Latest Benchmark Contributions to the 2015 Edition of the ICSBEP Handbook

Nuclear Data Week 2015
BNL, NY
November 2-6, 2015

Presented by Andrew Hummel (INL)

on behalf of John Bess (INL)

and

Jim Gulliford (OECD NEA)

www.inl.gov

Idaho National Laboratory

Acknowledgments

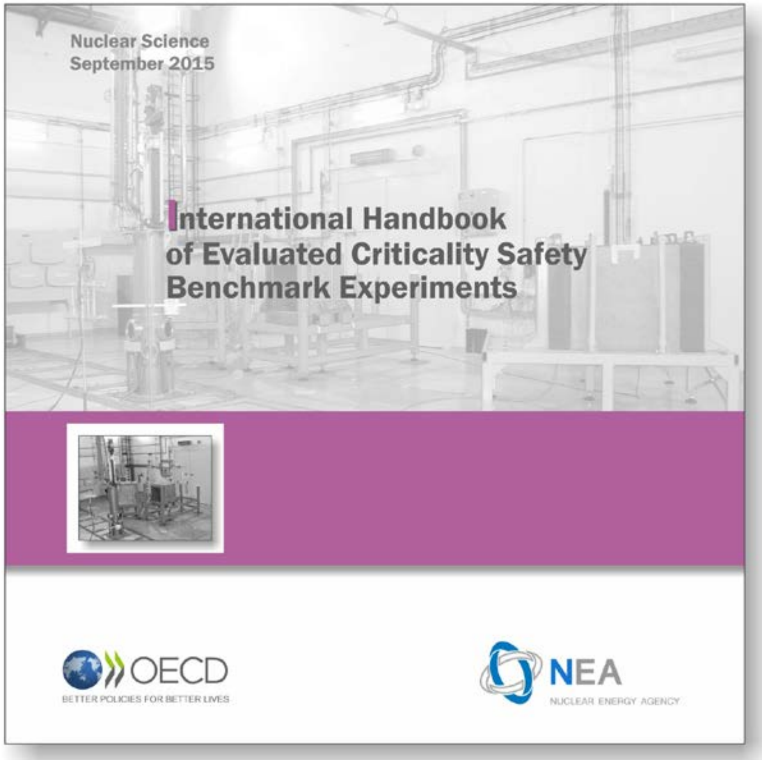
- The authors would like to express their gratitude to all the individuals and countries that have participated in development of the ICSBEP Handbook; especially,
  - Chris White for her years providing high-quality technical drawings
  - Lori Scott for collating and preparing the ever-growing handbook
  - Ian Hill for database development and reviewing everything with a fine-tooth comb

This paper was prepared at Idaho National Laboratory for the U.S. Department of Energy under Contract Number (DE-AC07-05ID14517)

International Handbook of Evaluated Criticality Safety Benchmark Experiments

September 2015 Edition

- 20 Contributing Countries
- ~69,000 Pages
- 567 Evaluations
  - 4,874 Critical, Near-Critical, or Subcritical Configurations
  - 31 Criticality Alarm Placement/Shielding Configurations
  - 207 Configurations with Fundamental Physics Measurements
  - 829 Unacceptable Experiment Configurations



http://icsbep.inl.gov/

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

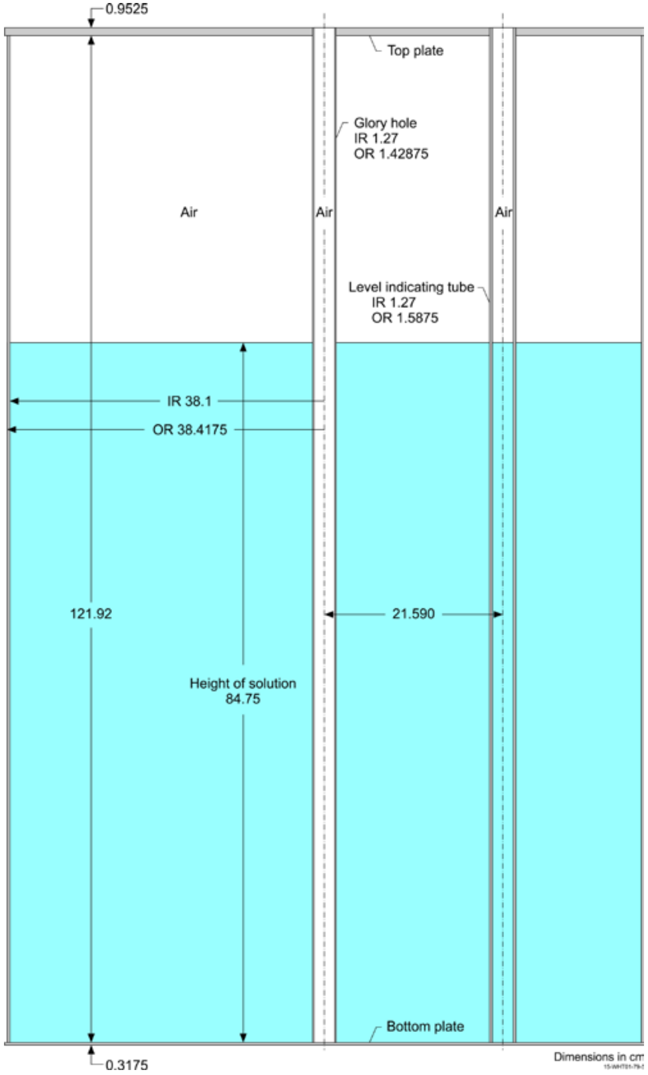
Revisions to Existing Evaluations

Identifier	Title(s)	Revision Notes
HEU-SOL-THERM-020	Unreflected Cylinders of Uranyl-Fluoride Solutions in Heavy Water	Revised Diameter of Level Indicator Pipe
LEU-COMP-THERM-039	Incomplete Arrays of Water-Reflected 4.738-wt.%-Enriched Uranium Dioxide Fuel-Rod Arrays	Corrected a Figure and Updated APOLLO-MORET Calculations
HEU-MET-FAST-099	Fast Neutron Spectrum Potassium Worth Space Power Reactor Design Validation	Adopted from IRPhEP
HEU-COMP-FAST-004	Critical Configurations for Beryllium-Reflected Assemblies of U(93.15)O_2 Fuel Rods (1.506-cm Pitch and 7-Tube Clusters)	Included Two New Critical Configurations for the Evaluation of Potassium Worth
IEU-MET-FAST-020	The FR0 Series 1: Copper-Reflected “Cylinderical” Uranium (20 % ^{235}U) Metal	Updated with Newly Released Data
IEU-MET-FAST-022	The FR0 Experiments with Diluted 20%-Enriched “Cylindrical” Uranium Metal Reflected by Copper	Updated with Newly Released Data
IEU-COMP-THERM-015	Single Cores of 30.14% 235U Enriched UO2/Wax Mixtures – Bare and with Single Reflector Materials	Updated Input Decks

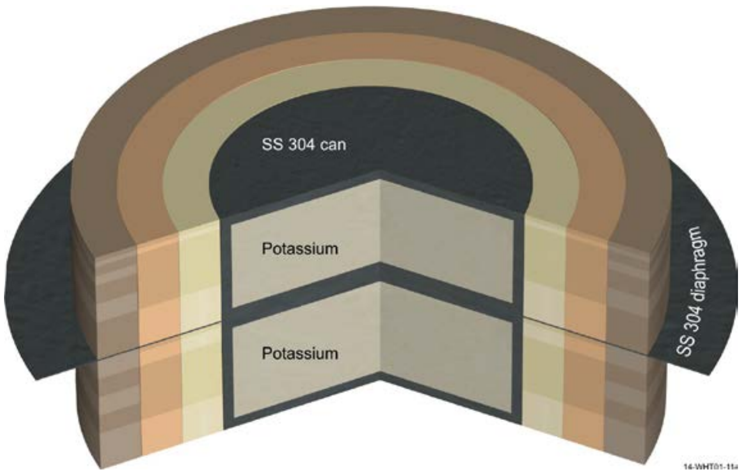
HEU-SOL-THERM-020
Uranyl-Fluoride Solutions in Heavy Water

- Fixed diameter of level indicator tube in models and input decks

Code (Cross Section Set)→ Case Number↓	MCNP6.1 (Continuous-Energy ENDF/B-V)	$\frac{C-E}{E}\%$	MCNP6.1 (Continuous-Energy ENDF/B-VII.1)	$\frac{C-E}{E}\%$
1	1.00249 ± 0.00011	0.59 ± 1.17	0.99123 ± 0.00011	-0.54 ± 1.16
2	1.00455 ± 0.00011	0.90 ± 0.94	0.99593 ± 0.00011	0.03 ± 0.93
3	1.00997 ± 0.00012	1.43 ± 0.80	1.00518 ± 0.00011	0.95 ± 0.80
4	1.00945 ± 0.00011	1.40 ± 0.79	1.00471 ± 0.00011	0.93 ± 0.79
5	1.01433 ± 0.00011	1.85 ± 0.79	1.01467 ± 0.00011	1.88 ± 0.79



HEU-MET-FAST-099
Potassium Fast-Spectrum Validation



C/E-1 ~ -70%

Analysis Code	Neutron Cross Section Library	Calculated			Benchmark Experiment			$\frac{C-E}{E}\%$		
		ρ(¢)	±	σ	ρ(¢)	±	σ			
MCNP6	ENDF/B-VII.1	3.8	±	0.4	11.4	±	1.2	-67	±	5
	ENDF/B-VII.0	3.1	±	0.4				-73	±	5
	JEFF-3.1	2.3	±	0.4				-80	±	4
	JENDL-3.3	2.4	±	0.4				-79	±	4

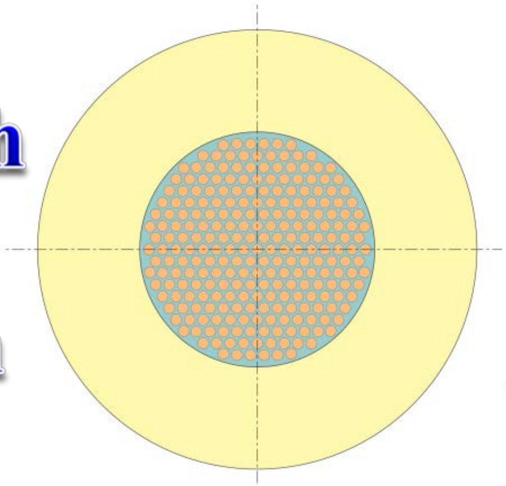
HEU-COMP-FAST-004
Additional Configurations of HEU with Potassium

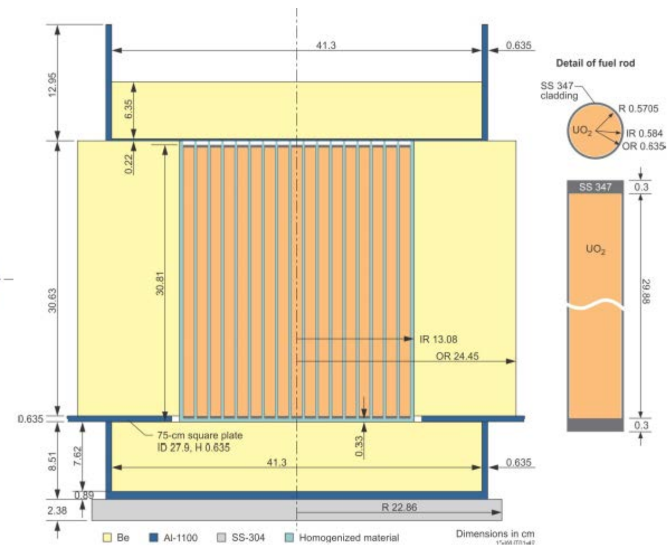
Model	Benchmark			Calculated							
				MCNP5 ENDF/B-VII.0[a]			$\frac{C-E}{E}$[b]	MCNP5 ENDF/B-VII.1[a]			$\frac{C-E}{E}$[b]
	k_{eff}	±	σ	k_{eff}	±	σ		k_{eff}	±	σ	
Case 1	0.9989	±	0.0008	0.99289	±	0.00006	-0.60%	0.99742	±	0.00001	-0.15%
Case 2	0.9998	±	0.0008	0.99463	±	0.00006	-0.52%	0.99930	±	0.00001	-0.05%
Case 3	1.0001	±	0.0008	0.98909	±	0.00001	-1.10%	0.99349	±	0.00001	-0.66%
Case 4	1.0015	±	0.0009	0.98884	±	0.00001	-1.26%	0.99352	±	0.00001	-0.79%

(a) Results obtained using either 100,000 histories for 2150 cycles or 1,100,000 histories and 3150 cycles, skipping the first 150 cycles.

(b) 'E' is the expected or benchmark value. 'C' is the calculated value.

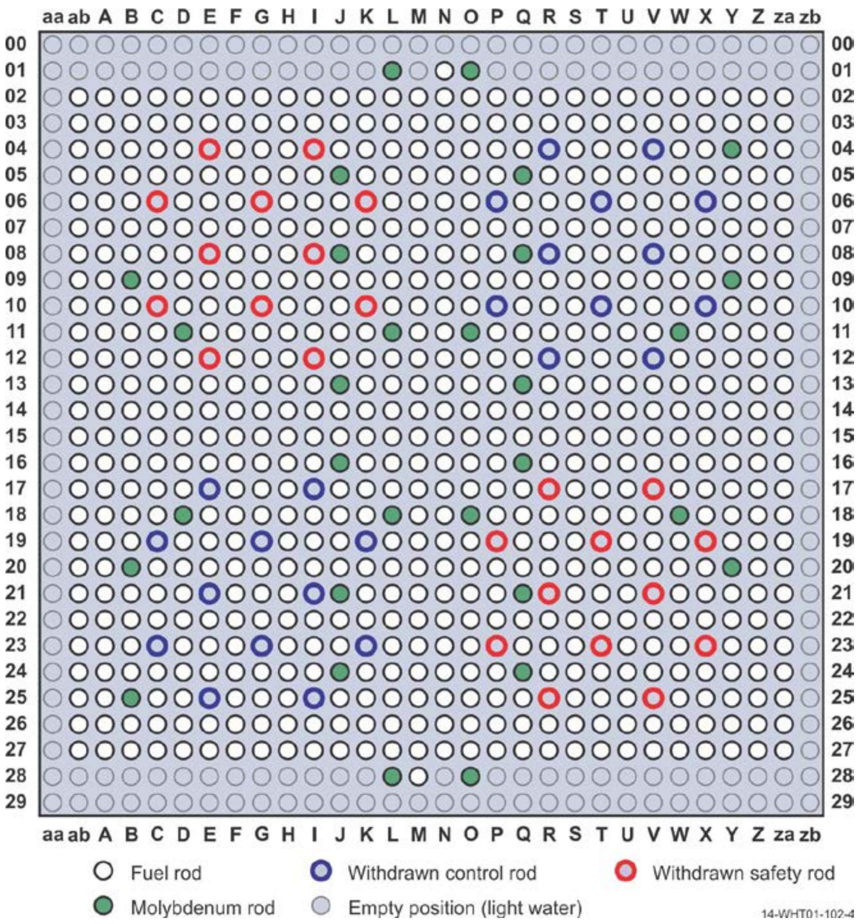
Calculated worth doesn't match measured worth of potassium



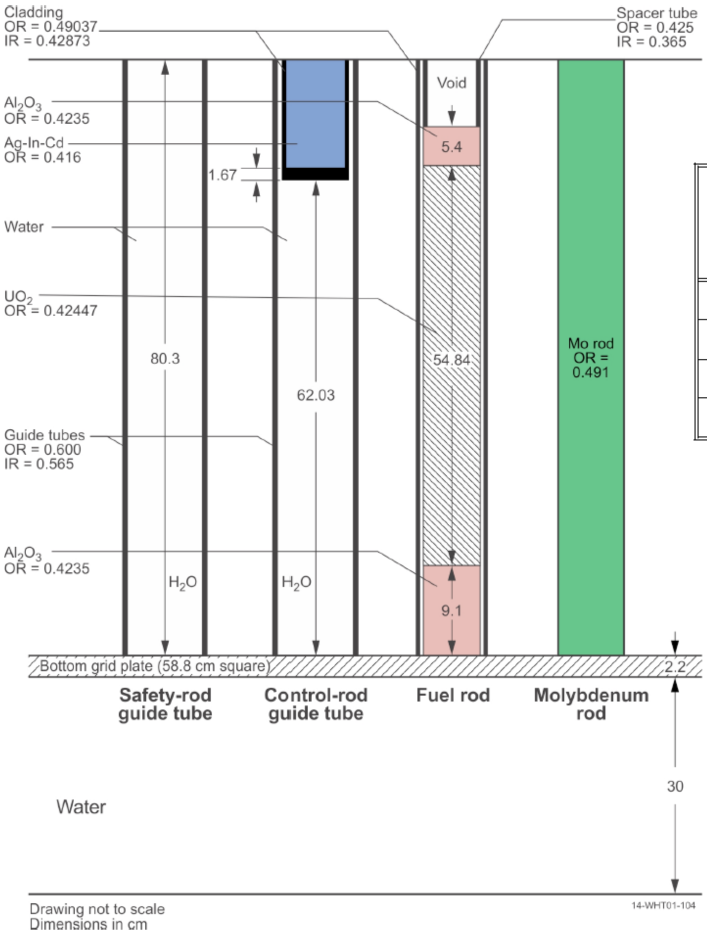


LEU-COMP-THERM-067
IPEN/MB-01 Reactor with Mo Rods

- Critical Loading Configurations of the IPEN/MB-01 Reactor with Fuel and Molybdenum Rods
- IPEN – Brazil
  - Adimir dos Santos
- 4 Configurations
  - 20, 24, 28, 30 Mo Rods



LEU-COMP-THERM-067
IPEN/MB-01 Reactor with Mo Rods

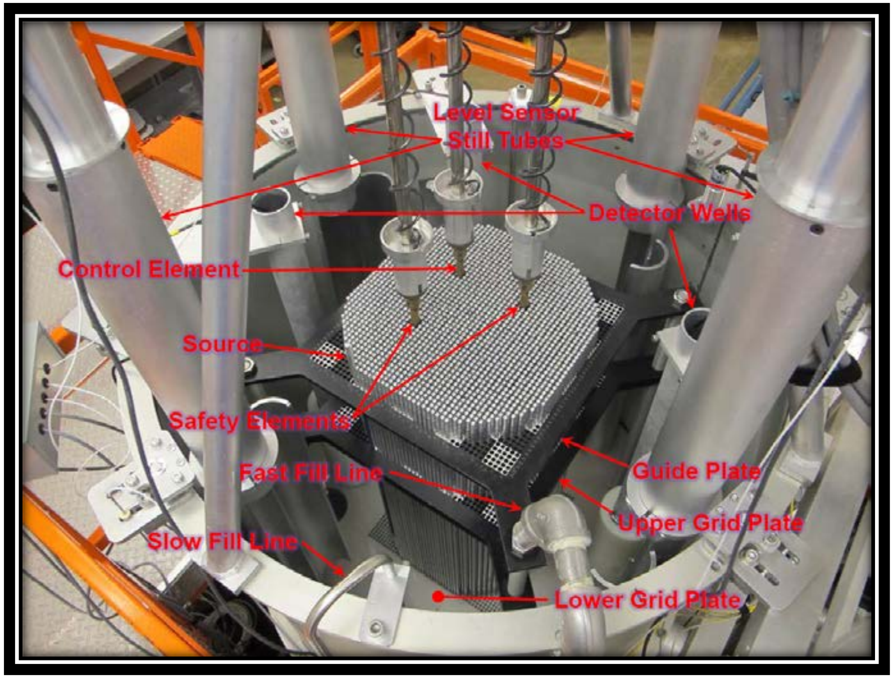


Code (Cross Section Set) → Case Number ↓	MCNP5 (Continuous Energy ENDF/B-VII.0)	Benchmark Value $k_{eff} \pm \sigma$	(C-E)/E %
1	1.00086 ± 0.00004	1.0005 ± 0.0005	0.036 ± 0.048
2	1.00068 ± 0.00004	1.0004 ± 0.0005	0.028 ± 0.048
3	1.00082 ± 0.00004	1.0004 ± 0.0005	0.042 ± 0.048
4	1.00094 ± 0.00004	1.0005 ± 0.0005	0.044 ± 0.048

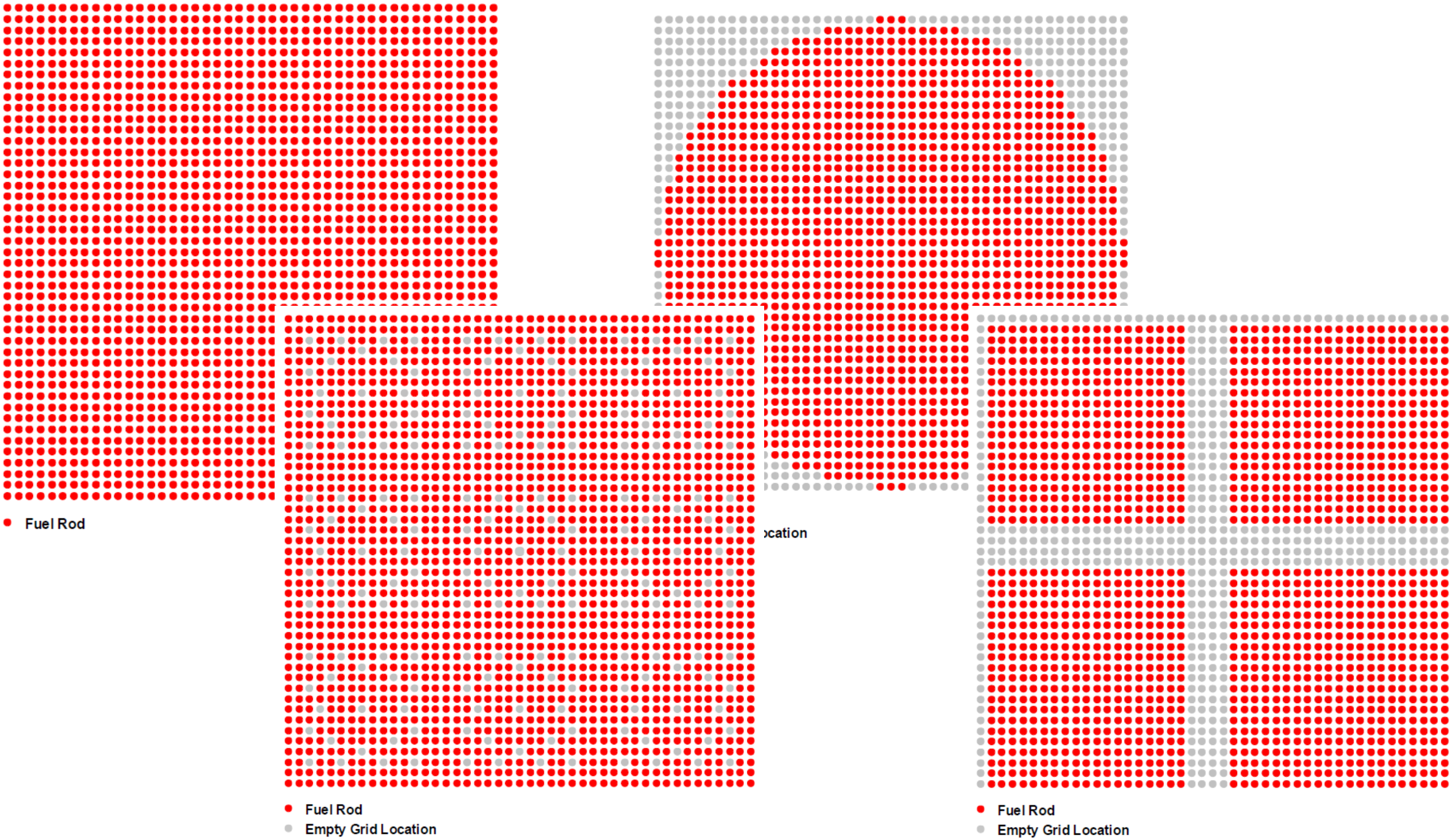
Adds to the comprehensive database of IPEN/MB-01 benchmark evaluations

LEU-COMP-THERM-096
7uPCX Lattice Experiments

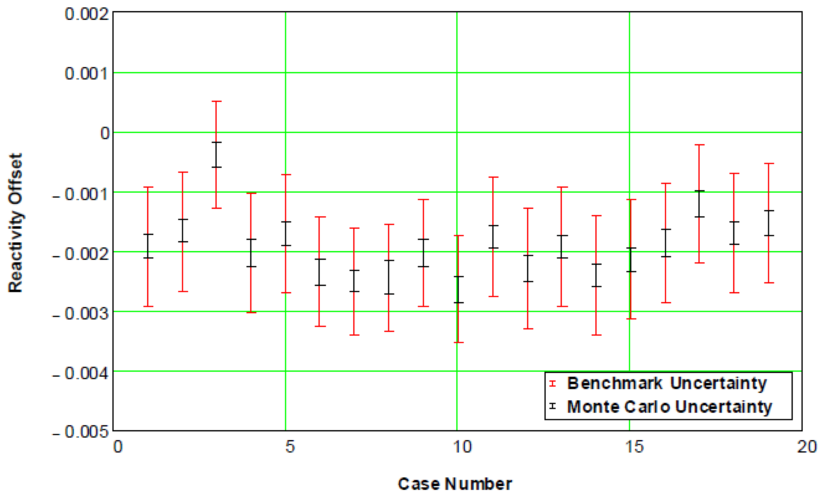
- Partially-Reflected Water-Moderated Square-Pitched $U(6.90)O_2$ Fuel Rod Lattices with 0.67 Fuel to Water Volume Ratio (0.800 cm Pitch)
- SNL – USA
  - Gary Harms
- 19 Configurations
  - Varying holes and gaps



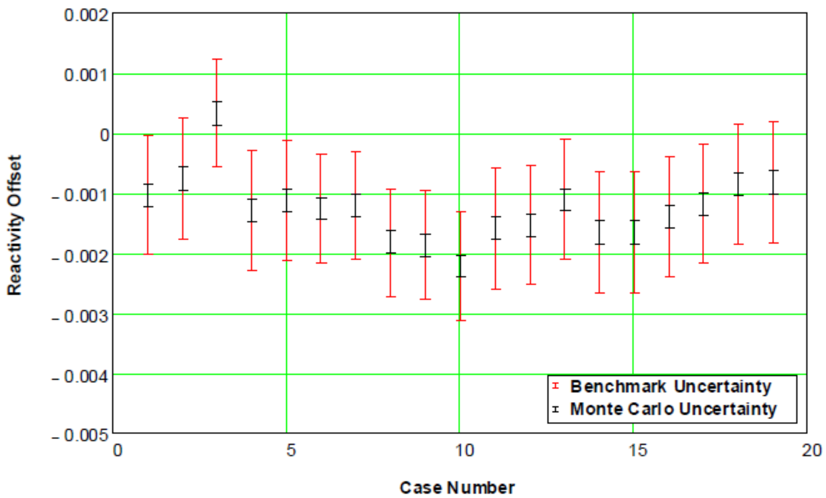
LEU-COMP-THERM-096
7uPCX Lattice Experiments



LEU-COMP-THERM-096
7uPCX Lattice Experiments



KENO-V.a
ENDF/B-VII.0 CE

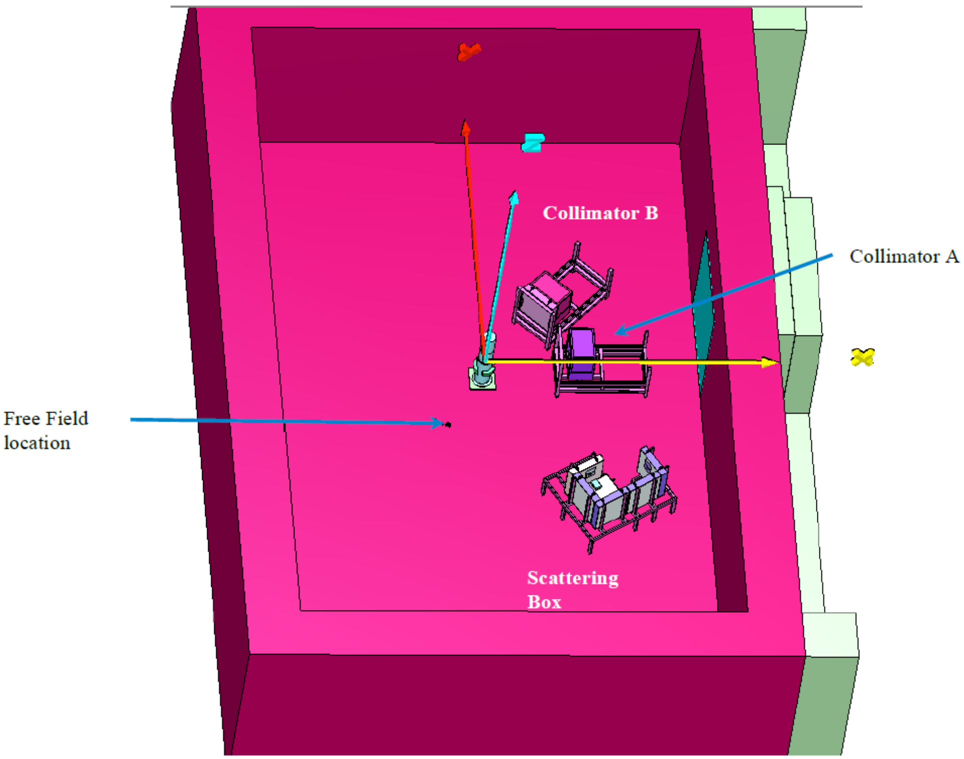


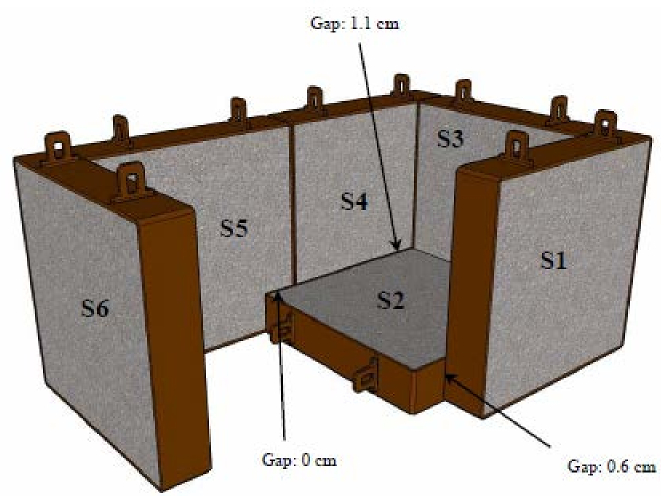
MCNP-6.1
ENDF/B-VII.0 CE

ALARM-TRAN-AIR-SHIELD-001
Neutron Activation and TLD Response to SILENE

- Neutron Activation and Thermoluminescent Detector Responses to a Bare Pulse of the CEA Valduc
- Valduc
  - Thomas Miller, et. al
    - ORNL, USA
    - Plus CEA, France
- 1 Configuration
  - 2 Collimator Boxes
  - Free Field Position
  - 4 Scattering Box Locations

ALARM-TRAN-AIR-SHIELD-001
Neutron Activation and TLD Response to SILENE





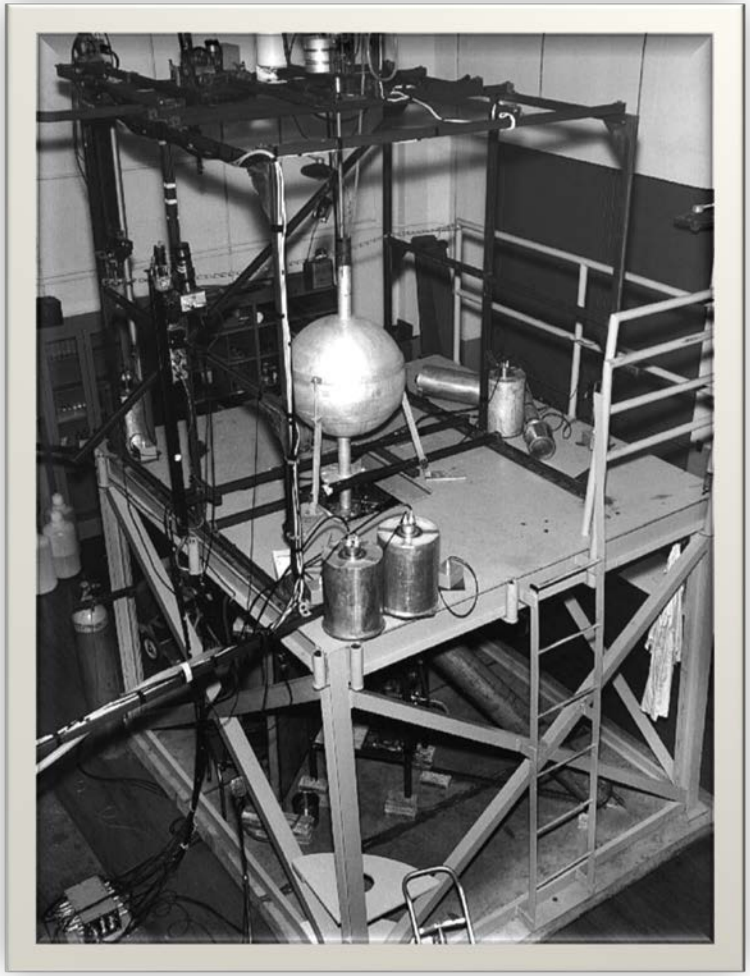
ALARM-TRAN-AIR-SHIELD-001

Position	TLD Type	Dose (Gy)	Monte Carlo Relative Uncertainty	C/E	C/E Relative Uncertainty
Case 1 Collimator A	Al_2O_3	4.811E+00	0.0047	0.7279	0.0786
Case 2 Collimator B	Al_2O_3	6.732E-01	0.0066	0.8209	0.0982
Case 3 Free Field	Al_2O_3	4.172E+00	0.0034	1.1215	0.0788
Case 4 Scattering Box 1	Al_2O_3	4.292E-01	0.0090	0.7400	0.0851
Case 5 Scattering Box 2	Al_2O_3	3.018E-01	0.0078	0.6859	0.0821
Case 6 Scattering Box 3	Al_2O_3	1.194E+00	0.0063	0.6785	0.0784
Case 7 Scattering Box 4	Al_2O_3	1.281E+00	0.0042	0.6848	0.0908

Position	Reaction	Activity (Bq/g)	Monte Carlo Relative Uncertainty	C/E	C/E Relative Uncertainty
Case 1 Collimator A	$^{59}Co(n,\gamma)^{60}Co$	7.498E+01	0.0016	1.1343	0.0663
	$^{115}In(n,\gamma)^{116}In$	9.932E+06	0.0019	1.0902	0.0706
	$^{115}In(n,n'\gamma)^{115m}In$	7.687E+03	0.0023	0.9573	0.0630
	$^{54}Fe(n,p)^{54}Mn$	2.095E-01	0.0020	1.0158	0.0640
	$^{56}Fe(n,p)^{56}Mn$ + $^{55}Mn(n,\gamma)^{56}Mn$	2.411E+03	0.0022	1.0435	0.0641
	$^{24}Mg(n,p)^{24}Na$	6.717E+01	0.0046	1.0993	0.0641
	$^{58}Ni(n,p)^{58}Co$	1.376E+01	0.0019	0.9581	0.0628
Case 2 Collimator B	$^{59}Co(n,\gamma)^{60}Co$	2.848E+01	0.0013	1.2701	0.0819
	$^{197}Au(n,\gamma)^{198}Au$	3.008E+04	0.0019	1.2400	0.0836
	$^{115}In(n,\gamma)^{116}In$	3.642E+06	0.0015	1.2141	0.0847
	$^{115}In(n,n'\gamma)^{115m}In$	1.308E+03	0.0020	1.0936	0.1139
	$^{54}Fe(n,p)^{54}Mn$	3.515E-02	0.0021	1.1304	0.1214
	$^{56}Fe(n,p)^{56}Mn$ + $^{55}Mn(n,\gamma)^{56}Mn$	9.160E+02	0.0017	1.1759	0.0779
	$^{24}Mg(n,p)^{24}Na$	1.196E+01	0.0061	1.1957	0.1338
	$^{58}Ni(n,p)^{58}Co$	2.330E+00	0.0020	1.0991	0.1170
Case 3 Free Field	$^{59}Co(n,\gamma)^{60}Co$	7.782E+01	0.0022	1.1755	0.0660
	$^{197}Au(n,\gamma)^{198}Au$	7.858E+04	0.0037	1.1307	0.0642
	$^{115}In(n,\gamma)^{116}In$	9.442E+06	0.0029	1.0754	0.0706
	$^{115}In(n,n'\gamma)^{115m}In$	6.609E+03	0.0020	0.9635	0.0628
	$^{54}Fe(n,p)^{54}Mn$	1.949E-01	0.0016	0.9941	0.0642
	$^{56}Fe(n,p)^{56}Mn$ + $^{55}Mn(n,\gamma)^{56}Mn$	2.662E+03	0.0029	1.1080	0.0630
	$^{24}Mg(n,p)^{24}Na$	6.549E+01	0.0043	1.1081	0.0644
	$^{58}Ni(n,p)^{58}Co$	1.271E+01	0.0016	0.9786	0.0628
Case 4 Scattering Box 1	$^{59}Co(n,\gamma)^{60}Co$	2.947E+01	0.0014	1.3233	0.0770
	$^{197}Au(n,\gamma)^{198}Au$	2.939E+04	0.0017	1.2174	0.0810
	$^{115}In(n,\gamma)^{116}In$	3.357E+06	0.0014	1.2386	0.0761
	$^{115}In(n,n'\gamma)^{115m}In$	5.321E+02	0.0040	1.0135	0.1015
	$^{54}Fe(n,p)^{54}Mn$	1.155E-02	0.0034	1.0919	0.1214
	$^{56}Fe(n,p)^{56}Mn$ + $^{55}Mn(n,\gamma)^{56}Mn$	1.033E+03	0.0018	1.2183	0.0670
	$^{58}Ni(n,p)^{58}Co$	7.888E-01	0.0033	1.1173	0.1147
Case 5 Scattering Box 2	$^{59}Co(n,\gamma)^{60}Co$	3.396E+01	0.0010	1.3269	0.0711
	$^{197}Au(n,\gamma)^{198}Au$	3.261E+04	0.0015	1.2845	0.0691
	$^{58}Ni(n,p)^{58}Co$	4.244E-01	0.0049	1.4636	0.1232
Case 6 Scattering Box 3	$^{59}Co(n,\gamma)^{60}Co$	5.373E+01	0.0010	1.2201	0.0694
	$^{197}Au(n,\gamma)^{198}Au$	5.310E+04	0.0014	1.1906	0.0679
	$^{58}Ni(n,p)^{58}Co$	3.277E+00	0.0024	1.0115	0.0659
Case 7 Scattering Box 4	$^{59}Co(n,\gamma)^{60}Co$	4.881E+01	0.0010	1.2224	0.0700
	$^{197}Au(n,\gamma)^{198}Au$	4.790E+04	0.0014	1.2376	0.0684
	$^{58}Ni(n,p)^{58}Co$	3.451E+00	0.0031	1.0362	0.0658

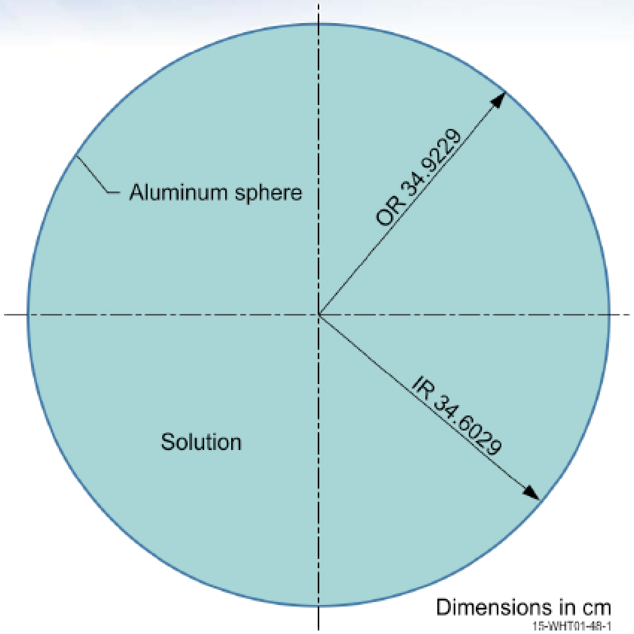
IEU-SOL-THERM-005
U(37 %)O_2F_2 Sphere

- Critical Spherical Dimensions of Aqueous Solution of U(37%)O_2F_2
- ORCEF – USA
  - Tanja Kaiba
    - IJS, Slovenia
- 1 Configuration
  - 69.2-cm-diameter sphere



IEU-SOL-THERM-005 U(37 %)O_2F_2 Sphere

Benchmark model k_{eff}	Uncertainty
1.0041	0.0065

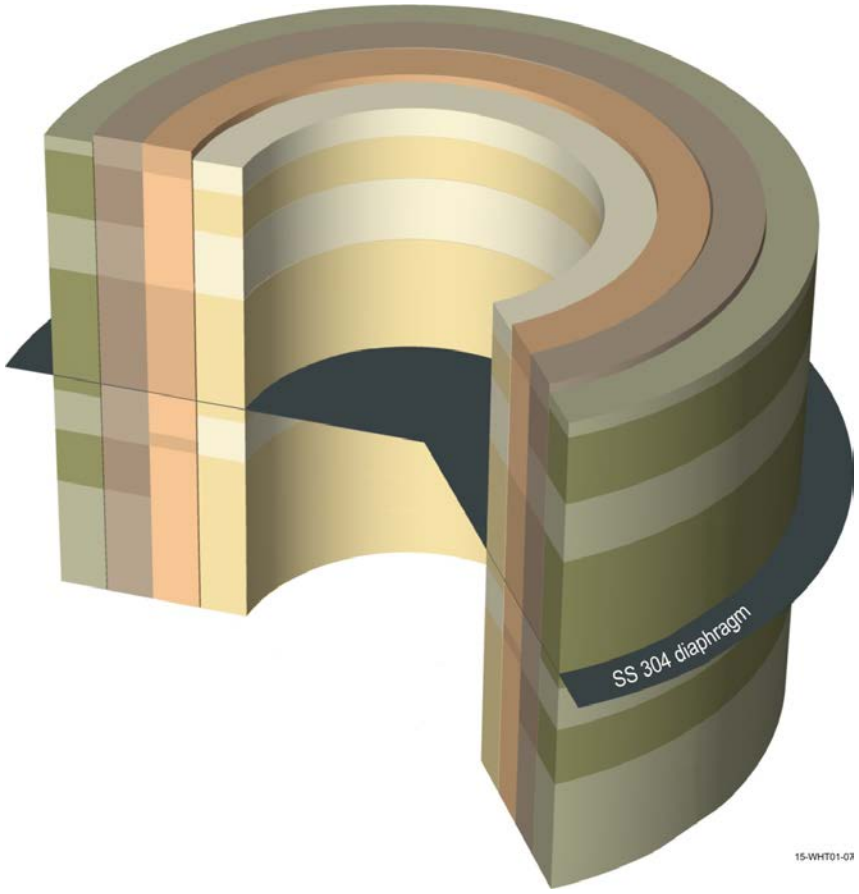


	k_{eff}	$\pm\ \sigma_{MCNP}$	Calculation Bias (Δk_{eff})	Relative deviation (C-E)/E[(a)]
MCNP 6 1.0	0.99940	± 0.00006	-0.00470	-0.5 %
COG 11.1 [(b)]	0.99943	± 0.00013	-0.00467	-0.5 %
KENO V.a [(c)]	0.99934	± 0.00008	-0.00476	-0.5 %

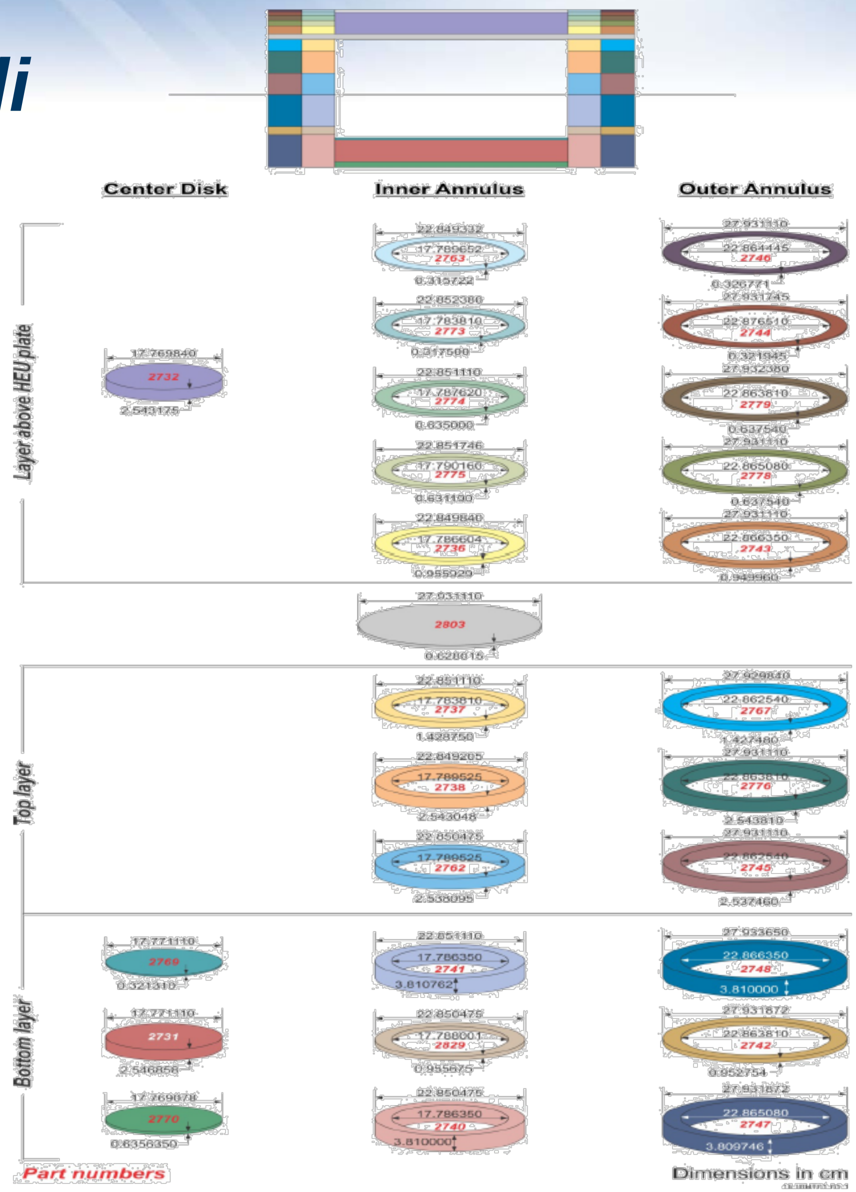
(a) ‘C’ is the calculate value. ‘E’ is the expected or benchmark value.
(b) Acknowledgement to Dr. Soon Sam Kim, Lawrence Livermore National Laboratory.
(c) Acknowledgement to Dr. Soon Sam Kim, Lawrence Livermore National Laboratory.

HEU-MET-FAST-074
Oralloy Bare Metal Annuli

- Oralloy (93.2 ^{235}U) Bare Metal Annuli
- ORCEF – USA
  - Andrew Hummel
    - INL
- 4 Configurations
  - 7”-11”
  - 7”-13”
  - 11”-13”
  - 13”-15”



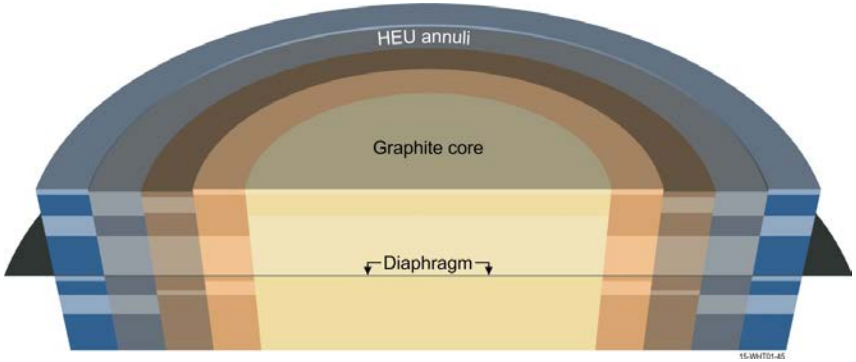
HEU-MET-FAST-074
Oralloy Bare Metal Annuli



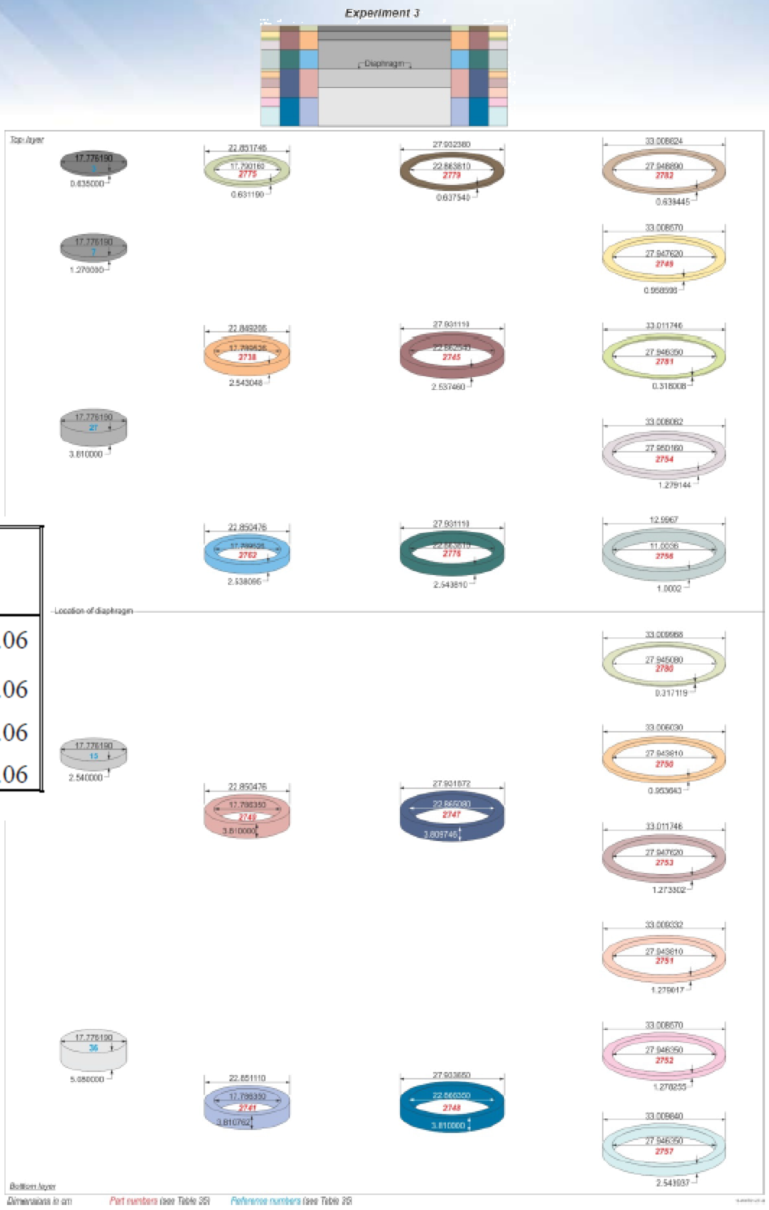
Case	Calculated k_{eff}	±	σ	Benchmark Experiment k_{eff}	±	σ	$\frac{C-E}{E}$ %	±	
1	0.99640	±	0.00002	0.9988	±	0.0005	-0.24	±	0.05
2	0.99629	±	0.00002	0.9979	±	0.0005	-0.16	±	0.05
3	0.99471	±	0.00002	0.9970	±	0.0005	-0.23	±	0.05
4	0.99593	±	0.00002	0.9975	±	0.0005	-0.16	±	0.05

HEU-MET-FAST-077
Oralloy Annuli with Graphite Cores

- Experiments with HEU (93.14 wt.%) Metal Annuli with Internal Graphite Cylinder
- ORCEF – USA
  - Xiaobo Liu
    - INPC/CAEP, China (visiting INL)
- 3 Configurations
  - 7"-13"
  - 7"-15"
  - 9"-15"



HEU-MET-FAST-077 Oralloy Annuli with Graphite Cores

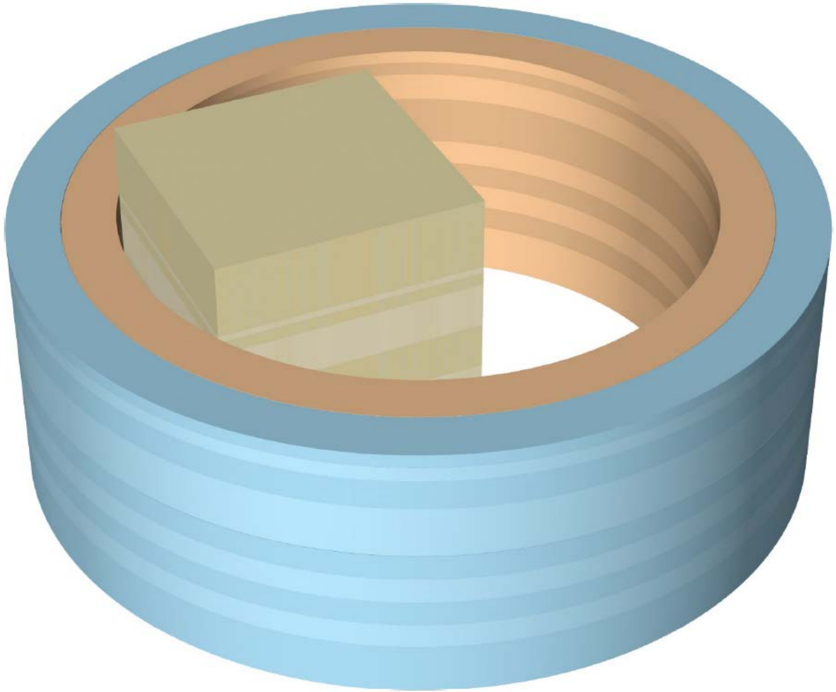


Analysis Code	Neutron Cross Section Library	Calculated			Benchmark Experiment			$\frac{C-E}{E}$ %		
		k_{eff}	±	σ	k_{eff}	±	σ			
MCNP6-1.0	ENDF/B-VII.1	0.99886	±	0.00004	1.0001	±	0.0006	-0.12	±	0.06
	ENDF/B-VII.0	0.99893	±	0.00004				-0.12	±	0.06
	JEFF-3.1[(a)]	0.99568	±	0.00004				-0.44	±	0.06
	JENDL-3.3[(a)]	1.00218	±	0.00004				0.21	±	0.06

(a) Results provided by John D. Bess from Idaho National Laboratory.

HEU-MET-FAST-083 (next handbook publication) *Oralloy Complex Bare Metal Annuli*

- Complex Geometry Bare Oralloy (93.2 ^{235}U) Metal Annuli Experiments
- ORCEF – USA
  - Quinton Beaulieu
    - INL/ISU
- 3 Configurations
  - 11”-15” Annulus
    - 7” Cylinder
    - 5” x 5” Box
    - Split 5” x 5” Box



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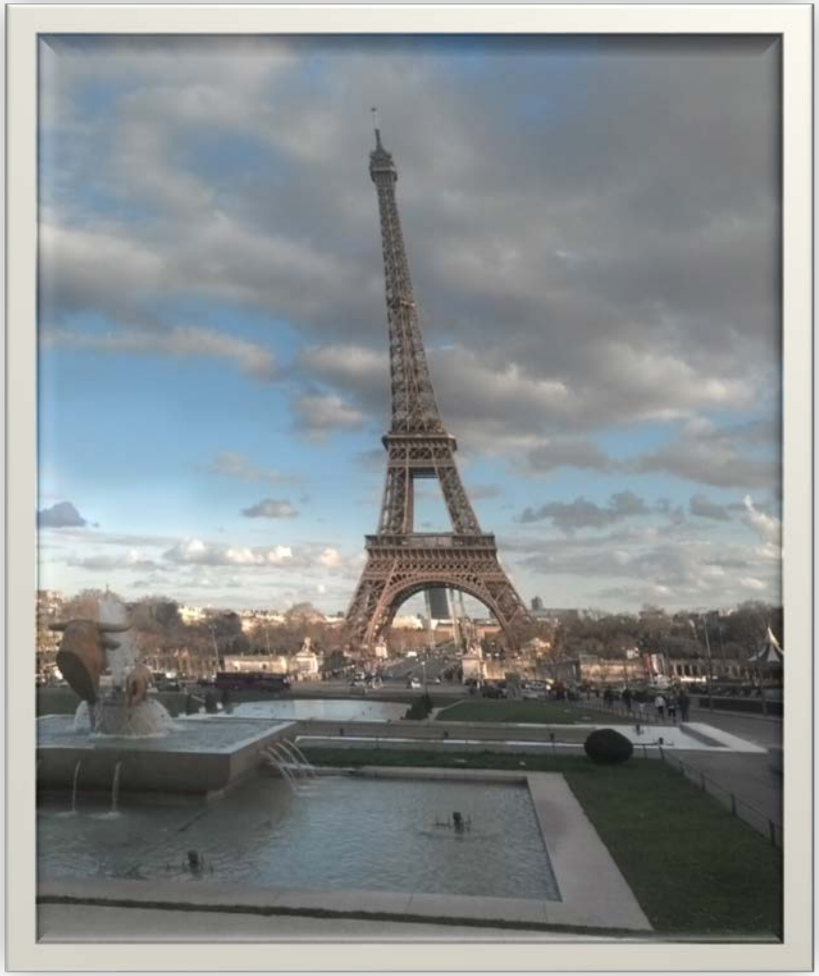
When is the Next ICSBEP Meeting?

- To be held in conjunction with the IRPhEP Meeting
- April 18-22, 2016
- Independent Reviews need completed by end of February 2016
- Let me know if you plan on participating
  - Evaluations
  - Review
  - Meeting Attendance



Plans for the Future ICSBEP Handbook Publications

Subject	Evaluator(s)	Facility-Country
TRX Critical Experiments	Mike Zerkle	BAPL-USA
7uPCX Experiments with Titanium	Gary Harms	SNL-USA
SILENE Pb and Poly Experiments	Thomas Miller, et. al	ORNL-USA and CEA-France
Spherical UF_6 Gas Core Reactor	Margaret Marshall	INL-USA
Westinghouse UO2 Lattice Experiments	Brittney Saenz	INL(intern)-USA
SNAP-10 Water Immersion Criticals	James Totten	INL(intern)-USA
Tungsten-Reflected Plutonium Sphere Subcritical Noise Measurements	Jesson Hutchinson, et. al	LANL-USA
Reevaluation of HEU FLATTOP	Jesson Hutchinson, et. al	LANL-USA
TRACY Supercritical Configuration	Kotaro Tonoike & Yuichi Yamane	JAEA-Japan
SNOOPY 134	Dave Heinrichs	LLNL-USA
GODIVA IV (Revision)	Joetta Goda	LANL-USA
TREAT Minimum Mass Critical Core	John Bess	INL-USA
AGN Reactor	Bob Busch	UNM-USA

Conclusion

- 13 new, revised, or draft benchmarks added into the ICSBEP Handbook (September 2015 Edition)
- 1 new evaluation missed handbook publication and will be available next year
- Validation of computational methods and improvement of integral neutron data
- Look forward to evaluation and inclusion of many more reactor physics benchmarks
- April 18-22, 2016 for the next ICSBEP/IRPhEP Technical Review Meetings in Paris

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Questions?