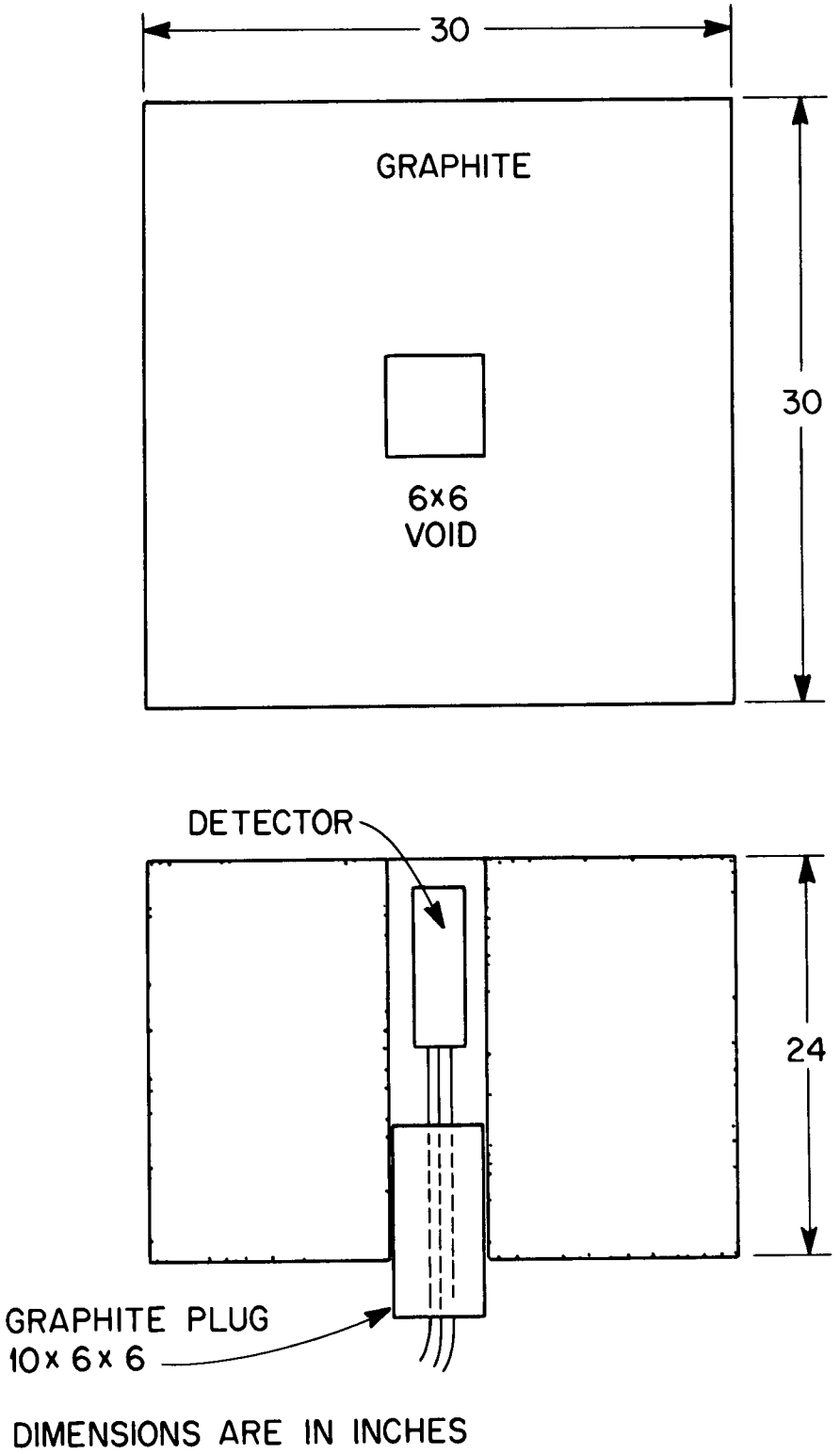

Fig 5 Graphite Block Used in TSF CRBR Ex-Vessel Experiment

That is, the DOT code was used in two-dimensional cylindrical geometry, together with the standard 50-group cross sections P_3 scattering and S_8 quadrature, and the source was that given in Table 3 The cross sections again were based on ENDF-II Revised and ENDF-III data, and the number densities assumed for the materials were as listed in Table 4

The calculated responses for the TSF No 16 ^{235}U counter and the ^{3}He detector are compared with the measured responses in Table 8 As has consistently been the case for this series of experiments, the calculated response for the ^{235}U counter is lower than the measured response On the other hand, the calculated response for the ^{3}He detector is higher than the measured response The ^{3}He comparison may not be a good one, however, since the detector had not been accurately calibrated and this was a first attempt at calculating its response The ^{3}He pressure was 10 atm, giving rise to a substantial self-shielding effect Since the ^{3}He detector measurements were not a primary concern of the experiment, the cause of the disagreement was not pursued

Table 8 Comparison of Calculated and Measured Detector Responses in CRBR Ex-Vessel Experiment[a]

Detector	Detector Response
Bare ^{235}U (TSF No 16)	
Calculated	2,430 cpm/MW
Measured	3,710 cpm/MW
Ratio Calc /Meas	0 65
^{3}He Detector	
Calculated[b]	472 cpm kW^{-1} sec^{-1} g^{-1}
Measured	284 cpm kW^{-1} sec^{-1} g^{-1}
Ratio Calc /Meas	1 7

[a]For configuration with 4 in of graphite preceding graphite box

[b]The calculated value has been multiplied by 0 63 to account for self shielding of this detector

In an attempt to understand at what positions in the configuration the calculations and measurements were most at variance uranium foils were exposed in the experimental configuration between the slabs making up the uranium radial blanket stainless steel reflector, and inconel radial restraint, and calculations for the same points were performed The foil positions are shown in Fig 6, and the comparisons of the calculated and measured values are given in Table 9 (The fission rates are all normalized to unity at position 1) These results show that for positions within the radial blanket the calculated curve is somewhat low and for positions within the reflector and inconel restraint they are somewhat high but overall they can be considered to be in good agreement Since the fission rate is proportional to the neutron flux, the values in Table 9 are indicative of the variation of the flux within the shield While the foil measurements are relative rather than absolute this comparison shows that the relative reaction rates are predicted with fair accuracy from the spectrum modifier out to the restraint region

Measurements were also made with the bare and cadmium-covered ^{235}U fission detector (TSF No 16) and with the cadmium-covered BF_3 detector in

Table 9 Comparison of Calculated and Measured Uranium Foil Fission Rates Within CRBR Configuration[a]

Foil Position	Fission Rate (Relative) Calculated	Measured	Ratio Calc /Meas
1	1	1	1
4	0 487	0 586	0 83
7	0 365	0 432	0 84
10	0 463	0 436	1 06
11	0 401	0 340	1 18
12	0 223	0 202	1 10

[a]See Figs 3 and 6

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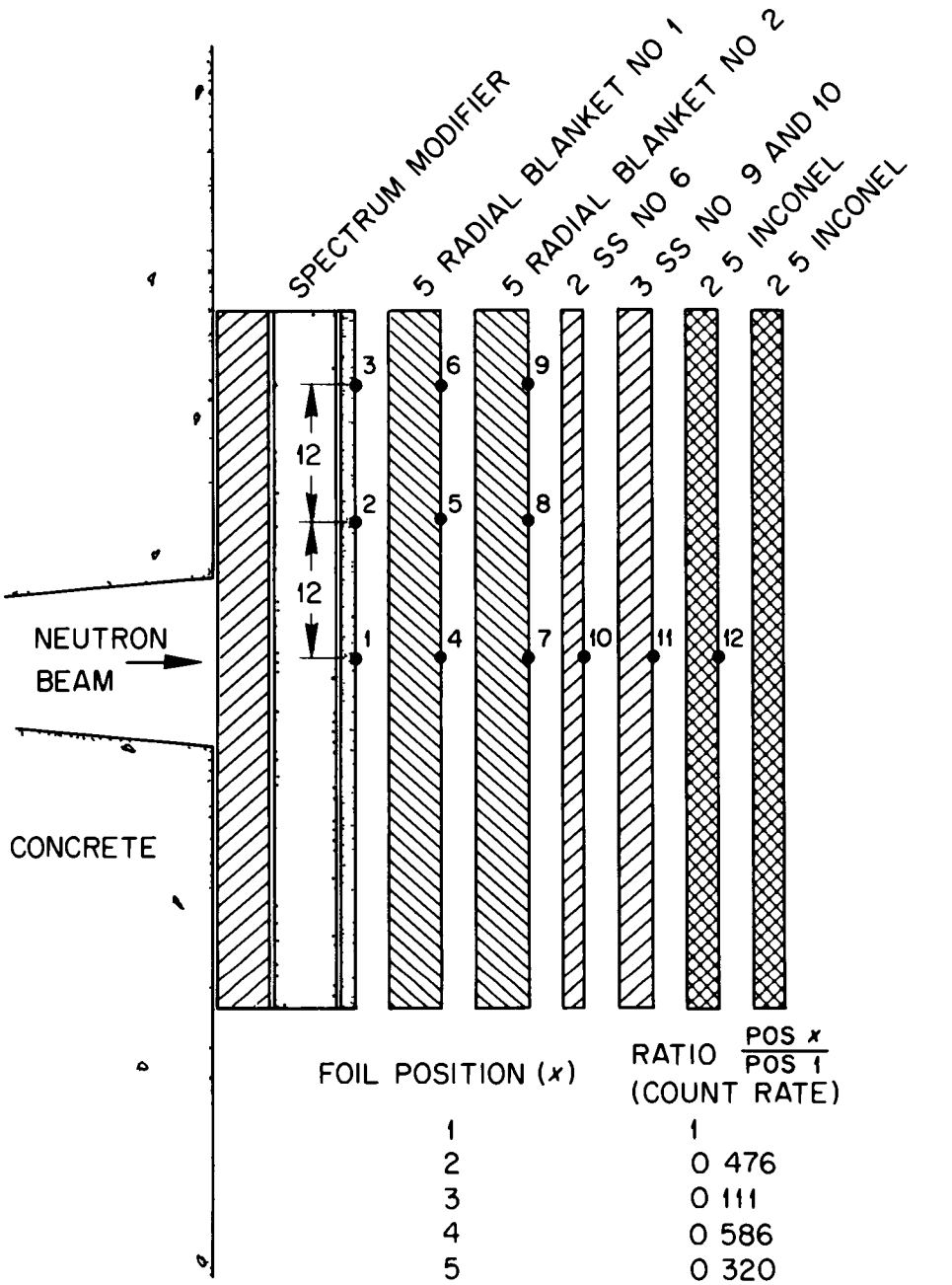

FOIL POSITION (x)	RATIO $\frac{\text{POS } x}{\text{POS } 1}$ (COUNT RATE)
1	1
2	0 476
3	0 111
4	0 586
5	0 320
6	0 0917
7	0 432
8	0 258
9	0 0762
10	0 436
11	0 340
12	0 202

DIMENSIONS ARE IN INCHES

Fig 6 Locations of Uranium Foil Exposures in CRBR Ex-Vessel Experiment

a 2 5-in -thick void in the center of the inconel restraint (see Fig 3) Comparisons of these measurements with the corresponding calculations are given in Table 10 Here the calculated and measured values for the bare ^{235}U fission counter are in better agreement than when the counter was in the graphite block, but the calculation is still low The agreement for the cadmium-covered ^{235}U detector is somewhat better than that for the bare counter In the case of the BF_3 detector, the calculation is high

Table 10 Comparison of Calculated and Measured Detector Responses in Middle of Inconel Region in CRBR Ex-Vessel Experiment

Detector	Detector Response
Bare ^{235}U (I and C)	
Calculated	1,610 fissions kW^{-1} sec^{-1} g^{-1}
Measured	2,250 fissions kW^{-1} sec^{-1} g^{-1}
Ratio Calc /Meas	0 72
Cd-Covered ^{235}U (I and C)	
Calculated	1,560 fissions kW^{-1} sec^{-1} g^{-1}
Measured	1,900 fissions kW^{-1} sec^{-1} g^{-1}
Ratio Calc /Meas	0 82
Cd-Covered BF_3 Detector	
Calculated	55,100 cpm/kW
Measured	42,300 cpm/kW
Ratio Calc /Meas	1 30

4 ANALYSIS OF MEASUREMENTS IN MODIFIED CRBR CONFIGURATION

After the analyses for the first-fission and ex-vessel experiments had been performed, an additional set of measurements[4] was made for a CRBR configuration in which the LLFM detector housing mockup had been removed The measurements were performed in a 3 5-in gap just beyond the vessel mockup A 4-in -thick iron slab following the detector served as a reflector and background shield

The calculated and measured results for the bare and cadmium-covered ^{235}U fission counter (TSF No 16) and the cadmium-covered BF_3 detector are given in Table 11 In this case the agreement for the cadmium-covered BF_3 detector is excellent and the agreement for the cadmium-covered ^{235}U detector is very good As before, the poorest agreement is for the bare ^{235}U detector

[NOTE An additional experiment was performed at the TSF in which the CRBR stored fuel itself was mocked up This experiment has been described in ORNL-TM-4868 (ref 9), which is incorrectly identified as an FTR report and the analysis will be described in ORNL-TM-5058 (ref 10)]

5 SUMMARY

In this study and the related study for FFTF,[1] reaction rates were calculated and compared with measurements for reactions sensitive to low-energy neutrons and located at several different positions in prototype radial shields The results of this limited study are, unfortunately, inconclusive and are best termed observations for further resolution

The measurements beyond the shield exit, configurations 2 and 4, were made first and later deemphasized because of the greater likelihood of end effects and background Also the bare fission and BF_3 counter measurements are deemphasized relative to the cadmium-covered measurements because of the greater problems with thermal (subcadmium) neutron background Lastly, the fission counter results are deemphasized relative to the BF_3

Table 11 Comparison of Calculated and Measured Detector Responses in Outermost Void Region in Modified CRBR Configuration[a]

Detector	Detector Response (cpm/MW)
Bare ^{235}U (TSF No 16)	
Calculated	1,660
Measured	1,990
Ratio Calc /Meas	0 83
Cd-Covered ^{235}U (TSF No 16)	
Calculated	1,470
Measured	1,570
Ratio Calc /Meas	0 94
Cd-Covered BF_3 Detector	
Calculated	53,400
Measured	54,200
Ratio Calc /Meas	0 98

[a]See Fig 7

measurements because multiple fission detectors were used with varying degrees of uncertainty in their efficiencies While the TSF No 16 detector was considered accurate and well understood, more experience and confidence is vested in the BF_3 measurements

Emphasis is then placed on internal measurements for the cadmium-covered BF_3 and ^{235}U detector the bare fission foils, and the bare ^{235}U detector measurement in the graphite LLFM box The comparisons show that the bare fission detector reaction rate in the graphite LLFM box is predicted fairly well (C/E = 0 65) For the position in the gap in the inconel restraint region, the cadmium-covered fission counter ratio is C/E = 0 82, while for the cadmium-covered BF_3 it is C/E = 1 3, a substantial inconsistency Also for the cadmium-covered fission and BF_3 detectors at the LLFM position with iron rather than graphite reflector, the C/E's are 0 94 and 0 98 The fission foil comparisons show that the

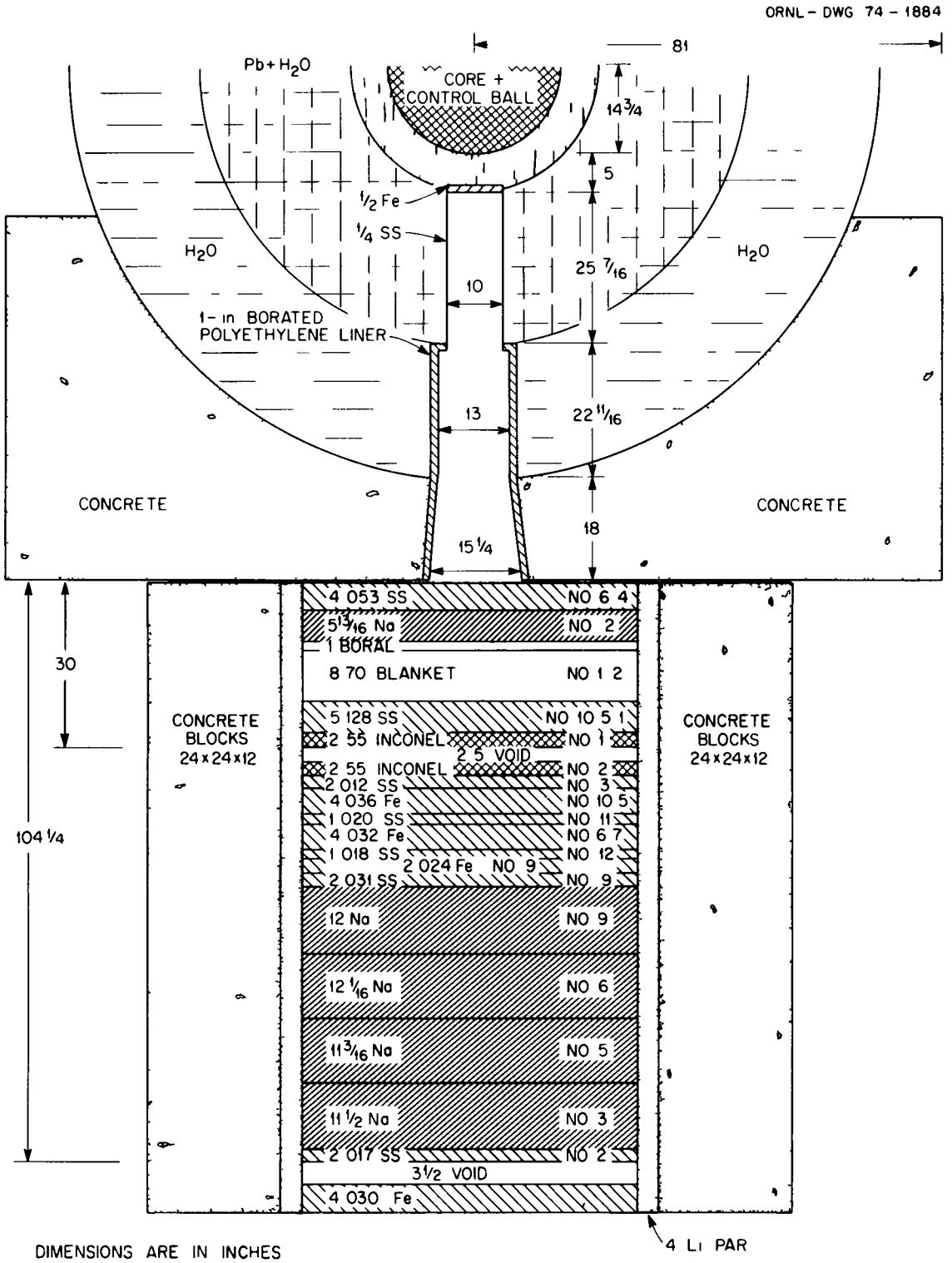

Fig 7 Modified CRBR Configuration Used for Measurements Internal to the Shield (See Table 11)

relative ^{235}U reaction rate is consistent from the front of the blanket to the inconel restraint region

The conclusions from these experiments are that the C/E for the BF_3 detector in the graphite LLFM assembly is 0 65 but that comparable C/E's in the inconel restraint region and at the LLFM position with an iron reflector are more nearly unity Subsequent to this experiment stored fuel was essentially removed from the CRBR design only five locations (three storage plus two transfer tubes) are provided and these will not be used for fuel storage during reactor operation The C/E at the stored-fuel location is 0 65 from external measurements only Because of the inconsistency of the comparisons, an uncertain (1σ) of 30/ is recommended for the LLFM position and stored-fuel position C/E's

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