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Experiment Summary for n/γ Attenuation through Materials (Environments 1A)

K. Russell DePriest

Prepared by Sandia National Laboratories
Albuquerque, New Mexico 87185 and Livermore, California 94550
Applied Nuclear Technologies

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K. Russell DePriest
Applied Nuclear Technologies
Sandia National Laboratories
PO Box 5800
Albuquerque, NM 87185-1146

Abstract

The Radiation Effects Sciences (RES) program is responsible for conducting Neutron Gamma Energy Transport (NuGET) code validation. In support of this task, a series of experiments were conducted in the annular core research reactor (ACRR) to investigate the modification of the incident neutron/gamma environment by aluminum (Al6061) and high-density polyethylene (HDPE) spheres with 4-in and 7-in-diameter. The experiment series described in this report addresses several NuGET validation concerns. The validation experiment series also addresses the design and execution of proper reactor testing to match the hostile radiation environments and to match the component stresses that arise from the hostile radiation environments. This report summarizes the RES Validation: n/γ Attenuation through Materials, Environments 1A, experiments conducted at the ACRR in FY 2003 using ACRR Experiment Plans 933 and 949.

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Acronyms and Abbreviations

ACRR	annular core research reactor
ACRR-CC	annular core research reactor central cavity
C/E	calculated to experimental
C7	Campaign 7
FPS	full power seconds
HDPE	high-density polyethylene
MCNP	Monte Carlo N-Particle Transport Code
MCNPX	Monte Carlo N-Particle eXtended Transport Code
NuGET	Neutron Gamma Energy Transport
RES	Radiation Effects Sciences
RML	Radiation Metrology Laboratory
SNL	Sandia National Laboratories
TLD	thermo luminescent dosimeter

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Experiment Summary for n/γ Attenuation through Materials (Environments 1A)

1.0 n/γ Attenuation through Materials (7-in-dia HDPE and Al6061 Spheres with Ni and Cd-covered Au Foils)

1.1 Introduction

A series of irradiations were performed in the annular core research reactor (ACRR) central cavity (CC) with spheres of high-density polyethylene (HDPE) and aluminum (Al6061) are given in Table 1-1. The spheres were essentially solid with cavities scrolled out along the equator to allow the insertion of activation foils. The cavities were configured in the sphere such that there were no radiation streaming paths or large void volumes. In addition to the foils located on the interior of the spheres, an external Ni activation foil was attached to the equator on the exterior of the spheres. The external Ni foil provides normalization back to the free-field reactor spectrum characterization and allows comparison between different reactor operations with the same sphere.

Table 1-1. Composition of 7-in-dia Spheres.

Material	Element	Weight %
HDPE*	Hydrogen	14.37
	Carbon	85.63
Al6061+	Magnesium	1.00
	Aluminum	96.55
	Silicon	0.60
	Titanium	0.15
	Chromium	0.20
	Manganese	0.15
	Iron	0.70
	Copper	0.25
	Zinc	0.25
	Others^	0.15

*HDPE is a polymer with a chemical formula of $-(-CH_2--CH_2-)_n-$.
+Metals Handbook, Volume 2, 10th Edition, ASM International (1990).
^"Others" is assumed to be vanadium based on another source [1].

The irradiations were carried out in the well-characterized dosimetry bucket. A centering mechanism in the bucket ensured that the equator of the sphere was located at the fuel centerline in the ACRR-CC. Only one type of activation foil was used in a given reactor run (except the external Ni foils). This section discusses the experimental results of the 7-in-dia Al6061 and HDPE spheres with Ni foils and Cd-covered Au foils. Additionally, an MCNP (Monte Carlo N-Particle Transport Code) [2] and/or MCNPX (Monte Carlo N-Particle eXtended Transport Code) [3] model of the spheres was/were created and used for comparison to the experimental results. The model uses a 640-group representation of the ACF9 neutron energy spectrum [4]. The MCNP/MCNPX model is found in Appendix A.

1.2 Experimental Procedure

1.2.1 Ni Foil Irradiations

Both of the 7-in-dia spheres (Al6061 and HDPE) were disassembled into three components (see Appendix B for schematic of spheres). A Sandia National Laboratories (SNL) custom Ni foil (0.010 mil thickness) was inserted into the slot in the center of each sphere. This location is identified as Position 0, and the foil in this location is in a vertical orientation at the fuel centerline when the spheres are placed in the reactor. After inserting the center foil, the center plate of the sphere is screwed onto the lower portion of the sphere. SNL custom Ni foils are then placed in the void regions of the center plate. These locations are identified as Positions 1–8 (Figure 1-1 and Table 1-2). Finally, the top portion of the sphere was attached to the other components, and a SNL custom Ni foil was attached to the exterior of the sphere at the equator. The location of the external Ni foil is identified as Position 9. Figure 1-2 shows the fully assembled spheres with the Ni foil attached to the exterior.

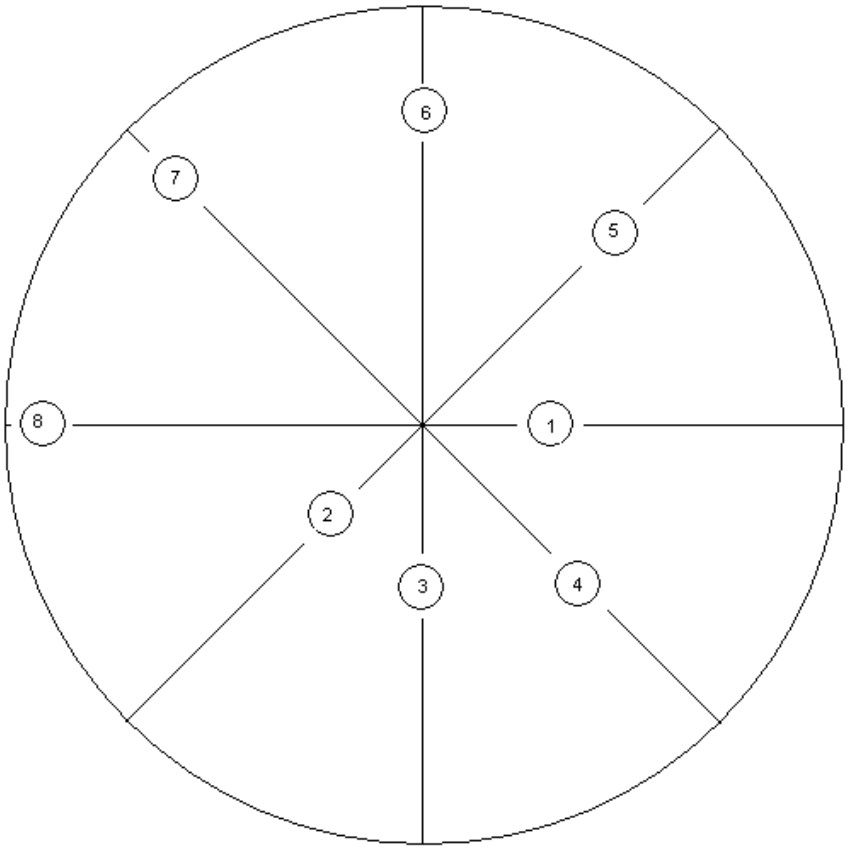

Figure 1-1. Location of Foils in the 7-in-dia Sphere.

Table 1-2. Location Numbers in 7-in Sphere.

Location	Radius from Center of Sphere (in)	Angle From Reference (deg)
Position 1	0.75	0
Position 2	1.63	225
Position 3	1.80	270
Position 4	2.01	315
Position 5	2.43	45
Position 6	2.64	90
Position 7	2.85	135
Position 8	3.09	180

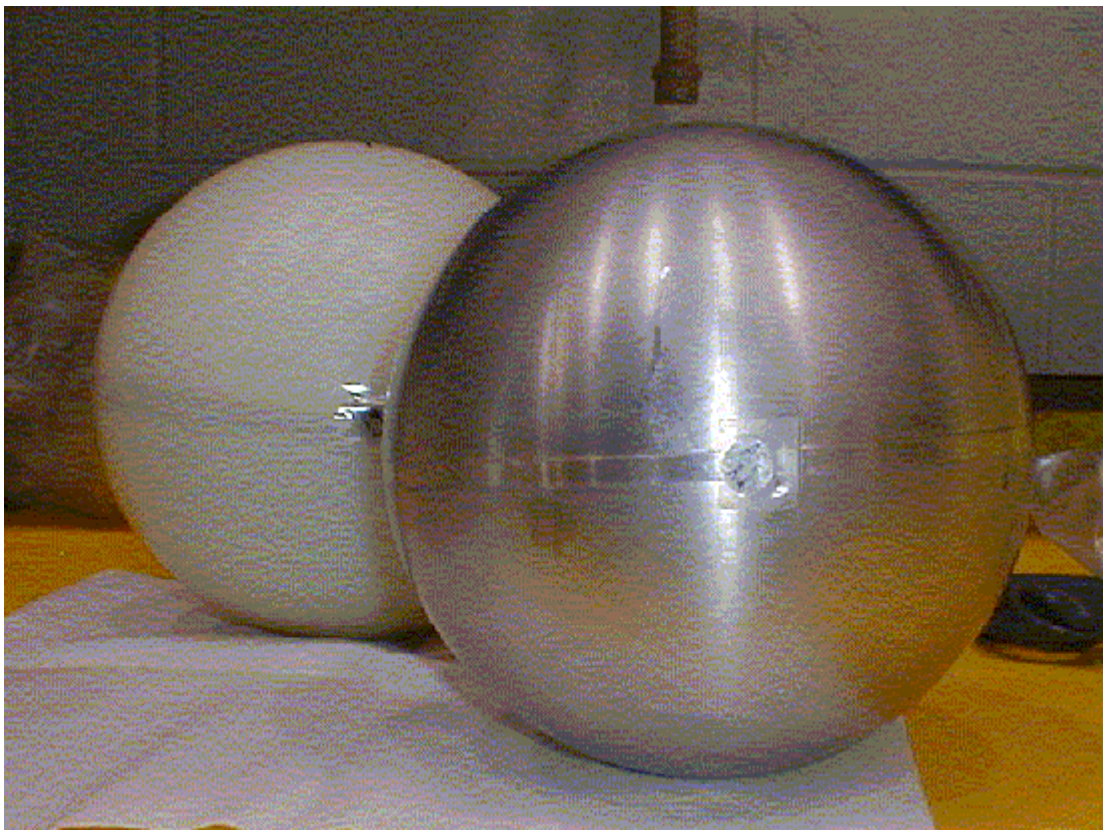

Figure 1-2. Fully assembled 7-in Spheres with Ni Foils on Exterior at the Equator.

After assembly, the HDPE sphere was placed in the dosimetry bucket. The dosimetry bucket contains a centering mechanism with stand-offs that ensure that the activation foils are located at the fuel centerline (oriented horizontally). The dosimetry bucket was then placed in the ACRR-CC on both the 32-in and 8-in pedestals. The experiment package was then irradiated at 5% steady state power for 16.7 full power seconds (FPS) or 40 MJ (ACRR Run 7654). The package was allowed to sit in the reactor after shutdown for ~25 minutes. The HDPE sphere was removed from the dosimetry bucket and replaced with the Al6061 sphere. The Al6061 sphere was then

placed in the ACRR-CC, and the experiment package was irradiated at 5% steady state power for 16.7 FPS (40 MJ) (ACRR Run 7655). The experiment package was removed from the reactor ~15 hours after the irradiation. Three days after the irradiation, the spheres were disassembled to remove the Ni foils. The Ni foils were then delivered to the SNL Radiation Metrology Laboratory (RML) for assay. The order of the irradiations was chosen to reduce the radiation exposures to the reactor operators and experimenter.

1.2.2 Cd-Covered Au Foil Irradiations

The procedure for these irradiations was identical to the Ni foil irradiations described above with one exception. The custom Ni foils in Positions 0–8 (0 being the center) were replaced with Cd-covered Au foils. The Cd covers were the small covers available from the SNL RML. The Au foils were the dilute Al/Au foils (0.1134% Au by weight). In addition, the Al/Au foils were cut into one-quarter sections before being placed in the Cd covers. The ACRR run numbers were 7670 for the HDPE sphere and 7671 for the Al6061 sphere.

1.3 Results

The results of the RML assay of the Ni are displayed in Tables 1-3 and 1-4. These data are shown graphically in Figure 1-3. The results of the RML assay of the Cd-covered Au foils are displayed in Tables 1-5, 1-6, and Figure 1-4. Included in the tables are the uncertainties in consecutive counts from different detectors (% Delta Counts), the 1σ uncertainty in the activity as reported by RML (1σ % Error), the measurement uncertainty (calculated by summing the previous uncertainties in quadrature), and the RML record number. The RML record number is included to provide traceability for the reported results to the data recorded by the dosimetry laboratory [5].

Note that a component of the uncertainty is not addressed in this presentation of the results. Any systematic uncertainty in these measurements has been excluded. The RML staff has discussed supplying this uncertainty metric when it becomes available. When available, the systematic uncertainty will be included in any further analysis of this data.

Table 1-3. Ni Activation in 7-in HDPE Sphere (ACRR Run 7654).

Location and Radius (in)	Ni Activity (Bq/g)	% Delta Counts	1σ % Error	Measurement Uncertainty (%)	RML Record Number (Sample ID)
0 -- Center	7.3940E+03	0.00	2.14	2.14	Ni-P0 AC7654 DEPRIES 08981 D01G02 08991 D02G02
1 -- 0.75	7.8980E+03	0.10	2.14	2.14	Ni-P1 AC7654 DEPRIES 08982 D01G02 08992 D02G02
2 -- 1.63	8.8315E+03	0.87	2.14	2.31	Ni-P2 AC7654 DEPRIES 08983 D01G02 08993 D02G02
3 -- 1.80	9.3615E+03	0.95	2.14	2.34	Ni-P3 AC7654 DEPRIES 08984 D01G02 08994 D02G02
4 -- 2.01	1.0195E+04	0.88	2.14	2.31	Ni-P4 AC7654 DEPRIES 08985 D01G02 08995 D02G02
5 -- 2.43	1.1435E+04	0.61	2.14	2.23	Ni-P5 AC7654 DEPRIES 08986 D01G02 08996 D02G02
6 -- 2.64	1.2145E+04	0.25	2.14	2.15	Ni-P6 AC7654 DEPRIES 08987 D01G02 08997 D02G02
7 -- 2.85	1.2940E+04	0.15	2.14	2.15	Ni-P7 AC7654 DEPRIES 08988 D01G02 08998 D02G02
8 -- 3.09	1.4430E+04	0.42	2.14	2.18	Ni-P8 AC7654 DEPRIES 08989 D01G02 08999 D02G02
9 -- 3.5 (External)	1.8360E+04	0.11	2.14	2.14	Ni-P9 AC7654 DEPRIES 09000 D01G02 09022 D02G02

Table 1-4. Ni Activation in 7-in Al6061 Sphere (ACRR Run 7655).

Location and Radius (in)	Ni Activity (Bq/g)	% Delta Counts	1σ % Error	Measurement Uncertainty (%)	RML Record Number (Sample ID)
0 -- Center	1.5640E+04	0.38	2.14	2.17	Ni-A0 AC7655 DEPRIES 09001 D01G02 09011 D02G02
1 -- 0.75	1.6065E+04	0.56	2.14	2.21	Ni-A1 AC7655 DEPRIES 09026 D01G02 09023 D02G02
2 -- 1.63	1.6830E+04	0.71	2.14	2.25	Ni-A2 AC7655 DEPRIES 09003 D01G02 09013 D02G02
3 -- 1.80	1.7245E+04	0.64	2.14	2.23	Ni-A3 AC7655 DEPRIES 09004 D01G02 09014 D02G02
4 -- 2.01	1.7360E+04	0.69	2.14	2.25	Ni-A4 AC7655 DEPRIES 09005 D01G02 09024 D02G02
5 -- 2.43	1.7705E+04	0.96	2.14	2.35	Ni-A5 AC7655 DEPRIES 09006 D01G02 09016 D02G02
6 -- 2.64	1.7745E+04	0.62	2.14	2.23	Ni-A6 AC7655 DEPRIES 09007 D01G02 09017 D02G02
7 -- 2.85	1.8630E+04	0.86	2.14	2.31	Ni-A7 AC7655 DEPRIES 09008 D01G02 09018 D02G02
8 -- 3.09	1.9430E+04	0.93	2.14	2.33	Ni-A8 AC7655 DEPRIES 09009 D01G02 09025 D02G02
9 -- 3.5 (External)	2.0640E+04	0.68	2.14	2.25	Ni-A9 AC7655 DEPRIES 09010 D01G02 09020 D01G02

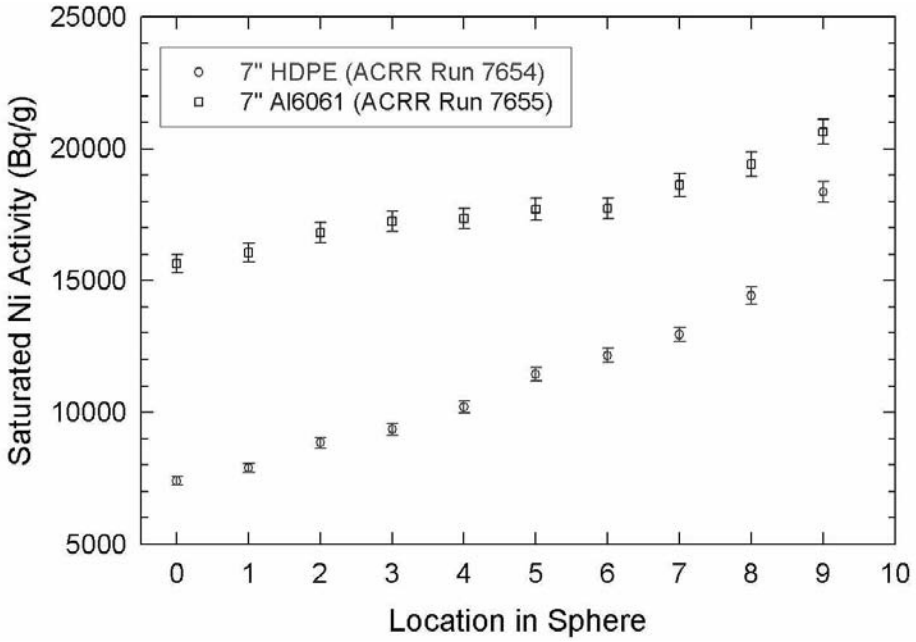

Figure 1-3. Ni Activation in 7-in HDPE and Al6061 Spheres.

Table 1-5. Cd-Covered Au Activation in 7-in HDPE Sphere (ACRR Run 7670).g

Location and Radius (in)	Au Activity (Bq/g)	% Delta Counts	1σ % Error	Measurement Uncertainty (%)	RML Record Number (Sample ID)
0 -- Center	1.2890E+08	0.00	4.46	4.46	AU-P0 C AC7670 DPRST 09072 D01G02 09081 D02G02
1 -- 0.75	1.3310E+08	0.45	4.46	4.48	AU-P1 C AC767O DPRST 09073 D01G02 09082 D02G02
2 -- 1.63	1.7085E+08	0.76	4.46	4.52	AU-P2 C AC7670 DPRST 09125 D01G02 09083 D02G02
3 -- 1.80	1.8255E+08	0.27	4.46	4.47	AU-P3 C AC7670 DPRST 09075 D01G02 09084 D02G02
4 -- 2.01	1.9305E+08	1.30	4.46	4.65	AU-P4 C AC7670 DPRST 09076 D01G02 09085 D02G02
5 -- 2.43	2.4675E+08	0.45	4.46	4.48	AU-P5 C AC7670 DPRST 09077 D01G02 09086 D02G02
6 -- 2.64	2.6820E+08	1.04	4.46	4.58	AU-P6 C AC7670 DPRST 09078 D01G02 09087 D02G02
7 -- 2.85	3.0040E+08	0.67	4.46	4.51	AU-P7 C AC7670 DPRST 09079 D01G02 09088 D02G02
8 -- 3.09	3.1605E+08	1.04	4.46	4.58	AU-P8 C AC7670 DPRST 09080 D01G02 09089 D02G02
9 -- 3.5 (External Ni Foil)	Ni Activity 1.8525E+04	1.24	2.14	2.47	NI-P9 C AC7670 DPRST 09090 D01G02 09091 D02G02

Table 1-6. Cd-Covered Au Activation in 7-in Al6061 Sphere (ACRR Run 7671).

Location and Radius (in)	Au Activity (Bq/g)	% Delta Counts	1σ % Error	Measurement Uncertainty (%)	RML Record Number (Sample ID)
0 -- Center	3.1755E+08	0.35	4.46	4.47	AU-A0 C AC7671 DPRST 09101 D01G02 09092 D02G02
1 -- 0.75	3.2170E+08	0.31	4.46	4.47	AU-A1 C AC7671 DPRST 09102 D01G02 09093 D02G02
2 -- 1.63	3.1940E+08	0.00	4.46	4.46	AU-A2 C AC7671 DPRST 09103 D01G02 09094 D02G02
3 -- 1.80	3.2095E+08	1.96	4.46	4.87	AU-A3 C AC7671 DPRST 09104 D01G02 09095 D02G02
4 -- 2.01	3.1895E+08	2.29	4.46	5.01	AU-A4 C AC7671 DPRST 09105 D01G02 09096 D02G02
5 -- 2.43	3.2480E+08	1.48	4.45	4.69	AU-A5 C AC7671 DPRST 09106 D01G02 09097 D02G02
6 -- 2.64	3.3635E+08	0.45	4.46	4.48	AU-A6 C AC7671 DPRST 09107 D01G02 09098 D02G02
7 -- 2.85	3.3230E+08	1.02	4.45	4.57	AU-A7 C AC7671 DPRST 09108 D01G02 09099 D02G02
8 -- 3.09	3.2510E+08	1.48	4.46	4.70	AU-A8 C AC7671 DPRST 09109 D01G02 09100 D02G02
9 -- 3.5 (External Ni Foil)	Ni Activity 2.0955E+04	1.29	2.14	2.50	NI-A9 C AC7671 DPRST 09110 D01G02 09111 D02G02

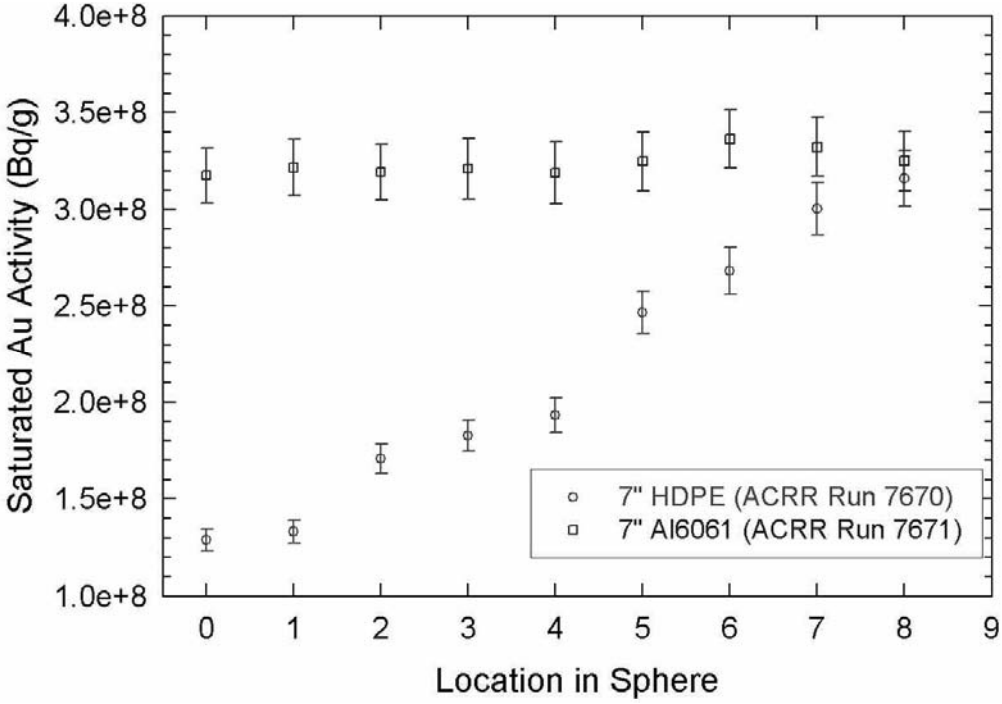

Figure 1-4. Cd-Covered Au Activation in 7-in HDPE and Al6061 Spheres.

1.4 Analysis

Using the MCNP/MCNPX input deck found in Appendix A (with appropriate changes in the comment cards), the foil activities were calculated for each of the cases outlined above. For comparison, the MCNP-calculated activity for Position 9 was normalized to the experimental value in each case. The results of the calculations/comparisons are given below.

The HDPE (Ni) results are shown in Figures 1-5 and 1-6. Figure 1-5 shows the comparison of the normalized Ni activities at each of the 10 locations found on the sphere. The error bars on the calculation results represent the Monte Carlo statistical sampling uncertainty only. Fully defined error bars for the calculation would include the cross section uncertainty for the materials used in the transport in addition to the uncertainty in the partial cross section ^{58}Ni(n,p) used in calculating the activity. Additional calculational uncertainties include the material densities, material compositions, and simplifications of the actual geometry. These uncertainties will be addressed in future analysis. Figure 1-6 shows the ratio of calculated to experimental (C/E) activity. The figure includes an arbitrarily determined band between 0.9 and 1.1. The band represents a nominal 10% deviation between the calculation and experiment. The error bars in the figure are the uncertainties from the measurement added in quadrature with the Monte Carlo statistical uncertainties.

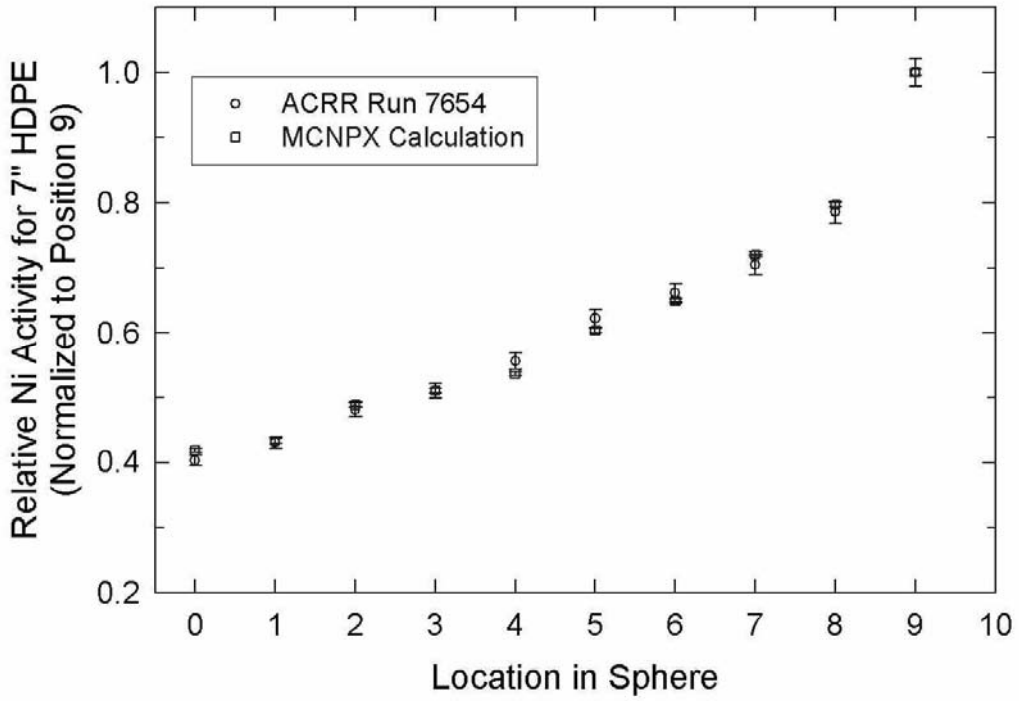

Figure 1-5. Comparison of Normalized Ni Activity for 7-in HDPE Sphere.

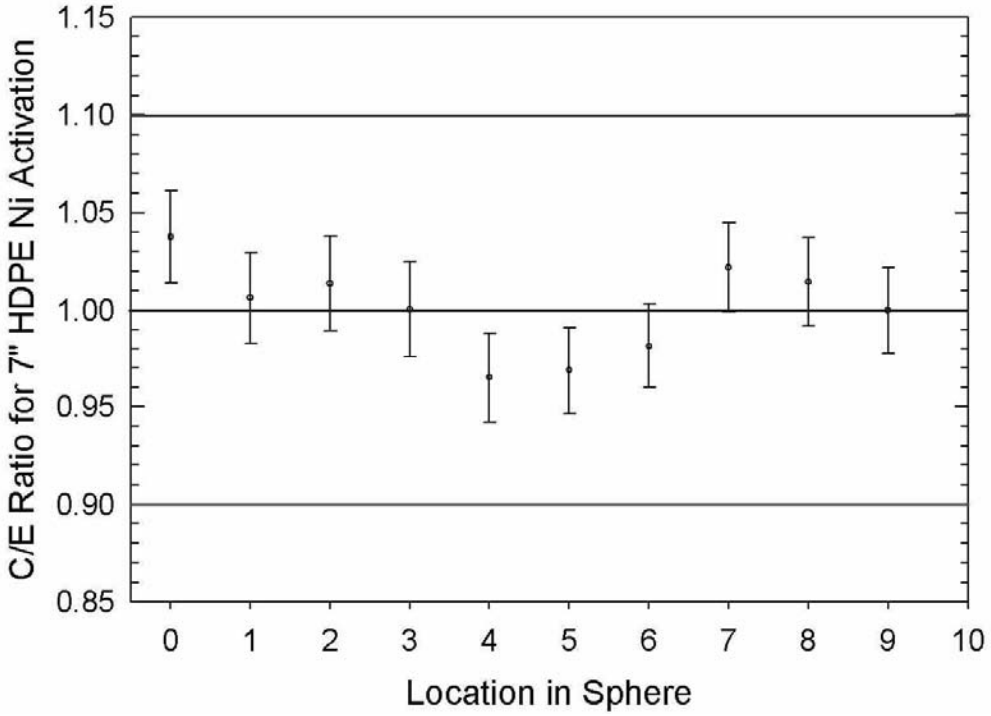

Figure 1-6. C/E Ratio for Ni Activation for 7-in HDPE Sphere.

The Al6061 (Ni) results are shown in Figures 1-7 and 1-8. Figure 1-7 shows the comparison of the normalized Ni activities at each of the 10 locations found on the sphere. Figure 1-8 shows the ratio of C/E activity. The error bars in both figures are equivalent to those described for Figures 1-5 and 1-6.

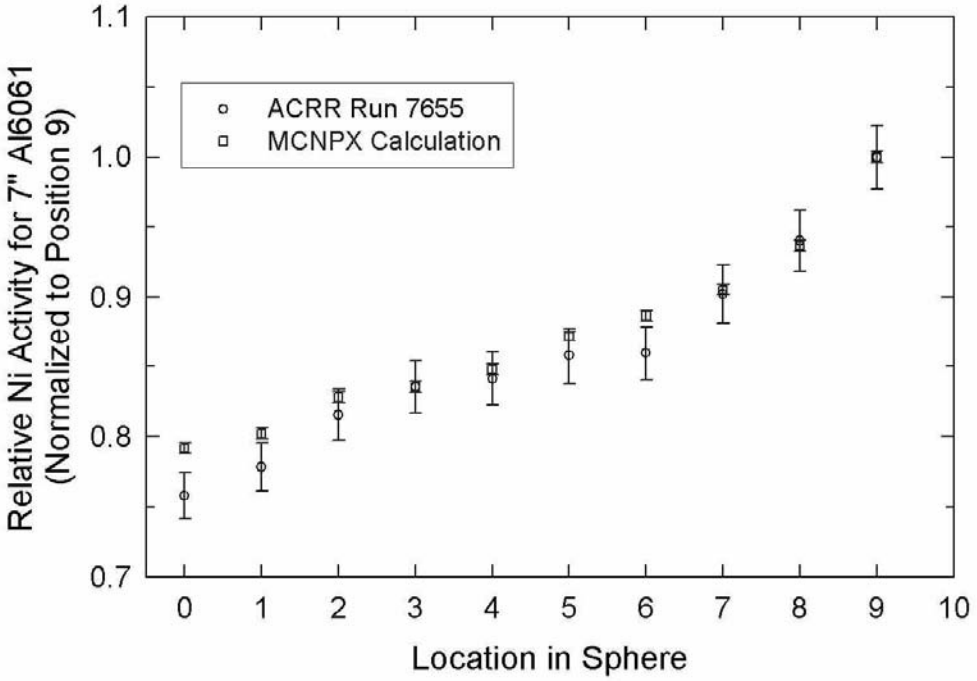

Figure 1-7. Comparison of Normalized Ni Activity for 7-in Al6061 Sphere.

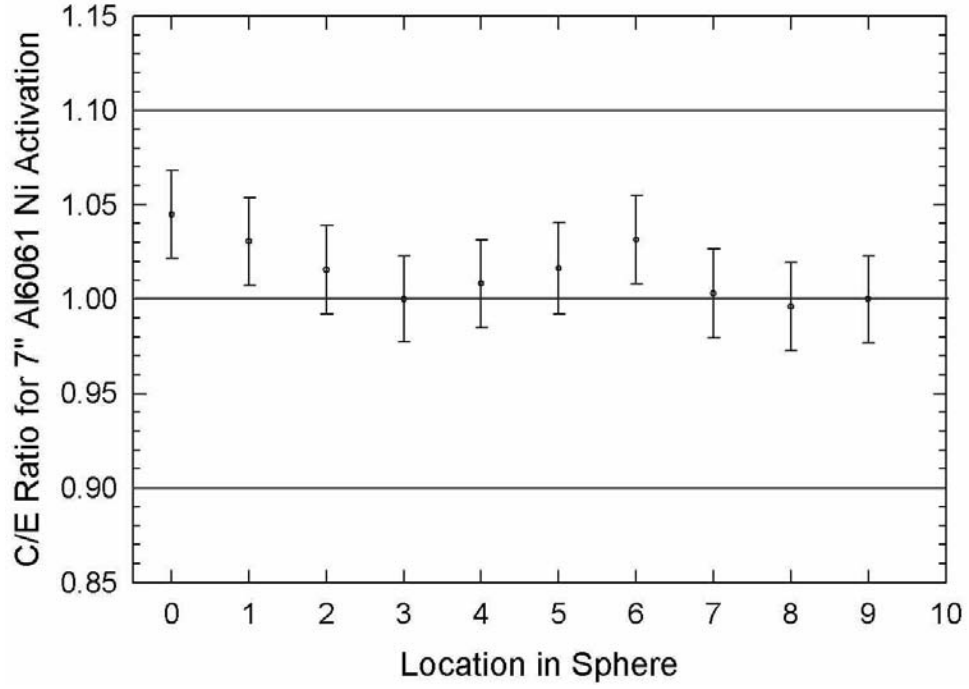

Figure 1-8. C/E Ratio for Ni Activation for 7-in Al6061 Sphere.

The HDPE (Au/Cd) results are shown in Figures 1-9 and 1-10. Figure 1-9 shows the comparison of the normalized Cd-covered Au activities at each of the nine locations found on the sphere. There are three sets of calculations for comparison. The first calculation was performed without the S(α, β) treatment for the polyethylene sphere. The S(α, β) treatment is an adjustment of the neutron cross section in the energy region where the molecular interactions of the material are important. This energy region is generally less than 4 eV. The second calculation included the S(α, β) treatment. The final calculation includes the S(α, β) treatment and updated cross sections for the Cd covers. Figure 1-10 displays the ratio of C/E activity for all three calculations. The error bars in both figures are equivalent to those described for Figures 1-5 and 1-6.

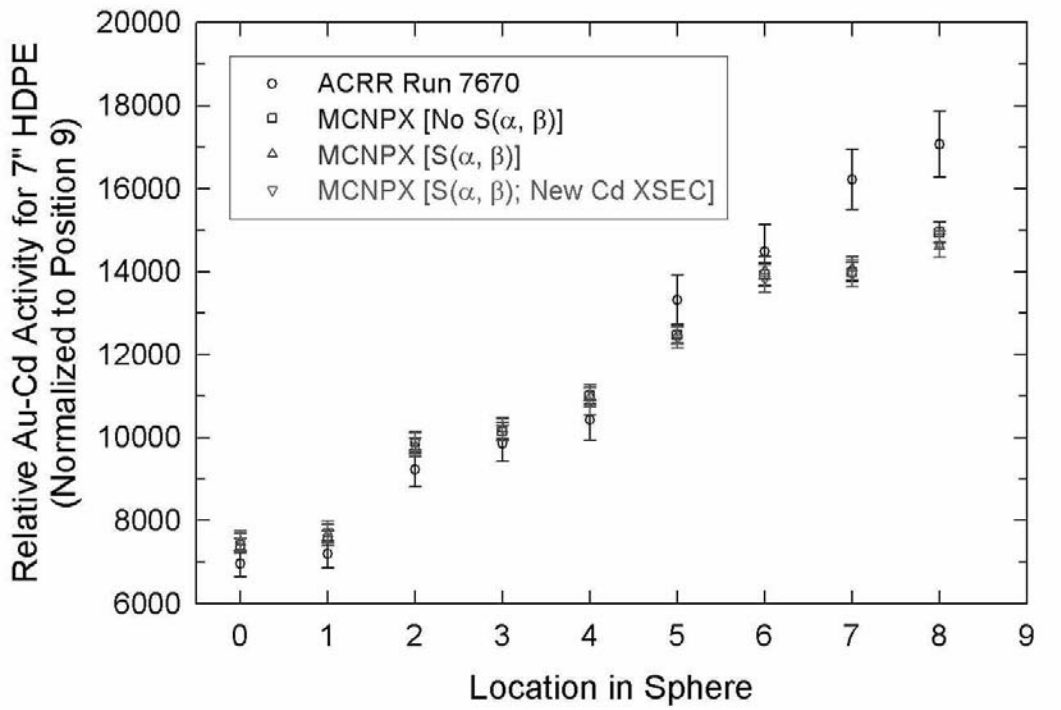

Figure 1-9. Comparison of Normalized Cd-covered Au Activity for 7-in HDPE Sphere.

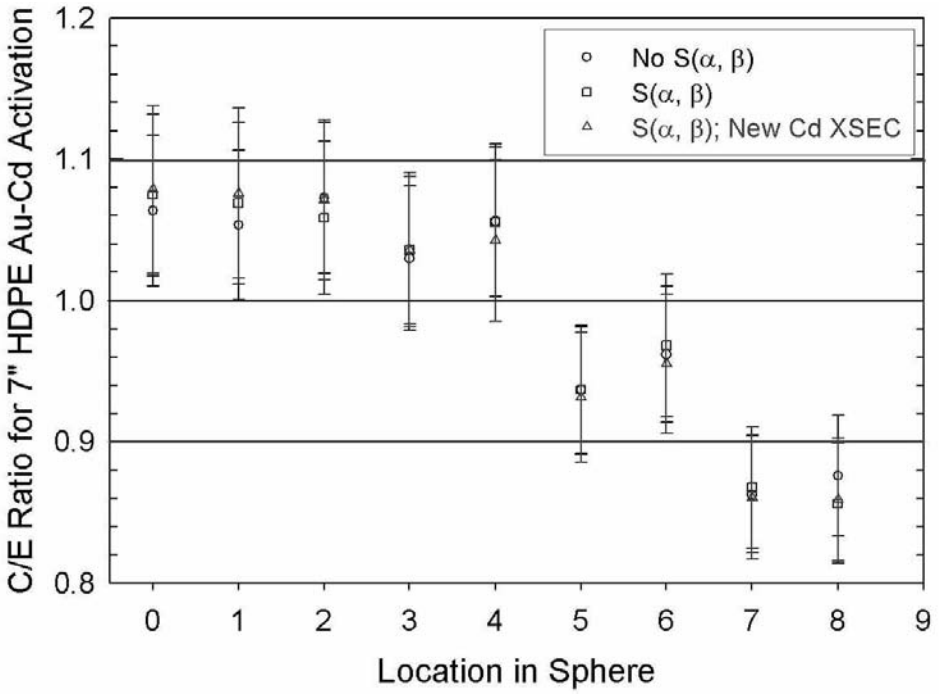

Figure 1-10. C/E Ratio for Cd-covered Au Activation for 7-in HDPE Sphere.

The Al6061 (Au/Cd) results are shown in Figures 1-11 and 1-12. Figure 1-11 shows the comparison of the normalized Cd-covered Au activities at each of the nine locations found on the sphere. Figure 1-12 displays the ratio of C/E activity. Updated Cd cross sections were not used in this analysis. Future analysis will include the updated cross sections. The error bars in both figures are equivalent to those described for Figures 1-5 and 1-6.

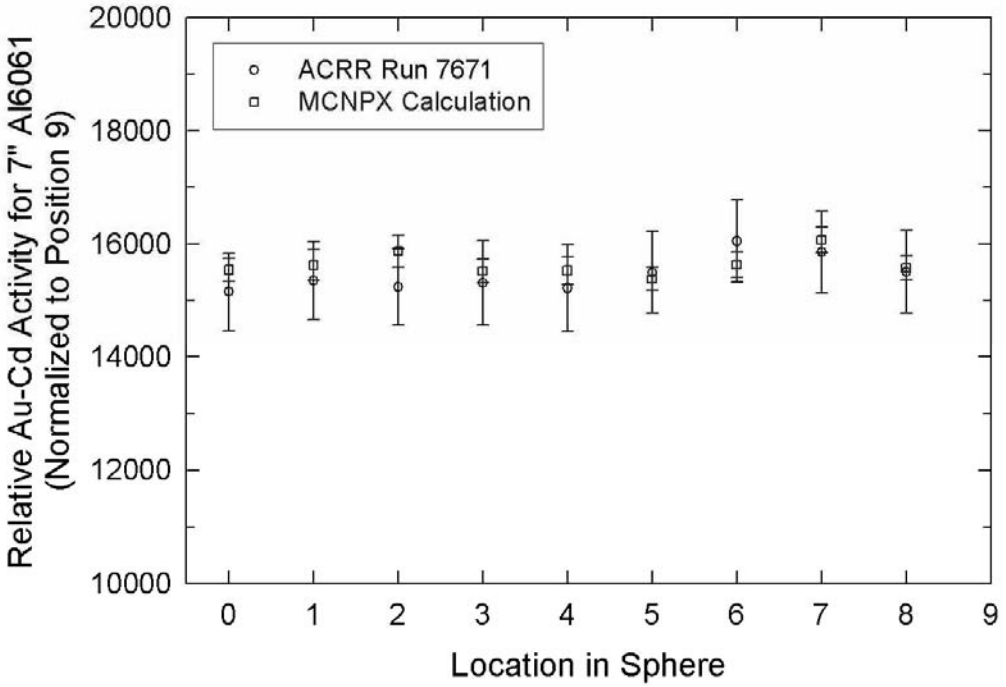

Figure 1-11. Comparison of Normalized Cd-covered Au Activity for 7-in Al6061 Sphere.

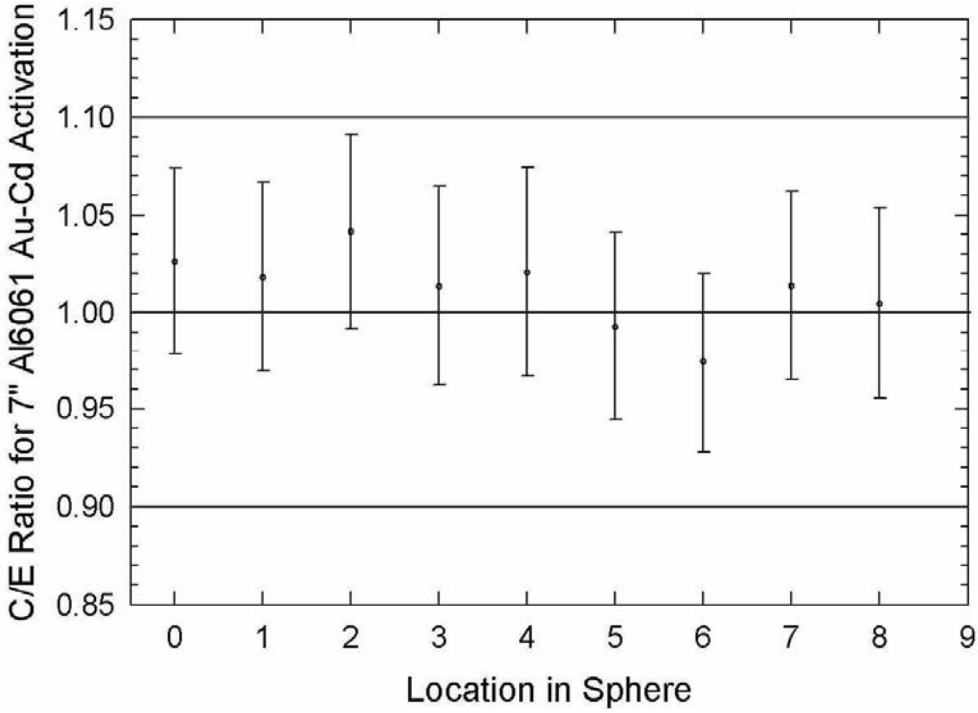

Figure 1-12. C/E Ratio for Cd-covered Au Activation for 7-in Al6061 Sphere.

Upon examination of the figures with C/E ratios, it was found that Figure 1-10 (HDPE with Cd-covered Au foils) is the only one with points outside the nominal range of 10%. Figure 1-10 shows that the calculated points closest to the surface of the sphere fall outside the 10% range. The most likely cause of the discrepancy is perturbation of the external neutron energy spectrum by the HDPE sphere. The neutron energy spectrum in the central cavity is perturbed by the presence of test objects located in the cavity. All calculations described in this report assumed that the neutron energy spectrum external to the sphere was the ACF9 spectrum [4] and was thus unaffected by any perturbations caused by the test object.

To test this as the cause of the discrepancy mentioned above, the ratio of the external Ni foil activation (Position 9) on the Al6061 sphere to the external Ni foil activation on the HDPE sphere must be examined. These ratios were obtained for both the experiments and calculations. The results of these ratio calculations are given in Table 1-7. The table shows that there is a ~10% difference between ratios of experiments and calculations. The differences shown by this ratio indicate that the neutron fluence and neutron energy spectrum incident on the sphere has changed when the test object changes from Al6061 to HDPE.

It is also worth noting that the deviations are in the location closest to the exterior of the HDPE sphere. The neutron energy spectrum in the interior of the HDPE sphere is likely to be completely thermalized. Thus, any shift in the external neutron energy spectrum will have very little (if any) effect on the neutron energy spectrum deep inside the HDPE sphere.

Table 1-7. Ratio of External Ni Foils (Al6061/HDPE).

Experiment Type of Sphere and Foil	Ni Activity (Bq/g)	Exp. Uncertainty (%)	Ratio of Al6061 to HDPE
Al6061 (Ni)	2.0640e+4	2.25	---
HDPE (Ni)	1.8360e+4	2.14	---
Ni Foil Runs			**1.12418**
Al6061 (Au/Cd)	2.0955e+4	2.50	---
HDPE (Au/Cd)	1.8525e+4	2.47	---
Cd-covered Au Foil Runs			**1.13117**
Calculation Type of Sphere and Foil	**MCNP Tally (RXNs/cm^3/n/cm^2)**	**MC Uncertainty Relative Error**	**Ratio of Al6061 to HDPE**
Al6061 (Ni)	2.20475e-3	0.0044	---
HDPE (Ni)	1.77087e-3	0.0049	---
Ni Foil Runs			**1.24501**
Al6061 (Au/Cd)	2.19103e-3	0.0037	---
HDPE (Au/Cd)*	1.76998e-3	0.0094	---
Cd-covered Au Foil Runs			**1.23788**

*The results shown here are the average of the three calculations performed for the HDPE (Au/Cd).

The calculation for Ni activity with the HDPE sphere appears to be valid without considering the shift in the neutron energy spectrum. The Q-value for the ^{58}Ni(n, p) reaction is 0.402 MeV, while the ^{197}Au(n, γ) is not a threshold reaction and can occur at all neutron energies found in a reactor. However, the ^{197}Au(n, γ) reaction will be dominated by the thermal part of the neutron spectrum. Thus, the Ni reaction will be less sensitive to shifts (down scatters) in the neutron energy spectrum.

Further analysis and calculations are needed to resolve the discrepancies seen in the HDPE (Au/Cd) results. That analysis is beyond the original scope of the experiment design and execution and is more appropriately included in a validation calculation associated with the Neutron Gamma Energy Transport (NuGET) code. The further calculations would include a full-scale model of the ACRR with the NuGET HDPE sphere (with the proper dosimetry foils) located in the central cavity. This type of calculation would include the feedback (or perturbation) in the neutron energy spectrum caused by the presence of the test object in the reactor.

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2.0 n/γ Attenuation through Materials (4-in-dia HDPE and Al6061 Spheres with Ni and Cd-covered Au Foils)

2.1 Introduction

A series of irradiations were performed in the ACRR-CC with spheres of HDPE and Al6061. The nominal compositions for HDPE and Al6061 are given in Table 2-1. The spheres were essentially solid with cavities scrolled out along the equator to allow the insertion of activation foils. The cavities were configured in the sphere such that there were no radiation streaming paths or large void volumes. In addition to the foils located on the interior of the spheres, an external Ni activation foil was attached to the equator on the exterior of the spheres. The external Ni foil provides normalization back to the free-field reactor spectrum characterization and allows comparison between different reactor operations with the same sphere.

Table 2-1. Composition of 4-in-dia Spheres.

Material	Element	Weight %
HDPE*	Hydrogen	14.37
	Carbon	85.63
Al6061+	Magnesium	1.00
	Aluminum	96.55
	Silicon	0.60
	Titanium	0.15
	Chromium	0.20
	Manganese	0.15
	Iron	0.70
	Copper	0.25
	Zinc	0.25
	Others^	0.15

*HDPE is a polymer with a chemical formula of $-(-CH_2--CH_2-)_n-$.
+Metals Handbook, Volume 2, 10th Edition, ASM International (1990).
^ "Others" is assumed to be vanadium based on another source [1].

The irradiations were carried out in the well-characterized dosimetry bucket. A centering mechanism in the bucket ensured that the equator of the sphere was located at the fuel centerline in the ACRR-CC. Only one type of activation foil was used in a given reactor run (except the external Ni foil). This section discusses the experimental results of the 4-in-dia Al6061 and HDPE spheres with Ni foils and Cd-covered Au foils. Additionally, an MCNP [2] and/or MCNPX [3] model of the spheres was created and used for comparison to the experimental results. The model uses a 640-group representation of the ACF9 neutron energy spectrum [4]. The MCNP/MCNPX model is found in Appendix A.

2.2 Experimental Procedure

2.2.1 Ni Foil Irradiations

Both of the 4-in-dia spheres (Al6061 and HDPE) were disassembled into three components (see Appendix B for schematic of spheres). A SNL custom Ni foil (0.010 mil thickness) was inserted into the slot in the center of each sphere. This location is identified as Position 0, and the foil in

this location is in a vertical orientation at the fuel centerline when the spheres are placed in the reactor. After inserting the center foil, the center plate of the sphere is screwed onto the lower portion of the sphere. SNL custom Ni foils are then placed in the void regions of the center plate. These locations are identified as Positions 1–5 (Figure 2-1 and Table 2-2). Finally, the top portion of the sphere was attached to the other components, and a SNL custom Ni foil was attached to the exterior of the sphere at the equator. The location of the external Ni foil is identified as Position 6. Figure 2-2 shows the 4-in spheres with the Ni foil attached to the exterior of the HDPE spheres and the foils inside the Al6061 sphere.

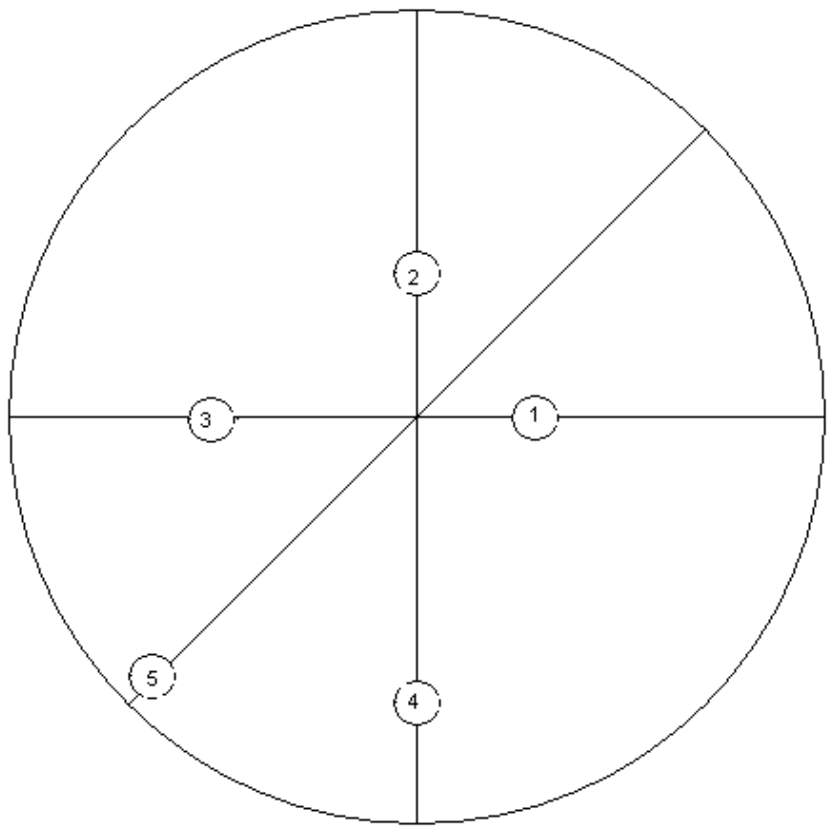

Figure 2-1. Location of Foils in the 4-in-dia Sphere.

Table 2-2. Location Numbers in 4-in Sphere.

Location	Radius from Center of Sphere (in)	Angle From Reference (deg)
Position 1	0.75	0
Position 2	0.96	90
Position 3	1.17	180
Position 4	1.38	270
Position 5	1.63	225

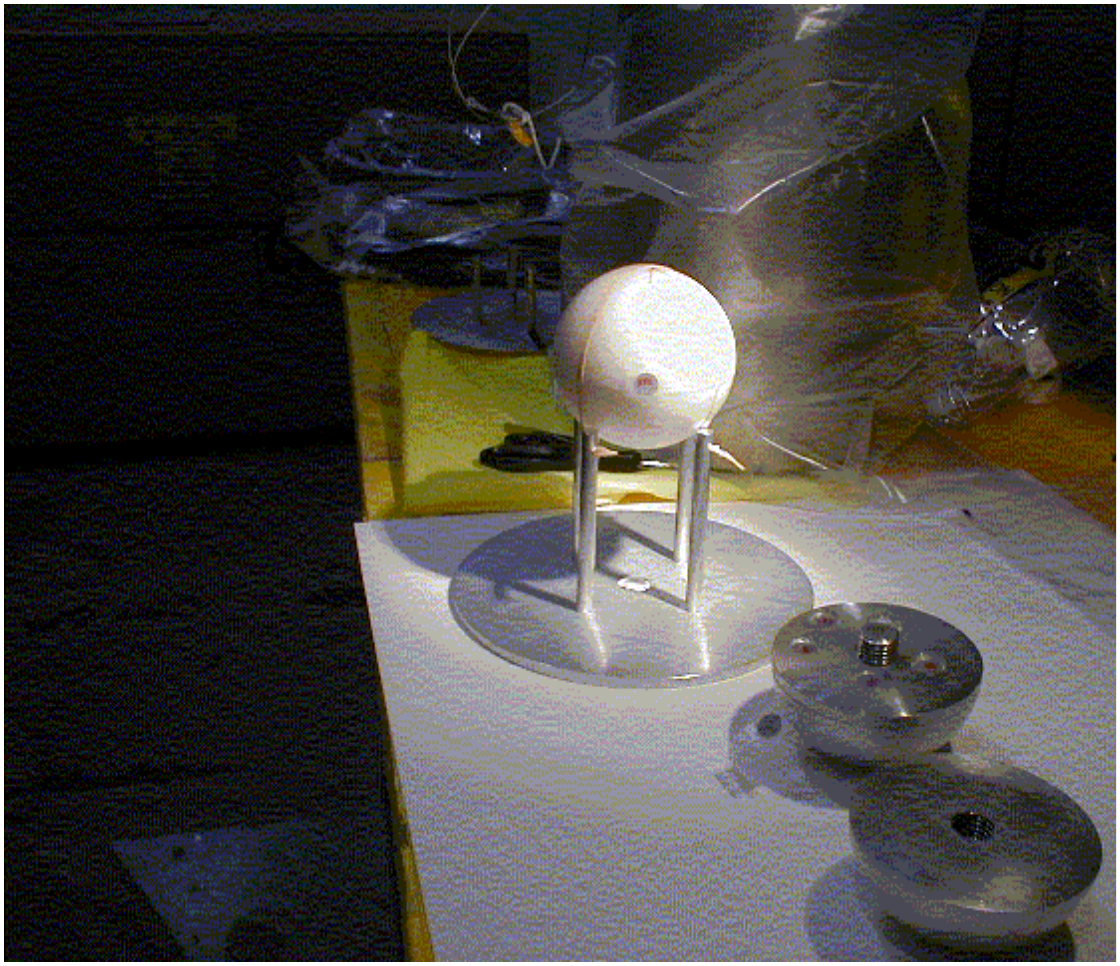

Figure 2-2. 4-in Spheres with Ni Foils.

After assembly, the HDPE sphere was placed in the dosimetry bucket. The dosimetry bucket contains a centering mechanism with stand-offs that ensure that the activation foils are located at the fuel centerline (oriented horizontally). The dosimetry bucket was then placed in the ACRR-CC on both the 32-in and 8-in pedestals. The experiment package was then irradiated at 5% steady state power for 16.7 FPS or 40 MJ (ACRR Run 7726). The package was allowed to sit in the reactor after shutdown for ~25 minutes. The HDPE sphere was removed from the dosimetry bucket and replaced with the Al6061 sphere. The Al6061 sphere was then placed in the ACRR-CC, and the experiment package was irradiated at 5% steady state power for 16.7 FPS (40 MJ) (ACRR Run 7727). The experiment package was removed from the reactor ~1 hour after the irradiation. Three days after the irradiation, the spheres were disassembled to remove the Ni foils. The Ni foils were then delivered to the SNL RML for assay. The order of the irradiations was chosen to reduce the radiation exposures to the reactor operators and experimenter.

2.2.2 Cd-Covered Au Foil Irradiations

The procedure for these irradiations was identical to the Ni foil irradiations described above with one exception. The custom Ni foils in Positions 0–5 (0 being the center) were replaced with Cd-covered Au foils. The Cd covers were the small covers available from the SNL RML. The Au

foils were the dilute Al/Au foils (0.1134% Au by weight). In addition, the Al/Au foils were cut into one-quarter sections before being placed in the Cd covers. The ACRR run numbers were 7837 for the HDPE sphere and 7838 for the Al6061 sphere.

2.3 Results

The results of the RML assay of the Ni are displayed in Tables 2-3 and 2-4. These data are shown graphically in Figure 2-3. The results of the RML assay of the Cd-covered Au foils are displayed in Tables 2-5, 2-6, and Figure 2-4. Included in the tables are the uncertainties in consecutive counts from different detectors (% Delta Counts), the 1σ uncertainty in the activity as reported by RML (1σ % Error), the measurement uncertainty (calculated by summing the previous uncertainties in quadrature), and the RML record number. The RML record number is included to provide traceability for the reported results to the data recorded by the dosimetry laboratory [6].

Note that a component of the uncertainty is not addressed in this presentation of the results. Any systematic uncertainty in these measurements has been excluded. The RML staff has discussed supplying this uncertainty metric when it becomes available. When available, the systematic uncertainty will be included in any further analysis of this data.

Table 2-3. Ni Activation in 4-in HDPE Sphere (ACRR Run 7726).

Location and Radius (in)	Ni Activity (Bq/g)	% Delta Counts	1σ % Error	Measurement Uncertainty (%)	RML Record Number (Sample ID)
0 -- Center	1.2715E+04	0.24	2.14	2.15	NI58-P0 A7726 DEPRST 09526 D01G02 09533 D02G02
1 -- 0.75	1.3560E+04	0.44	2.14	2.18	NI58-P1 A7726 DEPRST 09527 D01G02 09534 D02G02
2 -- 0.96	1.4080E+04	0.85	2.14	2.30	NI58-P2 A7726 DEPRST 09528 D01G02 09535 D02G02
3 -- 1.17	1.4510E+04	0.83	2.14	2.30	NI58-P3 A7726 DEPRST 09565 D01G02 09536 D02G02
4 -- 1.38	1.5055E+04	1.53	2.14	2.63	NI58-P4 A7726 DEPRST 09530 D01G02 09537 D02G02
5 -- 1.63	1.6315E+04	0.31	2.14	2.16	NI58-P5 A7726 DEPRST 09531 D01G02 09538 D02G02
6 -- 2.00 (External)	1.9415E+04	1.49	2.14	2.61	NI58-P6 A7726 DEPRST 09567 D01G02 09588 D02G02

Table 2-4. Ni Activation in 4-in Al6061 Sphere (ACRR Run 7727).

Location and Radius (in)	Ni Activity (Bq/g)	% Delta Counts	1σ % Error	Measurement Uncertainty (%)	RML Record Number (Sample ID)
0 -- Center	1.9545E+04	0.15	2.14	2.15	NI58-A0 A7727 DEPRST 09540 D01G02 09547 D02G02
1 -- 0.75	2.0130E+04	0.60	2.14	2.22	NI58-A1 A7727 DEPRST 09541 D01G02 09548 D02G02
2 -- 0.96	2.0255E+04	0.44	2.14	2.18	NI58-A2 A7727 DEPRST 09542 D01G02 09549 D02G02
3 -- 1.17	2.0415E+04	0.05	2.14	2.14	NI58-A3 A7727 DEPRST 09543 D01G02 09550 D02G02
4 -- 1.38	2.1145E+04	0.99	2.14	2.36	NI58-A4 A7727 DEPRST 09544 D01G02 09551 D02G02
5 -- 1.63	2.1400E+04	0.75	2.14	2.27	NI58-A5 A7727 DEPRST 09545 D01G02 09568 D02G02
6 -- 2.00 (External)	2.2625E+04	1.90	2.14	2.86	NI58-A6 A7727 DEPRST 09586 D01G02 09553 D02G02

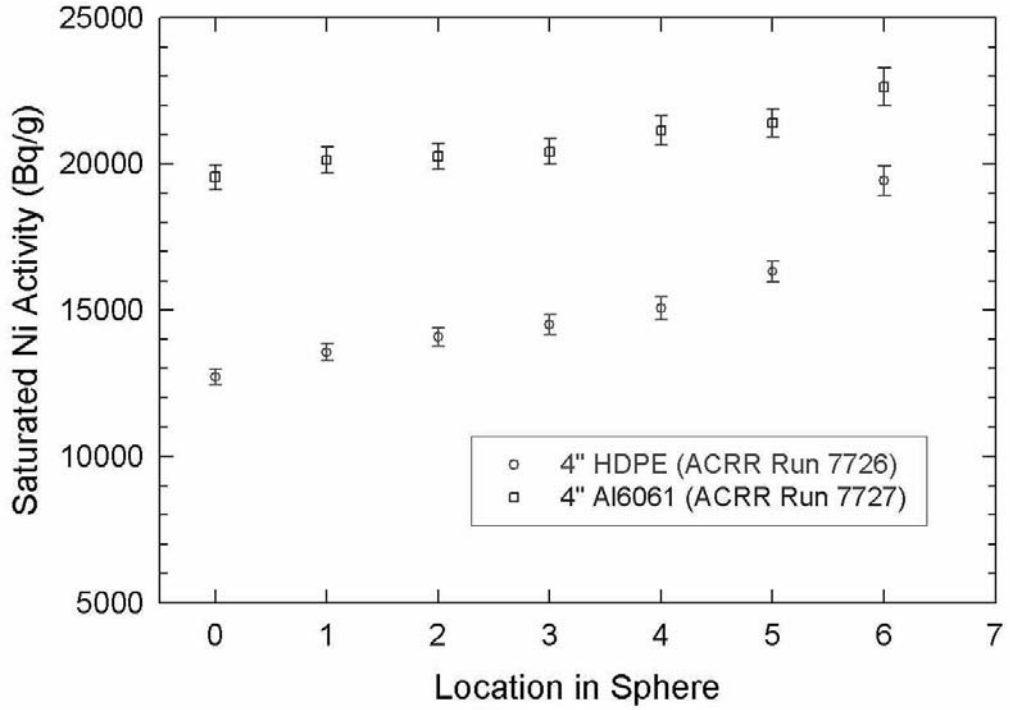

Figure 2-3. Ni Activation in 4-in HDPE and Al6061 Spheres.

Table 2-5. Cd-Covered Au Activation in 4-in HDPE Sphere (ACRR Run 7837).

Location and Radius (in)	Au Activity (Bq/g)	% Delta Counts	1σ % Error	Measurement Uncertainty (%)	RML Record Number (Sample ID)
0 -- Center	3.1820E+08	1.13	4.46	4.60	AU197-P0 A7837 DPRES 10273 D01G02 10280 D02G02
1 -- 0.75	3.4160E+08	0.29	4.46	4.47	AU197-P1 A7837 DPRES 10274 D01G02 10281 D02G02
2 -- 0.96	3.4320E+08	1.05	4.46	4.58	AU197-P2 A7837 DPRES 10275 D01G02 10282 D02G02
3 -- 1.17	3.4835E+08	0.60	4.46	4.50	AU197-P3 A7837 DPRES 10276 D01G02 10283 D02G02
4 -- 1.38	3.7260E+08	0.21	4.46	4.46	AU197-P4 A7837 DPRES 10277 D01G02 10284 D02G02
5 -- 1.63	3.7030E+08	0.38	4.46	4.48	AU197-P5 A7837 DPRES 10278 D01G02 10285 D02G02
6 -- 2.00 (External Ni Foil)	Ni Activity 1.9640E+04	0.41	2.14	2.18	NI58-P4-E A7837DPRES 10272 D01G02 10279 D02G02

Table 2-6. Cd-Covered Au Activation in 4-in Al6061 Sphere (ACRR Run 7838).

Location and Radius (in)	Au Activity (Bq/g)	% Delta Counts	1σ % Error	Measurement Uncertainty (%)	RML Record Number (Sample ID)
0 -- Center	3.3415E+08	0.57	4.46	4.50	AU197-A0 A7838 DPRES 10287 D01G02 10294 D02G02
1 -- 0.75	3.3375E+08	0.45	4.46	4.48	AU197-A1 A7838 DPRES 10288 D01G02 10295 D02G02
2 -- 0.96	3.3805E+08	2.28	4.46	5.01	AU197-A2 A7838 DPRES 10289 D01G02 10296 D02G02
3 -- 1.17	3.3485E+08	0.33	4.46	4.47	AU197-A3 A7838 DPRES 10290 D01G02 10297 D02G02
4 -- 1.38	3.3625E+08	0.86	4.46	4.54	AU197-A4 A7838 DPRES 10291 D01G02 10298 D02G02
5 -- 1.63	3.4380E+08	0.35	4.46	4.47	AU197-A5 A7838 DPRES 10292 D01G02 10299 D02G02
6 -- 2.00 (External Ni Foil)	Ni Activity 2.3075E+04	0.22	2.14	2.15	NI58-A4-E A7838DPRES 10286 D01G02 10293 D02G02

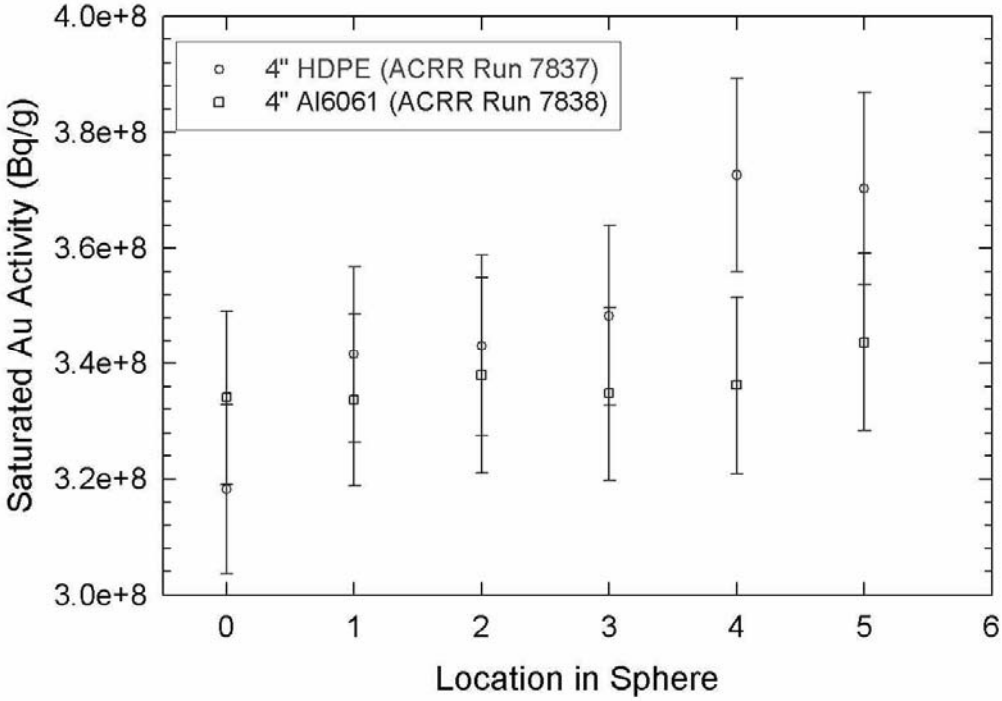

Figure 2-4. Cd-Covered Au Activation in 4-in HDPE and Al6061 Spheres.

2.4 Analysis

Using the MCNP/MCNPX input deck found in Appendix A (with appropriate changes in the comment cards), the foil activities were calculated for each of the cases outlined above. For comparison, the MCNP-calculated activity for Position 6 was normalized to the experimental value in each case. The results of the calculations/comparisons are given below.

The HDPE (Ni) results are shown in Figures 2-5 and 2-6. Figure 2-5 shows the comparison of the normalized Ni activities at each of the seven locations found on the sphere. The error bars on the calculation results represent the Monte Carlo statistical sampling uncertainty only. Fully defined error bars for the calculation would include the cross section uncertainty for the materials used in the transport in addition to the uncertainty in the partial cross section (^{58}Ni(n,p)) used in calculating the activity. Additional calculational uncertainties include the material densities, material compositions, and simplifications of the actual geometry. These uncertainties will be addressed in future analysis. Figure 2-6 displays the ratio of C/E activity. The figure includes an arbitrarily determined band between 0.9 and 1.1. The band represents a nominal 10% deviation between the calculation and experiment. The error bars in the figure are the uncertainties from the measurement added in quadrature with the Monte Carlo statistical uncertainties.

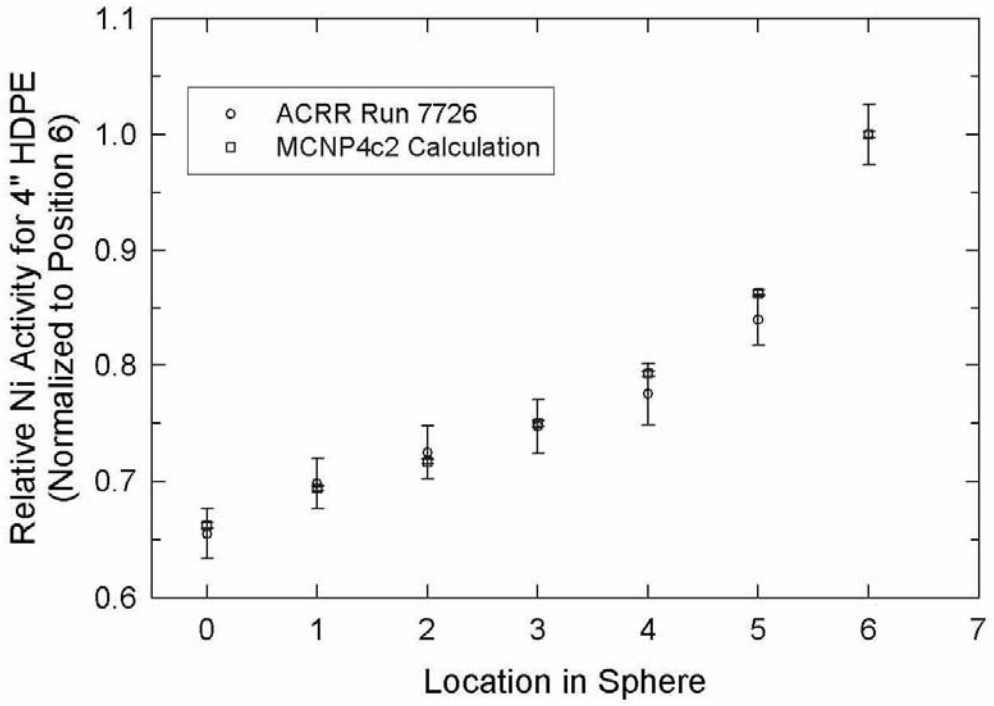

Figure 2-5. Comparison of Normalized Ni Activity for 4-in HDPE Sphere.

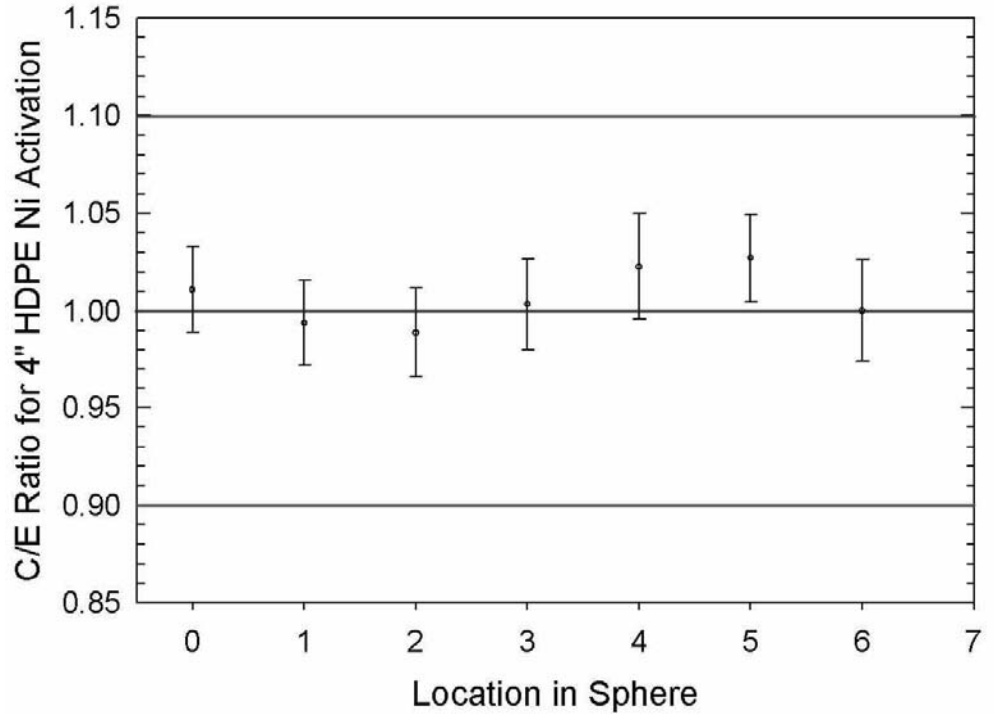

Figure 2-6. C/E Ratio for Ni Activation for 4-in HDPE Sphere.

The Al6061 (Ni) results are shown in Figures 2-7 and 2-8. Figure 2-7 shows the comparison of the normalized Ni activities at each of the seven locations found on the sphere. Figure 2-8

displays the ratio of C/E activity. The error bars in both figures are equivalent to those described for Figures 2-5 and 2-6.

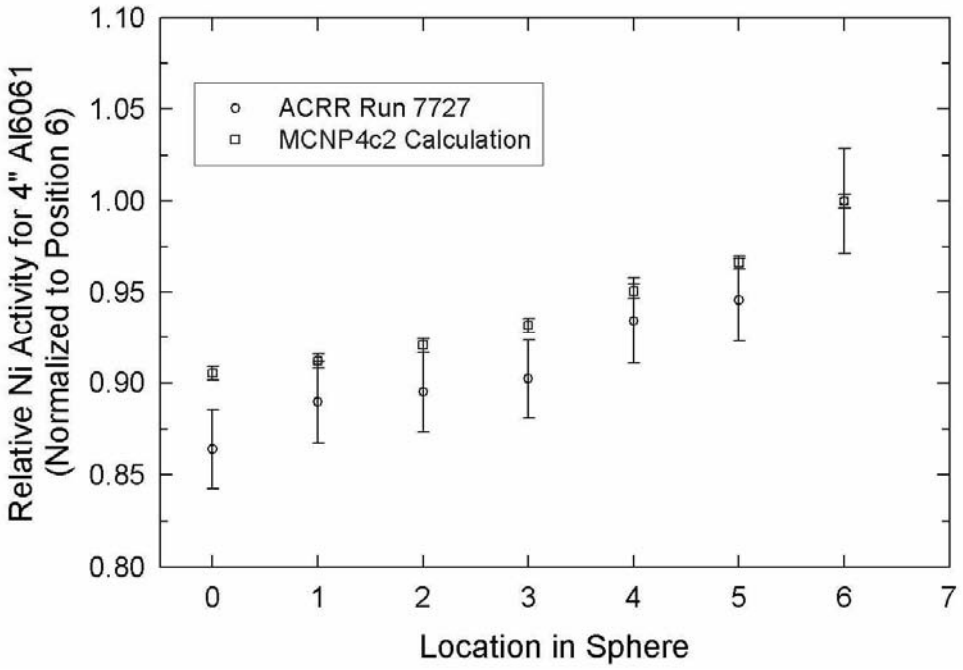

Figure 2-7. Comparison of Normalized Ni Activity for 4-in Al6061 Sphere.

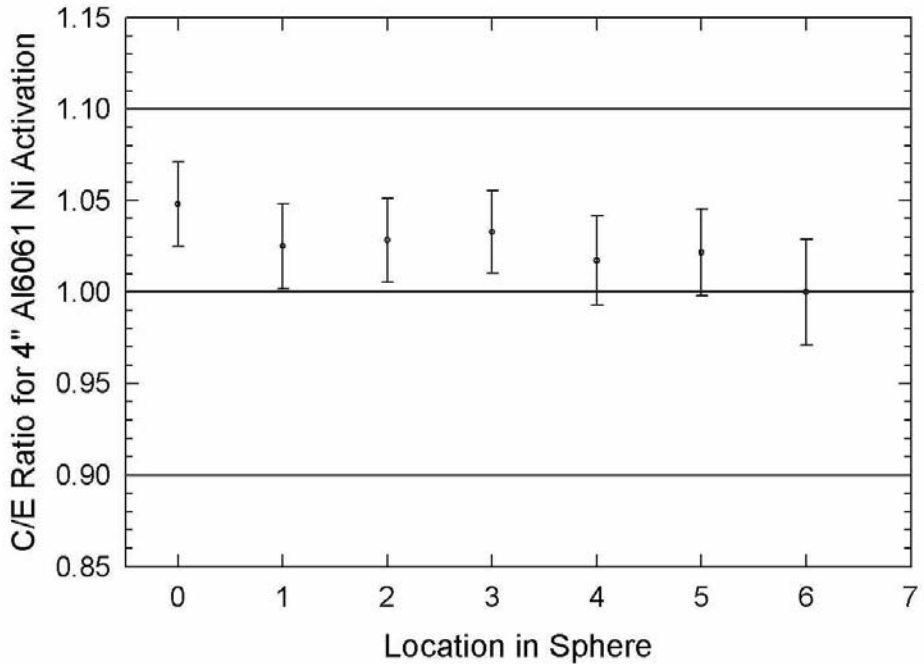

Figure 2-8. C/E Ratio for Ni Activation for 4-in Al6061 Sphere.

The HDPE (Au/Cd) results are shown in Figures 2-9 and 2-10. Figure 2-9 shows the comparison of the normalized Cd-covered Au activities at each of the six locations found on the sphere. This

calculation includes the S(α, β) treatment for the HDPE and updated cross sections for the Cd covers. The S(α, β) treatment is an adjustment of the neutron cross section in the energy region where the molecular interactions of the material are important. This energy region is generally less than 4 eV. Figure 2-10 displays the ratio of C/E activity. The error bars in both figures are equivalent to those described for Figures 2-5 and 2-6.

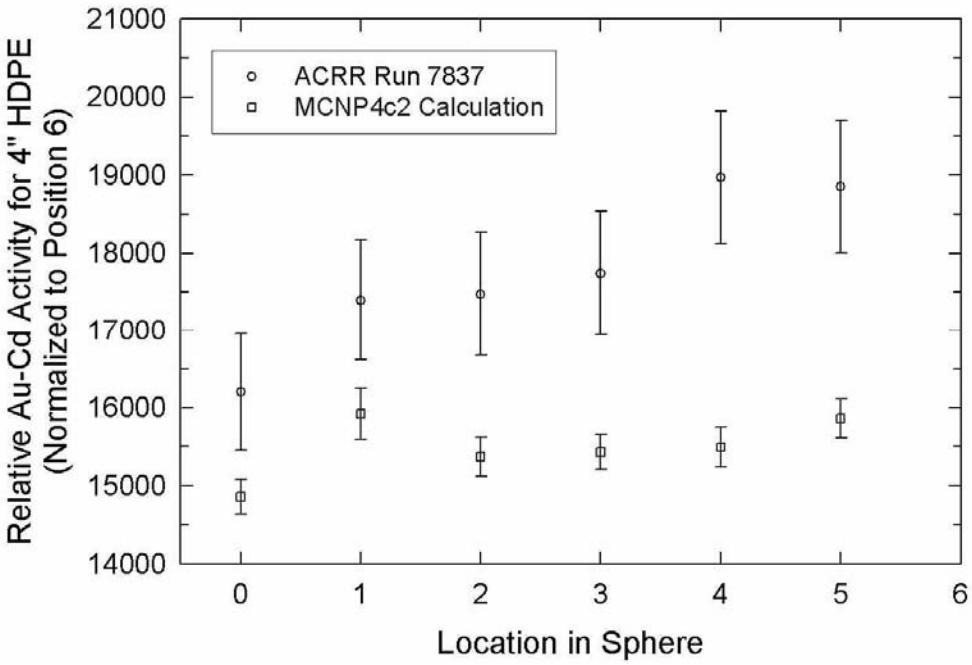

Figure 2-9. Comparison of Normalized Cd-covered Au Activity for 4-in HDPE Sphere.

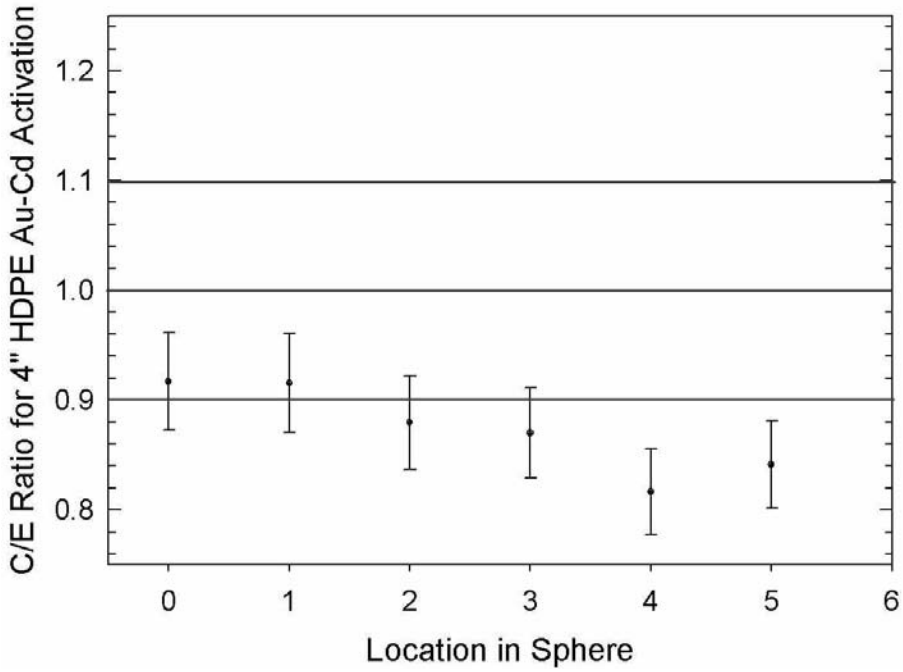

Figure 2-10. C/E Ratio for Cd-covered Au Activation for 4-in HDPE Sphere.

The Al6061 (Au/Cd) results are shown in Figures 2-11 and 2-12. Figure 2-11 shows the comparison of the normalized Cd-covered Au activities at each of the six locations found on the sphere. Figure 2-12 shows the ratio of C/E activity. Updated Cd cross sections were used in this analysis. The error bars in both figures are equivalent to those described for Figures 2-5 and 2-6.

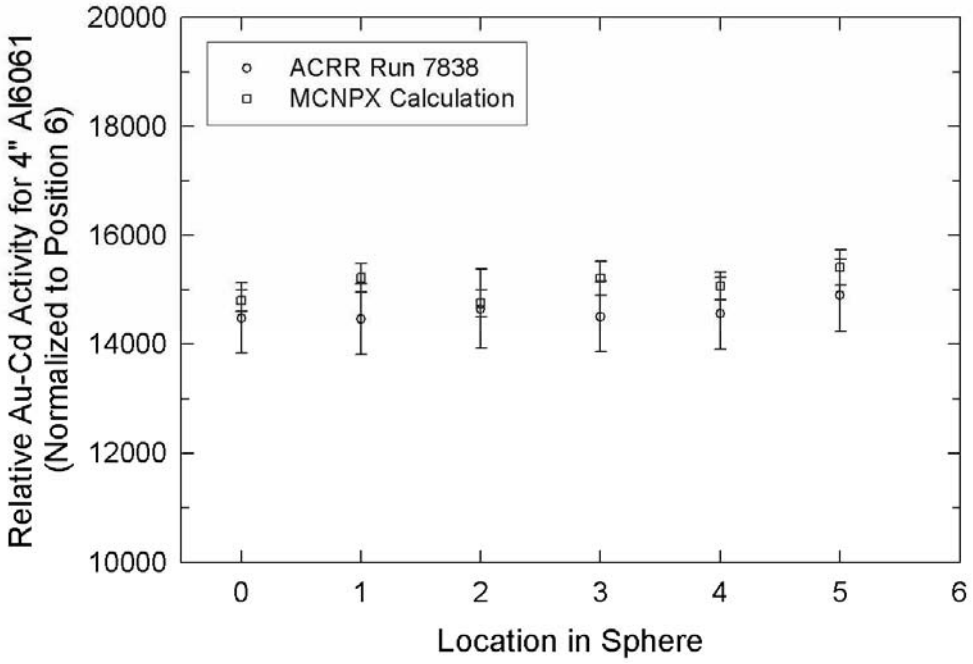

Figure 2-11. Comparison of Normalized Cd-covered Au Activity for 4-in Al6061 Sphere.

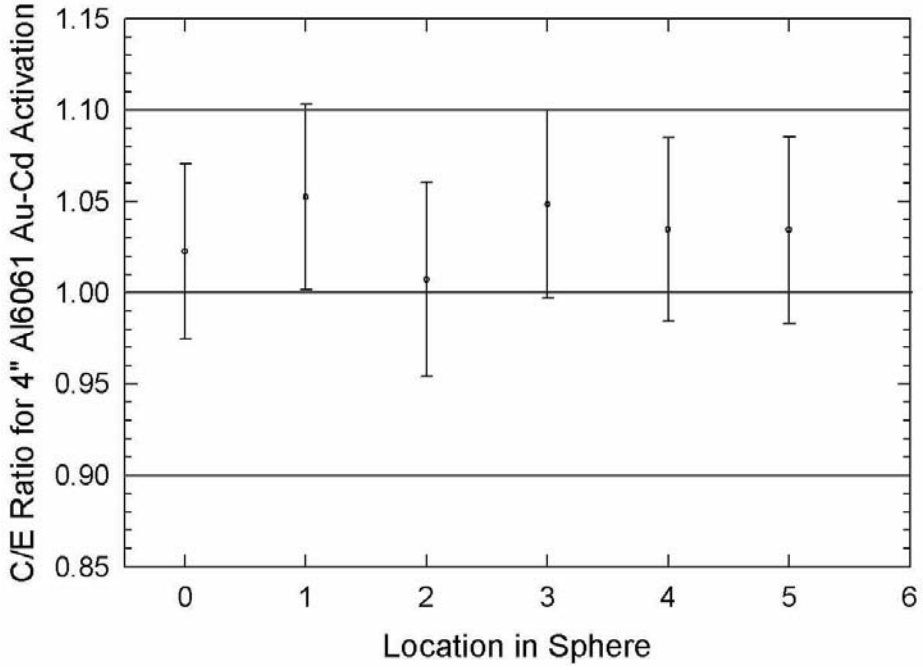

Figure 2-12. C/E Ratio for Cd-covered Au Activation for 4-in Al6061 Sphere.

Upon examination of all figures with C/E ratios, it was found that Figure 2-10 (HDPE with Cd-covered Au foils) is the only one with points outside the nominal range of 10%. Figure 2-10 shows that the calculated points closest to the surface of the sphere fall outside the 10% range. The most likely cause of the discrepancy is perturbation of the external neutron energy spectrum by the HDPE sphere. The neutron energy spectrum in the central cavity is perturbed by the presence of test objects located in the cavity. All calculations described in this report assumed that the neutron energy spectrum external to the sphere was the ACF9 spectrum [4] and was thus unaffected by any perturbations caused by the test object.

To test this as the cause of the discrepancy mentioned above, the ratio of the external Ni foil activation (Position 6) on the Al6061 sphere to the external Ni foil activation on the HDPE sphere must be examined. These ratios were obtained for both the experiments and calculations. The results of these ratio calculations are given in Table 2-7. The table shows that there is not a statistically significant difference between ratios of experiments and calculations. Thus, a spectrum shift is not likely responsible for the differences seen in Figure 2-10. Another cause of the discrepancy could be the location in the sphere. The isotropic nature of the source in the simulation does not consider the possible variation in the source distribution in the reactor. This will be investigated in the future analysis of the experimental data.

Table 2-7. Ratio of External Ni Foils (Al6061/HDPE).

Experiment Type of Sphere and Foil	Ni Activity (Bq/g)	Exp. Uncertainty (%)	Ratio of Al6061 to HDPE
Al6061 (Ni)	2.2625E+04	2.86	---
HDPE (Ni)	1.9415E+04	2.61	---
Ni Foil Runs			**1.1653**
Al6061 (Au/Cd)	2.3075E+04	2.15	---
HDPE (Au/Cd)	1.9640E+04	2.18	---
Cd-covered Au Foil Runs			**1.1749**
Calculation Type of Sphere and Foil	**MCNP Tally (RXNs/cm^3/n/cm^2)**	**MC Uncertainty Relative Error**	**Ratio of Al6061 to HDPE**
Al6061 (Ni)	2.32598E-03	0.0037	---
HDPE (Ni)	1.98002E-03	0.0026	---
Ni Foil Runs			**1.1747**
Al6061 (Au/Cd)	2.32774E-03	0.0032	---
HDPE (Au/Cd)	1.97276E-03	0.0036	---
Cd-covered Au Foil Runs			**1.1799**

The other calculation (for Ni activity) with the HDPE sphere appears to be valid without considering the shift in the neutron energy spectrum. The Q-value for the ^{58}Ni(n, p) reaction is 0.402 MeV, while the ^{197}Au(n, γ) is not a threshold reaction and can occur at all neutron energies

found in a reactor. However, the $^{197}Au(n, \gamma)$ reaction will be dominated by the thermal part of the neutron spectrum. Thus, the Ni reaction will be less sensitive to shifts (down scatters) in the neutron energy spectrum.

Further analysis and calculations are needed to resolve the discrepancies seen in the HDPE (Au/Cd) results. That analysis is beyond the original scope of the experiment design and execution and is more appropriately included in a validation calculation associated with the NuGET code. The further calculations would include a full-scale model of the ACRR with the HDPE sphere (with the proper dosimetry foils) located in the central cavity. This type of calculation would include the feedback (or perturbation) in the neutron energy spectrum caused by the presence of the test object in the reactor.

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3.0 n/γ Attenuation through Materials (7-in-dia HDPE and Al6061 Spheres with Various Foils)

3.1 Introduction

A series of irradiations were performed in the ACRR-CC with spheres of HDPE and Al6061. The nominal compositions for HDPE and Al6061 are given in Table 3-1. The spheres were essentially solid with cavities scrolled out along the equator to allow the insertion of activation foils. The cavities were configured in the sphere such that there were no radiation streaming paths or large void volumes. In addition to the foils located on the interior of the spheres, an external Ni activation foil was attached to the equator on the exterior of the spheres. The external Ni foil provides normalization back to the free-field reactor spectrum characterization and allows comparison between different reactor operations with the same sphere.

Table 3-1. Composition of 7-in-dia Spheres.

Material	Element	Weight %
HDPE*	Hydrogen	14.37
	Carbon	85.63
Al6061+	Magnesium	1.00
	Aluminum	96.55
	Silicon	0.60
	Titanium	0.15
	Chromium	0.20
	Manganese	0.15
	Iron	0.70
	Copper	0.25
	Zinc	0.25
	Others^	0.15

*HDPE is a polymer with a chemical formula of $-(-CH_2--CH_2-)_n-$.
+Metals Handbook, Volume 2, 10th Edition, ASM International (1990).
^"Others" is assumed to be vanadium based on another source [1].

The irradiations were carried out in the well-characterized dosimetry bucket. A centering mechanism in the bucket ensured that the equator of the sphere was located at the fuel centerline in the ACRR-CC. Only one type of dosimeter was used in a given reactor run (except the external Ni foil). This section discusses the experimental results of the 7-in-dia Al6061 and HDPE spheres with Cd-covered Co, Sc, and Ti foils. The results obtained from S pellets and SNL normal equilibrated thermo luminescent dosimeters (TLDs) are also discussed in this section. For details concerning the irradiation of Ni and Cd-covered Au foils in both 7-in and 4-in spheres, see Sections 1 and 2 [5], [6].

3.2 Experimental Procedure

3.2.1 Foil Irradiations

Both of the 7-in-dia spheres (Al6061 and HDPE) were disassembled into three components (see Appendix B for schematic of spheres). Activation foils, S pellets, or TLDs were placed in the locations shown in Figure 3-1 and Table 3-2. For all the irradiations, a Ni foil was placed on the exterior surface of the sphere for normalization purposes. For the bare foils, a bare foil was

placed on the exterior surface of the sphere close to the Ni normalization foil. For the S pellet and TLDs, a Ni foil was placed in the center slot and on the exterior surface of the sphere.

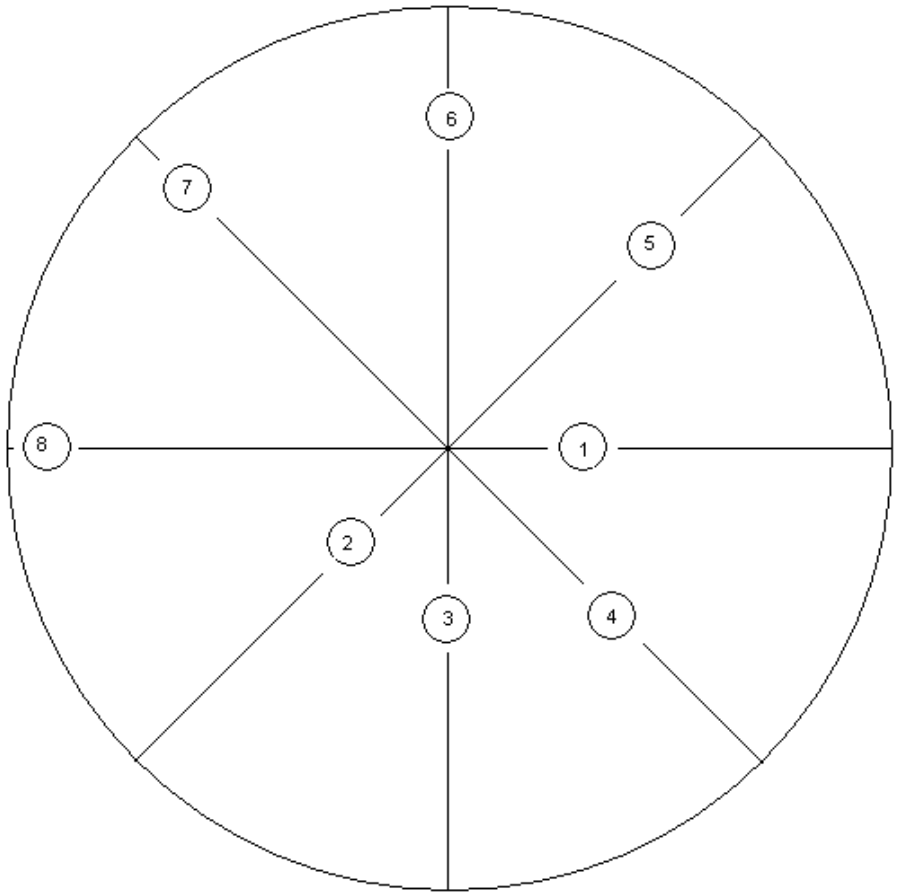

Figure 3-1. Location of Foils in the 7-in-dia Sphere.

Table 3-2. Location Numbers in 7-in Sphere.

Location	Radius from Center of Sphere (in)	Angle From Reference (deg)
Position 1	0.75	0
Position 2	1.63	225
Position 3	1.80	270
Position 4	2.01	315
Position 5	2.43	45
Position 6	2.64	90
Position 7	2.85	135
Position 8	3.09	180

After assembly, a sphere was placed in the dosimetry bucket. The dosimetry bucket contains a centering mechanism with stand-offs that ensure that the activation foils are located at the fuel

centerline (oriented horizontally). The dosimetry bucket was then placed in the ACRR-CC on both the 32-in and 8-in pedestals. The sphere was then irradiated. The specifics of each reactor run are given in Table 3-3. The dosimetry was removed as soon as possible after the irradiation and delivered to the SNL RML for assay.

Table 3-3. Details of ACRR Irradiations of 7-in-dia Spheres.

ACRR Run Number	7-in Sphere Type	Dosimetry	Irradiation Type	Integrated Power
7679	HDPE	Ni, CaF_2:Mn (TLDs)	2% Steady State	16.7 MJ
7680	Al6061	Ni, CaF_2:Mn (TLDs)	2% Steady State	16.7 MJ
7728	HDPE	Ni, S Pellets	5% Steady State	40.0 MJ
7729	Al6061	Ni, S Pellets	5% Steady State	40.0 MJ
7742	HDPE	Ni, Sc	5% Steady State	40.0 MJ
7743	Al6061	Ni, Sc	5% Steady State	40.0 MJ
7807	HDPE	Ni, Cd-covered Co	5% Steady State	40.0 MJ
7831	Al6061	Ni, Cd-covered Co	5% Steady State	40.0 MJ
8042	Al6061	Ni, Ti	5% Steady State	40.0 MJ
8043	HDPE	Ni, Ti	5% Steady State	60.0 MJ

3.3 Results

The results of the RML assay of the ACRR foil irradiations are displayed in Tables 3-4 through 3-15. These data are shown graphically in Figures 3-2 through 3-7. Included in the tables are the uncertainties in consecutive counts from different detectors (% Delta Counts), the 1σ uncertainty in the activity as reported by RML (1σ % Error), the measurement uncertainty (calculated by summing the previous uncertainties in quadrature), and the RML record number. The RML record number is included to provide traceability for the reported results to the data recorded by the dosimetry laboratory [7].

Note that a component of the uncertainty is not addressed in this presentation of the results. Any systematic uncertainty in these measurements has been excluded. The RML staff has discussed supplying this uncertainty metric when it becomes available. When available, the systematic uncertainty will be included in any further analysis of this data.

Table 3-4. TLD Dosimetry in 7-in HDPE Sphere (ACRR Run 7679).

Location and Radius (in)	TLD Reading Rad[CaF_2]			Measurement Uncertainty (%)	RML Record Number (Sample ID)
1 -- 0.75	2.7600E+05			6.6	TLD_DATA_22889.dat
2 -- 1.63	2.8390E+05			6.6	TLD_DATA_22889.dat
3 -- 1.80	3.0780E+05			6.9	TLD_DATA_22889.dat
4 -- 2.01	2.9620E+05			6.8	TLD_DATA_22889.dat
5 -- 2.43	2.6730E+05			6.5	TLD_DATA_22889.dat
6 -- 2.64	2.4960E+05			6.3	TLD_DATA_22889.dat
7 -- 2.85	2.4840E+05			6.3	TLD_DATA_22889.dat
8 -- 3.09	1.8000E+05			7.6	TLD_DATA_22889.dat
Location and Radius (in)	**Ni Activity (Bq/g)**	**% Delta Counts**	**1σ % Error**	**Measurement Uncertainty (%)**	**RML Record Number (Sample ID)**
Ni 0 -- 0.00 (Center)	3.1625E+03	0.35	2.14	2.17	NI-PCEN AC7679 DPRST 09166 D01G02 09171 D02G02
Ni 9 -- 3.5 (External)	7.7990E+03	0.95	2.14	2.34	NI-PEXT AC7679 DPRST 09162 D01G02 09164 D02G02

Table 3-5. TLD Dosimetry in 7-in Al6061 Sphere (ACRR Run 7680).

Location and Radius (in)	TLD Reading Rad[CaF_2]			Measurement Uncertainty (%)	RML Record Number (Sample ID)
1 -- 0.75	1.5270E+05			7.4	TLD_DATA_22890.dat
2 -- 1.63	1.5390E+05			7.4	TLD_DATA_22890.dat
3 -- 1.80	1.4350E+05			7.4	TLD_DATA_22890.dat
4 -- 2.01	1.5150E+05			7.4	TLD_DATA_22890.dat
5 -- 2.43	1.7630E+05			7.5	TLD_DATA_22890.dat
6 -- 2.64	1.6590E+05			7.5	TLD_DATA_22890.dat
7 -- 2.85	1.1690E+05			7.2	TLD_DATA_22890.dat
8 -- 3.09	1.7780E+05			7.5	TLD_DATA_22890.dat
Location and Radius (in)	**Ni Activity (Bq/g)**	**% Delta Counts**	**1σ % Error**	**Measurement Uncertainty (%)**	**RML Record Number (Sample ID)**
Ni 0 -- 0.00 (Center)	7.1465E+03	0.99	2.14	2.36	NI-ACEN AC7680 DPRST 09167 D01G02 09169 D02G02
Ni 9 -- 3.5 (External)	9.3680E+03	1.17	2.14	2.44	NI-AEXT AC7680 DPRST 09163 D01G02 09165 D02G02

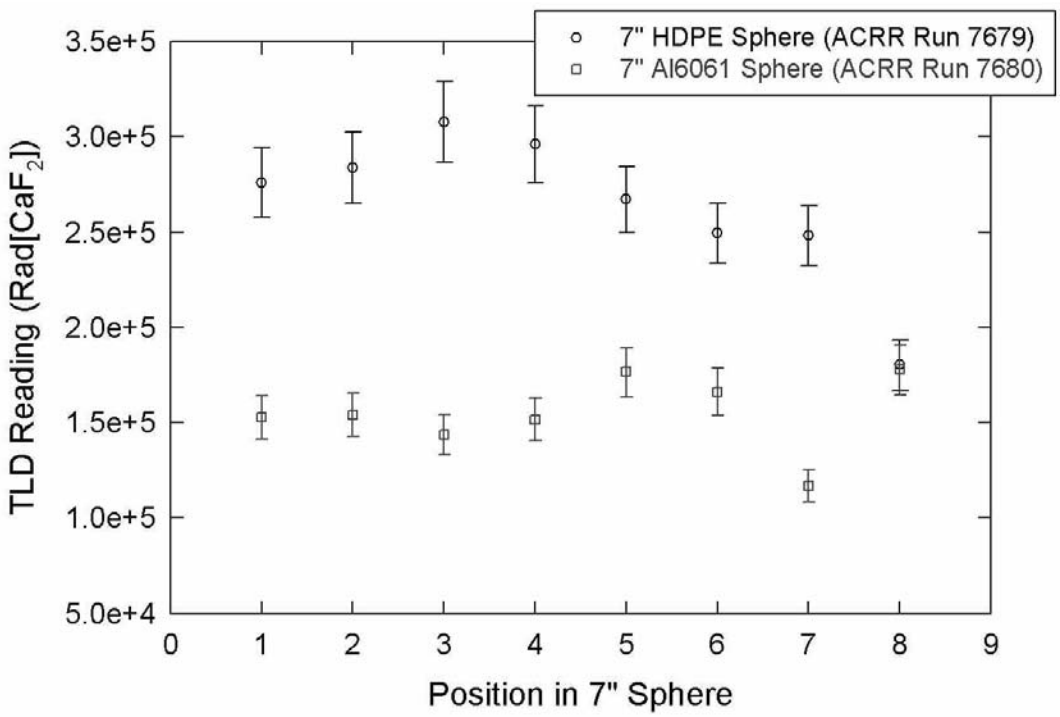

Figure 3-2. CaF_2:Mn TLD Dose in 7-in HDPE and Al6061 Spheres.

Table 3-6. S Dosimetry in 7-in HDPE Sphere (ACRR Run 7728).

Location and Radius (in)	Cf Equiv Fluence (n/cm^2)			Measurement Uncertainty (%)	RML Record Number (Sample ID)
1 -- 0.75	5.103E+13			3.0	SUL_datb_07863.dat
2 -- 1.63	6.283E+13			3.0	SUL_datb_07863.dat
3 -- 1.80	6.574E+13			3.0	SUL_datb_07863.dat
4 -- 2.01	6.589E+13			3.0	SUL_datb_07863.dat
5 -- 2.43	7.641E+13			3.0	SUL_datb_07863.dat
6 -- 2.64	8.999E+13			2.9	SUL_datb_07863.dat
7 -- 2.85	9.282E+13			2.9	SUL_datb_07863.dat
8 -- 3.09	1.012E+14			2.9	SUL_datb_07863.dat
Location and Radius (in)	**Ni Activity (Bq/g)**	**% Delta Counts**	**1σ % Error**	**Measurement Uncertainty (%)**	**RML Record Number (Sample ID)**
Ni 0 -- 0.00 (Center)	7.3465E+03	0.29	2.14	2.16	NI58-PC A7728 DEPRST 09554 D01G02 09558 D02G02
Ni 9 -- 3.5 (External)	1.8535E+04	1.67	2.14	2.71	NI58-PE A7728 DEPRST 09555 D01G02 09559 D02G02

Table 3-7. S Dosimetry in 7-in Al6061 Sphere (ACRR Run 7729).

Location and Radius (in)	Cf Equiv Fluence (n/cm^2)			Measurement Uncertainty (%)	RML Record Number (Sample ID)
1 -- 0.75	1.180E+14			2.9	SUL_datb_07864.dat
2 -- 1.63	1.162E+14			2.9	SUL_datb_07864.dat
3 -- 1.80	1.181E+14			2.9	SUL_datb_07864.dat
4 -- 2.01	1.226E+14			2.9	SUL_datb_07864.dat
5 -- 2.43	1.239E+14			2.9	SUL_datb_07864.dat
6 -- 2.64	1.326E+14			2.9	SUL_datb_07864.dat
7 -- 2.85	1.342E+14			2.9	SUL_datb_07864.dat
8 -- 3.09	1.391E+14			2.9	SUL_datb_07864.dat
Location and Radius (in)	**Ni Activity (Bq/g)**	**% Delta Counts**	**1σ % Error**	**Measurement Uncertainty (%)**	**RML Record Number (Sample ID)**
Ni 0 -- 0.00 (Center)	1.6450E+04	0.00	2.14	2.14	NI58-AC A7729 DEPRST 09556 D01G02 09560 D02G02
Ni 9 -- 3.5 (External)	2.0915E+04	0.05	2.14	2.14	NI58-AE A7729 DEPRST 09557 D01G02 09561 D02G02

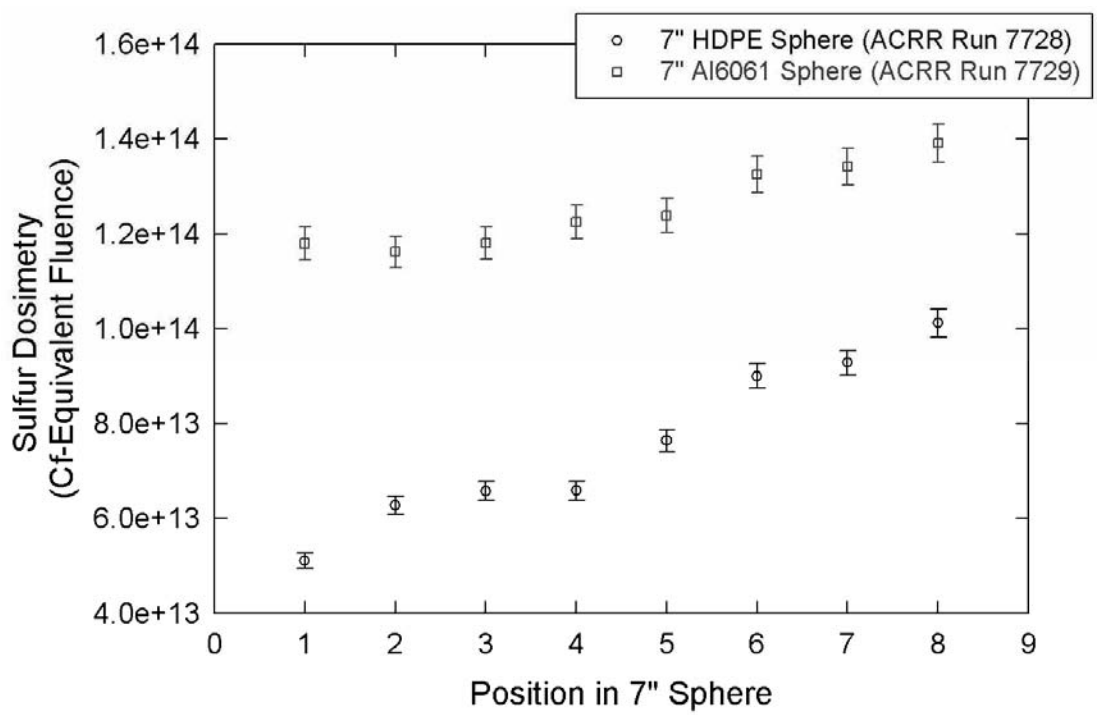

Figure 3-3. S Dosimetry in 7-in HDPE and Al6061 Spheres.

Table 3-8. Sc Activation in 7-in HDPE Sphere (ACRR Run 7742).

Location and Radius (in)	Sc Activity (Bq/g)	% Delta Counts	1σ % Error	Measurement Uncertainty (%)	RML Record Number (Sample ID)
0 -- Center	2.3350E+07	0.00	2.08	2.08	SC45 P0 A7742 DEPRST 09691 D03G03 09701 D04G03
1 -- 0.75	2.3845E+07	1.05	2.07	2.32	SC45 P1 A7742 DEPRST 09692 D03G03 09702 D04G03
2 -- 1.63	2.4355E+07	0.70	2.09	2.20	SC45 P2 A7742 DEPRST 09693 D03G03 09703 D04G03
3 -- 1.80	2.3965E+07	0.21	2.08	2.09	SC45 P3 A7742 DEPRST 09694 D03G03 09704 D04G03
4 -- 2.01	2.4090E+07	0.66	2.09	2.19	SC45 P4 A7742 DEPRST 09695 D03G03 09705 D04G03
5 -- 2.43	2.3910E+07	0.59	2.08	2.16	SC45 P5 A7742 DEPRST 09696 D03G03 09706 D04G03
6 -- 2.64	2.1550E+07	0.93	2.09	2.29	SC45 P6 A7742 DEPRST 09697 D03G03 09707 D04G03
7 -- 2.85	1.8335E+07	0.49	2.08	2.14	SC45 P7 A7742 DEPRST 09698 D03G03 09708 D04G03
8 -- 3.09	1.5565E+07	1.61	2.08	2.63	SC45 P8 A7742 DEPRST 09699 D03G03 09709 D04G03
9 -- 3.5 (External)	6.1380E+06	0.46	2.08	2.13	SC45 P9 A7742 DEPRST 09700 D03G03 09710 D04G03
Ni 9 -- 3.5 (External)	Ni Activity 1.7970E+04	0.00	2.14	2.14	NI58-SA A7742 DEPRST 09689 D01G02 09690 D02G02

Table 3-9. Sc Activation in 7-in Al6061 Sphere (ACRR Run 7743).

Location and Radius (in)	Sc Activity (Bq/g)	% Delta Counts	1σ % Error	Measurement Uncertainty (%)	RML Record Number (Sample ID)
0 -- Center	2.1690E+06	1.38	2.09	2.50	SC45 A0 A7743 DEPRST 09713 D03G03 09723 D04G03
1 -- 0.75	2.1470E+06	1.49	2.07	2.55	SC45 A1 A7743 DEPRST 09714 D03G03 09724 D04G03
2 -- 1.63	2.2015E+06	0.23	2.09	2.10	SC45 A2 A7743 DEPRST 09715 D03G03 09725 D04G03
3 -- 1.80	2.1725E+06	0.78	2.08	2.22	SC45 A3 A7743 DEPRST 09716 D03G03 09726 D04G03
4 -- 2.01	2.1490E+06	1.30	2.07	2.44	SC45 A4 A7743 DEPRST 09717 D03G03 09727 D04G03
5 -- 2.43	2.1695E+06	0.60	2.07	2.16	SC45 A5 A7743 DEPRST 09718 D03G03 09728 D04G03
6 -- 2.64	2.2125E+06	0.32	2.08	2.10	SC45 A6 A7743 DEPRST 09719 D03G03 09729 D04G03
7 -- 2.85	2.2510E+06	0.18	2.08	2.09	SC45 A7 A7743 DEPRST 09720 D03G03 09730 D04G03
8 -- 3.09	2.2935E+06	0.31	2.08	2.10	SC45 A8 A7743 DEPRST 09721 D03G03 09731 D04G03
9 -- 3.5 (External)	2.3260E+06	0.17	2.08	2.09	SC45 A9 A7743 DEPRST 09722 D03G03 09732 D04G03
Ni 9 -- 3.5 (External)	Ni Activity 2.0805E+04	0.24	2.14	2.15	NI58-AE A7743 DEPRST 09711 D01G02 09712 D02G02

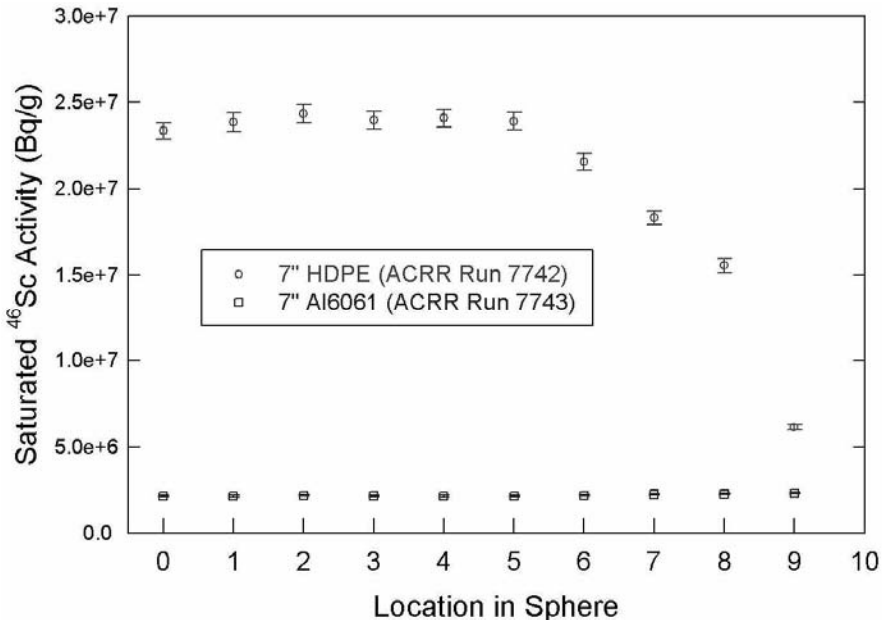

Figure 3-4. Sc Activation in 7-in HDPE and Al6061 Spheres.

Table 3-10. Cd-covered Co Activation in 7-in HDPE Sphere (ACRR Run 7807).

Location and Radius (in)	Co Activity (Bq/g)	% Delta Counts	1σ % Error	Measurement Uncertainty (%)	RML Record Number (Sample ID)
0 -- Center	1.9205E+04	2.55	3.23	4.12	CO59-P7-0 A7807DPRES 10037 D01G02 10028 D02G02
1 -- 0.75	2.0625E+04	0.15	3.23	3.23	CO59-P7-1 A7807DPRES 10038 D01G02 10029 D02G02
2 -- 1.63	2.6335E+04	0.11	3.22	3.22	CO59-P7-1 A7807DPRES 10039 D01G02 10030 D02G02
3 -- 1.80	2.9065E+04	2.37	3.11	3.91	CO59-P7-1 A7807DPRES 10040 D01G02 10031 D02G02
4 -- 2.01	3.1985E+04	1.16	3.16	3.37	CO59-P7-1 A7807DPRES 10041 D01G02 10032 D02G02
5 -- 2.43	3.6820E+04	0.54	3.17	3.22	CO59-P7-1 A7807DPRES 10042 D01G02 10033 D02G02
6 -- 2.64	3.9915E+04	0.93	3.09	3.23	CO59-P7-1 A7807DPRES 10043 D01G02 10034 D02G02
7 -- 2.85	4.3245E+04	2.47	3.15	4.00	CO59-P7-1 A7807DPRES 10044 D01G02 10047 D02G02
8 -- 3.09	4.6205E+04	1.17	3.14	3.58	CO59-P7-1 A7807DPRES 10045 D01G02 10036 D02G02
Ni 9 -- 3.5 (External)	Ni Activity 1.9985E+04	1.15	2.14	2.43	NI58-7P AC7807 DPRST 10026 D01G02 10027 D02G02

Table 3-11. Cd-covered Co Activation in 7-in Al6061 Sphere (ACRR Run 7831).

Location and Radius (in)	Co Activity (Bq/g)	% Delta Counts	1σ % Error	Measurement Uncertainty (%)	RML Record Number (Sample ID)
0 -- Center	5.2380E+04	2.10	3.16	3.79	CO59-A7-0 A7831DPRES 10222 D01G02 10232 D02G02
1 -- 0.75	5.0900E+04	1.02	3.16	3.32	CO59-A7-1 A7831DPRES 10223 D01G02 10233 D02G02
2 -- 1.63	5.1495E+04	2.35	3.17	3.95	CO59-A7-2 A7831DPRES 10224 D01G02 10234 D02G02
3 -- 1.80	5.1430E+04	0.78	3.18	3.27	CO59-A7-3 A7831DPRES 10225 D01G02 10235 D02G02
4 -- 2.01	5.2105E+04	2.40	3.17	3.98	CO59-A7-4 A7831DPRES 10226 D01G02 10236 D02G02
5 -- 2.43	5.0660E+04	2.96	3.16	4.33	CO59-A7-5 A7831DPRES 10227 D01G02 10256 D02G02
6 -- 2.64	5.0400E+04	2.26	3.18	3.90	CO59-A7-6 A7831DPRES 10228 D01G02 10238 D02G02
7 -- 2.85	5.0590E+04	1.90	3.18	3.70	CO59-A7-7 A7831DPRES 10261 D01G02 10265 D02G02
8 -- 3.09	5.0355E+04	0.97	3.18	3.32	CO59-A7-8 A7831DPRES 10262 D01G02 10240 D02G02
Ni 9 -- 3.5 (External)	Ni Activity 2.1630E+04	0.28	2.14	2.16	NI58-A7-E A7831DPRES 10221 D01G02 10231 D02G02

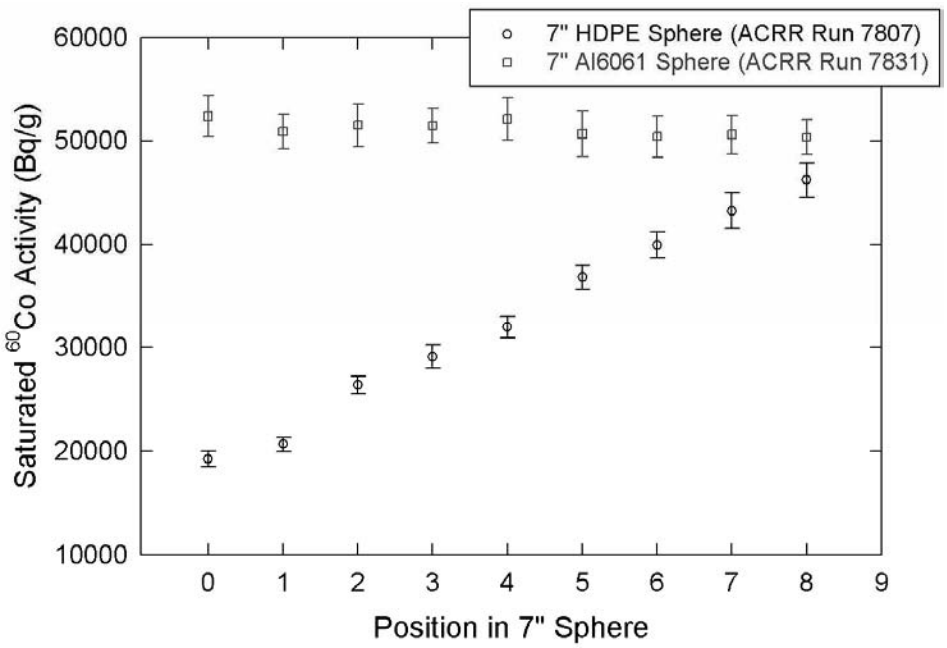

Figure 3-5. Cd-covered Co Activation in 7-in HDPE and Al6061 Spheres.

Table 3-12. Ti-47 Activation in 7-in Al6061 Sphere (ACRR Run 8042).

Location and Radius (in)	Ti Activity (Bq/g)	% Delta Counts	1σ % Error	Measurement Uncertainty (%)	RML Record Number (Sample ID)
0 -- Center	7.1175E+04	0.40	2.03	2.07	TI-A0 A8042 DEPRIEST 11814 D01G02 11824 D02G02
1 -- 0.75	7.1168E+04	2.91	2.04	3.55	TI-A1 A8042 DEPRIEST 11815 D01G02 11825 D02G02
2 -- 1.63	7.2855E+04	0.78	1.99	2.14	TI-A2 A8042 DEPRIEST 11816 D01G02 11826 D02G02
3 -- 1.80	7.4379E+04	0.07	2.02	2.02	TI-A3 A8042 DEPRIEST 11817 D01G02 11827 D02G02
4 -- 2.01	7.4766E+04	0.71	2.04	2.16	TI-A4 A8042 DEPRIEST 11818 D01G02 11828 D02G02
5 -- 2.43	7.8855E+04	1.66	2.00	2.60	TI-A5 A8042 DEPRIEST 11819 D01G02 11829 D02G02
6 -- 2.64	8.0732E+04	0.54	1.99	2.06	TI-A6 A8042 DEPRIEST 11820 D01G02 11830 D02G02
7 -- 2.85	8.4031E+04	0.50	2.10	2.16	TI-A7 A8042 DEPRIEST 11821 D01G02 11869 D02G02
8 -- 3.09	8.1310E+04	0.75	1.99	2.13	TI-A8 A8042 DEPRIEST 11900 D01G02 11886 D02G02
9 -- 3.5 (External)	8.9800E+04	1.53	2.00	2.52	TI-A9 A8042 DEPRIEST 11823 D01G02 11833 D02G02
Ni 9 -- 3.5 (External)	Ni Activity 1.8885E+04	1.22	2.18	2.50	NI58-A 8042 DEPRIEST 11860 D01G02 11861 D03G02

Table 3-13. Ti-48 Activation in 7-in Al6061 Sphere (ACRR Run 8042).

Location and Radius (in)	Ti Activity (Bq/g)	% Delta Counts	1σ % Error	Measurement Uncertainty (%)	RML Record Number (Sample ID)
0 -- Center	1.4128E+03	2.97	5.52	6.27	TI-A0 A8042 DEPRIEST 11814 D01G02 11824 D02G02
1 -- 0.75	1.3475E+03	1.55	6.99	7.16	TI-A1 A8042 DEPRIEST 11815 D01G02 11825 D02G02
2 -- 1.63	1.5110E+03	2.51	5.61	6.15	TI-A2 A8042 DEPRIEST 11816 D01G02 11826 D02G02
3 -- 1.80	1.5354E+03	1.77	5.83	6.09	TI-A3 A8042 DEPRIEST 11817 D01G02 11827 D02G02
4 -- 2.01	1.6134E+03	5.29	5.81	7.86	TI-A4 A8042 DEPRIEST 11818 D01G02 11828 D02G02
5 -- 2.43	1.6039E+03	3.97	5.59	6.86	TI-A5 A8042 DEPRIEST 11819 D01G02 11829 D02G02
6 -- 2.64	1.7103E+03	0.79	5.88	5.93	TI-A6 A8042 DEPRIEST 11820 D01G02 11830 D02G02
7 -- 2.85	1.8343E+03	4.95	7.18	8.72	TI-A7 A8042 DEPRIEST 11821 D01G02 11869 D02G02
8 -- 3.09	1.7170E+03	0.95	10.94	10.98	TI-A8 A8042 DEPRIEST 11900 D01G02 11886 D02G02
9 -- 3.5 (External)	2.0206E+03	5.50	6.43	8.46	TI-A9 A8042 DEPRIEST 11823 D01G02 11833 D02G02
Ni 9 -- 3.5 (External)	Ni Activity 1.8885E+04	1.22	2.18	2.50	NI58-A 8042 DEPRIEST 11860 D01G02 11861 D03G02

Table 3-14. Ti-47 Activation in 7-in HDPE Sphere (ACRR Run 8043).

Location and Radius (in)	Ti Activity (Bq/g)	% Delta Counts	1σ % Error	Measurement Uncertainty (%)	RML Record Number (Sample ID)
0 -- Center	4.3312E+04	0.85	2.19	2.35	TI-P0 A8043 DEPRIEST 11794 D01G02 11804 D02G02
1 -- 0.75	4.5597E+04	2.54	2.14	3.32	TI-P1 A8043 DEPRIEST 11795 D01G02 11805 D02G02
2 -- 1.63	5.5291E+04	1.03	2.10	2.34	TI-P2 A8043 DEPRIEST 11796 D01G02 11806 D02G02
3 -- 1.80	5.5767E+04	0.29	2.19	2.21	TI-P3 A8043 DEPRIEST 11797 D01G02 11807 D02G02
4 -- 2.01	5.6767E+04	1.27	2.18	2.52	TI-P4 A8043 DEPRIEST 11798 D01G02 11808 D02G02
5 -- 2.43	6.6488E+04	0.08	2.09	2.09	TI-P5 A8043 DEPRIEST 11799 D01G02 11809 D02G02
6 -- 2.64	7.6004E+04	2.67	2.13	3.42	TI-P6 A8043 DEPRIEST 11800 D01G02 11810 D02G02
7 -- 2.85	8.5739E+04	0.70	2.09	2.20	TI-P7 A8043 DEPRIEST 11870 D01G02 11885 D02G02
8 -- 3.09	9.7378E+04	0.91	1.93	2.13	TI-P8 A8043 DEPRIEST 11802 D01G02 11893 D02G02
9 -- 3.5 (External)	1.1302E+05	1.25	1.98	2.34	TI-P9 A8043 DEPRIEST 11803 D01G02 11813 D02G02
Ni 9 -- 3.5 (External)	Ni Activity 2.4735E+04	1.58	3.93	4.24	NI58-P 8043 DEPRIEST 11862 D01G02 11863 D04G02

Table 3-15. Ti-48 Activation in 7-in HDPE Sphere (ACRR Run 8043).

Location and Radius (in)	Ti Activity (Bq/g)	% Delta Counts	1σ % Error	Measurement Uncertainty (%)	RML Record Number (Sample ID)
0 -- Center	1.6120E+03	4.29	5.16	6.71	TI-P0 A8043 DEPRIEST 11794 D01G02 11804 D02G02
1 -- 0.75	1.5314E+03	2.83	5.14	5.87	TI-P1 A8043 DEPRIEST 11795 D01G02 11805 D02G02
2 -- 1.63	1.8885E+03	2.08	4.61	5.06	TI-P2 A8043 DEPRIEST 11796 D01G02 11806 D02G02
3 -- 1.80	1.8072E+03	2.02	5.66	6.01	TI-P3 A8043 DEPRIEST 11797 D01G02 11807 D02G02
4 -- 2.01	1.8492E+03	1.39	5.66	5.83	TI-P4 A8043 DEPRIEST 11798 D01G02 11808 D02G02
5 -- 2.43	2.0802E+03	2.35	5.38	5.87	TI-P5 A8043 DEPRIEST 11799 D01G02 11809 D02G02
6 -- 2.64	2.0911E+03	0.52	5.75	5.77	TI-P6 A8043 DEPRIEST 11800 D01G02 11810 D02G02
7 -- 2.85	2.1758E+03	2.68	7.09	7.58	TI-P7 A8043 DEPRIEST 11870 D01G02 11885 D02G02
8 -- 3.09	2.7931E+03	6.60	4.56	8.02	TI-P8 A8043 DEPRIEST 11802 D01G02 11893 D02G02
9 -- 3.5 (External)	2.9270E+03	3.76	4.70	6.02	TI-P9 A8043 DEPRIEST 11803 D01G02 11813 D02G02
Ni 9 -- 3.5 (External)	Ni Activity 2.4735E+04	1.58	3.93	4.24	NI58-P 8043 DEPRIEST 11862 D01G02 11863 D04G02

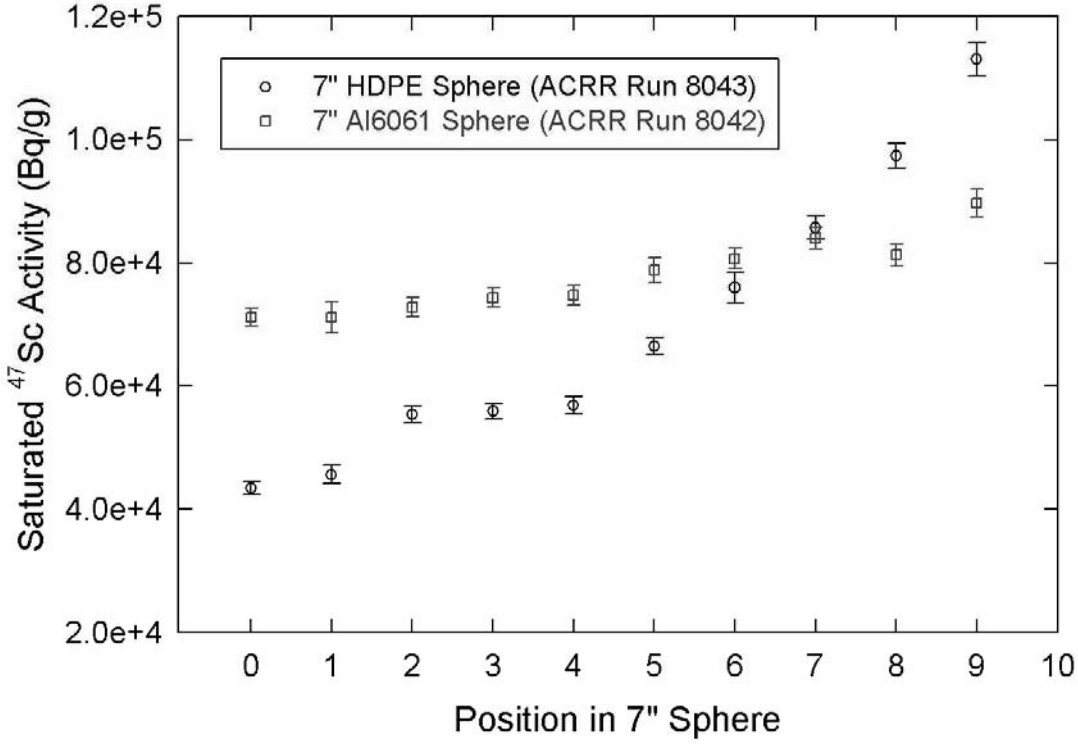

Figure 3-6. Ti-47 Activation in 7-in HDPE and Al6061 Spheres.

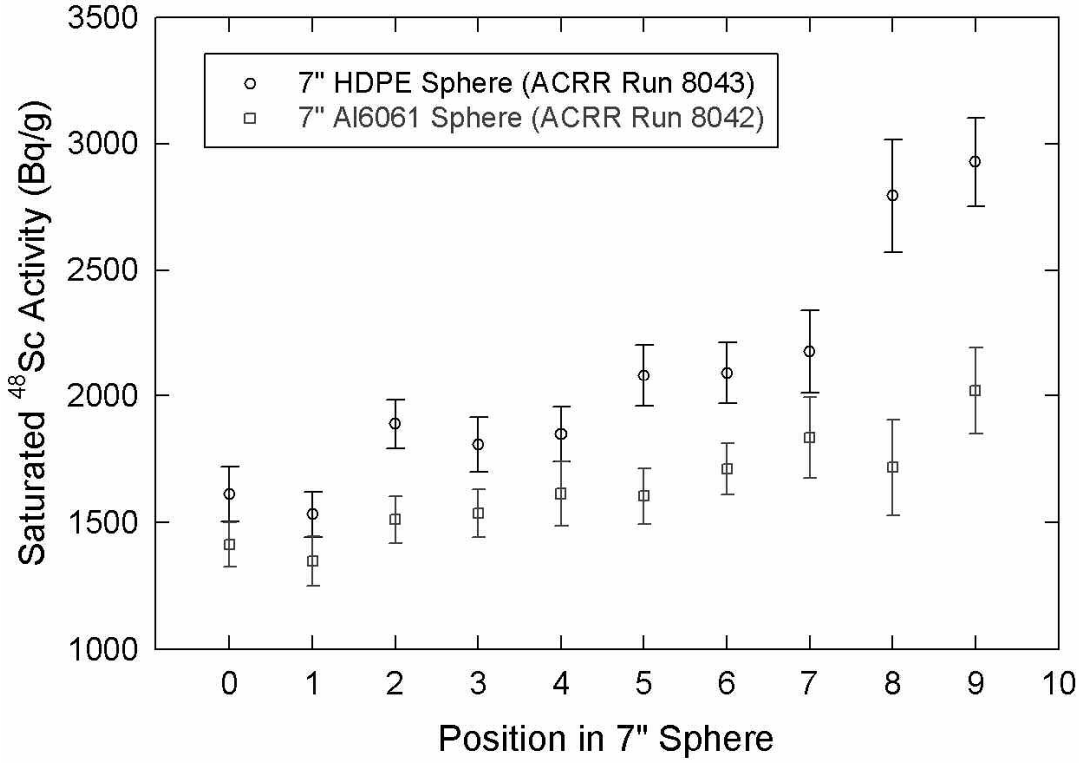

Figure 3-7. Ti-48 Activation in 7-in HDPE and Al6061 Spheres.

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4.0 n/γ Attenuation through Materials (4-in-dia HDPE and Al6061 Spheres with Various Foils)

4.1 Introduction

A series of irradiations were performed in the ACRR-CC with spheres of HDPE and aluminum (Al6061). The nominal compositions for HDPE and Al6061 are given in Table 4-1. The spheres were essentially solid with cavities scrolled out along the equator to allow the insertion of activation foils. The cavities were configured in the sphere such that there were no radiation streaming paths or large void volumes. In addition to the foils located on the interior of the spheres, an external Ni activation foil was attached to the equator on the exterior of the spheres. The external Ni foil provides normalization back to the free-field reactor spectrum characterization and allows comparison between different reactor operations with the same sphere.

Table 4-1. Composition of 4-in-dia Spheres.

Material	Element	Weight %
HDPE*	Hydrogen	14.37
	Carbon	85.63
Al6061+	Magnesium	1.00
	Aluminum	96.55
	Silicon	0.60
	Titanium	0.15
	Chromium	0.20
	Manganese	0.15
	Iron	0.70
	Copper	0.25
	Zinc	0.25
	Others^	0.15

*HDPE is a polymer with a chemical formula of $-(-CH_2--CH_2-)_n-$.
+Metals Handbook, Volume 2, 10th Edition, ASM International (1990).
^"Others" is assumed to be vanadium based on another source [1].

The irradiations were carried out in the well-characterized dosimetry bucket and in the Pb-B_4C bucket. A centering mechanism in the bucket ensured that the equator of the sphere was located at the fuel centerline in the ACRR-CC. Only one type of dosimeter was used in a given reactor run (except the external Ni foil). This section discusses the experimental results of the 4-in-dia Al6061 and HDPE spheres with Sc and Cd-covered Co. The results obtained from S pellets and SNL normal equilibrated TLDs are also discussed in this section. The irradiations of Ni and Cd-covered Au foils in the Pb-B_4C bucket are also included here. For details concerning the central cavity irradiations of Ni and Cd-covered Au foils in both 7-in and 4-in spheres, see Sections 1 and 2 [5], [6].

4.2 Experimental Procedure

4.2.1 Foil Irradiations

Both of the 4-in-dia spheres (Al6061 and HDPE) were disassembled into three components (see Appendix B for schematic of spheres). Activation foils, S pellets, or TLDs were placed in the locations shown in Figure 4-1 and Table 4-2. For all the irradiations, a Ni foil was placed on the exterior surface of the sphere for normalization purposes. For the bare foils, a bare foil was placed on the exterior surface of the sphere close to the Ni normalization foil. For the S pellet and TLDs, a Ni foil was placed in the center slot and on the exterior surface of the sphere.

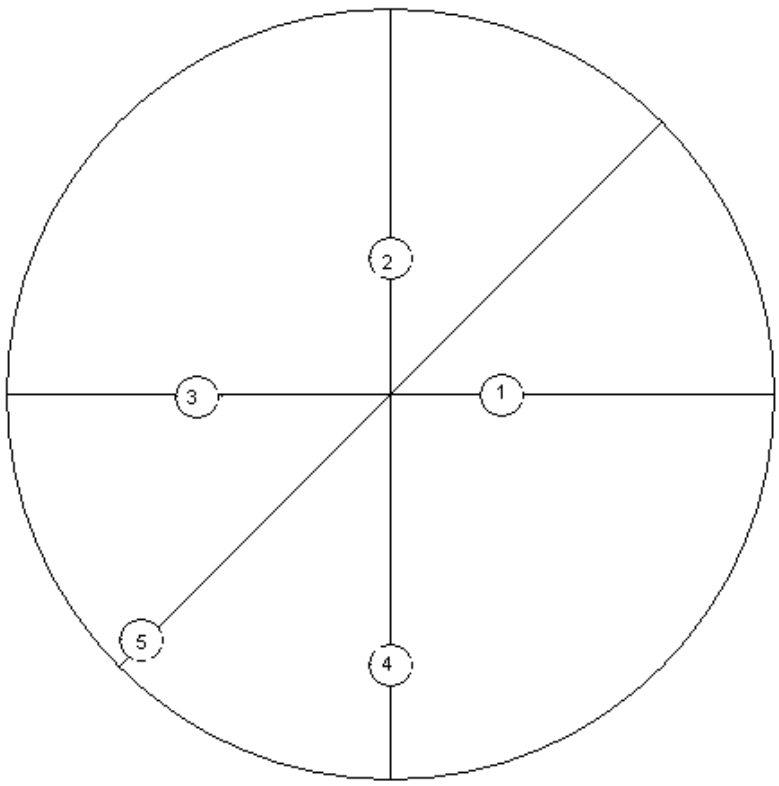

Figure 4-1. Location of Foils in the 4-in-dia Sphere.

Table 4-2. Location Numbers in 4-in Sphere.

Location	Radius from Center of Sphere (in)	Angle From Reference (deg)
Position 1	0.75	0
Position 2	0.96	90
Position 3	1.17	180
Position 4	1.38	270
Position 5	1.63	225

After assembly, a sphere was placed in the dosimetry bucket. The dosimetry bucket contains a centering mechanism with stand-offs that ensure that the activation foils are located at the fuel centerline (oriented horizontally). The dosimetry bucket was then placed in the ACRR-CC on both the 32-in and 8-in pedestals. Irradiations in the Pb-B_4C bucket were located on only the 32-in pedestal. The sphere was then irradiated. The specifics of each reactor run are given in Table 4-3. The dosimetry was removed as soon as possible after the irradiation and delivered to the SNL RML for assay.

Table 4-3. Details of ACRR Irradiations of 4-in-dia Spheres.

ACRR Run Number	4-in Sphere Type	Dosimetry	Irradiation Type	Integrated Power
ACRR-CC Irradiations				
7891	HDPE	Ni, CaF_2:Mn (TLDs)	2% Steady State	16.7 MJ
7892	Al6061	Ni, CaF_2:Mn (TLDs)	2% Steady State	16.7 MJ
7753	HDPE	Ni, S Pellets	5% Steady State	40.0 MJ
7765	Al6061	Ni, S Pellets	5% Steady State	40.0 MJ
7740	HDPE	Ni, Sc	5% Steady State	40.0 MJ
7741	Al6061	Ni, Sc	5% Steady State	40.0 MJ
7806	HDPE	Ni, Cd-covered Co	5% Steady State	40.0 MJ
7832	Al6061	Ni, Cd-covered Co	5% Steady State	40.0 MJ
Pb-B_4C Bucket Irradiations				
8046	HDPE	Ni	5% Steady State	40.0 MJ
8003	Al6061	Ni	5% Steady State	40.0 MJ
8128	HDPE	Ni, Cd-covered Au	5% Steady State	80.0 MJ
8151	Al6061	Ni, Cd-covered Au	5% Steady State	100.0 MJ
8047	Al6061	Ni, Cd-covered Co	5% Steady State	40.0 MJ
8056	HDPE	Ni, Sc	5% Steady State	40.0 MJ
8022	Al6061	Ni, Sc	5% Steady State	40.0 MJ
8092	HDPE	Ni, CaF_2:Mn (TLDs)	2% Steady State	16.7 MJ
8023	Al6061	Ni, CaF_2:Mn (TLDs)	2% Steady State	16.7 MJ
8093	HDPE	Ni, S Pellets	5% Steady State	40.0 MJ
8038	Al6061	Ni, S Pellets	5% Steady State	40.0 MJ

4.3 Results

The results of the RML assay of the ACRR foil irradiations are displayed in Tables 4-4 through 4-22. These data are shown graphically in Figures 4-2 through 4-11. Included in the tables are the uncertainties in consecutive counts from different detectors (% Delta Counts), the 1σ uncertainty in the activity as reported by RML (1σ % Error), the measurement uncertainty (calculated by summing the previous uncertainties in quadrature), and the RML record number. The RML record number is included to provide traceability for the reported results to the data recorded by the dosimetry laboratory [8].

Note that a component of the uncertainty is not addressed in this presentation of the results. Any systematic uncertainty in these measurements has been excluded. The RML staff has discussed supplying this uncertainty metric when it becomes available. When available, the systematic uncertainty will be included in any further analysis of this data.

Table 4-4. Sc Activation in 4-in HDPE Sphere (ACRR Run 7740).

Location and Radius (in)	Sc Activity (Bq/g)	% Delta Counts	1σ % Error	Measurement Uncertainty (%)	RML Record Number (Sample ID)
0 -- Center	2.6990E+07	0.59	2.08	2.16	SC45 SP0 7740 DEPRST 09659 D03G03 09666 D04G03
1 -- 0.75	2.5380E+07	0.47	2.09	2.14	SC45 SP1 7740 DEPRST 09660 D03G03 09667 D04G03
2 -- 0.96	2.4000E+07	0.75	2.09	2.22	SC45 SP2 7740 DEPRST 09661 D03G03 09668 D04G03
3 -- 1.17	2.1640E+07	1.20	2.08	2.40	SC45 SP3 7740 DEPRST 09662 D03G03 09669 D04G03
4 -- 1.38	1.9940E+07	0.60	2.08	2.16	SC45 SP4 7740 DEPRST 09663 D03G03 09670 D04G03
5 -- 1.63	1.3505E+07	0.07	2.08	2.08	SC45 SP5 7740 DEPRST 09664 D03G03 09671 D04G03
6 -- 2.00 (External)	4.7895E+07	0.65	2.08	2.18	SC45 SP6 7740 DEPRST 09672 D04G03 09665 D03G03
Ni 6 -- 2.00 (External)	Ni Activity 1.9850E+04	0.60	2.14	2.22	NI58-SP A7740 DEPRST 09657 D01G02 09658 D02G02

Table 4-5. Sc Activation in 4-in Al6061 Sphere (ACRR Run 7741).

Location and Radius (in)	Sc Activity (Bq/g)	% Delta Counts	1σ % Error	Measurement Uncertainty (%)	RML Record Number (Sample ID)
0 -- Center	2.2575E+06	0.13	2.08	2.08	SC45 SA0 7741 DEPRST 09675 D03G03 09682 D04G03
1 -- 0.75	2.3040E+06	1.30	2.08	2.45	SC45 SA1 7741 DEPRST 09676 D03G03 09683 D04G03
2 -- 0.96	2.2495E+06	1.20	2.08	2.40	SC45 SA2 7741 DEPRST 09677 D03G03 09684 D04G03
3 -- 1.17	2.2935E+06	0.22	2.07	2.08	SC45 SA3 7741 DEPRST 09678 D03G03 09685 D04G03
4 -- 1.38	2.3020E+06	0.70	2.08	2.19	SC45 SA4 7741 DEPRST 09679 D03G03 09686 D04G03
5 -- 1.63	2.3070E+06	0.78	2.08	2.22	SC45 SA5 7741 DEPRST 09680 D03G03 09687 D04G03
6 -- 2.00 (External)	2.3615E+06	1.31	2.08	2.46	SC45 SA6 7741 DEPRST 09681 D03G03 09688 D04G03
Ni 6 -- 2.00 (External)	Ni Activity 2.1870E+04	1.01	2.14	2.37	NI58-SA A7741 DEPRST 09673 D01G02 09674 D02G02

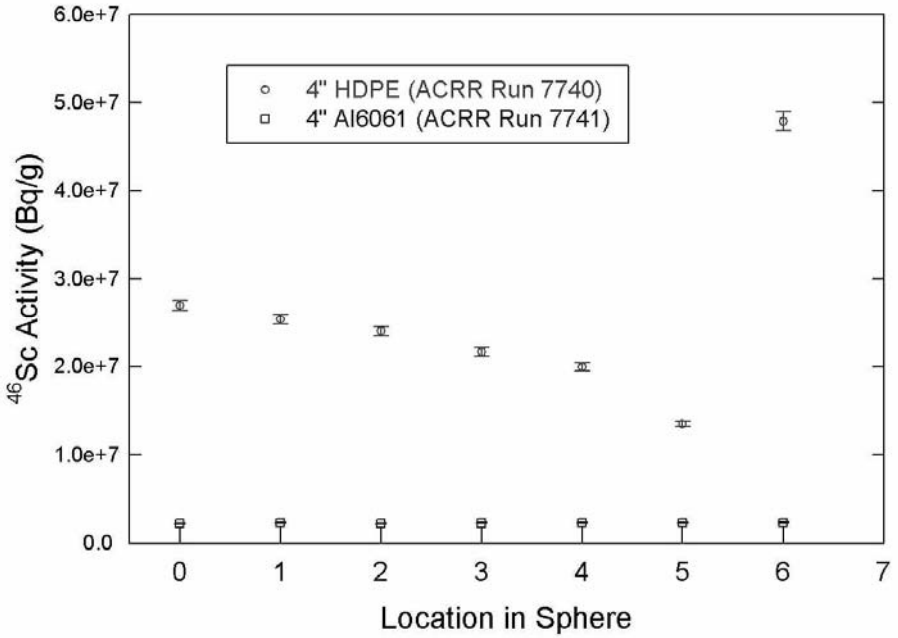

Figure 4-2. Sc Activation in 4-in HDPE and Al6061 Spheres.

Table 4-6. S Dosimetry in 4-in HDPE Sphere (ACRR Run 7753).

Location and Radius (in)	Cf Equiv Fluence (n/cm^2)			Measurement Uncertainty (%)	RML Record Number (Sample ID)
1 -- 0.75	9.372E+13			3.00	SUL_datb_07893.dat
2 -- 0.96	9.631E+13			3.00	SUL_datb_07893.dat
3 -- 1.17	9.603E+13			3.00	SUL_datb_07893.dat
4 -- 1.38	1.037E+14			3.00	SUL_datb_07893.dat
5 -- 1.63	1.108E+14			3.00	SUL_datb_07893.dat
Location and Radius (in)	**Ni Activity (Bq/g)**	**% Delta Counts**	**1σ % Error**	**Measurement Uncertainty (%)**	**RML Record Number (Sample ID)**
Ni 0 -- 0.00 (Center)	1.2530E+04	0.32	2.14	2.16	NI58 CENT 7753 DEPRI 09855 D01G02 09856 D02G02
Ni 6 -- 2.00 (External)	1.9585E+04	0.66	2.14	2.24	NI58 EXT 7753 DEPRI 09811 D01G02 09817 D02G02

Table 4-7. S Dosimetry in 4-in Al6061 Sphere (ACRR Run 7765).

Location and Radius (in)	Cf Equiv Fluence (n/cm^2)			Measurement Uncertainty (%)	RML Record Number (Sample ID)
1 -- 0.75	1.365E+14			2.90	SUL_datb_07907.dat
2 -- 0.96	1.407E+14			2.90	SUL_datb_07907.dat
3 -- 1.17	1.393E+14			2.90	SUL_datb_07907.dat
4 -- 1.38	1.413E+14			2.90	SUL_datb_07907.dat
5 -- 1.63	1.442E+14			2.90	SUL_datb_07907.dat
Location and Radius (in)	**Ni Activity (Bq/g)**	**% Delta Counts**	**1σ % Error**	**Measurement Uncertainty (%)**	**RML Record Number (Sample ID)**
Ni 0 -- 0.00 (Center)	1.9880E+04	0.50	2.14	2.20	NI58 CENT 7765 DEPRI 09857 D01G02 09858 D02G02
Ni 6 -- 2.00 (External)	2.2405E+04	0.58	2.14	2.22	NI58 EXT 7765 DEPRI 09853 D01G02 09854 D02G02

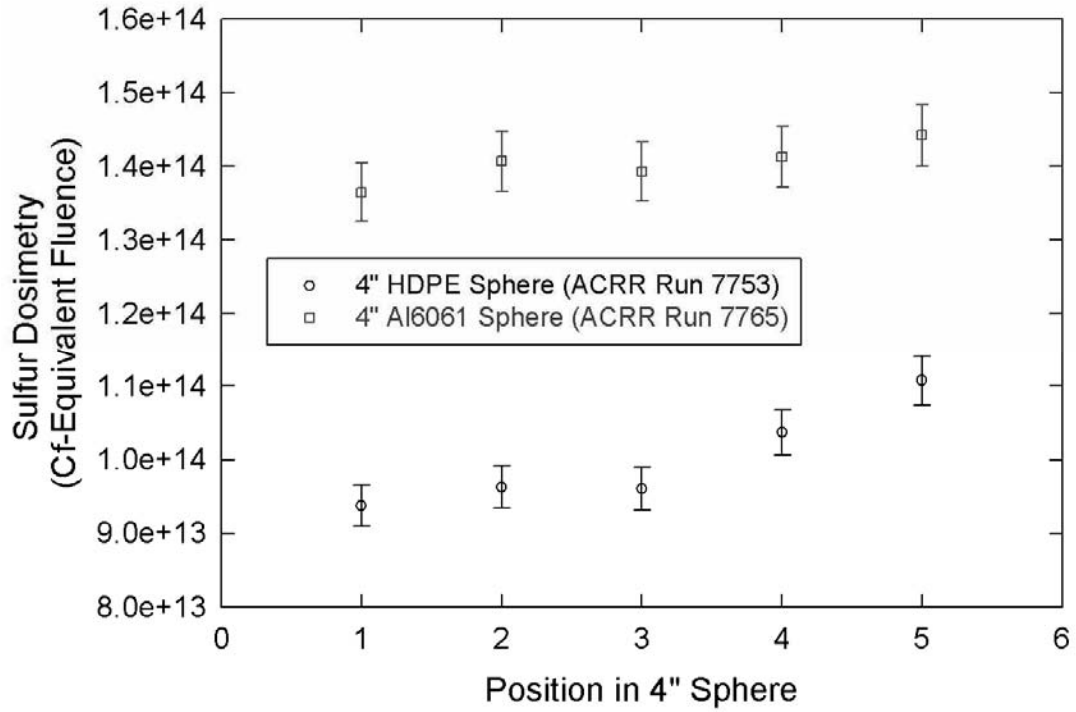

Figure 4-3. S Dosimetry in 4-in HDPE and Al6061 Spheres.

Table 4-8. Cd-covered Co Activation in 4-in HDPE Sphere (ACRR Run 7806).

Location and Radius (in)	Co Activity (Bq/g)	% Delta Counts	1σ % Error	Measurement Uncertainty (%)	RML Record Number (Sample ID)
0 -- Center	4.2925E+04	2.31	3.14	3.90	CO59-P4-0 A7806DPRES 10014 D01G02 10020 D02G02
1 -- 0.75	6.8525E+04	1.88	3.12	3.64	CO59-P4-1 A7806DPRES 10015 D01G02 10021 D02G02
2 -- 0.96	4.8675E+04	1.54	3.08	3.44	CO59-P4-2 A7806DPRES 10016 D01G02 10022 D02G02
3 -- 1.17	5.0490E+04	2.69	3.07	4.08	CO59-P4-3 A7806DPRES 10017 D01G02 10023 D02G02
4 -- 1.38	5.0105E+04	1.98	3.09	3.67	CO59-P4-4 A7806DPRES 10018 D01G02 10024 D02G02
5 -- 1.63	5.3090E+04	1.92	3.16	3.70	CO59-P4-5 A7806DPRES 10019 D01G02 10025 D02G02
Ni 6 -- 2.00 (External)	Ni Activity 1.9305E+04	1.19	2.14	2.45	NI58-4P AC7806 DPRST 10012 D01G02 10013 D02G02

Table 4-9. Cd-covered Co Activation in 4-in Al6061 Sphere (ACRR Run 7832).

Location and Radius (in)	Co Activity (Bq/g)	% Delta Counts	1σ % Error	Measurement Uncertainty (%)	RML Record Number (Sample ID)
0 -- Center	5.1220E+04	2.62	3.13	4.08	CO59-A4-0 A7832DPRES 10242 D01G02 10249 D02G02
1 -- 0.75	4.8075E+04	1.23	3.14	3.37	CO59-A4-1 A7832DPRES 10243 D01G02 10250 D02G02
2 -- 0.96	4.8120E+04	1.16	3.13	3.34	CO59-A4-2 A7832DPRES 10244 D01G02 10266 D02G02
3 -- 1.17	4.7920E+04	2.67	3.08	4.08	CO59-A4-3 A7832DPRES 10245 D01G02 10252 D02G02
4 -- 1.38	4.7710E+04	1.34	3.12	3.40	CO59-A4-4 A7832DPRES 10264 D01G02 10253 D02G02
5 -- 1.63	4.7415E+04	0.61	3.17	3.23	CO59-A4-5 A7832DPRES 10247 D01G02 10260 D02G02
Ni 6 -- 2.00 (External)	Ni Activity 2.2305E+04	1.03	2.14	2.38	NI58-A4-E A7832DPRES 10241 D01G02 10248 D02G02

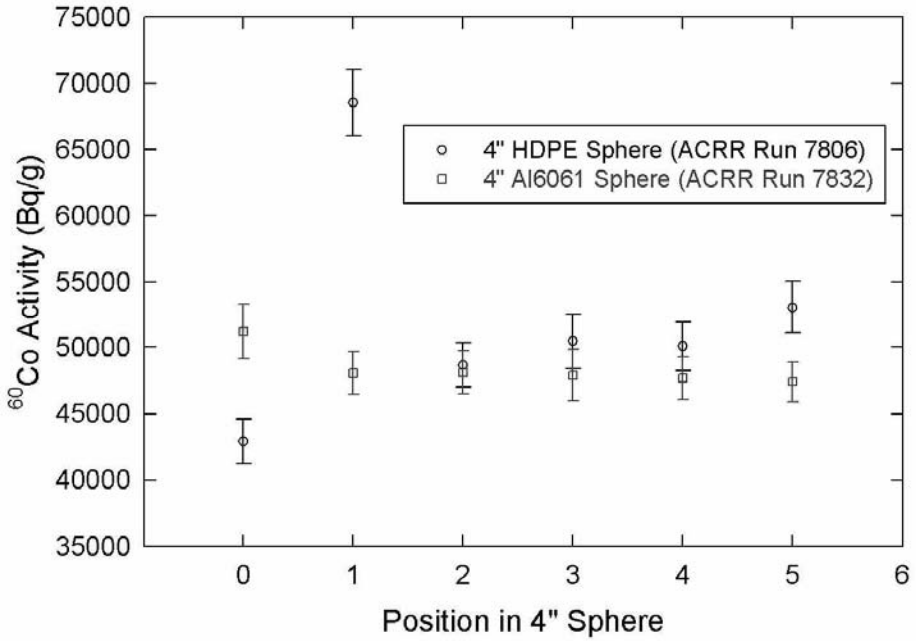

Figure 4-4. Cd-covered Co Activation in 4-in HDPE and Al6061 Spheres.

Table 4-10. Thermo Luminescent Dosimeter (TLD) Dosimetry in 4-in HDPE Sphere (ACRR Run 7891).

Location and Radius (in)	TLD Reading Rad[CaF_2]			Measurement Uncertainty (%)	RML Record Number (Sample ID)
1 -- 0.75	2.4830E+05			10.9	TLD_DATA_23650.dat
2 -- 0.96	2.4960E+05			10.9	TLD_DATA_23650.dat
3 -- 1.17	2.5570E+05			11.1	TLD_DATA_23650.dat
4 -- 1.38	2.5830E+05			11.1	TLD_DATA_23650.dat
5 -- 1.63	2.3620E+05			10.7	TLD_DATA_23650.dat
Location and Radius (in)	**Ni Activity (Bq/g)**	**% Delta Counts**	**1σ % Error**	**Measurement Uncertainty (%)**	**RML Record Number (Sample ID)**
Ni 0 -- 0.00 (Center)	5.7095E+03	0.16	2.14	2.15	NI-P0-C A7891 DPRST 10705 D01G02 10709 D02G02
Ni 6 -- 2.00 (External)	8.9815E+03	0.19	2.14	2.15	NI-P0-E A7891 DPRST 10706 D01G02 10710 D02G02

Table 4-11. TLD Dosimetry in 4-in Al6061 Sphere (ACRR Run 7892).

Location and Radius (in)	TLD Reading Rad[CaF_2]			Measurement Uncertainty (%)	RML Record Number (Sample ID)
1 -- 0.75	1.8970E+05			10.8	TLD_DATA_23651.dat
2 -- 0.96	1.8060E+05			10.6	TLD_DATA_23651.dat
3 -- 1.17	----			----	----
4 -- 1.38	1.9920E+05			10.0	TLD_DATA_23651.dat
5 -- 1.63	1.8740E+05			10.8	TLD_DATA_23651.dat
Location and Radius (in)	**Ni Activity (Bq/g)**	**% Delta Counts**	**1σ % Error**	**Measurement Uncertainty (%)**	**RML Record Number (Sample ID)**
Ni 0 -- 0.00 (Center)	9.0600E+03	0.60	2.13	2.21	NI-A1-C A7892 DPRST 10707 D01G02 10711 D02G02
Ni 6 -- 2.00 (External)	1.0185E+04	0.88	2.14	2.31	NI-A1-E A7892 DPRST 10708 D01G02 10712 D02G02

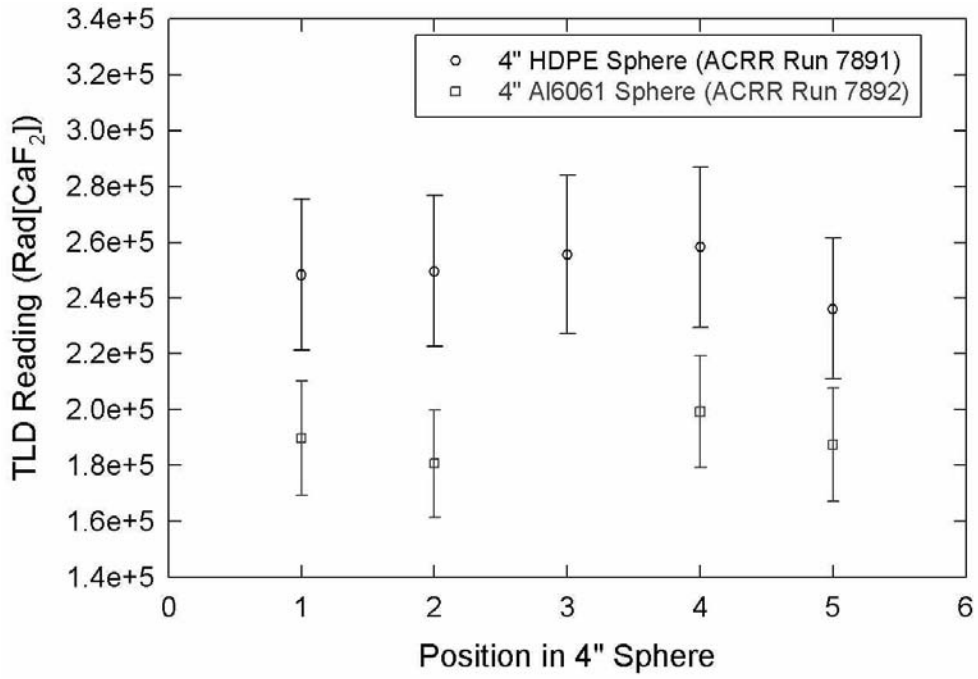

Figure 4-5. CaF_2:Mn Dose in 4-in HDPE and Al6061 Spheres.

Table 4-12. Ni Activation in 4-in HDPE Sphere in Pb-B_4C (ACRR Run 8046).

Location and Radius (in)	Ni Activity (Bq/g)	% Delta Counts	1σ % Error	Measurement Uncertainty (%)	RML Record Number (Sample ID)
0 -- Center	7.2080E+03	1.05	2.14	2.38	NI58-P0 A8046 DPRST 11914 D01G02 11921 D02G02
1 -- 0.75	7.5050E+03	1.89	2.14	2.86	NI58-P1 A8046 DPRST 11915 D01G02 11922 D02G02
2 -- 0.96	7.8800E+03	1.29	2.14	2.50	NI58-P2 A8046 DPRST 11916 D01G02 11923 D02G02
3 -- 1.17	8.4705E+03	0.20	2.14	2.15	NI58-P3 A8046 DPRST 11917 D01G02 11924 D02G02
4 -- 1.38	8.6375E+03	1.93	2.14	2.88	NI58-P4 A8046 DPRST 11918 D01G02 11952 D02G02
5 -- 1.63	9.5105E+03	0.98	2.14	2.35	NI58-P5 A8046 DPRST 11919 D01G02 11926 D02G02
6 -- 2.00 (External)	1.0275E+04	0.68	2.14	2.25	NI58-P6 A8046 DPRST 11920 D01G02 11927 D02G02

Table 4-13. Ni Activation in 4-in Al6061 Sphere in Pb-B_4C (ACRR Run 8003).

Location and Radius (in)	Ni Activity (Bq/g)	% Delta Counts	1σ % Error	Measurement Uncertainty (%)	RML Record Number (Sample ID)
0 -- Center	1.2535E+04	0.72	2.14	2.26	NI58-A0 A8003 DEPRST 11627 D01G02 11634 D02G02
1 -- 0.75	1.2735E+04	0.71	2.14	2.25	NI58-A1 A8003 DEPRST 11628 D01G02 11635 D02G02
2 -- 0.96	1.3015E+04	1.00	2.14	2.36	NI58-A2 A8003 DEPRST 11691 D01G02 11636 D02G02
3 -- 1.17	1.3060E+04	1.53	2.14	2.63	NI58-A3 A8003 DEPRST 11630 D01G02 11637 D02G02
4 -- 1.38	1.2825E+04	0.39	2.14	2.18	NI58-A4 A8003 DEPRST 11631 D01G02 11638 D02G02
5 -- 1.63	1.2980E+04	0.77	2.14	2.27	NI58-A5 A8003 DEPRST 11632 D01G02 11639 D02G02
6 -- 2.00 (External)	1.3825E+04	1.95	2.14	2.90	NI58-A6 A8003 DEPRST 11692 D01G02 11640 D02G02

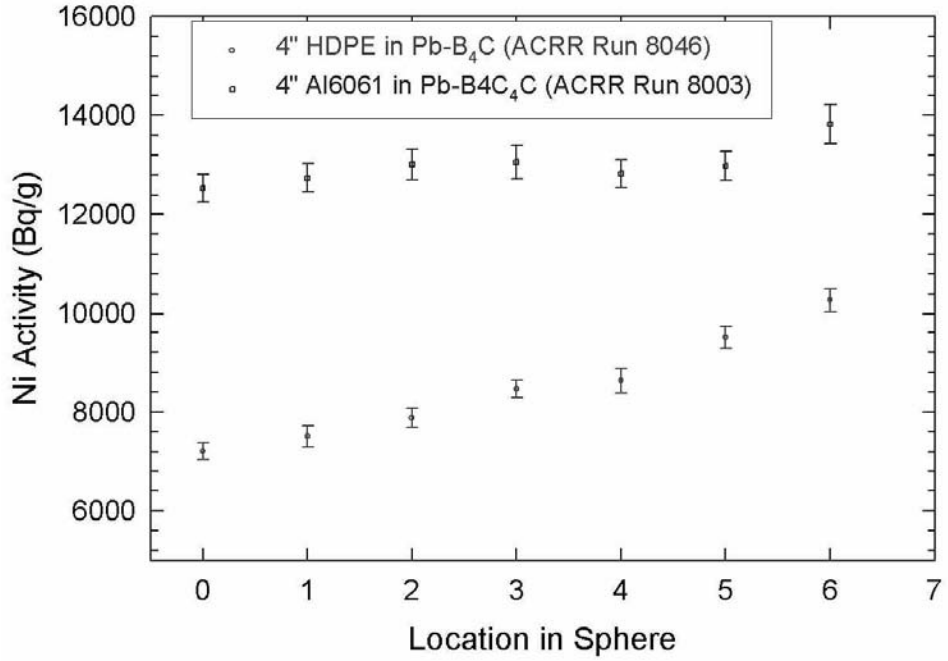

Figure 4-6. Ni Activation in 4-in HDPE and Al6061 Spheres in Pb-B_4C.

Table 4-14. Cd-covered Au Activation in 4-in HDPE Sphere in Pb-B_4C (ACRR Run 8128).

Location and Radius (in)	Au Activity (Bq/g)	% Delta Counts	1σ % Error	Measurement Uncertainty (%)	RML Record Number (Sample ID)
0 -- Center	4.5420E+08	0.84	4.46	4.54	AU197-P0 A8128 DEPRI 12253 D01G02 12259 D02G02
1 -- 0.75	4.5680E+08	0.53	4.46	4.49	AU197-P1 A8128 DEPRI 12254 D01G02 12260 D02G02
2 -- 0.96	5.7010E+08	0.49	4.45	4.48	AU197-P2 A8128 DEPRI 12255 D01G02 12261 D02G02
3 -- 1.17	4.3130E+08	1.67	4.45	4.75	AU197-P3 A8128 DEPRI 12256 D01G02 12262 D02G02
4 -- 1.38	4.1365E+08	0.51	4.46	4.49	AU197-P4 A8128 DEPRI 12257 D01G02 12263 D02G02
5 -- 1.63	3.9245E+08	0.28	4.46	4.47	AU197-P5 A8128 DEPRI 12258 D01G02 12264 D02G02
Ni 6 -- 2.00 (External)	Ni Activity 2.0695E+04	0.43	2.22	2.26	NI58- A8128 DEPRI 12267 D01G02 12268 D02G02

Table 4-15. Cd-covered Au Activation in 4-in Al6061 Sphere in Pb-B_4C (ACRR Run 8151).

Location and Radius (in)	Au Activity (Bq/g)	% Delta Counts	1σ % Error	Measurement Uncertainty (%)	RML Record Number (Sample ID)
0 -- Center	3.8410E+07	0.31	4.50	4.51	AU197-A0 CD 8151 DEP 12325 D01G02 12332 D02G02
1 -- 0.75	3.9385E+07	0.18	4.46	4.46	AU197-A1 CD 8151 DEP 12326 D01G02 12333 D02G02
2 -- 0.96	3.6290E+07	2.37	4.46	5.05	AU197-A2 CD 8151 DEP 12327 D01G02 12334 D02G02
3 -- 1.17	3.6400E+07	1.65	4.46	4.76	AU197-A3 CD 8151 DEP 12328 D01G02 12335 D02G02
4 -- 1.38	3.9810E+07	1.61	4.47	4.75	AU197-A4 CD 8151 DEP 12329 D01G02 12336 D02G02
5 -- 1.63	3.7100E+07	1.78	4.49	4.83	AU197-A5 CD 8151 DEP 12330 D01G02 12337 D02G02
Ni 6 -- 2.00 (External)	Ni Activity 3.2460E+04	1.47	2.14	2.60	NI58-A-EX 8151 DEPRI 12331 D01G02 12338 D02G02

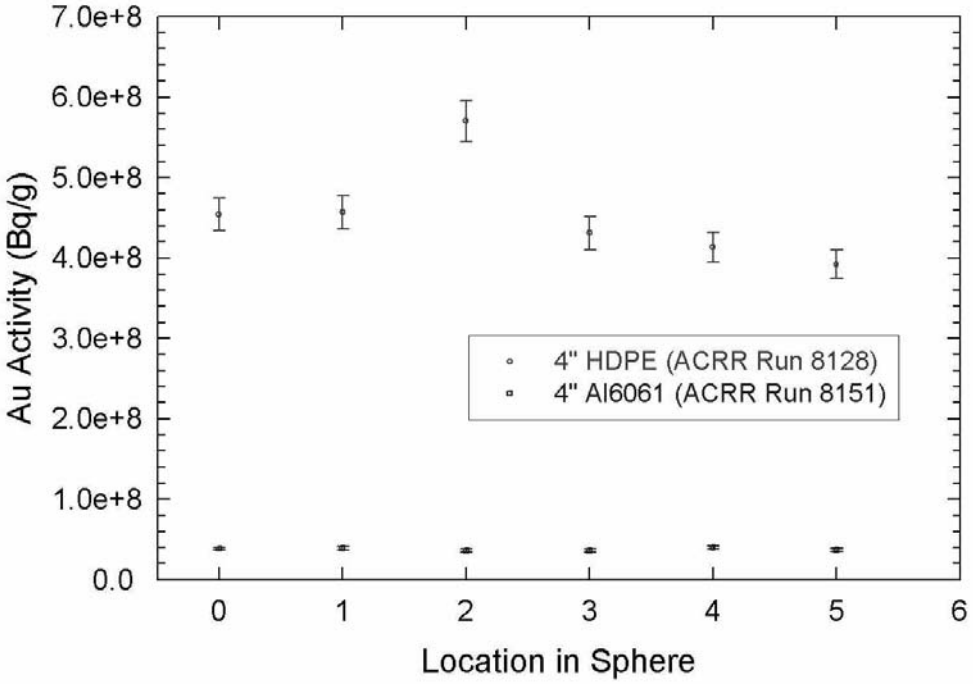

Figure 4-7. Cd-covered Au Activation in 4-in HDPE and Al6061 Spheres in Pb-B_4C.

Table 4-16. Cd-covered Co Activation in 4-in Al6061 Sphere in Pb-B_4C (ACRR Run 8047).

Location and Radius (in)	Co Activity (Bq/g)	% Delta Counts	1σ % Error	Measurement Uncertainty (%)	RML Record Number (Sample ID)
0 -- Center	1.2215E+04	0.08	3.13	3.13	CO59-AO A8047 DEPRST 11969 D01G02 11977 D02G02
1 -- 0.75	1.1940E+04	1.84	3.12	3.62	CO59-A1 A8047 DEPRST 11970 D01G02 11978 D02G02
2 -- 0.96	1.1940E+04	0.84	3.11	3.22	CO59-A2 A8047 DEPRST 11971 D01G02 11979 D02G02
3 -- 1.17	1.1955E+04	1.59	3.10	3.48	CO59-A3 A8047 DEPRST 11972 D01G02 11980 D02G02
4 -- 1.38	1.1880E+04	2.02	3.10	3.70	CO59-A4 A8047 DEPRST 11973 D01G02 11981 D02G02
5 -- 1.63	1.1960E+04	1.00	3.09	3.25	CO59-A5 A8047 DEPRST 11974 D01G02 11982 D02G02
6 -- 2.00 (External)	1.2065E+04	1.91	3.08	3.62	CO59-A6 A8047 DEPRST 11975 D01G02 11983 D02G02
Ni 6 -- 2.00 (External)	Ni Activity 1.2965E+04	1.93	2.14	2.88	NI58-EX A8047 DEPRST 11976 D01G02 11984 D02G02

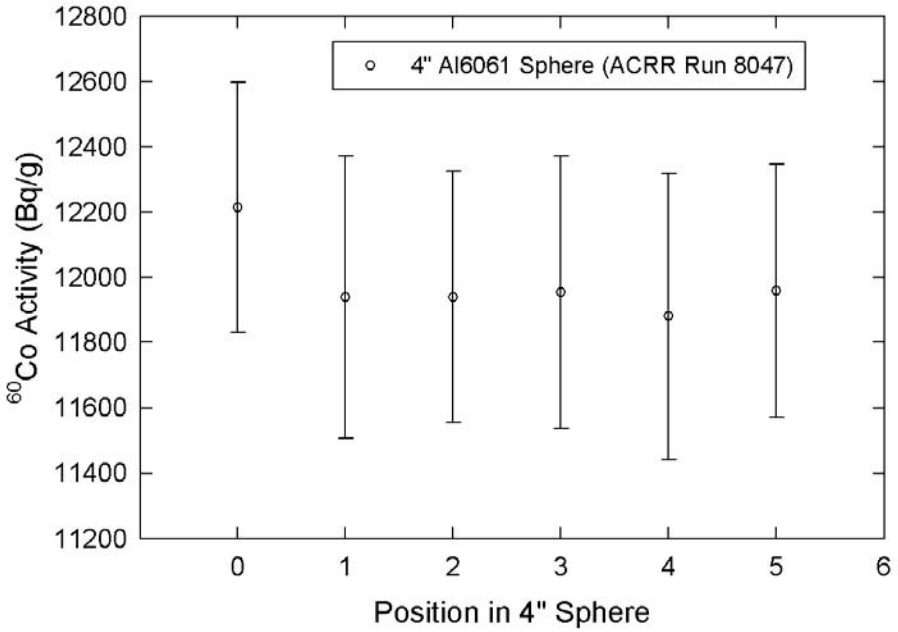

Figure 4-8. Cd-covered Co Activation in 4-in Al6061 Sphere in Pb-B_4C.

Table 4-17. Sc Activation in 4-in HDPE Sphere in Pb-B_4C (ACRR Run 8056).

Location and Radius (in)	Sc Activity (Bq/g)	% Delta Counts	1σ % Error	Measurement Uncertainty (%)	RML Record Number (Sample ID)
0 -- Center	1.7150E+07	2.10	3.47	4.06	SC45-P0 A8056 DEPRST 11992 D01G03 12000 D02G03
1 -- 0.75	1.5815E+07	0.19	3.47	3.48	SC45-P1 A8056 DEPRST 11993 D01G03 12001 D02G03
2 -- 0.96	1.3015E+07	1.31	3.47	3.71	SC45-P2 A8056 DEPRST 11994 D01G03 12002 D02G03
3 -- 1.17	1.3060E+07	1.07	3.47	3.63	SC45-P3 A8056 DEPRST 11995 D01G03 12003 D02G03
4 -- 1.38	1.0655E+07	1.78	3.46	3.89	SC45-P4 A8056 DEPRST 11996 D01G03 12004 D02G03
5 -- 1.63	7.5385E+06	0.73	3.46	3.54	SC45-P5 A8056 DEPRST 11997 D01G03 12005 D02G03
6 -- 2.00 (External)	1.6870E+06	0.47	3.47	3.50	SC45-P6 A8056 DEPRST 11998 D01G03 12006 D02G03
Ni 6 -- 2.00 (External)	Ni Activity 1.0030E+04	0.20	2.14	2.15	NI58-EX A8056 DEPRST 11999 D01G02 12007 D02G02

Table 4-18. Sc Activation in 4-in Al6061 Sphere in Pb-B_4C (ACRR Run 8022).

Location and Radius (in)	Sc Activity (Bq/g)	% Delta Counts	1σ % Error	Measurement Uncertainty (%)	RML Record Number (Sample ID)
0 -- Center	3.9540E+04	0.86	3.82	3.92	SC45-A0 A8022 DEPRST 11722 D01G02 11597 D04G02
1 -- 0.75	3.9085E+04	0.49	3.82	3.85	SC45-A1 A8022 DEPRST 11723 D01G02 11598 D04G02
2 -- 0.96	3.9330E+04	0.20	3.81	3.82	SC45-A2 A8022 DEPRST 11724 D01G02 11599 D04G02
3 -- 1.17	3.9190E+04	1.63	3.81	4.14	SC45-A3 A8022 DEPRST 11725 D01G02 11600 D04G02
4 -- 1.38	3.8760E+04	2.17	3.83	4.40	SC45-A4 A8022 DEPRST 11726 D01G02 11601 D04G02
5 -- 1.63	3.8830E+04	2.11	3.81	4.36	SC45-A5 A8022 DEPRST 11727 D01G02 11602 D04G02
6 -- 2.00 (External)	4.0570E+04	1.63	3.82	4.15	SC45-A6 A8022 DEPRST 11728 D01G02 11603 D04G02
Ni 6 -- 2.00 (External)	Ni Activity 1.4190E+04	1.13	3.93	4.09	NI58-EX A8022 DEPRST 11729 D01G02 11604 D04G02

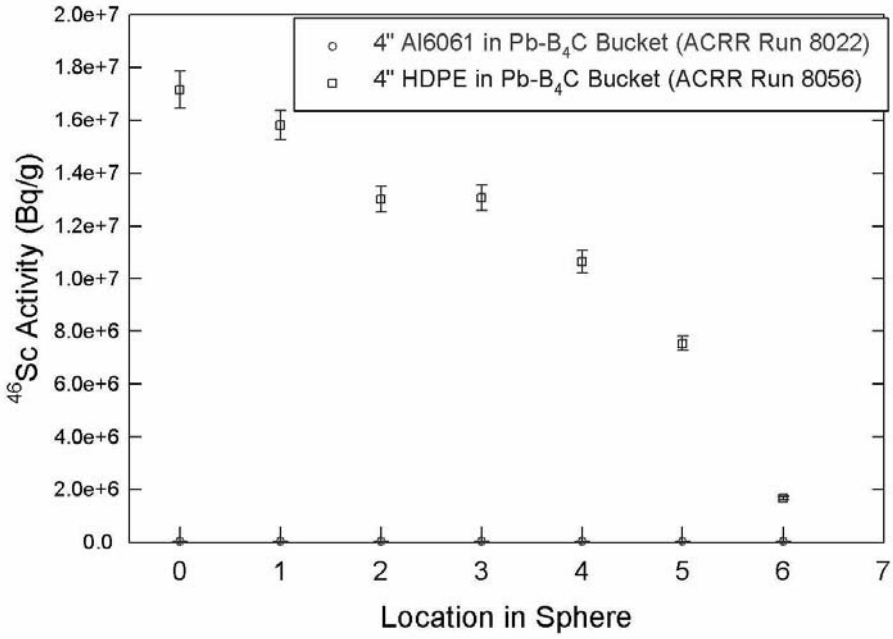

Figure 4-9. Sc Activation in 4-in HDPE and Al6061 Spheres in Pb-B_4C.

Table 4-19. TLD Dosimetry in 4-in HDPE Sphere in Pb-B_4C (ACRR Run 8092).

Location and Radius (in)	TLD Reading Rad[CaF_2]			Measurement Uncertainty (%)	RML Record Number (Sample ID)
1 -- 0.75	5.0970E+04			7.9	TLD_DATA_24390.dat
2 -- 0.96	4.7810E+04			7.8	TLD_DATA_24390.dat
3 -- 1.17	4.1940E+04			7.8	TLD_DATA_24390.dat
4 -- 1.38	3.6650E+04			7.5	TLD_DATA_24390.dat
5 -- 1.63	3.4710E+04			7.4	TLD_DATA_24390.dat
Location and Radius (in)	**Ni Activity (Bq/g)**	**% Delta Counts**	**1σ % Error**	**Measurement Uncertainty (%)**	**RML Record Number (Sample ID)**
Ni 0 -- 0.00 (Center)	3.0080E+03	0.27	2.14	2.16	NI58-INT 8092 DEPRST 12117 D01G02 12121 D02G02
Ni 6 -- 2.00 (External)	4.6885E+03	0.11	2.14	2.14	NI58-EXT 8092 DEPRST 12118 D01G02 12122 D02G02

Table 4-20. TLD Dosimetry in 4-in Al6061 Sphere in Pb-B_4C (ACRR Run 8023).

Location and Radius (in)	TLD Reading Rad[CaF_2]			Measurement Uncertainty (%)	RML Record Number (Sample ID)
1 -- 0.75	2.219E+04			9.1	TLD_DATA_24059.dat;1
2 -- 0.96	2.320E+04			9.1	TLD_DATA_24059.dat;1
3 -- 1.17	2.243E+04			9.1	TLD_DATA_24059.dat;1
4 -- 1.38	2.149E+04			9.1	TLD_DATA_24059.dat;1
5 -- 1.63	2.128E+04			9.1	TLD_DATA_24059.dat;1
Location and Radius (in)	**Ni Activity (Bq/g)**	**% Delta Counts**	**1σ % Error**	**Measurement Uncertainty (%)**	**RML Record Number (Sample ID)**
Ni 0 -- 0.00 (Center)	5.4990E+03	1.20	2.14	2.45	NI58-INT A8023 DPRST 11649 D01G02 11659 D02G02
Ni 6 -- 2.00 (External)	6.0045E+03	0.72	2.14	2.26	NI58-EXT A8023 DPRST 11650 D01G02 11660 D02G02

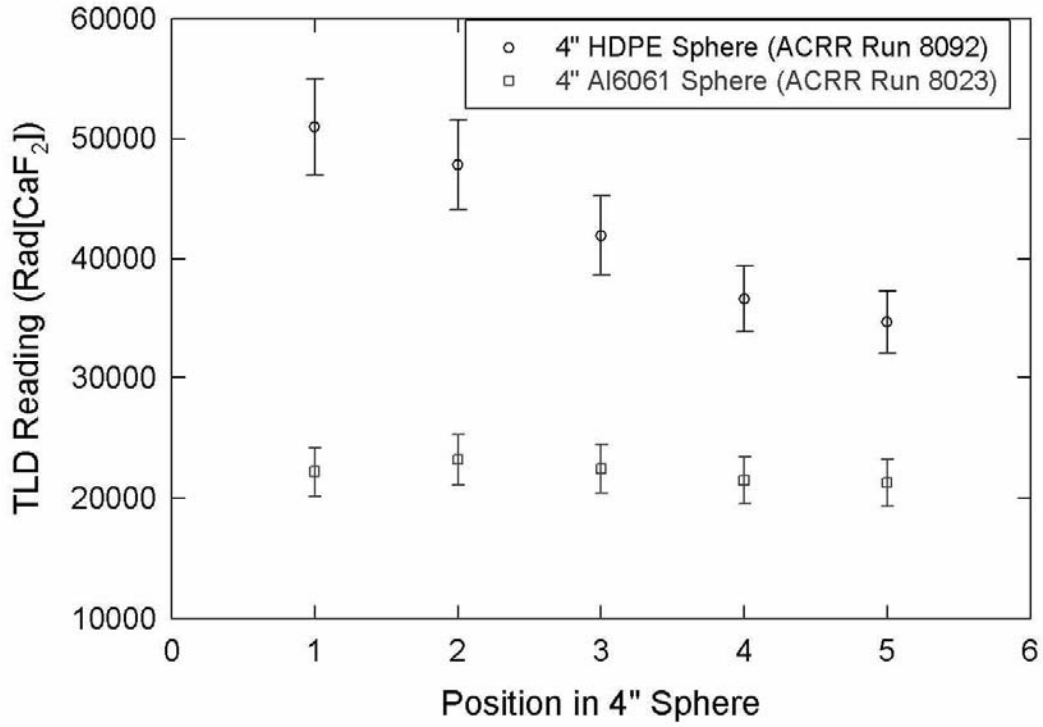

Figure 4-10. CaF_2:Mn Dose in 4-in HDPE and Al6061 Spheres in Pb-B_4C.

Table 4-21. S Dosimetry in 4-in HDPE Sphere in Pb-B_4C (ACRR Run 8093).

Location and Radius (in)	Cf Equiv Fluence (n/cm^2)			Measurement Uncertainty (%)	RML Record Number (Sample ID)
1 -- 0.75	5.005E+13			3.00	SUL_datb_08184.dat
2 -- 0.96	5.179E+13			3.00	SUL_datb_08184.dat
3 -- 1.17	5.342E+13			3.00	SUL_datb_08184.dat
4 -- 1.38	5.637E+13			3.00	SUL_datb_08184.dat
5 -- 1.63	6.028E+13			3.00	SUL_datb_08184.dat
Location and Radius (in)	**Ni Activity (Bq/g)**	**% Delta Counts**	**1σ % Error**	**Measurement Uncertainty (%)**	**RML Record Number (Sample ID)**
Ni 0 -- 0.00 (Center)	6.7985E+03	0.10	2.14	2.14	NI58-INT 8093 DEPRST 12119 D01G02 12123 D02G02
Ni 6 -- 2.00 (External)	1.0410E+04	1.73	2.14	2.75	NI58-EXT 8093 DEPRST 12120 D01G02 12124 D02G02

Table 4-22. S Dosimetry in 4-in Al6061 Sphere in Pb-B_4C (ACRR Run 8038).

Location and Radius (in)	Cf Equiv Fluence (n/cm^2)			Measurement Uncertainty (%)	RML Record Number (Sample ID)
1 -- 0.75	8.583E+13			2.90	SUL_datb_08150.dat
2 -- 0.96	8.218E+13			3.00	SUL_datb_08150.dat
3 -- 1.17	8.549E+13			2.90	SUL_datb_08150.dat
4 -- 1.38	8.517E+13			3.00	SUL_datb_08150.dat
5 -- 1.63	8.724E+13			2.90	SUL_datb_08150.dat
Location and Radius (in)	**Ni Activity (Bq/g)**	**% Delta Counts**	**1σ % Error**	**Measurement Uncertainty (%)**	**RML Record Number (Sample ID)**
Ni 0 -- 0.00 (Center)	1.2075E+04	0.91	3.93	4.03	NI58-CENT A8038 DPRS 11841 D03G02 11842 D04G02
Ni 6 -- 2.00 (External)	1.3245E+04	0.08	3.93	3.93	NI58-EXT A8038 DPRS 11843 D03G02 11844 D04G02

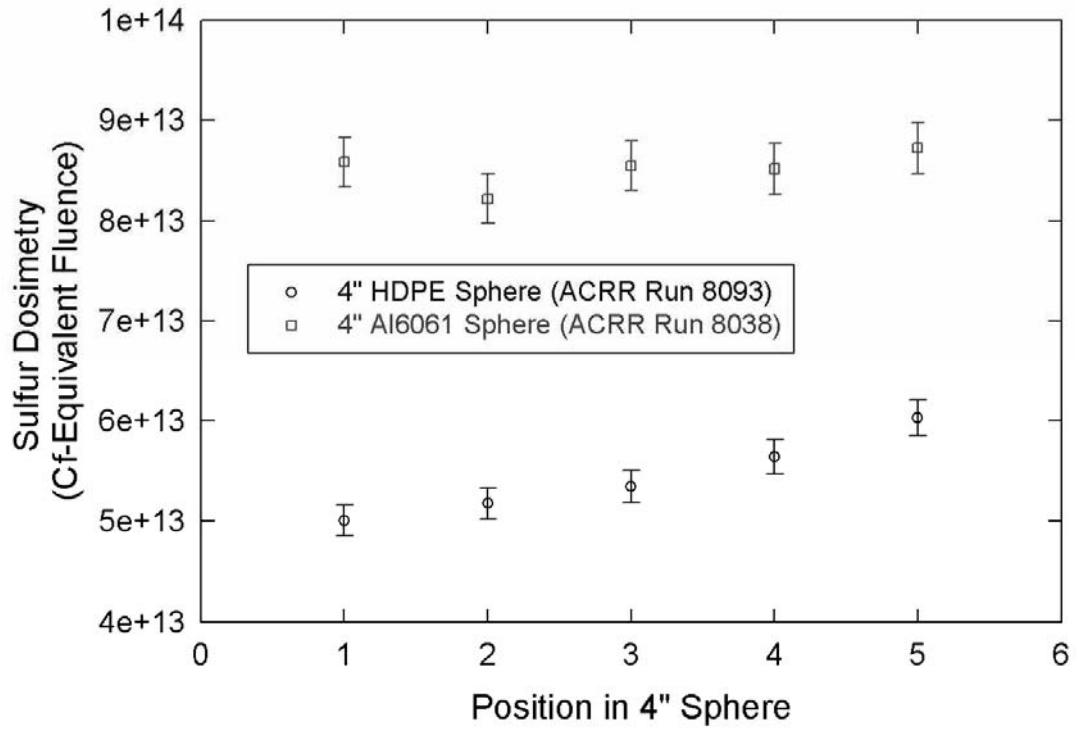

Figure 4-11. S Dosimetry in 4-in HDPE and Al6061 Spheres in Pb-B_4C.

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5.0 References

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APPENDIX A
MCNP/MCNPX Model of n/γ Attenuation through Materials Experiments

```
(n,gamma) Attenuation Through Materials
C
C RES Validation Experiment
C The spheres are Cell 500 (both 7" and 4").
C The detectors are 600's.
C Detectors are Ni, Cd/Au, etc.
C Materials are 600's as well.
C Isotropic spherical source with diameter the same as ACRR-CC (900).
C This deck uses ACF9 640 neutron group spectrum as the source.
C
C ***********************************************************************
C *                            CELL CARDS                               *
C ***********************************************************************
C ---+----+---------+---------+---------+---------+---------+-----------
C  Main Sphere (Add or Remove C to change spheres)
 500  600   -2.7000   -500 700 701 702 703 704
                       705 706 707 708       IMP:N=1  $Al Sphere (7")
C 500  601   -0.9450   -500 700 701 702 703 704
C                       705 706 707 708       IMP:N=1  $HDPE Sphere (7")
C 500  600   -2.7000   -500 700 701 702
C                       402 403 404          IMP:N=1  $Al Sphere (4")
C 500  601   -0.9450   -500 700 701 702
C                       402 403 404           IMP:N=1  $HDPE Sphere (4")
C
C  Cavities for foils  (700's for 7"; 400's for 4")
C   Comment out 703-708 and remove C from 402-404 for 4" sphere.
C
 700  605 -1.0245e-3   -700 800            IMP:N=1  $Location #0
 701  605 -1.0245e-3   -701 801            IMP:N=1  $Location #1
 702  605 -1.0245e-3   -702 802            IMP:N=1  $Location #2 or 5(4")
 703  605 -1.0245e-3   -703 803            IMP:N=1  $Location #3
 704  605 -1.0245e-3   -704 804            IMP:N=1  $Location #4
 705  605 -1.0245e-3   -705 805            IMP:N=1  $Location #5
 706  605 -1.0245e-3   -706 806            IMP:N=1  $Location #6
 707  605 -1.0245e-3   -707 807            IMP:N=1  $Location #7
 708  605 -1.0245e-3   -708 808            IMP:N=1  $Location #8
C
C 402  605 -1.0245e-3   -402 822            IMP:N=1  $Location #2
C 403  605 -1.0245e-3   -403 823            IMP:N=1  $Location #3
C 404  605 -1.0245e-3   -404 824            IMP:N=1  $Location #4
C
C Cd covers or air (M=604 is cd, M605 is air)
C  Change '605 -1.0245e-3' to '604   -8.6500' for Cd Cover.
C  Comment out 803-808 and remove C from 822-824 for 4" sphere.
C  Also comment out 813-818 and remove C from 832-834 for 4" sphere.
C  810-818 and 832-834 are cells for air gap.
C  800-808 and 822-824 are cells for cd covers.
C
 800  605 -1.0245e-3   -800 810            IMP:N=1  $Location #0
 801  605 -1.0245e-3   -801 811            IMP:N=1  $Location #1
 802  605 -1.0245e-3   -802 812            IMP:N=1  $Location #2 or 5(4")
 803  605 -1.0245e-3   -803 813            IMP:N=1  $Location #3
 804  605 -1.0245e-3   -804 814            IMP:N=1  $Location #4
```

```
 805  605 -1.0245e-3   -805 815            IMP:N=1  $Location #5
 806  605 -1.0245e-3   -806 816            IMP:N=1  $Location #6
 807  605 -1.0245e-3   -807 817            IMP:N=1  $Location #7
 808  605 -1.0245e-3   -808 818            IMP:N=1  $Location #8
C
 810  605 -1.0245e-3   -810 600            IMP:N=1  $Location #0
 811  605 -1.0245e-3   -811 601            IMP:N=1  $Location #1
 812  605 -1.0245e-3   -812 602            IMP:N=1  $Location #2
 813  605 -1.0245e-3   -813 603            IMP:N=1  $Location #3
 814  605 -1.0245e-3   -814 604            IMP:N=1  $Location #4
 815  605 -1.0245e-3   -815 605            IMP:N=1  $Location #5
 816  605 -1.0245e-3   -816 606            IMP:N=1  $Location #6
 817  605 -1.0245e-3   -817 607            IMP:N=1  $Location #7
 818  605 -1.0245e-3   -818 608            IMP:N=1  $Location #8
C
C 822  605 -1.0245e-3   -822 832            IMP:N=1  $Location #2
C 823  605 -1.0245e-3   -823 833            IMP:N=1  $Location #3
C 824  605 -1.0245e-3   -824 834            IMP:N=1  $Location #4
C
C 832  605 -1.0245e-3   -832 612            IMP:N=1  $Location #2
C 833  605 -1.0245e-3   -833 613            IMP:N=1  $Location #3
C 834  605 -1.0245e-3   -834 614            IMP:N=1  $Location #4
C
C  Foils  M=602 is Ni, M=603 is Dilute Au
C   Change '602   -8.9020' to '603   -2.6989' for Au rather than Ni.
C  Comment out 603-609 and remove C from 612-614 & 616 for 4" sphere.
C
 600  602   -8.9020    -600                IMP:N=1  $Foil 0
 601  602   -8.9020    -601                IMP:N=1  $Foil 1
 602  602   -8.9020    -602                IMP:N=1  $Foil 2 or 5(4")
 603  602   -8.9020    -603                IMP:N=1  $Foil 3
 604  602   -8.9020    -604                IMP:N=1  $Foil 4
 605  602   -8.9020    -605                IMP:N=1  $Foil 5
 606  602   -8.9020    -606                IMP:N=1  $Foil 6
 607  602   -8.9020    -607                IMP:N=1  $Foil 7
 608  602   -8.9020    -608                IMP:N=1  $Foil 8
C  Foil #9 is on surface of sphere and always Ni
 609  602   -8.9020    -609                IMP:N=1  $Foil 9
C
C  612  602   -8.9020    -612               IMP:N=1  $Foil 2
C  613  602   -8.9020    -613               IMP:N=1  $Foil 3
C  614  602   -8.9020    -614               IMP:N=1  $Foil 4
C
C  Foil #6 is on surface of sphere and always Ni
C  616  602   -8.9020    -616               IMP:N=1  $Foil 6
C
C  Outside World
 900  605 -1.0245e-3   -900 500 609        IMP:N=1   $Use for 7"
C 900  605 -1.0245e-3   -900 500 616        IMP:N=1   $Use for 4"
C
 901   0                900                IMP:N=0

C ***********************************************************************
C *                          SURFACE CARDS                              *
C ***********************************************************************
 500  so   8.89     $Sphere of 7" diameter
C 500  so   5.08     $Sphere of 4" diameter
```

```
C Locations in 4" sphere  (400's) 400==700 401==701 405==702
 402  rcc  0.000000  2.438400 -0.200000   0.000000 0.000000 0.400000
           0.873125
 403  rcc -2.971800  0.000000 -0.200000   0.000000 0.000000 0.400000
           0.873125
 404  rcc  0.000000 -3.505200 -0.200000   0.000000 0.000000 0.400000
           0.873125
C Locations in 7" sphere  (700's)
 700  rcc -0.200000  0.000000  0.000000   0.400000 0.000000 0.000000
           0.873125
 701  rcc  1.905000  0.000000 -0.200000   0.000000 0.000000 0.400000
           0.873125
 702  rcc -2.927563 -2.927563 -0.200000   0.000000 0.000000 0.400000
           0.873125
 703  rcc  0.000000 -4.572000 -0.200000   0.000000 0.000000 0.400000
           0.873125
 704  rcc  3.610063 -3.610063 -0.200000   0.000000 0.000000 0.400000
           0.873125
 705  rcc  4.364404  4.364404 -0.200000   0.000000 0.000000 0.400000
           0.873125
 706  rcc  0.000000  6.705600 -0.200000   0.000000 0.000000 0.400000
           0.873125
 707  rcc -5.118746  5.118746 -0.200000   0.000000 0.000000 0.400000
           0.873125
 708  rcc -7.848600  0.000000 -0.200000   0.000000 0.000000 0.400000
           0.873125
C  Foils (600's)
C  Assume detector foils are 0.002" Thick w/ R=0.25"
C  600 - 609 are for 7" spheres
 600  rcc -0.002540  0.000000  0.000000   0.005080 0.000000 0.000000
           0.635000
 601  rcc  1.905000  0.000000 -0.002540   0.000000 0.000000 0.005080
           0.635000
 602  rcc -2.927563 -2.927563 -0.002540   0.000000 0.000000 0.005080
           0.635000
 603  rcc  0.000000 -4.572000 -0.002540   0.000000 0.000000 0.005080
           0.635000
 604  rcc  3.610063 -3.610063 -0.002540   0.000000 0.000000 0.005080
           0.635000
 605  rcc  4.364404  4.364404 -0.002540   0.000000 0.000000 0.005080
           0.635000
 606  rcc  0.000000  6.705600 -0.002540   0.000000 0.000000 0.005080
           0.635000
 607  rcc -5.118746  5.118746 -0.002540   0.000000 0.000000 0.005080
           0.635000
 608  rcc -7.848600  0.000000 -0.002540   0.000000 0.000000 0.005080
           0.635000
 609  rcc  8.890000  0.000000  0.000000   0.005080 0.000000 0.000000
           0.635000
C
C  610 - 615 are for 4" spheres (610==600 611==601 615==602)
 612  rcc  0.000000  2.438400 -0.002540   0.000000 0.000000 0.005080
           0.635000
 613  rcc -2.971800  0.000000 -0.002540   0.000000 0.000000 0.005080
           0.635000
 614  rcc  0.000000 -3.505200 -0.002540   0.000000 0.000000 0.005080
           0.635000
```

```
 616  rcc  5.080000  0.000000  0.000000   0.005080 0.000000 0.000000
           0.635000
C  800's cd covers/change to air for no cover
C  800-808 & 822-824 are cd cover; 810-818 & 832-834 are air gaps
 800  rcc -9.1059e-2  0.000000  0.000000  0.1905031 0.000000 0.000000
           0.831850
 801  rcc  1.905000  0.000000 -9.1059e-2  0.000000 0.000000 0.1905031
           0.831850
 802  rcc -2.927563 -2.927563 -9.1059e-2  0.000000 0.000000 0.1905031
           0.831850
 803  rcc  0.000000 -4.572000 -9.1059e-2  0.000000 0.000000 0.1905031
           0.831850
 804  rcc  3.610063 -3.610063 -9.1059e-2  0.000000 0.000000 0.1905031
           0.831850
 805  rcc  4.364404  4.364404 -9.1059e-2  0.000000 0.000000 0.1905031
           0.831850
 806  rcc  0.000000  6.705600 -9.1059e-2  0.000000 0.000000 0.1905031
           0.831850
 807  rcc -5.118746  5.118746 -9.1059e-2  0.000000 0.000000 0.1905031
           0.831850
 808  rcc -7.848600  0.000000 -9.1059e-2  0.000000 0.000000 0.1905031
           0.831850
C
 810  rcc -4.0767e-2  0.000000  0.000000   0.081534 0.000000 0.000000
           0.773176
 811  rcc  1.905000  0.000000 -4.0767e-2   0.000000 0.000000 0.081534
           0.773176
 812  rcc -2.927563 -2.927563 -4.0767e-2   0.000000 0.000000 0.081534
           0.773176
 813  rcc  0.000000 -4.572000 -4.0767e-2   0.000000 0.000000 0.081534
           0.773176
 814  rcc  3.610063 -3.610063 -4.0767e-2   0.000000 0.000000 0.081534
           0.773176
 815  rcc  4.364404  4.364404 -4.0767e-2   0.000000 0.000000 0.081534
           0.773176
 816  rcc  0.000000  6.705600 -4.0767e-2   0.000000 0.000000 0.081534
           0.773176
 817  rcc -5.118746  5.118746 -4.0767e-2   0.000000 0.000000 0.081534
           0.773176
 818  rcc -7.848600  0.000000 -4.0767e-2   0.000000 0.000000 0.081534
           0.773176
C
 822  rcc  0.000000  2.438400 -9.1059e-2  0.000000 0.000000 0.1905031
           0.831850
 823  rcc -2.971800  0.000000 -9.1059e-2  0.000000 0.000000 0.1905031
           0.831850
 824  rcc  0.000000 -3.505200 -9.1059e-2  0.000000 0.000000 0.1905031
           0.831850
C
 832  rcc  0.000000  2.438400 -4.0767e-2   0.000000 0.000000 0.081534
           0.773176
 833  rcc -2.971800  0.000000 -4.0767e-2   0.000000 0.000000 0.081534
           0.773176
 834  rcc  0.000000 -3.505200 -4.0767e-2   0.000000 0.000000 0.081534
           0.773176
C Source Sphere
 900  so  11.43     $9" Diameter = ACRR-CC Dimensions
```

```
C ***********************************************************************
C *                          DATA CARDS                                 *
C ***********************************************************************
MODE N
C ********************
C *  SOURCE CARDS    *
C ********************
SDEF  SUR=900 NRM=-1 WGT=410.4330581 ERG=D2
C  WGT=PI*(radius of sphere)^2
C  Weighted to give 1 n/cm^2/src-n
SC2   Source is 640 Group ACF9 Spectrum
SI2 H 1.000E-10 1.050E-10 1.100E-10 1.150E-10 1.200E-10 1.275E-10
      1.350E-10 1.425E-10 1.500E-10 1.600E-10 1.700E-10 1.800E-10
      1.900E-10 2.000E-10 2.100E-10 2.200E-10 2.300E-10 2.400E-10
      2.550E-10 2.700E-10 2.800E-10 3.000E-10 3.200E-10 3.400E-10
      3.600E-10 3.800E-10 4.000E-10 4.250E-10 4.500E-10 4.750E-10
      5.000E-10 5.250E-10 5.500E-10 5.750E-10 6.000E-10 6.300E-10
      6.600E-10 6.900E-10 7.200E-10 7.600E-10 8.000E-10 8.400E-10
      8.800E-10 9.200E-10 9.600E-10 1.000E-09 1.050E-09 1.100E-09
      1.150E-09 1.200E-09 1.275E-09 1.350E-09 1.425E-09 1.500E-09
      1.600E-09 1.700E-09 1.800E-09 1.900E-09 2.000E-09 2.100E-09
      2.200E-09 2.300E-09 2.400E-09 2.550E-09 2.700E-09 2.800E-09
      3.000E-09 3.200E-09 3.400E-09 3.600E-09 3.800E-09 4.000E-09
      4.250E-09 4.500E-09 4.750E-09 5.000E-09 5.250E-09 5.500E-09
      5.750E-09 6.000E-09 6.300E-09 6.600E-09 6.900E-09 7.200E-09
      7.600E-09 8.000E-09 8.400E-09 8.800E-09 9.200E-09 9.600E-09
      1.000E-08 1.050E-08 1.100E-08 1.150E-08 1.200E-08 1.275E-08
      1.350E-08 1.425E-08 1.500E-08 1.600E-08 1.700E-08 1.800E-08
      1.900E-08 2.000E-08 2.100E-08 2.200E-08 2.300E-08 2.400E-08
      2.550E-08 2.700E-08 2.800E-08 3.000E-08 3.200E-08 3.400E-08
      3.600E-08 3.800E-08 4.000E-08 4.250E-08 4.500E-08 4.750E-08
      5.000E-08 5.250E-08 5.500E-08 5.750E-08 6.000E-08 6.300E-08
      6.600E-08 6.900E-08 7.200E-08 7.600E-08 8.000E-08 8.400E-08
      8.800E-08 9.200E-08 9.600E-08 1.000E-07 1.050E-07 1.100E-07
      1.150E-07 1.200E-07 1.275E-07 1.350E-07 1.425E-07 1.500E-07
      1.600E-07 1.700E-07 1.800E-07 1.900E-07 2.000E-07 2.100E-07
      2.200E-07 2.300E-07 2.400E-07 2.550E-07 2.700E-07 2.800E-07
      3.000E-07 3.200E-07 3.400E-07 3.600E-07 3.800E-07 4.000E-07
      4.250E-07 4.500E-07 4.750E-07 5.000E-07 5.250E-07 5.500E-07
      5.750E-07 6.000E-07 6.300E-07 6.600E-07 6.900E-07 7.200E-07
      7.600E-07 8.000E-07 8.400E-07 8.800E-07 9.200E-07 9.600E-07
      1.000E-06 1.050E-06 1.100E-06 1.150E-06 1.200E-06 1.275E-06
      1.350E-06 1.425E-06 1.500E-06 1.600E-06 1.700E-06 1.800E-06
      1.900E-06 2.000E-06 2.100E-06 2.200E-06 2.300E-06 2.400E-06
      2.550E-06 2.700E-06 2.800E-06 3.000E-06 3.200E-06 3.400E-06
      3.600E-06 3.800E-06 4.000E-06 4.250E-06 4.500E-06 4.750E-06
      5.000E-06 5.250E-06 5.500E-06 5.750E-06 6.000E-06 6.300E-06
      6.600E-06 6.900E-06 7.200E-06 7.600E-06 8.000E-06 8.400E-06
      8.800E-06 9.200E-06 9.600E-06 1.000E-05 1.050E-05 1.100E-05
      1.150E-05 1.200E-05 1.275E-05 1.350E-05 1.425E-05 1.500E-05
      1.600E-05 1.700E-05 1.800E-05 1.900E-05 2.000E-05 2.100E-05
      2.200E-05 2.300E-05 2.400E-05 2.550E-05 2.700E-05 2.800E-05
      3.000E-05 3.200E-05 3.400E-05 3.600E-05 3.800E-05 4.000E-05
      4.250E-05 4.500E-05 4.750E-05 5.000E-05 5.250E-05 5.500E-05
      5.750E-05 6.000E-05 6.300E-05 6.600E-05 6.900E-05 7.200E-05
      7.600E-05 8.000E-05 8.400E-05 8.800E-05 9.200E-05 9.600E-05
```

```
      1.000E-04 1.050E-04 1.100E-04 1.150E-04 1.200E-04 1.275E-04
      1.350E-04 1.425E-04 1.500E-04 1.600E-04 1.700E-04 1.800E-04
      1.900E-04 2.000E-04 2.100E-04 2.200E-04 2.300E-04 2.400E-04
      2.550E-04 2.700E-04 2.800E-04 3.000E-04 3.200E-04 3.400E-04
      3.600E-04 3.800E-04 4.000E-04 4.250E-04 4.500E-04 4.750E-04
      5.000E-04 5.250E-04 5.500E-04 5.750E-04 6.000E-04 6.300E-04
      6.600E-04 6.900E-04 7.200E-04 7.600E-04 8.000E-04 8.400E-04
      8.800E-04 9.200E-04 9.600E-04 1.000E-03 1.050E-03 1.100E-03
      1.150E-03 1.200E-03 1.275E-03 1.350E-03 1.425E-03 1.500E-03
      1.600E-03 1.700E-03 1.800E-03 1.900E-03 2.000E-03 2.100E-03
      2.200E-03 2.300E-03 2.400E-03 2.550E-03 2.700E-03 2.800E-03
      3.000E-03 3.200E-03 3.400E-03 3.600E-03 3.800E-03 4.000E-03
      4.250E-03 4.500E-03 4.750E-03 5.000E-03 5.250E-03 5.500E-03
      5.750E-03 6.000E-03 6.300E-03 6.600E-03 6.900E-03 7.200E-03
      7.600E-03 8.000E-03 8.400E-03 8.800E-03 9.200E-03 9.600E-03
      1.000E-02 1.050E-02 1.100E-02 1.150E-02 1.200E-02 1.275E-02
      1.350E-02 1.425E-02 1.500E-02 1.600E-02 1.700E-02 1.800E-02
      1.900E-02 2.000E-02 2.100E-02 2.200E-02 2.300E-02 2.400E-02
      2.550E-02 2.700E-02 2.800E-02 3.000E-02 3.200E-02 3.400E-02
      3.600E-02 3.800E-02 4.000E-02 4.250E-02 4.500E-02 4.750E-02
      5.000E-02 5.250E-02 5.500E-02 5.750E-02 6.000E-02 6.300E-02
      6.600E-02 6.900E-02 7.200E-02 7.600E-02 8.000E-02 8.400E-02
      8.800E-02 9.200E-02 9.600E-02 1.000E-01 1.050E-01 1.100E-01
      1.150E-01 1.200E-01 1.275E-01 1.350E-01 1.425E-01 1.500E-01
      1.600E-01 1.700E-01 1.800E-01 1.900E-01 2.000E-01 2.100E-01
      2.200E-01 2.300E-01 2.400E-01 2.550E-01 2.700E-01 2.800E-01
      3.000E-01 3.200E-01 3.400E-01 3.600E-01 3.800E-01 4.000E-01
      4.250E-01 4.500E-01 4.750E-01 5.000E-01 5.250E-01 5.500E-01
      5.750E-01 6.000E-01 6.300E-01 6.600E-01 6.900E-01 7.200E-01
      7.600E-01 8.000E-01 8.400E-01 8.800E-01 9.200E-01 9.600E-01
      1.00 1.10 1.20 1.30 1.40 1.50 1.60 1.70 1.80 1.90 2.00 2.10
      2.20 2.30 2.40 2.50 2.60 2.70 2.80 2.90 3.00 3.10 3.20 3.30
      3.40 3.50 3.60 3.70 3.80 3.90 4.00 4.10 4.20 4.30 4.40 4.50
      4.60 4.70 4.80 4.90 5.00 5.10 5.20 5.30 5.40 5.50 5.60 5.70
      5.80 5.90 6.00 6.10 6.20 6.30 6.40 6.50 6.60 6.70 6.80 6.90
      7.00 7.10 7.20 7.30 7.40 7.50 7.60 7.70 7.80 7.90 8.00 8.10
      8.20 8.30 8.40 8.50 8.60 8.70 8.80 8.90 9.00 9.10 9.20 9.30
      9.40 9.50 9.60 9.70 9.80 9.90 10.00 10.10 10.20 10.30 10.40
      10.50 10.60 10.70 10.80 10.90 11.00 11.10 11.20 11.30 11.40
      11.50 11.60 11.70 11.80 11.90 12.00 12.10 12.20 12.30 12.40
      12.50 12.60 12.70 12.80 12.90 13.00 13.10 13.20 13.30 13.40
      13.50 13.60 13.70 13.80 13.90 14.00 14.10 14.20 14.30 14.40
      14.50 14.60 14.70 14.80 14.90 15.00 15.10 15.20 15.30 15.40
      15.50 15.60 15.70 15.80 15.90 16.00 16.10 16.20 16.30 16.40
      16.50 16.60 16.70 16.80 16.90 17.00 17.10 17.20 17.30 17.40
      17.50 17.60 17.70 17.80 17.90 18.00 18.10 18.20 18.30 18.40
      18.50 18.60 18.70 18.80 18.90 19.00 19.10 19.20 19.30 19.40
      19.50 19.60 19.70 19.80 19.90 20.00
C
SP2  D 0.00000E+00 4.22801E-08 4.43342E-08 4.63883E-08 4.84423E-08
       7.65150E-08 8.11153E-08 8.57370E-08 9.03374E-08 1.27611E-07
       1.35798E-07 1.43958E-07 1.52117E-07 1.60276E-07 1.68436E-07
       1.76595E-07 1.84726E-07 1.92856E-07 3.04520E-07 3.22792E-07
       2.25323E-07 4.74952E-07 5.07304E-07 5.39599E-07 5.71723E-07
       6.04246E-07 6.36199E-07 8.40182E-07 8.90821E-07 9.40746E-07
       9.89959E-07 1.03989E-06 1.08981E-06 1.13902E-06 1.18895E-06
       1.49179E-06 1.56282E-06 1.63301E-06 1.70404E-06 2.38161E-06
```

2.50600E-06	2.63038E-06	2.75477E-06	2.87801E-06	3.00126E-06
3.12336E-06	4.07681E-06	4.26652E-06	4.45624E-06	4.64596E-06
7.31985E-06	7.74137E-06	8.15860E-06	8.57584E-06	1.20764E-05
1.28039E-05	1.35256E-05	1.42417E-05	1.49521E-05	1.56568E-05
1.63557E-05	1.70490E-05	1.77365E-05	2.78801E-05	2.93949E-05
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1.49036E-03	1.41276E-03	1.34315E-03	1.28039E-03	1.22219E-03
1.16969E-03	1.39564E-03	1.32960E-03	1.26969E-03	1.21477E-03
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1.72088E-03	1.62131E-03	1.53201E-03	1.45213E-03	1.38280E-03
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1.42674E-03	1.36055E-03	1.30007E-03	1.84783E-03	1.73742E-03
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1.66467E-03	1.58265E-03	1.50277E-03	1.41290E-03	1.32090E-03
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1.72094E-03	1.60690E-03	1.50591E-03	1.41625E-03	1.76481E-03
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1.15543E-03	1.09723E-03	1.03989E-03	9.60289E-04	1.20050E-03
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1.07184E-03	2.07464E-03	1.95196E-03	1.88121E-03	1.84925E-03
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1.96423E-03	1.87793E-03	1.80946E-03	1.73742E-03	1.66467E-03
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2.79228E-03	2.67888E-03	2.58045E-03	2.49059E-03	3.16959E-03
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       6.56457E-08 6.09098E-08 5.65163E-08 5.24357E-08 4.86423E-08
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       2.13199E-08 1.97793E-08 1.83471E-08 1.70202E-08 1.57909E-08
       1.46469E-08
C ********************
C *  MATERIAL CARDS  *
C ********************
C  Al-6061
M600  13027.60c -0.965500  12000.60c -0.010000  14000.60c -0.006000
      22000.60c -0.001500  24050.60c -0.000084  24052.60c -0.001674
      24053.60c -0.000193  24054.60c -0.000049  25055.60c -0.001500
      26054.60c -0.000395  26056.60c -0.006434  26057.60c -0.000151
      26058.60c -0.000020  29063.60c -0.001712  29065.60c -0.000788
      30000.42c -0.002500  23000.60c -0.001500
C HDPE-> (C2H4)n    --          --
C                   |   H    H   |
C                   |   |    |   |
C                  -|-  C -- C  -|-
C                   |   |    |   |
C                   |   H    H   |
C                   --          --
M601   1001.60c  0.666667   6000.60c  0.333333
MT601  poly.01t
C  Ni Foils
M602  28058.60c -0.6719780 28060.60c -0.2677586 28061.60c -0.0118346
      28062.60c -0.0383429 28064.60c -0.0100859
C  Dilute Gold (Source is 3/02 CVH FOIL.LIST)
M603  79197.60c -0.001134  13027.60c -0.998866
C  Cadmium Covers
M604  48000.42c  1.000000
C  Air in Albuquerque
C  See Attix p.532
M605   7014.60c -0.752308   7015.60c -0.002960   8016.60c -0.231687
       8017.60c -0.000094   6000.60c -0.000124  18000.42c -0.012827
C ********************
C * NEUTRON TALLIES  *
C ********************
FQ0   E  F
C
C  Multiply tallies number of source neutrons and divide by the
C   atom density (atoms/cc) to get Bq/Atom.
C
FC4    Ni-58(n,p) reaction rate (RXNs/cc/source-n/cm^2)
C
C  Tally 4 is the tally for Ni. Add or remove C to change between
C   7" sphere and 4" sphere.
C
F4:N   600 601 602 603 604 605 606 607 608 609
C F4:N   600 601 612 613 614 602 616
C  1st Number of FM4 is Atoms/b-cm for pure Ni-58 (0.09253256)
FM4    0.09253256  1602  103
M1602  28058.60c  1.00000
C
C  Comment out F4 Cards and remove C's from F14 to change from Ni
```

```
C   to Au tallies.
C  Tally 14 is the tally for Au/Cd. Add or remove C to change between
C   7" sphere and 4" sphere.
C
C FC14   Au-197(n,g) reaction rate (RXNs/cc/source-n)
C F14:N  600 601 602 603 604 605 606 607 608 609
C F14:N  600 601 612 613 614 602 616
C  1st Number of FM4 is Atoms/b-cm for pure Au-197
C FM14   0.058710543  1603  102
M1603  79197.60c  1.00000
C
NPS 2000000000
PRDMP  1j -400  0  1
DBCN   12j 1517
```

APPENDIX B
Schematics of the RES Spheres

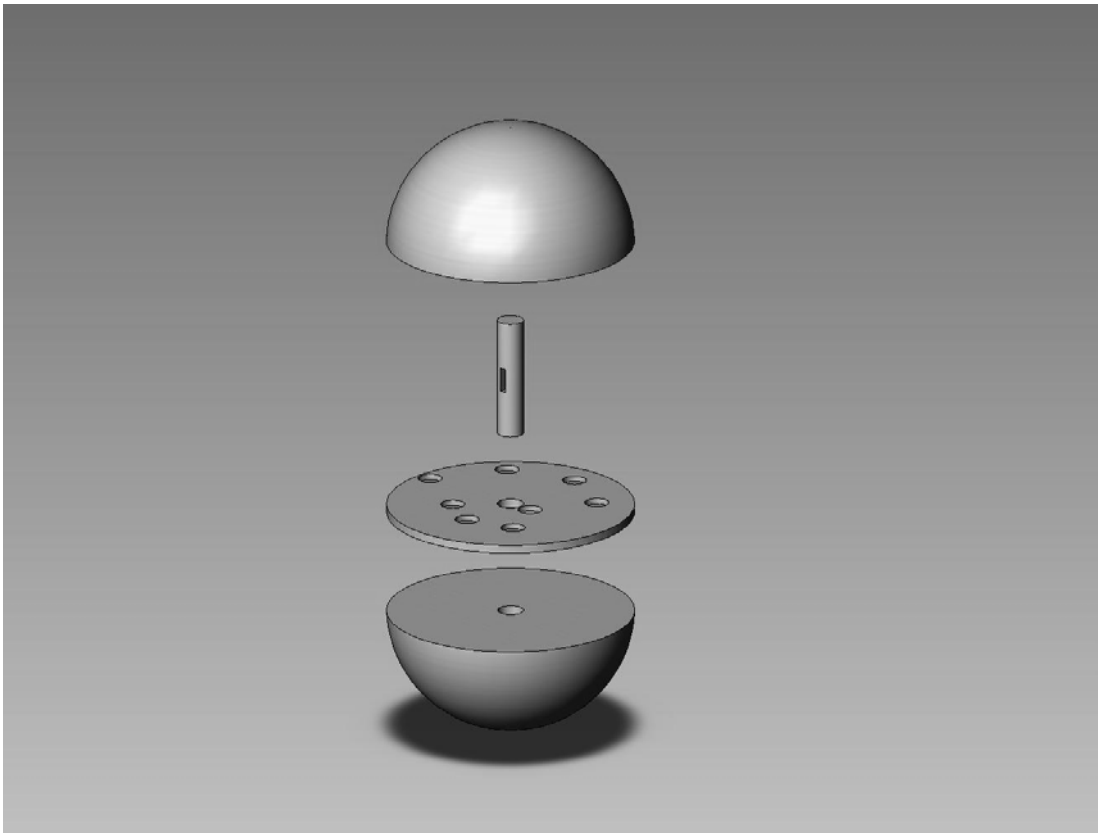

Figure B-1. Exploded View of the Construction of the 7-in-dia Sphere.

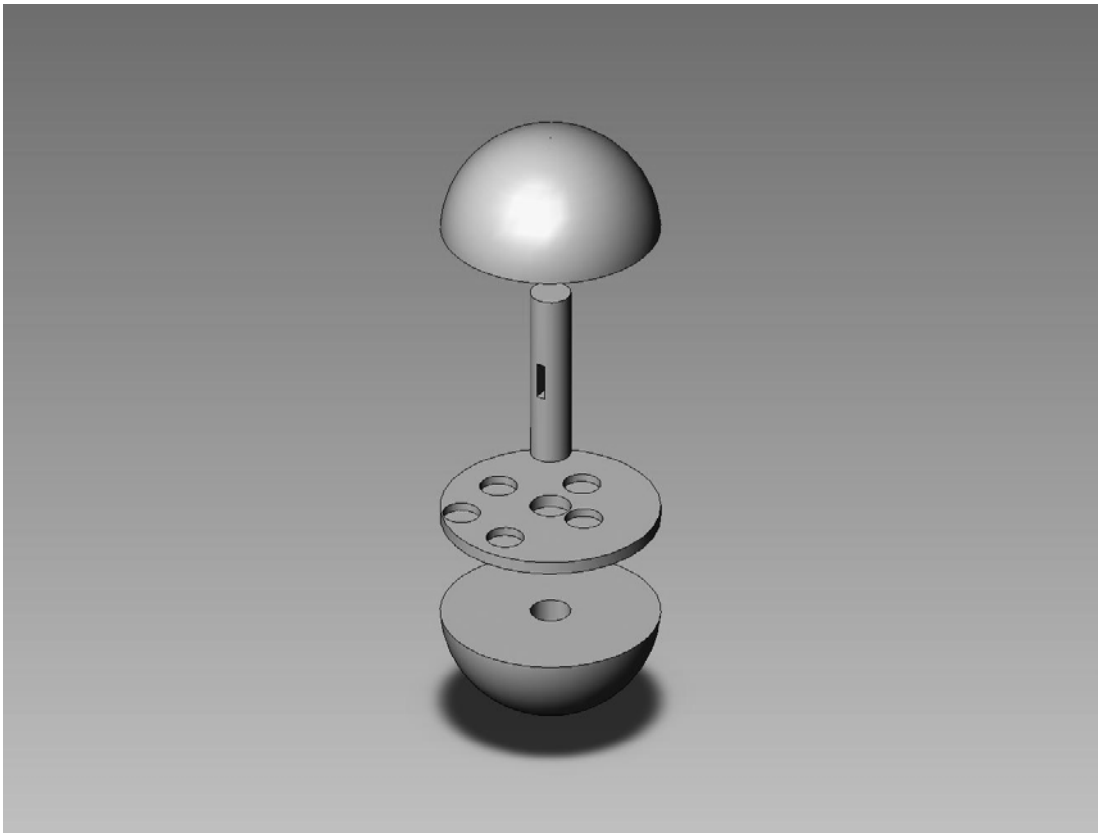

Figure B-2. Exploded View of the Construction of the 4-in-dia Sphere.

Distribution:

1 W. Daniel Reece
Nuclear Science Center
Texas A&M University
3575 TAMU
College Station, TX 77845-3575

1 John Williams
Nuclear Research Laboratory
Engineering Building (20)
University of Arizona
P.O. Box 210020
Tucson, AZ 85721-0020

1 T. Michael Flanders
Reactor Physics Division
STEWS-DT-R
WSMR, NM 88002-5158

1 David M. Gilliam
NIST
Reactor Bldg/B-182
Gaithersburg, MD 20899-8461

1 Robert Keith
ITT Advanced Engineering & Sciences
P.O. Box 39550 (80949-9550)
Colorado Springs, CO 80919

1 Hamilton T. Hunter
RSICC SINBAD Contact
Oak Ridge National Laboratory
P.O. Box 2008 MS6086
Oak Ridge, TN 37831-6086

1 MS 0316 S. A. Hutchinson, 1437
1 MS 0574 B. C. Bedeaux, 5924
1 MS 1169 J. R. Lee, 1300
1 MS 0828 M. Pilch, 1533
1 MS 0828 A. A. Giunta, 1533
1 MS 1136 D. W. Vehar, 1382
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