Expanding Benchmarks for Nuclear Data Validation

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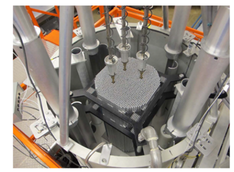
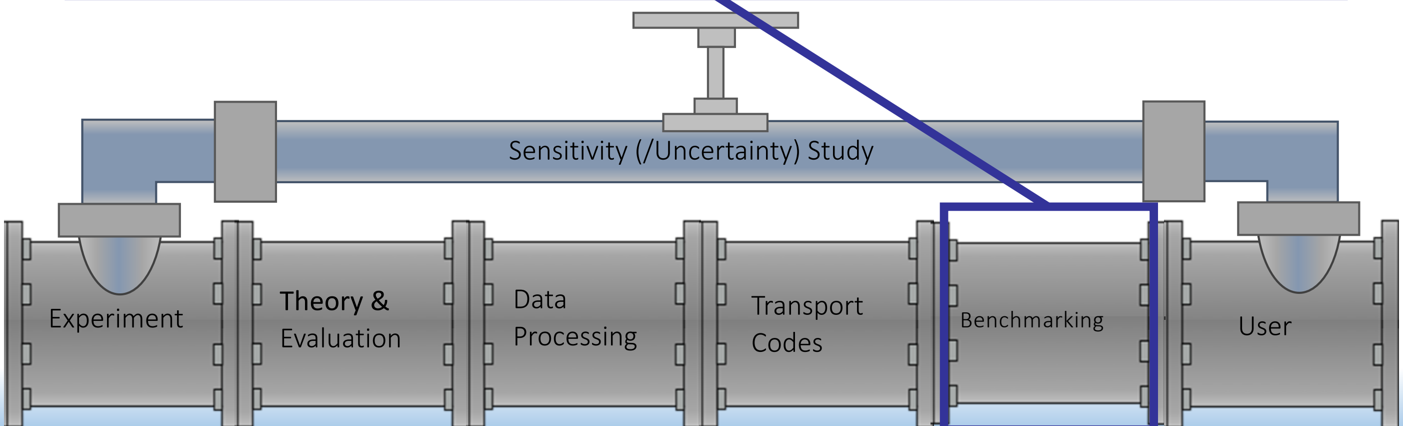
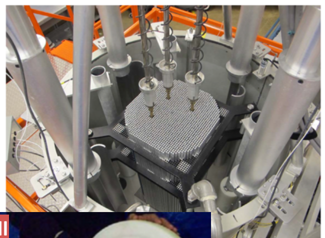
Benchmarking: Comparison to Experimental Truth

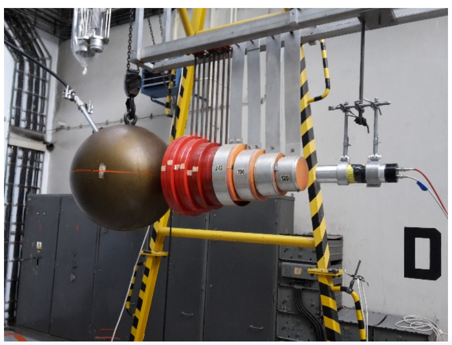
Validation that analytical method adequately represents reality for a given application
Integrated test of:
- **Evaluated nuclear data**
- **Nuclear data processing codes**
- **Transport codes**





Integral Experiments



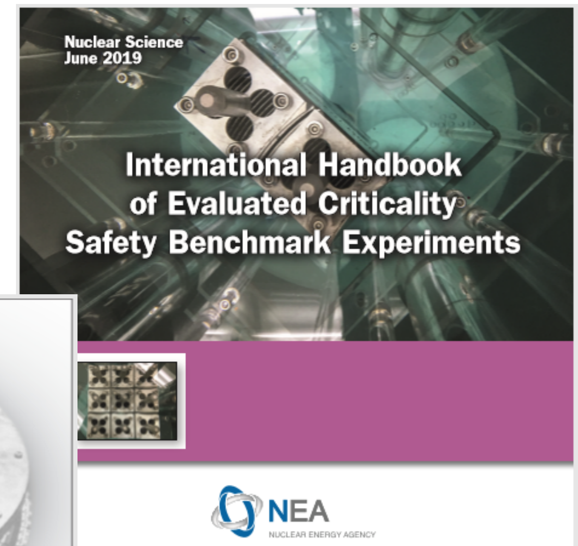


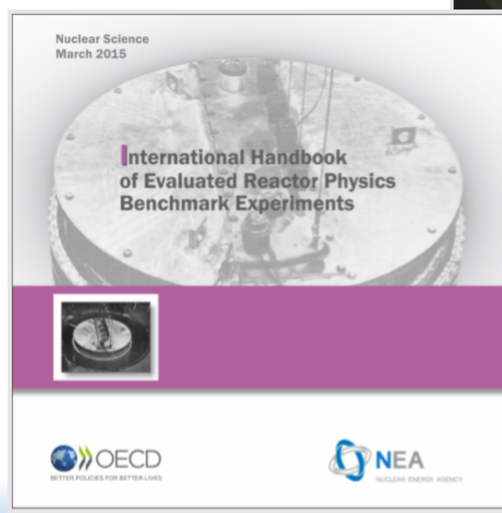
- Tests multiple data (isotopes, reactions, energies) at once
  - May be designed to be particularly sensitive to one piece of data
- Examples:
  - Critical assemblies
  - Subcritical assemblies
  - Engineering mockup critical assemblies
  - Reactor startup experiments
  - Reactor operation data
  - Shielding experiments

Benchmarks Are Evaluated Experiments

- Well characterized experiments
- Evaluate all experimental uncertainties
- Bias and uncertainty for model simplifications
  - Geometry simplifications
  - Room return
  - Material impurities
- Describe benchmark model
- Sample calculation results
- Disseminate for broader use
- Established Handbooks
  - ICSBEP (criticality safety)
  - IRPhEP (reactor physics)
  - SINBAD (shielding)

Skip Kahler and Ian Hill will discuss **Past, Present, and Future Benchmark Efforts**

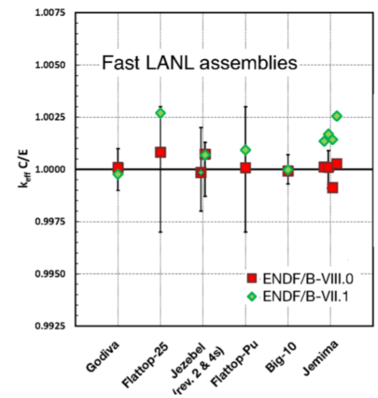


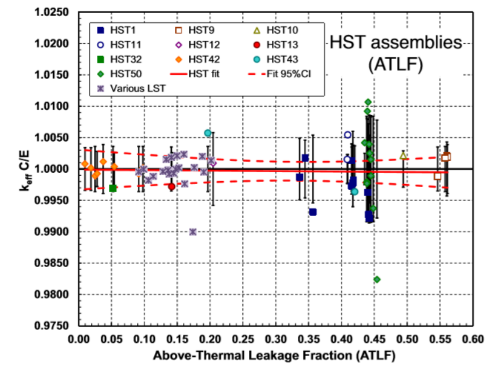


Jerry McKamy will discuss **The Nuclear Criticality Safety Validation Model**

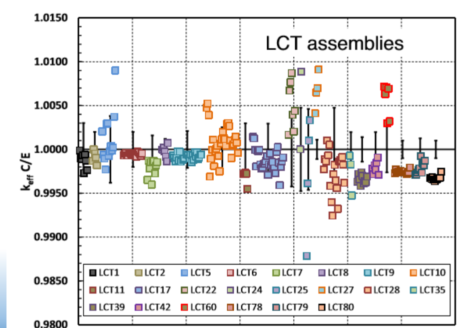
Validation Testing

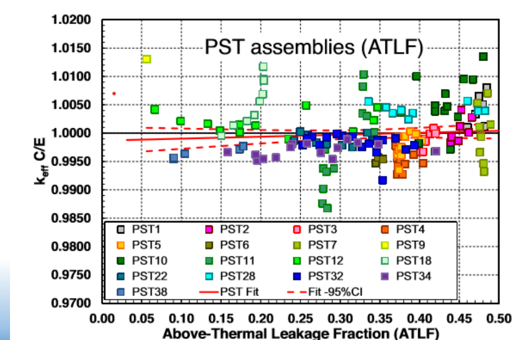
- Suite of benchmarks to validate evaluated nuclear data **for applications**
- Provides feedback to measurement and evaluation community
    - Currently dominated by critical benchmarks, NEED representation from other applications
- Drives improvements in evaluated nuclear data

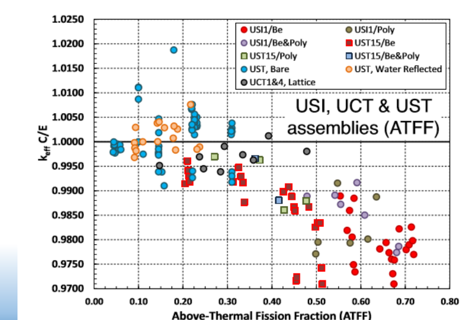




Ref: D. A. Brown, et al., *Nuclear Data Sheets*, **148**, 1 (2018)

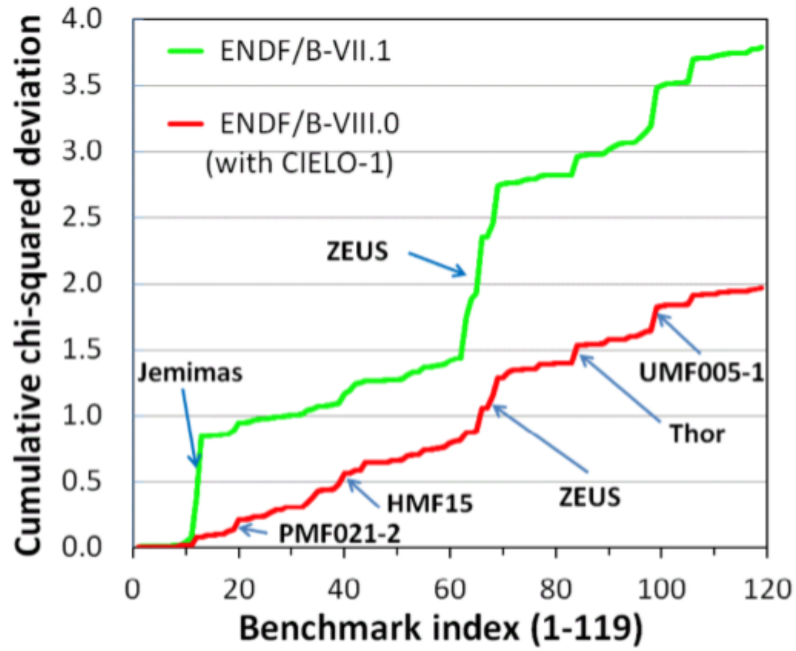






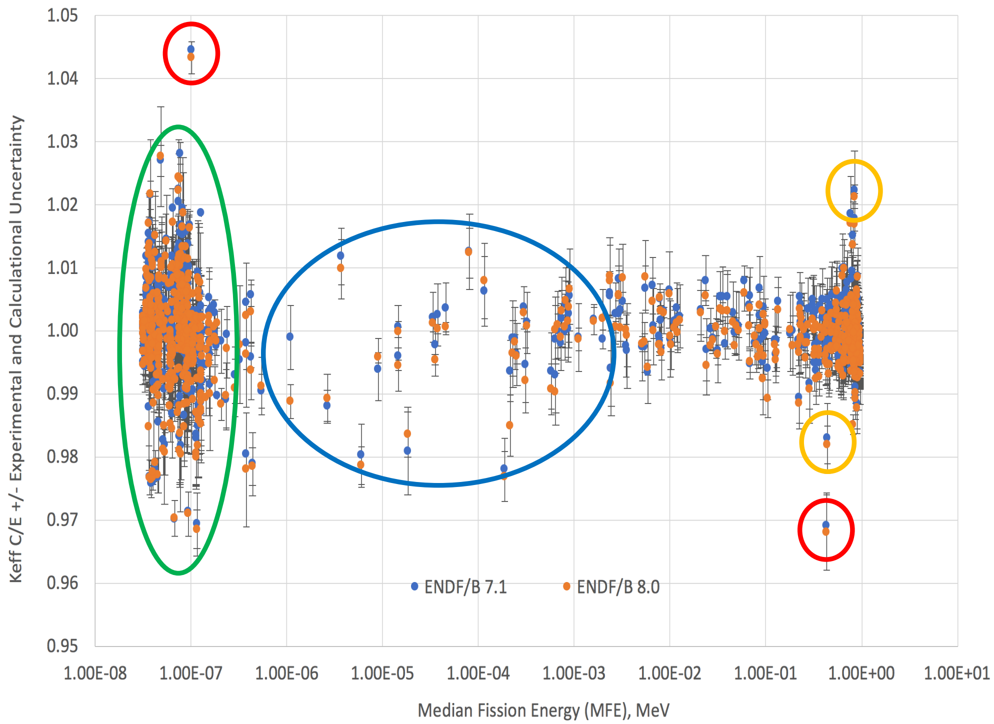
Validation End Product

- **Ultimate goal is to improve evaluated nuclear data for applications**
- Example shows improvement in fast metal systems for ENDF/B-VIII.0
  - Again, critical benchmark dominate
- Provides end-users confidence they can use codes and nuclear data for their applications



M.B. Chadwick et al, Nuclear Data Sheets 148, 189 (2018)

Validation Highlights Errors in the Nuclear Data Pipeline that Affect Applications

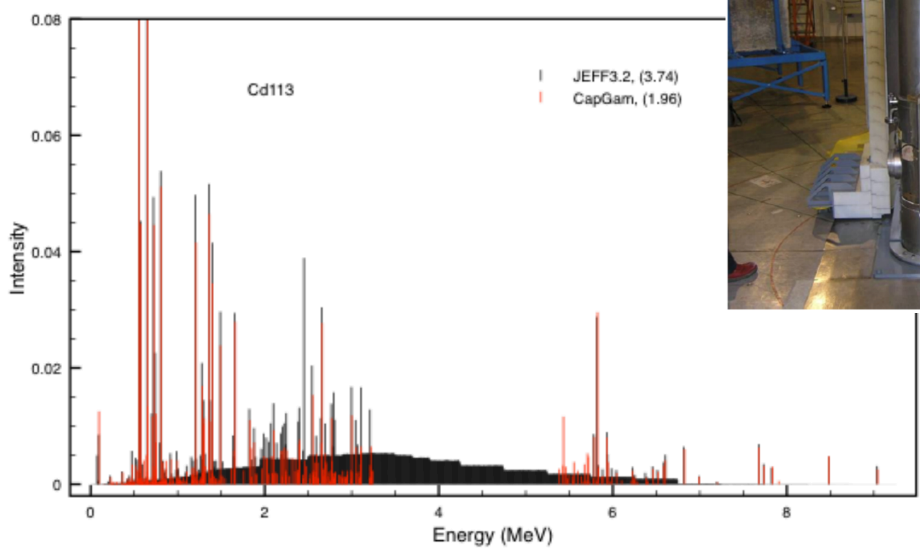


- Could be many issues:
  - Deficiencies in Differential Data
  - Theory/Model Limitations
  - Evaluation Assumptions or Errors
  - Data Processing Problems
  - Code Bug
  - Faulty Benchmark
- Validation allows for systematic prioritization of nuclear data needs
  - Helps determine which data really matters for your application
  - Where will you get the biggest bang for your buck

Example: Missing Cd Capture Gammas in ENDF

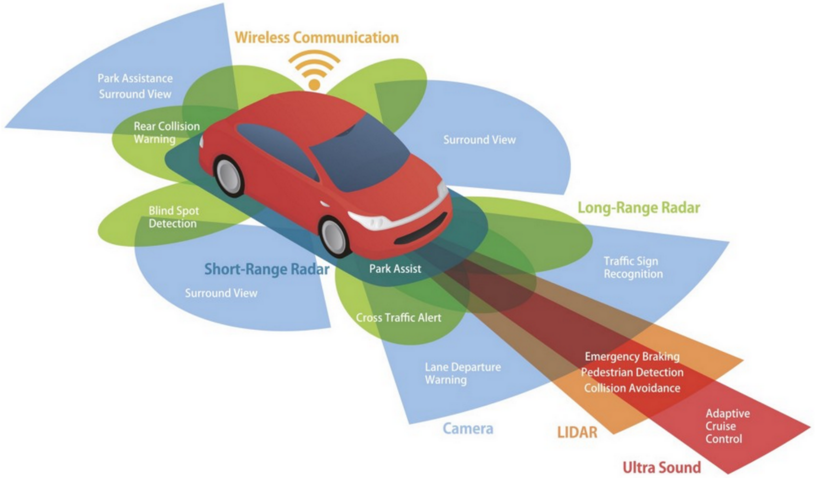
- Comparison of calculation to experiment of gamma dose from the SILENE Pulsed reactor showed **40% discrepancy** when the cadmium-lined polyethylene reactor shield was used

- ENDF/B-VII.1 had **NO gamma production data for ^{113}Cd**, a strong thermal neutron absorber
    - Likely introduced when switching from elemental evaluations to isotopic evaluations
- European data file (JEFF 3.2) did have capture gammas, but they differed significantly from US reference capture gamma database (CapGam)
- New (n, gamma) evaluation needed- still a problem in ENDF/B-VIII.0!



Additional Types of Experiments are Needed to Test Data Used in Applications

- Critical Experiments dominate current validation for all applications
  - Subject to fortuitous cancellation of errors
  - Doesn't test all data for all applications (gamma data, scattering data, time history of fission, etc)
- Many types of integral/semi-integral measurements can provide useful information for validation
  - These supplement/complement existing critical experiments
  - Overlapping coverage, similar to sensor fusion
  - Having multiple types of experiments within validation will help to constrain potential solutions (in this case constrain the nuclear data)
- Here we will present some examples of types of experiments which provide such complimentary information

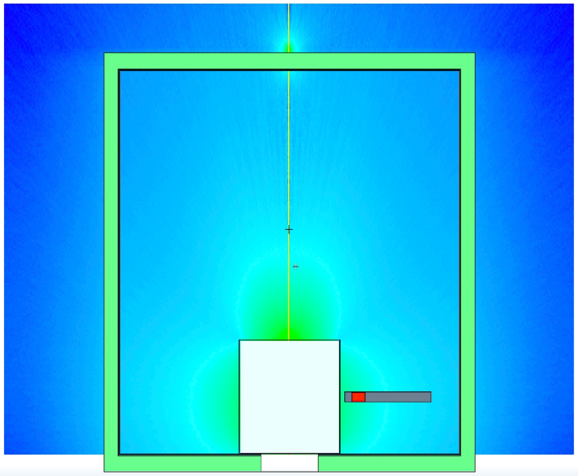


Sensor fusion example of a self-driving car.

Validation Experiments Do Not Have To Be Complicated and Expensive

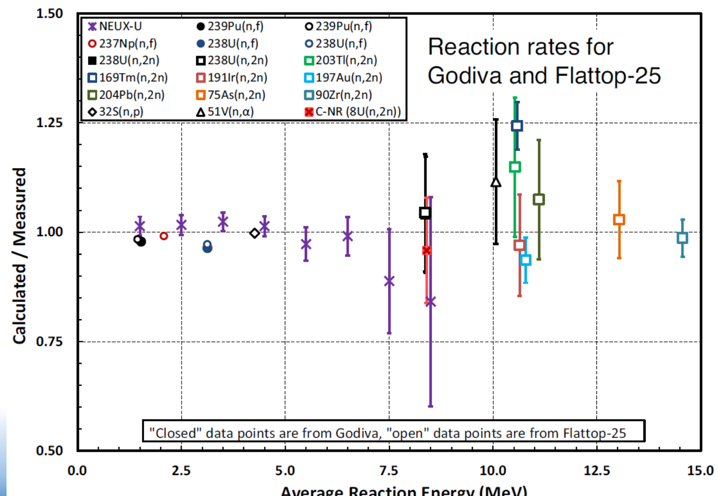
Many existing experiments can become benchmarks in the future (this will be discussed by 5 speakers).

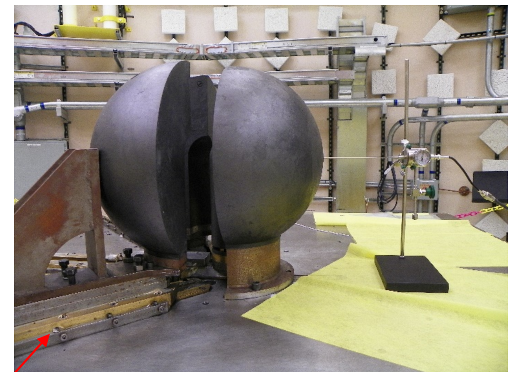
- Example: Pulsed Neutron Die-Away Experiments
- Setup: Neutron Generator, Block of Test Material, Shielded Box, Neutron Detector
  - Uses neutron generator incident on a moderating target, neutrons detected as a function of time highly reliant on Thermal Scattering Law
- Validation: Model experiment in radiation transport code, see how well you can predict neutron detector response



Activation Foil and Fission Chamber Measurements

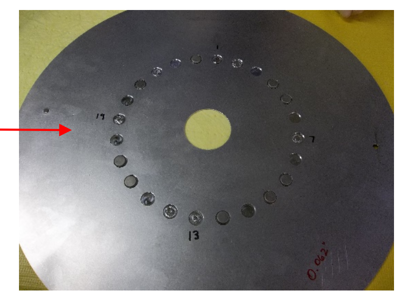
- Used to help infer neutron spectra and reaction rate ratios
  - Ratios have low uncertainties because measurements are correlated
- There is a section on these types of measurements in the ENDF/B-VIII.0 paper (Section XII.D), but it only uses very old critical assemblies





Fission chamber measurements with Flat-Top

Foils used for Comet Zeus irradiation



Reactor Kinetics Measurements

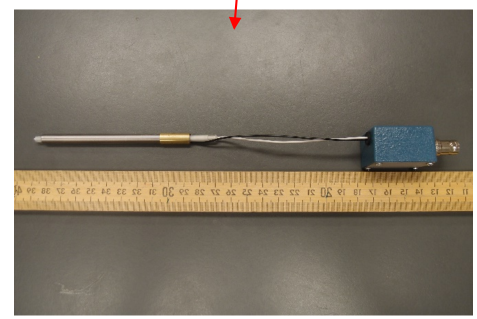
- Reactor kinetics parameters including α, neutron lifetime, and delayed neutron fraction
- The ENDF/B-VIII.0 paper only uses very old critical assemblies for validation
- Recent measurements have been performed on many critical assemblies (NCERC, IPEN, etc.)

TABLE XXXV. The values for $C/E-1$ for the Rossi-α calculations. The uncertainty quoted for $C/E-1$ includes only the statistical uncertainty of the calculation. All the cases have a thermal spectrum, except for Big Ten.

	Experiment $-\alpha$ (s^{-1})	ENDF/B VIII.0 $C/E-1$ (%)	ENDF/B VII.1 $C/E-1$ (%)	JENDL 4.0 $C/E-1$ (%)	JEFF 3.1.1 $C/E-1$ (%)
SHE/core8	6.53e-3 (5.2%)	0.1±1.0	-1.2±1.2	-2.1±1.0	-3.5±1.0
Sheba-II	200.3e-6 (1.8%)	-4.0±1.4	-3.7±1.5	1.6±1.5	4.7±1.4
Stacy/run-029	122.7e-6 (3.3%)	-0.9±1.2	-0.2±1.2	0.1±1.2	3.5±1.2
Stacy/run-033	116.7e-6 (3.3%)	-0.4±1.2	-1.0±1.2	0.3±1.2	0.2±1.2
Stacy/run-046	106.2e-6 (3.5%)	-1.3±1.2	0.2±1.2	-2.3±1.2	0.7±1.1
Stacy/run-030	126.8e-6 (2.3%)	1.3±1.2	-1.3±1.2	0.1±1.2	0.9±1.2
Stacy/run-125	152.8e-6 (1.7%)	-0.6±1.2	0.9±1.2	3.3±1.2	3.2±1.2
Stacy/run-215	109.2e-6 (1.6%)	-1.1±1.2	-1.5±1.2	-1.3±1.2	0.0±1.2
Winco	1109.3e-6 (0.1%)	1.4±1.0	1.6±1.0	-1.9±1.0	0.7±1.0
Big Ten	117.0e-6 (0.9%)	-2.1±1.4	1.6±1.5	4.1±1.4	-0.3±1.5

ENDF/B-VIII.0 α validation

Small He-3 tubes: 4 He-3 tubes (40 atm), ¼" in diameter, often used for Rossi-α measurements



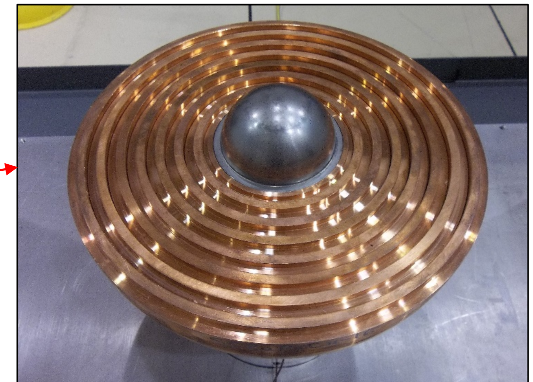
Experiment	Measured (s^{-1})	Simulated (s^{-1})	(C-E)/E
Polyethylene Class Foils	-1.994 E2	-2.040 E2	0.0231
HEU Zeus	-8.991 E4	-1.000 E5	0.1128
HEU/Pb Zeus	-3.826 E4	-4.626 E4	0.2092
IEU/Pb Zeus	-5.635 E4	-6.229 E4	0.1053
KRUSTY	-1.136 E3	-1.201 E3	0.0568
Jupiter	-1.731 E4	-1.930 E4	0.1145

McKenzie, ICNC 2019

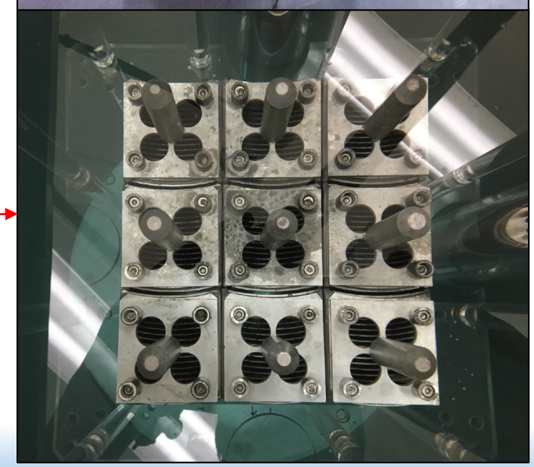
Subcritical Measurements

- Subcritical experiments can provide useful information about neutron multiplicity
- Useful for both nuclear data (detailed physics of fission) and computational methods validation (FREYA and CGMF)
- Many different data can be validated from a single measurement
- Important for several application areas
  - Safeguards and treaty verification
  - Nonproliferation
  - In-core/spent fuel monitoring

SCRaP experiment (4.5 kg Pu with Cu reflection)



ISSA experiment (water-moderated HEU uranium oxide)



Experiment summary

- In addition to the measurement types discussed here, many other integral/semi-integral measurements should be considered for use in validation:
  - Pulsed spheres/transmission measurements
  - Gamma/neutron spectra
  - Reactivity coefficients
  - And many others
- Three types of experiments will be explored in this session:
  - Those that are already benchmarks but are under-utilized
  - Those that have been performed but are not benchmarks
  - Gaps in which new experiments are needed to meet application needs

All Applications Need Validation

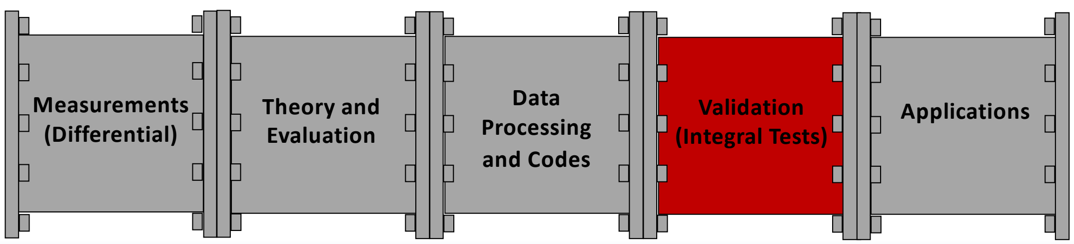
1) Understand what nuclear data are being used (reactions, isotopes, etc)

2) Look at your validation suite and ensure all the important data are being tested and benchmarked against “ground truth”

3) Ensure that the validation data (and sensitivities) can be easily utilized

4) Ultimately use results of validation to prioritize funding of all other pipeline sections
   - Likely starting with funding validation experiments and expanding benchmarks!

Four specific application areas will be presented (and additional application areas will be discussed).



Mike Rising and Denise Neudecker will discuss **Data Evaluation and Sensitivity and Uncertainty Methods Development**

Session Schedule

- **Overview of Benchmarks and their Uses for Nuclear Data**
  - Jesson Hutchinson (LANL), Catherine Percher (LLNL), Michael Zerkle (NNL)
- **Past, Present, and Future Benchmark Efforts for Nuclear Data Validation**
  - Skip Kahler (LANL retired), Ian Hill (OECD/NEA)
- **Experimental Measurements that Could Become Benchmarks**
  - Sara Pozzi (UM), Jesse Holmes (NNL), Yaron Danon (RPI), Amanda Lewis (NNL), John Mattingly (NCSU)
- **The Nuclear Criticality Safety Validation Model**
  - Jerry McKamy (DOE NCSP, retired)
- **Application Areas- Nuclear Data, Validation Methods, and Integral Needs**
  - Thomas Miller (ORNL), Brad Reardon (X-Energy), David Matters (NA-22), Pablo Romojaro (SCK CEN)
- **Data Evaluation and Sensitivity and Uncertainty Methods Development**
  - Denise Neudecker (LANL), Michael Rising (LANL)