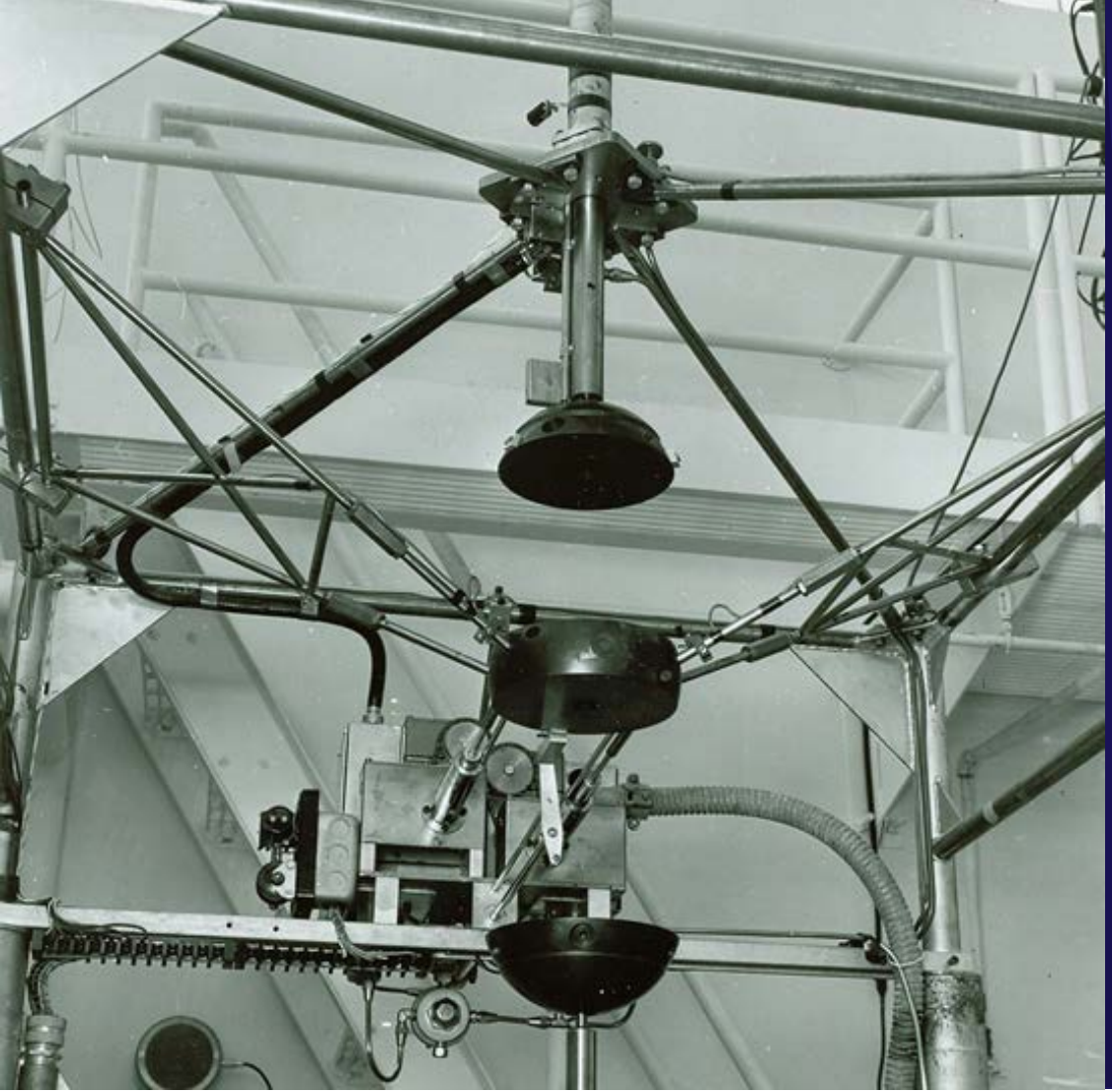

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and promote world stability

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

T. Cutler, J. Hutchinson, R. Bahran, J. Arthur, M. Nelson

Los Alamos National Laboratory

ANS Annual 2018

Overview

- Introduction
- Experiment Design
- Experiment Overview
- Preliminary Temperature Results
- Future work

Introduction

Design/Conduct/Analyze Subcritical Validation Experiments

- **Nuclear Data and Transport Codes**
  - Fill integral experiment database deficiencies

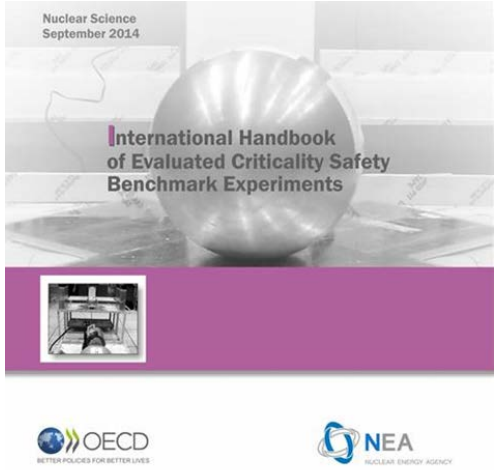
  +
  - Find differential nuclear data library deficiencies

  For different….
    - Energy Ranges (Thermal, Intermediate, Fast)
    - Multiplication Ranges (Low, Medium, High)
    - Materials (Fissile, Moderator, Reflector)
    - Neutron Reactions

- **Uncertainty Quantification Methodology Development*****

Recent Advances in Subcritical Experiments

- **We have come a long way since the first subcritical measurements at CP-1 in 1942.**
- **Many organizations (LANL, LLNL, SNL, IAEA, IRSN, CEA, universities, and others) have pursued subcritical experiments and/or simulations in recent years.**
- **The BeRP ball reflected by nickel benchmark evaluation was published in the 2014 edition of the ICSBEP handbook.**
- **This benchmark was the first:**
  - Published benchmark evaluation of measurements performed at DAF.
  - Benchmark evaluation using new MCNP® capabilities for subcritical systems (the MCNP5 list-mode patch and MCNP6 list-mode capabilities).
  - Benchmark using the Feynman Variance-to-Mean method.
  - LANL-led subcritical experiment in the ICSBEP handbook.
- **This benchmark was the culmination of several years of subcritical experiment research.**
- **BeRP-tungsten published in 2016 edition of ICSBEP handbook.**

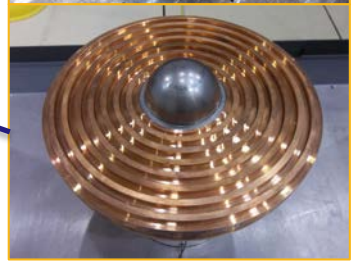


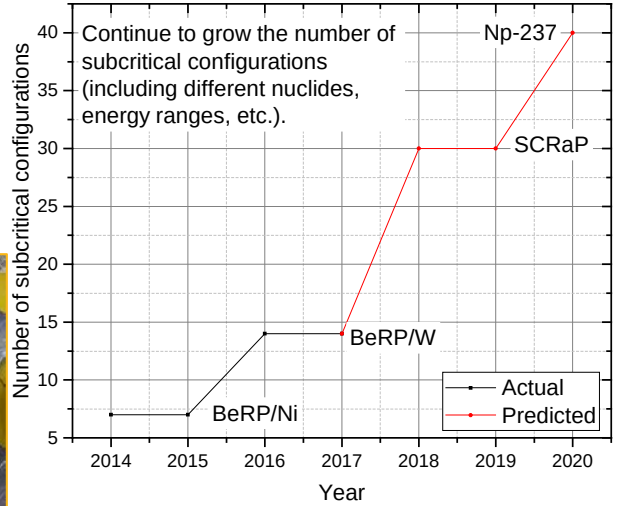
Validating Codes and Data with Subcritical Experiments

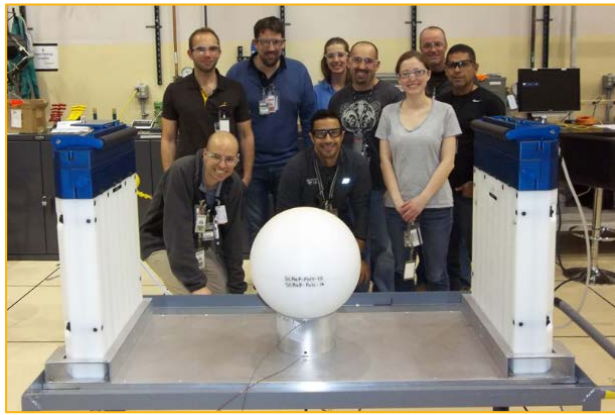
- **Growing dataset of neutron multiplication benchmarks experiments/evaluations**
  - Culmination of several years of sub-critical experiment research
  - Goal is to validate nuclear data and computational methods

Chronology: 2012 - Present

- **BeRP-Ni (published in 2014)**
  - Executed in 2012, ICSBEP evaluation published in 2014
- **BeRP-W (published in 2016)**
  - Sub-critical tungsten-reflected α-phase Pu
  - Executed in 2012, ICSBEP evaluation published in 2016
- **SCRαP (to be published in 2018?)**
  - Sub-critical copper/poly-reflected α-phase Pu
  - Executed in 2016, ICSBEP evaluation published in 2018
- **Neptunium (to be published in 2020?)**
  - Sub-critical Neptunium w/various reflectors, in design phase







Experiment Design

Experiment Design

- **SCRαP Experiment Design**
  - o BeRP (Beryllium-Reflected Plutonium).
    - 4.5-kg WG α-phase stainless-steel clad plutonium sphere.
    - Originally used in Be-reflected critical experiment (no Be was present for this experiment).
  - o High-purity nested copper shells
    - C101 Cu alloy (99.99 wt.% Cu).

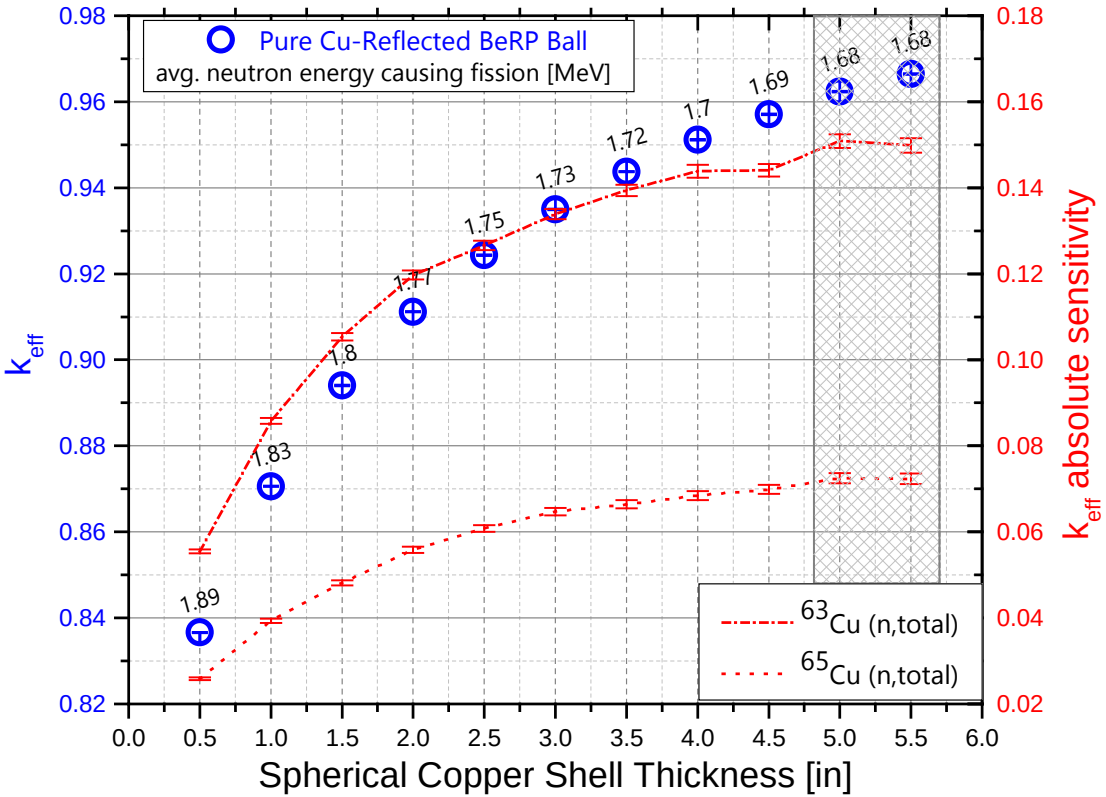
Experiment Design

- **SCRαP Experiment Design**
  - o High-density interleaved polyethylene shells
- **Wide range of achievable subcritical multiplication values will help:**
  - Identify deficiencies and quantify uncertainties in nuclear data
  - Validate computational methods related to neutron multiplication inference.

Two purposes for the configurations with polyethylene:
- Allows for higher multiplication factor than with copper alone
- Allows for a different neutron spectra (and resulting sensitivity) for the same multiplication factor.

Experiment Design

- **Final configurations were chosen based upon:**
  - Criticality results
  - Sensitivity results: total
  - Sensitivity results: intermediate energy
  - Average neutron energy causing fission
  - Cost
  - Criticality safety
  - Practicality (weight of shells, etc.)
- **Described in detail in an experimental design document.**



Experiment Design: Temperature Data

- **Temperature Data in Historical Measurement**
  - BERP/Ni: a few on the BERP ball
  - BERP/W: none
  - Other documented BERP measurements: sparse
- **BERP ball uses**
  - Used extensively for detector validation, program validation, and general measurements for a variety of customers

Experiment Design: Temperature Data

- **BERP/Ni ICSBEP Meeting**
  - Acknowledged that very little temperature data was taken, so a knowledge gap existed
- **BERP/W ICSBEP**
  - Reaffirmed need for temperature data in subcritical Fundamental Physics Benchmarks
  - Benchmark measurements taken before BERP/Ni Meeting, so lesson could not be passed on
- **Further Data Review**
  - After the ICSBEP Meetings, research was done on previous BERP Measurements, which are plentiful
    - NO discrete data could be found!

Experiment Design: Temperature Data

- **SCRaP Final Design**
  - Incorporated many lessons learned from BERP/Ni and BERP/W, including the need for temperature measurements
- **Temperature Data Locations Selected**
  - Directly touching the BERP ball
  - Against the outermost reflector
  - Ambient Room
    - This included humidity and air pressure

Many lessons-learned from the previous Ni and W benchmarks were used to minimize experimental uncertainties.

Experiment Design: Detector

- **NoMAD (Neutron Multiplicity ^{3}He Array Detector) was used to measure three benchmark parameters:**
  - o Detector singles count rate (R_1) i.e. the count rate in the detector system
  - o Doubles count rate (R_2) i.e. the rate in the detector system in which two neutrons from the same fission chain are detected
  - o Leakage multiplication (M_L) i.e. the number of neutrons escaping a system per starter neutron.
- **SAME benchmark parameters as BERP/Ni and BERP/W**

Records list-mode data (a time list of every recorded neutron event to a resolution of 128 nsec).

Photograph and MCNP® model of the NoMAD detector system.

15 He-3 tubes inside polyethylene.

Experiment Overview

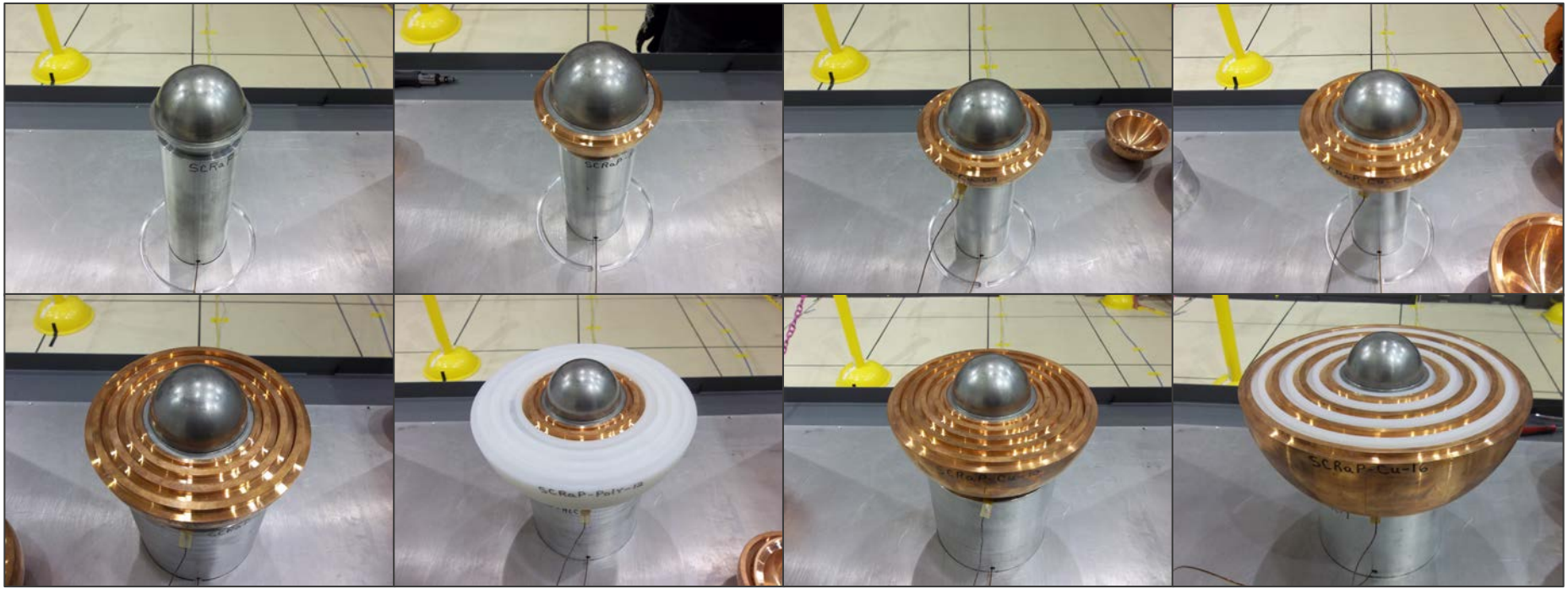
Experiment configurations

- **17 total configurations:**
  - o 1 Bare
  - o 8 Cu-only configurations
  - o 7 Cu+HDPE configurations
  - o 1 HPDE-only configuration
- **In order to determine the detector efficiency, Cf-252 source replacement measurements were performed.**
  - o The source strength of the ^{252}Cf source at the time of the measurements was 7.59e5 fissions/sec +/- 1.0%.

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

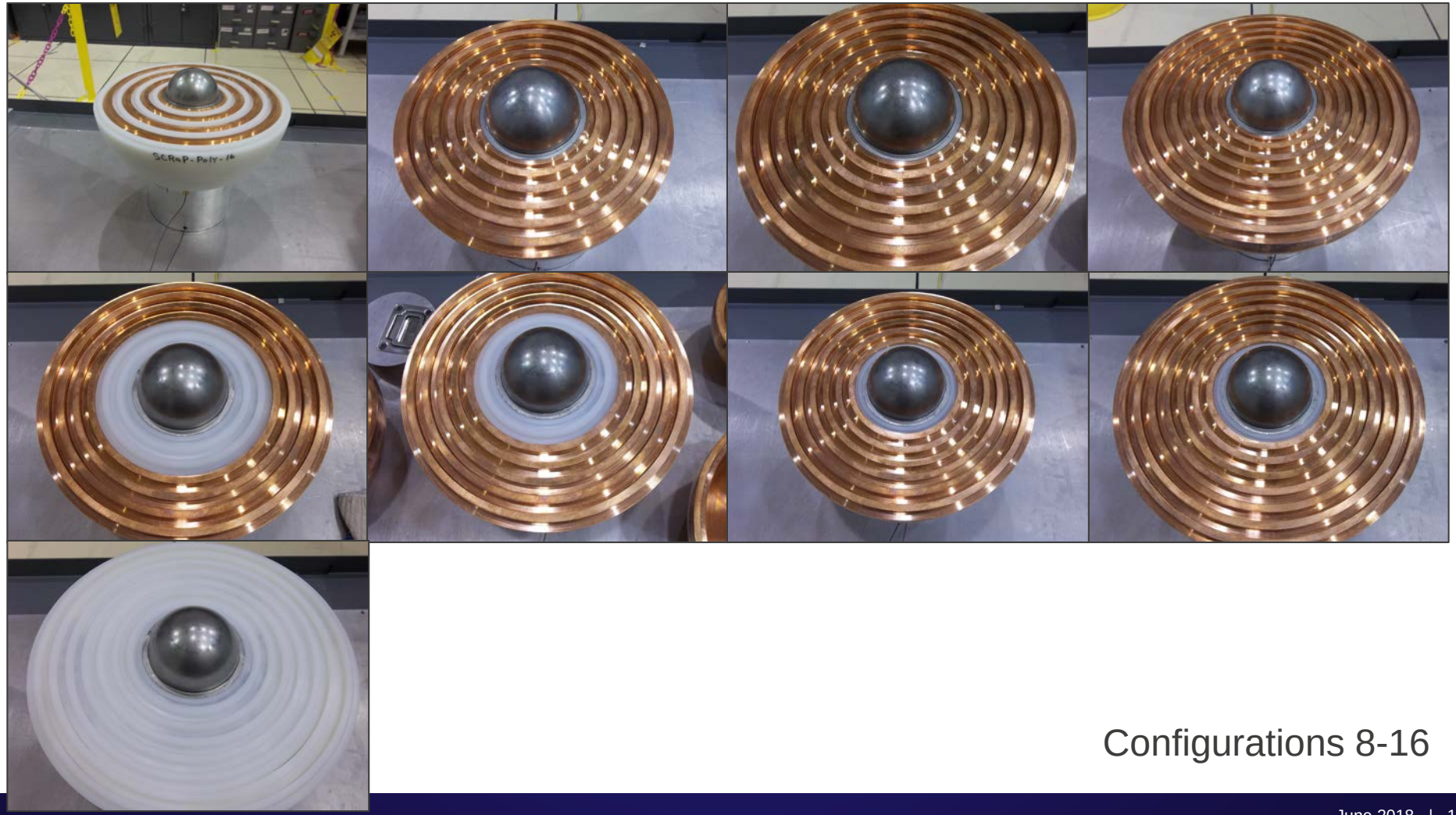
Orange is for Cu
Grey is for HDPE

Experiment configurations



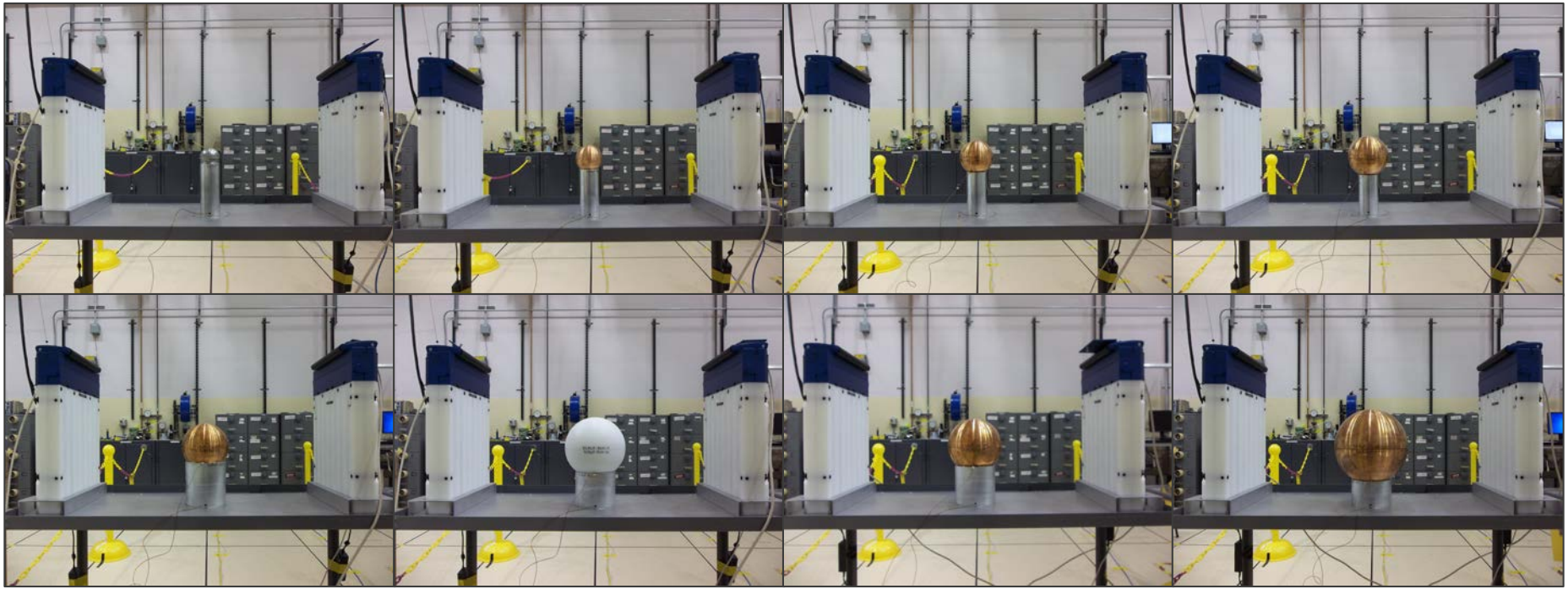
Configurations 0-7

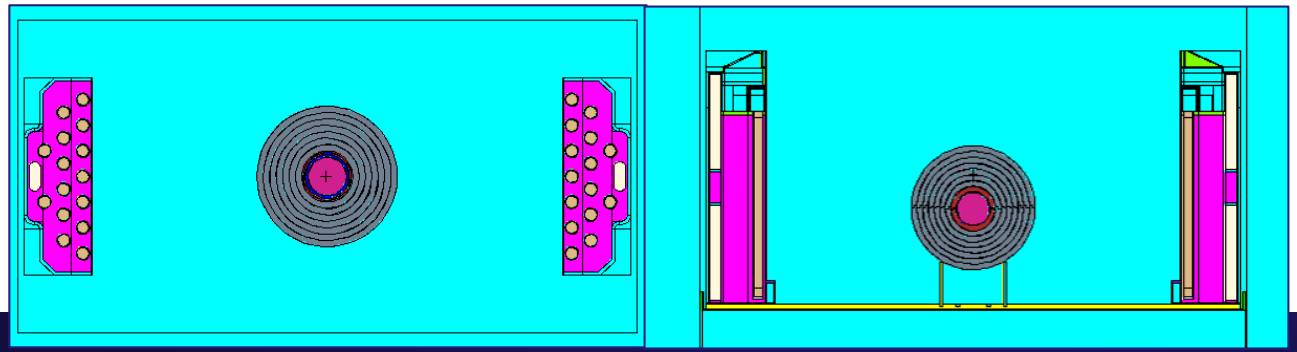
Experiment configurations



Configurations 8-16

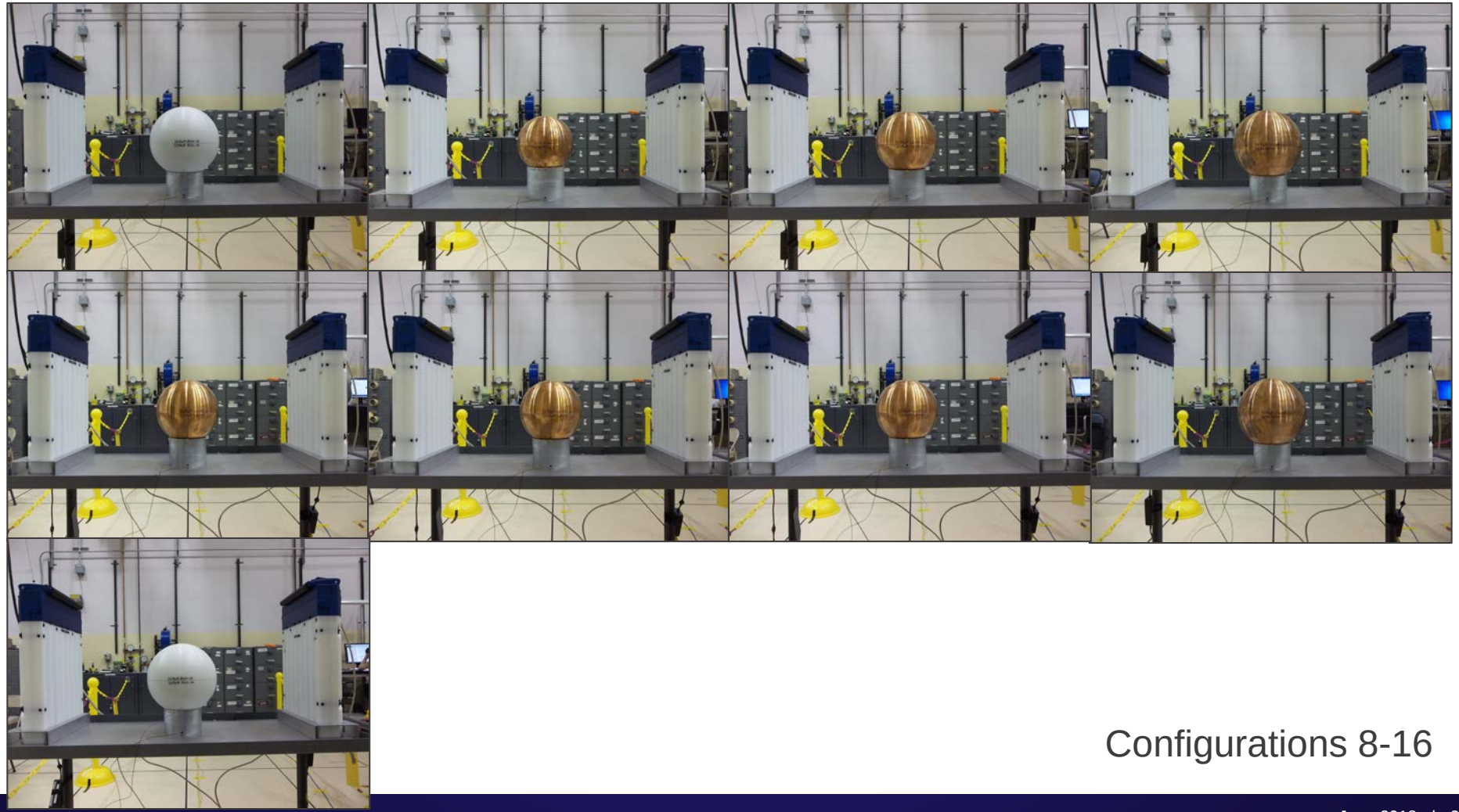
Experiment configurations





Configurations 0-7

Experiment configurations

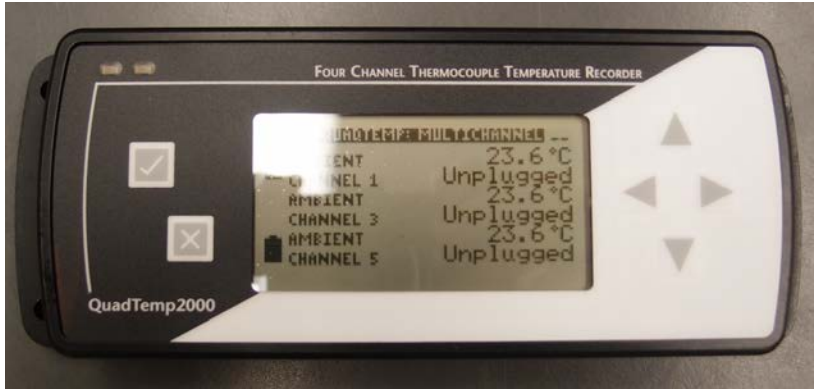


Configurations 8-16

Preliminary Temperature Results

Temperature Measurement Method

- **BERP ball:** Type T Thermocouple
- **Outer Reflector:** Type J Thermocouple
- **Data Collection:** NIST-calibrated QuadTemp2000 Data Logger
- **Ambient:** NIST Calibrated OM-CP-PRHTemp2000
- **Data Collection Frequency:** At least every 250 ms (varied by configuration)



QuadTemp2000 Data Logger

Omega ® OM-CP-PRHTemp2000 Device

Temperature Measurement: BERP Ball Results

Experiment Number	BERP Avg Temp (°C)	BERP Temperature Std. Dev. (°C)	BERP Start Temp (°C)	BERP End Temp (°C)
0	47.9	0.0	47.9	47.9
1	41.7	1.0	39.4	43.2
2	37.8	1.9	33.7	40.5
3	35.6	1.0	34.3	37.3
4	35.0	0.1	34.8	35.2
5	36.1	1.1	34.1	37.8
6	28.3	0.7	26.7	29.4
7	35.6	1.4	32.8	37.8
8	35.9	1.7	31.9	38.1
9	31.0	0.3	30.8	31.7
10	31.4	0.2	31.0	31.8
11	31.6	0.3	31.2	32.1
12				
13				
14	39.7	0.3	38.5	39.9
15	31.4	0.9	29.2	32.6
16	44.0	4.0	34.7	46.9

Temperature Measurement: Outer Reflector Results

Experiment Number	Outer Reflector Avg Temp (°C)	Outer Reflector Temperature Std. Dev. (°C)	Outer Reflector Start Temp (°C)	Outer Reflector End Temp (°C)
0				
1	35.7	0.8	35.7	36.5
2	27.0	0.4	25.8	27.4
3	32.8	1.0	30	34.2
4	30.5	0.1	30.3	30.6
5	25.2	0.1	25.0	25.4
6	25.5	0.3	24.8	25.9
7	26.3	0.1	26.2	26.4
8	25.9	0.1	25.9	26
9	28.7	0.6	27.4	29.5
10	28.3	0.3	27.4	28.8
11	29.0	0.4	28.0	29.5
12				
13				
14	25.5	0.4	26.1	25.6
15	23.1	0.2	22.8	23.4
16	28.5	0.8	27	29.5

Temperature Measurement: Ambient Results

Experiment Number	Ambient Avg Temp (°C)	Ambient Temperature Std. Dev. (°C)	Ambient Avg Pressure (psi)	Ambient Pressure Std. Dev. (psi)	Ambient Avg Humidity (% RH)	Humidity Std. Dev. (% RH)
0	25.500	0.000	12.824	0.005	10.084	0.037
1	26.166	0.047	12.839	0.003	10.343	0.055
2	26.254	0.052	12.824	0.004	10.395	0.032
3	26.391	0.028	12.812	0.003	10.438	0.102
4	26.229	0.050	12.801	0.002	9.859	0.063
5	26.395	0.034	12.802	0.002	9.765	0.105
6	26.472	0.210	12.793	0.003	9.776	0.168
7	27.623	0.109	12.786	0.005	11.138	0.113
8	27.900	0.002	12.763	0.006	11.241	0.164
9	27.996	0.035	12.752	0.002	11.105	0.035
10	28.236	0.086	12.751	0.001	11.481	0.175
11	28.507	0.025	12.750	0.001	11.905	0.071
12						
13						
14	25.916	0.091	12.911	0.004	8.975	0.138
15	22.977	0.230	12.944	0.007	8.964	0.091
16	28.549	0.077	12.767	0.010	11.330	0.500

Temperature Measurement: General Results

- **Temperature Variations in the BERP Ball Occur More in Thin Metal Reflectors, and with >3 Layers Polyethylene**
  - 0,1,2,5,7,8,16
  - Polyethylene is an insulator, so it traps heat
  - Air is a poor heat conductor
- Additional Cause Related to Results
  - Thin metal cases had shortest measurement time, so least time to reach equilibrium temperature
- The Bare configuration (0) was measured over the weekend but benchmark time was limited to the last few hours
  - Config 16 had similar issue (used last few hours of measurement time)
  - The decreased time allowed these to be evenly compared with other configurations

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

Temperature Measurement: General Results

- **Temperature Variations in the Outer Reflector Occur Tell a Different Story…**
  - Thick total reflector, regardless of Cu or Poly, have the smallest change in outer reflector temperature
  - Thin metal and >3 layers polyethylene have the smallest change in outer reflector temperature

Explanation of Temperature Results

- **BERP Ball and Outer Reflector Temperature Relation to Benchmarks**
  - These temperatures effect the singles and doubles count rate of the system
  - BERP/Ni and BERP/W considered this in S/U only in relation to radius of the BERP ball
    - Temperature effects were bounded by the uncertainty in the radius
    - Did not account for reflector effects
- **Preliminary Review of Data**
  - Temperature swings in Case 0 over the full weekend caused significant swings in count rate
    - Limits the amount of usable data, hence benchmark will only use the last few hours

Conclusion on Temperature Results

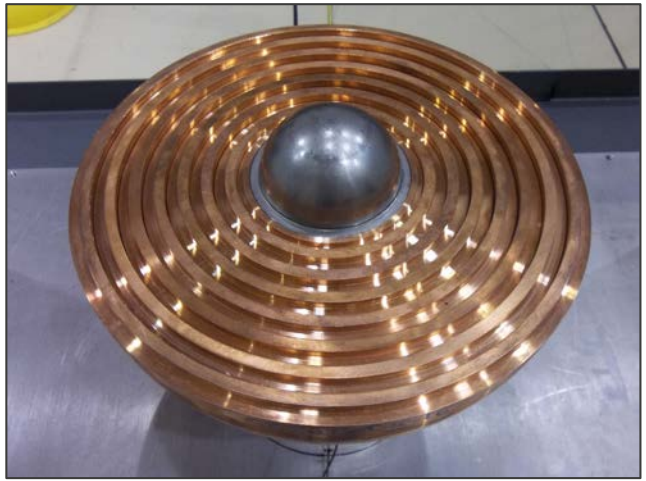
- **First subcritical benchmark to include detailed temperature information**
  - First time detailed temperature information of the BERP ball has been taken in 25+ years of validation work
  - Will be incorporated into SCRaP ICSBEP evaluation
  - Likely to explain count rate swings and anomalies in measurement results between metals and insulating materials
  - Results are not expected to impact BERP/W and BERP/Ni
  - since those were all metal reflectors and measurement times all very similar
  - Implementation of lessons-learned from BERP/W and BERP/Ni

Future work

What's next?

- This experiment will be evaluated and documented in an upcoming version of the ICSBEP handbook.
- ALL parameters will be compared to simulated list-mode data.
- Simulations will be compared for a variety of codes using the temperature variation information.
- Results will hopefully be used to improve cross-section libraries.
- Data set will also be used to validate subcritical analysis methods.

Thank you for your attention.



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