OECD NEA International Benchmark Projects: ICSBEP & IRPhEP 2018

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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
    - 20 in IRPhEP
  - Without these dedicated individuals, these benchmark projects would not exist.

IRPhEP & ICSBEP
Annual Technical Review Meetings

- October 23-26, 2017
- Washington, DC, USA
- Hosted by US NCSP at GWU

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

International Handbook of Evaluated Criticality Safety Benchmark Experiments

October 2018 Edition

- **22 Contributing Countries**
- **~70,000 Pages**
- **574 Evaluations**
  - **4,916 Critical, Near-Critical, or Subcritical Configurations**
  - **45 Criticality-Alarm-Placement/Shielding Configurations**
  - **215 Configurations with Fundamental Physics Measurements**
  - **838 Unacceptable Experiment Configurations**

NEA
NUCLEAR ENERGY AGENCY

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
  - 1407 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
- 8 fundamental physics experiments
  - 215 unique measurements such as fission rates, transmission measurements, and subcritical neutron multiplication measurements

New Content in the Handbook 2018 Edition

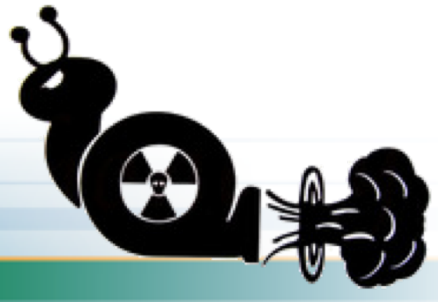
- 37 Revised Evaluations
  - 34 Minor
  - 3 More Notable
- 4 New Evaluations
- Guides
  - Reference Guide
  - Uncertainty Guide
    - IRPhEP

Minor Revisions to the Handbook 1-4:

- **PU-MET-FAST-001**
  - Table 54 referenced correctly in text.
  - Heading of Table 54 corrected.
- **PU-MET-MIXED-001**
  - Updated MCNP sample input decks due to lost particles.
- **PU-SOL-THERM-019**
  - Corrections to Figures 16 and 17: clarification of channel positions.
- **PU-SOL-THERM-039**
  - Corrected the exponent for O of Case 5 in Table 3-6 from “E02” to E-02”.

Minor Revisions to the Handbook 5-9:

- **HEU-MET-FAST-073**
  - Swapped fast and intermediate fission distribution values in Table 36.
- **HEU-MET-FAST-083**
  - Removed the verbiage "(Case 1)" from the headings of Tables 29 and 30.
- **HEU-MET-THERM-032**
  - Table 13 change value 0.0065 to 0.00065.
- **HEU-MET-MIXED-005**
  - Updated MCNP sample input decks due to lost particles.
- **HEU-SOL-THERM-046**
  - Corrections to Figures 16 and 17: clarification of channel positions.

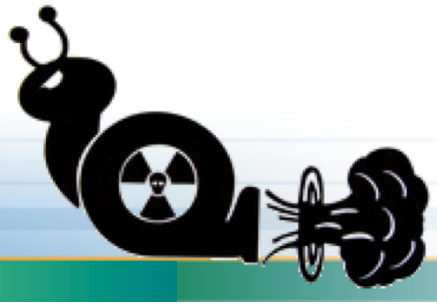


Minor Revisions to the Handbook 10-13:

- **IEU-COMP-FAST-001**
  - Headers of Table 27 for the second and third columns renamed as “Radial Blanket RR1” and “Radial Blanket RR2 & Matrix”, respectively.
- **IEU-MET-FAST-011**
  - Update title, cross-link, and verbiage to match MIX-MET-FAST-008
- **IEU-MET-FAST-013**
  - Replaced the atom density for Mg in Table 18 for AR3 material with the value 1.52717E-4 a/b-cm.
- **IEU-MET-FAST-020**
  - Various corrections and clarifications in the text

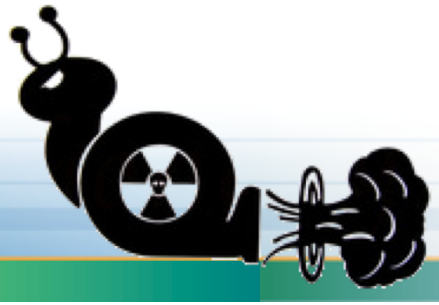
Minor Revisions to the Handbook 14-16:

- **LEU-COMP-THERM-067**
  - Corrected Figure 14: moved Mo rod from position S11 to U11.
- **LEU-COMP-THERM-076**
  - Corrected Figure 29: position of fuel rods and steel baffle shifted three grid positions to the left.
- **LEU-COMP-THERM-080**
  - In the paragraph between Tables 38 and 39, the coordinates in the text have been swapped: “x=25.43 cm, y=7.2 cm” is now “x=-7.2 cm, y=25.43 cm”, and “x=-25.43 cm, y=5.6 cm” is now “x=-5.6 cm, y=*25.43 cm”.



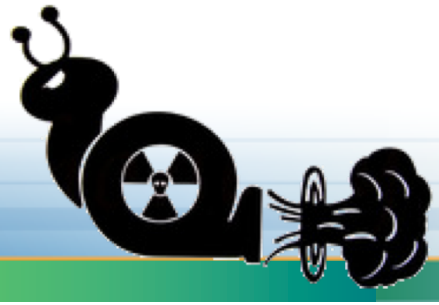
Minor Revisions to the Handbook 17-18:

- **LEU-COMP-THERM-096**
  - Corrected Figure 33: fixed fuel rod lattice arrangement.
  - Corrected Figure 36: fixed alignment for line for "(top of model)".
  - Corrected Figure 56: fixed fuel rod lattice arrangement
  - In the paragraph after Table 40, the coordinates in the text have been swapped: "x=32.385 cm, y=6.4 cm" is now "x=6.4 cm, y=-32.385 cm", and "x=-32.385 cm, y=-6.4 cm" is now "x=-6.4 cm, y=32.385 cm".
  - Updated sample calculations in Section 4 and input decks.
- **LEU-COMP-THERM-097**
  - Corrected Figure 42: aluminum rod outer diameter (OD) is 0.638736 cm.
  - Corrected Figure 52: placement of one fuel rod updated.
  - Corrected Figure 62: added three fuel rods for a total of 1097.



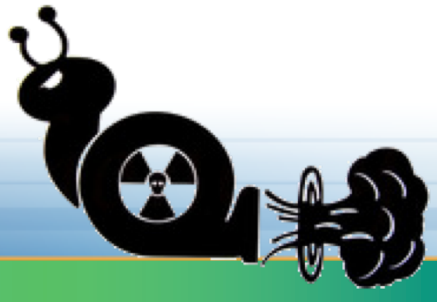
Minor Revisions to the Handbook 19-21:

- **LEU-MET-THERM-003**
  - Corrected Figure 3-5: the dump line radius is 22.066 cm.
- ~~**LEU-MET-THERM-005**~~
- **IEU-MET-THERM-001**
  - Changed Identifier
  - Corrected Figures 1-20, 1-21, 3-5, and 3-6 and Table 1-7: Core 0 has 36 unit cells, not 31.
  - Corrected Figure 3.3 and Table 3-14: now includes control rod positions for Core 0.
- **LEU-MET-THERM-006**
  - Included MCNP6 sample calculations in Section 4 (Table 13.c) and input decks in Appendix A.3. These were provided by Bor Kos from Jožef Stefan Institute, Slovenia.



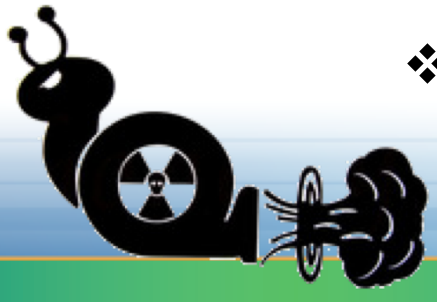
Minor Revisions to the Handbook 22-26:

- **LEU-MISC-THERM-001**
  - Replaced Figure 8.a with Figure 9.a found in LEU-MISC-THERM-006 and -007.
- **LEU-MISC-THERM-002**
  - Replaced Figure 8.a with Figure 9.a found in LEU-MISC-THERM-006 and -007.
- **LEU-MISC-THERM-003**
  - Replaced Figure 8.a with Figure 9.a found in LEU-MISC-THERM-006 and -007.
- **LEU-MISC-THERM-005**
  - Replaced Figure 8.a with Figure 9.a found in LEU-MISC-THERM-006 and -007.
- **LEU-MISC-THERM-007**
  - Corrected Table 13.b: Second “Case 8” should be “Case 9”



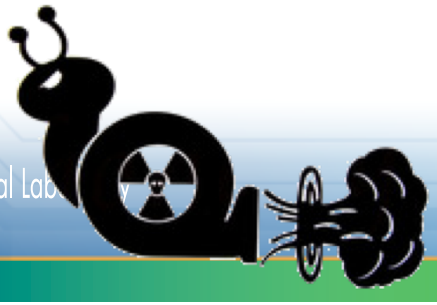
Minor Revisions to the Handbook 27-30:

- **MIX-COMP-THERM-011**
  - Corrected Figure 10: Distance from top of Fuel pin to top of Tie-rod is 34.2 cm, not 34.8 cm.
  - Corrected KENO input decks and updated Section 4 sample calculations.
- **MIX-MET-INTER-001**
  - Updated title, cross-link, and verbiage to match MIX-MET-FAST-008
- **MIX-MISC-THERM-002**
  - Corrected exponent of water densities in Table 19 to be "E-02" instead of "E-01".
  - Corrected Figure 15: distance between Outer tank and Support plate should be 27.34 cm, not 27.14 cm.
  - Corrected Table 15.a: pitch is 2.5 cm, not 2 cm; the solution and stainless steel volume fractions are 18.41 % and 81.59 %, respectively, for Bottom grid outside fuel assembly.
- **MIX-MISC-THERM-003**
  - Various clarifications in the text.
  - Corrected Figures 8, 9, and 10: added grid diameter of 28.5 cm. Corrected critical height position.



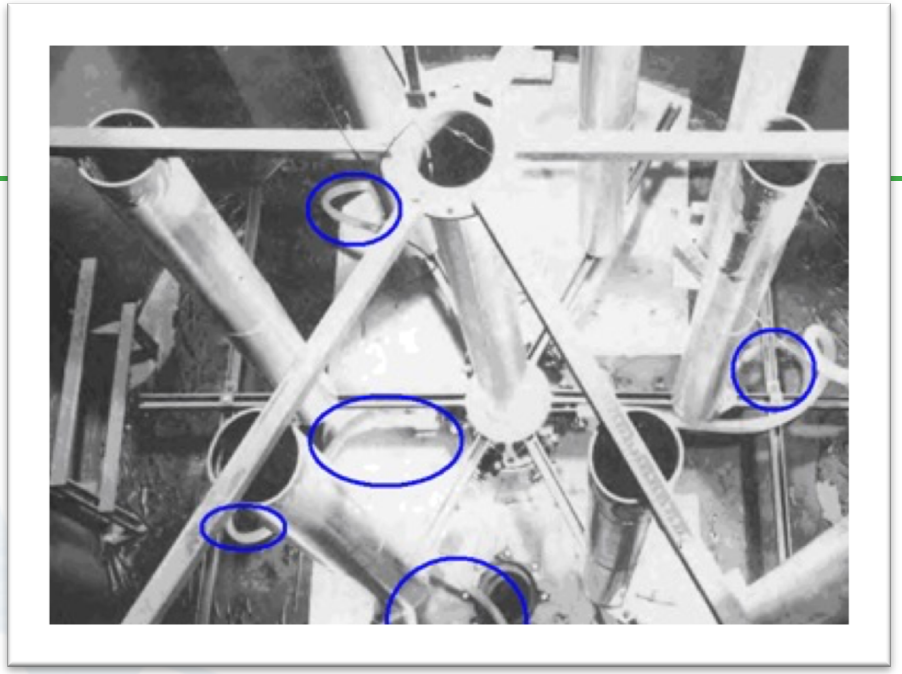
Minor Revisions to the Handbook 31-34:

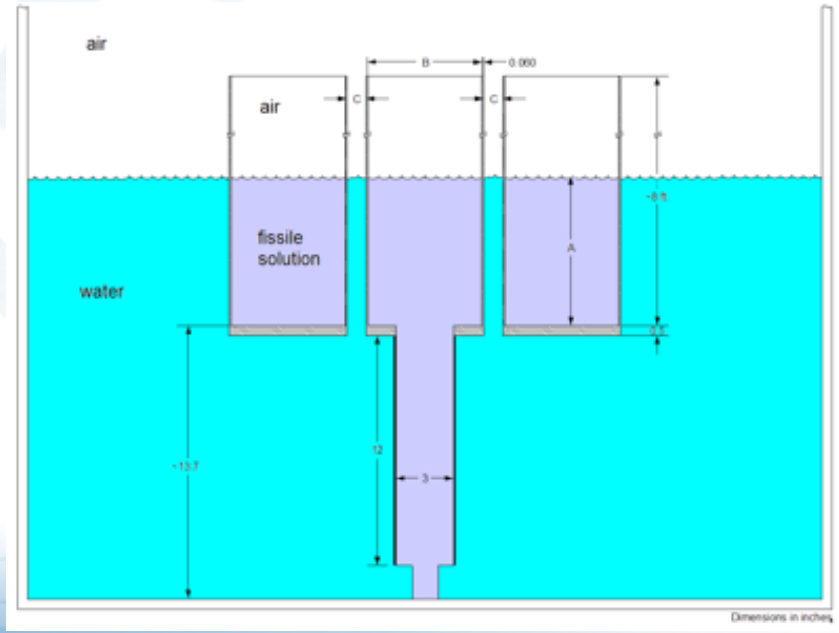
- **FUND-IPPE-VdG-MULT-TRANS-001**
  - Corrected Tables 2, 4, 7, 11, B.4, B.5, B.6: data was shifted across rows
- **ALARM-TRAN-AIR-SHIELD-001**
  - Removed sentence from Appendix A that incorrectly indicated that weight window input files were available on the handbook.
- **ALARM-TRAN-CH2-SHIELD-001**
  - Removed sentence from Appendix A that incorrectly indicated that weight window input files were available on the handbook.
- **ALARM-TRAN-PB-SHIELD-001**
  - Removed sentence from Appendix A that incorrectly indicated that weight window input files were available on the handbook.



Noteworthy Revision 1: HEU-SOL-THERM-048

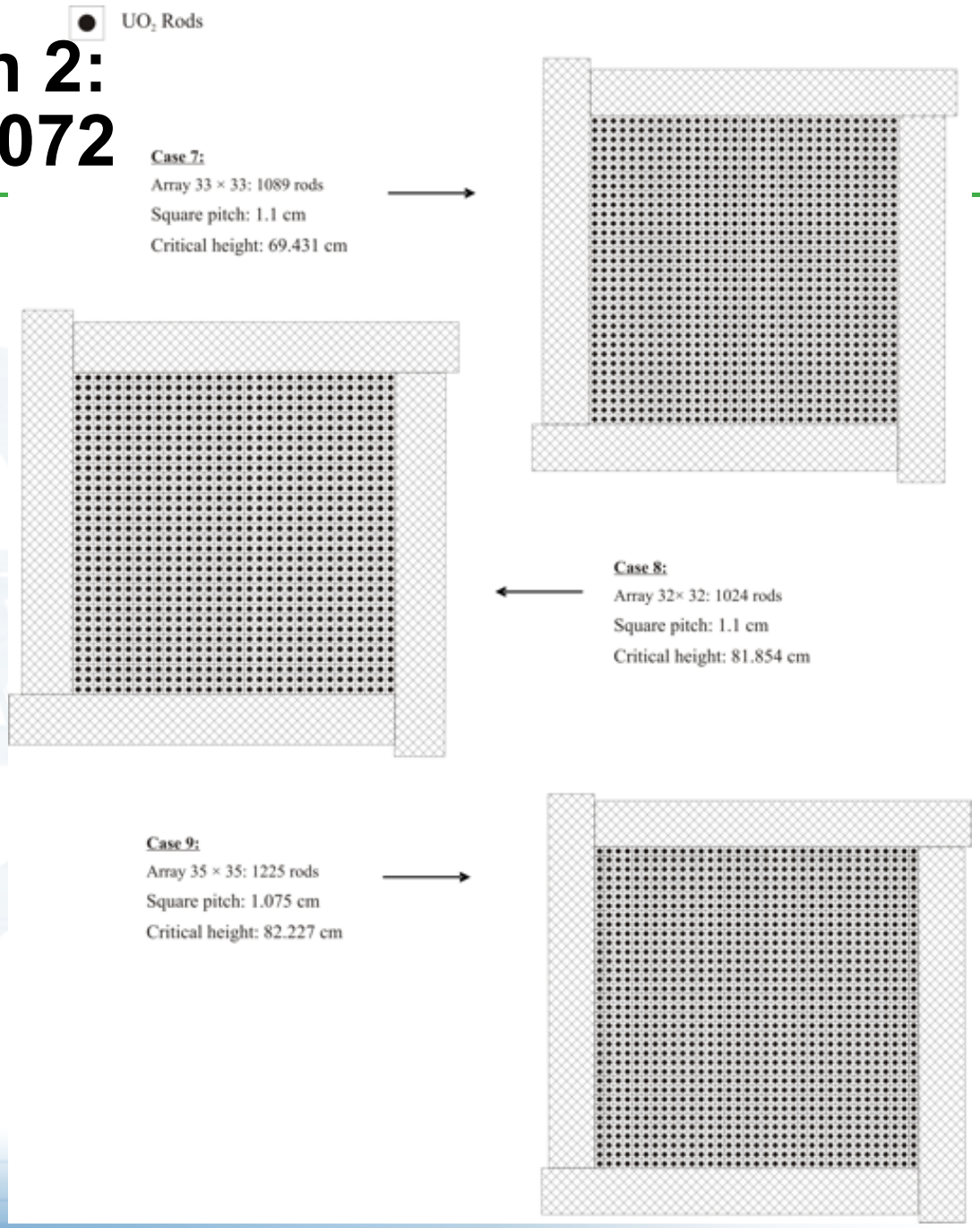
- Reevaluated uncertainty in tygon tubing
  - Section 2.5.2
  - Effectively doubled uncertainty
- Reduced total number of acceptable benchmarks
  - 20 → 11
  - Within 2σ
    - 340 – 930 pcm uncertainty



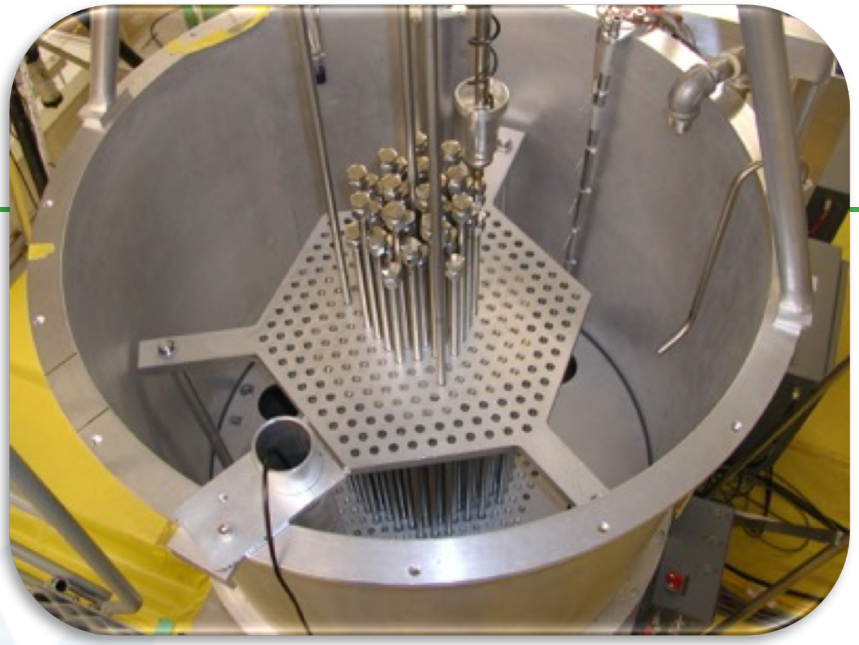


Noteworthy Revision 2: LEU-COMP-THERM-072

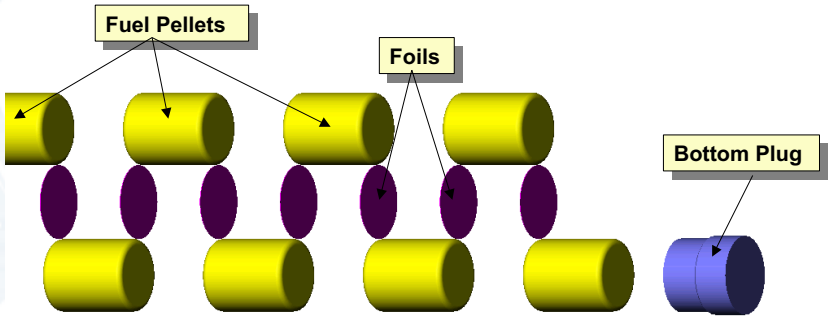
- Improved quality of Figures 4 and 12
- Provided additional data for C_2H_2 blocks
  - Section 1.3.10
- Minor update to uncertainty analysis
- Updated Section 4 sample calculations

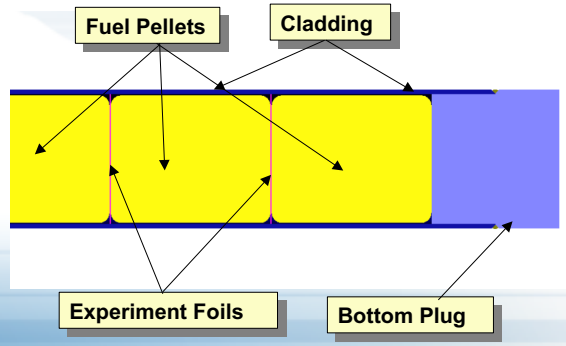


Noteworthy Revision 3: LEU-COMP-THERM-079

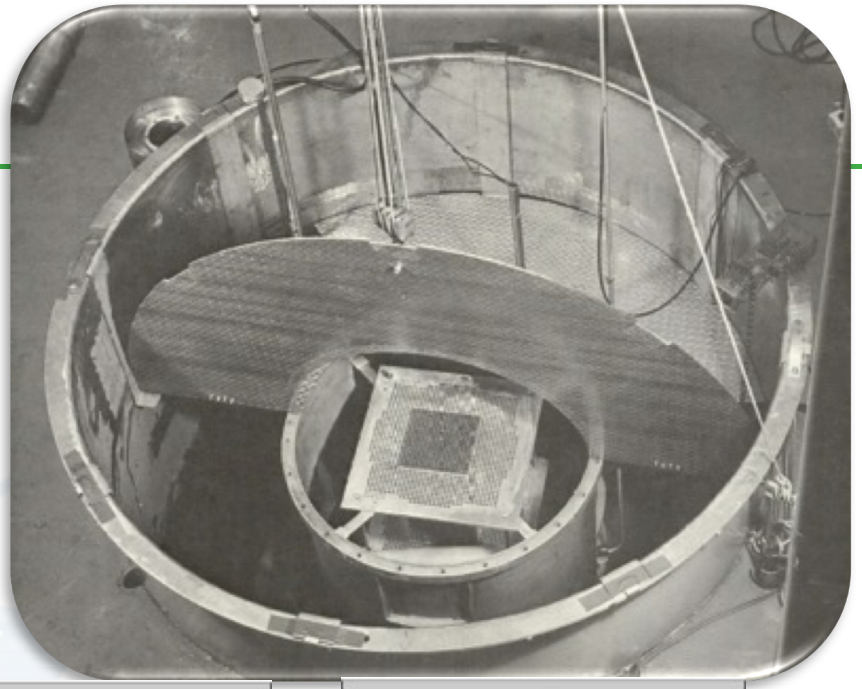


- Minor update to array pitch
- Reevaluated uncertainties
  - Fuel element outer diameter
  - Array pitch
  - Temperature corrections

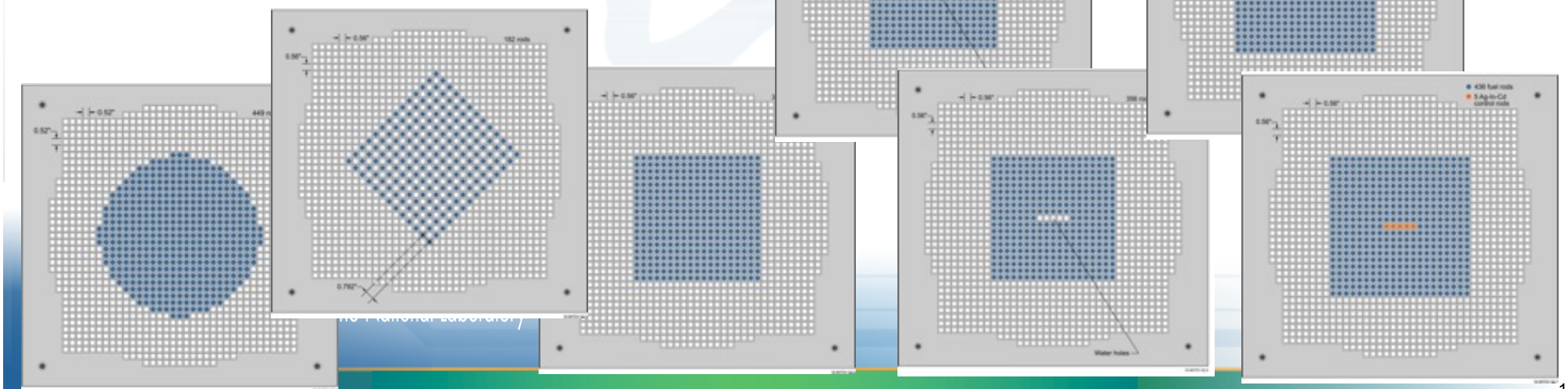




New 1: LEU-COMP-THERM-98



- (WREC) SPP Criticals
  - UO_2 loadings only
  - 7 critical configurations
- Evaluation results pending final review

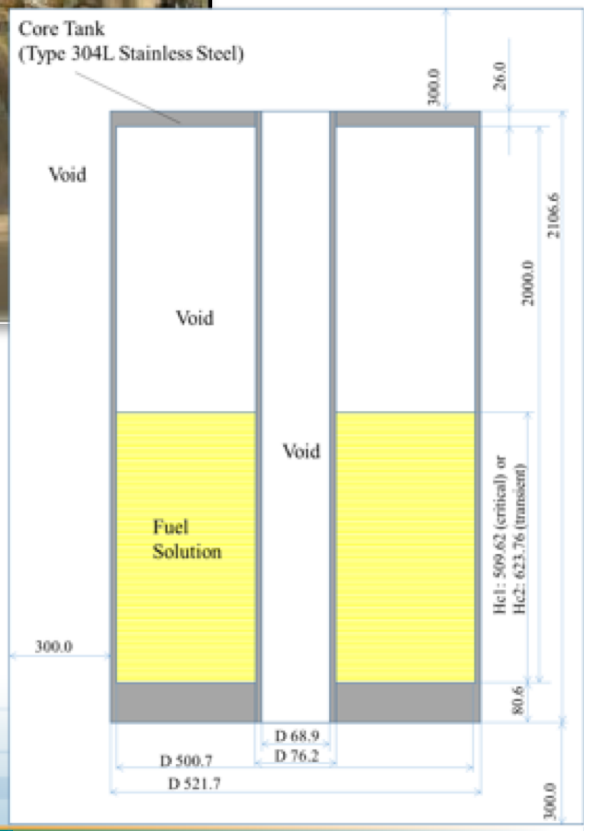


New 2: LEU-COMP-THERM-100

- (IRSN) UO_2 rods around polytetrafluoroethylene block
  - 2 critical configurations
- Evaluated
  - Uncertainty ~80 pcm
  - Sample calculations within 0.48σ to 2.16σ

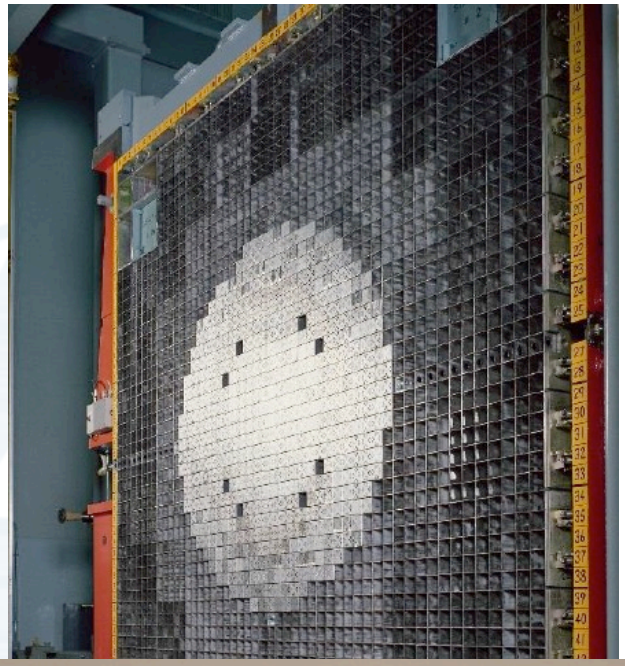
New 3: LEU-SOL-THERM-012

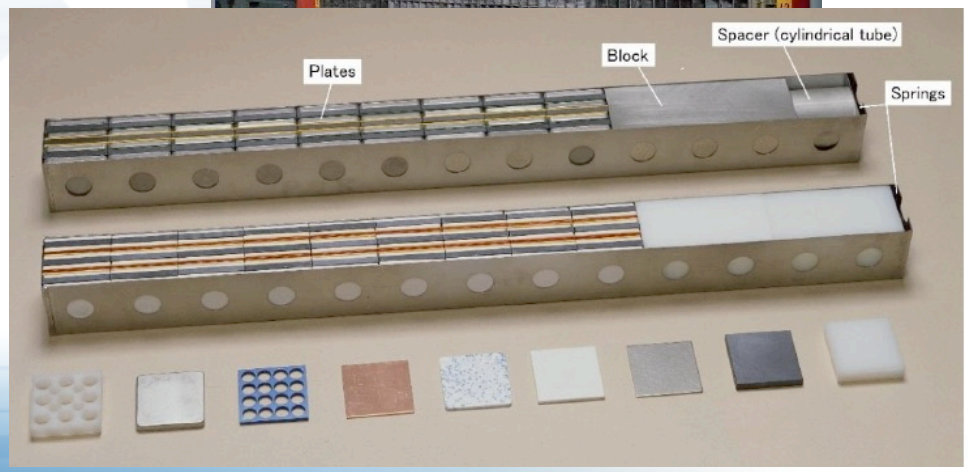
- (JAEA) TRACY
  - 10%, uranyl nitrate
  - 1 critical
  - 1 supercritical, 3$
- Evaluated
  - Uncertainty ~110 pcm
  - Sample calculations within 0.27%, 3σ



New 4: IEU-MET-FAST-024

- (JAEA) FCA IX-7
  - Fundamental configuration prior to minor actinide measurements
- Evaluated
  - Heterogeneous and Homogenous critical benchmark models
  - Uncertainty ~140 pcm
  - Sample calculations within 0.4 %, 3σ

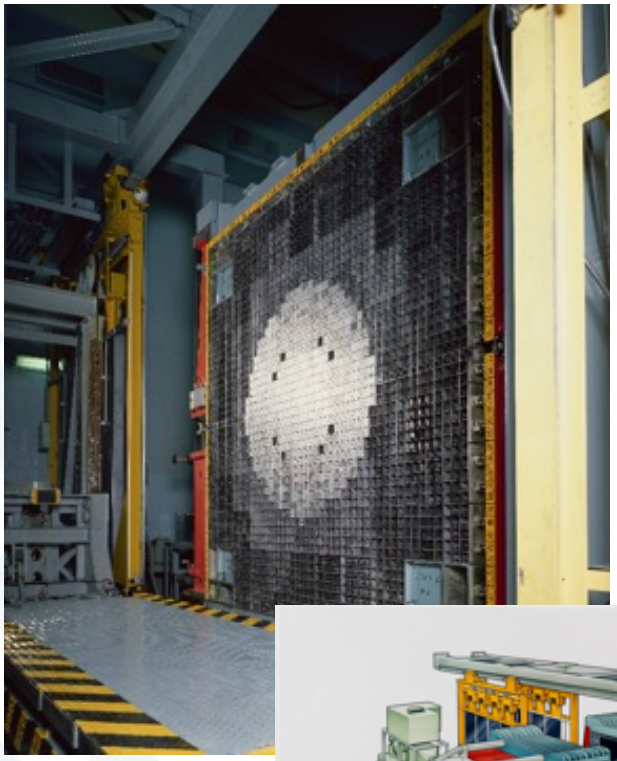


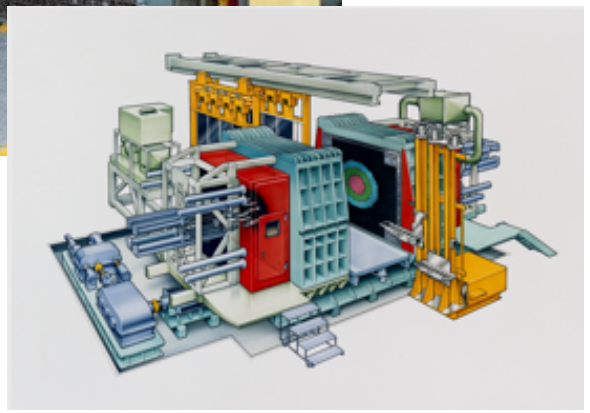


International Handbook of Evaluated Reactor Physics Benchmark Experiments

October 2018 Edition

- 20 Contributing Countries
- 54 Reactor Facilities
- Data from 159 Experimental Series
  - 156 Approved Benchmarks
  - 3 DRAFT Benchmarks





http://irphep.inl.gov/

http://www.oecd-nea.org/science/wprs/irphe/

Breakdown of Current Reactor Facilities on IRPhEP Handbook

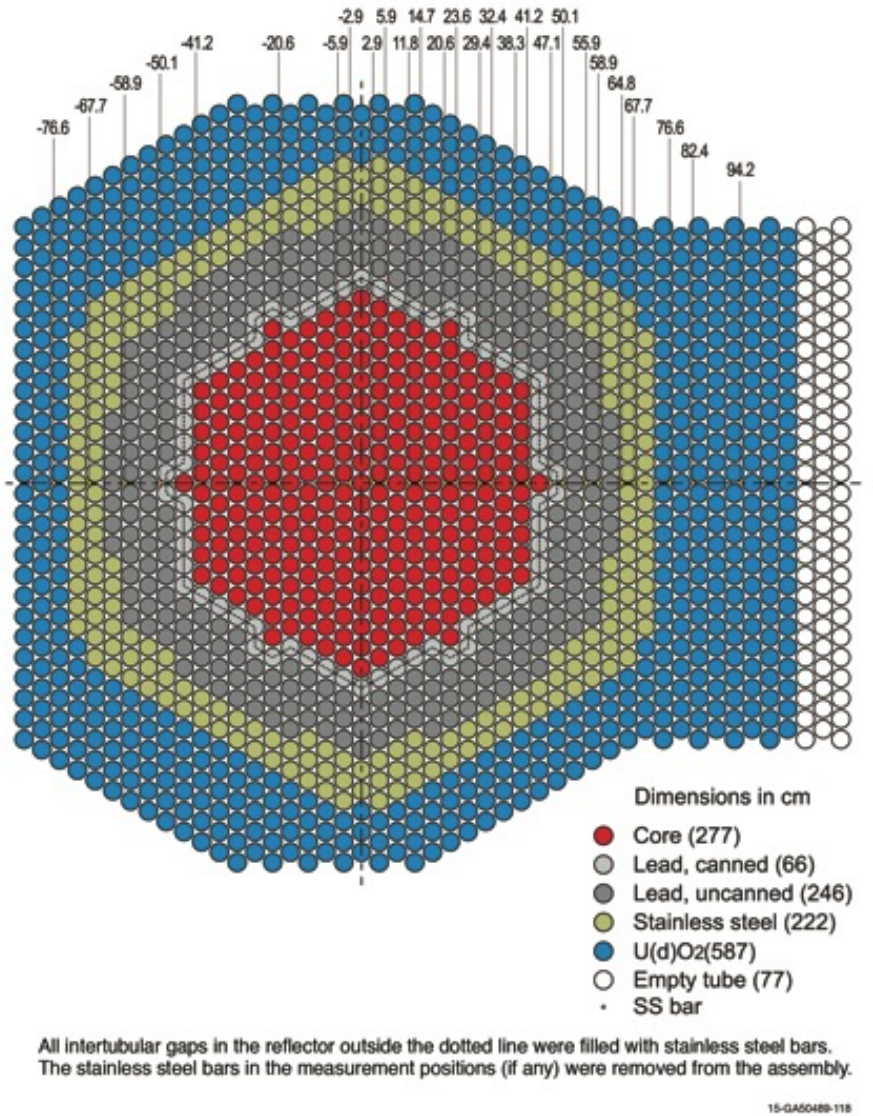
- 6 Pressurized Water Reactor (PWR)
  - DIMPLE, DUKE, EOLE, OTTOHAHN, SSCR, VENUS
- 3 Vodo-Vodynaoi Energetichesky Reactor (VVER)
  - LR-0, P-Facility, ZR-6
- 0 Boiling Water Reactor (BWR)
- 10 Liquid Metal Fast Reactor (LMFR)
  - BFS-1, BFS-2, BR2, EBR-II, FFTF, JOYO, SNEAK, ZEBRA, ZPPR, ZPR
- 5 Gas Cooled (Thermal) Reactor (GCR)
  - ASTRA, HTR10, HTTR, PROTEUS, VHTRC
- 1 Gas Cooled Fast Reactor (GCFR)
  - PROTEUS
- 5 Light Water Reactor (LWR)
  - CROCUS, DIMPLE, IPEN(MB01), KRITZ, TCA
- 3 Heavy Water Reactor (HWR)
  - DCA, ETA, ZED2
- 0 Molten Salt Reactor (MSR)
- 1 Reaktor Bolshoy Moshchnosti Kanalniy (RBMK)
  - RBMK(CF)
- 6 Space Reactor (SPACE)
  - ORCEF, SCCA, TOPAZ, UKS1M, ZPPR, ZPR
- 22 Fundamental Physics Reactor Measurements (FUND)
  - ATR, BFS-1, BFS-2, CORAL(1), FCA, FR0, HECTOR, IGR, KUCA, LAMPRE, MINERVE, NRAD, ORCEF, ORSPHERE, PBF, RA-6, RB, RHF, TREAT, TRIGA, ZEBRA, ZPR

New Content in the Handbook 2018 Edition

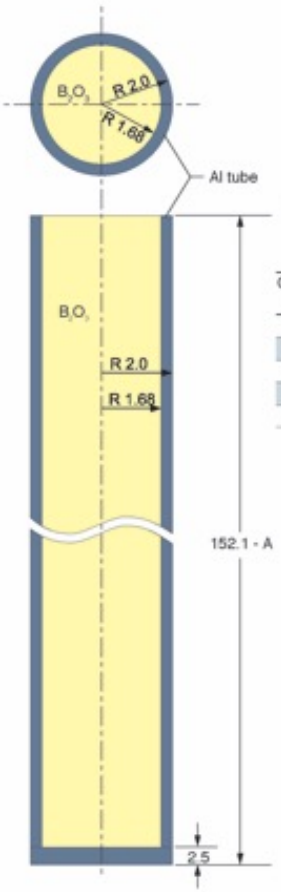
- 6 Revised Evaluations
- 2 Draft Evaluations Finalized and Approved
- 8 New Evaluation
- IRPhEP Uncertainty Guide

Revision 1: BFS1-LMFR-EXP-002

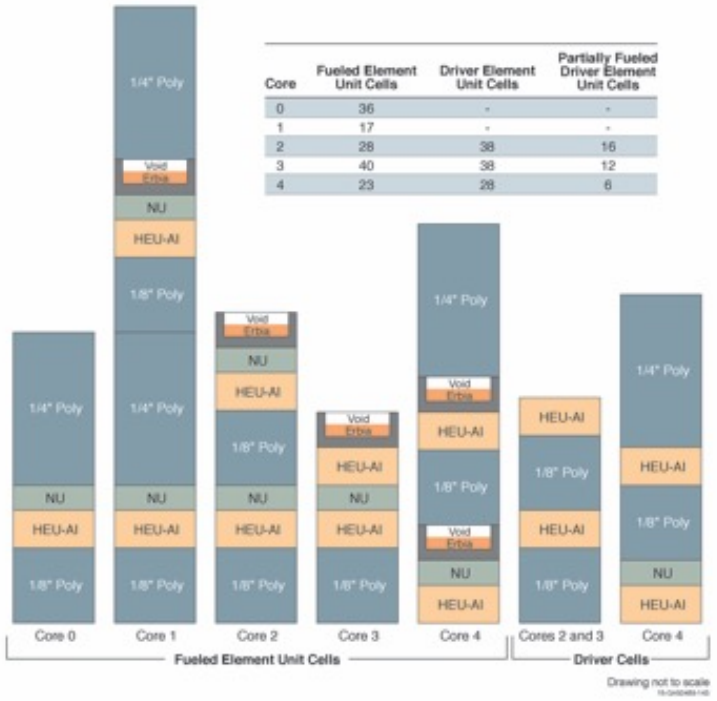
- (IPPE) BFS-61
- Revisions
  - Clarification that steel rods were not in instrument positions
  - Position of fission rate measurements at 76.6 cm, not 77.6 cm



Revision 2: KUCA-FUND-RESR-001



Core ↓	A			
	Safety Rod	C1	C2	C3
0	120.0	120.105	120.101	67.844
1	120.0	120.122	71.914	120.128
2	120.0	120.118	120.119	60.517
3	120.0	120.123	120.118	71.111
4	120.0	120.121	120.120	71.723

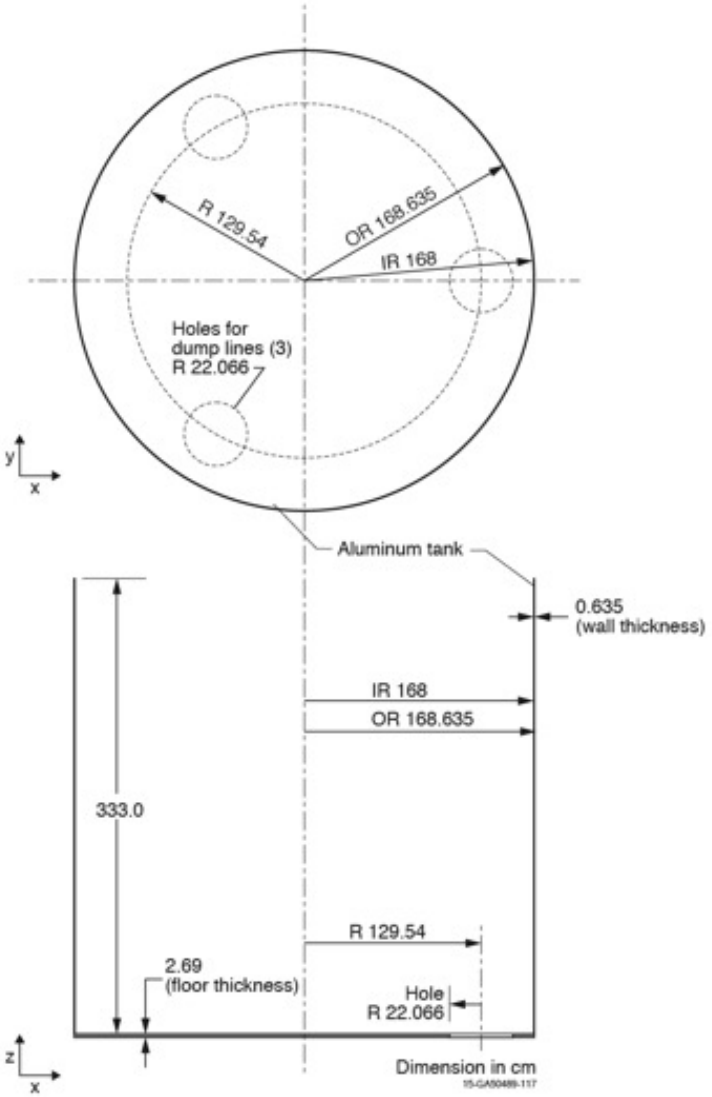


Core	Fueled Element Unit Cells	Driver Element Unit Cells	Partially Fueled Driver Element Unit Cells
0	36	-	-
1	17	-	-
2	28	38	16
3	40	38	12
4	23	28	6

- Kyoto University Critical Assembly
- Revisions
  - Control rod position information provided for Core 0
  - Number of unit cells in Core 0 corrected from 31 to 36

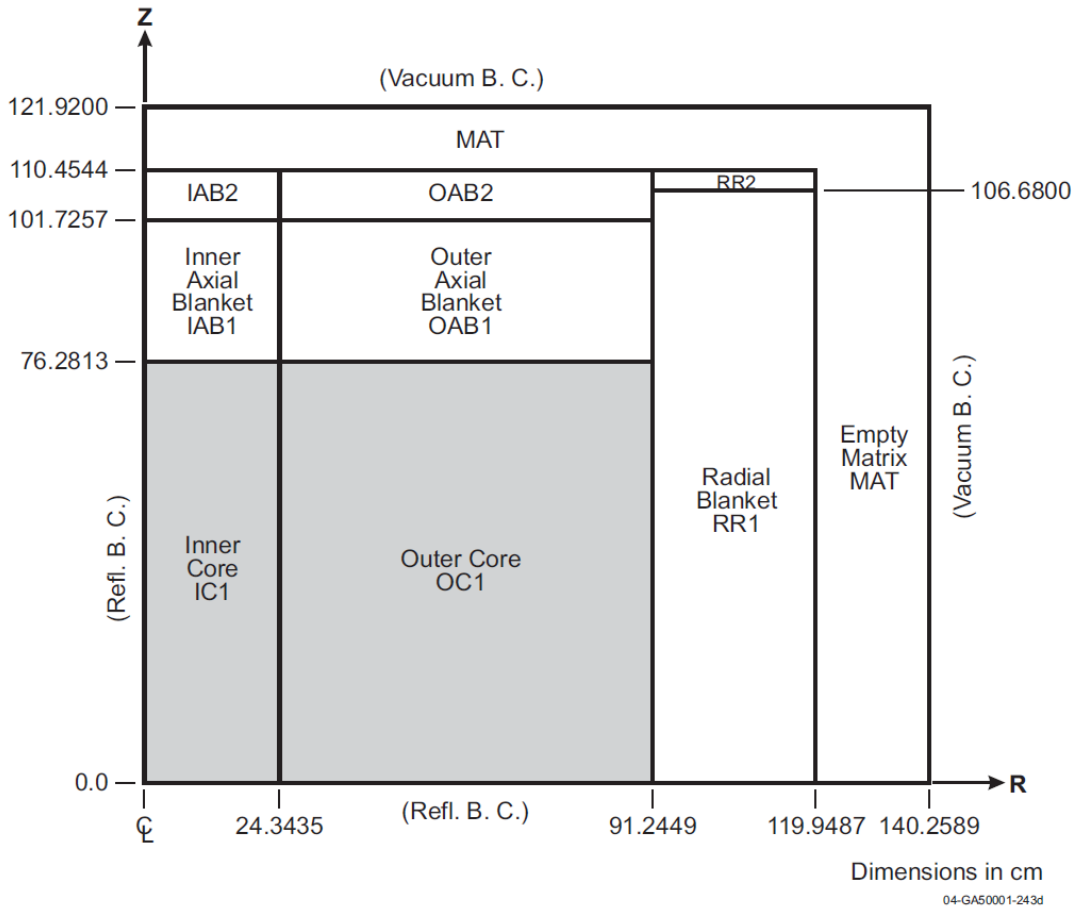
Revisions 3 & 4: ZED2-HWR-EXP-001 & -002

- (CNL) ZED-2
- Revision
  - Corrected radius of dump line hole in calandria from 23.1775 cm to 22.066 cm



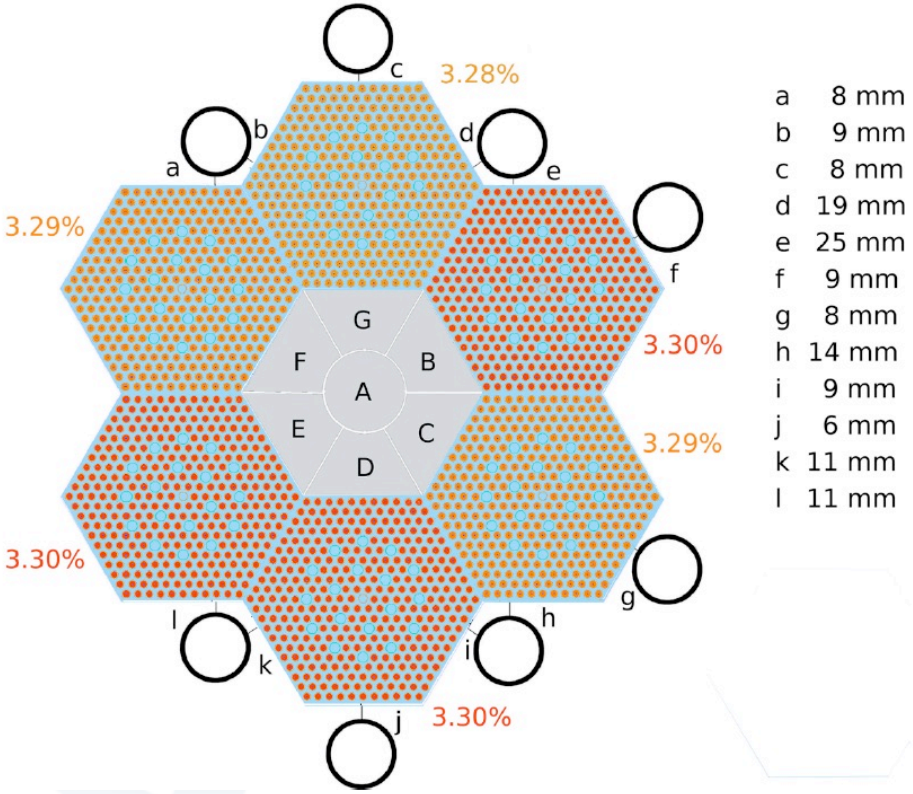
Revision 5: ZPR-FUND-EXP-008

- (ANL) ZPR-6/6A
- Revision
  - Clarified composition to be utilized for the radial blanket region, RR2



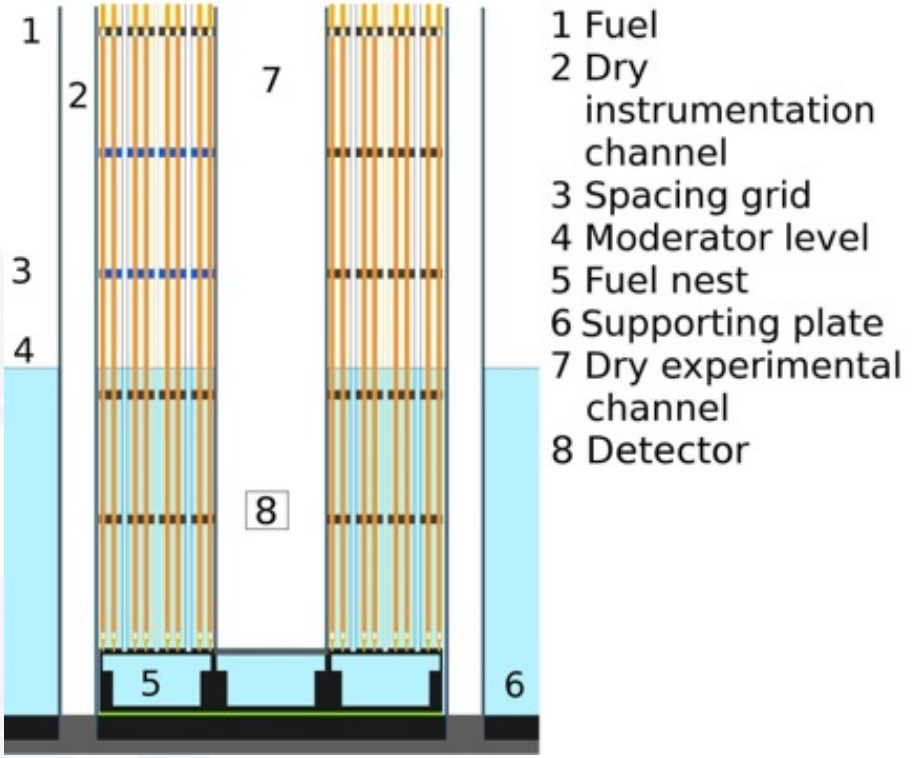
Revision 6 (New Data): LR(0)-VVER-RESR-003

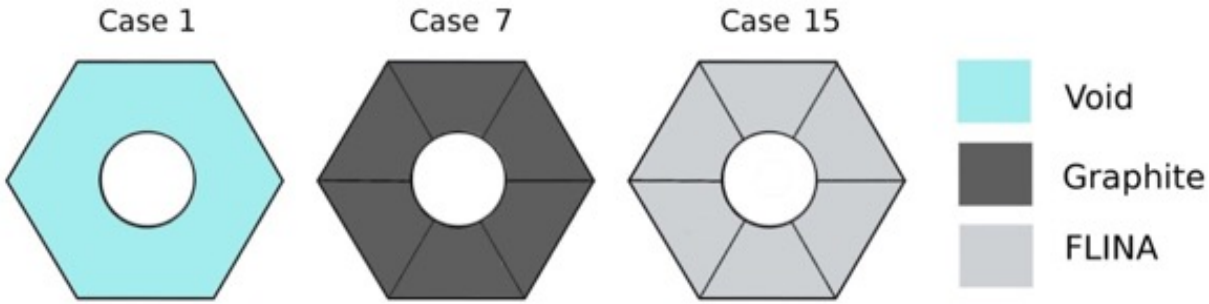
- Research Center Rez (VVER-1000)
- Investigate reactor physics problems for MSR and FHR
  - FLINA and FLIBE
  - Criticality only last year



Revision 6 (New Data): LR(0)-VVER-RESR-003

- Neutron spectra measured for three central loadings
  - 40-group
  - ~1-2 % relative uncertainty





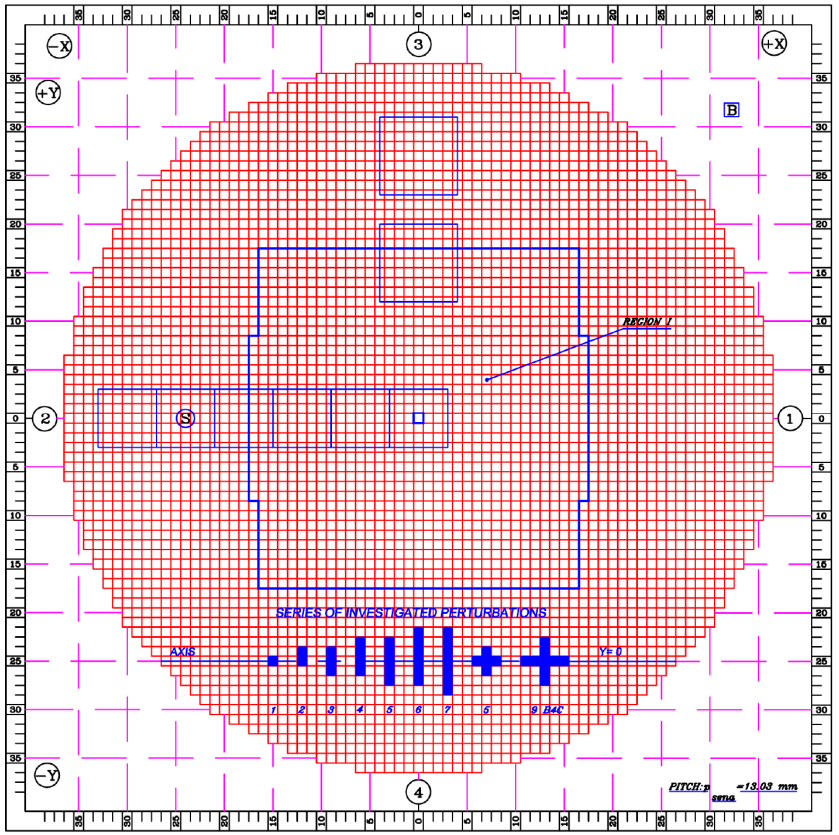
Draft Approved 1: DUKE-PWR-POWER-001

- PWR Depletion Reactivity Measurements
  - Kord Smith (MIT)
  - Dale Lancaster
- EPRI/NRC Benchmark Validation Effort
- Use of inferred reactivities to determine mean reactivity change due to burnup

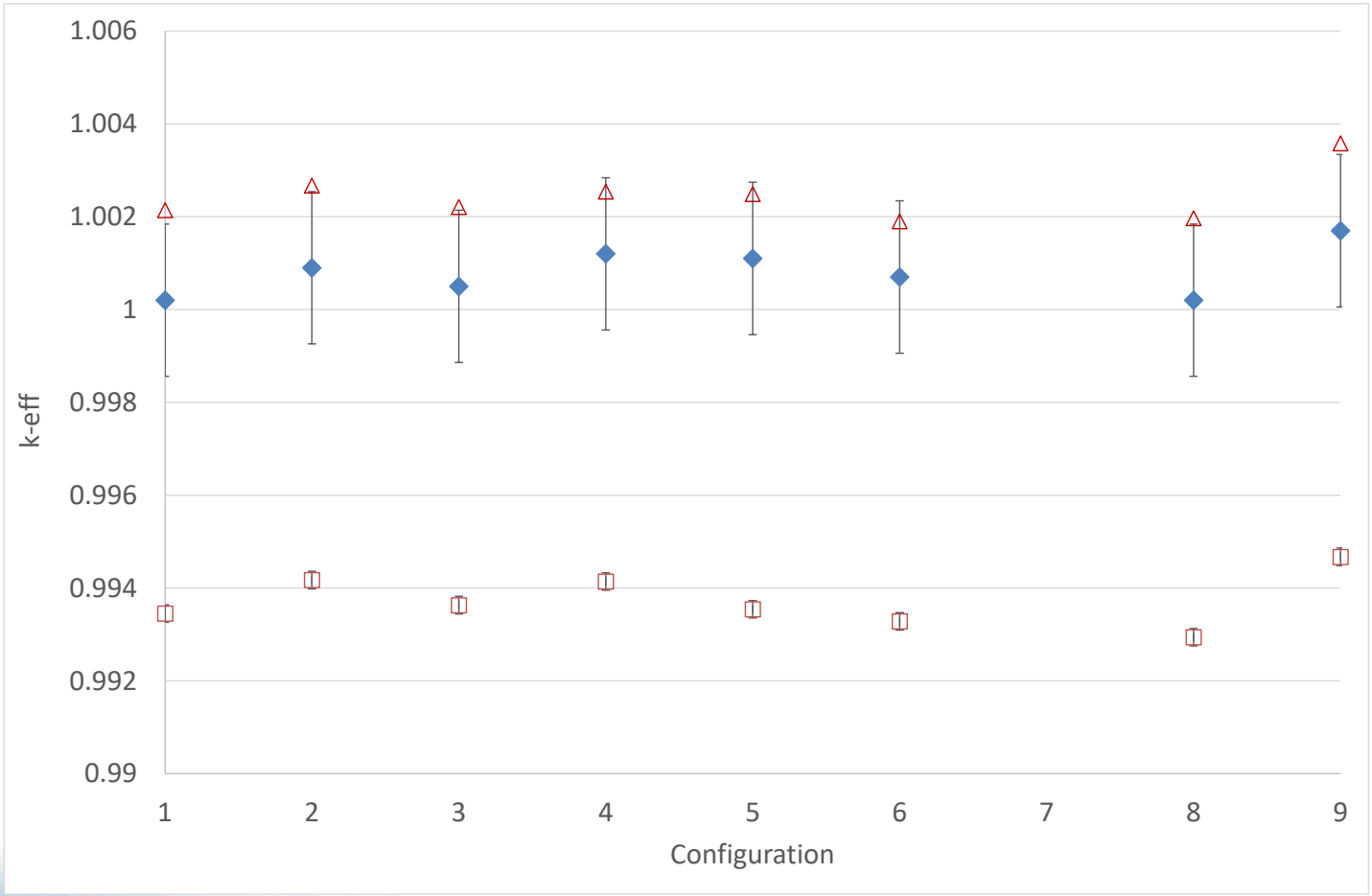
Fuel Burnup GWd/T	Lattice Calculated $k_{infinity}$	Lattice Monte Carlo 1σ uncertainty	Lattice Calculated Reactivity	Experimental Benchmark Reactivity	Depletion Reactivity Bias (C–E)	Depletion Reactivity (C-E)/E (%)
0	1.1045	0.0001				
10	1.1127	0.0001	0.0082	+0.0100	-0.0018	-17.7
20	1.0611	0.0001	-0.0434	-0.0416	-0.0018	4.4
30	0.9944	0.0001	-0.1101	-0.1080	-0.0021	1.9
40	0.9327	0.0001	-0.1718	-0.1714	-0.0004	0.2
50	0.8772	0.0001	-0.2273	-0.2278	+0.0005	-0.2
60	0.8316	0.0001	-0.2729	-0.2752	+0.0023	-0.9

Draft Approved 2: VENUS-PWR-EXP-006

- VENUS-17 Plutonium Recycle Physics Project (Belgium)
  - Kevin Hesketh (UK)
- Study of different MOX fuel with varying Pu content and isotopics



Draft Approved 2: VENUS-PWR-EXP-006



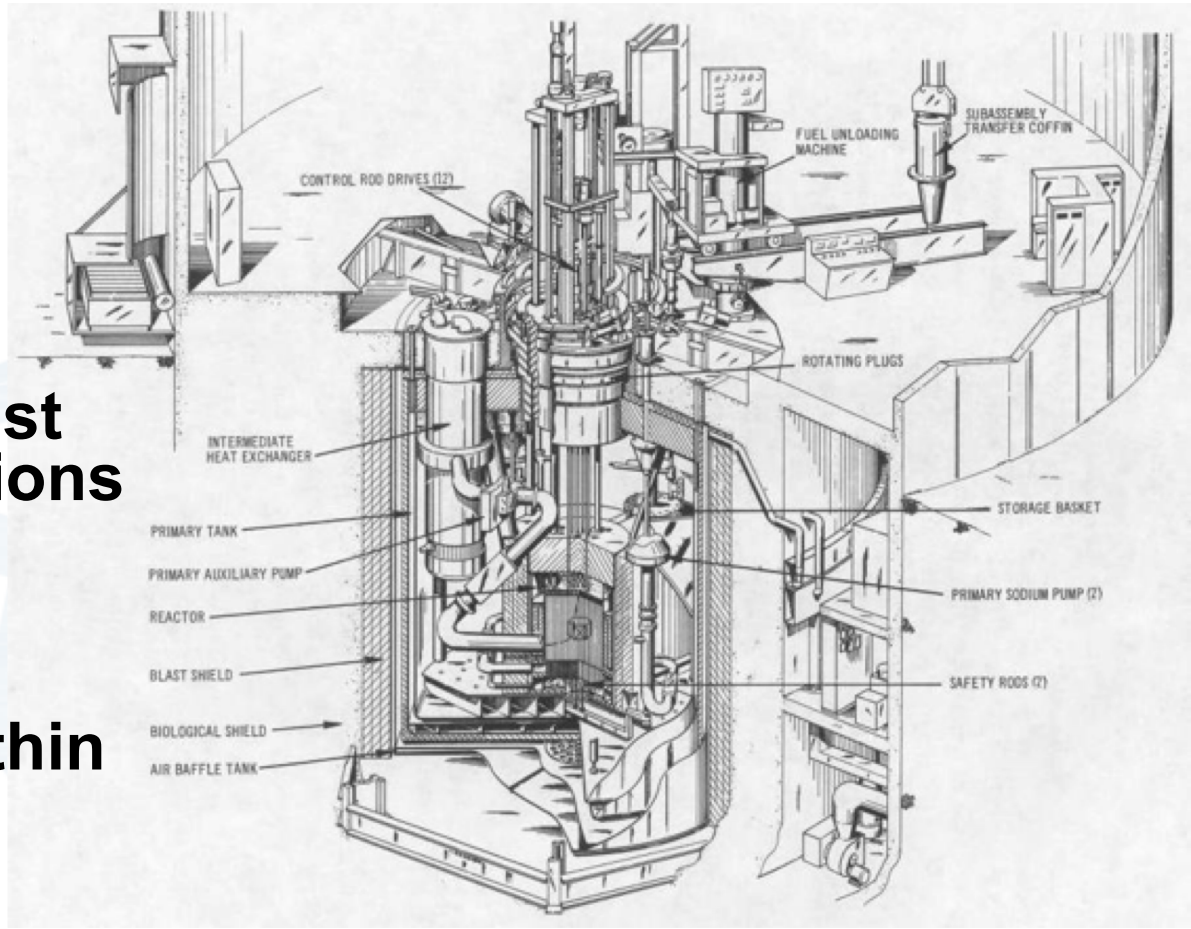
MCNP6.1.1
ENDF/B-VII.1

Benchmark

MCNP5.1
ENDF/B-VI.8

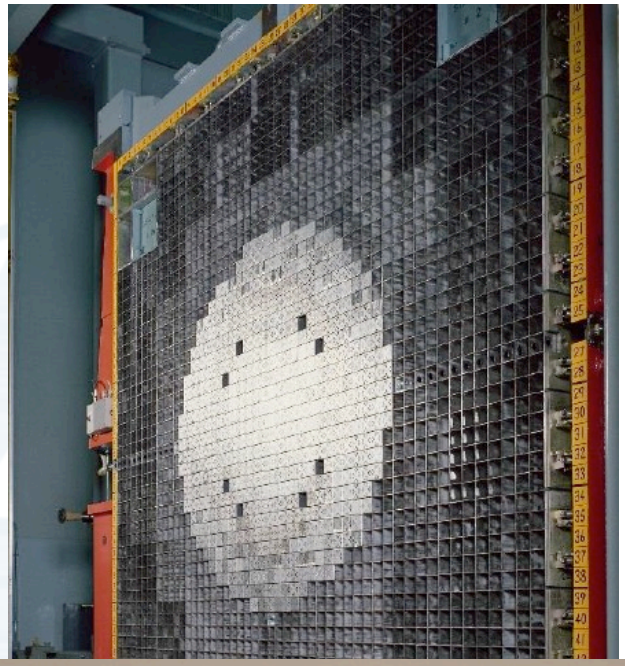
New 1: EBR2-LMFR-RESR-001

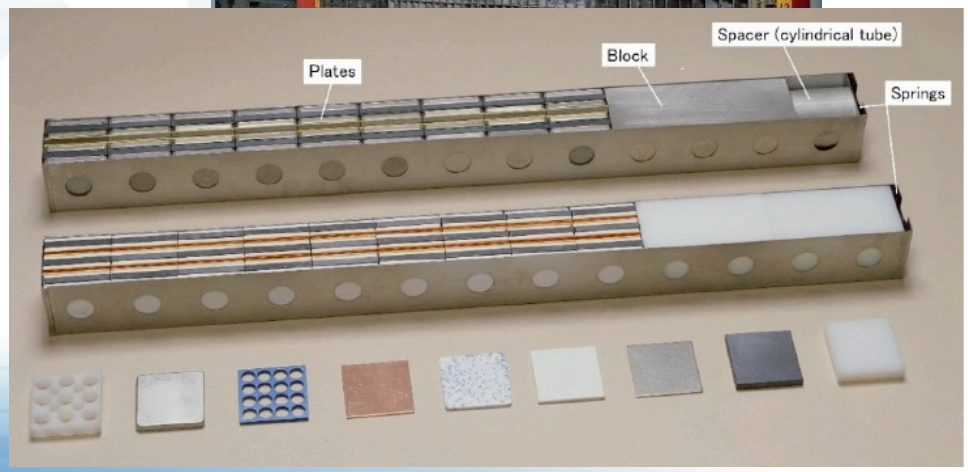
- (INL) EBR-II
  - Run 138B
  - Safety Heat Removal Test (SHRT) 45
  - Represent largest accident conditions
- Evaluated
  - Criticality
  - Calculations within 0.24%, 1σ



New 2: FCA-FUND-EXP-001

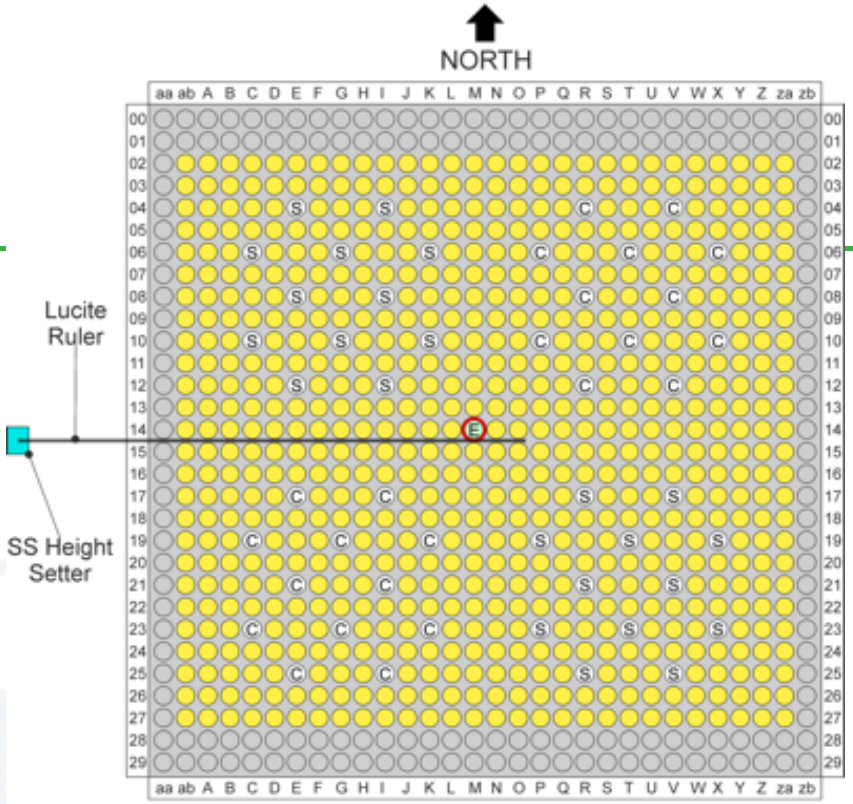
- (JAEA) FCA IX-7
  - Fundamental configuration prior to minor actinide measurements
- Evaluated
  - Heterogeneous and Homogenous critical benchmarks
  - Calculations within 0.4 %, 3σ

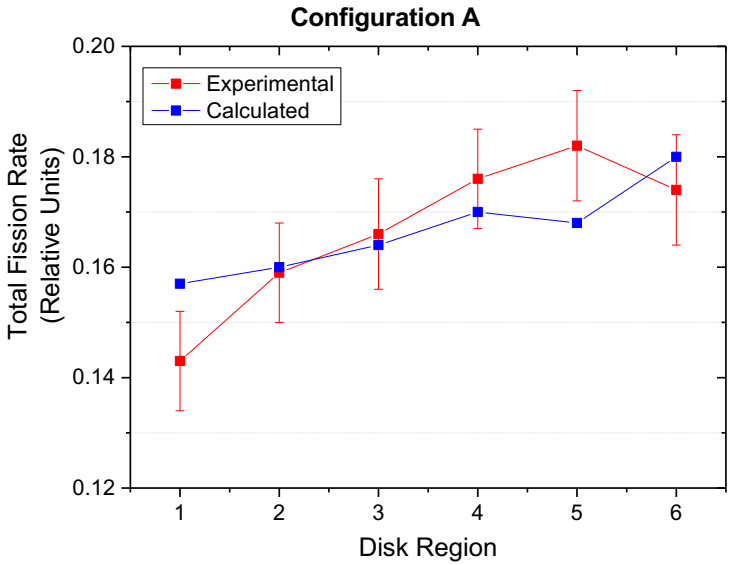


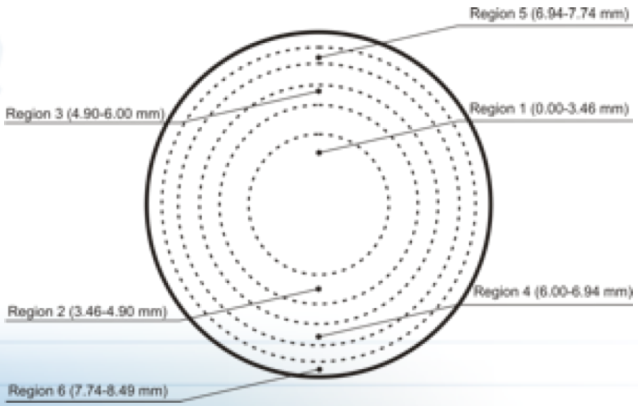


New 3: IPEN(MB-01)-LWR-RESR-019

- (IPEN) UO_2 LWR
- Evaluated
  - Radial reaction-rate measurements in fuel

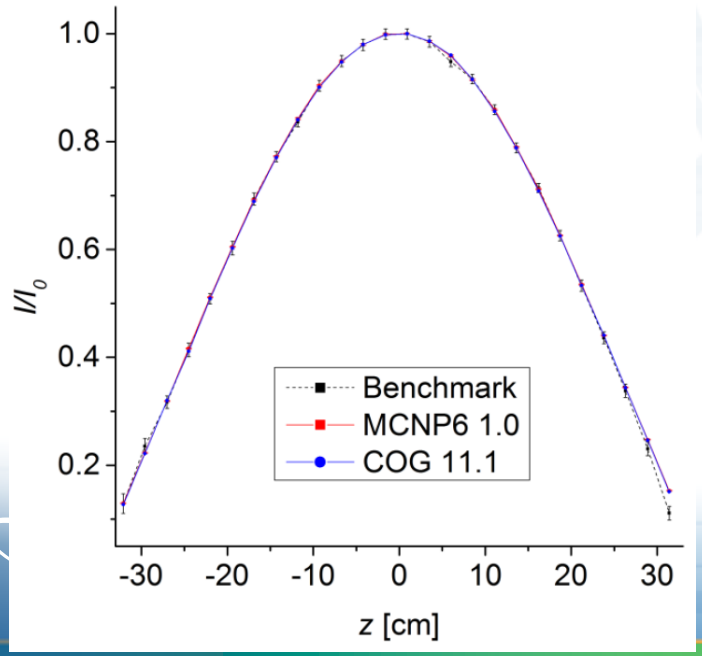


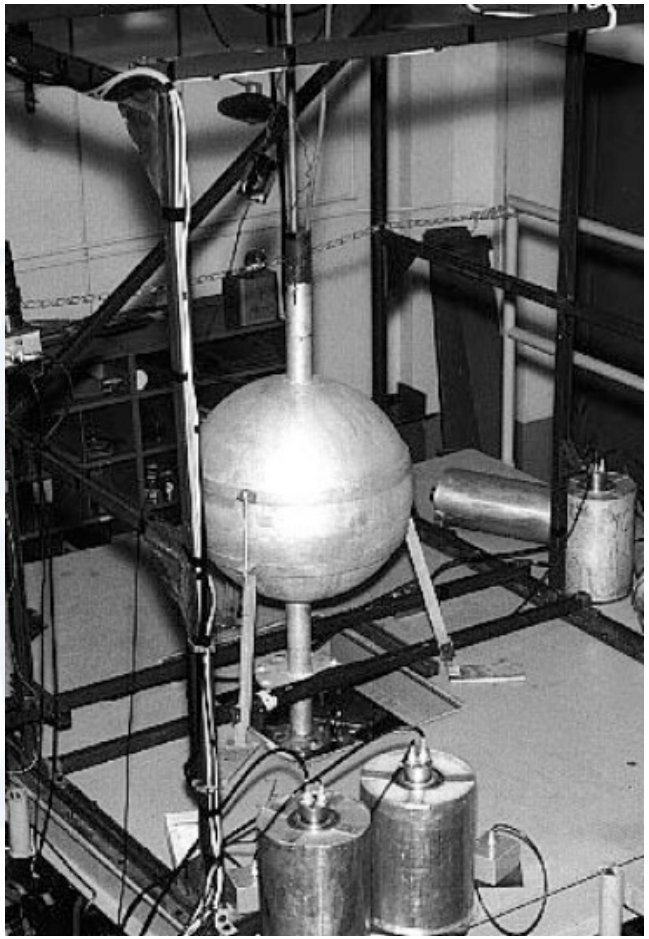




New 4: ORCEF-FUND-EXP-001

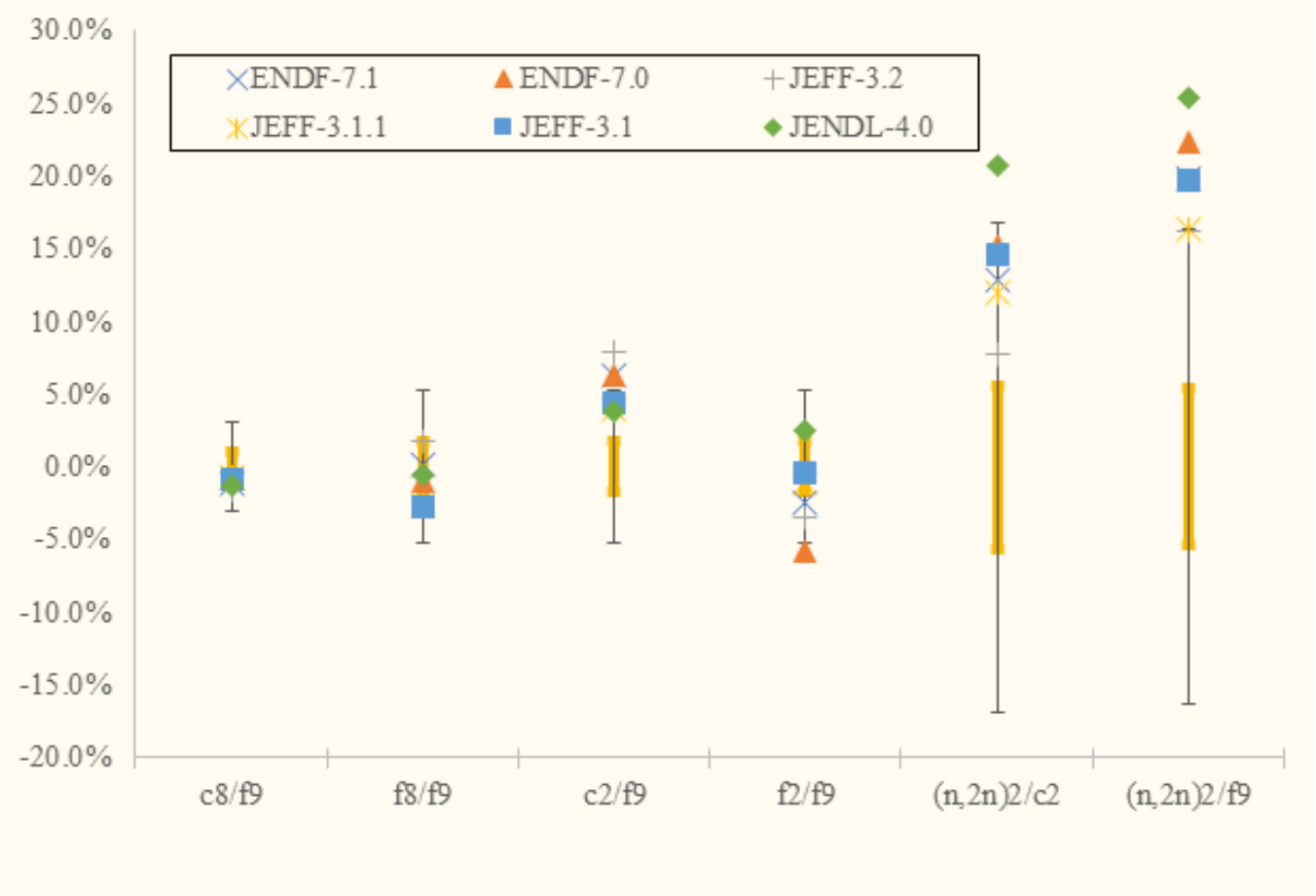
- (ORNL) ORCEF
  - $U(37\%)O_2F_2$ Sphere
  - Performed by JSI
- Evaluated
  - Radial fission rates





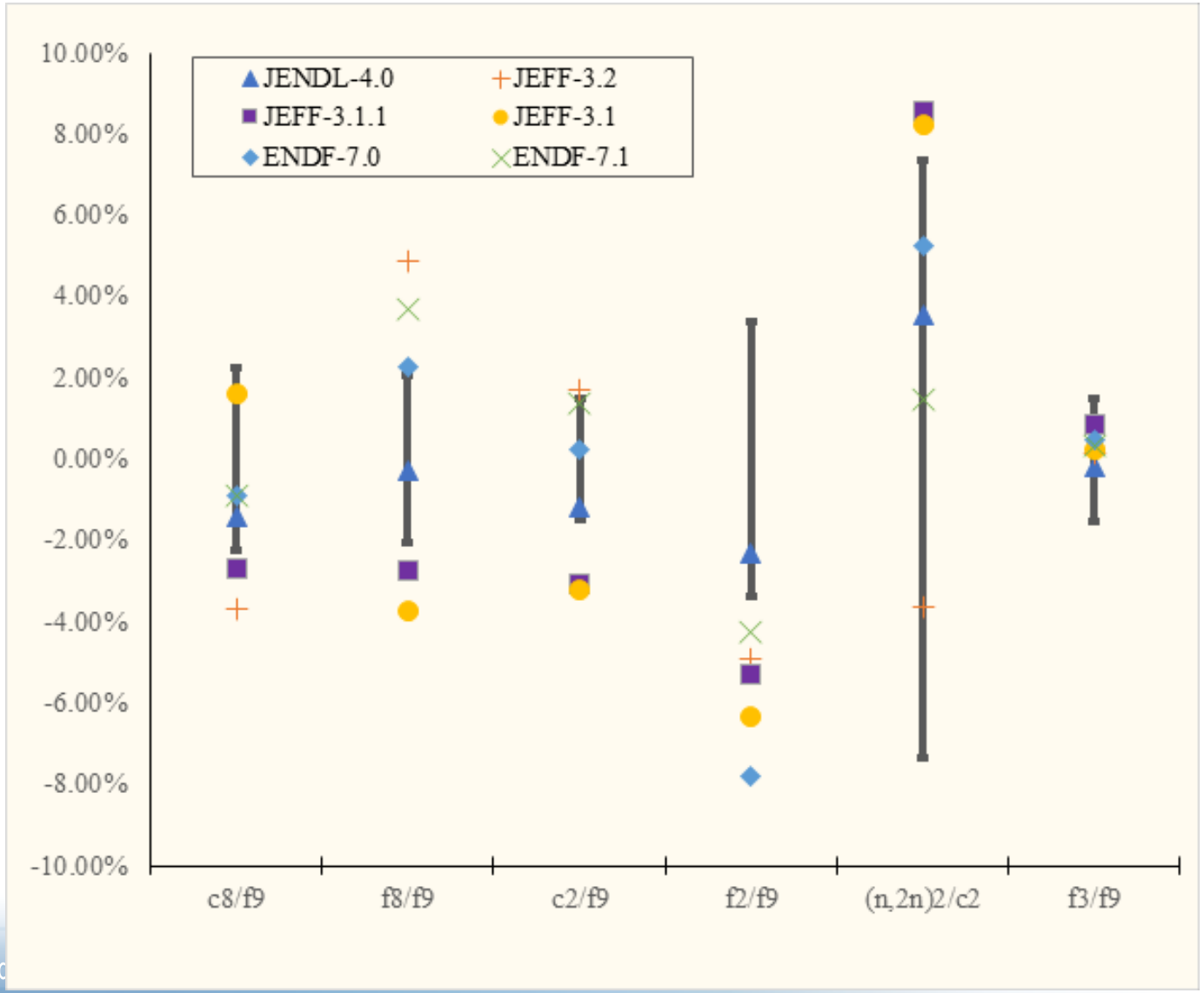
New 5: PROTEUS-GCFR-RESR-002

- (PSI) GCFR-PROTEUS Core 12
  - MOX with ThO_2 Test Region
  - Gareth Newman (UF)
- Coupled fast-thermal reactor spectral measurements
  - Generally good agreement except a few outliers



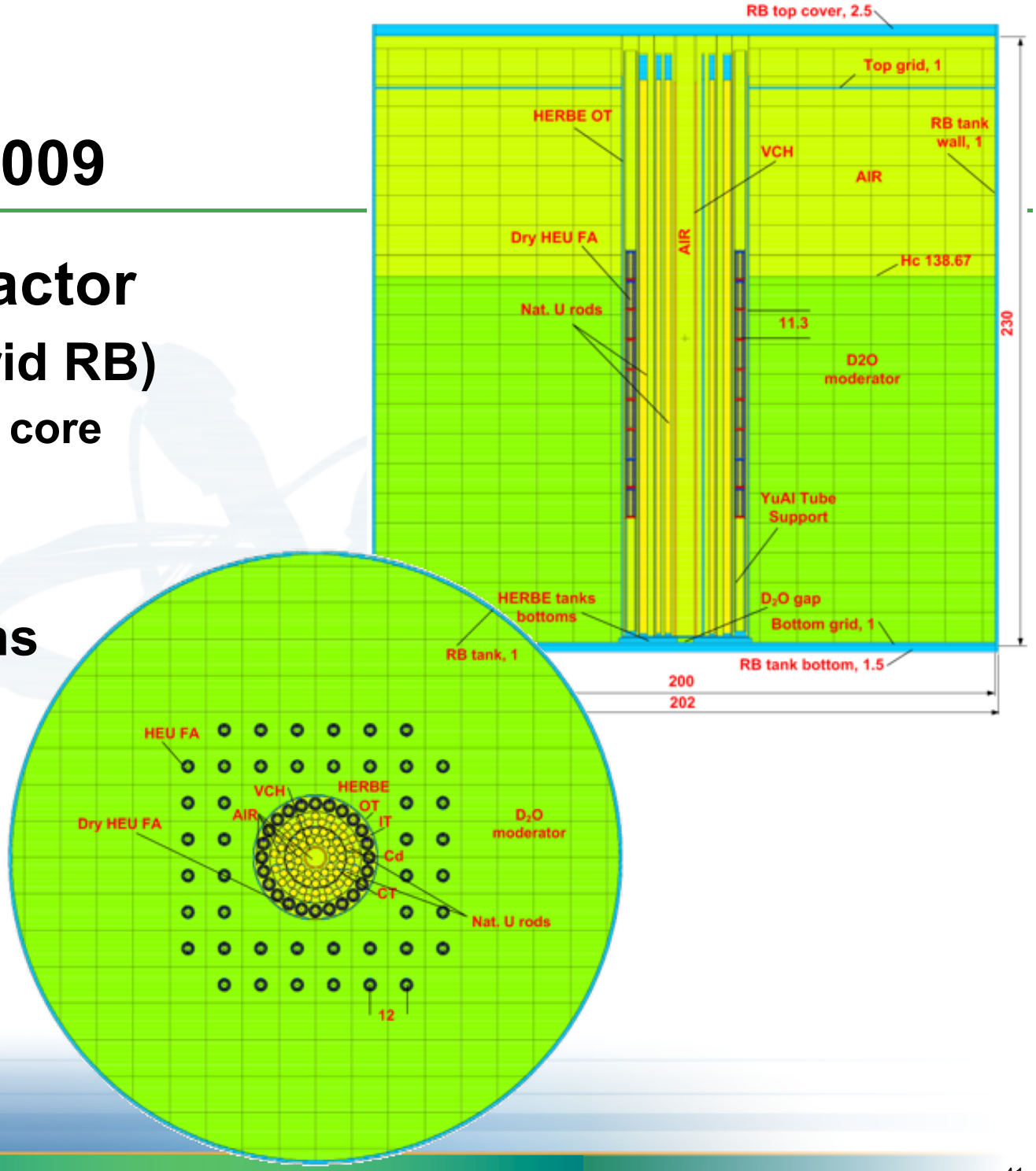
New 6: PROTEUS-GCFR-RESR-003

- (PSI) GCFR-PROTEUS Core 15
  - MOX with Th metal test region
  - Gareth Newman (UF)
- Coupled fast-thermal reactor spectral measurements
  - Generally good agreement except a few outliers



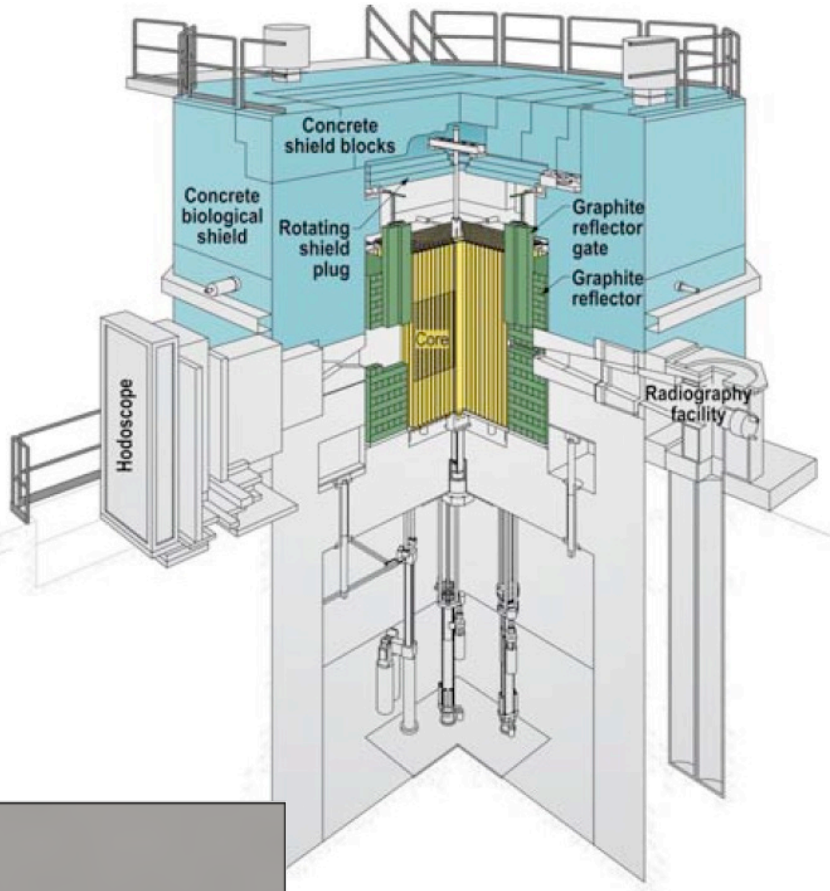
New 7: RB-FUND-EXP-009

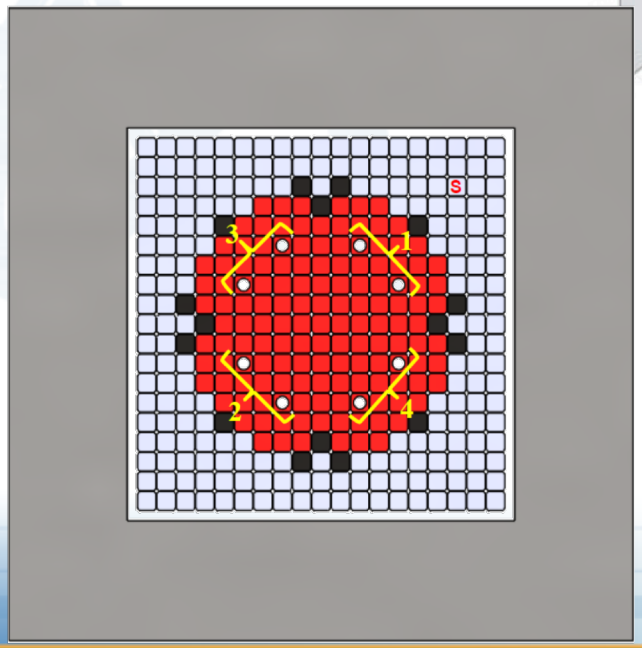
- **Serbia RB Reactor**
  - **HERBE (Hybrid RB)**
    - **Fast-thermal core**
- **Evaluated**
  - **3 Critical Configurations**
  - **Calculations within 0.6%, 3σ**



New 8: TREAT-FUND-RESR-001

- (INL) Transient Test Reactor
  - Performed by U. Michigan
- Evaluated
  - Initial minimum critical mass loadings
  - Sensitivity to fuel impurities
  - Sensitivity to graphite cross section data





Al-Clad Dummy Fuel Assembly

Standard Fuel Assembly

Zircaloy-Clad Dummy Fuel Assembly

Control Rod Fuel Assembly

Permanent Reflector

S Startup Source Assembly

A Short Guide on Citing of the ICSBEP/IRPhEPHandbooks and Individual Evaluations

Prepared by

Žiga Štancar

Luka Snoj

Jožef Stefan Institute

IRPhEP Handbook:

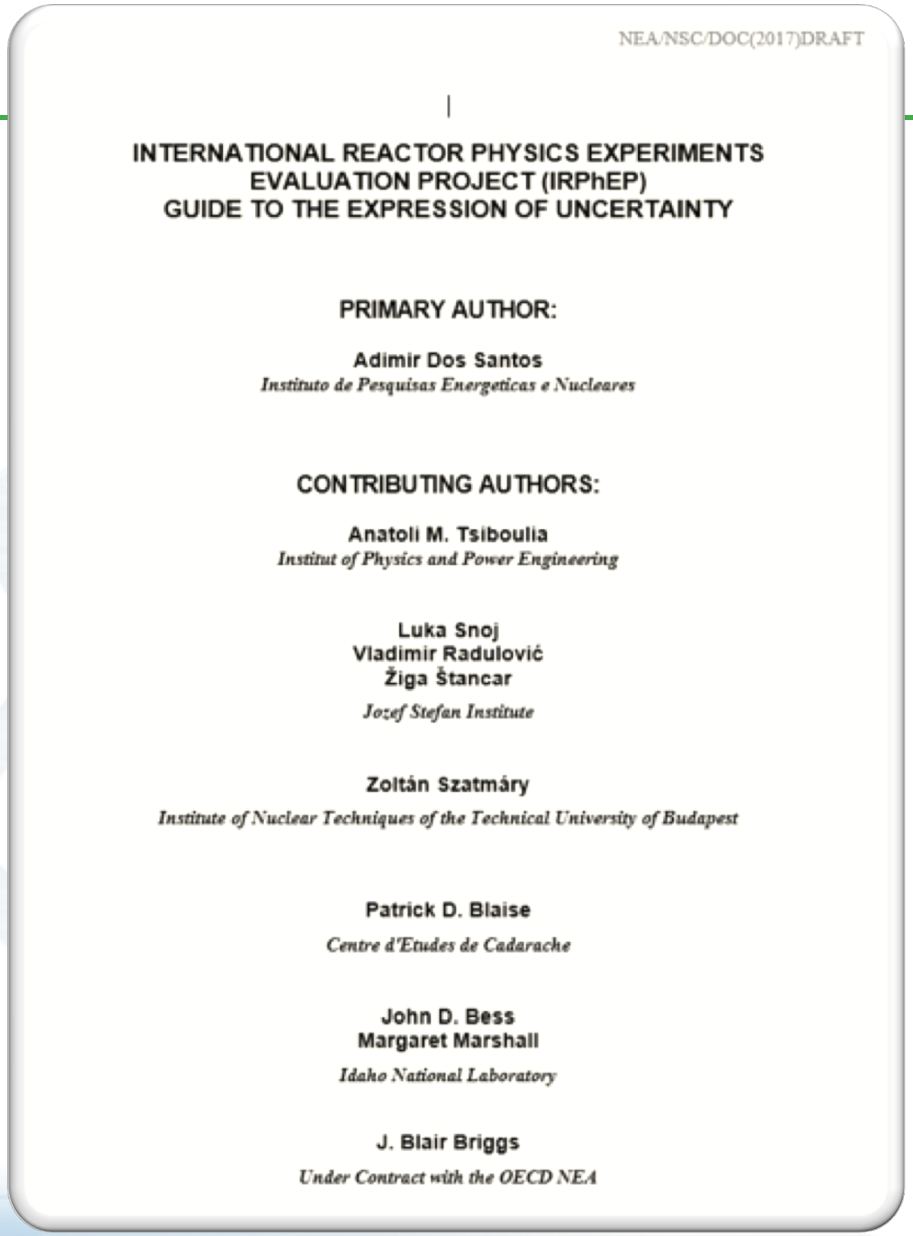
International Handbook of Evaluated Reactor Physics Benchmark Experiments / Nuclear Energy Agency. - Paris : OECD Nuclear Energy Agency, 2017. -(NEA;7329). ISBN #

IRPhEP Individual Evaluations:

Štancar, Ž., et al. Reaction Rate Distribution Experiments at the Slovenian JSI TRIGA Mark II Research Reactor, TRIGA-FUND-RESR-002. In: *International Handbook of Evaluated Reactor Physics Benchmark Experiments* /Nuclear Energy Agency. - Paris : OECD Nuclear Energy Agency, 2017. - 251 pp. - (NEA;7329). ISBN #

IRPhEP Uncertainty Guide

- Criticality
  - ICSBEP
- Buckling (ref report)
  - Zoltán Szatmáry
  - U. Budapest
- Spectral Characteristics
- Reactivity Effects
  - Reactivity Coefficients
- Kinetics
- Reaction-Rate Distribution
  - Power Distribution
- Not yet available
  - Isotopic measurements
  - Other miscellaneous types



NEA/NSC/DOC(2017)DRAFT

INTERNATIONAL REACTOR PHYSICS EXPERIMENTS
EVALUATION PROJECT (IRPhEP)
GUIDE TO THE EXPRESSION OF UNCERTAINTY

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John D. Bess
Margaret Marshall
Idaho National Laboratory

J. Blair Briggs
Under Contract with the OECD NEA

Guidance for Proprietary Data (In Progress)

(Reactor Name)-(Reactor Type)-(Facility Type)-(Three-Digit Numerical Identifier)
(Measurement Type(s)) (PROP[(3)])

(3) Measurements labelled PROP contain proprietary information that cannot be released without an approved nondisclosure agreement (NDA). It is required that the Evaluators and Internal Reviewers are able to access the information, as well as other technical review group members who agree to sign any necessary NDA.

International Legacy of the ICSBEP

- Success with ICSBEP and IRPhEP has led to ongoing endeavors to similarly benchmark shielding, spent fuel composition, and multiphysics experiment data
- SINBAD
  - https://www.oecd-nea.org/science/wprs/shielding/
- SFCOMPO
  - https://www.oecd-nea.org/science/wpncs/sfcompo/
- EGMPEBV
  - https://www.oecd-nea.org/science/egmpebv/

Pilot SINBAD Technical Review Meeting

- Integrated with ICSBEP/IRPhEP
- 23 Oct 2018
- OECD NEA, Paris
- Chair:
  - Pedro Ortego
    SEA Engineering
    (Spain)
- Interested in participating…

Continued success requires engaged experts and programmatic support

Future Evaluations in Progress

- ATR Experiments
- ATR CIC 2020
- BEAVRS
- DIMPLE CERES
- FCA IX MA
- IPEN Subcriticals
- KRITZ-1
- LR(0) n,2n
- MASURCA BERENICE
- MSRE
- ASPIS-Fe
- PBF
- PFR – MA Irradiations
- PROTEUS GCFR 13
- RB Reactor
- SNEAK 12A & 12B
- TCA Am-241
- TREAT M8CAL
- TREAT M2/M3CAL
- TREAT Restart
- TRIGA Au(n,g)
- VR1 with IRT-4M Fuel
- ZED-2 Reaction Rates

Conclusions

- The IRPhEP and ICSBEP 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?

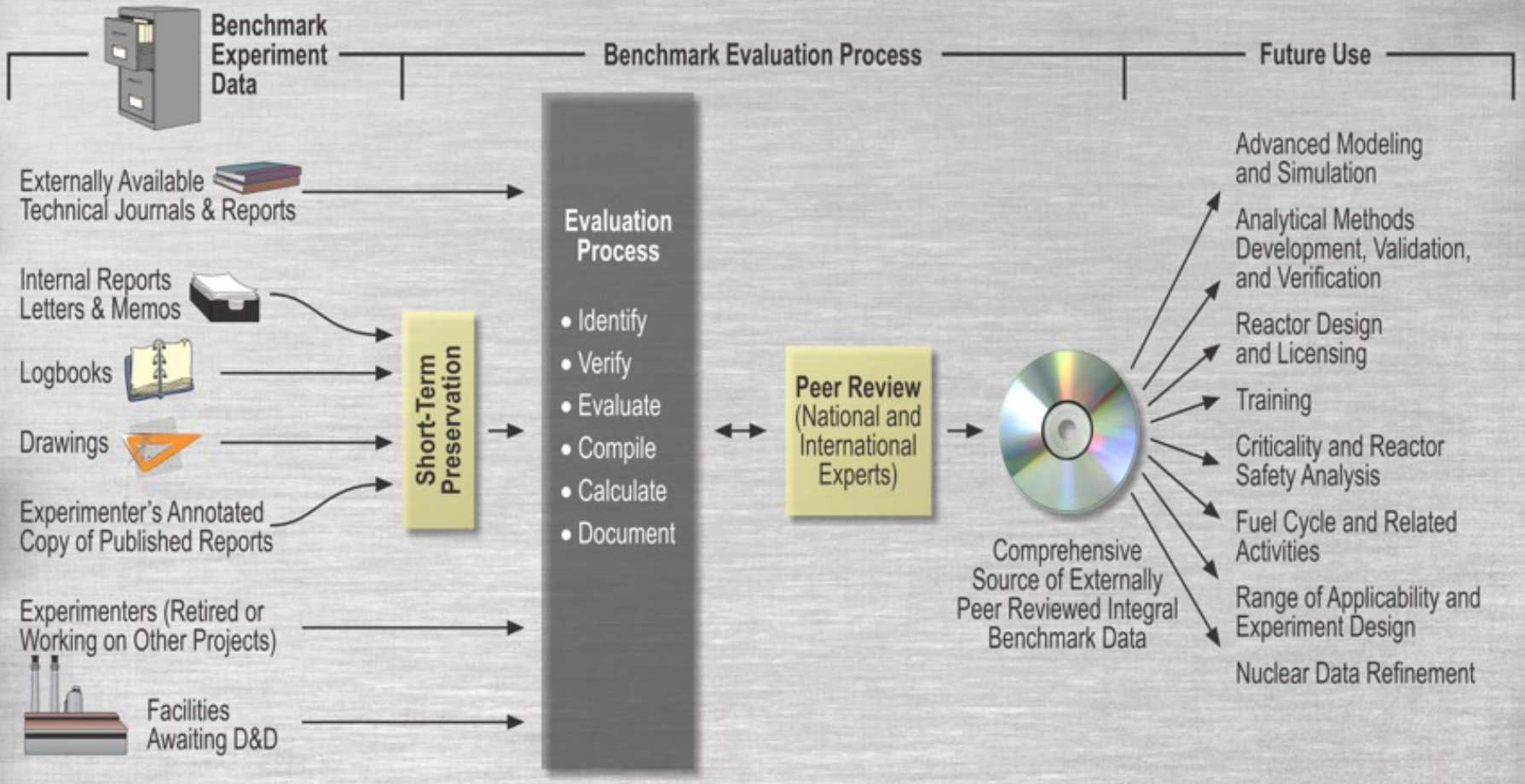
Extra Slides

INTERNATIONAL BENCHMARK PROGRAMS

NEA NUCLEAR ENERGY AGENCY

OECD BETTER POLICIES FOR BETTER LIVES

INL Idaho National Laboratory

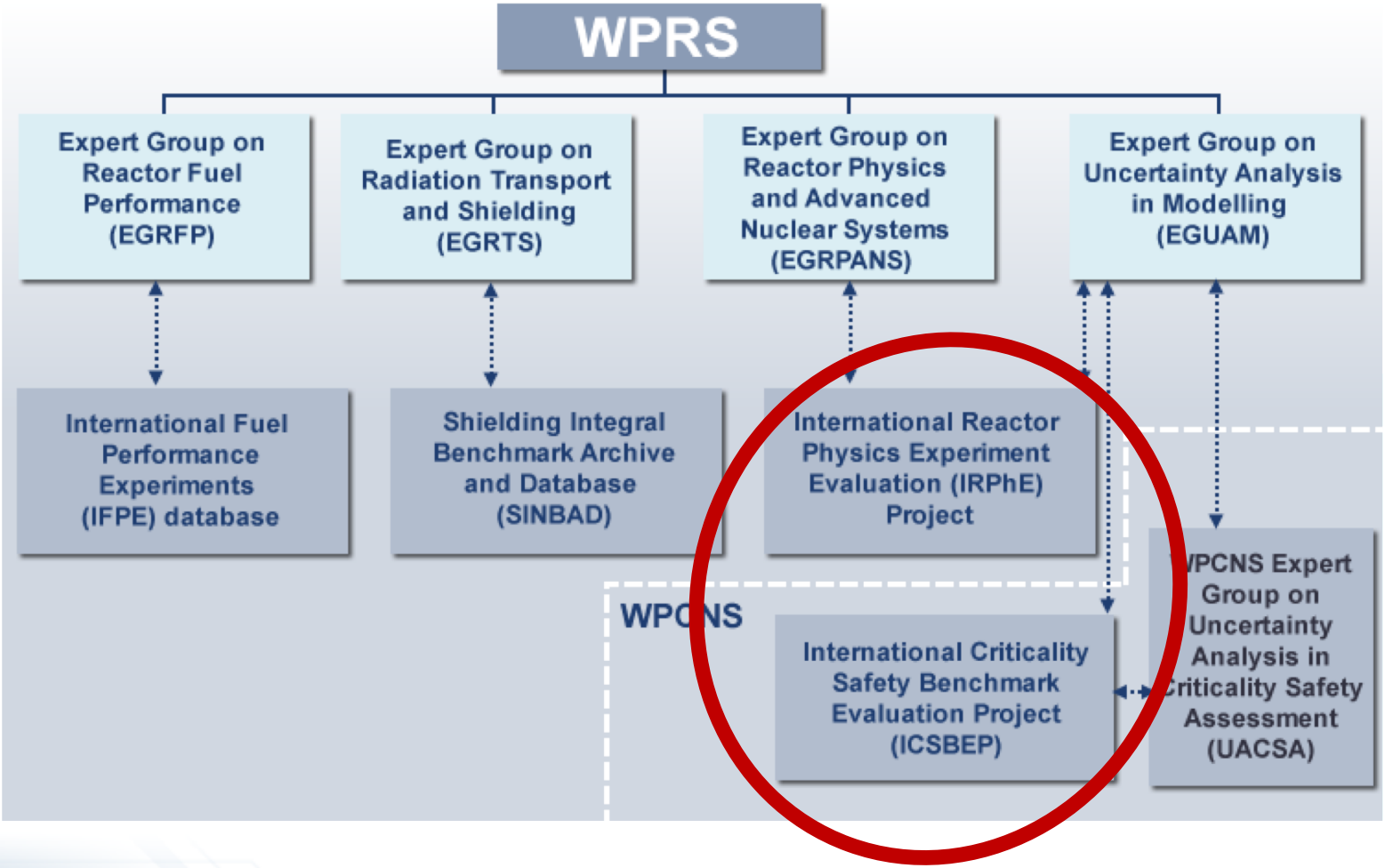


Countries Participating in the ICSBEP & IRPhEP

- 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

Directed and Distributed via the OECD NEA



Idaho National Laboratory

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Chile	Ireland	Norway	Switzerland
Czech Republic	Israel	Poland	Turkey
Denmark	Italy	Portugal	United Kingdom
Estonia	Japan	Romania	United States
Finland	Korea		

Available to Member Countries and Active Participating Facilities