

The 2019 Edition of the ICSBEP Handbook

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Subcontracted to INL



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Acknowledgments

- **The ICSBEP and IRPhEP are a collaborative effort**
 - ❖ **Scientists, engineers, administrative support, program sponsors**
 - ❖ **26 different countries have participated**
 - 22 in ICSBEP
 - 21 in IRPhEP
 - ❖ **Without these dedicated individuals, these benchmark projects would not exist.**



IRPhEP & ICSBEP Annual Technical Review Meetings

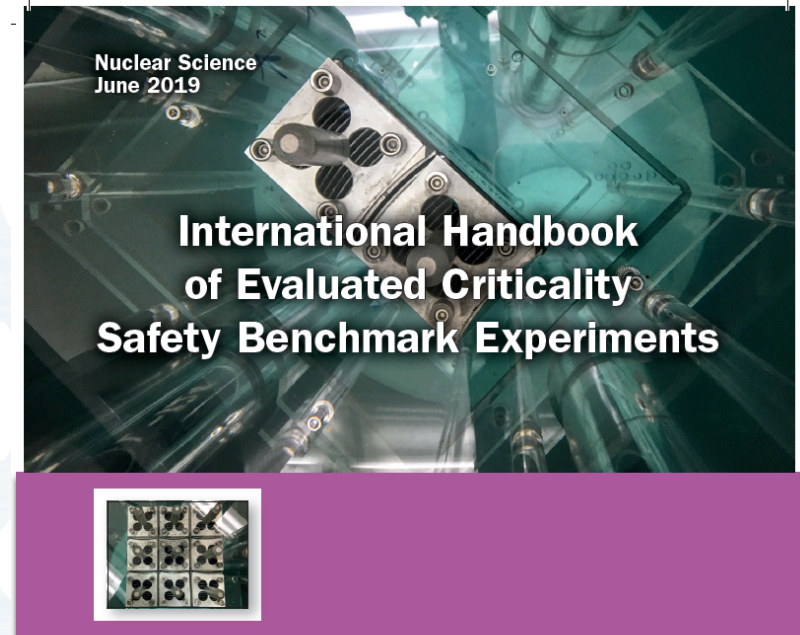
- 22-25 October 2018
- 20-25 October 2019
- OECD NEA, Paris, France
- OECD NEA, Paris, France



International Handbook of Evaluated Criticality Safety Benchmark Experiments

September 2019 Edition

- 22 Contributing Countries
- ~70,000 Pages
- 577 Evaluations
 - ❖ 4,973 Critical, Near-Critical, or Subcritical Configurations
 - ❖ 45 Criticality-Alarm-Placement/Shielding Configurations
 - ❖ 237 Configurations with Fundamental Physics Measurements
 - ❖ 838 Unacceptable Experiment Configurations



<http://icsbep.inl.gov/>

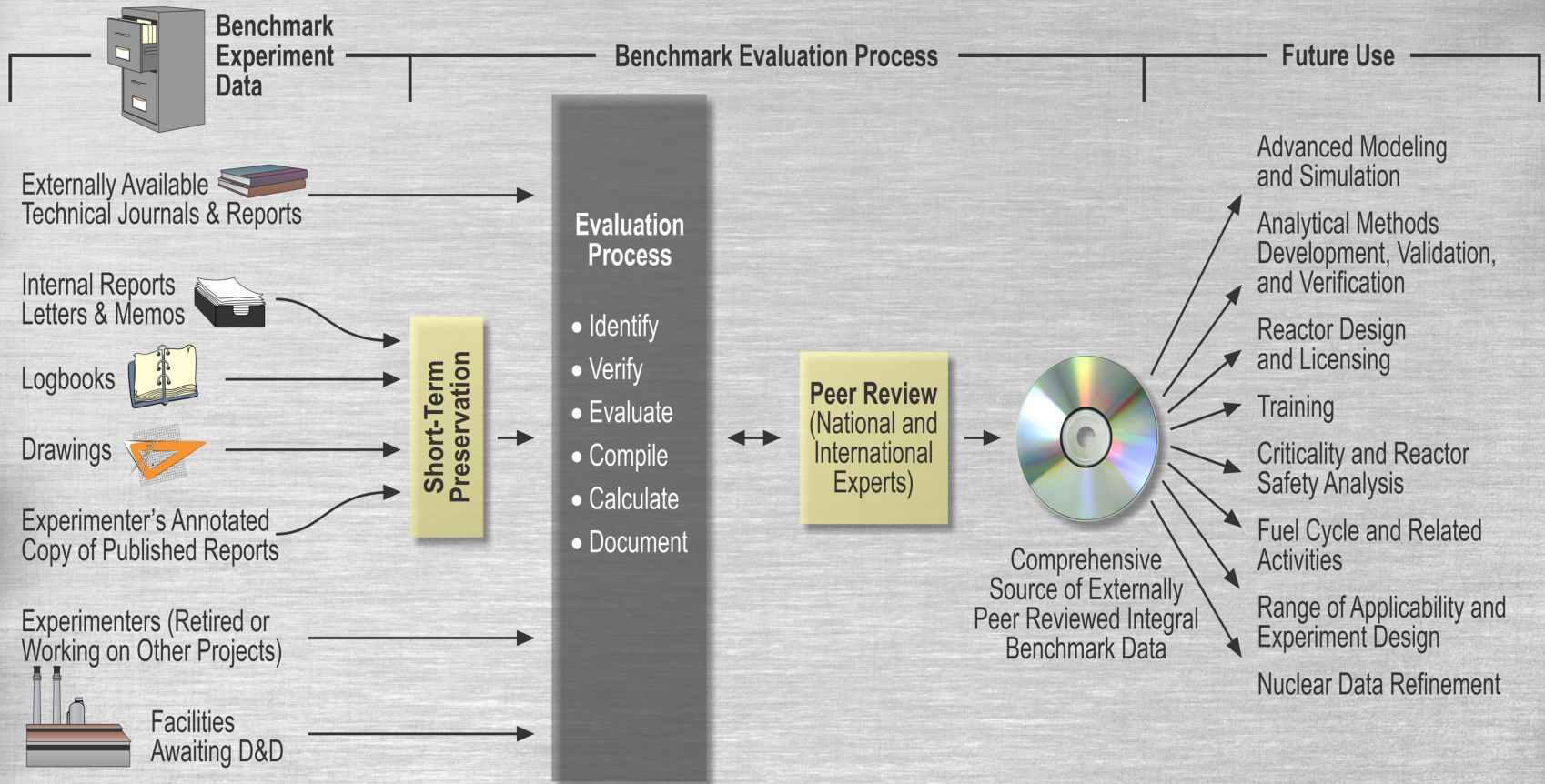
<https://www.oecd-nea.org/science/wpncs/icsbep/>

Breakdown of Current ICSBEP Benchmark Specifications

- **748 plutonium experiments**
 - ❖ 36 compound
 - ❖ 123 metal
 - ❖ 589 solution
- **1426 highly enriched uranium experiments**
 - ❖ 291 compound
 - ❖ 601 metal
 - ❖ 527 solution
 - ❖ 2 mixed compound/solution
 - ❖ 5 mixed metal/solution
- **274 intermediate- and mixed-enrichment uranium experiments**
 - ❖ 156 compound
 - ❖ 53 metal
 - ❖ 65 solution
- **1668 low enriched uranium experiments**
 - ❖ 1464 compound
 - ❖ 82 metal
 - ❖ 119 solution
 - ❖ 60 mixed compound/solution
- **244 ^{233}U experiments**
 - ❖ 6 compound
 - ❖ 11 metal
 - ❖ 227 solution
- **536 mixed plutonium-uranium experiments**
 - ❖ 301 compound
 - ❖ 52 metal
 - ❖ 86 solution
 - ❖ 76 mixed compound/solution
 - ❖ 21 mixed metal/compound
- **20 special isotope experiments**
 - ❖ metal (^{237}Np , ^{238}Pu , ^{242}Pu , & ^{244}Cm)
- **9 criticality-alarm/shielding experiments**
 - ❖ 45 unique configurations with numerous dose points
- **10 fundamental physics experiments**
 - ❖ 237 unique measurements such as fission rates, transmission measurements, and subcritical neutron multiplication measurements



INTERNATIONAL BENCHMARK PROGRAMS



New Content in the Handbook 2019 Edition

➤ 10 Revised Evaluations

- ❖ 9 Minor

- ❖ 1 Significant

➤ 5 New Evaluations



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Summary of Minor Revisions 1-3:

➤ **PU-MET-FAST-003**

- ❖ Removed incorrect reference to PU-MET-THERM-001 in Section 1.1

➤ **PU-MET-FAST-045**

- ❖ Removed bad KENO inputs from Appendix A.1 and accompanying subfolder on the handbook.

➤ **HEU-MET-FAST-085**

- ❖ In Section 1.1, revised to indicate that only six of the 13 evaluated configurations were determined to be acceptable benchmark experiments.
- ❖ In Table 18, renumbered the cases properly as Cases 1 through 6.



Summary of Minor Revisions 4-6:

➤ HEU-MET-FAST-096

- ❖ Input decks for Cases 7 and 14 revised and updated in Appendix A.
- ❖ Results for detailed and simple models recalculated and updated in Section 4 results.

➤ LEU-COMP-THERM-048

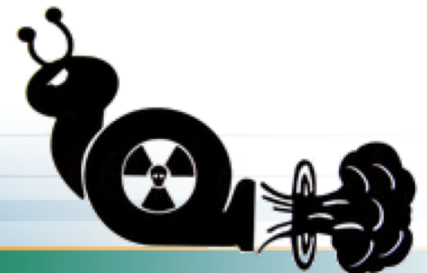
- ❖ KENO input decks in Appendix A.2 are incorrect; text revised to point user to correct input decks found in subfolder on the handbook.

➤ HEU-MET-THERM-012

- ❖ Figure 18 was replaced; the value of 36.46932 cm is now 36.5125 cm.



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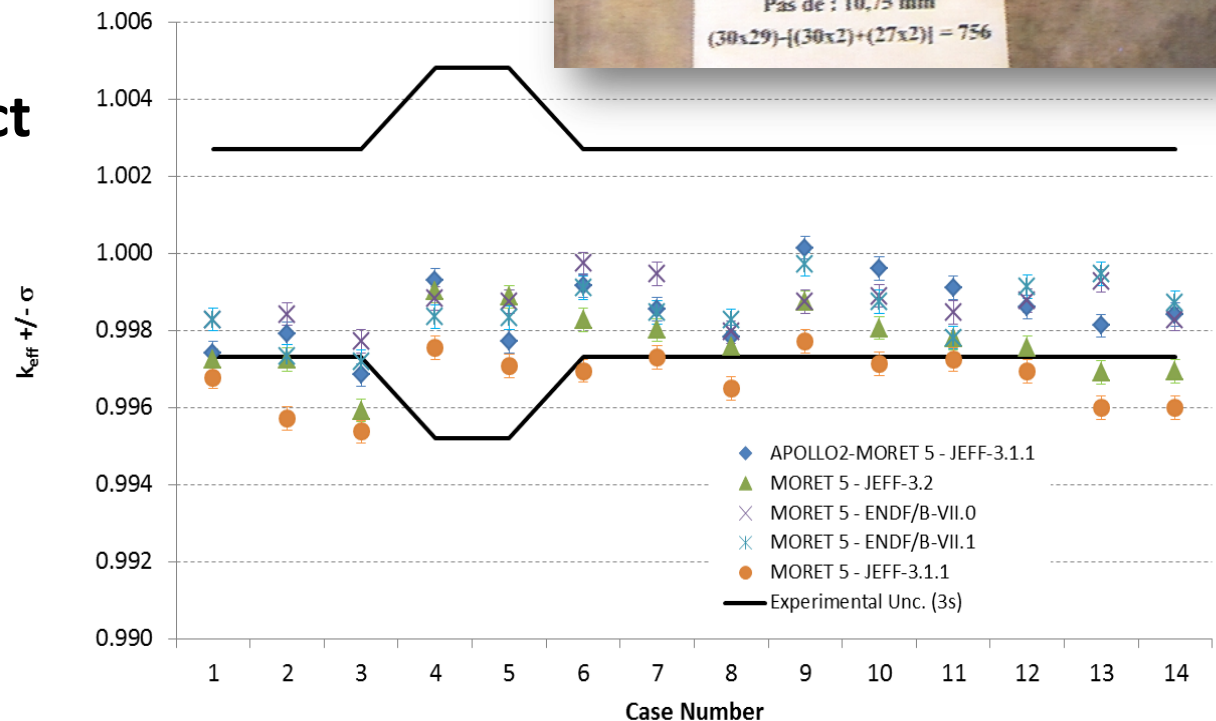
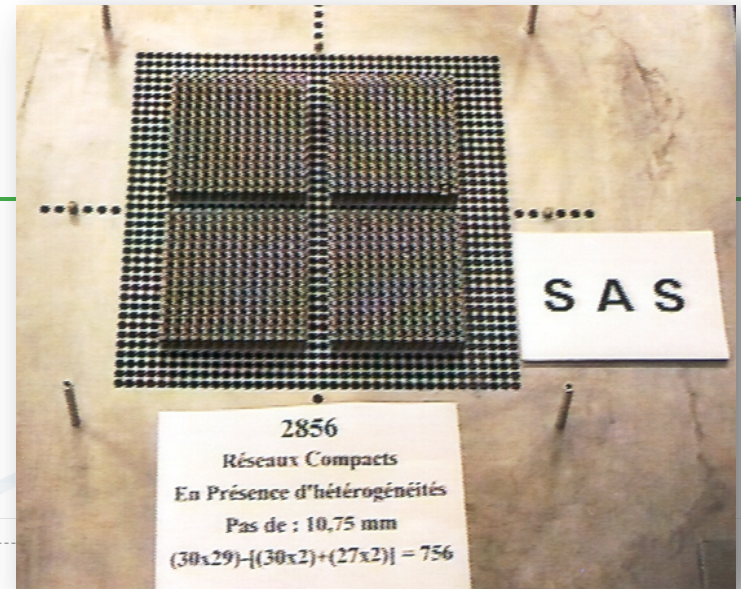
Summary of Minor Revisions 7-9:

- **LEU-COMP-THERM-071**
 - ❖ Additional clarification provided based upon uncertainty analyses updated in LEU-COMP-THERM-073.
- **MIX-SOL-THERM-012**
 - ❖ Table 23 updated to indicate that there are seven cases, not six.
- **LEU-COMP-THERM-072**
 - ❖ Additional clarification provided based upon uncertainty analyses updated in LEU-COMP-THERM-073.



Significant Revision 1: LEU-COMP-THERM-073

- Improved quality of Figures 4 and 12.
- Updated uncertainty analyses.
 - ❖ Minor impact on results.
- Updated Section 4 sample calculations.



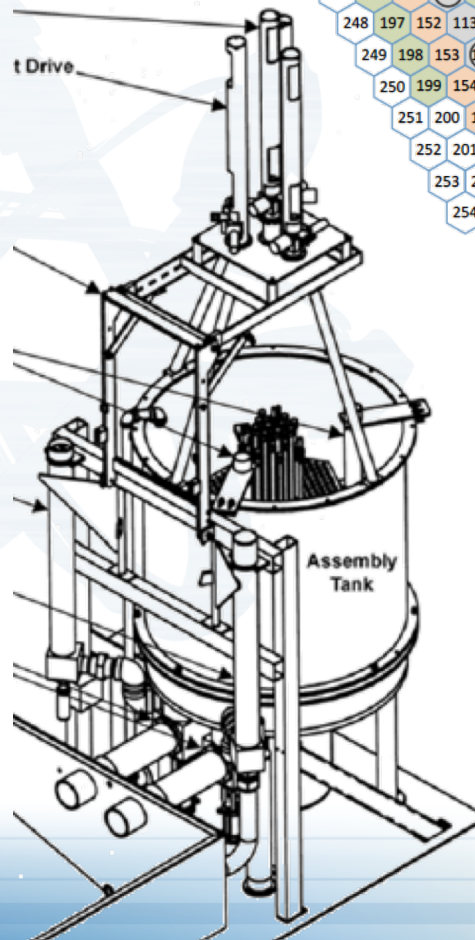
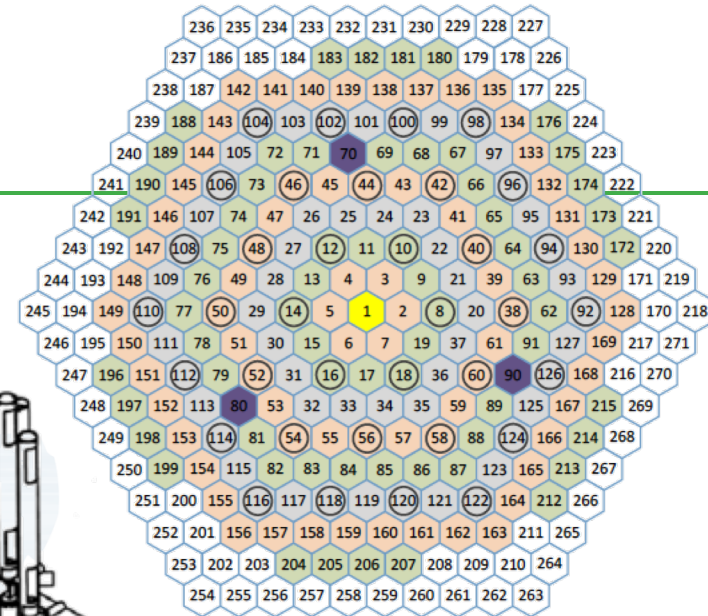
New Approved Evaluation 1: LEU-COMP-THERM-99

➤ Sandia National Lab

- ❖ UO_2 fuel in water
- ❖ 4.31 wt.% U-235
- ❖ 17 critical configurations
- ❖ Ti and/or Al sleeves around fuel

➤ Results

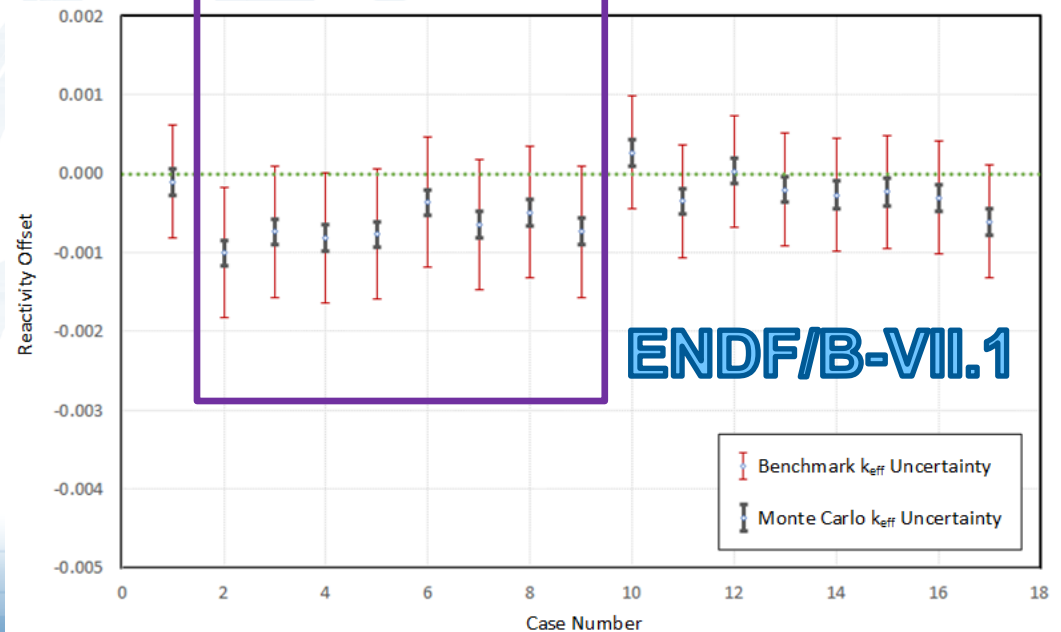
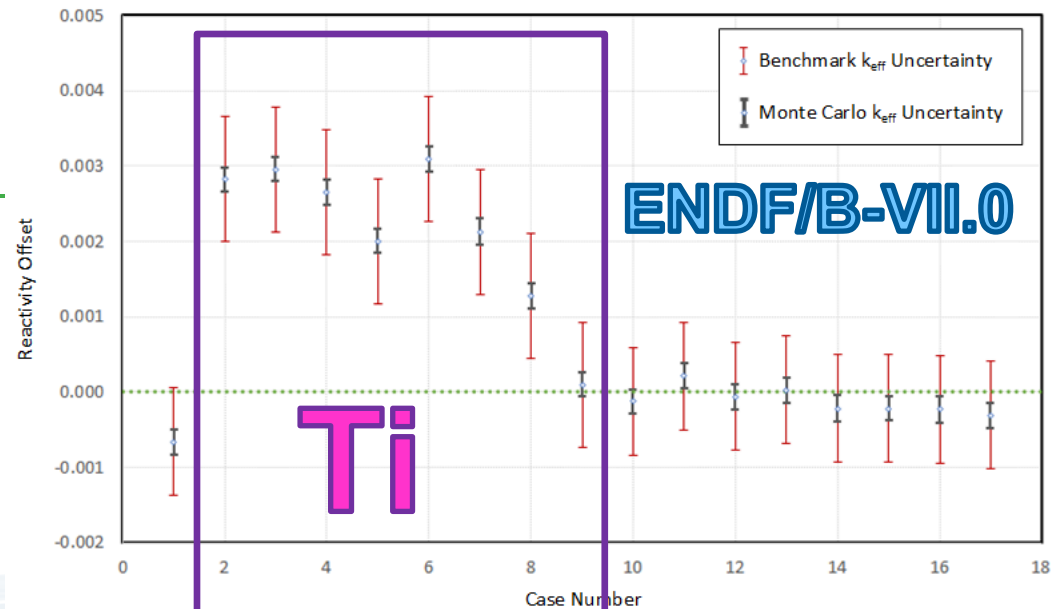
- ❖ Calculations with various modern codes/libraries within 1σ to 2σ .



Titanium Improvements

➤ Results

- ❖ Calculations with various modern codes/libraries within 1σ to 2σ .

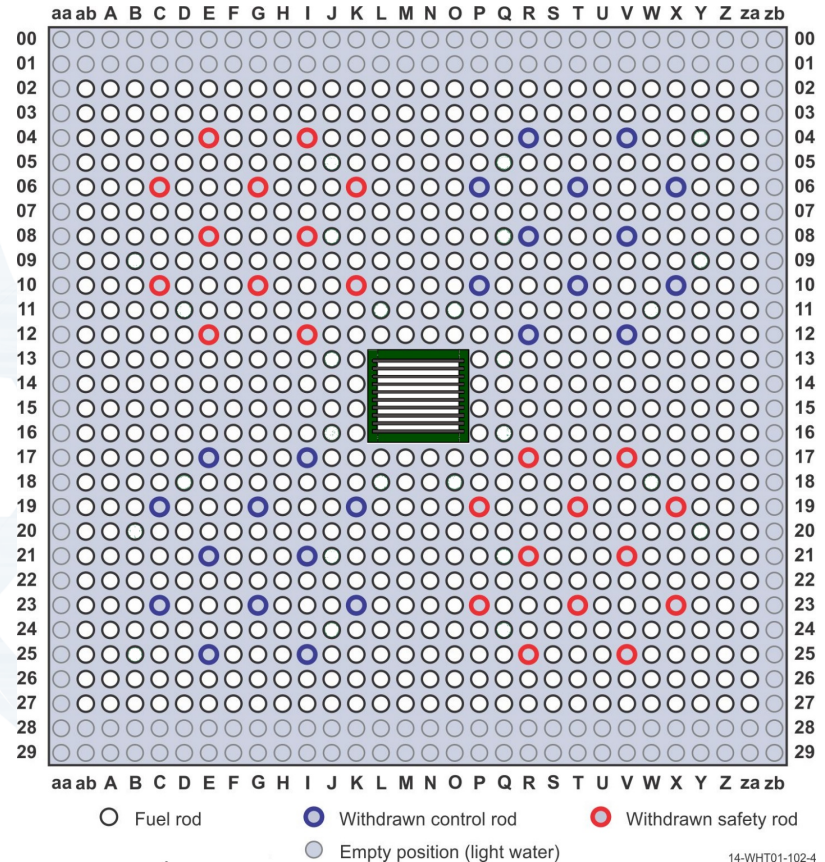


New Approved Evaluation 2: LEU-COMP-THERM-103

➤ MB-01 Reactor

- ❖ IPEN (Brazil)
- ❖ LWR w/ UO_2 rods (4.346 wt. % ^{235}U)
- ❖ U7Mo (19.80 wt. % ^{235}U) plates in core center

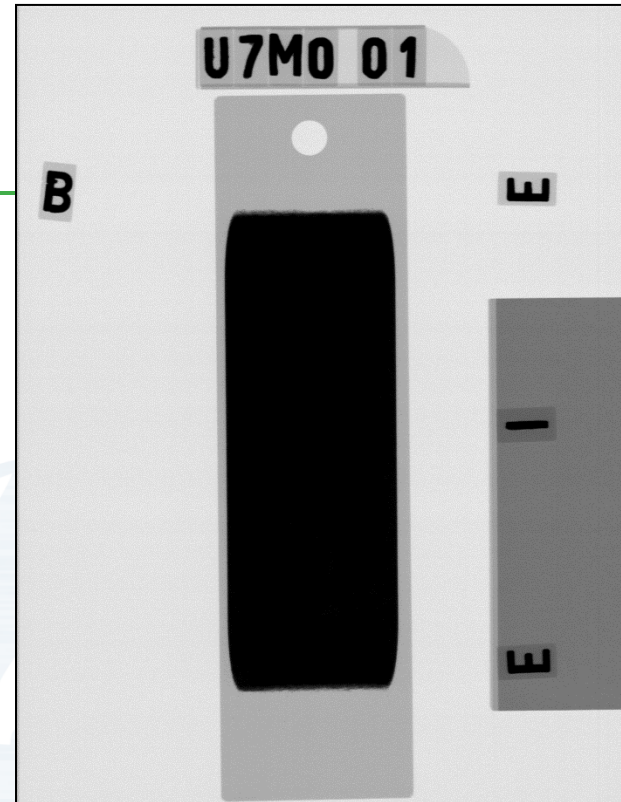
➤ Part of an extensive series of benchmarks for this reactor facility



Results

➤ Evaluated

- ❖ 3 critical configurations
- ❖ MCNP5.1 w/ ENDF/B-VII.0 results within 1σ - 2σ



Code (Cross Section Set) → Case Number ↓	MCNP5 (Continuous Energy ENDF/B-VII.0)	Benchmark Value $k_{eff} \pm \sigma$	(C-E)/E %
C1	0.99994 ± 0.00001	1.0003 ± 0.0008	-0.037 ± 0.080
C3	1.00012 ± 0.00001	1.0003 ± 0.0008	-0.018 ± 0.080
C5	1.00049 ± 0.00001	1.0004 ± 0.0008	0.0089 ± 0.080

New Approved Evaluation 3: LEU-COMP-THERM-104

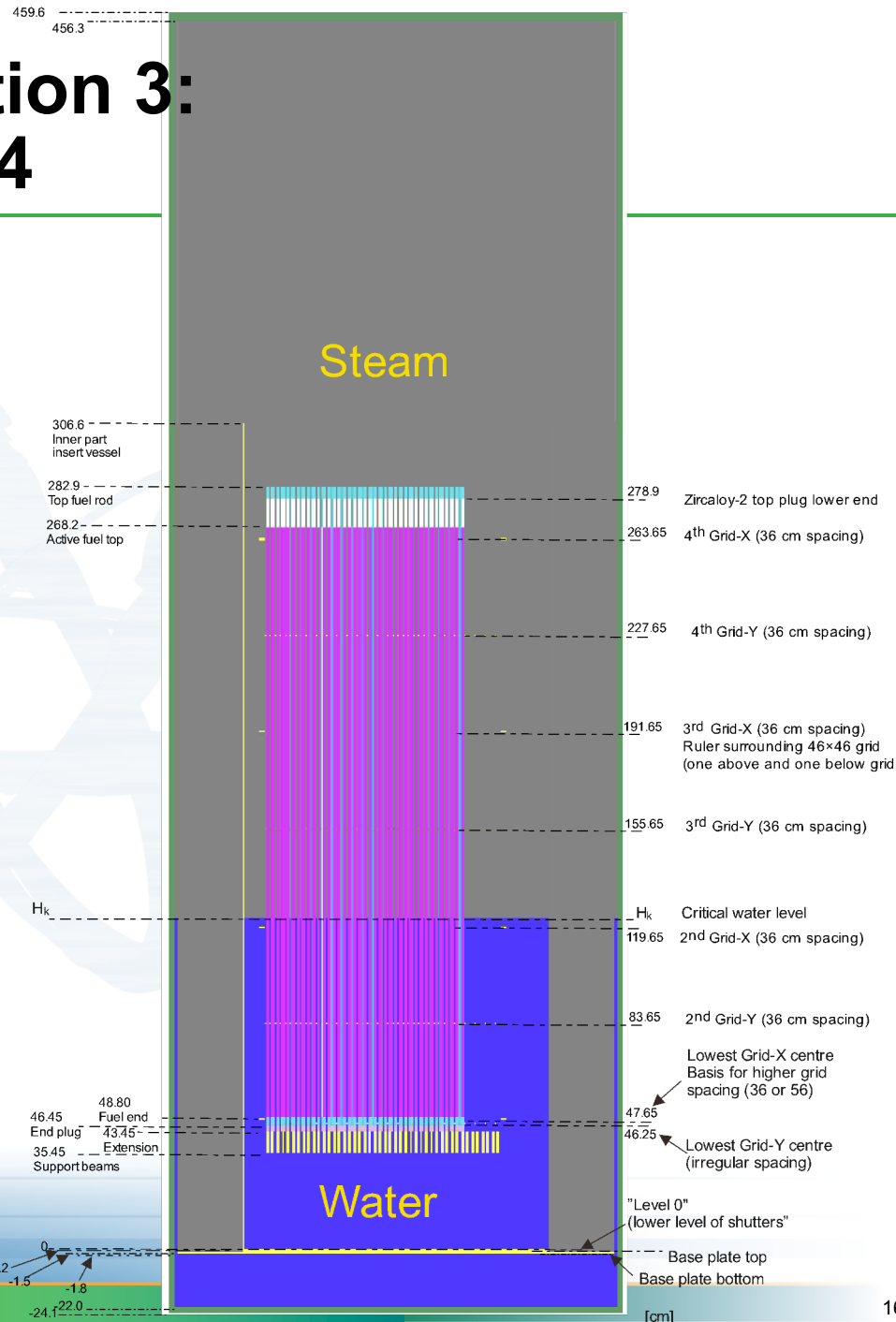
➤ Studsvik KRITZ-1

❖ Sweden

❖ Various LWR
lattices with $T = 20$
to $250\text{ }^{\circ}\text{C}$

❖ Zr-2-clad UO_2 (1.35
wt.% ^{235}U)

❖ Marviken Boiling
Heavy Water
Reactor (BHWR)
fuel



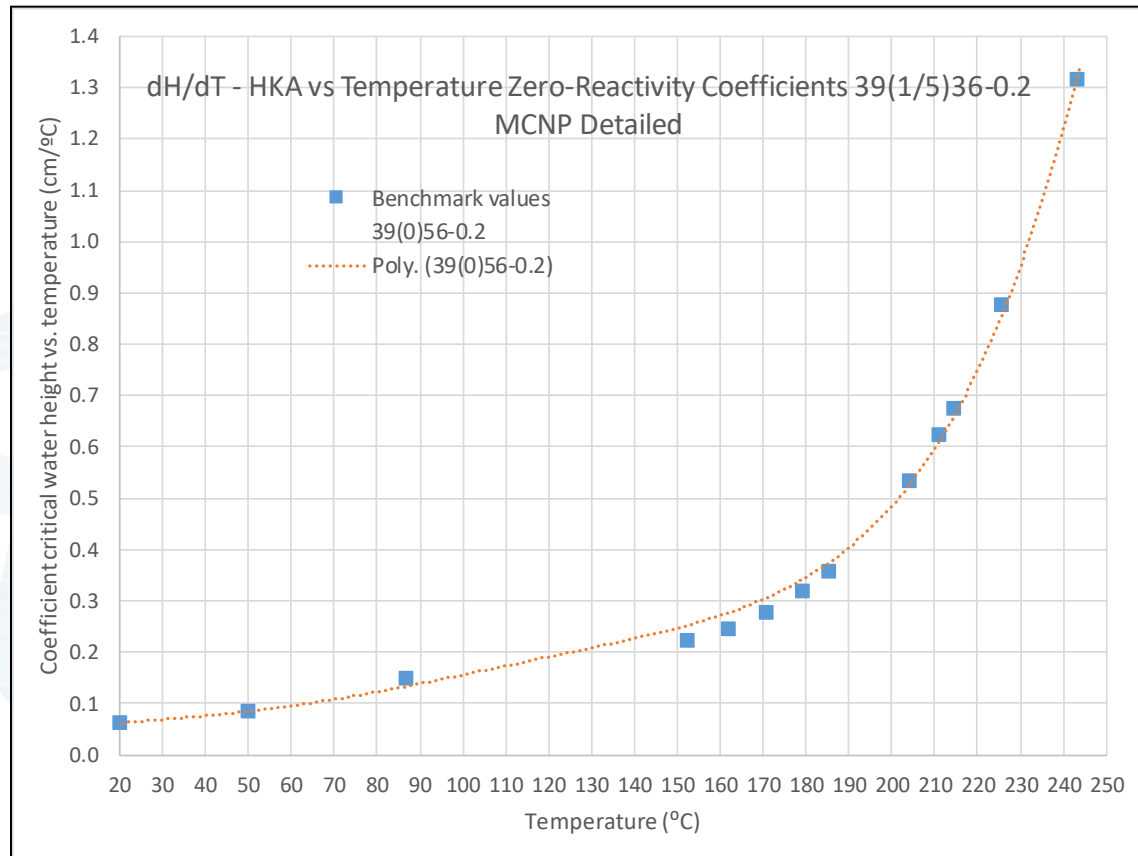
Example Results

➤ Evaluated

- ❖ Criticality
- ❖ Reactivity Worth
- ❖ Reactivity Coefficients

➤ Criticality

- ❖ MCNP6 and ENDF/B-VIII.0
 - Within 0.5 %
- ❖ SCALE 6.2.3 and ENDF/B-VII.1
 - Within 0.7 %
- ❖ MONK 11A DEV and ENDF/B-VII.1
 - Within 0.7 %



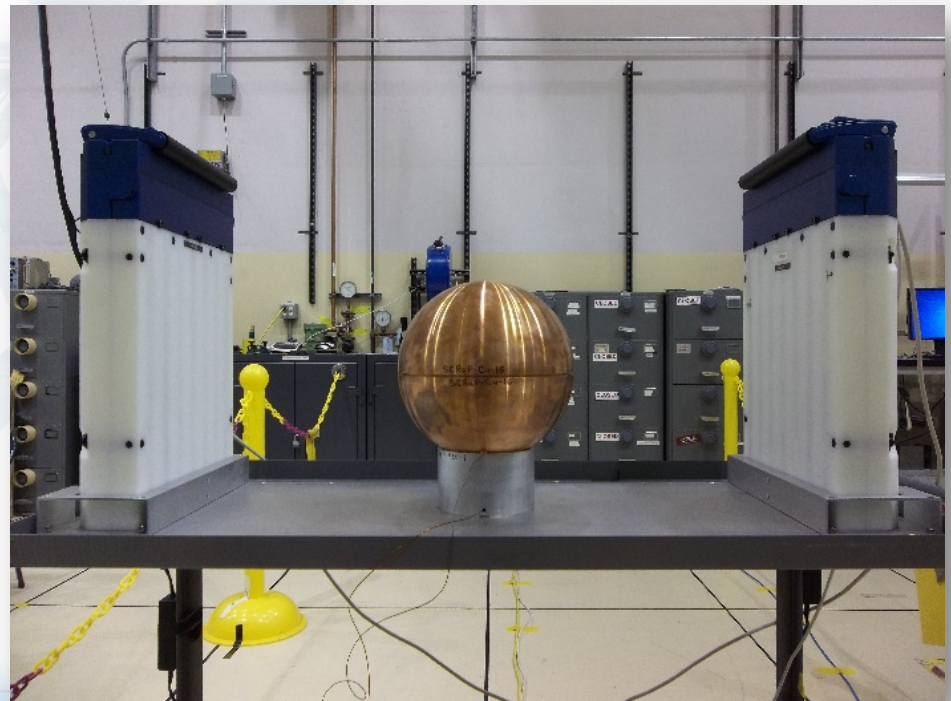
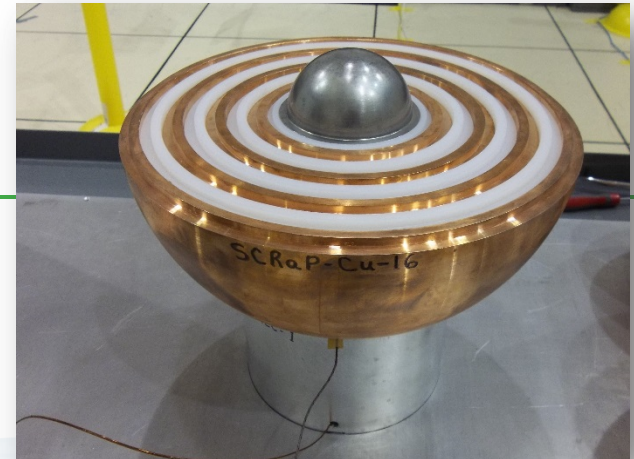
New Approved Evaluation 4: FUND-NCERC-PU -HE3-MULT-003

➤ National Criticality Experiments Research Center (NCERC)

- ❖ 17 subcritical configurations with Cu and/or poly reflected ^{239}Pu ball

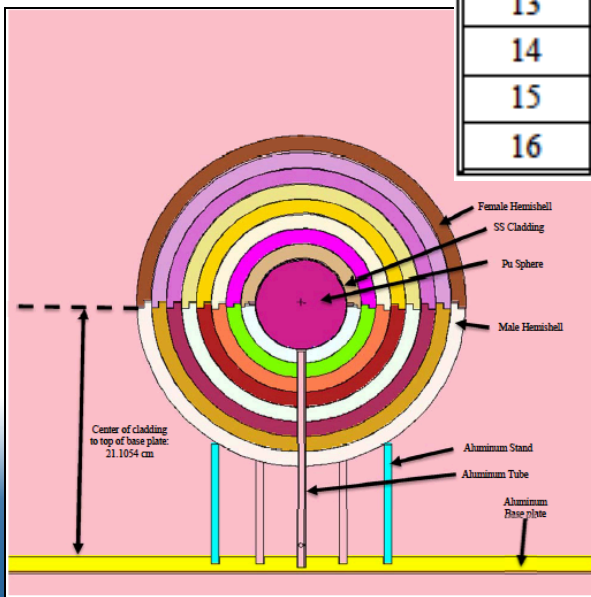
➤ Results

- ❖ MCNP6.2 w/ ENDF/B-VIII.0
 - Mostly within 5%, a few parameters 20%



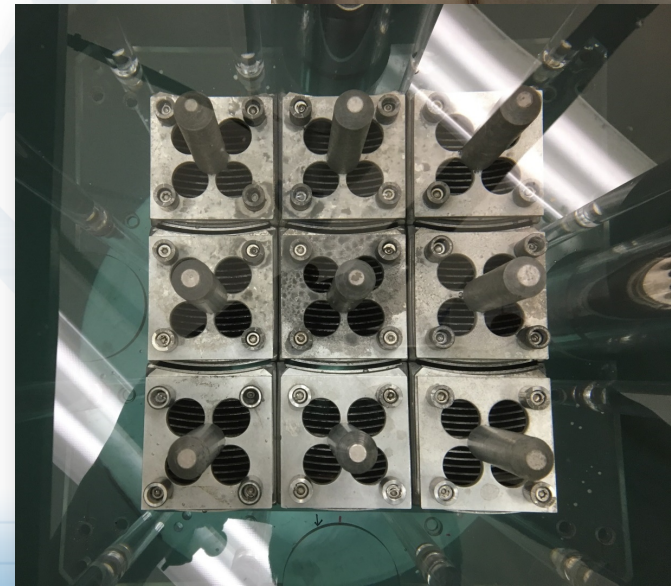
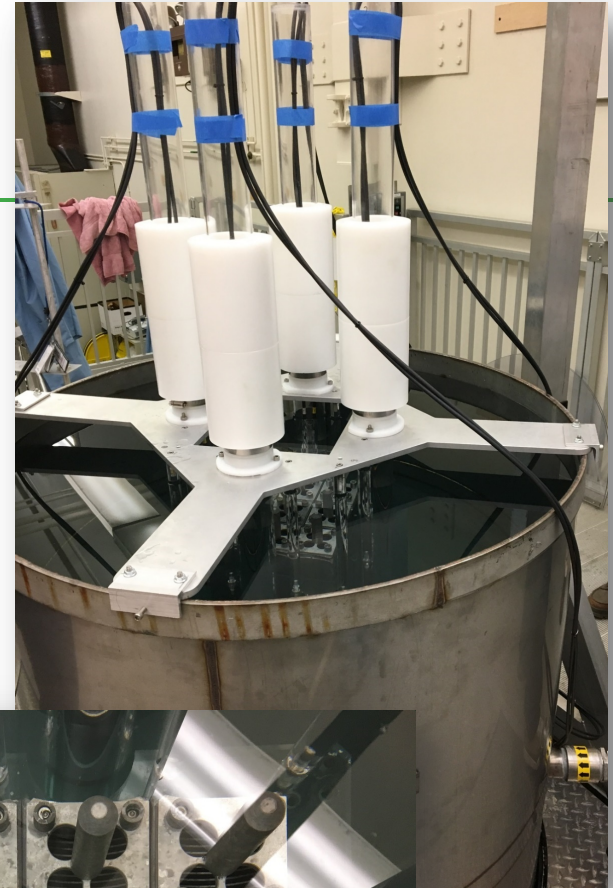
Results

Case	R_1 (cts/s)	σ	(C-E)/E (%)	R_2 (cts/s)	σ	(C-E)/E (%)	M_L	σ	(C-E)/E (%)
0	20206.17	7.65	6.03	7609.01	47.87	4.54	3.07	0.03	-7.18
1	26566.56	9.99	4.36	17000.37	83.20	-1.73	3.85	0.05	-10.64
2	32971.04	12.66	3.26	32207.04	135.87	-4.49	4.67	0.06	-11.11
3	39483.15	15.56	2.20	53962.68	208.02	-8.45	5.38	0.04	-12.92
4	46812.63	19.08	1.28	87442.31	317.06	-10.88	6.15	0.05	-13.68
5	45610.27	18.94	-0.91	87869.39	322.46	-16.70	6.57	0.05	-14.52
6	53547.56	22.53	0.33	128038.05	449.99	-13.80	6.84	0.05	-15.04
7	37729.08	17.09	-0.34	70696.80	262.28	-12.55	7.66	0.06	-12.45
8	38405.81	17.30	-1.38	72637.51	269.09	-14.93	7.53	0.06	-13.02
9	60418.60	26.38	-0.60	182125.03	623.28	-15.52	7.61	0.06	-15.22
10	67364.26	30.32	-1.59	246924.21	831.43	-18.69	8.32	0.07	-16.26
11	74375.98	34.54	-2.51	327024.12	1085.32	-20.66	9.08	0.07	-16.47
12	58721.09	27.86	3.41	212148.84	737.48	-3.34	9.79	0.07	-10.32
13	71205.96	34.38	1.22	328683.50	1131.77	-9.93	10.32	0.08	-12.74
14	74208.35	34.88	-2.64	334398.30	1121.30	-20.61	9.52	0.07	-16.20
15	82460.01	40.20	-5.58	452397.69	1503.97	-28.12	10.45	0.08	-19.38
16	37049.11	17.10	2.13	75458.29	311.84	-6.32	8.76	0.07	-9.61



New Approved Evaluation 5: FUND-LLNL-ALPHAN -U235-MULT-001

- **Inherently Safe
Subcritical
Assembly (IISA) at
LLNL**
 - ❖ 5 configurations
 - ❖ Materials Test
Reactor (MTR) fuel in
water
- **Results**
 - ❖ COG11.3 w/ ENDF/B-
VII.1 and –VIII.0
 - Within < 26 %
 - ❖ MORET5 w/ ENDF/B-
VII.1 and JEFF3.2
 - Within < 17 %



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Sample Results

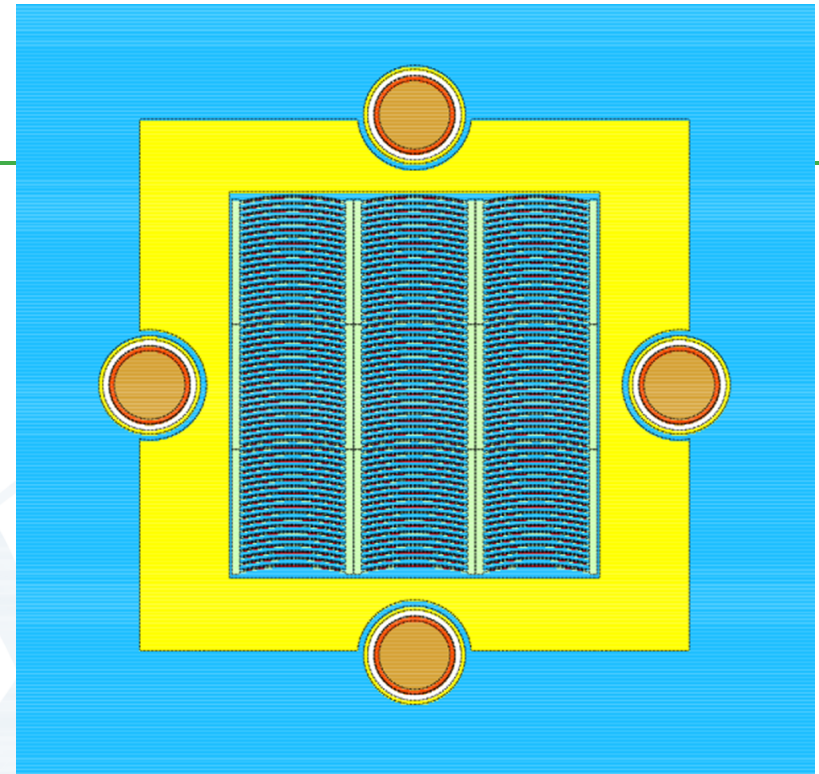
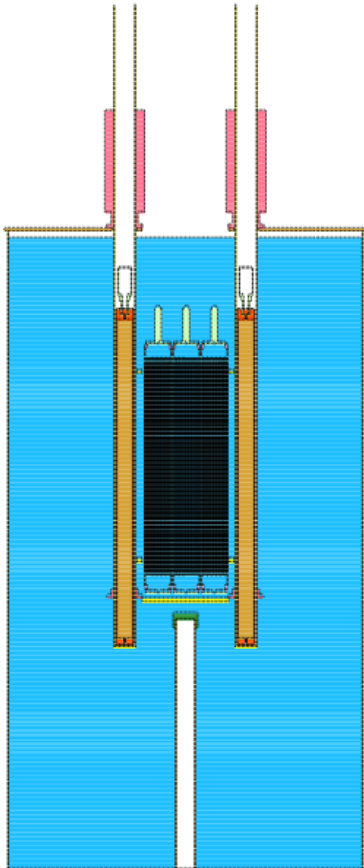


Table 4-2. Calculation Results Using COG11.3 with ENDF/BVIII.0.

Case	Number of Assemblies	R_{2F}	σ	(C-E)/E	R_{3F}	σ	(C-E)/E
1	1	0.04564	0.00029	-0.37%	0.00538	0.00019	-18.67%
2	2	0.10845	0.00054	-3.71%	0.02668	0.00064	-25.30%
3	4	0.39772	0.00165	-8.32%	0.34159	0.00523	-22.95%
4	6	0.91013	0.00399	-8.44%	1.80154	0.02754	-18.63%
5	9	4.50590	0.02958	-8.30%	42.24712	1.01848	-17.14%

Evaluations Planned for Future Publications

➤ Brazil

- ❖ IPEN/MB-01 with Boric Acid

➤ France

- ❖ MIRTE-1
- ❖ Pu Nitrate Annular Cylinders

➤ Japan

- ❖ TRACY Transients
- ❖ Zeus LEU/Pb
- ❖ STACY w/ Debris

➤ Slovenia

- ❖ Lucite-Moderated and -Reflected HEU Foils

➤ United States

- ❖ 7UpCX Experiments
- ❖ GODIVA-IV Revision
- ❖ ISSA Subcritical Multiplicity
- ❖ KRUSTY
- ❖ TEX Experiments
- ❖ BAPL Solution Critical
- ❖ Zeus HEU/Pb
- ❖ Jupiter Pu/Pb
- ❖ University New Mexico AGN Reactor
- ❖ Np Subcritical Measurements
- ❖ HOTBOX
- ❖ BeRP Ball with CH₂/Ni Composite Reflector
- ❖ TRX Critical Experiments



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Conclusions

- **The ICSBEP and IRPhEP continue to provide high-quality integral benchmark data**
- **Valuable for nuclear data testing, uncertainty reduction, criticality safety, reactor physics, advanced modeling and simulation**
- **Data contributed from 26 countries**
- **Enable current and future activities supported by experimental validation**



¿Questions?



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Extra Slides

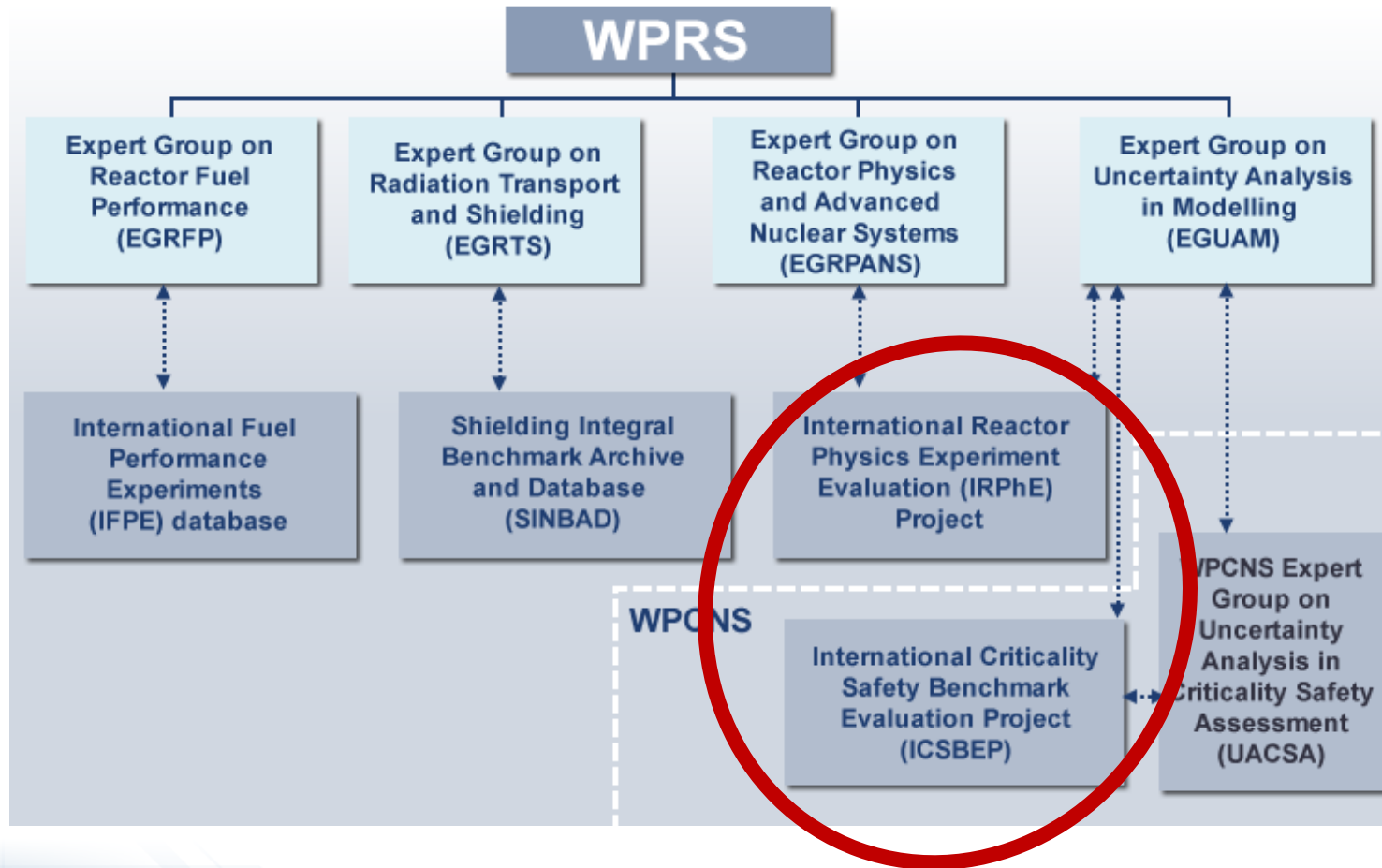


Countries Participating in the ICSBEP & IRPhEP

- Argentina
- Belgium
- Brazil
- Canada
- People's Republic of China
- Czech Republic
- France
- Germany
- Hungary
- India
- Israel
- Italy
- Japan
- Kazakhstan
- Poland
- Republic of Korea
- Russian Federation
- Serbia
- Slovenia
- South Africa
- Spain
- Sweden
- Switzerland
- United Kingdom
- United States of America



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