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Shielding Analysis of the LMR In-Vessel Fuel Storage Experiments*

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SHIELDING ANALYSIS OF THE LMR IN-VESSEL FUEL STORAGE EXPERIMENTS

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ABSTRACT

The In-Vessel Fuel Storage (IVFS) experiments analyzed in this paper were conducted at the Oak Ridge National Laboratory's Tower Shielding Reactor (TSR) as part of the Japanese-American Shielding Program for Experimental Research (JASPER). These IVFS experiments, described in Ref. 1, were designed to study source multiplication and three-dimensional effects related to in-vessel storage of spent fuel elements in liquid metal reactor (LMR) systems. The present paper, based on Ref. 2, describes the 2- and 3-D calculations and results corresponding to a limited subset of those IVFS experiments in which the U.S. LMR program had a particular interest.

INTRODUCTION

Experimental measurements were made downstream of several different spectral modifiers including one composed of 2 iron slabs, 3 aluminum slabs, 1 boral slab, and 6 sodium-filled tanks (having a total of 205 cm of sodium), which then served as the basic spectral modifier for six additional LMR shielding configurations shown in Fig. 1. These included a radial blanket assembly mockup, a homogeneous fuel assembly mockup containing 4.81 wt% enriched fuel pins dispersed more-or-less uniformly, or a heterogeneous fuel assembly mockup containing the same fuel pins dispersed in three widely separated compartments with 15.24 cm of aluminum between each compartment (cf. Fig. 2). The latter configuration was included to determine the importance of any 3-D effects that might be overlooked in a simplified 2-D shielding anal-

ysis. Results of a 3-D XYZ TORT discrete ordinates analysis for the heterogeneous fuel slab were compared against measured results. Additional configurations were also included so as to study the relative effectiveness of placing a B₄C shield upstream vs downstream of the homogeneous fuel slab.

ANALYTIC MODELS AND DATA

All of the shielding configurations in Fig. 1 except Config. IIIA were analyzed using the 2-D RZ DORT discrete ordinates code and an S₁₂ quadrature with P₃ scattering. Each model included a standard 61-group, radially dependent, 96-direction S₁₂ boundary source just upstream of the spectral modifiers shown in Fig. 1, and each model included all of the materials (spectral modifier+shield configuration+external voids) between that boundary source and the last detector 150 to 176 cm downstream. These benchmark analyses were performed using 166 radial mesh intervals and up to 450 axial mesh intervals, with average radial and axial mesh intervals of 0.60 to 0.75 cm in the shielding materials, and axial mesh intervals of 1 to 2 cm in the external voids. Complicating the analysis was the fact that the fissile material in the IVFS fuel slabs (and the radial blanket assembly mockup) was located downstream of very thick spectral modifiers - thus requiring accurate solution of a deep penetration problem as well as tight convergence of the spectrum within the fissile material downstream. Typically 10 or 11 outer (source) iterations were required, as well as a large number of inner (spatial) iterations per outer, to ensure that the flux at all points was converged to within 0.01%. In addition to the basic analysis for each

OVERVIEW OF THE JASPER IVFS EXPERIMENTS RELATED TO THE U.S. LMR PROGRAM

Fig. 1. Overview of the JASPER In-Vessel Fuel Storage (IVFS) shielding experiments of direct interest to the US LMR program.

Fig. 2a. Top view of the calculational model used for Configuration IIIA featuring the heterogeneous IVFS fuel slab. Axially, the model includes the IVFS fuel slab and the last of six sodium tanks, with a 3-D XYZ boundary source located at what would have been the interface between the fifth and sixth sodium tanks.

configuration, each was also analyzed using a large concrete ring (270.8 cm ID x 21.7 cm thick) extending 83.11 cm past the experimental test specimens in order to simulate background radiation scattering off the concrete pad on the ground, downstream of the experimental mockup - i.e., each mockup except Config IIIA was analyzed with and without this concrete ring.

Config. IIIA with the heterogeneous fuel slab illustrated in Figs. 2a and 2b was analyzed using the 3-D XYZ TORT discrete ordinates code and an S_{12} quadrature with P_3 scattering. This particular model included only those materials shown in Figs. 2a and 2b - i.e., it included only the last of the 6 sodium tanks and used a 61-group S_{12} position-dependent boundary source at that location based on the flux solution for Config. IIIB which was identical except for the arrangement of fuel pins in the homogeneous IVFS fuel slab. Unlike the fine mesh DORT analyses for the other configurations, the 3-D XYZ (30x57x32 mesh) model used here included a much coarser spatial mesh to minimize the CPU time. The mesh intervals in the fuel (1.95 cm x 3.80 cm x 1.56 cm, typically) were 2 to 4 times larger in each direction than those in the 2-D RZ models, while those in the environmental concrete shield off to the side were up to 4 cm thick in the Z direction and measured anywhere from 4 cm x 4 cm to 22 cm x 22 cm in the X and Y directions. Analyses were performed using the standard theta-weighted difference scheme and the slower but more accurate nodal method which is better suited for large intervals.

Fig. 2b. Cross section through the heterogeneous IVFS fuel slab corresponding to View AA in Fig. 2a for Config. IIIA.

One purpose of these benchmark analyses was to validate the VELM 61-group cross section library (Ref. 3) which had been developed specifically for sodium-cooled reactor shielding analyses based on a prototype LMR shield configuration involving an LMR spectrum followed by 1 ft of stainless steel, 15.1 ft of sodium, 3 ft of carbon steel, and 1.5 ft of lithium hydride. In the IVFS analyses, the VELM sodium cross sections closest to the source were used for the first 3 sodium tanks, while the VELM sodium data from the second (asymptotic) region was used for the next 2 tanks, and the VELM data from the third region (closest to the more absorptive carbon steel) was used for the sodium closest to the IVFS fuel slab or radial blanket assembly. Exceptions to the use of the original ANISN-formatted VELM cross section were made for the U-235 and U-238 in the IVFS fuel slabs and the radial blanket assembly mockup. Bonner ball responses based on initial calculations for Config. IIIF using that infinitely dilute cross-section data were all 1.86 to 1.92 times too low relative to the measured responses. Once the proper resonance self-shielded cross sections were used instead, the calculated Bonner ball responses 30 cm downstream of the shield were all found to be within 5 to 7% of the measured responses. Resonance self-shielded data for U-235 and U-238 was therefore used throughout.

Response functions for the 3, 4, 5, 8, 10, and 12-inch Bonner ball detectors were taken directly from the VELM 61-group cross section library, while those for the bare and cadmium-covered fission chambers were based on a simplified 1-D analysis of those detectors. Responses for the Bonner balls were calculated by averaging the calculated multigroup fluxes over that hemispherical portion of the detector facing the center of the experimental test specimen.

RESULTS

Table 1 shows comparisons of the calculated and measured Bonner ball responses on the centerline of the system at various distances downstream of each configuration shown in Fig. 1. The most reliable measurements of the fast, intermediate, and epithermal neutron fluxes were made with the 12, 10, 8, 5, 4, and 3-inch Bonner balls located along the centerline of the system, 30 cm downstream of the various con-

figurations. Because the calculated and measured responses at this location are less affected by background radiation, these C/E ratios provide the best and most meaningful indications of how well the codes and cross-section data can predict the transport of neutrons through the shielding configurations of interest. Excluding the results for Config. IIIE (discussed below), these comparisons show that 57% of the 108 remaining calculated values were within 5% of the measured values, while 92% were within 10% of the measured values, and the remainder were within 17% of the measured values. Results for the Config. IIIE with the B₄C slab directly upstream of the IVFS fuel slab are an exception for some yet unexplained reason. There, the C/E ratios were generally between 1.30 and 1.35. [Although the calculational uncertainty in this case is somewhat higher, this greater uncertainty is (from a design viewpoint) more than offset by the significantly lower fluxes actually present with the B₄C slab upstream of the IVFS fuel slab - i.e., while placing the B₄C slab downstream of the IVFS fuel slab (Config. IIID) reduced the fast and intermediate flux by a factor of 3 relative to what it would have been without the B₄C slab (Config. IIIB), placing the B₄C slab upstream of the IVFS slab (Config. IIIE) reduced the fast and intermediate flux by an additional order of magnitude.] At 150 cm downstream of the shield, the C/E ratios are not quite as good, and depend more on how one accounts for scattered background radiation. Excluding those comparisons that did not account for background radiation at all (denoted by footnote "c" alone), as well as those for Config. IIIE, one sees that 43% of the 90 remaining calculated values were within 5% of the measured values, while 73% were within 10% of the measured values, and 96% were within 20% of the measured values.

Table 2 shows comparisons of calculated and measured Bonner ball responses along a horizontal ($\pm X$) traverse 30 cm downstream of the heterogeneous and homogeneous LMR shield mockups corresponding to Configs. IIIA and IIIB. Agreement over the first ± 45 cm directly in front of the IVFS fuel slab (see Fig. 2a) is considered excellent. C/E ratios at points more than 70 or 80 cm off the centerline (i.e., in front of the lithiated paraffin and close to the concrete) are now known to have been affected by small modeling uncertainties and inconsistencies associated with the exact place-

Table 1. Comparison of calculated and measured Bonner ball responses on the centerline at various distances downstream of the various configurations shown in Fig.1. Shown here are the C/E ratios.

Config(a)	Location	3-inch BB	4-inch BB	5-inch BB	8-inch BB	10-inch BB	12-inch BB
IA (b)	30 cm	0.966	0.971	0.939	0.926	0.982	0.968
IA (c)	30 cm	0.904	0.932	0.909	0.908	0.967	0.957
IA/PB (b)	25 cm	0.989	-----	0.965	-----	0.918	-----
IA/PB (c)	25 cm	0.896	-----	0.925	-----	0.899	-----
IB (b)	30 cm	1.011	0.929	0.903	0.914	0.881	0.913
IB (c)	30 cm	0.952	0.895	0.876	0.896	0.866	0.899
IC (b)	30 cm	1.080	1.013	1.029	1.026	1.028	0.983
IC (c)	30 cm	1.072	1.007	1.024	1.021	1.023	0.978
IC/PB (b)	25 cm	1.029	-----	0.985	-----	0.983	-----
IC/PB (c)	25 cm	1.013	-----	0.973	-----	0.973	-----
IIIA (e,c)	30 cm	0.944	0.932	0.955	0.967	0.956	0.938
IIIA (f,c)	30 cm	0.957	0.943	0.961	0.961	0.949	0.934
IIIB (b)	30 cm	1.133	1.081	1.069	1.068	1.054	1.055
IIIB (c)	30 cm	1.102	1.056	1.047	1.052	1.041	1.044
IIIC (b)	30 cm	1.167	1.110	1.116	1.088	1.044	1.024
IIIC (c)	30 cm	1.139	1.085	1.092	1.069	1.029	1.011
IIID (b)	30 cm	1.140	1.084	1.067	1.054	1.027	1.007
IIID (c)	30 cm	1.070	1.049	1.041	1.039	1.016	0.998
IIIE (b)	30 cm	1.442	1.353	1.327	1.305	1.282	1.183
IIIE (c)	30 cm	1.389	1.319	1.298	1.284	1.264	1.167
IIIF (b)	30 cm	1.036	1.014	0.987	0.995	1.000	0.969
IIIF (c)	30 cm	0.937	0.962	0.948	0.972	0.982	0.955
IA (b)	150 cm	1.057	1.036	1.022	1.025	1.039	0.978
IA (c)	150 cm	0.801	0.863	0.880	0.923	0.954	0.912
IA (c,d)	150 cm	0.955	0.965	0.961	0.980	1.008	0.954
IB (b)	150 cm	1.080	0.992	0.958	0.971	0.952	0.943
IB (c)	150 cm	0.836	0.831	0.825	0.872	0.871	0.877
IB (c,d)	150 cm	0.991	0.927	0.899	0.924	0.918	0.921
IB (b)	179.1 cm	0.994	-----	0.946	-----	0.931	-----
IB (c)	179.1 cm	0.808	-----	0.846	-----	0.871	-----
IB (c,d)	179.1 cm	0.981	-----	0.940	-----	0.931	-----
IC (b)	150 cm	1.116	1.043	1.072	1.035	1.038	1.026
IC (c)	150 cm	1.041	0.980	1.010	0.981	0.988	0.981
IC (c,d)	150 cm	1.156	1.078	1.109	1.068	1.078	1.074
IIIB (b)	150 cm	1.098	1.155	1.191	1.191	1.164	1.143
IIIB (c)	150 cm	0.955	1.026	1.071	1.101	1.091	1.082
IIIB (c,d)	150 cm	1.012	1.080	1.124	1.670	1.128	1.118
IIIC (b)	150 cm	1.102	1.054	1.099	1.073	1.028	1.006
IIIC (c)	150 cm	0.979	0.944	0.990	0.981	0.949	0.937
IIIC (c,d)	150 cm	1.056	1.011	1.057	1.035	0.995	0.982
IIID (b)	150 cm	1.390	1.281	1.249	1.205	1.179	1.130
IIID (c)	150 cm	1.057	1.092	1.100	1.107	1.100	1.068
IIID (c,d)	150 cm	1.200	1.162	1.154	1.142	1.132	1.097
IIIE (b)	150 cm	1.253	1.285	1.349	1.323	1.269	1.187
IIIE (c)	150 cm	1.022	1.120	1.200	1.209	1.174	1.112
IIIE (c,d)	150 cm	1.164	1.227	1.299	1.280	1.238	1.169
IIIF (b)	150 cm	1.106	1.055	1.061	1.049	1.059	1.039
IIIF (c)	150 cm	0.788	0.862	0.904	0.943	0.973	0.971
IIIF (c,d)	150 cm	0.947	0.961	0.984	0.997	1.027	1.021

- (a) See Fig.1 for a brief description of each shield configuration.
(b) With extended concrete ring in calculation to simulate background radiation.
(c) Without extended concrete ring in calculation to simulate background radiation.
(d) Alternate C/E ratio for this Config = Calculated/Measured(Foreground-Background).
(e) 3-D TORT analysis performed using the (faster) theta-weighted difference technique.
(f) 3-D TORT analysis performed using the (slower, but more accurate) nodal method.

Table 2. Comparisons of calculated and measured Bonner ball responses along a horizontal traverse 30 cm downstream of the heterogeneous and homogeneous LMR shield mockups corresponding to Configs. IIIA and IIIB.

Distance from the centerline (cm)	Measured response for IIIA in CPS		C/E ratios for 3-inch Bonner ball				C/E ratios for 10-inch Bonner ball			
			IIIA		IIIB		IIIA		IIIB	
	3"BB	10"BB	(a,c)	(b,c)	(d)	(e)	(a,c)	(b,c)	(d)	(e)
100 South	----	---	-----	-----	1.209	0.771	-----	-----	0.543	0.458
90	0.88	----	0.546	0.530	-----	-----	-----	-----	-----	-----
80	-----	-----	-----	-----	1.202	1.003	-----	-----	1.130	1.049
79.5	-----	1.36	-----	-----	-----	-----	0.908	0.878	-----	-----
70	1.71	1.95	0.778	0.785	-----	-----	0.883	0.880	-----	-----
60	-----	-----	-----	-----	1.336	1.251	-----	-----	1.106	1.071
50	4.23	4.21	0.968	1.047	1.231	1.176	0.939	0.942	1.058	1.033
40	5.83	5.55	0.927	0.949	1.124	1.081	0.969	0.969	1.038	1.018
30	7.14	6.87	0.910	0.920	1.115	1.079	0.955	0.949	1.031	1.015
20	8.19	7.89	0.955	0.958	1.090	1.058	0.954	0.950	1.026	1.012
15	8.55	8.31	0.932	0.965	-----	-----	0.949	0.946	-----	-----
10	8.77	8.53	1.014	0.989	1.094	1.063	0.957	0.953	1.031	1.018
5	8.86	8.78	1.001	1.015	-----	-----	0.945	0.941	-----	-----
0	8.84	8.72	0.946	0.959	1.117	1.087	0.955	0.948	1.043	1.030
5	8.84	8.76	1.004	1.017	-----	-----	0.947	0.943	-----	-----
10	8.67	8.59	1.026	1.000	1.106	1.074	0.950	0.946	1.046	1.033
15	8.38	8.35	0.951	0.985	-----	-----	0.945	0.942	-----	-----
20	7.95	7.93	0.984	0.987	1.111	1.077	0.949	0.945	1.048	1.033
30	6.77	6.97	0.959	0.971	1.124	1.088	0.941	0.936	1.062	1.045
40	5.52	5.74	0.979	1.002	1.151	1.107	0.937	0.937	1.091	1.070
50	3.90	4.30	1.050	1.136	1.281	1.224	0.919	0.922	1.128	1.101
60	-----	-----	-----	-----	1.401	1.312	-----	-----	1.180	1.143
70	1.54	1.97	0.864	0.872	1.328	1.193	0.874	0.871	1.198	1.143
80	-----	1.33	-----	-----	-----	-----	0.914	0.880	-----	-----
88 North	0.87	-----	0.640	0.633	-----	-----	-----	-----	-----	-----

- (a) 3-D XYZ TORT analysis performed using the (faster) theta-weighted difference technique.
(b) 3-D XYZ TORT analysis performed using the (slower, but more accurate) nodal method.
(c) 3-D XYZ TORT analysis, without extended concrete ring to simulate background radiation.
(d) 2-D RZ DORT analysis, with extended concrete ring to simulate background radiation.
(e) 2-D RZ DORT analysis, without extended concrete ring to simulate background radiation.

ment of the concrete blocks in that region, and therefore should be discounted heavily. While the horizontal traverses 30 cm downstream of the heterogeneous IVFS fuel slab (IIIA) did not show any visible peaks or depressions in the flux, three-dimensional effects were still present as evidenced by the fact that the 12-inch Bonner ball response at the centerline was 16% lower than that for the homogeneous IVFS fuel slab, while the 3-inch Bonner ball response there was 55% higher, and the thermal flux as measured by the bare fission chamber 30 cm downstream of the IVFS fuel slab was 2.0 times higher than that for the homogeneous IVFS fuel slab.

Thermal and epithermal background radiation was a severe problem – both experimentally and calculationally. Figs. 3a, 3b, and 3c show the components of the thermal and epithermal flux (T and E) that are actually measured by a bare fission chamber di-

rectly downstream of the shield, downstream of a cadmium plate in front of the shield, and inside a cadmium hut enclosing both the detector and the shield. With these measurements, plus those from a cadmium covered fission chamber, one can only infer at most four groups of parameters: $(T_s + T_{EBRT})$, (T_B) , (T_{TBRT}) , and $(E_s + E_B + E_{EBRE})$, where the subscript $EBRE$, for example, denotes epithermal background radiation that gets reflected back off the face of the configuration as epithermal radiation, and $EBRT$ denotes epithermal background that gets reflected back as thermal. Note that the thermal flux coming "directly from the shield" (T_s) cannot be measured by itself. Analytically, all three experimental variations illustrated in Fig. 3 were modeled separately for each of the basic configurations in Fig. 1. These calculations were all performed both with and without the previously described extended concrete ring to simulate thermal background radiation. Table 3 shows the resulting fre-

Fig. 3a. Thermal and epithermal components of the flux measured by a bare fission chamber downstream of the basic shield configuration. Nomenclature is defined in the text.

Fig. 3b. Thermal and epithermal components of the flux measured by a bare fission chamber downstream of a cadmium plate placed over the face of the shield configuration.

Fig. 3c. Thermal and epithermal components of the flux measured by a bare fission chamber located inside a cadmium hut placed over the face of the shield configuration.

quency distribution of the C/E ratios for all of the bare and Cd-covered fission chamber measurements for all of the IVFS shielding experiments. When care was taken to artificially simulate background radiation in the calculational models, the most reliable data (at 0.7 cm downstream of the shield) showed that 45% of the calculated bare and Cd-covered fission chamber responses were within 5% of the corresponding measured values, that 76% of the calculated values were within 10% of the measured values, and that 93% of the calculated values were within 15% of the corresponding measured values along the centerline. With no simulation of thermal neutron background radiation, the calculated bare and Cd-covered fission chamber responses

sometimes underpredicted the measured responses by as much as a factor of 2 or 3. [Fortunately, this is only a problem for experimenters and experimental analysts, and is not a problem for shielding design engineers and analysts who seldom (if ever) have to worry about thermal neutron background radiation.] In those few cases where the measured thermal neutron background radiation appeared to be relatively negligible, the calculated values generally appeared to be within 5 to 15% of the measured values.

CONCLUSION

The fine mesh 2-D DORT results and 3-D TORT results for these deep penetration problems having fissile material far downstream are in excellent agreement with the measured results (generally within 10%), thus validating both the codes and the VELM cross-section library for this type of LMR shielding analysis. Resonance self-shielding of the fissile material, however, was found to be quite important. Three-dimensional effects associated with the heterogeneous IVFS fuel slab were manifested as generally lower fast flux levels and generally higher thermal flux levels downstream of the IVFS fuel slab. These 3-D effects were accurately calculated by the 3-D TORT code. Of all the configurations studied, only Config. III E (with the B₄C slab upstream of the IVFS fuel slab) seemed to overpredict the flux substantially (i.e., by 30-35%). While studied extensively, the cause of this peculiar behavior for this one configuration is still unknown.

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Table 3. Frequency distribution of the C/E ratios for all bare and Cd-covered fission chamber measurements in all of the IVFS shielding experiments.

Config	C/E at 0.7 cm	Config	C/E at 30 cm	Config	C/E at 150 cm
IIIF NB	0.473 (b)	IIIF NB	0.356 (b)	IIIE NB	0.130 (b)
IIIA RB	0.640 (b,a)	IA NB	0.452 (b)	IC NB	0.216 (b)
IIIA NB	0.683 (b,a)	IB NB	0.633 (b)	IIIF NB	0.225 (b)
IIIE NB	0.690 (b)	IA NC	0.634 (b)	IIID NB	0.338 (b)
IIIA RC	0.751 (b,a)	IIID NB	0.677 (b)	IB NB	0.372 (b)
IIIA NC	0.788 (b,a)	IIIF NC	0.704 (b)	IIIB NB	0.439 (b)
IIID NB	0.809 (b)	IIIA NB	0.705 (b)	IIIE RB	0.500
IIIF NC	0.809	IIIA RB	0.712	IA NC	0.534
IIIF RB	0.866	IB NC	0.750	IIIE NC	0.548
IIIF NB	0.866	IIIF H	0.758	IIIE P	0.587
IIIF H	0.869	IIIA NC	0.760	IIIF NC	0.606
IIIB H	0.894	IA RC	0.775	IB NC	0.659
IIIC H	0.918	IIIA RC	0.782	IIIC NB	0.725 (b)
IIID NC	0.920	IIID NC	0.849	IIID NC	0.764
IIIB NB	0.926	IC NB	0.880	IIIB NC	0.795
IC NB	0.927	IIIE NB	0.896	IIIC NC	0.824
IC H	0.953	IC P	0.901	IC NB	0.836
IIID H	0.958	IB RC	0.908	IIIB RB	0.892
IIIC NB	0.976	IC H	0.924	IC NC	0.907
IC NC	0.979	IIIC H	0.930	IIIF RB	0.927
IIIB NC	0.992	IC RB	0.952	IIIE RC	0.930
IC RB	1.000 (c)	IC NC	0.956	IIIF P	0.950
IC RC	1.000 (c)	IIIF RC	0.965	IA RC	0.959
IIIF RC	1.003	IIID H	0.967	IA RB	0.975
IIIE H	1.004	IC RC	0.974	IIIB RC	0.982
IIIF RB	1.010	IIIC NB	0.992	IIIC RC	0.987
IIIC NC	1.021	IA RB	0.994	IC RC	1.008
IIIE NC	1.026	IIIF RB	1.012	IC P	1.034
IIIB RC	1.027	IIIB NC	1.020	IC RB	1.080
IIIF RC	1.049	IIIC NC	1.022	IIIC P	1.112
IIIF NC	1.049	IIID RC	1.038	IB RC	1.151
IIID RC	1.053	IIIC RC	1.068	IIIB P	1.184
IIIC RC	1.054	IIIB RC	1.071	IIIF RC	1.203
IIIE RB	1.058	IIIB NB	1.083	IIIC RB	1.206
IIIB RB	1.064	IIIC P	1.103	IB RB	1.320
IIIC RB	1.095	IIIB H	1.108	IIID RC	1.433 (d)
IIIE RC	1.153	IIIE P	1.125	IIID RB	1.607 (d)
IIID RB	1.335 (d)	IIIF P	1.160	IIID P	1.609 (d)
		IIIB P	1.170		
		IIIC RB	1.173		
		IIIE RB	1.181		
		IB RB	1.188		
		IIIE NC	1.199		
		IIIB RB	1.265		
		IIIE H	1.270		
		IIIE RC	1.330		
		IIID RB	1.382 (d)		
		IIID P	1.382 (d)		

(R,N) Model used/did not use concrete ring to simulate background radiation.

(B,C) Denotes measurements with a bare/cadmium-covered fission chamber.

(H,P) Measurements with a bare fission chamber inside a Cd-hut/behind Cd-plate.

(a,d) See discussion of these results for Config IIIA/Config IIID in the text.

(b) These particular values should not be included in any overall judgements of quality for the reasons described in the text. Generally these models were not applicable since they had no mechanism for accounting for thermal and epithermal neutron background radiation to which the detectors are sensitive.

(c) Likewise, these two values for Config IC.6 should not be included since these two measured values were used to normalize the detector response functions.

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END