Expanding Benchmarks for Nuclear Data Validation

Michael Zerkle
Naval Nuclear Laboratory, USA

Catherine Percher
Lawrence Livermore National Laboratory, USA

Jesson Hutchinson
Los Alamos National Laboratory, USA

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)

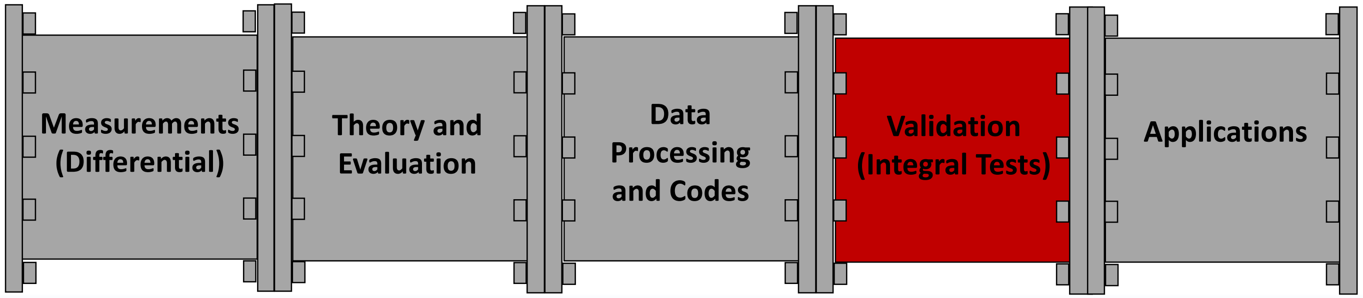
All Applications Need Validation

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"

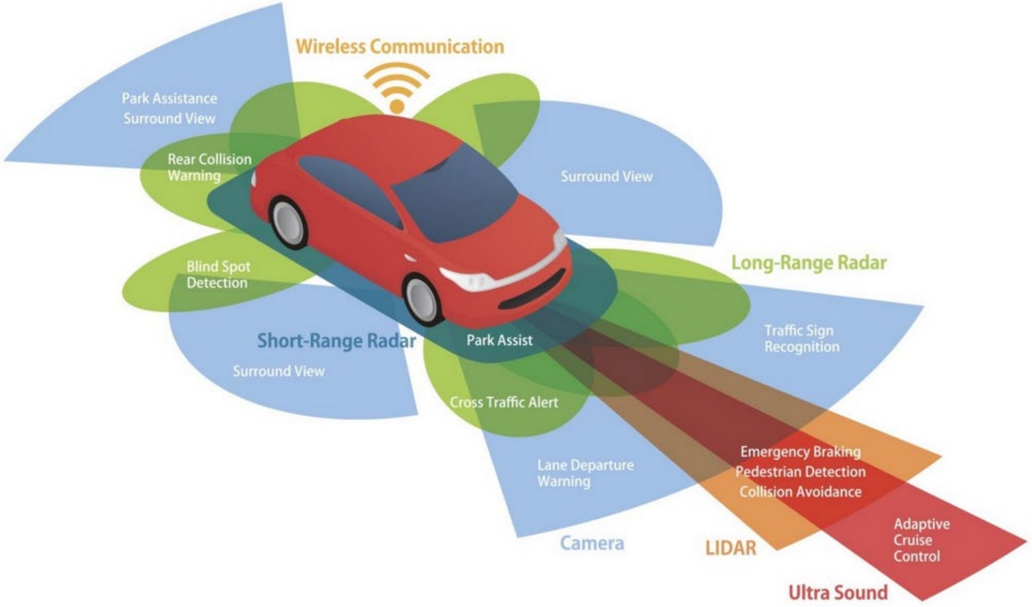
3) Ensure that the validation data (and sensitivities) can be easily utilized

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



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

- Current validation is dominated by critical experiments
- Many types of integral/semi-integral measurements can provide useful information for validation
  - Overlapping coverage, similar to sensor fusion
- Three types of experiments were 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



Sensor fusion example of a self-driving car.

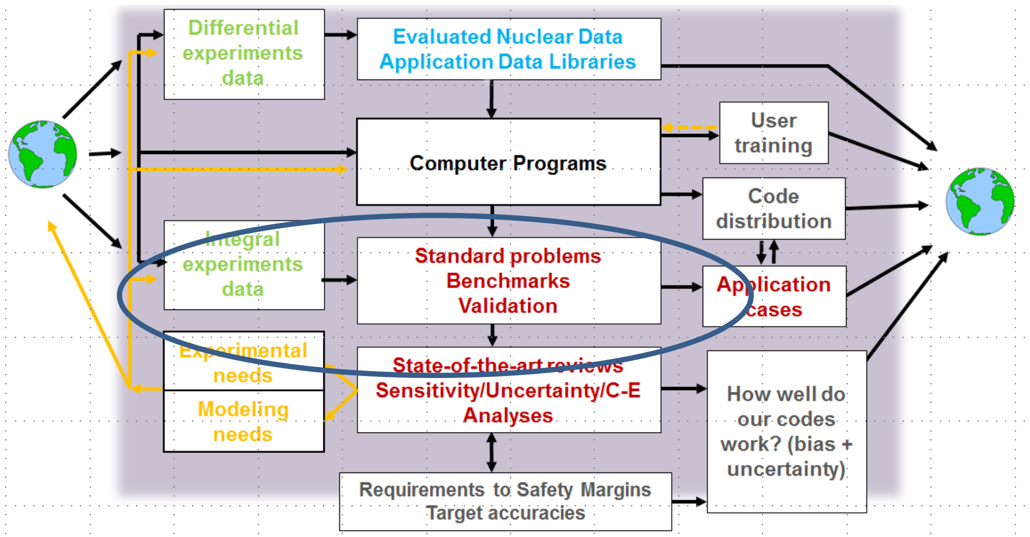
Oveview of Historical Experiments Used for Validation

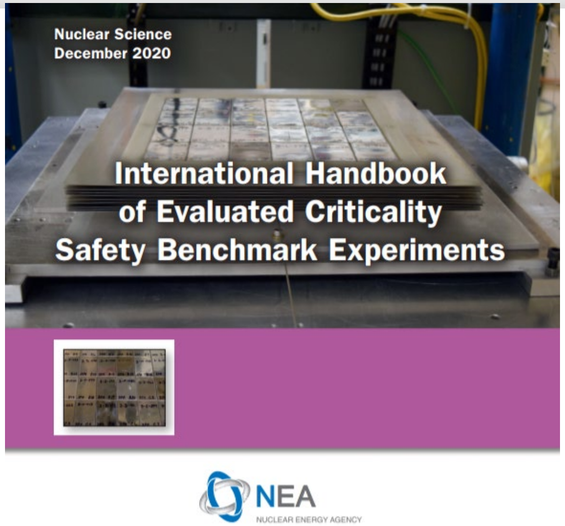
Skip Kahler, LANL (retired) “Don’t Forget What We Already Know”

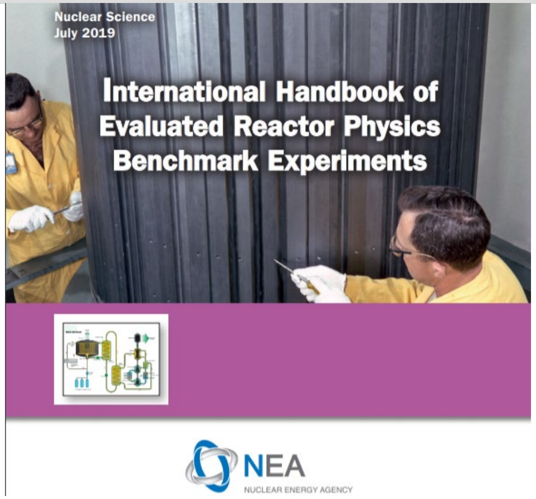
- CSEWG Benchmark Book
  - See links to ENDF-202, and more, at https://www.nndc.bnl.gov/endfdocs/.
  - Includes categories for FAST Reactor Benchmarks, THERMAL Reactor Benchmarks, SHIELDING Benchmarks, DOSIMETRY Benchmark
  - Unique Data not present elsewhere (actinide reaction rates, activation rates, Rossi-α, reactivity worth, and leakage spectra data)
- IAEA Technical Report Series #480: Research Reactor Database: Facility Specification and Experimental Data
- Many additional resources available through DOE’s OSTI
  - Extensive Koponen bibliography (mostly criticality experiments)

Ian Hill: Validation Benchmarks

Experiments, Nuclear Data, Computer Programs, Verification & Validation, Feedback, Users







ICSBEP
~5000 Cases
~620 Evaluations
~4000 SDFs
IRPhEP
~200 REAC
~200 SPEC
SINBAD
~100 Experiments
SFCOMPO
~700 Samples

ICSBEP → IRPhEP → SINBAD** → SFCOMPO

CIELO O16

Sized by: Trust, Usability*

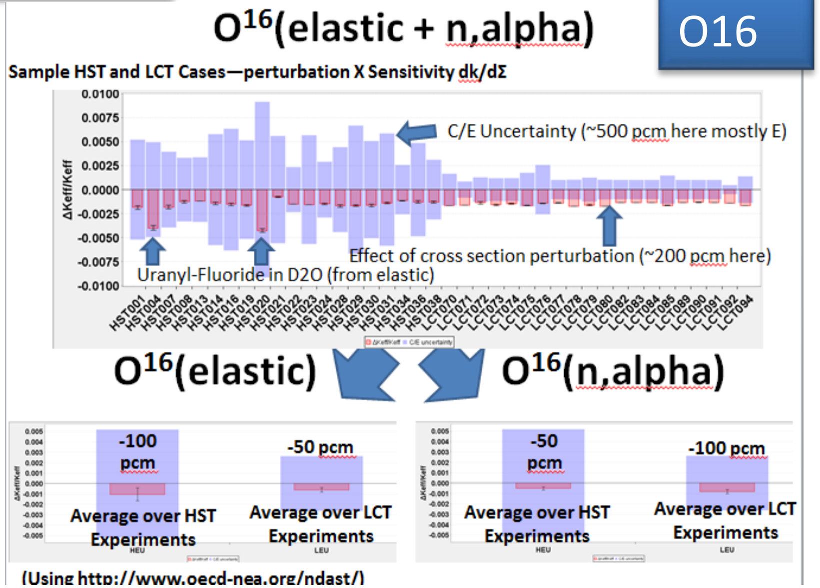
* Knowledge/retrievability of resource, Availability of inputs, Response functions
**In cooperation with RSICC

Efforts underway to improve SINBAD and SFCOMPO

Speed and Signal to Noise Ratio:

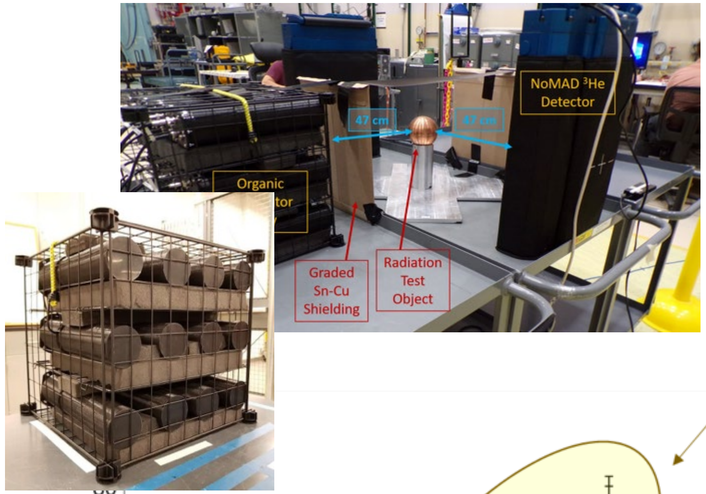
Recently Developed Rapid feedback tools linking sensitivity profiles and Integral experiments were used for ENDF/B-VIII.0

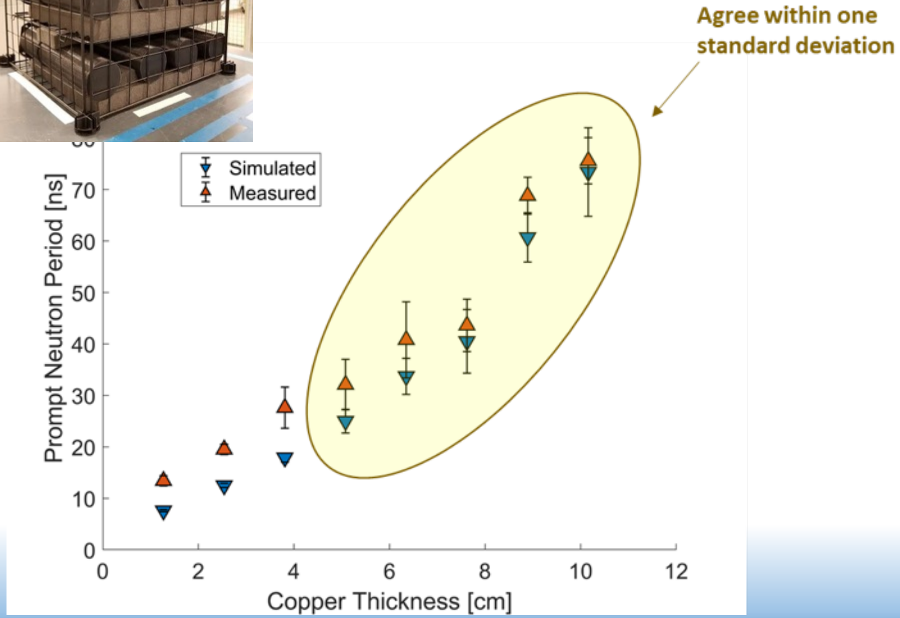
- Feedback loop changed months into minutes.
- But some feedback loops take years (even a decade); can be reduced to minutes also!
- NDaST, ADVANCED, CRATER.



Experiment Types: Subcritical Experiments

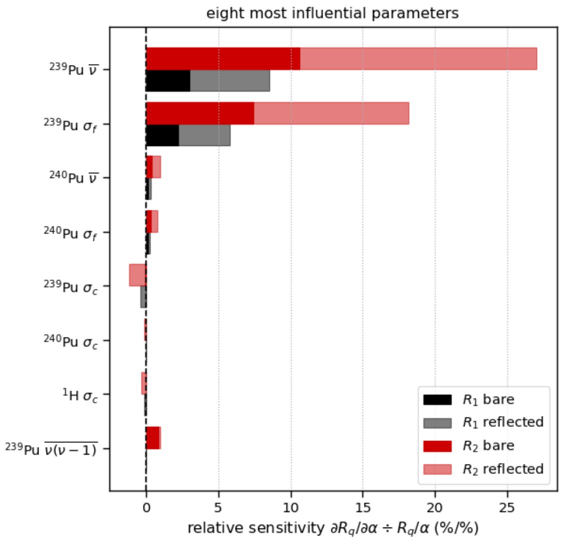
Sara Pozzi, UM, Organic Scintillators





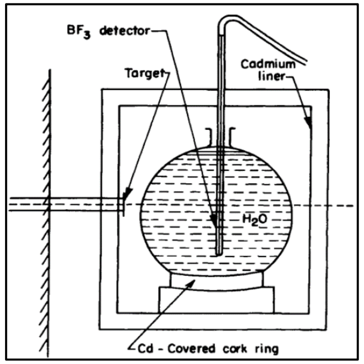
- Useful for both nuclear data (**neutron multiplicity**, detailed physics of fission) and **computational methods validation** (FREYA and CGMF)
- Many different data can be validated from a single measurement
- **Important for several application areas**
  - Safeguards and treaty verification
  - Nonproliferation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

John Mattingly, NCSU, Data Feedback



Experiment Types: Quasi-Integral Measurements

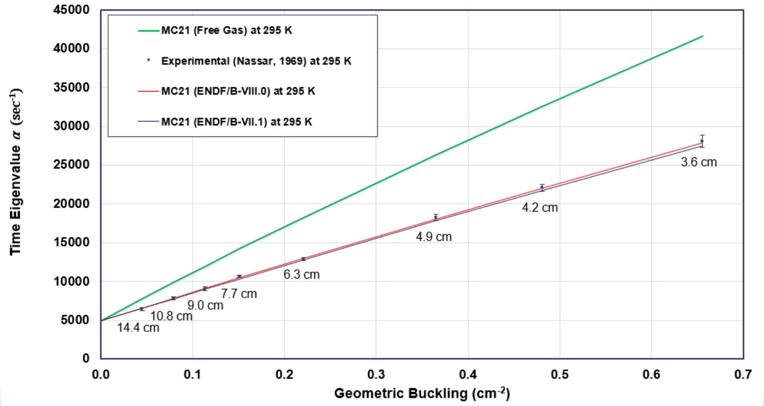
Jesse Holmes, NNL, Pulsed-Neutron Die Away



Highly sensitive to Thermal Scattering

Inexpensive experiments with no fissile materials

Low experimental uncertainties with shielded measurements

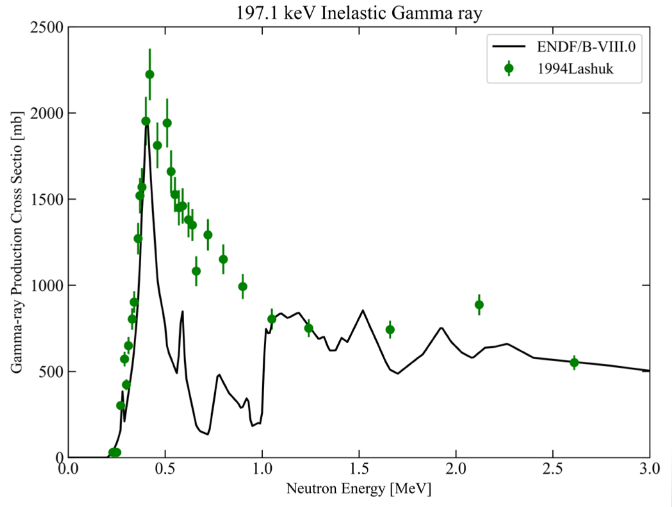


Amanda Lewis, UCBerkeley/NNL, Baghdad Atlas Gamma Spectra

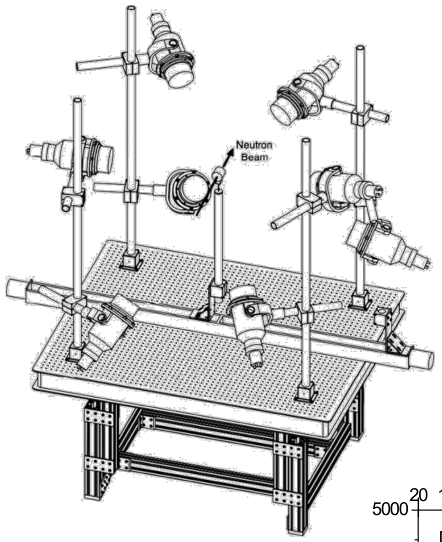
Neutron flux from 1970's Baghdad reactor used to induce gamma rays from 105 targets

Uncertainties come from fitted neutron flux, detector response and efficiency

New, similar experiments would be useful



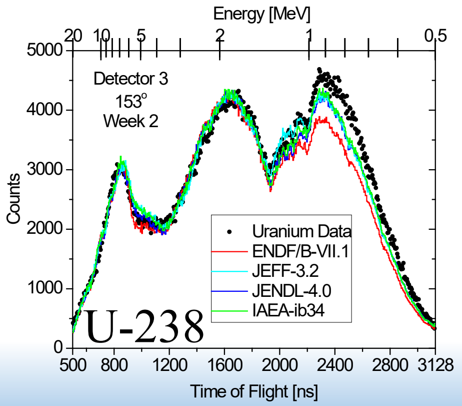
Yaron Danon, RPI Neutron Induced Neutron Emission



Typical systematic uncertainty is of the order of 5%

Experiments performed for Be, Mo, Fe, Pb, Cu, Zr, U-238, U-235, Pu-239

Sensitive to elastic and inelastic scattering



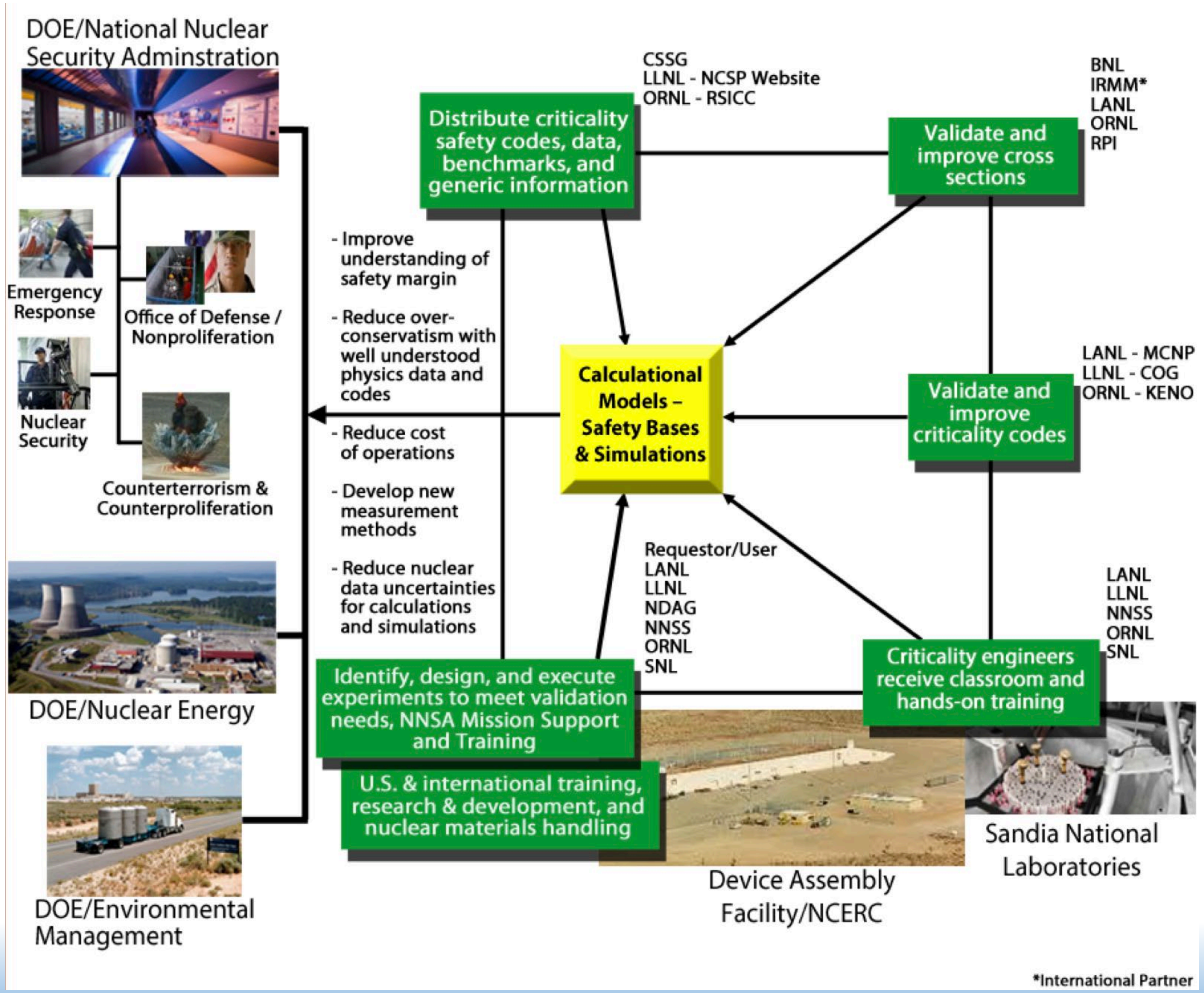
The Nuclear Criticality Safety Program Model

Jerry McKamy (DOE, Retired)

Calculations depend on:

- The physics and calculations of the code being accurate with no errors;
- Having all needed differential nuclear data measured with known precision; and,
- The evaluated nuclear data files used by the code accurately representing the differential nuclear data.

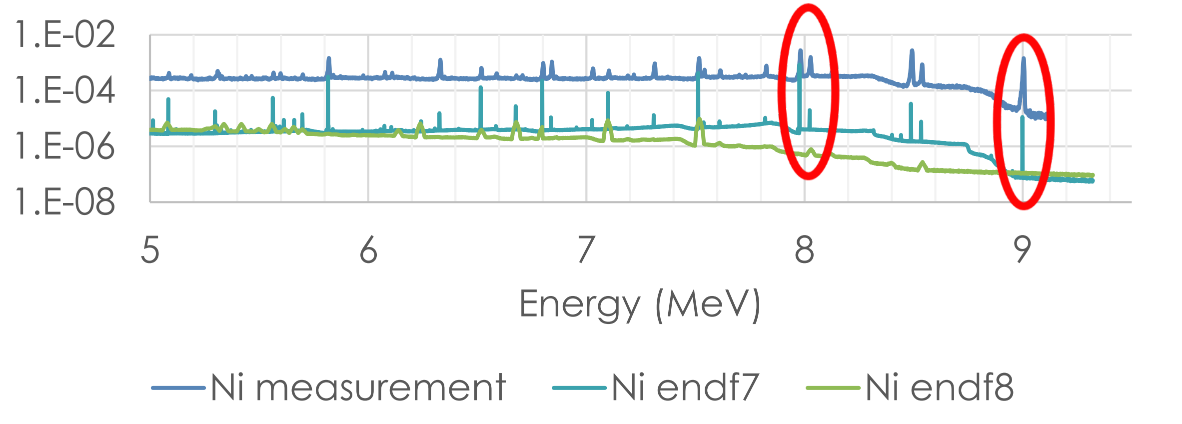
NCSP has a validation-driven holistic approach to funding the entire nuclear data pipeline



Benchmark Needs: Gamma Data from (n,ɣ) (n,n' ɣ)

Thomas Miller, ORNL
Shielding Needs

- Benchmarks measuring integral quantities like gamma dose are helpful and needed
- **Benchmarks that measure gamma spectra would be ideal**
  - Be sure one can identify the element/isotope producing the gammas
  - Be sure the neutron energy is well defined



David Matters, NA-22
Defense Nonproliferation Needs

NA-22 needs benchmark data on elements that comprise structural and shielding materials, controlled or dangerous substances, and detector materials

Gamma Production Data Priorities for Active Neutron Interrogation

First Priority	Follow-up	Remaining	
H	He	F	Gd
C	Li	Mg	Bi
N	Be	P	Np
O	B	S	Am
Na	Cl	Ar	
Al	Cr	K	
Si	Mn	Ca	
Fe	Ni	Ti	
Cu	Ge	As	
Pb	Br	Kr	
W	Cd	Mo	
U	I	Sn	
Pu	Cs	Sb	
	La	Xe	

Benchmark Needs: Advanced Reactor Nuclear Design Products (NDPs)

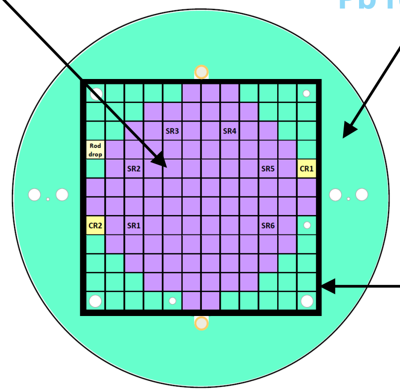
Brad Reardon, X-Energy
Advanced Reactor Needs

- Small and precise reactors require optimized power and lifetime predictions
  - **Power distribution, Reactivity control and shutdown margin, Fission product inventories**
- Close proximity to public and need for low mass solutions require **precise source term and shielding data**
  - Prompt neutrons and gammas from fission, Gamma emissions from fission product decay, Material activation and decay, Neutron and gamma attenuation
- **Thermal scattering law data**
  - Unique moderators/coolants
  - Large temperature ranges
- Irradiation damage assessment is needed for wide range of materials

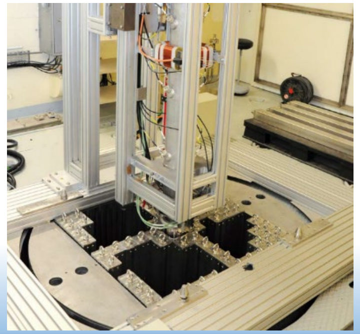
Pablo Romojaro, SCK-CEN
Accelerator Driven System for Transmutation

30% U metallic fuel + Pb "coolant" (solid Pb, alternatively Bi)

Pb reflector



SS



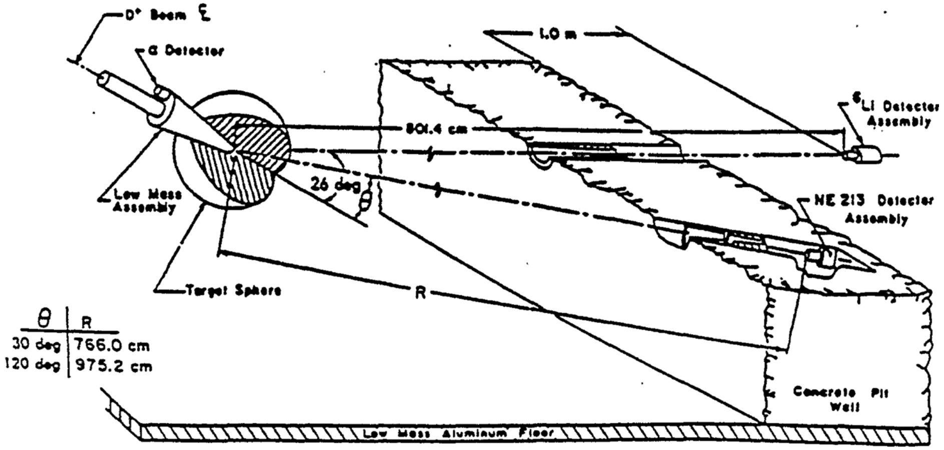
Conducted targeted benchmark experiments during MYRRHA design

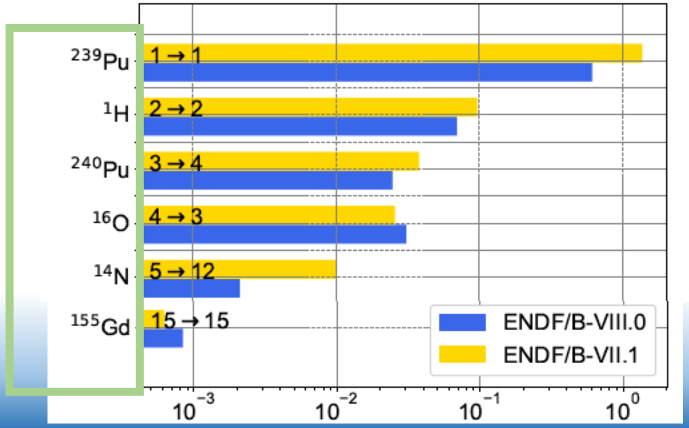
Nuclear data needs in JEFF-3.3 for MYRRHA:

- Adoption of JENDL-4.0 evaluation for ^{204}Pb or re-evaluation in the RRR and URR
- New evaluation ^{57}Fe(n,inel.) including missing resonances
- Re-evaluation ^{10}B(n,inel.) uncertainty
- Covariance evaluation for ^{209}Bi(n,n) and ^{209}Bi(n,γ)
- Covariance evaluation for ν_T, ν_p, ν_d ^{240}Pu & ν_d ^{235,238}U and ^{239,242}Pu
- Reduction of uncertainty ^{240}Pu(n,f)
- Reduction of uncertainty ^{54,57}Fe(n,n)
- Reduction of uncertainty ^{208}Pb(n,n)
- Reduction of uncertainty ^{238}U(n,inel.)

Constraining Nuclear Data and S/U Methods Development

Denise Neudecker, LANL
Constraining Data with Pulsed Spheres





Mike Rising, LANL
Data Analysis Tools for Other Benchmark Types

High-fidelity sensitivity tools and methods are needed to perform **modern validation** for more diverse benchmarks and applications

- Criticality (k_{eff})
  - ICSBEP - criticality safety analyses
- Subcritical Multiplication
  - Singles/doubles rate, leakage multiplication
- Electron/photon physics
- High-energy physics (model physics)
- Reactor physics and kinetics
  - Reaction rates
  - Reactivity/void coefficients
  - Rossi-alpha, β_{eff}
- Shielding, fixed-source applications
  - SINBAD neutron/photon benchmarks

Summary

- All Applications need Benchmarks
  - Test the data that are important
  - Test the codes that make predictions
    - Application codes
    - Data processing codes
    - Sensitivity and uncertainty tools
  - Sharing benchmarks with the nuclear data validation community will result in more robust nuclear data and improved predictions for your applications
- Criticality benchmarks dominate data validation because of the NCSP investment in experiments, benchmarking, codes, and data
  - Current ICSBEP framework can support additional experiment types (don’t need to reinvent the wheel)
- Many cross-cutting benchmark needs across applications (opportunities for shared funding)