Temperature Measurements of the BeRP Ball During the Subcritical Copper-Reflected α-Phase Plutonium (SCRαP) Experiment

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INTRODUCTION

A Subcritical Copper-Reflected α-Phase Plutonium (SCRαP) integral benchmark experiment was completed in December 2016 (Ref. 1). During SCRαP, temperature measurements, to be used for multiple purposes described below, were taken. In this experiment, multiplication was approximated using correlated neutron data from a detector system consisting of ^{3}He tubes inside high density polyethylene. The measurements were used to validate the properties of the material, and guide in understanding the nuclear data uncertainties. As such, it will be published in the International Criticality Safety Benchmark Evaluation Project (ICSBEP) Handbook as a Fundamental Physics Benchmark (Ref. 2).

BACKGROUND

This experiment was the third of its kind. The prior two experiments were completed in 2012 with nickel and tungsten reflectors (Refs. 3,4). The nickel measurements contained a few temperature measurements but the tungsten measurements had no temperature data taken. Both used the same plutonium sphere, known as the BeRP Ball (Beryllium Reflected Plutonium Ball). This piece of plutonium is 4.5 kg α-phase plutonium with a thin stainless steel cladding. The BeRP Ball was fabricated in 1980 at Los Alamos, and since then, has been used extensively for detector validation, program validation, and general measurements for a variety of customers.

During the Benchmark writing process for the two measurements taken in 2012, which were published in the ICSBEP in 2014 and 2016, it was noted that very little temperature data was taken, and thus a knowledge gap existed (Refs. 2-4). It was further noted that very little temperature data existed for any of the measurements taken with the BeRP Ball over its many years of use. The lack of temperature data was documented as a “lessons learned” from the 2012 measurements. The many “lessons learned” from these measurements were documented during the planning and design phase of the SCRαP experiment.

Temperature measurements were incorporated into the design of the SCRαP experiment. This included temperature data from three locations: directly touching the BeRP Ball on the bottom, against the outermost reflector, and of the ambient room.

EXPERIMENT DESCRIPTION

Seventeen different configurations were measured as part of the SCRαP experiment. These had the bare BeRP Ball and the BeRP Ball surrounded by 0.5” to 4.0” of copper and polyethylene in various combinations, including both copper and polyethylene at 4.0” individually. The purpose initially was to validate and quantify the uncertainty in the copper nuclear data via integral measurements. The polyethylene was added to tweak the system (energy spectrum and additional reactivities), and additional pure polyethylene measurements taken to validate the subset of measurements. The seventeen configurations are shown in Table I (Refs. 1,5,6). Figure 1 shows the whole setup for configuration 7. Figure 2 shows configuration 7 (without the top hemishells), and the thermocouple spots are evident in the image.

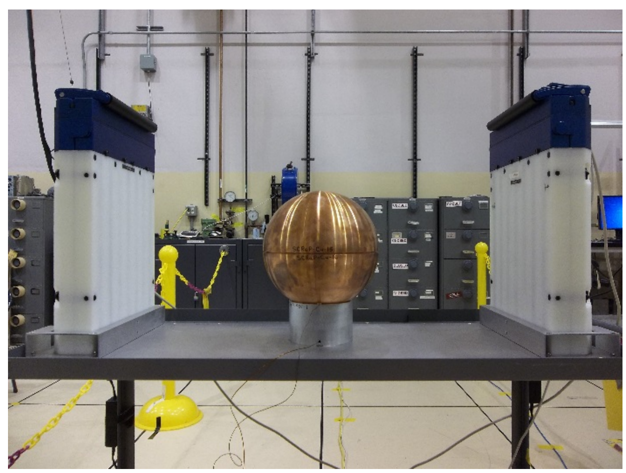

Figure 1.Overview of Configuration 7, including the multiplicity detectors.

Figure 2. Configuration 7, which shows the various layers of polyethylene and copper, as well as where the thermocouples enter the system.

Table I. The Seventeen Configurations measured in the SCRαP experiment. Orange represents Cu and light grey is used for polyethylene.

Configuration #	Layer number (each layer is 0.5 inches thick)							
	1	2	3	4	5	6	7	8
0								
1	orange							
2	orange	orange						
3	orange	orange	orange					
4	orange	orange	orange	orange				
5	orange	orange	light grey	light grey	light grey	light grey		
6	orange	orange	orange	orange	orange			
7	light grey	orange	light grey	orange	light grey	orange	light grey	orange
8	orange	light grey	orange	light grey	orange	light grey	orange	light grey
9	orange	orange	orange	orange	orange	orange		
10	orange	orange	orange	orange	orange	orange	orange	
11	orange	orange	orange	orange	orange	orange	orange	orange
12	light grey	light grey	light grey	orange	orange	orange	orange	
13	light grey	light grey	orange	orange	orange	orange	orange	
14	light grey	orange	orange	orange	orange	orange	orange	
15	light grey	orange	orange	orange	orange	orange	orange	orange
16	light grey	light grey	light grey	light grey	light grey	light grey	light grey	light grey

Measurement times for each configuration were based on the total time available, and the time estimated to achieve necessary statistics (based on simulations) (Ref. 7). Procedural limitations also effected the maximum time for some configurations, but again, all met minimum statistics. Given this, some configurations reached an equilibrium temperature state, while others did not (the statistics for leakage multiplication were met in all configurations). Some configurations ran for only 30 minutes, while others ran overnight.

The temperature of the BeRP ball was measured with a Type T thermocouple, and the temperature of the outer reflector surface was measured with a Type J thermocouple. The data was collected with a multichannel thermocouple data logger, all of which, including the thermocouples, was NIST calibrated. Measurements were taken at a frequency of at least once every 250 milliseconds during the measurements.

RESULTS

The largest temperature change occurred for Configuration 16, which had 4 in. of polyethylene reflector and was measured overnight (the bare BeRP ball configuration was the only other configuration that ran overnight). Data is currently unavailable for configurations 12 and 13, due to data port failure. Table II lists the average and standard deviation of the BeRP ball temperature, for each configuration. Table III lists the average and standard deviation of outer reflector temperature for each configuration, except the bare configuration since it had no reflector.

Table II. The BeRP Ball Temperature and Standard Deviation for the Configurations measured in the SCRαP experiment.

Experiment Number	**BeRP Avg Temp (°C)**	**BeRP Temp Std. Dev. (°C)**
0	47.13	0.751
1	41.71	1.006
2	37.83	1.931
3	35.64	0.997
4	35.01	0.133
5	36.06	1.071
6	28.30	0.731
7	35.61	1.390
8	35.87	1.662
9	30.97	0.264
10	31.42	0.241
11	31.64	0.251
14	39.75	0.265
15	31.37	0.943
16	51.24	4.554

It can be observed that the temperature of the BeRP ball changes more with thin metal reflectors, and with cases where there is significant amounts of polyethylene (Cases 1, 2, and 5, 7, 8, and 16, respectively). This result was expected since polyethylene is an insulator and copper is a conductor. The significance and noticeability of the change was not expected. The thin copper cases were also the shortest in measurement time, so they had the least amount of time to trend towards equilibrium. As stated above, the bare BeRP ball (Config 0) was measured over the weekend so statistics associated with measurement time skew the results.

A plot of the BeRP ball temperature during the time of Configuration 2 is shown in Figure 3 below.

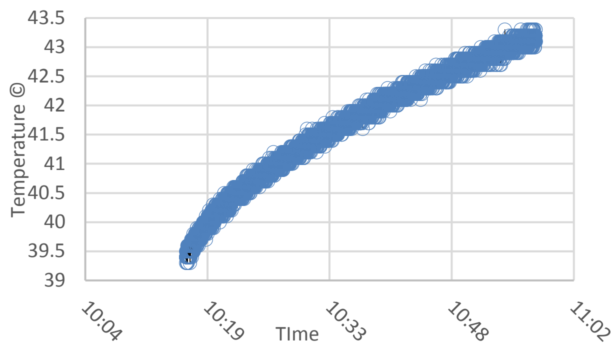

Figure 3. BeRP ball temperature during Configuration 2.

Table III. The Outer Reflector Temperature and Standard Deviation for the Configurations measured in the SCRαP experiment.

Experiment Number	Outer Reflector Avg Temp (°C)	Outer Reflector Temp Std. Dev. (°C)
0		
1	35.71	0.781
2	26.99	0.433
3	32.77	1.031
4	30.46	0.094
5	25.22	0.103
6	25.47	0.297
7	26.27	0.071
8	25.95	0.054
9	28.72	0.552
10	28.31	0.327
11	28.98	0.362
14	25.50	0.368
15	23.09	0.174
16	28.48	0.816

The Outer Reflector temperatures, as listed in Table III, tell a slightly different story. The configurations with thick total reflector, with the exception of Configuration 16 as described above, have the smallest change in temperature. On the other hand, they tell the flip side of the story from the BeRP ball temperatures- the thin metal and significant poly configurations have the smallest outer reflector temperature change.

EXPLANATION OF RESULTS

The BeRP Ball and outer reflector temperature effect the count rate of the system. In previous benchmarks, this has been considered in the sensitivity/ uncertainty analysis, and only expected to effect the radius (which of course effected the multiplication since density changes slightly) (Refs. 3,4). The sensitivity results related to the temperature change were bounded by the uncertainty in the radius though.

Preliminary review of the data shows that the temperature swings experienced by the BeRP ball over the full weekend that the measurement was conducted cause significant swings in count rate. This limits the amount of usable data for the benchmark (which will still be sequential in time and be sufficient for statistical requirements). A similar phenomena is likely seen in the polyethylene configurations.

CONCLUSIONS

The temperature of the BeRP ball and outer reflector were measured for all configurations during the SCRaP measurement. This is new in that detailed temperature data of the BeRP ball has not been taken in its 25+ years in validation work.

The temperature swings are likely to explain count rate swings and anomalies in measurements with metal and insulating reflectors. During the benchmark process for SCRaP, sensitivities/ uncertainties associated with the temperature swing will be evaluated. They are not expected to impact nickel or tungsten benchmark values.

The final presentation will include plots of the temperature during measurements and count rates associated with the temperature data, as well as analysis of temperature change as a function of time.

ACKNOWLEDGEMENTS

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