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UCRL - 74277 Rev. I
PREPRINT

REVISED 1/19/73

Conf-72117-- 2

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CALCULATIONAL MODELS FOR LLL PULSED SPHERES

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October 1972

Revised January 19, 1973

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THIS PAPER WAS PREPARED FOR SUBMISSION TO
The Data Testing Sub-Committee of the
Cross Section Evaluation Working Group

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CALCULATIONAL MODELS FOR LLL PULSED SPHERES*

Ernest F. Plechaty

Abstract

Calculational models for LLL pulsed spheres are presented, together with a discussion of the effects of simplifications. Data relevant to detector response functions, pertinent geometric configurations and all other information required to calculate time spectra of detected neutrons are included.

INTRODUCTION

The pulsed sphere experiments done at LLL^{1,2} represent a set of simple geometric and material configurations for integral testing of neutron cross section evaluations at high energies. Reference 1 contains all the detailed experimental information and it will not be reproduced. A rather brief synopsis of the salient features necessary for understanding and doing meaningful calculation is included.

* This work was performed under the auspices of the U.S. Atomic Energy Commission.

MASTER

EXPERIMENTAL METHOD

The experiment is a ratio of counts with the sphere material in, to the counts with the sphere material out. Because of this experimental method neither the low mass target assembly, detector collimator, nor the air in the flight path between the target and the detector have any significant effect on the experimental data. The counting rate from neutrons scattering from the target assembly and collimator with the sphere out is 3 orders of magnitude less than the peak (uncollided neutrons) value. Therefore, only calculated values with the sphere in that have the same peak to valley changes in counting rate will be affected. This effect is only significant for Pb, U^{235} , U^{238} and Pu^{239} . The nominal 14.0 MeV source pulse from the ICT accelerator has a time behavior that is nearly Gaussian in shape, and this time spread in the source is characterized by its full width at half maximum (FWHM). The NE213 and PILOT-B scintillators were 5.08 cm diameter x 5.08 cm long. The pulsed sphere experimental data for U^{235} , U^{238} and Pu^{239} is not available in Ref. 1. These data will be published as an addendum to Ref. 1.

CALCULATIONAL MODELS

In the calculation, the time of arrival and the neutron energy are used in conjunction with a detector response function to calculate the experimental counting as a function of time. The efficiency of the detector is given as the product of the detector area A and the probability of detection ϵ . The neutron energy dependent response functions for PILOT-B and NE 213 are given in Tables I and II respectively. Table III has the energy-angle correlated source spectrum. The source is distributed uniformly over a disk of radius .62 cm located at the origin of the spherical material.

Figures 1 and 2 give the basic geometric description. Zero degrees for the source is along the Z axis in the positive direction.

The air between the sphere and the detector should not be included because it has been corrected for in the experiment. Some of the spheres had a very thin cladding for structural or safety reasons. The results were not altered by eliminating the cladding from the calculation. Appendix A gives the necessary information when used with figures 1 and 2 for calculation of the pulsed sphere experiments.

REFERENCES

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2. L.F. Hansen et al., Nucl. Sci. Eng. 35, 227 (1969); L.F. Hansen et al., Nucl. Sci. Eng. 40, 262 (1970); L.F. Hansen et al., "Sensitivity of Monte Carlo Calculations to the Neutron Cross Sections for Neutron Transport in Nitrogen and in Air," UCRL-51031, Lawrence Livermore Laboratory (1971); M. Stelts et al., Nucl. Sci. Eng. 46, 53 (1971); P.S. Brown et al., Trans. Am. Nucl. Soc. 14, 398 (1971).

Table I. PILOTB Detector Response Function

E(MeV)	A ϵ	E(MeV)	A ϵ	E(MeV)	A ϵ
1.600	0.001	6.600	4.791	11.600	3.733
1.700	0.669	6.700	4.747	11.700	3.716
1.800	1.239	6.800	4.720	11.800	3.700
1.900	1.727	6.900	4.684	11.900	3.685
2.000	2.151	7.000	4.641	12.000	3.670
2.100	2.515	7.100	4.615	12.100	3.657
2.200	2.833	7.200	4.568	12.200	3.643
2.300	3.108	7.300	4.479	12.300	3.630
2.400	3.349	7.400	4.429	12.400	3.618
2.500	3.558	7.500	4.400	12.500	3.608
2.600	3.726	7.600	4.362	12.600	3.598
2.700	3.887	7.700	4.340	12.700	3.588
2.800	4.010	7.800	4.325	12.800	3.580
2.900	4.088	7.900	4.320	12.900	3.573
3.000	4.242	8.000	4.309	13.000	3.565
3.100	4.366	8.100	4.313	13.100	3.560
3.200	4.408	8.200	4.317	13.200	3.557
3.300	4.446	8.300	4.316	13.300	3.556
3.400	4.483	8.400	4.314	13.400	3.556
3.500	4.527	8.500	4.304	13.500	3.557
3.600	4.572	8.600	4.296	13.600	3.560
3.700	4.615	8.700	4.287	13.700	3.571
3.800	4.660	8.800	4.278	13.800	3.583
3.900	4.707	8.900	4.260	13.900	3.600
4.000	4.774	9.000	4.243	14.000	3.613
4.100	4.765	9.100	4.216	14.100	3.625
4.200	4.766	9.200	4.189	14.200	3.638
4.300	4.761	9.300	4.171	14.300	3.651
4.400	4.786	9.400	4.153	14.400	3.664
4.500	4.807	9.500	4.136	14.500	3.677
4.600	4.824	9.600	4.120	14.600	3.690
4.700	4.832	9.700	4.103	14.700	3.703
4.800	4.835	9.800	4.086	14.800	3.716
4.900	4.839	9.900	4.066	14.900	3.729
5.000	4.845	10.000	4.045	15.000	3.741
5.100	4.846	10.100	4.030	15.100	3.753
5.200	4.847	10.200	4.006	15.200	3.765
5.300	4.845	10.300	3.985	15.300	3.777
5.400	4.840	10.400	3.960	15.400	3.789
5.500	4.836	10.500	3.943	15.500	3.801
5.600	4.833	10.600	3.920	15.600	3.813
5.700	4.833	10.700	3.900	15.700	3.825
5.800	4.836	10.800	3.880	15.800	3.837
5.900	4.840	10.900	3.860	15.900	3.849
6.000	4.842	11.000	3.840	16.000	3.861
6.100	4.844	11.100	3.820		
6.200	4.840	11.200	3.800		
6.300	4.832	11.300	3.783		
6.400	4.820	11.400	3.766		
6.500	4.805	11.500	3.750		

Table II. NE213 Detector Response Function

E(MeV)	A ϵ	E(MeV)	A ϵ	E(MeV)	A ϵ
1.600	0.003	6.600	4.155	11.600	3.116
1.700	0.615	6.700	4.126	11.700	3.101
1.800	1.139	6.800	4.107	11.800	3.088
1.900	1.586	6.900	4.091	11.900	3.074
2.000	1.974	7.000	4.069	12.000	3.062
2.100	2.306	7.100	4.050	12.100	3.050
2.200	2.596	7.200	4.020	12.200	3.040
2.300	2.846	7.300	3.954	12.300	3.031
2.400	3.065	7.400	3.918	12.400	3.022
2.500	3.255	7.500	3.898	12.500	3.013
2.600	3.417	7.600	3.882	12.600	3.006
2.700	3.555	7.700	3.830	12.700	2.998
2.800	3.668	7.800	3.814	12.800	2.992
2.900	3.744	7.900	3.805	12.900	2.988
3.000	3.876	8.000	3.787	13.000	2.984
3.100	3.984	8.100	3.767	13.100	2.982
3.200	4.027	8.200	3.771	13.200	2.981
3.300	4.064	8.300	3.761	13.300	2.980
3.400	4.100	8.400	3.744	13.400	2.980
3.500	4.140	8.500	3.727	13.500	2.981
3.600	4.180	8.600	3.704	13.600	2.982
3.700	4.217	8.700	3.684	13.700	2.987
3.800	4.255	8.800	3.663	13.800	2.992
3.900	4.294	8.900	3.641	13.900	2.998
4.000	4.325	9.000	3.618	14.000	3.004
4.100	4.342	9.100	3.588	14.100	3.010
4.200	4.344	9.200	3.562	14.200	3.016
4.300	4.340	9.300	3.542	14.300	3.021
4.400	4.359	9.400	3.525	14.400	3.027
4.500	4.375	9.500	3.506	14.500	3.032
4.600	4.388	9.600	3.486	14.600	3.038
4.700	4.392	9.700	3.468	14.700	3.043
4.800	4.392	9.800	3.450	14.800	3.049
4.900	4.389	9.900	3.429	14.900	3.055
5.000	4.386	10.000	3.410	15.000	3.061
5.100	4.379	10.100	3.393	15.100	3.067
5.200	4.371	10.200	3.375	15.200	3.073
5.300	4.362	10.300	3.355	15.300	3.078
5.400	4.353	10.400	3.333	15.400	3.083
5.500	4.332	10.500	3.312	15.500	3.087
5.600	4.318	10.600	3.293	15.600	3.092
5.700	4.304	10.700	3.275	15.700	3.097
5.800	4.286	10.800	3.255	15.800	3.102
5.900	4.269	10.900	3.238	15.900	3.106
6.000	4.250	11.000	3.217	16.000	3.110
6.100	4.228	11.100	3.200		
6.200	4.199	11.200	3.180		
6.300	4.102	11.300	3.162		
6.400	4.167	11.400	3.148		
6.500	4.155	11.500	3.130		

Table III. Neutron Source from Nominal 200 keV Deuterons

Angle (deg)	Energy (MeV)	Intensity
0	15.11	1.00
5	15.10	1.00
10	15.09	1.00
15	15.07	1.00
20	15.04	1.00
25	15.01	0.99
30	14.97	0.99
35	14.92	0.99
40	14.87	0.98
45	14.81	0.98
50	14.75	0.98
55	14.68	0.97
60	14.60	0.97
65	14.53	0.96
70	14.45	0.96
75	14.37	0.95
80	14.29	0.95
85	14.20	0.94
90	14.12	0.94
95	14.04	0.93
100	13.95	0.92
105	13.87	0.92
110	13.80	0.91
115	13.72	0.91
120	13.65	0.90
125	13.58	0.90
130	13.52	0.90
135	13.46	0.89
140	13.41	0.89
145	13.36	0.88
150	13.32	0.88
155	13.28	0.88
160	13.25	0.87
165	13.23	0.88
170	13.21	0.87
175	13.20	0.87
180	13.20	0.87

SURFACE 1, is either a cone or a cylinder specified by $X^2 + Y^2 + C(Z - Z_0)^2 = K^2$.

SURFACE 2, is a sphere specified by $X^2 + Y^2 + Z^2 = R^2$.

SURFACE 3, is a plane at $Z = M_Z$.

Figure 1. GEOMETRY TYPE I.

SURFACE 1, is a cylinder specified by $X^2+Y^2 = K^2$.

SURFACE 2 and 3, are spheres specified by $X^2+Y^2+Z^2 = R_{2,3}^2$.

Figure 2. GEOMETRY TYPE II.

APPENDIX A

DESCRIPTION OF PULSED SPHERE MODELS

LITHIUM-6

Figure 1

SURFACE 1

$$C = -3.64618 \times 10^{-3}, Z_0 = 25.117, K = \phi.\phi$$

SURFACE 2

$$R = 8.912$$

SURFACE 3

$$M_Z = .64$$

DETECTOR DESCRIPTION

$$FWHM = 4 \text{ NS}$$

DETECTOR TYPE

$$30^\circ \text{ PILOT-B, } 120^\circ \text{ NE213}$$

DISTANCE FROM CENTER OF SPHERE TO DETECTOR IN CM.

$$30^\circ 765.2, 120^\circ 977.2$$

MATERIAL DENSITY

$$.451 \text{ g/cm}^3$$

MATERIAL COMPOSITION (ATOM FRACTIONS)

$$\text{Li}^6 .95 \quad \text{Li}^7 .05$$

LITHIUM-7

Figure 1

SURFACE 1

$$C = -3.64618 \times 10^{-3}, Z_0 = 25.117, K = \phi.\phi$$

SURFACE 2

$$R = 8.912$$

SURFACE 3

$$M_Z = .64$$

DETECTOR DESCRIPTION

$$FWHM = 4 \text{ NS}$$

DETECTOR TYPE

$$30^\circ \text{ PILOT-B, } 120^\circ \text{ NE213}$$

DISTANCE FROM CENTER OF SPHERE TO DETECTOR IN CM.

$$30^\circ 765.2, 120^\circ 977.2$$

MATERIAL DENSITY

$$.515 \text{ g/cm}^3$$

MATERIAL COMPOSITION (ATOM FRACTIONS)

$$\text{Li}^7 .9739 \quad \text{Li}^6 .0261$$

BERYLLIUM

Figure 2

SURFACE 1

$$K = 2.86$$

SURFACE 2

$$R = 8.0$$

SURFACE 3

$$R = 12.58$$

DETECTOR DESCRIPTION

$$\text{FWHM} = 4 \text{ NS}$$

DETECTOR TYPE

30° PILOT-B, 120° ----

DISTANCE FROM CENTER OF SPHERE TO DETECTOR IN CM.

30° 765.2 , 120° ----

MATERIAL DENSITY

$$1.835 \text{ g/cm}^3$$

MATERIAL COMPOSITION (ATOM FRACTIONS)

Be_{1.0}

CARBON

Figure 1

SURFACE 1

$$C = \phi.\phi, Z_0 = \phi.\phi, K = 1.13$$

SURFACE 2

$$R = 4.187$$

SURFACE 3

$$M_Z = .131$$

DETECTOR DESCRIPTION

$$FWHM = 4 \text{ NS}$$

DETECTOR TYPE

$$30^\circ \text{ NE213}, 120^\circ \text{ NE213}$$

DISTANCE FROM CENTER OF SPHERE TO DETECTOR IN CM.

$$30^\circ 766.0, 120^\circ 975.2$$

MATERIAL DENSITY

$$1.866$$

MATERIAL COMPOSITION (ATOM FRACTIONS)

$$C_{1.0}$$

NITROGEN

Figure 1

SURFACE 1

$$C = -.00476, z_0 = 18.9, K = \phi.\phi$$

SURFACE 2

$$R = 19.05$$

SURFACE 3

$$M_Z = .782$$

DETECTOR DESCRIPTION

$$FWHM = 5 \text{ NS}$$

DETECTOR TYPE

$$30^\circ \text{ PILOT-B, } 120^\circ \text{ ----}$$

DISTANCE FROM CENTER OF SPHERE TO DETECTOR IN CM.

$$30^\circ 763.3, 120^\circ \text{ ----}$$

MATERIAL DENSITY

$$.808 \text{ g/cm}^3$$

MATERIAL COMPOSITION (ATOM FRACTIONS)

$$N_{1.0}$$

OXYGEN

Figure 1

SURFACE 1

$$C = -2.70868 \times 10^{-3}, z_0 = 27.918, K = \phi.\phi$$

SURFACE 2

$$R = 10.48$$

SURFACE 3

$$M_z = .25$$

DETECTOR DESCRIPTION

$$FWHM = 5 \text{ NS}$$

DETECTOR TYPE

$$30^\circ \text{ PILOT-B, } 120^\circ \text{ ----}$$

DISTANCE FROM CENTER OF SPHERE TO DETECTOR IN CM.

$$30^\circ \text{ } 754.0, \text{ } 120^\circ \text{ ----}$$

MATERIAL DENSITY

$$1.14 \text{ g/cm}^3$$

MATERIAL COMPOSITION (ATOM FRACTIONS)

$$O_{1.0}$$

MAGNESIUM

Figure 1

SURFACE 1

$$C = -3.64618 \times 10^{-3}, Z_0 = 25.117, K = \phi.\phi$$

SURFACE 2

$$R = 8.94$$

SURFACE 3

$$M_z = .64$$

DETECTOR DESCRIPTION

$$FWHM = 4 \text{ NS}$$

DETECTOR TYPE

$$30^\circ \text{ PILOT-B, } 120^\circ \text{ NE213}$$

DISTANCE FROM CENTER OF SPHERE TO DETECTOR IN CM.

$$30^\circ 765.2, 120^\circ 977.2$$

MATERIAL DENSITY

$$1.74 \text{ g/cm}^3$$

MATERIAL COMPOSITION (ATOM FRACTIONS)

$$\text{Mg}_{1.0}$$

ALUMINUM

Figure 1

SURFACE 1

$$C = -3.64618 \times 10^{-3}, Z_0 = 25.117, K = \phi.\phi$$

SURFACE 2

$$R = 8.94$$

SURFACE 3

$$M_Z = .64$$

DETECTOR DESCRIPTION

$$FWHM = 4 \text{ NS}$$

DETECTOR TYPE

30° PILOT-B, 120° NE213

DISTANCE FROM CENTER OF SPHERE TO DETECTOR IN CM.

30° 765.2 , 120° 977.2

MATERIAL DENSITY

$$2.70 \text{ g/cm}^3$$

MATERIAL COMPOSITION (ATOM FRACTIONS)

Al_{1.0}

TITANIUM

Figure 1

SURFACE 1

$$C = -3.64618 \times 10^{-3}, Z_0 = 25.117, K = \phi.\phi$$

SURFACE 2

$$R = 8.94$$

SURFACE 3

$$M_Z = .64$$

DETECTOR DESCRIPTION

$$FWHM = 4 \text{ NS}$$

DETECTOR TYPE

$$30^\circ \text{ PILOT-B, } 120^\circ \text{ ----}$$

DISTANCE FROM CENTER OF SPHERE TO DETECTOR IN CM.

$$30^\circ 765.2, 120^\circ \text{ ----}$$

MATERIAL DENSITY

$$4.54 \text{ g/cm}^3$$

MATERIAL COMPOSITION (ATOM FRACTIONS)

$$\text{Ti}_{1.0}$$

IRON

Figure 1

SURFACE 1

$$C = -4.889 \times 10^{-3}, Z_0 = 16.365, K = \phi.\phi$$

SURFACE 2

$$R = 4.46$$

SURFACE 3

$$M_Z = .475$$

DETECTOR DESCRIPTION

$$FWHM = 3 \text{ NS}$$

DETECTOR TYPE

$$30^\circ \text{ NE213}, 120^\circ \text{ NE213}$$

DISTANCE FROM CENTER OF SPHERE TO DETECTOR IN CM.

$$30^\circ 766.0, 120^\circ 975.2$$

MATERIAL DENSITY

$$7.85 \text{ g/cm}^3$$

MATERIAL COMPOSITION (ATOM FRACTIONS)

$$\text{Fe}_{1.0}$$

LEAD

Figure 1

SURFACE 1

$$C = -3.64618 \times 10^{-3}, Z_0 = 25.117, K = \phi.\phi$$

SURFACE 2

$$R = 8.97$$

SURFACE 3

$$M_Z = .64$$

DETECTOR DESCRIPTION

$$FWHM = 3 \text{ NS}$$

DETECTOR TYPE

$$30^\circ \text{ NE213}, 120^\circ \text{ NE213}$$

DISTANCE FROM CENTER OF SPHERE TO DETECTOR IN CM.

$$30^\circ 766.0, 120^\circ 975.2$$

MATERIAL DENSITY

$$11.35 \text{ g/cm}^3$$

MATERIAL COMPOSITION (ATOM FRACTIONS)

$$\text{Pb}_{1.0}$$

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 U^{235}

Figure 1

SURFACE 1

$$C = -4.889 \times 10^{-3}, Z_0 = 16.365, K = 0.0$$

SURFACE 2

$$R = 3.145$$

SURFACE 3

$$M_Z = .475$$

DETECTOR DESCRIPTION

$$FWHM = 3 \text{ NS}$$

DETECTOR TYPE

$$30^\circ \text{ NE213}, 120^\circ \text{ NE213}$$

DISTANCE FROM CENTER OF SPHERE TO DETECTOR IN CM.

$$30^\circ 766.0, 120^\circ 975.2$$

MATERIAL DENSITY

$$18.57 \text{ g/cm}^3$$

MATERIAL COMPOSITION (ATOM FRACTIONS)

$$\begin{array}{cc} U^{235} & U^{238} \\ .932 & .068 \end{array}$$

U^{238}

Figure 1

SURFACE 1

$$C = -4.889 \times 10^{-3}, Z_0 = 16.365, K = 0.0$$

SURFACE 2

$$R = 3.63$$

SURFACE 3

$$M_Z = .475$$

DETECTOR DESCRIPTION

$$FWHM = 4 \text{ NS}$$

DETECTOR TYPE .

$$30^\circ \text{ PILOT-B, } 120^\circ \text{ NE213}$$

DISTANCE FROM CENTER OF SPHERE TO DETECTOR IN CM.

$$30^\circ 765.2, 120^\circ 977.2$$

MATERIAL DENSITY

$$17.7 \text{ g/cm}^3$$

MATERIAL COMPOSITION (ATOM FRACTIONS)

$$U^{238}_{1.0}$$

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 Pu^{239}

Figure 1

SURFACE 1

$$C = -4.889 \times 10^{-3}, Z_0 = 17.50, K = 0.0$$

SURFACE 2

$$R = 3.22$$

SURFACE 3

$$M_Z = .475$$

DETECTOR DESCRIPTION

$$\text{FWHM} = 3. \text{ NS}$$

DETECTOR TYPE

$$30^\circ \text{ NE213}, 120^\circ \text{ NE213}$$

DISTANCE FROM CENTER OF SPHERE TO DETECTOR IN CM.

$$30^\circ 766.0, 120^\circ 975.2$$

MATERIAL DENSITY

$$15.80 \text{ g/cm}^3$$

MATERIAL COMPOSITION (ATOM FRACTIONS)

$$\text{Pu}_{1.0}^{239}$$