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Proceedings of the 2018 Nuclear Data Road-mapping and Enhancement Workshop (NDREW)

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Office of Defense Nuclear Nonproliferation Research and Development

Nuclear Data Roadmapping and Enhancement Workshop (NDREW) 2018

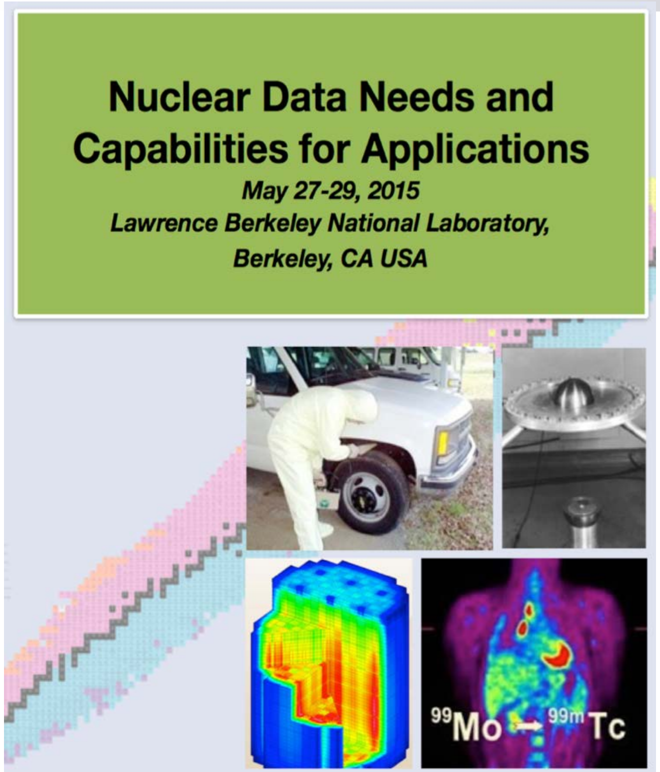
NDREW Goals and Historical Context

Catherine Romano
Oak Ridge National Laboratory

January 23 - 25, 2018

OUTLINE

- Definitions
- Historical Context
- Agenda and Meeting Structure
- Meeting Goals
- Participant Guidance



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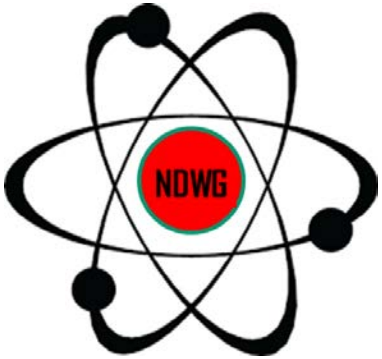
Cross-cutting needs

1. **Dosimetry Standards:** for E_n up to 60 MeV to support the International Fusion Materials Irradiation Facility (IFMIF), accelerator-driven systems (ADSs), and spallation sources
2. **Fission:** the "Mother of All Fission Experiments," where *TKE(A)*, *n*, *g*'s fragment yields for a range of actinides for E_n=thermal-20+ MeV
3. **Decay Data and g-Branching Ratios:** includes an International Atomic Energy Agency (IAEA) list of decay data for "certain medical isotopes"
4. **Neutron Transport Covariance Reduction:** particular need for actinide (n,x) cross sections from 1–1000 keV
5. **Expanded Integral Validation:** includes semi-integral data (e.g., pulsed sphere) to diagnose (n,n_{el}), (n,n_{inel}) shortcomings.
6. **Antineutrinos from Reactors:** includes a specific call for new data for ^{235,238}U and ^{239,241}Pu…fission yields for odd-odd nuclei and b-spectral measurements.

http://bang.berkeley.edu/events/NDNCA/whitepaper

Nuclear Data Working Group (NDWG)

- **Several program managers met to discuss a path forward**
- **Conclusion: it is beneficial and necessary to communicate and coordinate nuclear data efforts**
- **IDEA: facilitate communication and coordination through a group of program representatives made up of nuclear data experts at the national laboratories**
- **The NDWG will:**
  - Identify and prioritize nuclear data needs
  - Propose collaborative solutions



NDWG Participants

Partners	Program Manager	Program Area	NDWG Member	
NNSA/DNN R&D	Donny Hornback	Proliferation Detection	Catherine Romano Candido Pereira	ORNL ANL
DOE/SC/Nuclear Physics	Tim Hallman Ted Barnes	Nuclear Physics/Nuclear Data	Lee Bernstein Dave Brown	LLNL BNL
NNSA/DNN R&D	Tom Keiss	Forensics / Post Det.	Todd Bredeweg Jason Burke	LANL LLNL
DNDO	Namdoo Moon	Nuclear Detection		LANL
NNSA/NCSP	Angela Chambers	Criticality Safety	Mike Zerkle	LANL
NNSA/Defense Prog.	Ralph Schneider Staci Brown	Research and Development	Teresa Bailey	LLNL
NNSA/Defense Prog.	Douglas Wade	Physics and Engineering Models	Bob Little	LANL
DOE/Nuclear Energy	Dan Funk	Nuclear Energy	Brad Rearden	INL
DNDO /Forensics	William Ulicny Jeff Morrison	Forensics	Richard Essex	NIST
NNSA /Forensics	Tom Black Steve Goldberg	Nuclear Technical Forensics	Bob Rundberg	LANL
Isotope Program	Dennis Phillips	Isotope Production	Meiring Nortier	LANL
NNSA/Nuclear Safeguards	Arden Dougan	Safeguards Technology	Sean Stave	ORNL
NNSA/DNN R&D	Chris Ramos	Safeguards	Chris Pickett	ORNL
		Additional Expert Contributors	Mark Chadwick Patrick Talou Alejandro Sonzogni	LANL LANL BNL

FY 2016 NDWG Goal

Present a five-year experimental plan that best meets the needs of multiple programs while leveraging existing projects, facilities, and expertise to minimize costs

Why an Experimental Plan?

National Nuclear Security Administration

- OECD/NEA WPEC Nuclear Data High Priority Request List (HPRL), https://www.oecd-nea.org/dbdata/hprl/ (2015).
- R. Bahran, S. Croft, J. Hutchinson, M. Smith, and A. Sood, "A Survey of Nuclear Data Deficiencies Affecting Nuclear Non-Proliferation," *Proc. of the 2014 INMM Annual Meeting*, Atlanta GA, LANL Report LA-UR-14-26531.
- P. Santi, D. Vo, et al. "The Role of Nuclear Data in Advanced Safeguards," P*roc. Of Global 2007: Advanced Nuclear Fuel Cycles and Systems*, Boise, ID pp. 1670–1678 (2007).
- D. McNabb, *Nuclear Data Needs for Homeland Security*, LLNL Report UCRL-MI-207715 (2005).
- T. Yoshida et al., *Assessment of Fission Product Decay Data for Decay Heat Calculations*, OECD/NEA WPEC Subgroup 25, ISBN 978-92-64-99034-0 (2007).
- A. Plompen, *IAEA Report on Long-term Needs for Nuclear Data Development*, INDC(NDS)-0601 (2012).
- A.L. Nichols, S.M. Qaim, and R. Capote Noy, *IAEA Intermediate-term Nuclear Data Needs for Medical Applications*, INDC(NDS)-0596 (2015).
- IAEA 591, *Consultants' Meeting on Improvements in charged-particle monitor reactions and nuclear data for medical isotope production*, INDC(NDS)-0591 (2011).
- IAEA 596, *Technical Meeting on Intermediate-term Nuclear Data Needs for Medical Applications: Cross Sections and Decay Data,* INDC(NDS)-0596 (2011).
- IAEA 675, *Second Research Coordination Meeting on Nuclear Data for Charged-particle Monitor Reactions and Medical Isotope Production,* INDC(NDS)-0675 (2015).
- S. Croft and S.J. Tobin, *A Technical Review of Non-Destructive Assay Research for the Characterization of Spent Nuclear Fuel Assemblies Being Conducted Under the US DOE NGSI*, LANL Report LA-UR-10-08045 (2011).
- E. Bauge et al., "Coherent investigation of nuclear data at CEA DAM: Theoretical models, experiments and evaluated data," *Eur. Phys. J. A* 48:113 (2012).
- V.G. Pronyaev, *Summary report of the consultants' meeting on assessment of nuclear data needs for thorium and other advanced cycles,* INDC(NDS)-408, IAEA (1999).

Always propose a solution after presenting a problem.

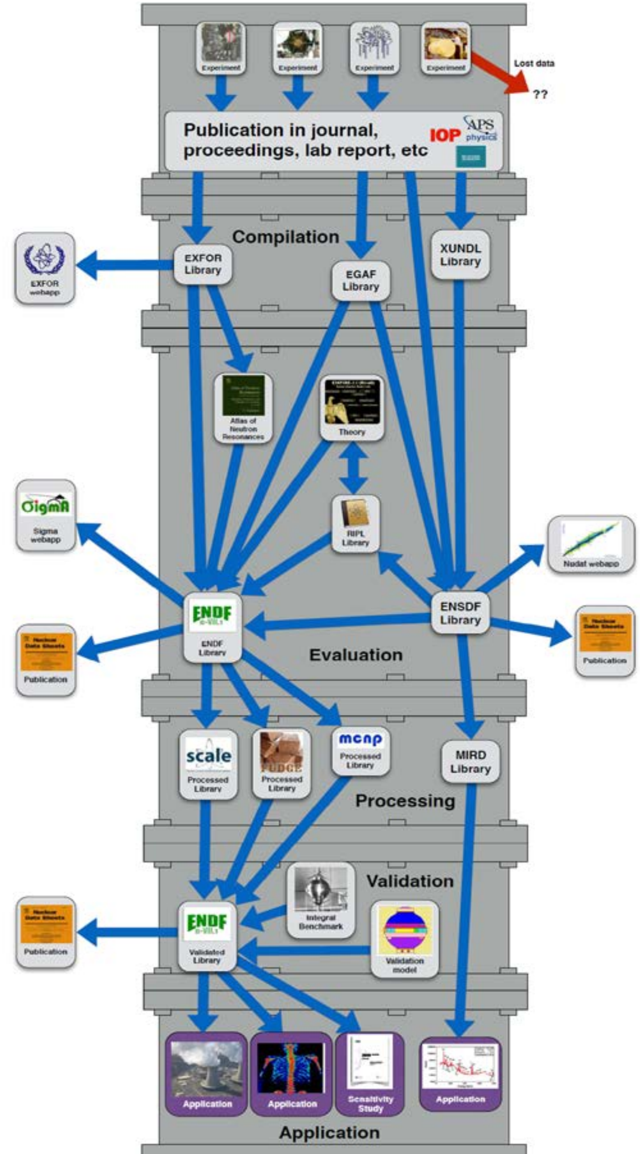
Selection Criteria for Proposed Work

- Limit to cross-cutting needs
- Reach out to the community to utilize the best facilities and expertise across the complex
- Include end-to-end data processing to ensure incorporation into ENDF
- Work with and leverage current planned experiments
- Minimize costs
- Propose the complete solution, not what fits an expected proposal call: unconfined by time and costs

Topic 1: The Pipeline

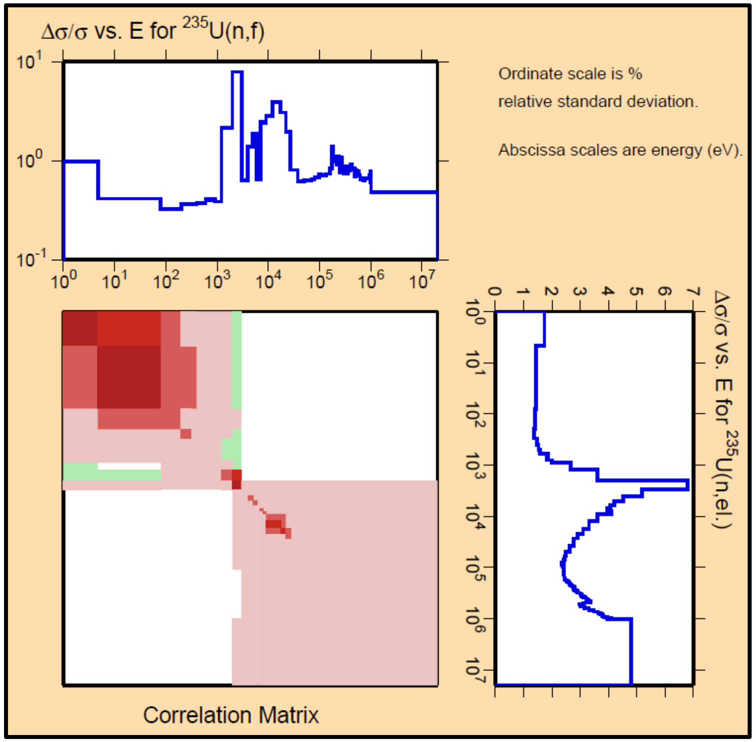
Dave Brown: Brookhaven National Laboratory

- **Goal:**
  - Update software and infrastructure
  - Train new workforce
- **Need to take a step back and build up the nuclear data platform**
- **Supports all users of nuclear data**



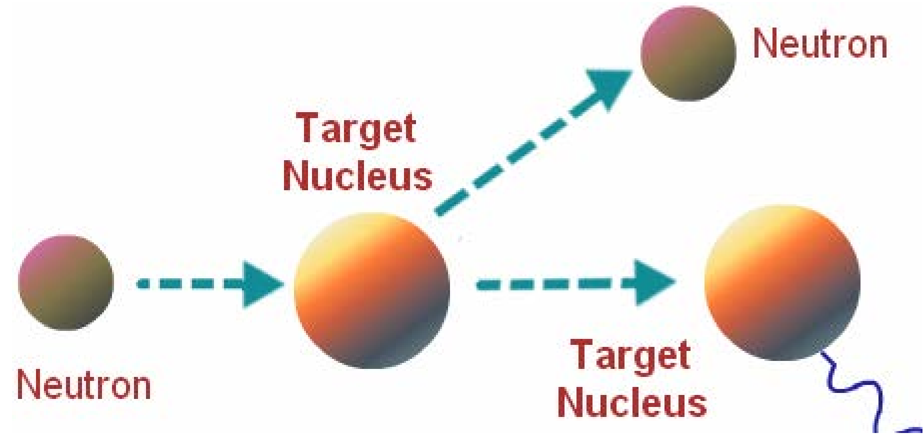
Topic 2: Covariance Data
Skip Kahler: Los Alamos National Laboratory

- **Goal:**
  - Provide uncertainties to the users for all data types
  - Enable capability to propagate uncertainties through the simulation
- **Need to take a step back and build the framework**
- ***Many in the nuclear reactor community consider this the number one need***
- **Supports all users of nuclear data**



Topic 3: Inelastic Scattering
Lee Bernstein
Lawrence Berkeley National Laboratory

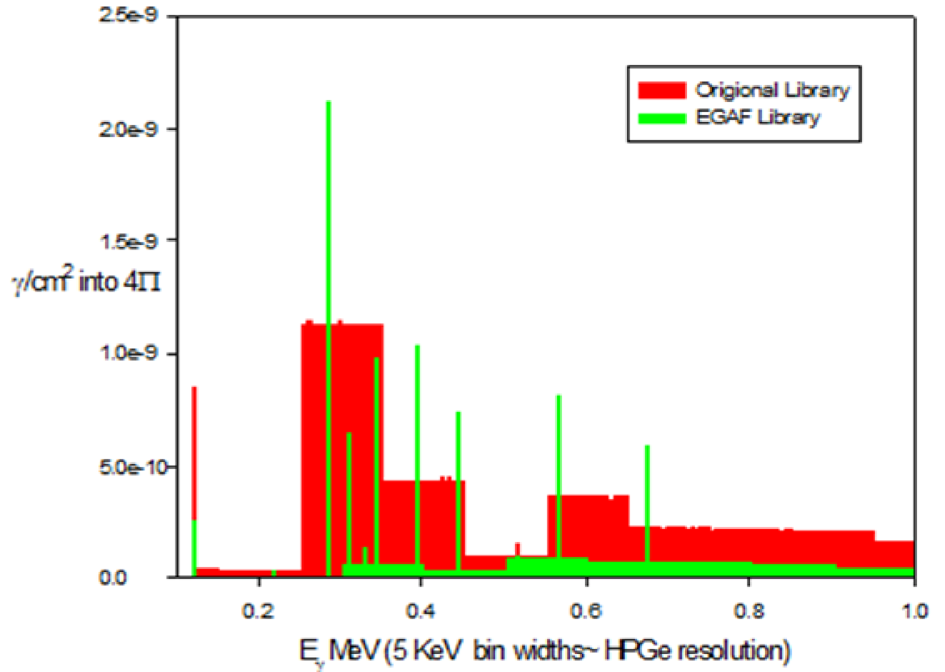
- **Goal:**
  - Perform experiments and evaluations of inelastic scattering cross sections on ^{238}U, ^{235}U, and ^{239}Pu from 1 keV to 3 MeV



- **Very large uncertainties**
- **Difficult experiment**
- **Supports power reactors, criticality safety, and other neutronics models**

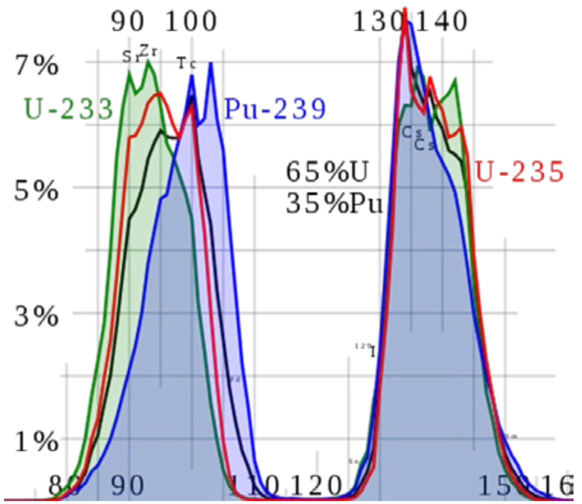
Topic 4: Capture Gamma Spectra
Brad Sleaford
Lawrence Livermore National Laboratory

- **Goal:**
  - Evaluate and incorporate into ENDF existing data files of high-resolution gamma spectra
- **Supports interpretation of any gamma spectroscopy measurement**



Topics 5–6: Fission Yields

Todd Bredeweg and Patrick Talou
Los Alamos National Laboratory

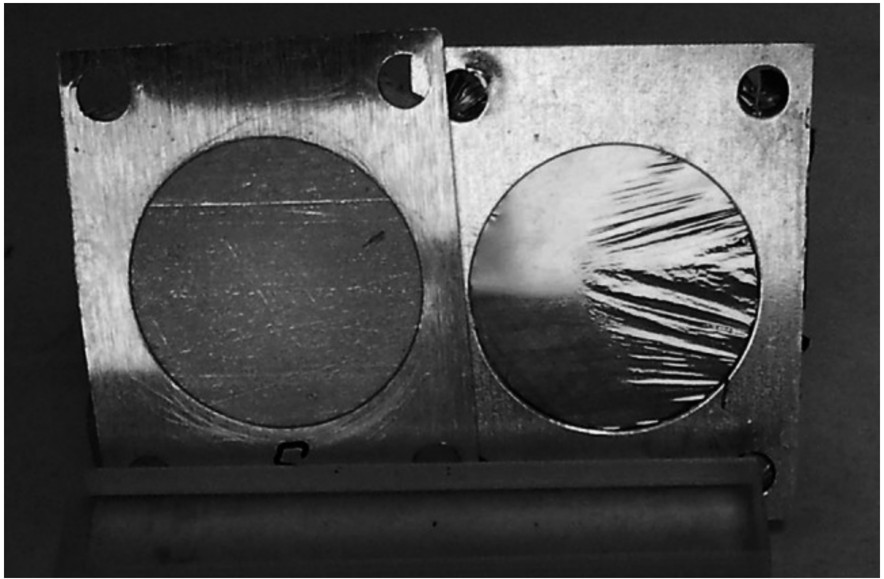


- **Goal:**
  - Understand fission yields
- **Uncertainties are large**
- **Theoretical models feed evaluations and simulated neutron and gamma emission**
- **Experiments validate the theory**
- **Precursor to antineutrino solution**
- **Supports nuclear forensics, reactor fuel depletion calculations, nondestructive analysis (NDA)**

Topic 7: Target Production to Support Fission Experiments

Catherine Romano: Oak Ridge National Laboratory

- **Goal:**
  - Re-establish capabilities dismantled in the 1980s, including vacuum evaporation and metal rolling
- **Reestablish vacuum evaporation capabilities for fission fragment energy experiments**
- **Small-scale metal conversion and rolling capabilities for delayed fission gamma measurements**



Self-supporting Cu foils prepared by vapor deposition

Stolarz, A. (2014). Target preparation for research with charged projectiles. Journal of Radioanalytical and Nuclear Chemistry, 299(2), 913–931.

The NDWG presented a 5-year $50M proposal to address cross-cutting nuclear data needs

- **The Nuclear Data Exchange Meeting (NDEM) was held in Washington DC, April 14, 2016**
- **Attendees included 25 federal representatives, with program managers from seven DOE/NNSA offices, the Defense Threat Reduction Agency (DTRA), and the Department of Homeland Security (DHS)**
- **A clear path forward was presented**
  - Best practices for data management
  - Expectations for project costs and timelines
  - Information on the nuclear data process

NDWG Lessons Learned

- **Communication and collaboration is required between nuclear data producers, users, and program managers**
- **Current funding mechanisms do not work for many nuclear data needs, as some nuclear data projects require over 5 years to complete**
- **Future discussions need to be open to entire community**
- **Some program managers did not like the proposal format**

HOWEVER

- **The proposal format gained attention**
  - Provided a solution
  - Showed the level of effort required
- **The NDWG effort created interest because it was a collaborative effort across the lab complex recommending a solution to nuclear data needs**

The Nuclear Data Interagency Working Group (NDIWG)

- **The program managers formed the Nuclear Data Interagency Working Group (NDIWG)**
  - Currently communicating on a regular basis
  - Meets twice a year
  - Led by the Office of Science/Nuclear Physics

NDIWG Funding Opportunity Announcement (FOA) Issued 4/26/2017

- **Collaborative FOA includes funding from the following programs:**
  - Nuclear Physics (NP)
  - Nuclear Energy (NE)
  - Isotope Program (IP)
  - Office of Defense Nuclear Nonproliferation R&D (NA-22)
  - Domestic Nuclear Detection Office (DNDO)
- **Incorporates NDWG recommendations for nuclear data management and evaluation**
- **Projects can be funded for up to 5 years**
- **Requires an USNDP representative to be included in the project**
- **The NDIWG FOAs are intended to be annual**
- **University call included for subsequent years**

New Funded Projects

- **NNSA / Defense Nuclear Nonproliferation (DNN) R&D and DOE NP agreed to co-fund the Fission in R-processes (FIRE) theory project**
- **The Nuclear Science and Security Consortium (NSSC) was awarded ($25M over 5 years) to Berkeley in part because of their nuclear data focus**
- **The DOE Office of Nuclear Energy (NE) is considering nuclear data needs for the first time since 2012**
- **FY17 DNDO funded nuclear data target development**
- **FY18 NA-22 funded O(alpha,n) evaluation**
- **NA-22 safeguards funded follow on project for the F(alpha,n) cross section measurement**
- **NDIAWG FOA FY18 funded:**
  - Improving the nuclear data on fission product decays at CARIBU, ANL
  - A novel approach for improving antineutrino spectral predictions for nonproliferation applications, ANL
  - 238U(p,xn) and 235U(d,xn) 235-237Np Nuclear Reaction Cross Sections Relevant to the Production of 236gNp, LANL

Why Should the Nonproliferation Community Fund Nuclear Data?

- **Nuclear data has been driven primarily by defense programs, criticality safety, and Naval Reactors programs**
  - Focus is on reaction rates (in general)
  - Data is validated to criticality experiments (k_{eff})
- **Nonproliferation requires information on observables**
  - Passive and active interrogation
    - o Correlated neutron and gamma emission information
  - Decay data for forensics and reactor fuel fission products
  - Software updates to better simulate observable data
  - UQ studies required to guide nuclear data priorities for unique mission space
  - Benchmark validation based on nonproliferation missions

NDREW GOAL

- **Primary Goal: Produce a roadmap that will inform a DNN R&D nuclear data investment strategy**

With the recognition that nuclear data solutions require

Communication – Coordination – Collaboration

NDREW brings together:

- **Multiple funding agencies**
  - NNSA multiple agencies
  - NE
  - NP
  - Isotopes
  - DTRA
  - DNDO
- **Nuclear Industry**
- **Nuclear data users**
  - NDA experts
  - Modeling and simulation experts
- **Nuclear data producers**
  - Experimentalists
  - Evaluators
  - Validation and testing experts
  - Uncertainty quantification experts
  - Theorists

NDREW Agenda

Tuesday Morning

- **Perspectives from funding agencies**
- **Panel:**
  - Perspectives from nuclear data users
  - Uncertainty quantification methods
  - The nuclear data pipeline

Tuesday afternoon – Thursday Lunch

- **Breakout Sessions**

Thursday Afternoon

- **Presentation of Conclusions**
- **Q&A**

NDREW Agenda

- **Breakout Sessions:**
  - Topic 1A: Uncertainty, Sensitivity, and Covariance
  - Topic 1B: Neutron Capture and Associated Spectra
  - Topic 1C: Fission I, Independent and Cumulative Yields
  - Topic 2A: Gamma-Induced Reactions
  - Topic 2B: Inelastic Neutron Scattering and Associated Spectra
  - Topic 2C: Fission II, Prompt Gammas and Neutrons
  - Topic 3A: (α,n) Reactions
  - Topic 3B: Targets, Facilities and Detector Systems
  - Topic 3C: Fission III, Decay Data
  - Topic 4A: Development of Benchmark Exercises
  - Topic 4B: Data Processing & Transport Code Needs
  - Topic 4C: Actinide Cross Sections

Breakout Session Goals

- **Determine mission-driven nuclear data priorities with targeted uncertainties**
- **Provide comprehensive roadmap tasks to ensure that nuclear data are available to users:**
  - Measurements – differential and integral
  - Evaluations
  - Processing
  - Covariance data
  - Validation
  - Testing
- **Ensure that roadmap tasks are peer reviewed**
- **Capture opportunities to leverage or enhance existing funded/planned work**
- **Shared expertise, facilities, equipment**

  Collaborative vs competing ideas
- **Think outside the confines of the typical funding mechanisms**

  What does it really take to get it done right?

Workshop Attendee Charge

Scientific Community

- Focus on the nonproliferation mission space
- Prioritize the mission over personal interests
- Find ways to leverage existing work
- Determine where needs overlap with other mission spaces
- Emphasize collaborative solutions

Program Manager Community

- Ask hard questions
- Let us know what information you need

Questions?

Thank you to DNN R&D for their support for the NDREW workshop and road mapping effort

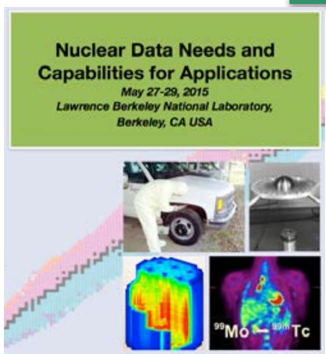
Nuclear Data Definitions

- **ENDF – evaluated nuclear data file**
  Evaluation of data typically funded by users with a small amount of funding from Office of Science
- **ENSDF – evaluated nuclear structure data file**
  ENSDF typically maintained and funded by the Office of Science with evaluation contributions from the international community
- **Differential Data/Experiment**
  Experiment that measures specific phenomena as a function of incident neutron/gamma energy, angle of particle emission, or energy of particle emission
- **Integral Data/Experiment**
  Experiment that measures a quantity integrated over a range of incident particle energies, angles of emission, or emitted energies
- **Validation Experiment or Benchmark Experiment**
  A well-controlled integral experiment used in nuclear data evaluations
- **Evaluation**
  A process in which the evaluator combines differential and benchmark data with theory and creates a cross section that is considered vetted for use in ENDF libraries
- **Covariance Data**
  Uncertainties captured in a matrix format that provide information on correlated uncertainties. The covariance is a result of the evaluation process and does not always reflect the full set of knowledge.
- **Nuclear Data Processing**
  The act of compiling ENDF and other nuclear data files to be used by modeling and simulation codes
- **Nuclear Data Testing**
  Analysis using new ENDF data in well-controlled models and comparing against experiments and previous models using older data

Recent Events in Nuclear Data

USNDP Review (7/14)

NDNCA Workshop (5/15)



NDNCA Whitepaper release (10/15)

Nuclear Data Working Group DOE-NP, DOE-NE, NNSA, DTRA, DNDO (11/15, 12/15, 2/16, 3/16)

Nuclear Data Exchange Meeting Presentations to Program Managers (4/16)

Nuclear Data Interagency Working Group (PMs) (6,7/16)

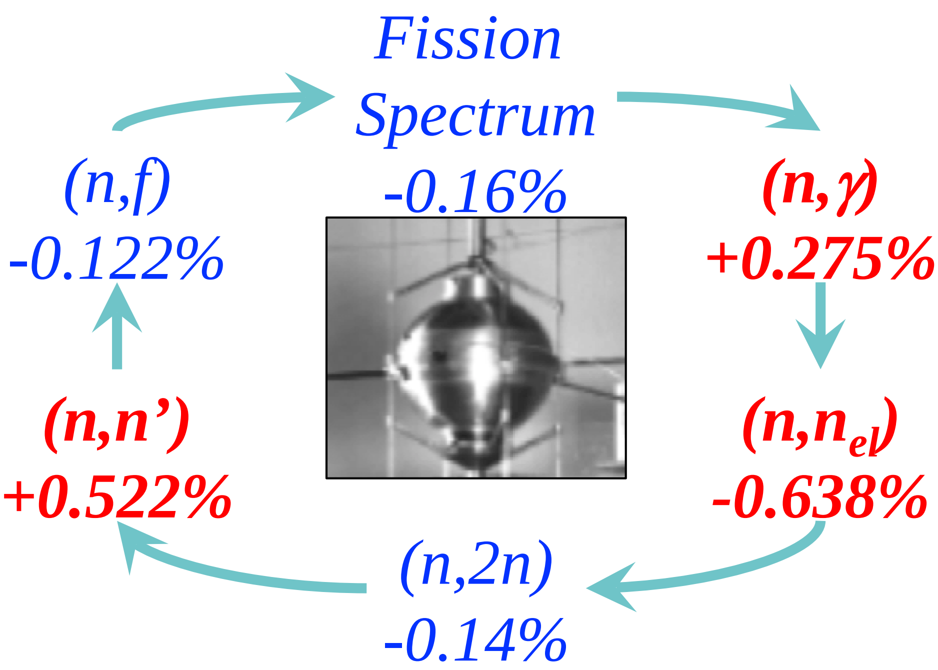
NSSC Renewal with new Nuclear Data Crosscutting Area (10/16)

NDIWG FOA Released NP, NE, IP, NA-22, DNDO (4/17)

NA-22 Nuclear Data Roadmapping Workshop (01/18)

Case Study: Compensating Errors in ^{239}Pu Cross Sections and Nubar

- The US (ENDF) and France (BRC09) validated ^{239}Pu differential data against the Jezebel ^{239}Pu critical assembly
- Both evaluations predict criticality (***k***$_{eff}$ = 1.00083 *vs.* 1.00060)
- Swapping one cross section at a time from BRC09 for one from ENDF produced
  - *small changes in **k**$_{eff}$ for well-known and small cross sections like (n,f), but*
  - *large changes for cross sections lacking good nuclear data, e.g., (n,n$_{el}$) and (n,n')*



Data deficiencies lead to *compensating errors* that introduce unknown uncertainties into the evaluated differential data.

How do compensating errors effect the nonproliferation mission?

- Multiplicity measurements at LANL required a 1.1% reduction in Pu-239 nubar from ENDF/B-VII to make multiplicity calculations match experiments.
- The higher the multiplicity of the system, the larger the discrepancy

Result: 5-year, $50M proposal to address cross-cutting nuclear data needs

NDEM: 25 federal representatives, including program managers from 7 DOE/NNSA offices, DTRA and DHS, Washington, DC (4/14/16)

1. Revitalize the Nuclear Data Pipeline (Dave Brown)
2. Expand Covariance Data and its use (Skip Kahler)
3. Improve Inelastic Scattering Data for Neutron Transport (Lee Bernstein)
4. Upgrade Capture Gamma-ray Data in ENDF (Brad Sleaford)
5. Improve Theory, Modeling, Data and Evaluation of Fission Fragment Yields (Todd Bredeweg, Patrick Talou)
6. Reestablishment of Actinide Target Production Capabilities (Cathy Romano)

Thursday Afternoon Agenda

1300	FOA information and Q&A	Donny Hornback, DNN R&D Ted Barnes, NP
	General Takeaways introduction to summary discussion	Catherine Romano, ORNL
	Modeling, UQ, Benchmarks	Session Leads
	Q&A	
	Fission I, II, III	Session Leads
	Q&A	
	Actinide Cross sections	Session Leads
	Q&A	
	Gamma Induced Reactions	Session Leads
	Q&A	
	Capture and Inelastic xsec and gamma spectrum	Session Leads
	Q&A	
1500	BREAK	
1520	alpha,n cross sections	Session Leads
	Q&A	
	Targets, Facilities, Detectors	Session Leads
	Q&A	
1645	Wrap up	Catherine Romano
1700	End	

Announcements

- **Session leads – send Tim and I your notes and we will have follow up**
- **All participants – please send your comments to your session leads by Valentine's Day**
  - Copy Tim Ault and Catherine Romano
- **May have program specific follow up meetings**
- **INMM in Baltimore, July 2018**
  - Full day special session on nuclear data
  - ANS?
- **We are looking into posting presentations on the registration website**

My General Takeaways

- **I learned a lot and felt this was beneficial**
- **Need to clarify a common language**
  - NDREW is a good first step
- **I highly encourage continued conversation via email and collaborative responses to FOA**
  - Stronger proposal with comprehensive solution
- **UQ in nuclear data a cross cutting topic critical to nonproliferation mission**
  - Nuclear data is a primary contributor in many instances
  - Need is scenario specific.
  - Safeguards looks for perturbations
  - ER needs to be able to interpret the unexpected
  - Even if we can’t reduce uncertainties, we can understand them

My General Takeaways

- **If a program wants CSEWG to address their specific needs, they need to show up.**
  - Recommend continuous representation at CSEWG
  - Example: How is the nuclear data validated – keff does not work for source term scenarios and may create compensating errors that show up in nonproliferation scenarios
  - Example: How is covariance data created? There are disagreements on how to do this for each application.

Two opposing opinions of interest:

- **We don't need to do expensive differential measurements, we only need to do calibration/benchmarks that are scenario specific and we know what we need to see. PANDA Manual**
- **We want to remove calibration so we become more predictive. As models improve, the data needs to improve**

Priority Needs */ **Additional Needs**	Thermal scattering (Paraffinic Oil, HF, Silicone Oil, UO_2F_2, PuH_2, UH_3, Paraffin, U_3O_8, U_3Si_2, UC, PuO_2, etc.), ^{239}Pu, Fe, Cr, ^{237}Np, Pb, ^{55}Mn, Ti, ^{240}Pu/ ^{233}U, Th, Be, ^{51}V, Zr, F, K, Ca, Mo, Na, La
Completed Evaluations (FY)	Minor Actinides (13), SiC(17), SiO_2 (17), $C_5O_2H_8$ (16), CH_2 (17), Be (17), BeO (17), Graphite (17), UO_2 (17), UN (17), ^{55}Mn (12), $^{58,60}Ni$ (14), $^{180,128,183,184,186}W$ (14), Ca (16), ^{59}Co (17), $^{63,65}Cu$(17)

	Materials	Pre FY2018	FY2018	FY2019	FY2020	FY2021	FY2022	Post-FY2022		
Measurements	Calcium (Ca)									
	Cerium (Ce)									
	Iron (Fe)									
	Molybdenum (Mo)									
	Tantalum (Ta)									
	Vanadium (V)									
	Zirconium (Zr)									
	Polyethylene (CH_2)	H_2O / CH_2								
	Lucite ($C_5O_2H_8$)									
	Materials	Pre FY2018	FY2018	FY2019	FY2020	FY2021	FY2022	Post-FY2022		
Evaluations	Calcium (Ca)									
	Cerium (Ce)									
	Cobalt (Co)									
	Copper (Cu)									
	Dysprosium (Dy)									
	Gadolinium (Gd)									
	Iron (Fe)									
	Lead (Pb)									
	Oxygen (O)									
	Rhodium (Rh)									
	Plutonium-239									
	Tantalum (Ta)									
	Uranium-234									
	Uranium-235									
	Uranium-236									
	Uranium-238									
	Vanadium (V)									
	Zirconium (Zr)									
	Lucite ($C_5O_2H_8$)									
	Polyethylene (CH_2)									
	Beryllium (metal)									
	Beryllium Oxide (BeO)									
	Crystal Graphite									
	Reactor Graphite									
	Silicon Carbide (SiC)									
	Silicon Dioxide (SiO_2)									
	Uranium Dioxide (UO_2)									

National Nuclear Security Administration

Priority Needs */ **Additional Needs**	Thermal scattering (Paraffinic Oil, HF, Silicone Oil, UO_2F_2, PuH_2, UH_3, Paraffin, U_3O_8, U_3Si_2, UC, PuO_2, etc.), ^{239}Pu, Fe, Cr, ^{237}Np, Pb, ^{55}Mn, Ti, ^{240}Pu/ ^{233}U, Th, Be, ^{51}V, Zr, F, K, Ca, Mo, Na, La
Completed Evaluations (FY)	Minor Actinides (13), SiC(17), SiO_2 (17), $C_5O_2H_8$ (16), CH_2 (17), Be (17), BeO (17), Graphite (17), UO_2 (17), UN (17), ^{55}Mn (12), ^{58,60}Ni (14), ^{180,128,183,184,186}W (14), Ca (16), ^{59}Co (17), ^{63,65}Cu(17)

Materials	Pre FY2018	FY2018	FY2019	FY2020	FY2021	FY2022	Post-FY2022		
Uranium Nitride (UN)									
Ice (H_2O)									
Yttrium Hydride (YH_2)									
Paraffinic Oil									
Hydrofluoric Acid (HF)									
Hydraulic Fluid (Silicone Oil)									
Paraffin (C_nH_{2n+2})									
Triuranium Octoxide (U_3O_8)									
Uranium Silicide (U_3Si_2)									
Uranium Carbide (UC)									
Plutonium Oxide (PuO_2)									
Plutonium Hydride (PuH_2)									
Uranium Hydride (UH_3)									
	ORNL	RPI	LANL	LLNL/ NCSU	IRSN	NNL			

- Requests for additional IE measurements: Ni, Mo, Cr (Fe-Cr alloys), Mn in intermediate energy range (VNIITF, NCERC).
- Continuing need for thermal scattering data.

*Note: work has been completed for some priority needs (e.g., ^{55}Mn, Ti, and Cr), and these isotopes/nuclides are maintained on the list for reference. Furthermore, the table represents the list of materials that can be addressed during the next five years under the current budget target. The additional priority needs will be addressed beyond the next five years.

THANK YOU

- **DNN R&D**
  - Donny Hornback
- **Program Managers**
- **International Collaborators and Industry Representatives**
- **Donna Raziano and Susan Uhlhorn**
- **Session Leads**
- **Note Takers**
- **Tim Ault**

Wrap Up

Office of Defense Nuclear Nonproliferation
Research and Development

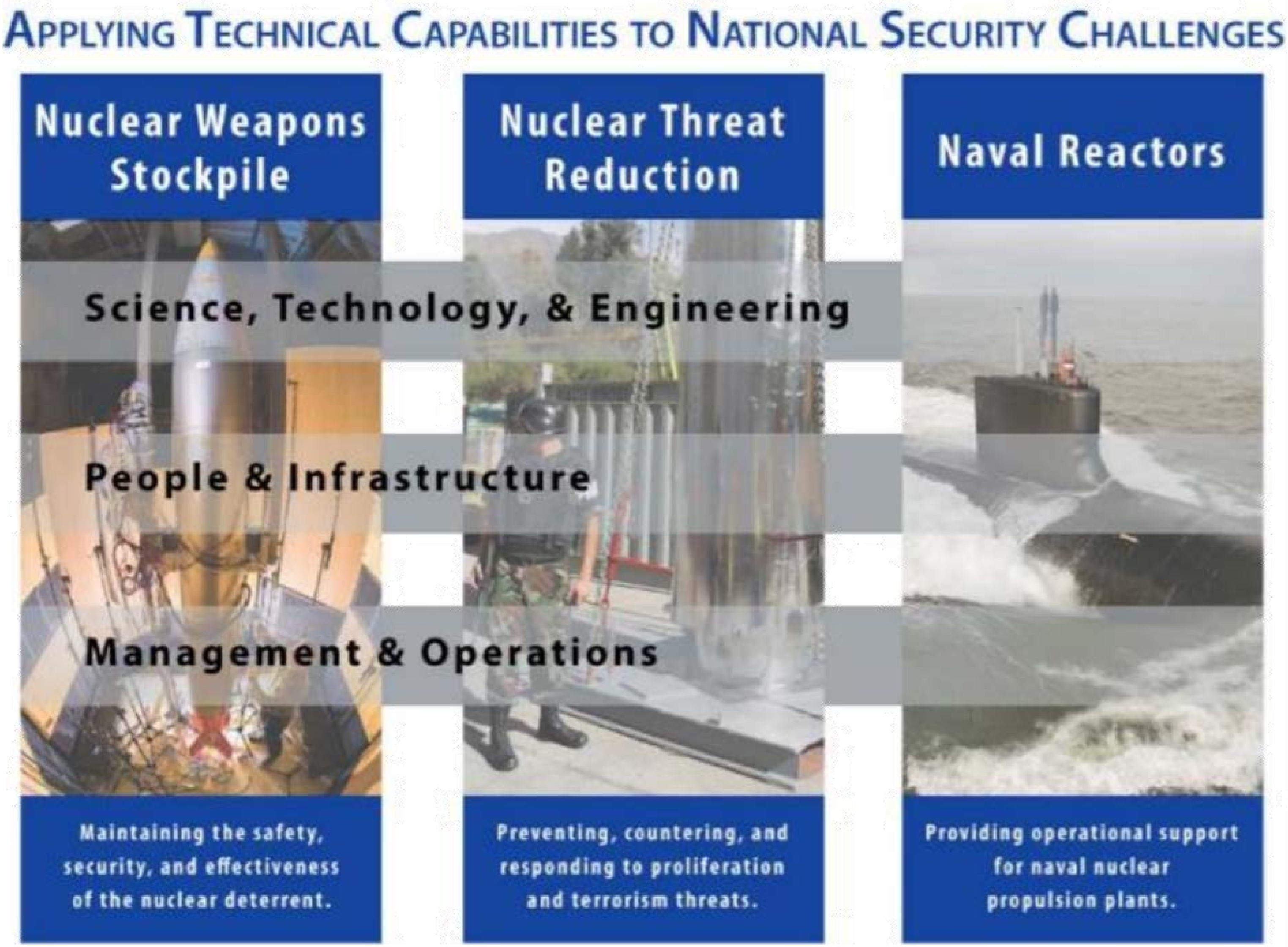
Nuclear Data Roadmap & Enhancement Workshop (NDREW) 2018

Development of Benchmarks & Validation Sets to Address Nuclear Data Needs for Nonproliferation

Rian Bahran
LANL

LA-UR-18-20631
January 23 - 25, 2018

Context is important (to re-iterate)



Context is important (to re-iterate)

Space-based Nuclear Detonation Detection

- Near real-time identification via signals at long range
- Sensors build capability of U.S. Nuclear Detonation (NuDet) Detection System (USNDS)

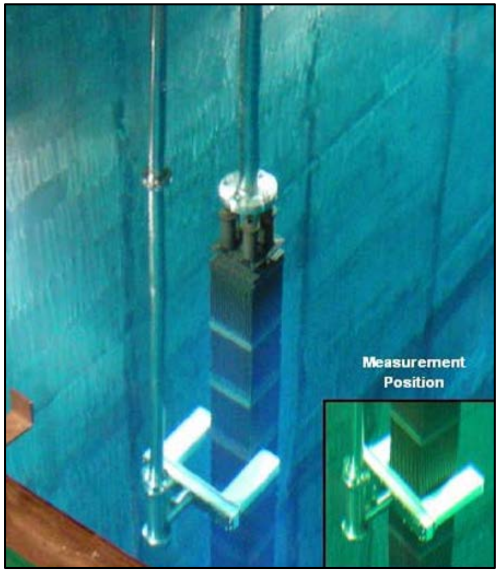
Nuclear Forensics Program

- Characterize Events to Answer Questions re Origin & Provenance
- Scenarios include near-surface low-yield urban detonations
- Local access to signals/samples

Ground-Based Nuclear Detonation Detection

- Detect signals at global, regional, and local distances
- Geophysical and radionuclide technologies relevant to U.S. Nuclear Data Center & US Atomic Energy Detection System (USAEDS)

Thousands of Application Measurements Exist with Various Quality and Needs



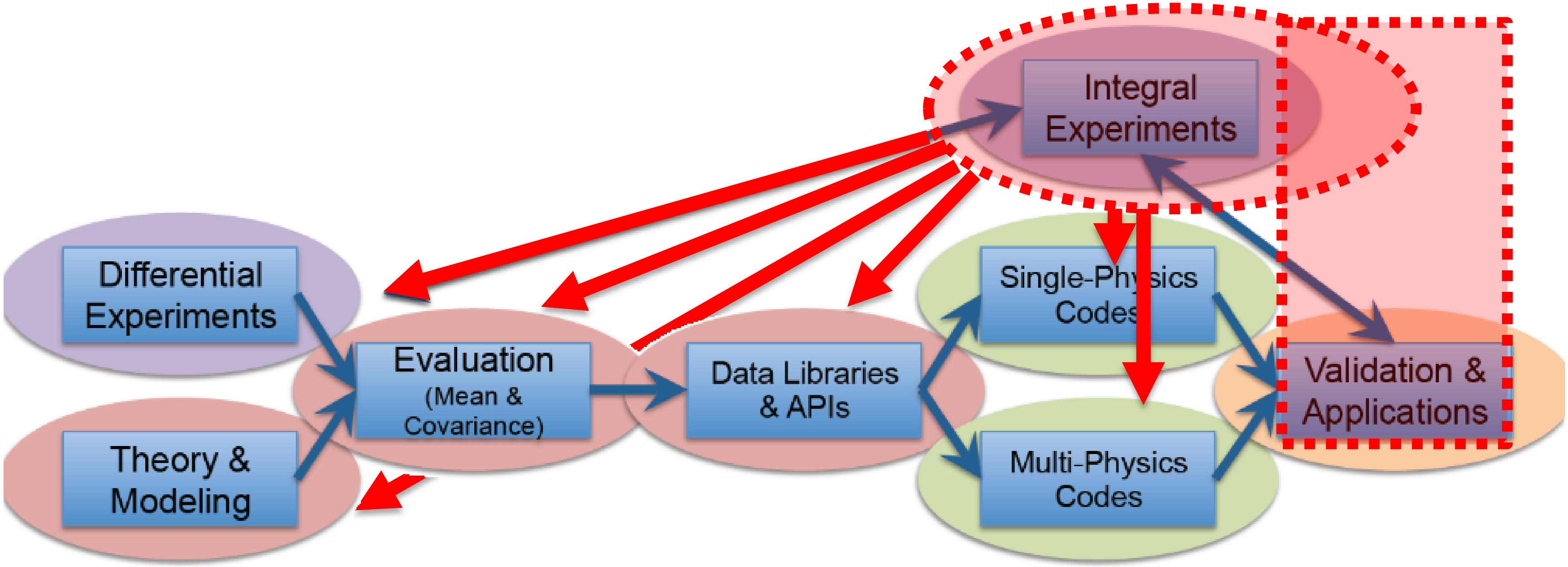
Why are benchmarks needed?

- **All application scientists want answers that often rely on validated modeling methodology (codes + nuclear data)**
  - Benchmarks are a major underpinning element for validation.

- **Notional application question: What's in the box?**
  - Criticality Safety Example
    - o Can I handle this box safely for my day-to-day duties?
  - Nuclear Energy Example
    - o How much electricity can this box produce?
  - Nuclear Threat Reduction Examples
    - o Safeguards: Has someone diverted material from this box that is subject to international safeguards in a fuel cycle facility?
    - o Arms Control: Does this box contain a nuclear warhead?
    - o Emergency Response: Is this box that I found on the side of the road a threat? How can I better search / characterize these types of boxes?

What do benchmarks provide?

- **Benchmarks and validation sets provide:**
  - o Iterative validation ability (data, codes, methods)
  - o Prioritization of need (deficiency and impact)



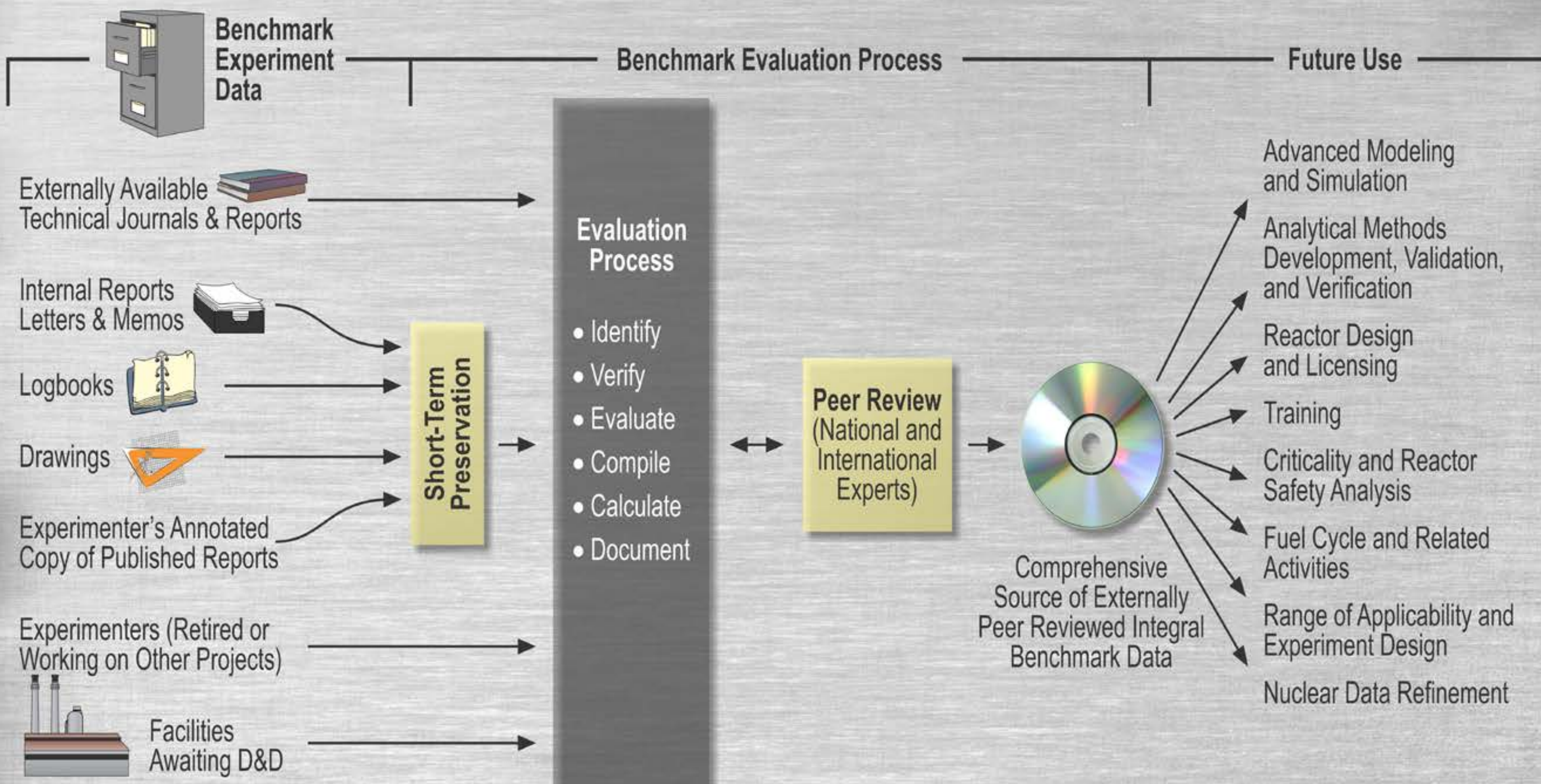
- **But what is a benchmark and/or validation set?**

What is a benchmark?

- **Integral Benchmark Evaluations (Nuclear Data Community)**
  - Measurements of integral parameters (often critical experiments) that can be accurately modeled with few assumptions and approximations, and designed specifically to validate nuclear data and codes.
  - Multi-year lifecycle: design, execution, analysis and evaluation
    - Sensitivity incorporated into the design (making sure it will be useful).
    - Statistical and systematic uncertainties quantified
    - Peer-reviewed and hosted in a repository ("coalition of the willing")
  - Plentiful for many isotopes, and used in ENDF evaluation by many
    - Deficiencies and gaps still exist.
- **Quasi-Integral Validation Measurements (In-Between)**
  - Measurements designed to validate data, but not considered integral benchmarks.
- **Application-Relevant Validation Sets ("User" Community)**
  - Application-relevant experiments, usually not designed for nuclear data purposes
  - Sometimes user-informed/agreed-upon suite of code/data validation examples
  - Often "onesie-twosie" datasets that have been historically helpful in assessing impact of nuclear data on specific application.

International Benchmark Programs

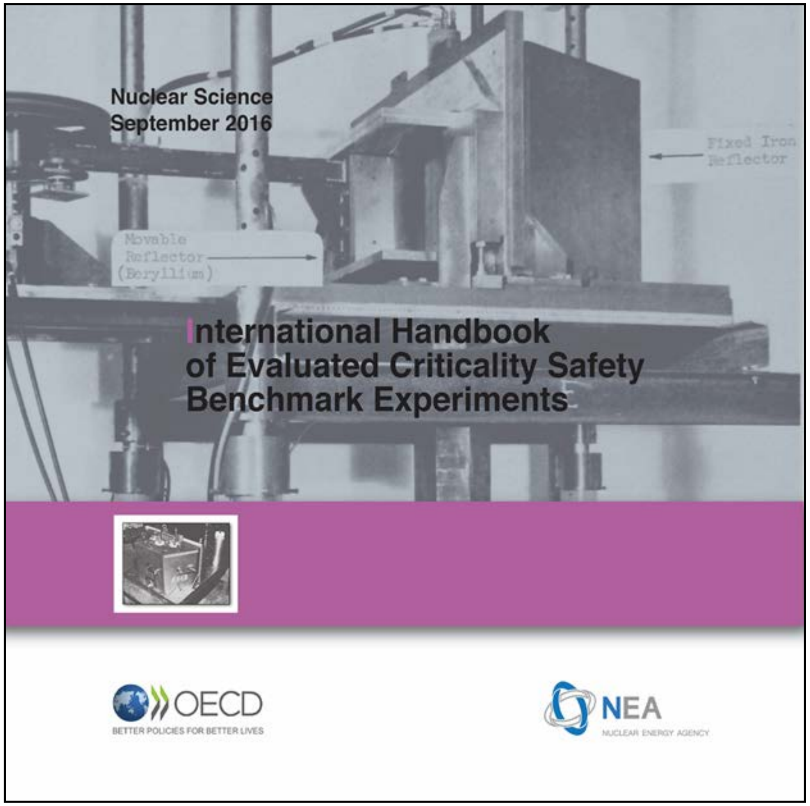
NEA Nuclear Energy Agency | OECD Better Policies for Better Lives | INL Idaho National Laboratory



International Handbook of Evaluated Criticality Safety Benchmark Experiments

December 2016 Edition

- **22 Contributing Countries**
- **~69,000 Pages**
- **570 Evaluations**
  - 4,913 Critical, Near-Critical, or Subcritical Configurations
  - 45 Criticality-Alarm-Placement/Shielding Configurations
  - 215 Configurations with Fundamental Physics Measurements
  - 829 Unacceptable Experiment Configurations
- **Note: Critical experiments are still useful for validating nuclear data and codes used in subcritical nonproliferation applications.**



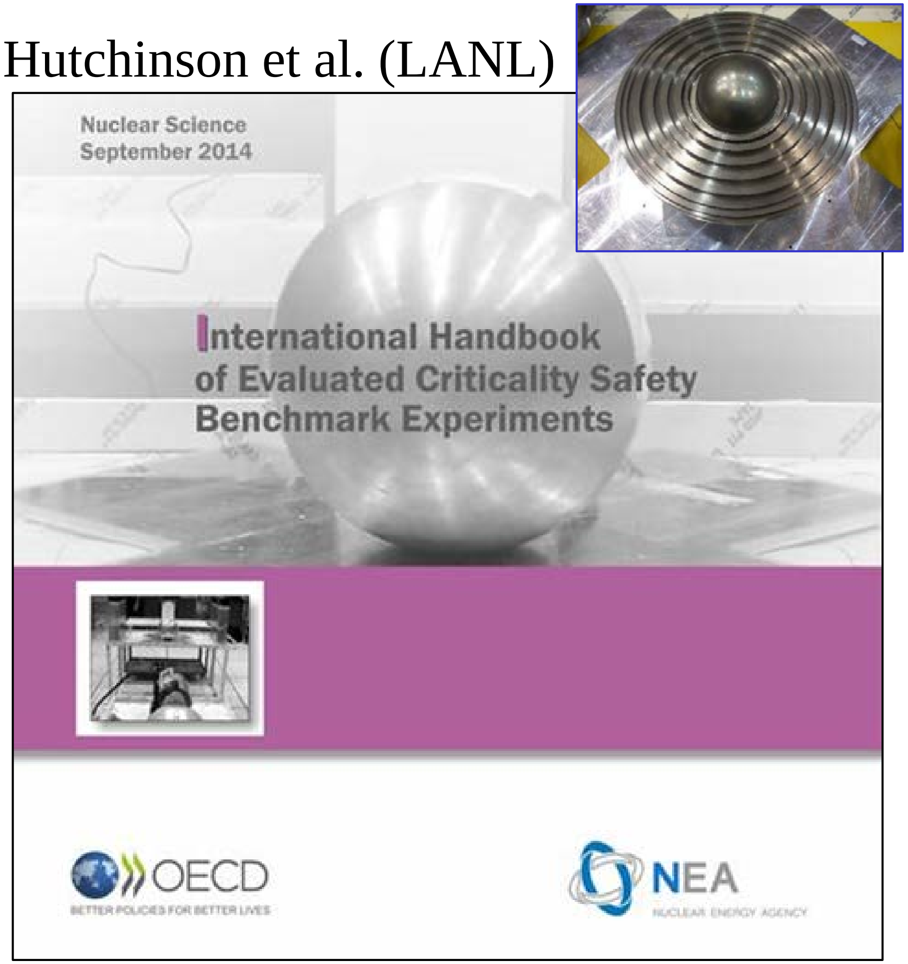
http://icsbep.inl.gov/

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

Neutron Multiplication Measurement Case Study

Mattingly et al. (SNL, NCSU)

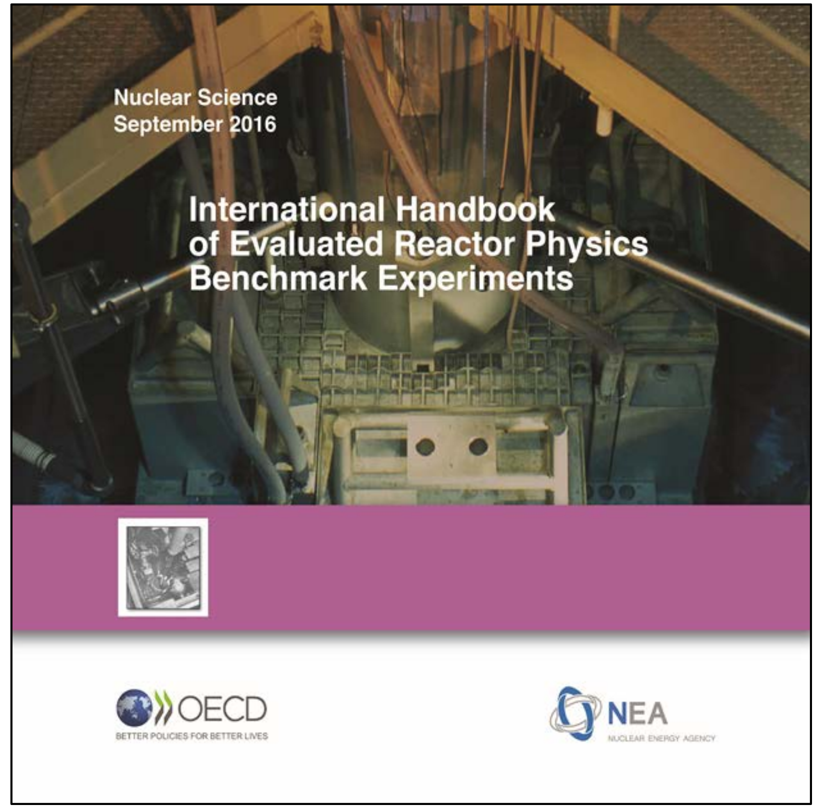
Hutchinson et al. (LANL)



International Handbook of Evaluated Reactor Physics Benchmark Experiments

March 2017 Edition

- **21 Contributing Countries**
- **50 Reactor Facilities**
- **Data from 151 Experimental Series**
  - 147 Approved Benchmarks
  - 4 DRAFT Benchmarks



http://irphep.inl.gov/

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

Example From CSWEG 2018…

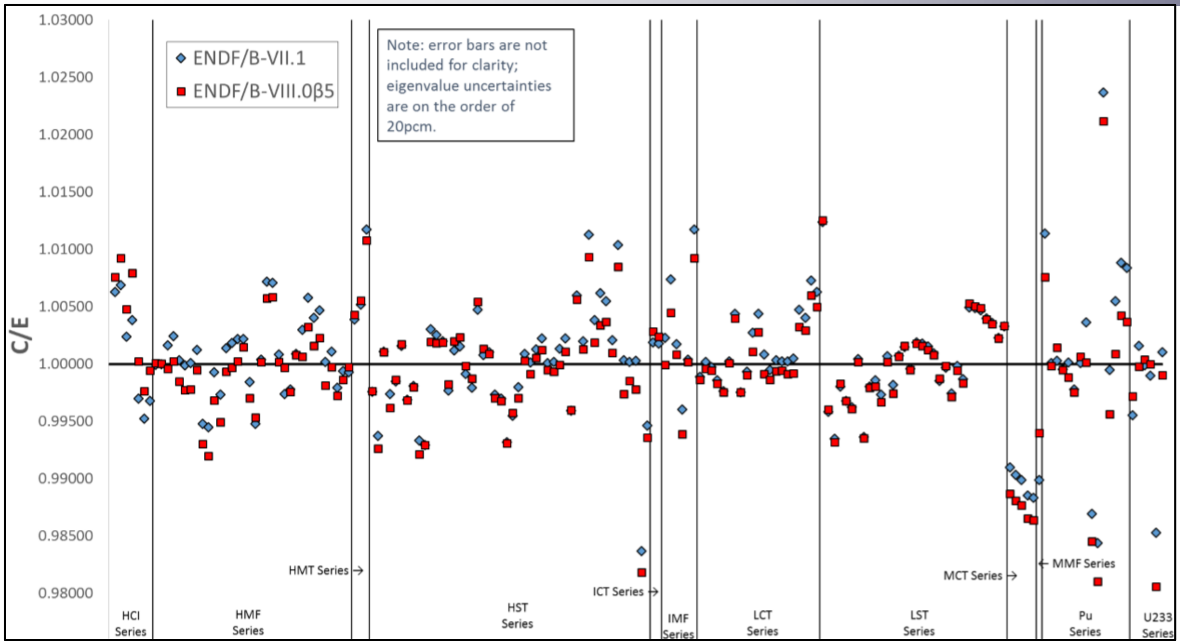


Figure from J. Thompson and A. Pavlou "Naval Nuclear Laboratory Analysis of the ENDF/B-VIII.0β5 Library" CSWEG 2018

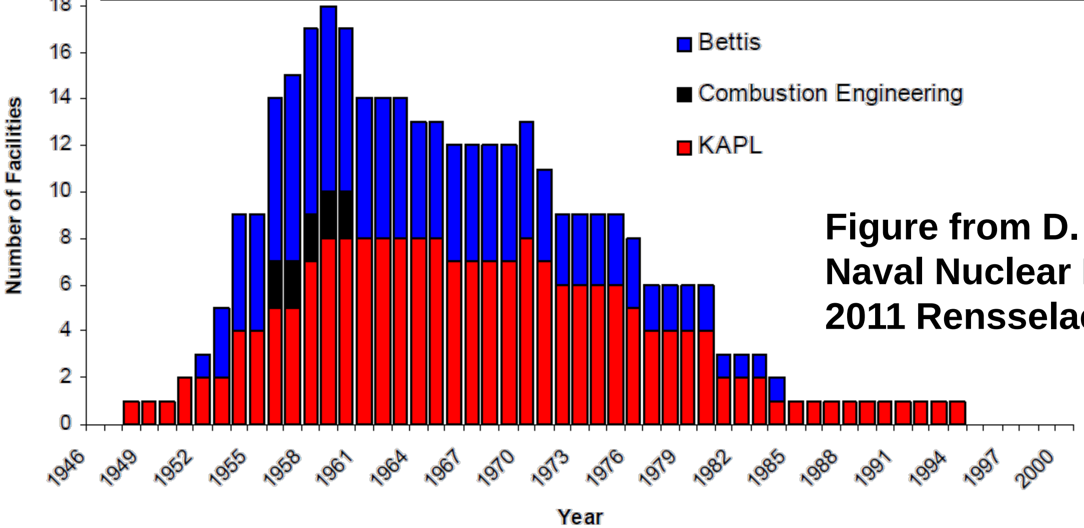


Figure from D. Dei "Importance of Nuclear Data to the Naval Nuclear Propulsion Program" Presentation at the 2011 Rensselaer Nuclear Data Symposium, Troy, NY

Notional Example for Illustration Purpose Only

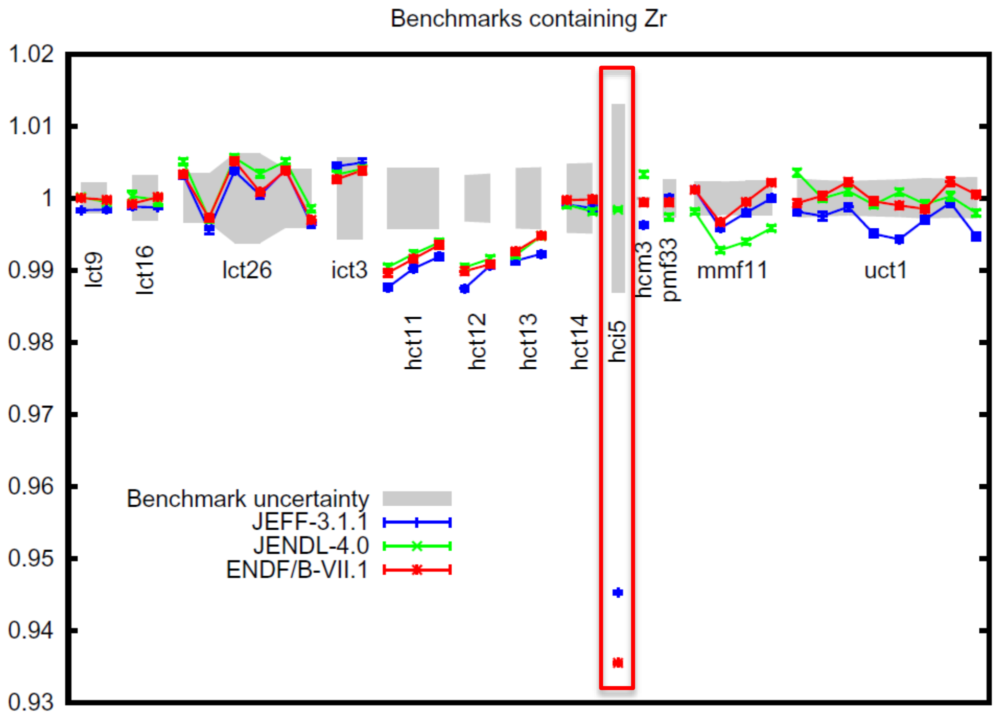
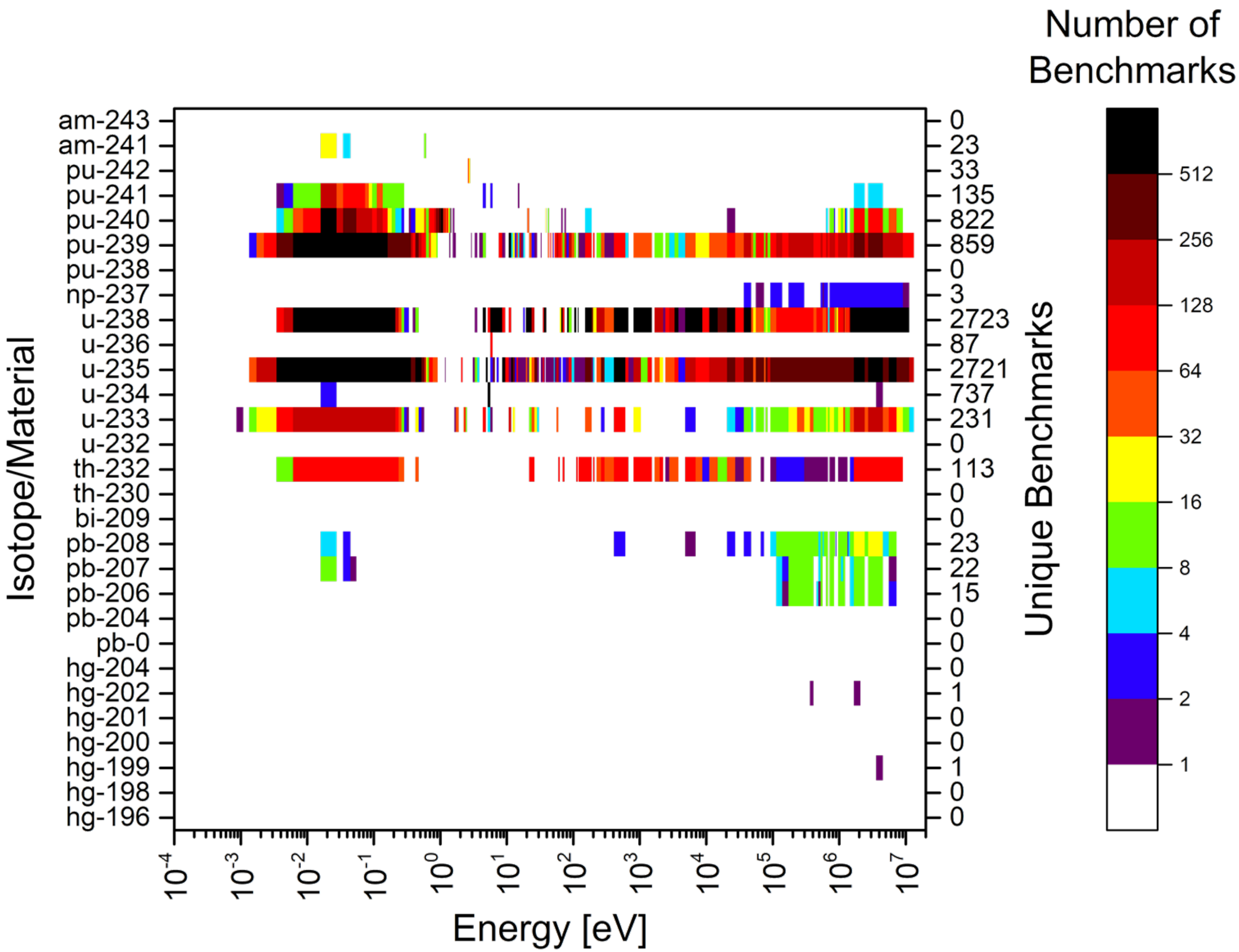


Figure from S. C. Mark "Benchmarking ENDF/B-VII.1, JENDL-4.0 and JEFF-3.1.1 with MCNP6" Nuclear Data Sheets 113 (2012) 2935–3005

Examples of US efforts (that I know of) to fix intermediate energy deficiencies:

- Differential Measurements (RPI, LASNCE, etc…)
- Evaluation (ORNL)
- Re-evaluation (BNL)
- Processing and Code development (MIT)
- Integral Benchmark (LANL)

For Illustration Only
Sensitivity Heat map

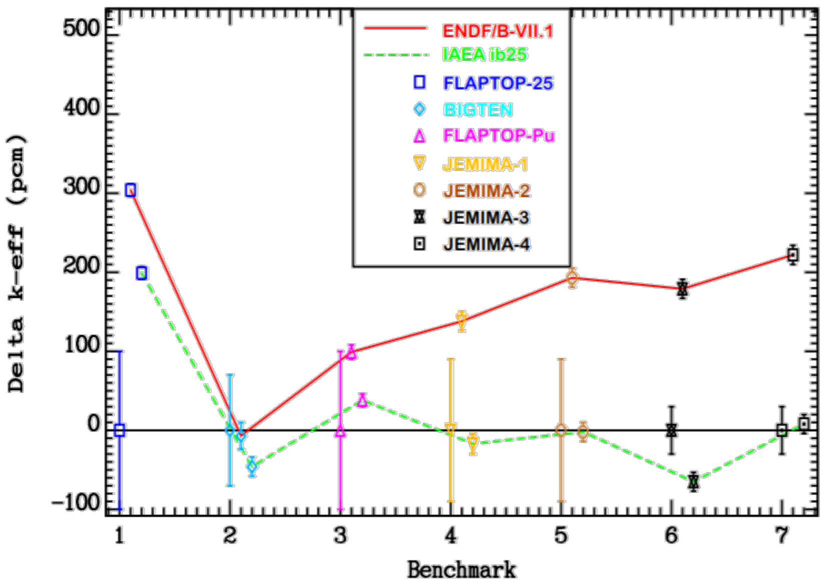


Notional Case Study “In-Between”

Physics of Neutron Interactions with ^{238}U: New Developments and Challenges

R. Capote,[1,*] A. Trkov,[2] M. Sin,[3] M. Herman,[4] A. Daskalakis,[5] and Y. Danon[5]

[1] *NAPC–Nuclear Data Section, International Atomic Energy Agency, PO Box 100, Vienna A–1400, Austria*
[2] *Jožef Stefan Institute, Jamova cesta 39, Ljubljana SI–1000, Slovenia*
[3] *Nuclear Physics Department, Bucharest University, Bucharest-Magurele RO–077125, Romania*
[4] *National Nuclear Data Center, Brookhaven National Laboratory, Upton, NY 11973–5000, USA*
[5] *Gaerttner LINAC Center, Rensselaer Polytechnic Institute, Troy, NY 12180, USA*



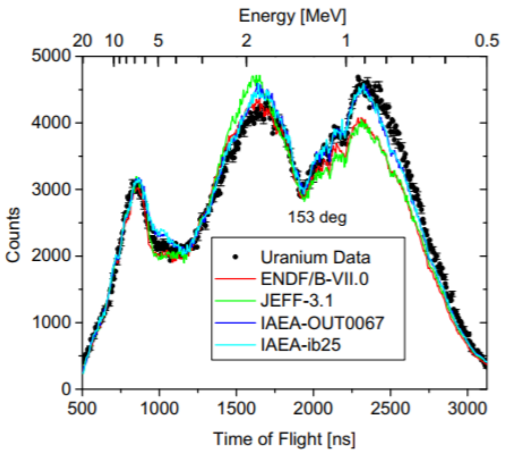


FIG. 6. Neutron yield at 153 degrees backward angle on ^{238}U target measured at the RPI (dots), and calculated using different nuclear data libraries as described in the text.

FIG. 5. k_{eff} calculations for selected ICSBEP criticality benchmarks sensitive to inelastic neutron scattering on ^{238}U. Calculation symbols are slightly shifted for clarity.

Notional Case Study
“Application Validation Set”

Steve Skutnik @sskutnik · Jan 4

TFW you post a whole long study about an issue with #nuclear data and it is summarily ignored. #science #academia

nndc.bnl.gov/exfor/servlet/...

doi.org/10.1016/j.anuc...

3 1 3

Annals of Nuclear Energy 99 (2017) 80–107

Contents lists available at ScienceDirect

Annals of Nuclear Energy

journal homepage: www.elsevier.com/locate/anucene

ELSEVIER

Proposed re-evaluation of the ^{154}Eu thermal (n, γ) capture cross-section based on spent fuel benchmarking studies

CrossMark

Steven E. Skutnik

Department of Nuclear Engineering, University of Tennessee-Knoxville, Knoxville, TN 37996, United States

Steve Skutnik
@sskutnik

Just discovered that the next-gen ENDF *still* doesn't include updated results from an experiment published in 2009 - despite being a known issue. Maybe I shouldn't feel so bad... #academia

10:16 AM - 4 Jan 2018

3

Other Datasets to Consider?

Re-evaluation of spent nuclear fuel assay data for the Three Mile Island unit 1 reactor and application to code validation ☆

CrossMark

I.C. Gauld *, J.M. Giaquinto, J.S. Delashmitt, J. Hu, G. Ilas, T.J. Haverlock, C. Romano

Oak Ridge National Laboratory, P.O. Box 2008, Oak Ridge, TN 37831, United States

Radiation shielding

Shielding Integral Benchmark Archive and Database (SINBAD)

A new release of the radiation shielding experiments database (SINBAD) was issued in 2012. Currently the SINBAD database contains compilations for 46 reactor shielding, 31 fusion neutronics and 23 accelerator shielding experiments. This work is jointly carried out by the Radiation Safety Information Computational Center (RSICC) and the NEA Data Bank. Data for 100 experiments has been collected. The major emphasis has so far been on fission reactor shielding. Facilities used for measurements have now been closed down and there was an urgent need to preserve the data. Data for fusion blanket neutronics are also considered, the rest being made up of accelerator shielding experiments. More data sets are in the process of being identified for future release. Emphasis will be on quality of the experiments and new compilations will address cases not yet sufficiently covered by the present set.

What is a benchmark?

- **Dictionary Definition**
  - a standardized problem or test that serves as a basis for evaluation or comparison
- **Integral Benchmark Evaluations (Nuclear Data Community)**
  - Measurements of integral parameters (often critical experiments) that can be accurately modeled with few assumptions and approximations, and designed specifically to validate nuclear data and codes.
  - Multi-year lifecycle: design, execution, analysis and evaluation
    - Sensitivity incorporated into the design (making sure it will be useful).
    - Statistical and systematic uncertainties quantified
    - Peer-reviewed and hosted in a repository (“coalition of the willing”)
- **Quasi-Integral Validation Measurements (In-Between)**
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  - Application-relevant experiments, usually not designed for nuclear data purposes
  - Sometimes user-informed/agreed-upon suite of code/data validation examples
  - Often “onesie-twosie” datasets that have been historically helpful in assessing impact of nuclear data on specific application.

Lets get back into it…

- **Discussion Points**
  - Consensus on definitions/categorization
    - This will take awhile, but it is important (will set expectations)
    - Have already talked to many here, in other sessions, and outside of NDREW
  - Peer review requirements “as a benchmark or validation set”
    - Sensitivities and uncertainties
    - Detector systems
  - Validation Suite Repository
    - Need (to influence evaluation) vs feasibility (ongoing SME support)
    - Coverage of applications (specific or wide) and how to approach prioritization
    - Host location
  - Current and Future Tools to Help with Benchmarks (More, Better, Simpler?)
    - SMEs needed to assess simple options and current tools for S/U and detector system understanding.
    - SMEs needed to assess future development needs for both.
  - Existing validation sets to consider
  - Other “radical” thoughts on how to make this a tractable issue…anything I missed?

Welcome to NDREW:

Introduction and Overview of DNN R&D and Its Intersections with Nuclear Data

Craig Sloan

Director, Proliferation Detection (NA-221)

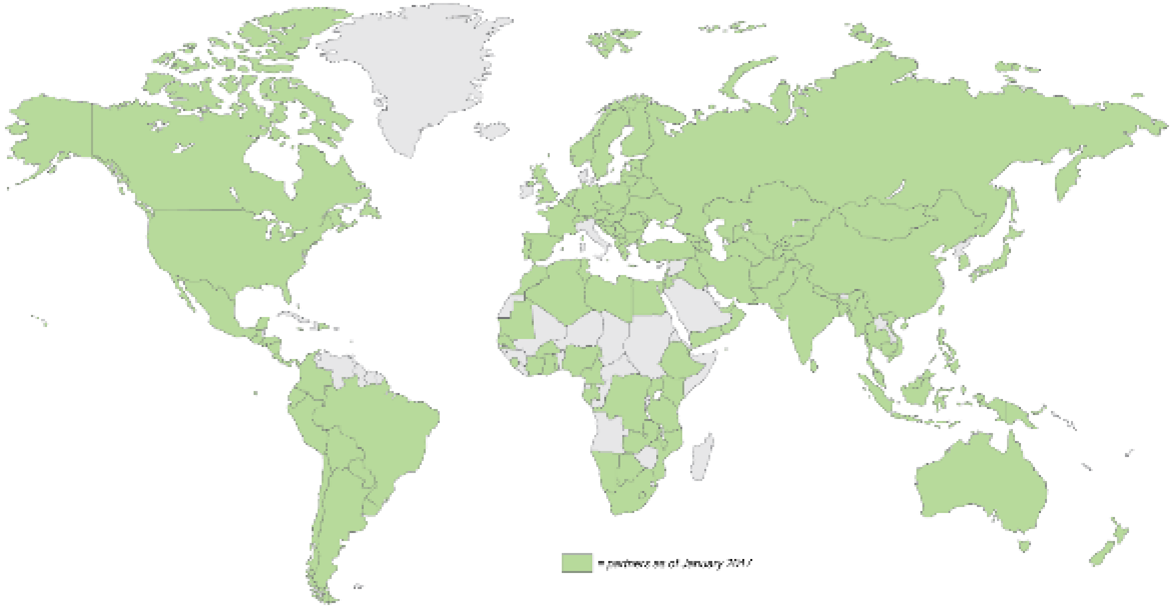
Office of Defense Nuclear Nonproliferation R&D (DNN R&D, NA-22)

January 23, 2017

NNSA Missions and Crosscutting Capabilities

Defense Nuclear Nonproliferation

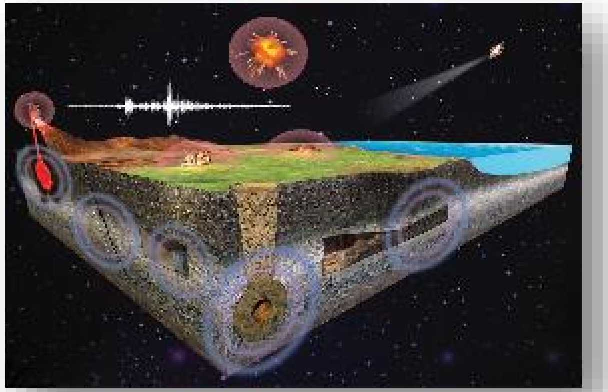
Mission: *Develop and implement policy and technical solutions to eliminate proliferation-sensitive materials and limit or prevent the spread of materials, technology, and expertise related to nuclear and radiological weapons and programs around the world.*



Vision: *We are committed to making the world a safer place by reducing nuclear and radiological dangers.*

DNN Research & Development Mission and Goals

Develop advanced technical capabilities in support of U.S. national nuclear security and nonproliferation goals



<u>Nuclear Proliferation Detection</u>
Strengthen U.S. capabilities to detect and characterize foreign nuclear programs.

<u>Nuclear Security Applications</u>
Advance U.S. capabilities to strengthen nuclear security across the threat spectrum.

<u>Nuclear Explosion Detection</u>
Improve U.S. capabilities to detect and characterize nuclear explosions.

DNN R&D Organization

Assistant Dep. Administrator
Edward Watkins
Assoc. Asst. Dep. Administrator
David LaGraffe
Senior Science Advisor
Darcie Dennis-Koller

Front Office Staff
Michelle Livingston
Ivy Martin
Timothy Ault, Fellow
Noel Nelson, Fellow
Blake Palles, Fellow
Sid Bartlett, CTR
Danika Mars, CTR
Travis Gitau, CTR

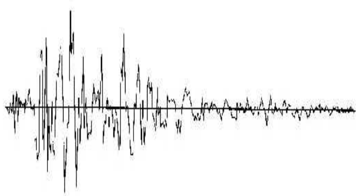
Office of Proliferation Detection
Craig Sloan, Director
LTC Ben Miller, Dep. Director
Patria Smith, CTR

Program Managers	Technical Advisors
Craig Sloan (Nuclear Test Detection)	Roger Petrin, LANL
LTC Ben Miller (Signatures and Data Science)	Kevin Jackman, LANL
Allen Bakel (U and Pu)	Chris Pickett, ORNL
Victoria Franques (Innovation)	Denise Lee, ORNL
Donny Hornback (Near-field Detection)	Riad Manaa, LLNL
LTC Michael Koehl (Emergency Response)	Frederik Tovesson, LANL
Summer Lockerbie (on detail)	
LTC Dan Mattei (Weaponization)	
James Peltz (on detail)	
Chris Ramos (Safeguards and Remote Detection)	

Office of Nuclear Detonation Detection
Thomas Kiess, Director
Angela Rachlin, CTR

Program Managers	Technical Advisors
Leslie Casey (Ground-based Nuclear Detonation Detection)	Brian Dougherty, LANL
Maj Alan Louie (Space-based Nuclear Detonation Detection)	Scott Jones, SNL
Vaughn Standley (on detail)	Greg Schaaff, Y-12
VACANT (Forensics)	Megan Slinkard, SNL
	Mark Sullivan, CTR

Office of Nuclear Detonation Detection (NDD)



Nuclear Detonation?
(e.g., test or illicit act)

Space-based Nuclear Detonation Detection

- Near real-time identification via signals at long range
- Sensors build capability of U.S. Nuclear Detonation (NuDet) Detection System (USNDS)

Nuclear Forensics Program

- Characterize Events to Answer Questions re Origin & Provenance
- Scenarios include near-surface low-yield urban detonations
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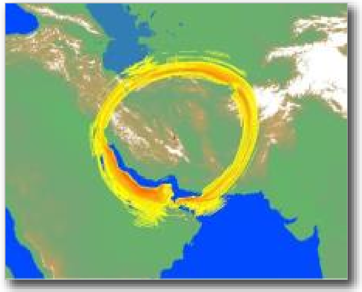
Ground-Based Nuclear Detonation Detection

- Detect signals at global, regional, and local distances
- Geophysical and radionuclide technologies relevant to U.S. Nuclear Data Center & US Atomic Energy Detection System (USAEDS)



Office of Proliferation Detection

Mission:

Advance U.S. capabilities for global detection of nuclear weapons development activities, including material production, movement, weaponization, and the characterization of nuclear explosions.

- *Uranium Production Detection*
- *Plutonium Production Detection*
- *International Safeguards*
- *Other Nuclear Processes*

- *Weapons Development Detection*
- *Emergency Response*
- *Nuclear Test Detection*

- *Innovation*
- *Near-field Detection*
- *Remote Detection*
- *Data Science*
- *Signature Physics*
- *Radiological Source Replacement*

Where Does DNN R&D Intersect with Nuclear Data?

By Discipline…

- Safeguards
- Nuclear Test Detection/ Forensics
- Stockpile Stewardship
- Emergency Response
- Radiation Detection

By Capability…

- Radiation Transport Codes
- Non-Destructive Assay
- Active Interrogation
- Misc. Calculations

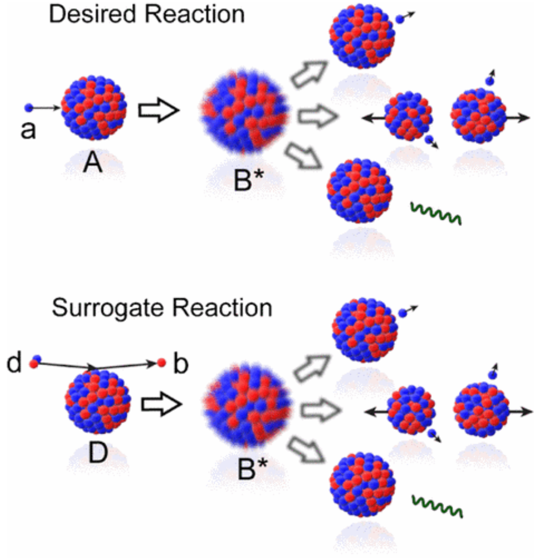
By Phenomenology…

- Gamma-Ray Spectra
- Neutron Spectra
- Anti-neutrinos
- Other Particles
- Decay Heat

Some Past and Current Nuclear Data Efforts Supported by DNN R&D

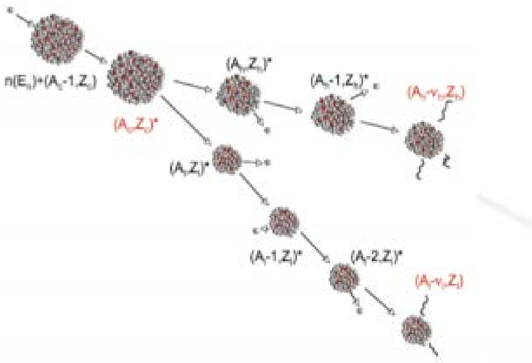
Radiochemistry for Am Cross Section Measurements (LANL, 2008-2017)

Nuclear Cross Section Measurements (LLNL, 2009-2011)

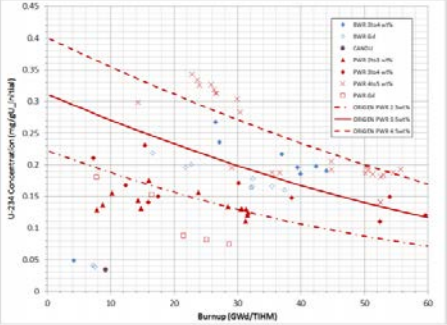


$^{19}F(\alpha,n)$ Cross-section for Nuclear Safeguards (ORNL/INL, 2012-2017)

Correlated Data in Fission Events (LANL, 2013-2017)



Reactor Benchmark Data and Improved Analysis Capabilities (ORNL, 2011-2015)



In total, at least $26 million in nuclear data-related projects in NA-22 since FY06

(not counting some portion of at least $50 million of interlab venture projects which included a data component)

Opportunity: Prioritize NA-22 Nuclear Data Requirements

- Collect subject matter expert input to support a nonproliferation nuclear data funding strategy, including gap prioritization and recommended solutions
- Ensure the funding strategy captures the intersections with the nuclear data needs and ongoing work of other programs
- Facilitate communication and collaboration among programs and organizations dependent on nuclear data
- Increase mutual awareness and understanding of different stakeholder segments of the nuclear data community, including experimentalists, evaluators, end-users and program managers

Looking Ahead: Workshop Structure

- This Morning:
  - Background talks by workshop organizers
  - Perspectives from other agencies
  - Panel consisting of data user and developer communities at national laboratories

- This Afternoon Through Thursday Morning
  - Breakouts into three parallel group roadmapping sessions at a time

- Thursday Afternoon:
  - Regroup and present cumulative findings to program managers

Thanks for attending and contributing!

Enjoy the workshop!

U.S. DEPARTMENT OF ENERGY | Office of Science

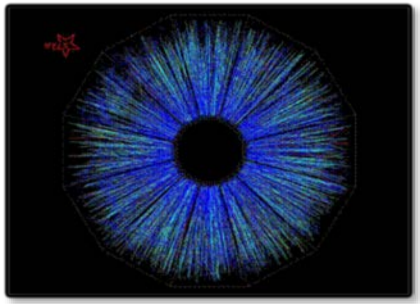
DOE-SC-NP & Interagency Coordination on Nuclear Data

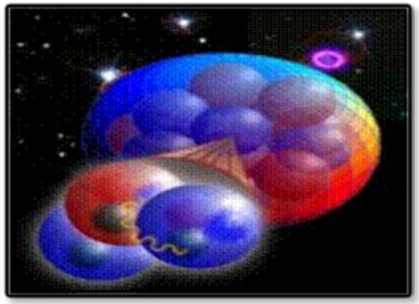
NDREW2018—Nuclear Data Roadmapping & Enhancement Workshop

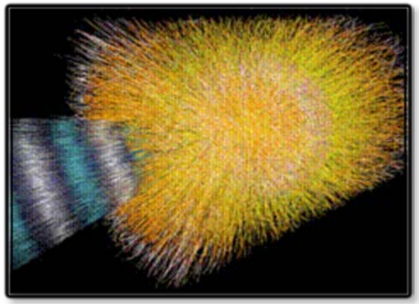
University of California Washington Center • Washington, DC

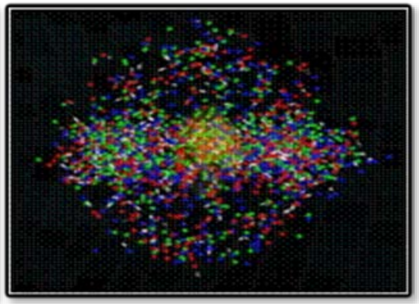
January 23 - 25, 2018

Dr. Timothy J. Hallman
Associate Director for Nuclear Physics
DOE Office of Science



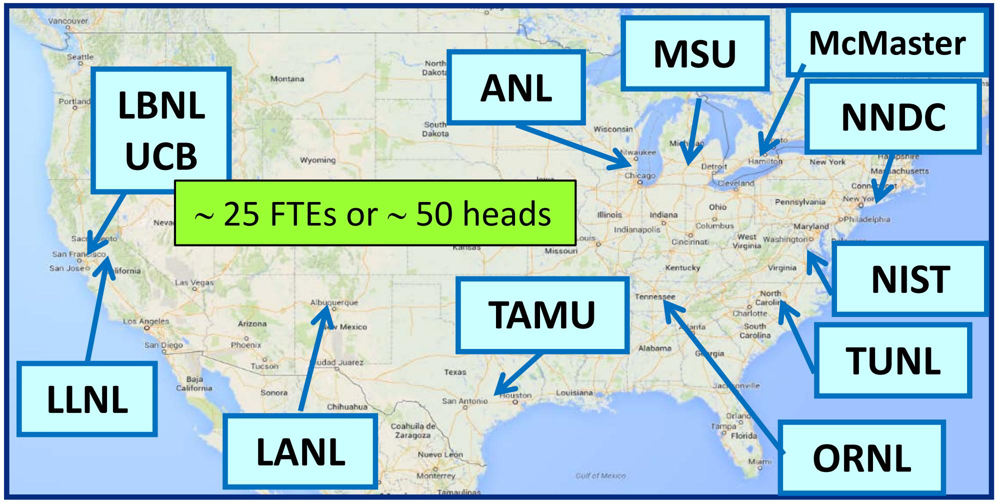


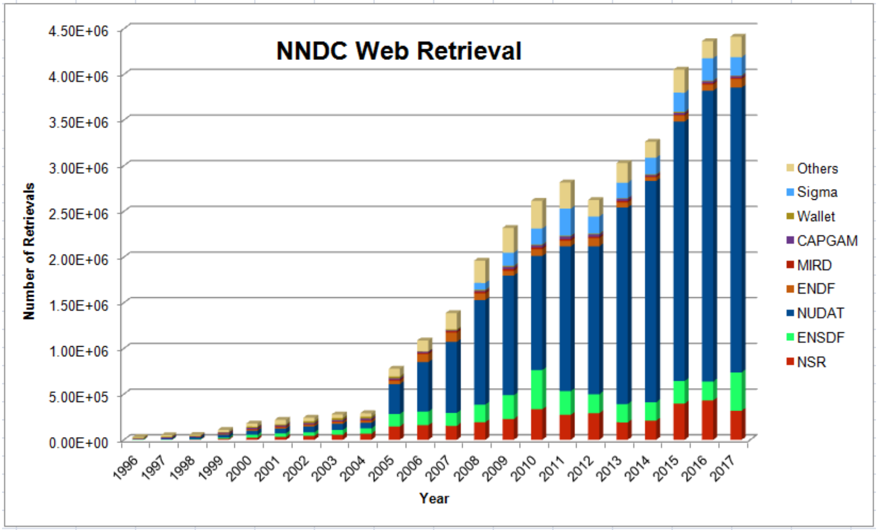




The DOE NP U.S. Nuclear Data Program (Established 1952)

DOE NP US Nuclear Data Program Groups





Nuclear Science References (NSR)
Articles indexed according to content

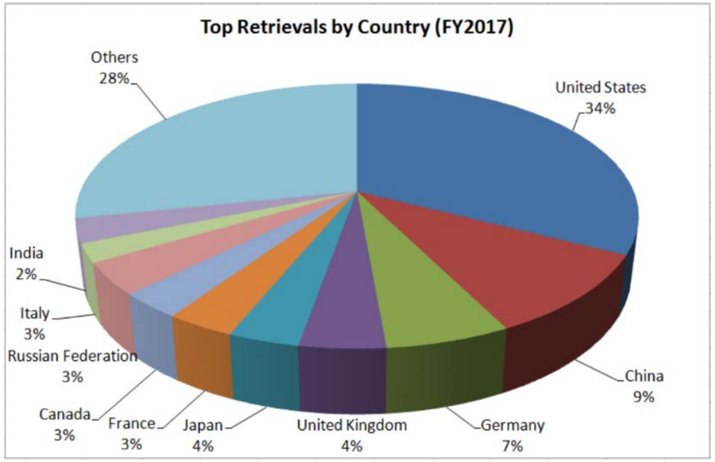
EXFOR
Compiled nuclear reaction data

XUNDL
Compiled nuclear structure and decay data

Evaluated Nuclear Structure Data File (ENSDF)
Recommended nuclear structure and decay data

ENDF
Recommended particle transport and decay data, emphasis on neutron-induced reaction data

Nuclear Data Sheets
Journal devoted to the publication of nuclear data



The DOE NP U.S. Nuclear Data Program

- Collects, analyzes, evaluates, and disseminates nuclear physics data for basic nuclear research and for applied nuclear technologies with emphasis on nuclear structure and low energy nuclear reactions.

- Combines the efforts of approximately 50 researchers at 7 national laboratories (Argonne, Brookhaven, Los Alamos, Lawrence Berkeley, Lawrence Livermore, the National Institute of Standards and Technology, and Oak Ridge) and 6 universities (Duke, McMaster, Michigan State, North Carolina State, Texas A&M, and University of California-Berkeley). Leadership for the USNDP at the national level is provided by the National Nuclear Data Center (NNDC) at Brookhaven National Lab (BNL).

- Nuclear Data activities date back to the Manhattan Project. They started at BNL in 1952 under the Brookhaven Neutron Cross Section Compilation Group, changed to the Sigma Center in 1961, which became the National Neutron Cross Section Center in 1967, and finally the NNDC in 1977.

- In 2017, working with the USNDP and the NNDC, NP and other interested federal offices initiated a pilot program of nuclear data experiments under a Nuclear Data Interagency Working Group (NDIAWG), with the goal of extracting high priority nuclear data of great importance to applications or to research that might otherwise not be addressed in the course of existing research programs. This program stipulates that the experiments supported have participation from the USNDP, so the results will be transferred to NNDC databases in a timely manner. An initial set of nuclear data experiments was approved in 2017, representing partnerships within DOE (NP and the Isotope Program) and between DOE NP and NNSA (NA-22). Several additional offices have expressed interest in joining this Interagency Nuclear Data program in 2018.

First Inter-Agency FOA on Nuclear Data

U. S. Department of Energy
Office of Science Nuclear Physics (Lab only call)
Nuclear Data Interagency Working Group / Research Program
DOE National Laboratory Announcement Number: LAB 17-1763
Announcement Type: Initial
Issue Date: 04/26/2017
Letter of Intent Due Date: 05/12/2017 at 5 PM Eastern Time
A Letter of Intent is required.
Encourage/Discourage Date: 05/26/2017 at 5 PM Eastern Time
Application Due Date: 07/21/2017 at 5 PM Eastern Time

Projects chosen to date for funding under the Nuclear Data Experiment FOA LAB 17-1763:

1. **Title: Improving the Nuclear Data on Fission Product Decays at CARIBU**
   PI: Savard, Guy (ANL); Start date 10/15/2017, Funding: NA-22 and NP

2. **Title: Novel Approach for Improving Antineutrino Spectral Predictions for Nonproliferation Applications**
   PI: Kondev, Filip (ANL); Start date 11/01/2017, Funding: NA-22 and NP

3. **Title: 238U(p,xn) and 235U(d,xn) 235-237Np Nuclear Reaction Cross Sections Relevant to the Production of 236gNp**
   PI: Fassbender, Michael (LANL); Start date 4/01/2018, Funding DOE NP and DOE NP IP

New 2018 FOA for Labs and Universities being developed by NP, NA-22, and …

The DOE NP U.S. Nuclear Data Program

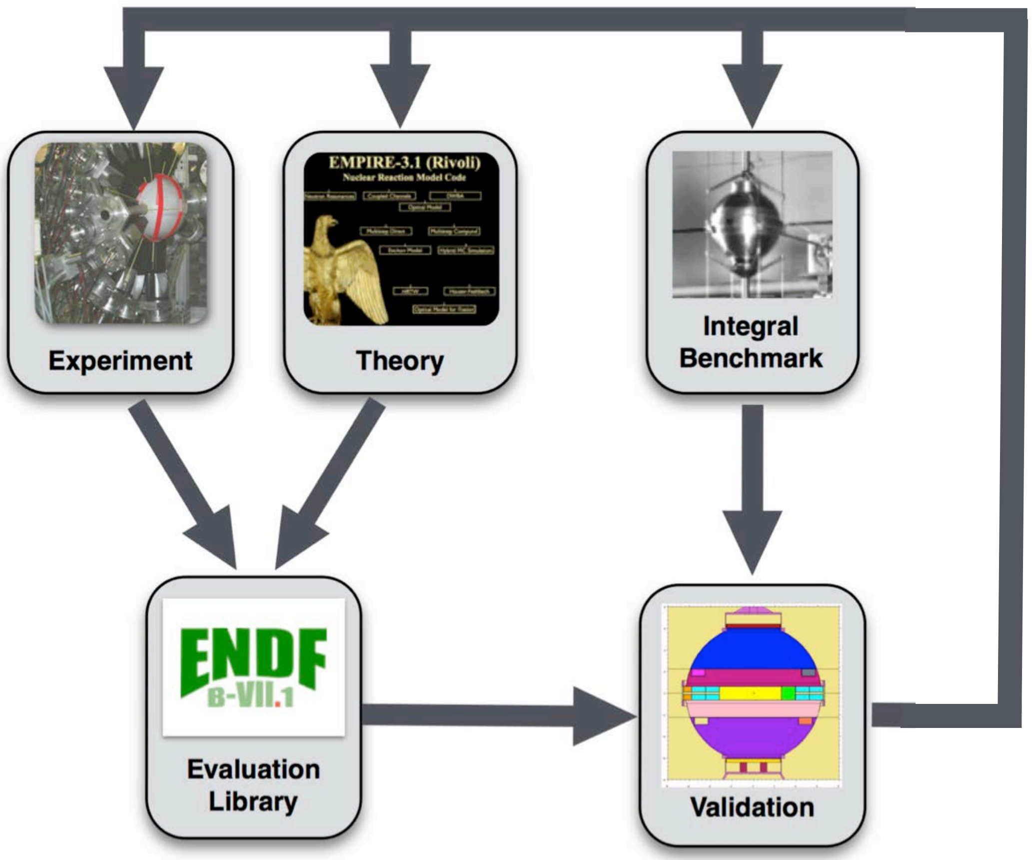
- NP and other Interagency partners believe that having reliable nuclear data that are comprehensive in key areas is a very high priority, and that currently, despite valiant efforts over decades, nuclear data compilations have significant and sometimes dangerous gaps where that is not the case. An attempt will be made to craft a mini-white paper to articulated the reasons for increased focus on this problem.

- A wide range of national and international organizations and research efforts in nuclear physics depend on the availability of the nuclear databases and expertise provided by the USNDP, with NNDC leadership. Examples include the IAEA in Vienna, which works with the USNDP to develop high priority lists of nuclear data needs; the entire range of Defense Programs that involve aspects of nuclear physics; offices concerned with nuclear reactor operations for research and applications; and essentially all of the low energy nuclear physics research and applications communities.

Case in Point 1: The Nuclear Reaction Evaluation Process

The process is iterated with the benchmark constrained until the evaluation converges

Reaction theory inputs are adjusted until they reproduce ***measured data*** (e.g., cross section as a function of E_n, q_n) to generate ***evaluated nuclear data libraries***

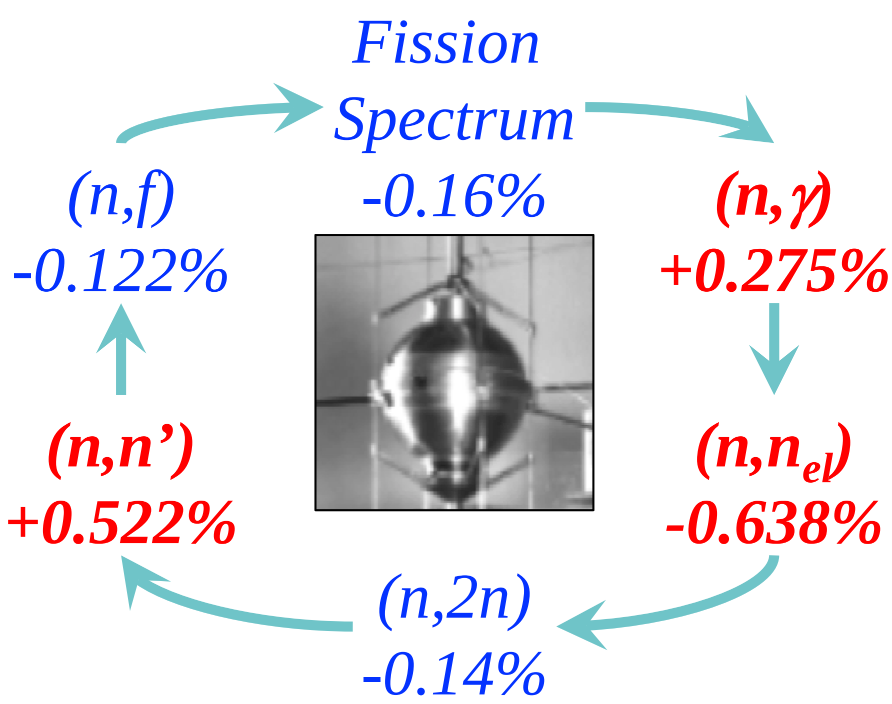


The cross sections from these models are ***validated*** against simulations of ***integral benchmarks*** such as a critical assembly and the result is used to guide the models

Case in Point 1: Compensating Errors in ^{239}Pu(n,n)*

- Reaction evaluations were performed in the US (ENDF) and France (BRC09) and validated against the Jezebel ^{239}Pu critical assembly.
- Both evaluations predict criticality (k_{eff} = 1.00083(11) vs. 1.00060(12))

  - Swapping one cross section at a time from BRC09 for one from ENDF produced small changes in k_{eff} for well-known and small cross sections like (n,f) and *huge changes for cross sections with a lack of good data such as (n,n_{el}) and (n,n')*



Data deficiencies lead to *compensating errors* that introduce unknown uncertainties into the interpretation of pre- and post-det forensics

Case in Point 2: A Cautionary note about the importance of good data: Ignition Campaign at the National Ignition Facility

- The National Ignition Facility (NIF) was designed to produce controlled thermonuclear fusion using a 1.8 MJ laser to drive

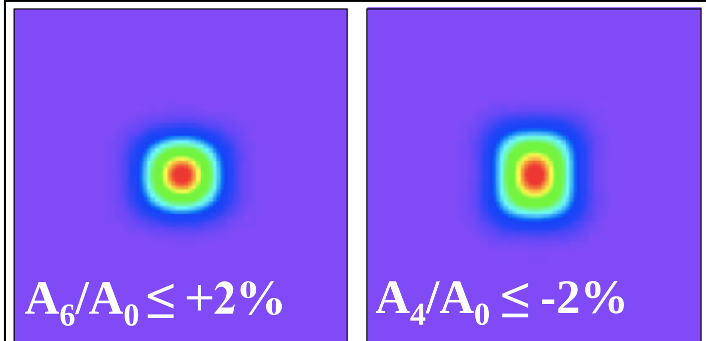
- Predictions based on modeling with *incomplete data* were that the laser drive would compress the capsule with a non-sphericity ≤ 2%[1]

- Measurements with neutron scattering, activation and imaging showed *a far more asymmetric shape*[2]

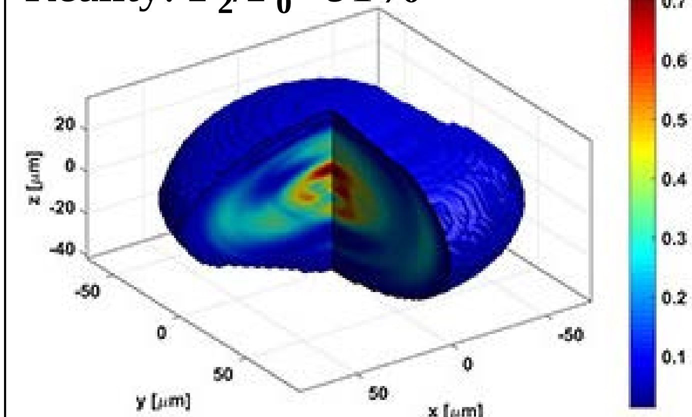
- Result: A failure to achieve ignition thermonuclear burn (Physics of Plasmas 21, 020501 (2014); https://doi.org/10.1063/1.4865400)

Models based on poor data can compromise decision making

Prediction: $R = \sum_{\ell} A_{\ell} P_{\ell}(cos\theta)$



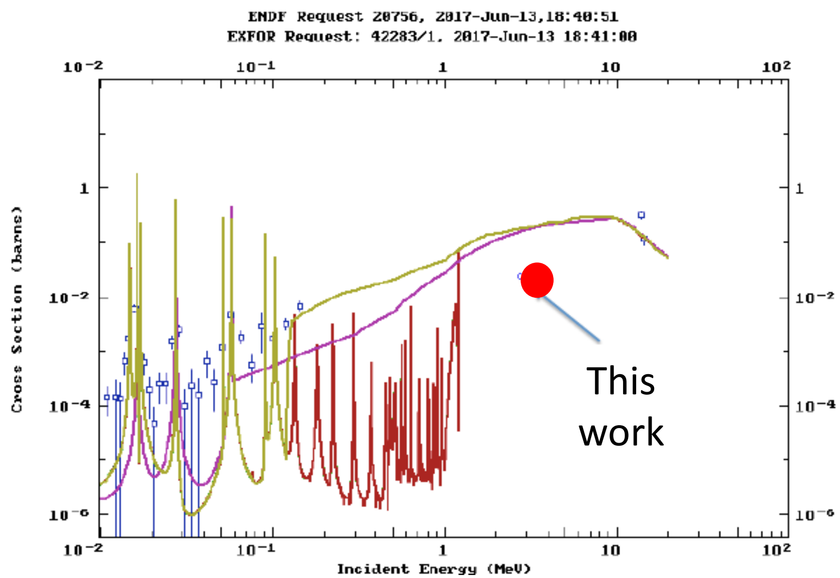
Reality: $P_2/P_0 \approx 31\%$



1 C. Cerjan *et al.*, UCRL-TRL-229780 (2007)

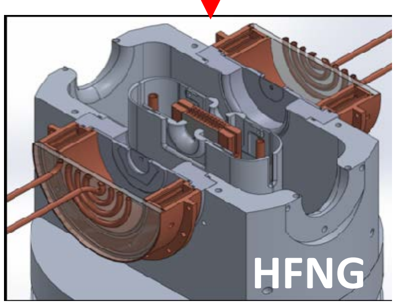
Case in Point 3: The USNDP is aiding the design of nuclear energy systems: the ^{35}Cl(n,p) cross section for molten salt reactors

- The ^{35}Cl(n,p) cross section is thought to be too large at fission energies (≈1 MeV) to allow for natural salt to be used in molten salt reactors, ***but there are no measurements between 100 keV and 14 MeV***

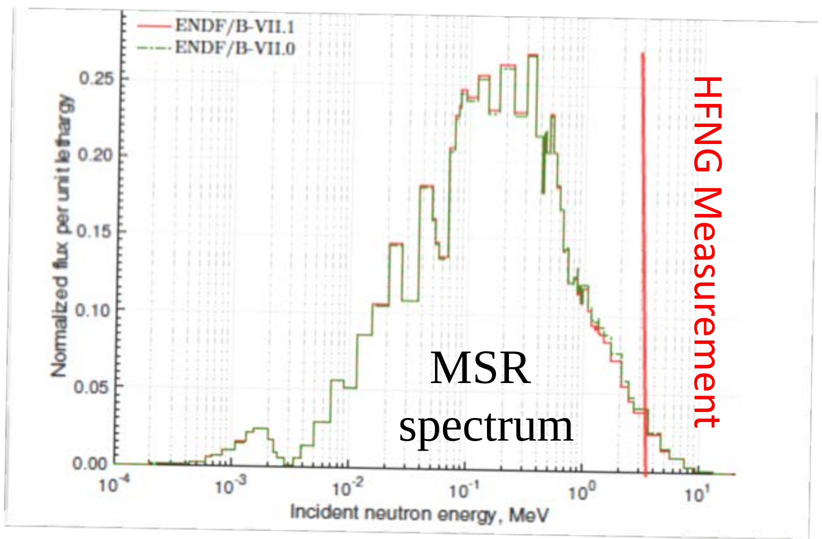


- The first measurement of the ^{35}Cl(n,p) and (n,a) cross sections were performed via activation in ratio to ^{115}In(n,n') at 2.7 MeV at the UC High Flux Neutron Generator (HFNG).

^{nat}In + NaCl samples mounted in the HFNG



The cross section is approximately a factor of 7 below the evaluation



Thanks to J.C. Batchelder and S.A. Chong

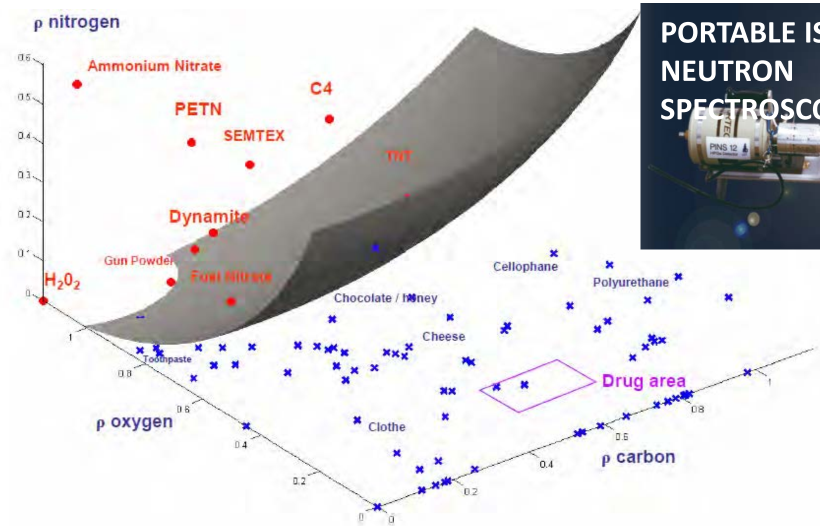
Case in Point 4:Active neutron interrogation for the interdiction of nuclear material requires good (n,xγ) and (γ,x) nuclear data

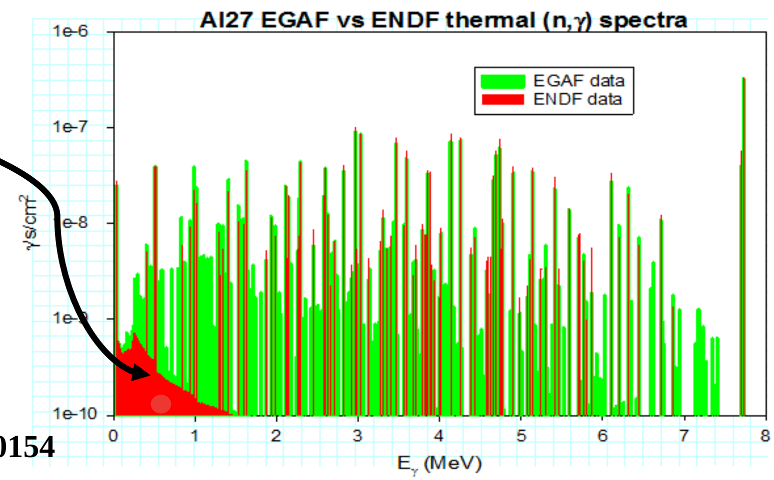
- (n,xγ) and (γ,x) g-rays provide a powerful tool for the interdiction of nuclear material, explosives and drugs, nuclear dismantlement, treaty verification[1,2]

- Their interpretation requires high-fidelity (n, γ), (n,n' γ) and (γ,xγ) data, but existing data is often incorrect of completely lacking.

- Example: ^{27}Al(n, γ) data contained few γ-rays and included background from ***Compton scattering***.

- The USNDP is working to address these issues by measuring, compiling and evaluating γ-ray data for the EGAF (https://www-nds.iaea.org/pgaa/egaf.html) and Baghdad Atlas database (http://nucleardata.berkeley.edu).





[1]M.Litz *et al.*, ARL-TR-5871
[2]J. Medalia, Congressional Research Service 7-5700 www.crs.gov R40154

Poor knowledge of γ-ray production hampers nuclear detection (e.g., CAARS)

Case in Point 5: Accurate Beta-Decay Data from Fission Products Needed for Forefront Basic Research: MTAS Results

Over 70 decays measured: 64% of direct production and 34% of cumulative yield in $^{235}U+n_{th}$ fission.

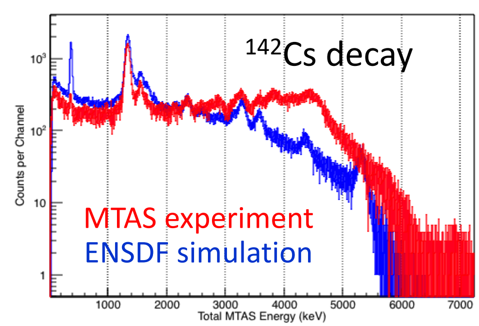
Evaluation of 8 activities, ^{86}Br, ^{89}Kr, ^{89}Rb, ^{90}Kr, $^{90m,gs}Rb$, ^{92}Rb and ^{139}Xe, yielded a reduction of the overall reactor anti-neutrino interactions by 1.2% for LEU power reactors and 1.5% for HEU research reactor like HFIR, when MTAS data replace respective entries in ENSDF.

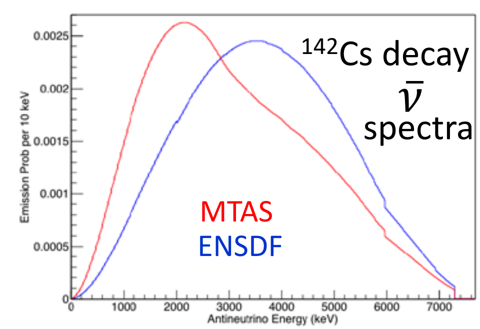
The reported 95(2)% anomaly is reduced, correspondingly. *[Fijałkowska et al.,2016]*

MTAS data on the top three activities contributing to the enhancement of anti-neutrino signals at 5-7 MeV, ^{92}Rb, ^{96}Y and ^{142}Cs, increases this ~ 10% effect to about 12%. *[Rasco, Wolińska et al., 2016]*

MTAS β-γ VANDLE β-n-γ

Priority for $\bar{\nu}$ Priority for decay heat





MTAS spectra of ^{142}Cs decay and anti-neutrinos emitted from ^{142}Cs. Red lines are MTAS data, blue lines are based on present ENSDF data. The MTAS data points to a shift of the ^{142}Cs decay to higher excited states and hence the anti-neutrino spectrum shifts towards lower energies.

Conclusion from MTAS measurements:

- "reactor anti-neutrino anomaly" is reduced
- high energy "anti-neutrino bump" is enhanced
- decay heat is enhanced

Outlook

For a broad spectrum of very important pursuits spanning the range from basic research to National Defense, having reliable nuclear data that are both comprehensive and correct in key areas is a very high priority. Without such, compromised decision making can lead to wasted resources, incorrect conclusions, and national security risks.

Currently, despite valiant efforts over decades, some nuclear data compilations have significant and in some cases dangerous gaps where reliable data do not exist.

DOE NP and its Interagency partners, including NA-22, put out a coordinated lab-only FOA call in FY2017 to field a pilot experimental measurements program in to begin to opportunistically address some of these issues.

In FY2018 the intention is to put out a coordinated lab and university FOA call targeting the same type of research. (For more information, NP POC is Ted Barnes).

DOE NP and NA-22 very much hope and look forward to being joined on this FOA by an expanded list of partners within and outside of SC who will consider making awards in this very important work.

DTRA Research and Development Nuclear Data Needs

NDREW – Jan 23-25, 2017

DISTRIBUTION STATEMENT A: Approved for public release, distribution is unlimited

Kevin Mueller
Overall Lead for Nuclear Data Program

Roger Roberts
Technical Lead for Nuclear Data Program

Dave Petersen
Academic Lead for Nuclear Data Program

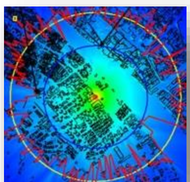
Topics

- Why DTRA cares about nuclear data
- What our nuclear data program looks like today
- Where we are going with our nuclear data program
- How you can help
- Efforts we find interesting

Why we care

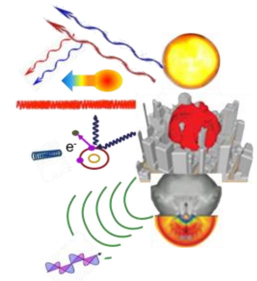
Nuclear Weapons Effects

Develop and transition nuclear weapons effects models and planning tools to support targeting and survivability



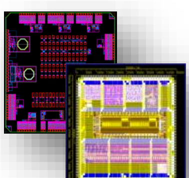

Nuclear Forensics

Develop and transition technologies to detect, characterize, and attribute nuclear explosions

Nuclear Survivability

Develop and transition standards, technologies, and test capabilities to ensure that mission critical systems survive in a nuclear environment



Nuclear Detection

Develop and transition technologies to detect and characterize nuclear threats



DTRA is a significant user of nuclear data

What our nuclear data program looks like today

- Internal to DTRA, there is disagreement on whether nuclear data projects are basic research or applied research, which has limited our investments

- The individuals closest to the mission usually can't provide specific nuclear data needs
  - Best we get is *"I need better nuclear data"*
  - Worst we get is *"What is nuclear data?"*

- We don't do a good job of presenting a unified message to the nuclear data community

Where our nuclear data program is going

Within 3 months:

- Establish a structure within DTRA Nuclear Technologies (NT) to manage and prioritize nuclear data requirements
- Get draft requirements from all NT users (eventually all DTRA users)
- Assess whether interagency FOA satisfies DTRA acquisition rules

Within 6 months:

- Identify recent, ongoing, and upcoming interagency-funded nuclear data projects and align against NT nuclear data requirements
- Assess evaluator bandwidth at LANL and LLNL and recommend a path forward to decrease the evaluation backlog for relevant data

Within 12 months:

- To be determined – fix evaluation pipeline, participate in interagency FOA?

How you can help

Defense Programs:

- We want to work with you to make sure the nuclear data pipeline has sufficient bandwidth to handle the measurements we have already made

Interagency:

- We have a team of post-docs tasked with running down interagency projects and aligning them against DTRA nuclear data requirements – please help them

Efforts we find interesting

Efforts of interest we are tracking

- **LLNL:**
  - **Evaluations of (n, γ), (n, n′), (n, 2n), (n, 3n), and (n, f) reactions for ^{236}Pu, ^{237}Pu, and ^{238}Pu using new fission xsec data with TALYS code.**
- **TUNL/Duke:**
  - **^{191,193}Ir(n, 2n)^{190,192}Ir measurements**
  - **^{63,65}Cu(n, γ)^{64,66}Cu measurements**
  - ***Noteworthy – Short lived (< 5 minutes) neutron-induced fission product yield measurements with plans to explore fission products existing < 1 second.**
- **RPI:**
  - **Co, Cu, Ta and Fe high energy (0.5 – 20 MeV) transmission and (n, γ) measurements.**

Planned academic efforts

- **Colorado School of Mines (CSM):**
  - **Investigating fission product yields from thermal to fast energy fission induced by both neutrons and photons.**
- **Pennsylvania State University (PSU):**
  - **Examining time-dependent neutron/gamma intensities resulting from short-lived fission fragments produced by fast neutron fission.**

Questions?

AFTAC Material Identification and Debris Analysis Overview

- Col. Steve Gorski, Commander
- Dr. Glenn Sjoden, Chief Scientist
- Dr. Bill Junek, Sr. Scientist, Office of the Chief Scientist

- Air Force Technical Applications Center
- Patrick AFB, FL

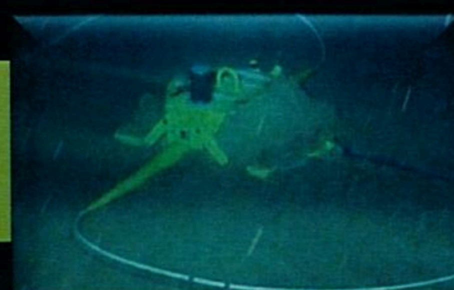
- January 2018

Nuclear Explosion Detection

Atmosphere and Space

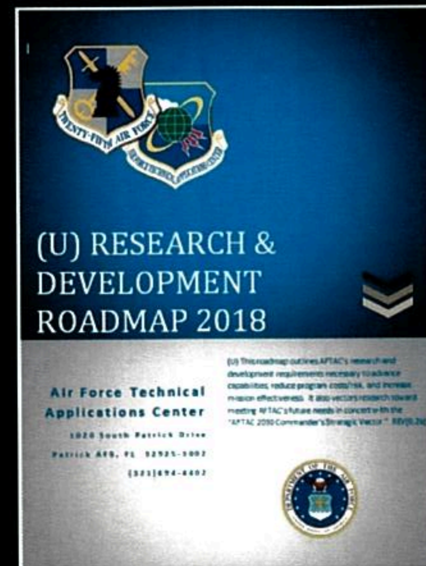
Nuclear Materials

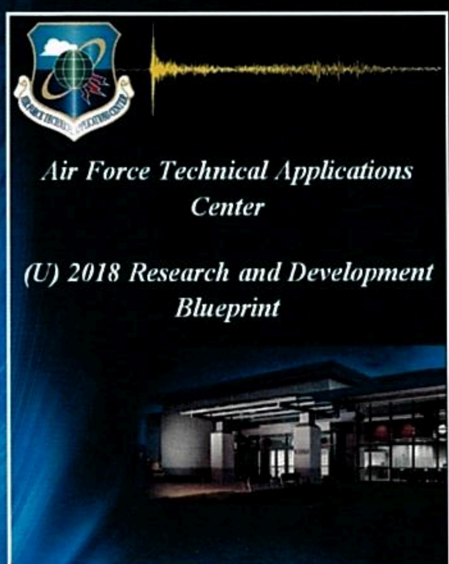
Geophysics



R&D Corporate Process

- The **R&D Roadmap** will identify AFTAC R&D Focus Areas (FA), gaps, and promising thrust areas. It will transmit prioritized /ranked technical guidance for R&D by vectoring outside research organizations to best support AFTAC's current and future missions





- The **R&D Blueprint** incorporates **value based decision models** based on AFTAC Roadmap priorities tied to requirements, objectives, and acquisition strategies to identify specific R&D projects toward operational capability across the broadly scoped AFTAC mission. **Value based decision metrics** can be altered to reflect Commander's intent for short and long term outlooks.

Nuclear Data Needs

1. **Referenceable compilation of existing data, includes but not limited to**
   - Cross section, mass, half life, fission yield
   - Data reference should not be limited to materials in community databases (e.g., ENSDF)

2. **Fuels other than U235, Pu249 (i.e., U233, Th232, etc.)**
   - Mid-energy cross sections between thermal and fast
   - R-values

3. **Experimentation needed for confirming decay yield and half life for selected materials (e.g., Sm153, Cd115m)**

Summary

- **AFTAC's mission is to monitor international compliance to nuclear test ban treaties.**

- **AFTAC will continue to develop its corporate R&D process through a "whole of Government approach"**
  - Quantitative prioritization process will enable CC to identify greatest R&D needs across all AFTAC mission areas

- **AFTAC's nuclear data roadmap needs are designed to support 24/7 operations**

Office of Defense Nuclear Nonproliferation Research and Development

Nuclear Data Roadmapping & Enhancement Workshop (NDREW) 2018

A thought process to establish Nuclear Data needs

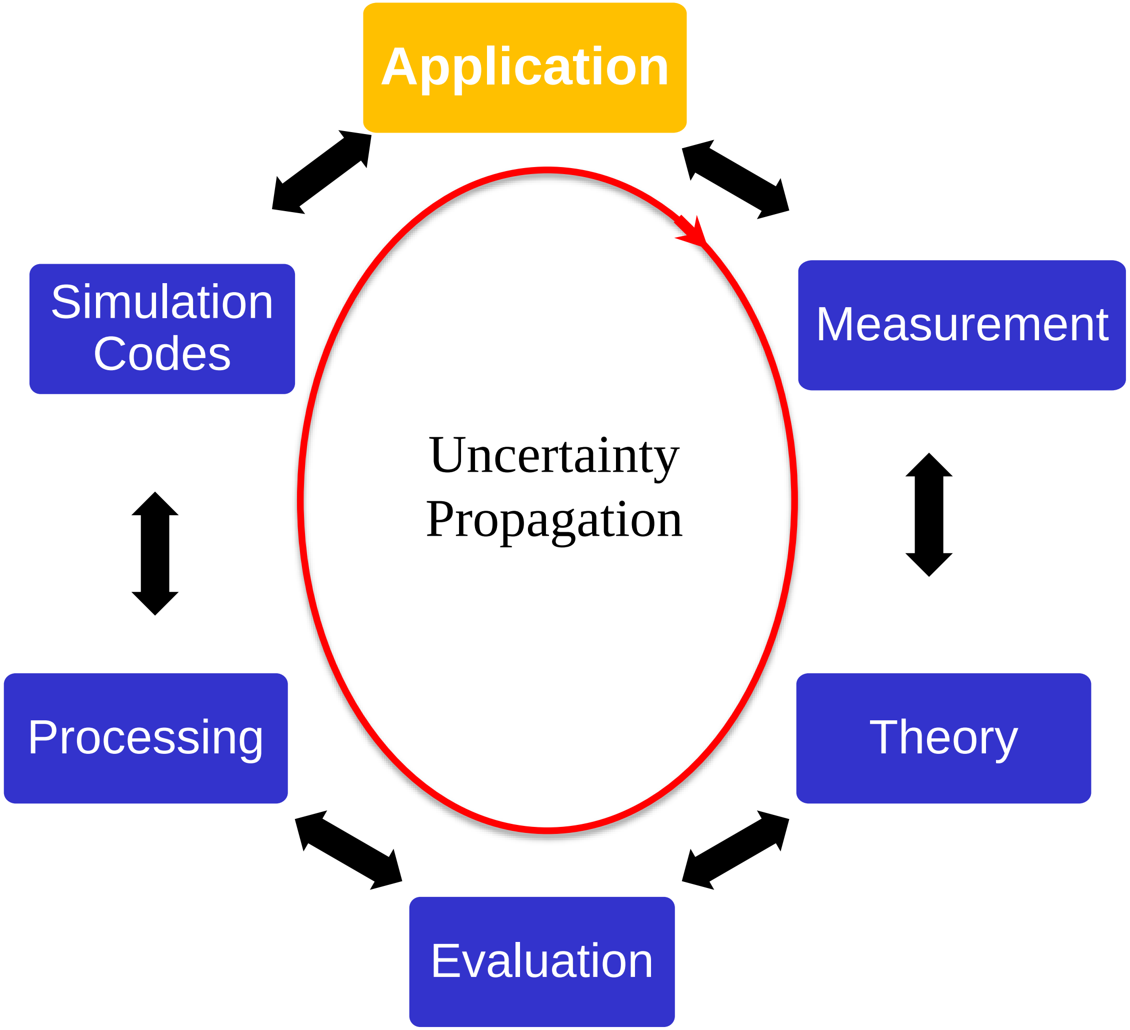
Teresa S. Bailey, Ph.D.
Lawrence Livermore National Laboratory

LLNL-PRES-744699

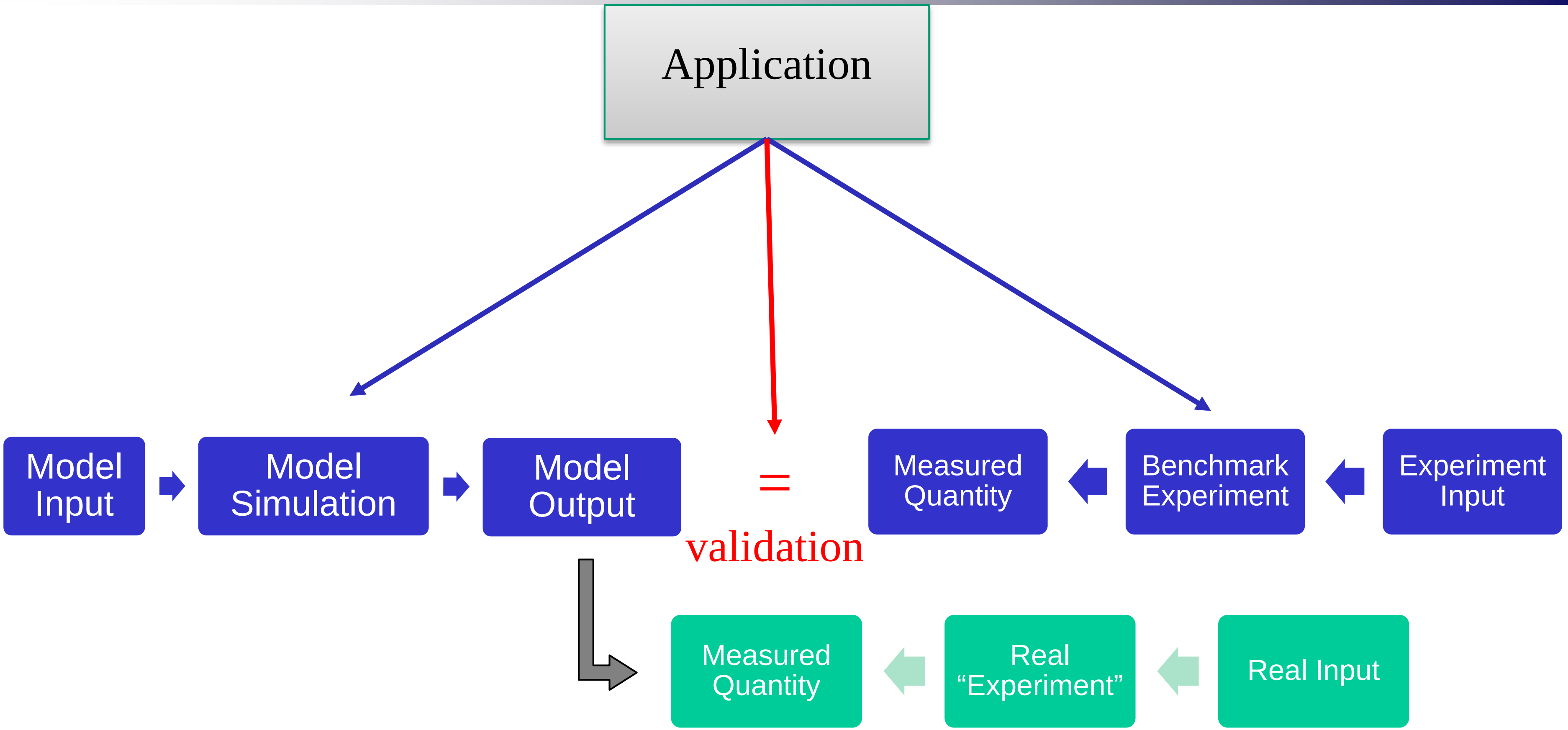
January 23 - 25, 2018

Applications drive Nuclear Data needs

- **The NDREW will include a discussion of the needs in each box**
- **Each piece of this cycle is essential**
- **We need a long-term strategy to maintain core competencies and facilities**
- **A key for the application is the development of high quality, relevant benchmarks**



Application scientists validate models using benchmarks to make assessments



- **Goal: Establish a validated modeling methodology that allows the application scientist to model, design and assess real systems**

- **Today’s applications are often Inverse Problems, where Reality is unknown**

Benchmarks must represent the application

- **Experimental Input**
  - In a high quality Benchmark Experiment, input is well-characterized
  - In the real world, this is often the unknown quantity we need to find

- **Benchmark Experiment**
  - Benchmarks should be representative of reality
  - Benchmark experiments can also be simplified, but exercise multiple parts of the physics

- **Measured Quantity**
  - Benchmark experiment is designed to allow for the measurement of a Quantity of Interest with a specified error bar
  - Often, the Quantity of Interest is inferred
  - Sometimes Nuclear Data is used (through simulation) to help infer this Quantity of Interest
  - Reducing error in the Quantity of Interest can lead to better assessment and prediction
  - In the real world, the measured Quantity of Interest is what is available to make an assessment

Models rely on many things. Nuclear Data is one of the most important pieces.

Model Input → Model Simulation → Model Output

- **Model Inputs**
  - Includes Nuclear Data, Geometry, Physics Settings and Models, Definition of Output
  - Each application has best practices
  - New application space require investigation to determine best practices
  - Documentation of best practices is very important

- **Model Simulation needs to be accurate, fast, and maintainable**
  - Accurate: Is the mathematical model correct? Does discretization satisfy correct limits?
  - Fast: Reduce accuracy to increase speed, the goal is optimizing accuracy and speed
  - Maintainable: Is the code supported, portable, V&V'd for the application?
  - Multiple methods for code-to-code comparison increase confidence – MC and S_N

- **Model Output**
  - Simulation output format matches the experimental measurement

We can establish Nuclear Data priorities using our benchmarks and models

- **Discovery that the Nuclear Data simply does not exist**
  - Platinum in ENDF B7 is an example
- **Use of UQ and Sensitivity studies to propagate nuclear data uncertainty to determine which reactions matter for improving application**
  - Defines target error bars for Nuclear Data
  - Helps set priorities about what to measure first
  - Mathematical framework helps to keep priorities application driven
- **Notice that a certain type of experiment is not modeled well**
  - Evidence of a systematic error in the Nuclear Data
  - Evidence of missing physics in the model
  - Evidence of problem with experiment
- **Numerical convergence of model does not lead to improved match to experiment**
  - Evidence that the underlying mathematical model is incorrect/insufficient
  - Evidence that discretization is incorrect/insufficient
  - Evidence of problem with experiment

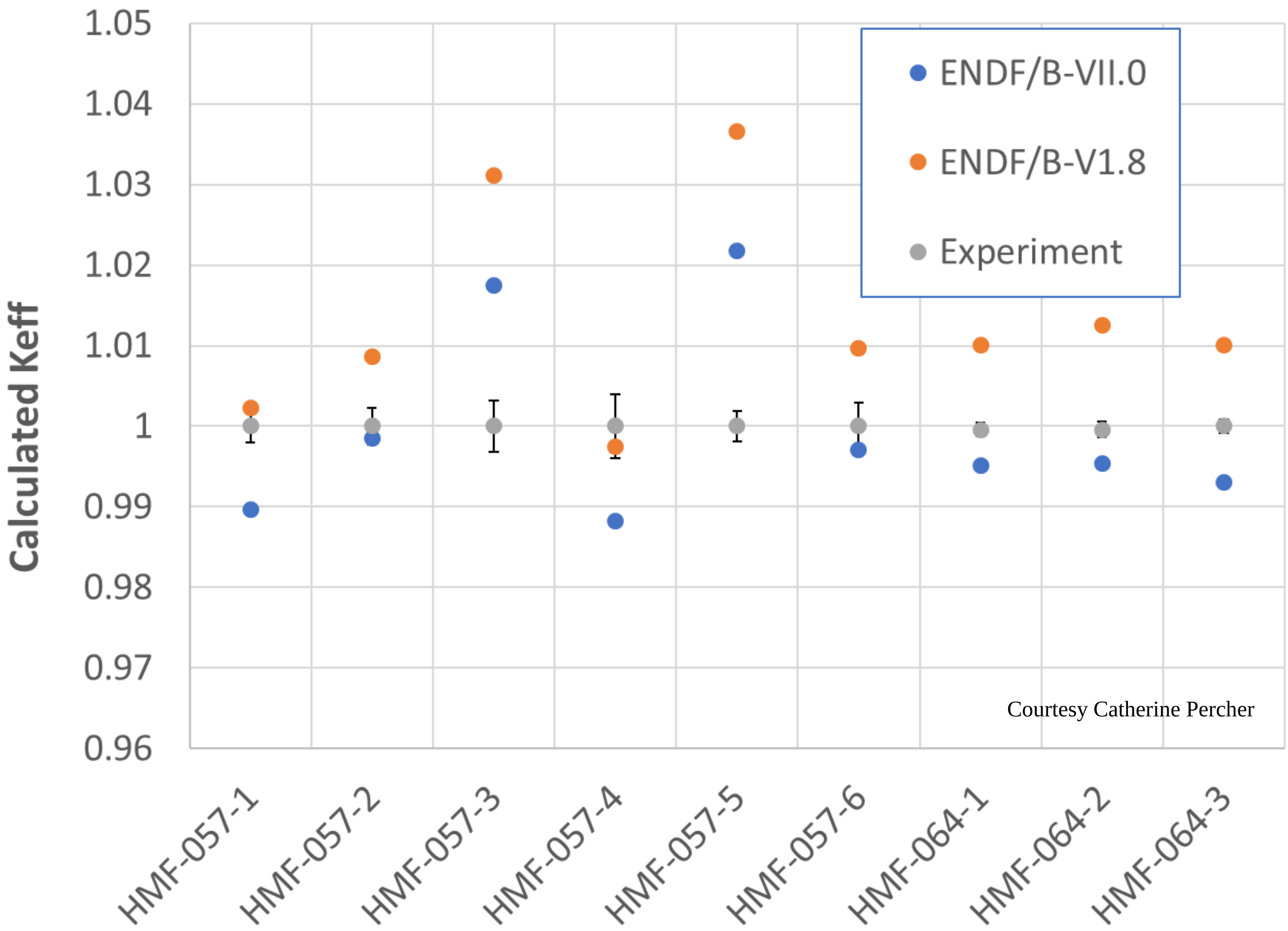
Quality Control is essential; errors and code bugs masquerade as “physics”

We can start defining needs by examining quality of each Nuclear Data pipeline component

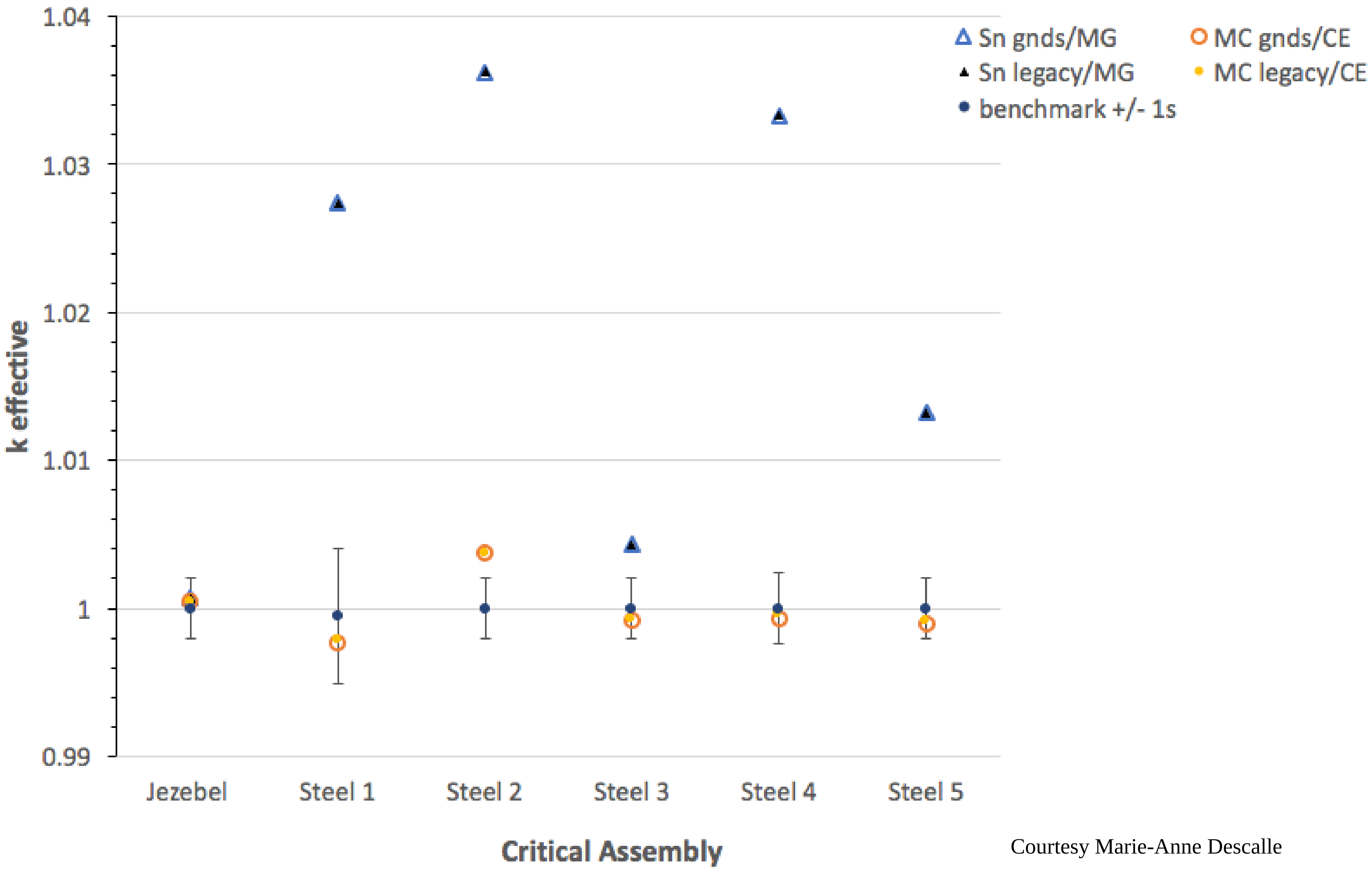
1. Application – Does a high quality benchmark suite exist that represents the application area and allows for assessment of uncertainty in a quantity of interest due to uncertainty in the fundamental data?
2. Measurement – If a new measurement is needed, is it feasible to perform this measurement?
3. Theory – Do theory models/codes exist for creating nuclear data for the application that cannot be determined experimentally?
4. Evaluation – Do we have national/international expertise and capability to produce Evaluated data for the needed nuclear data? What about co-variance information?
5. Processing – Do processing codes produce accurate/correct data for the application? Do the processing codes deliver databases that the Simulation Codes can utilize?
6. Simulation Codes – What improvements are needed in the transport simulations to allow for improved modeling of benchmarks (accuracy, speed, maintainability)?
7. Is there a methodology for propagating uncertainty through the benchmarks to help prioritize nuclear data needs for your application?

Each piece of this cycle is essential. We need a long-term strategy to maintain core competencies and facilities.

Example: Notice that a certain type of experiment is not modeled well



Example: Numerical convergence of model does not lead to improved match to experiment



Courtesy Marie-Anne Descalle

Office of Defense Nuclear Nonproliferation Research and Development

Nuclear Data Roadmapping & Enhancement Workshop (NDREW) 2018

Monte Carlo simulations and nuclear data

Jerome Verbeke
Lawrence Livermore National Laboratory

Lawrence Livermore National Laboratory, P. O. Box 808, Livermore, CA 94551

This work performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344

January 23 - 25, 2018

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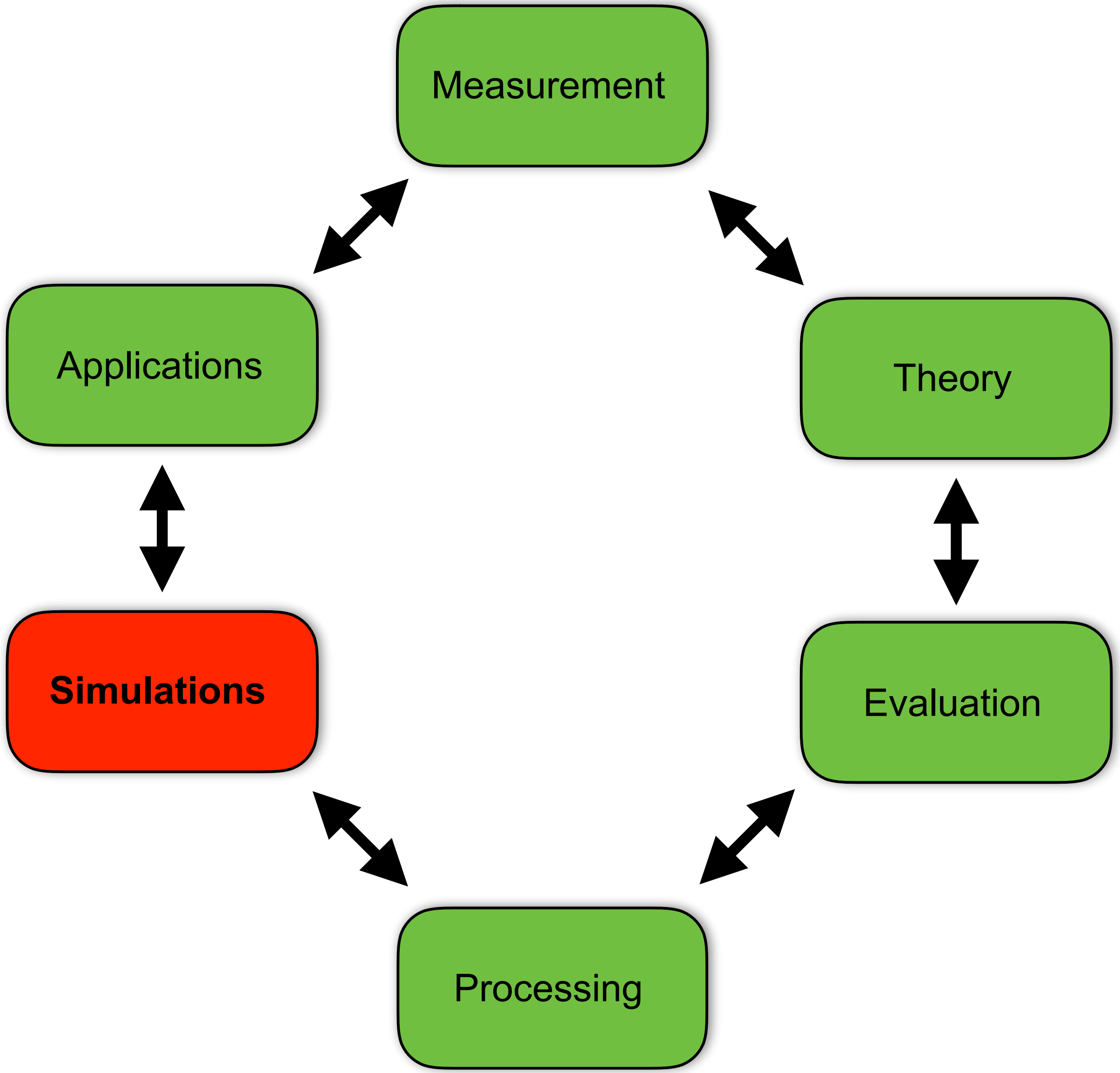
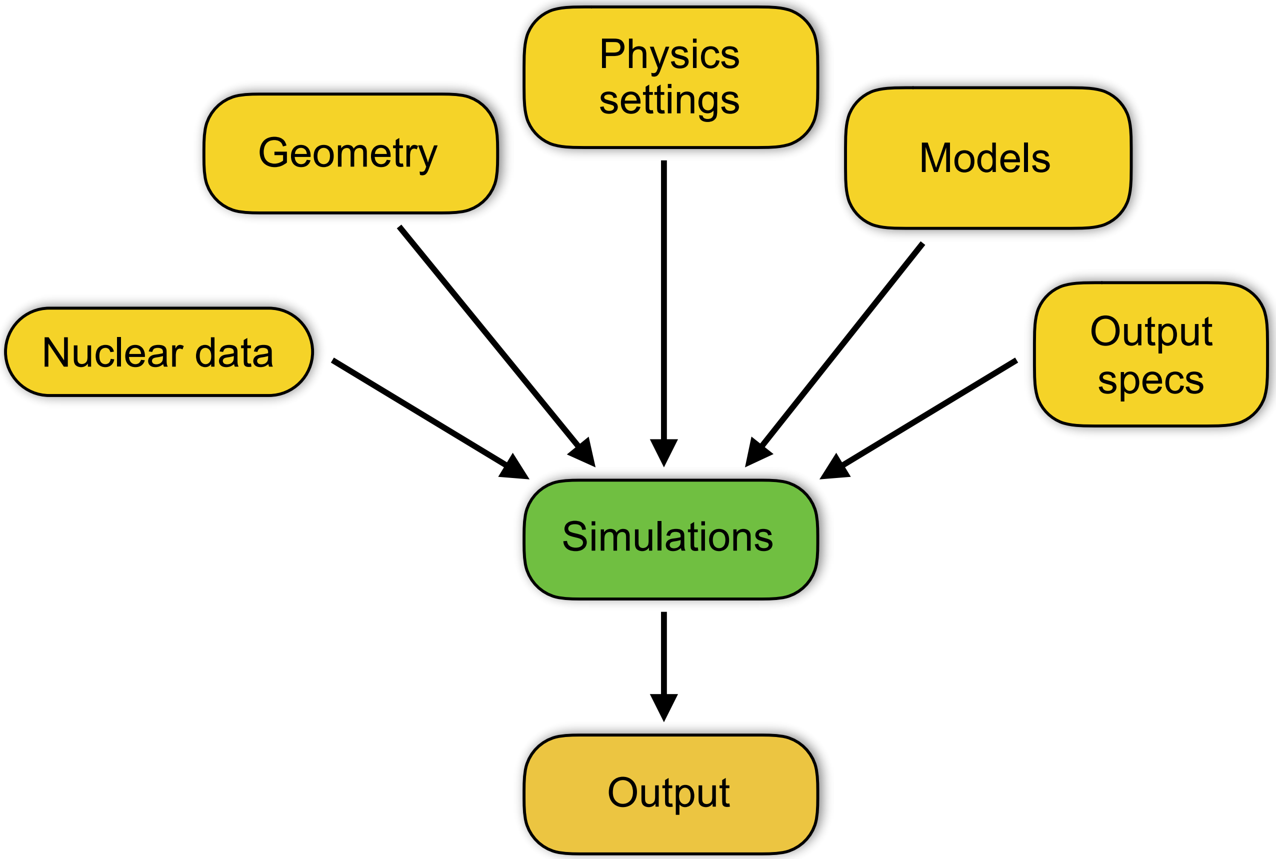
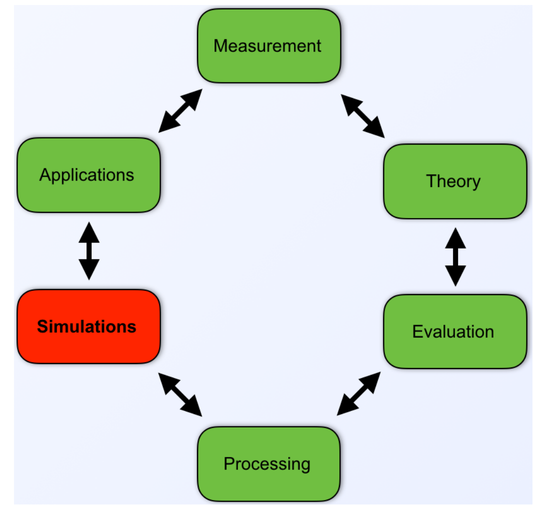
Data pipeline



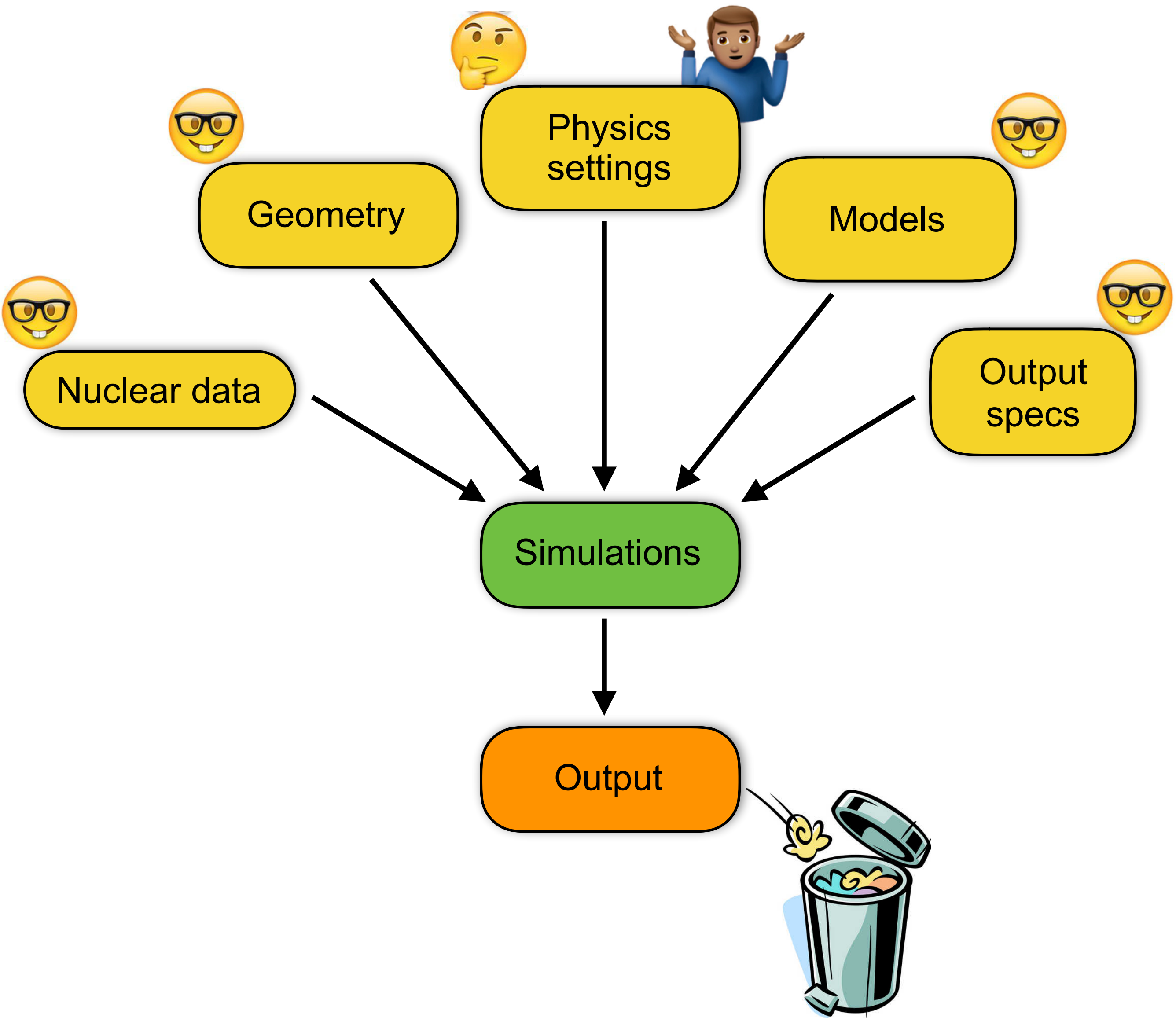
Simulations dependencies

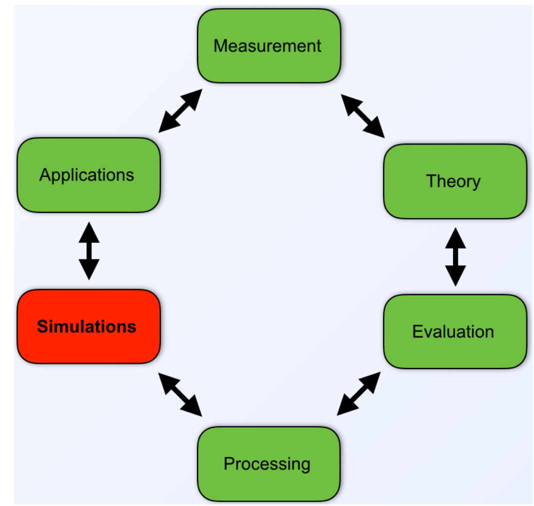




Accurate modeling depends on many parameters

Danger of using simulation tool as black box

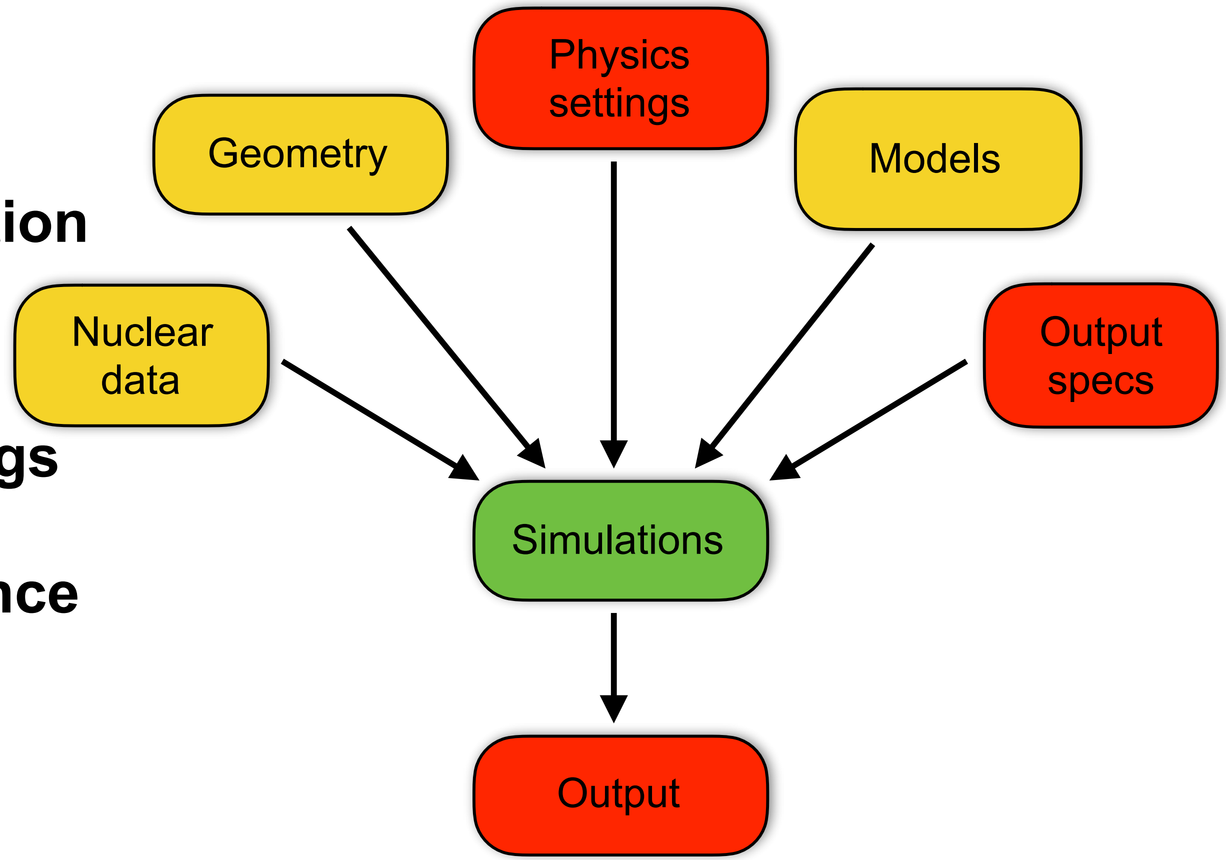




Guess work leads to errors

State of the art and objectives

- **Without expertise in transport codes, physics models and data, it is very easy to come up with unrealistic modeling**
  - **Make default physics behavior correct and useful for non-proliferation applications**
  - **Describe physics settings required for simulating reactor cores, coincidence counting, backgrounds, etc.**
  - **Document these lists**

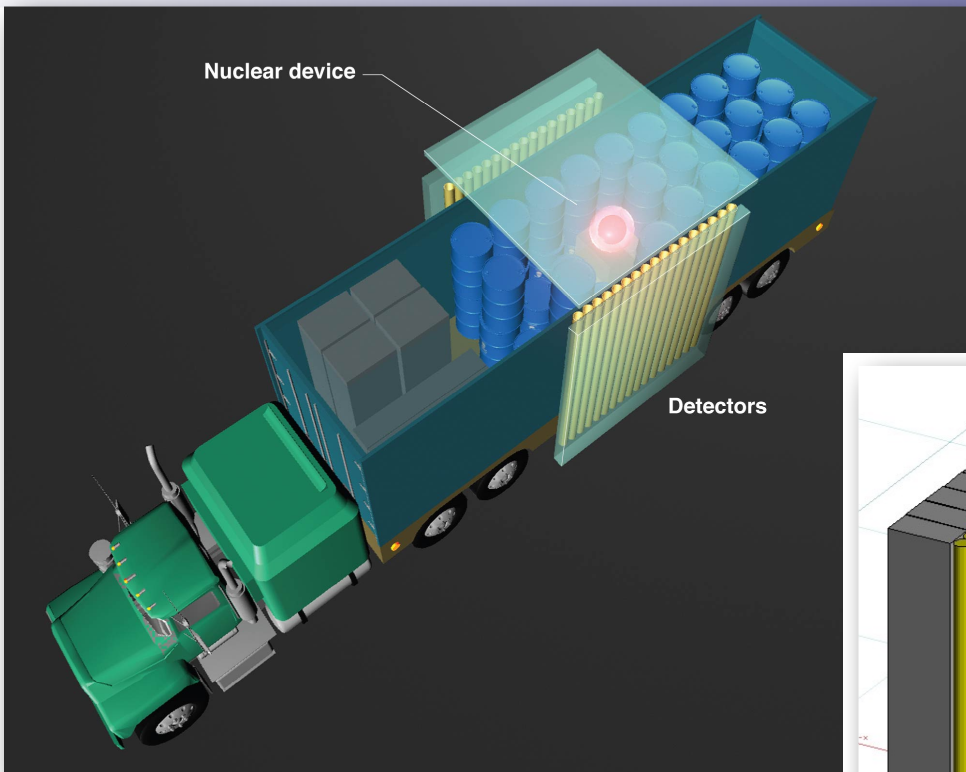


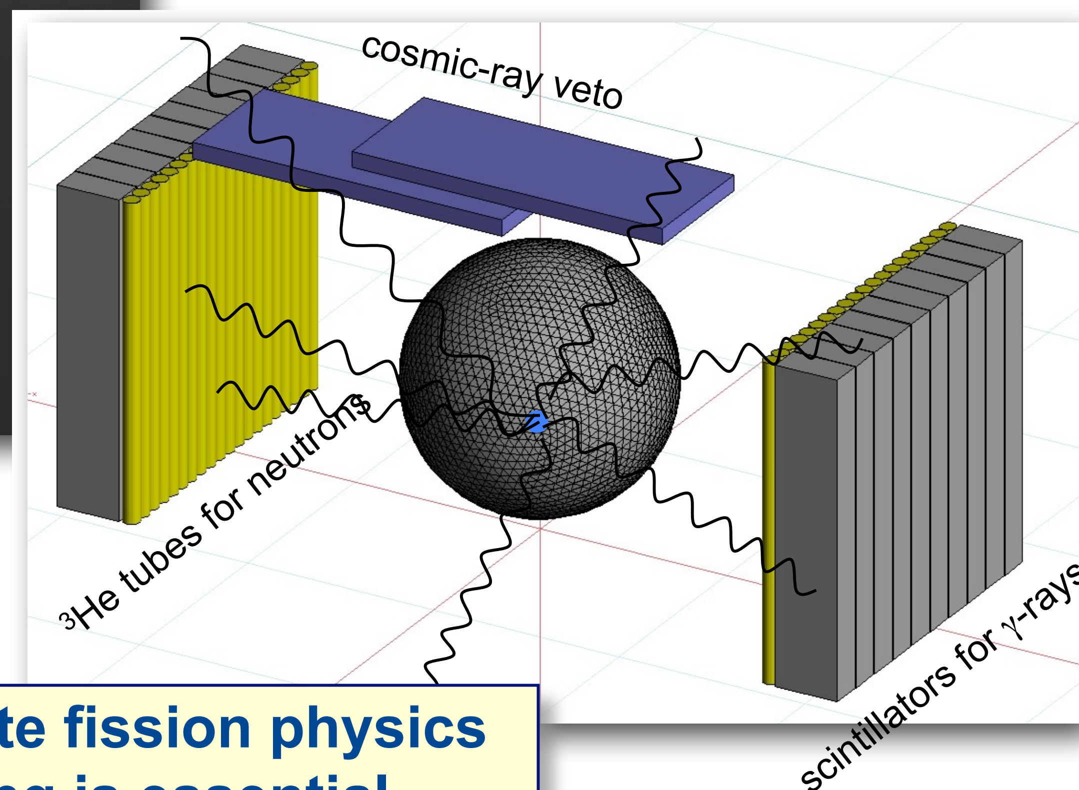
OUTLINE

- Passive detection of SNM:
  - Codes miss correlations between secondary neutrons and photons from (n,f)
  - Uncorrelated photons are randomly added
  - Neutrons and photons from inelastic scattering not in coincidence
- Active interrogation:
  - Limited prompt photon yields for (n,f)
  - No prompt photon yields for (γ,f)
  - Delayed background neutrons from γ+^{18}O difficult to model, x-section off by one order of magnitude
- 14 MeV neutron interrogation and imaging:
  - difficult to answer specific questions about particle tracks
  - list-mode data produces very large files

Passive detection of SNM using sf and (n,f)

Passive HEU detection relies on detection of large bursts of neutrons and gamma-rays from fission





Essential physics for fission-chain detector concept: can detect shielded HEU

Accurate fission physics modeling is essential

Fission multiplicity

Neutron-induced fission

FissLib = LLNL Fission Library+FREYA model

	# neutrons/fission	# γ-rays/fission	fission neutrons and γ-rays correlated ?
MCNPX 2.7*	w/ FissLib	w/ FissLib	w/ FissLib
MCNP 6.2 beta	w/ FissLib/CGMF☆	w/ FissLib/CGMF☆	Samples R_1 for neutron emission, R_2 for photon emission
GEANT 4.10.4	w/ FissLib✠	w/ FissLib✠	w/ FissLib✠
COG 11.2	Samples full P(v) dist	1	
TRIPOLI 4.10	w/ FissLib	w/ FissLib	w/ FissLib

*MCNPX 2.7 is past end-of-life

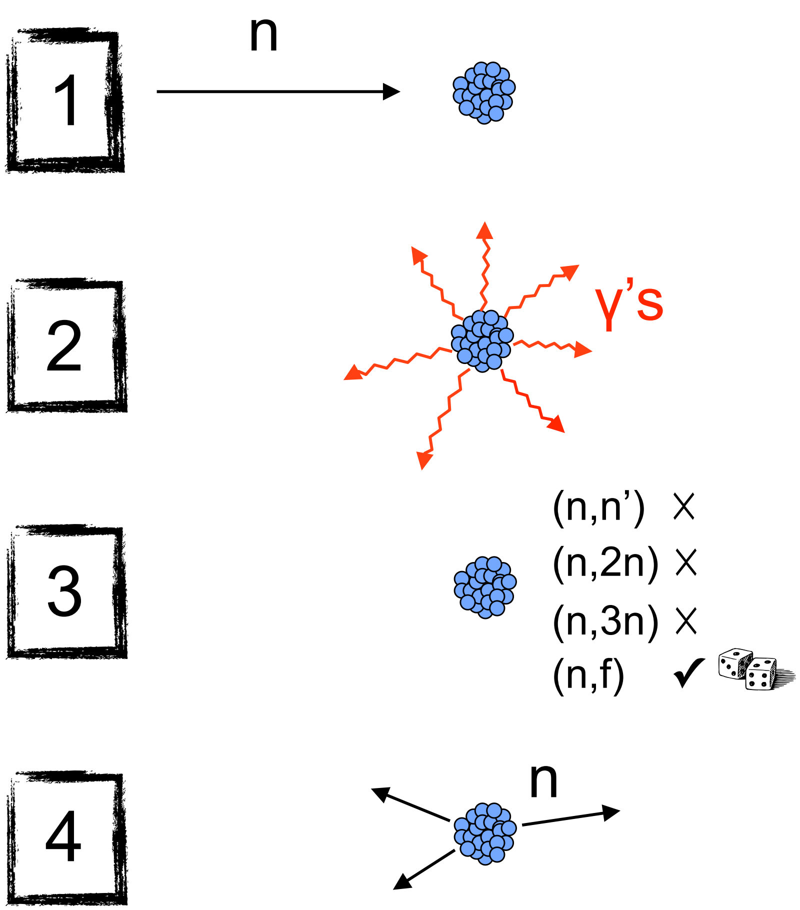
Complete analog fission physics often missing

✠ The number of isotopes is limited in HPneutron, not in LEND

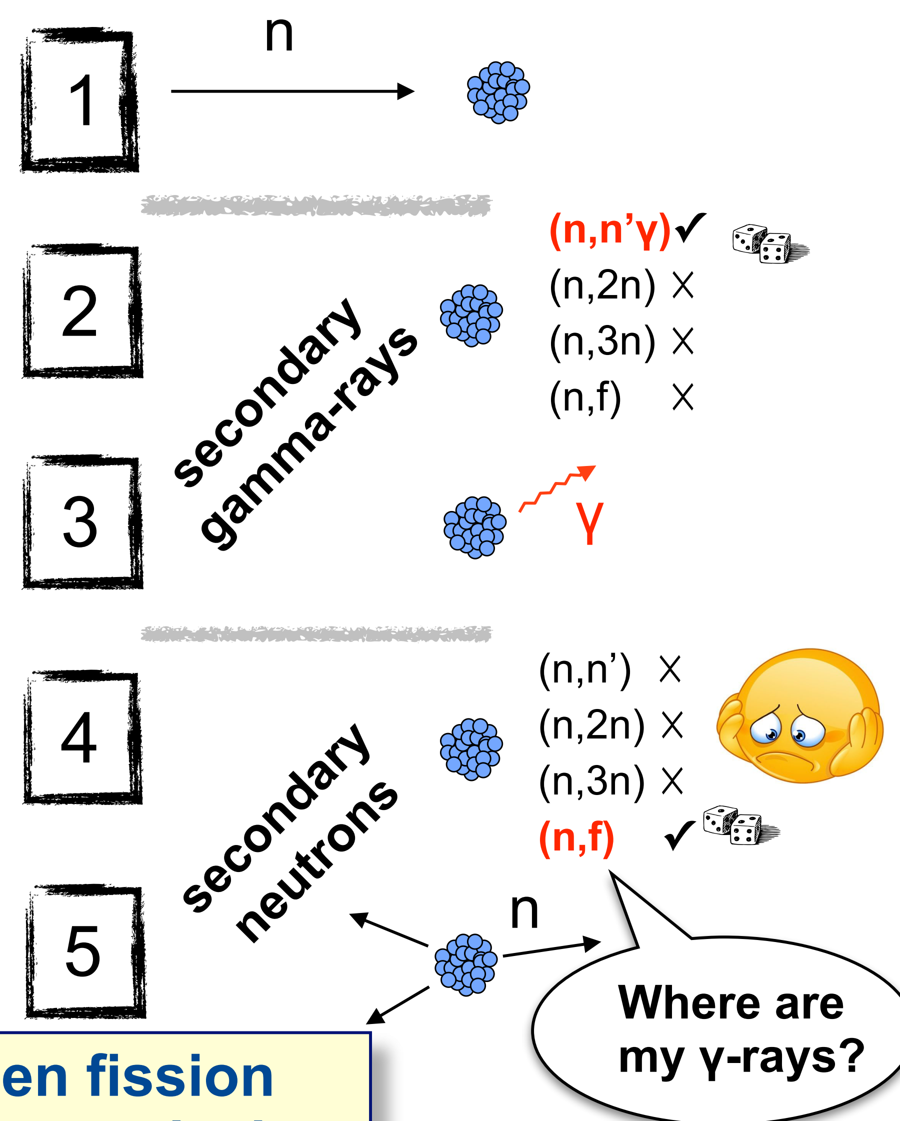
☆ Work supported by NA-22

Secondaries from fission not correlated

Default MCNP6.2 treatment



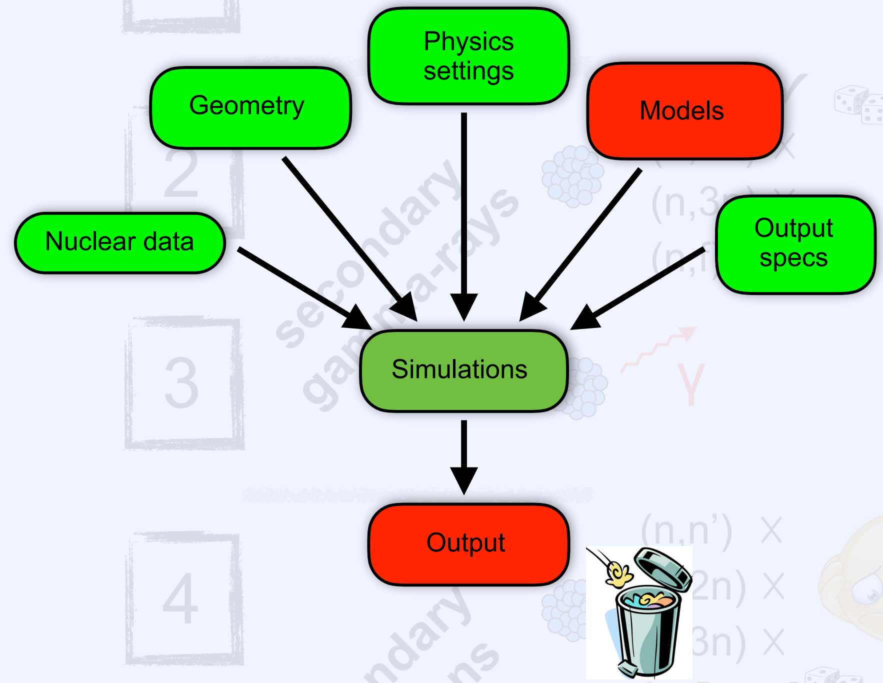
Improved MCNP6.2 treatment



Coincidences between fission neutrons and photons are missing

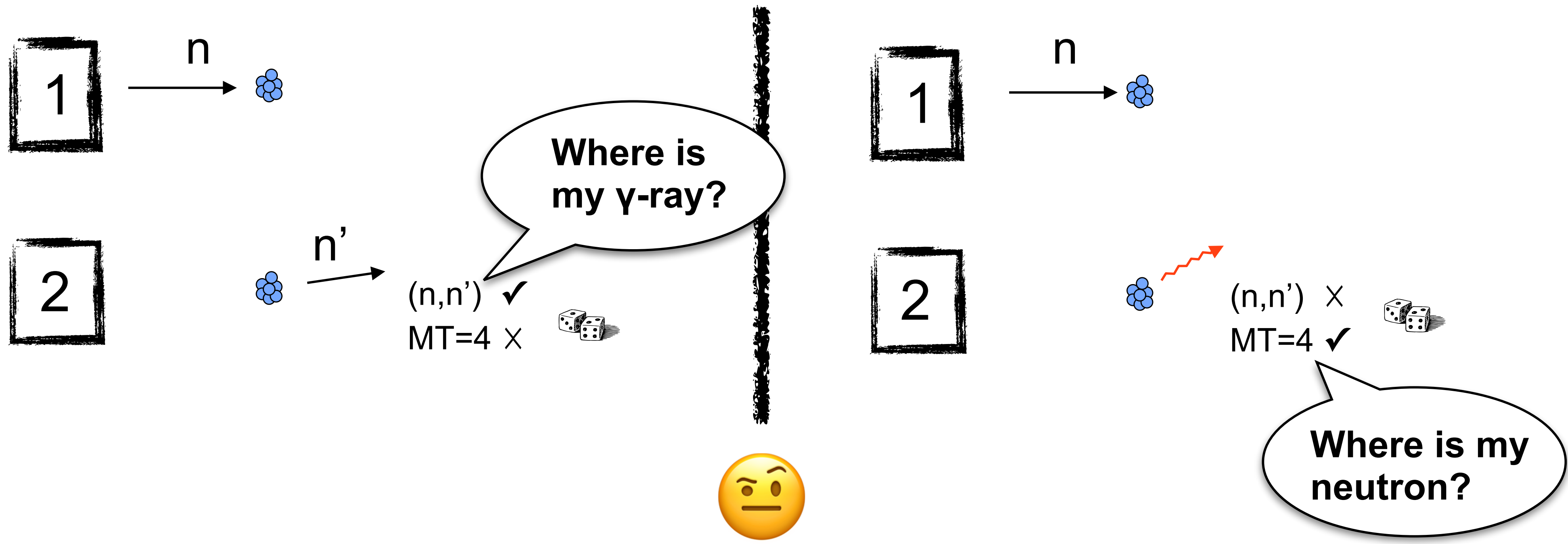
Secondaries from fission not correlated

	Reactors	Coincidence counting
MCNP6.2 beta		
MCNP 6.2 beta w/ FissLib/CGMF		



Fission model implementation not usable for coincidence counting

Neutrons and photons from inelastic scattering on ^{12}C, ^{14}N, ^{16}N



ENDF nuclear data separates

inelastically scattered neutron produced by (n,n') from the photon that should be emitted in coincidence.

Photon is emitted by catch-all reactions (MT=3 and 4).

n' and γ-ray not emitted in coincidence

Active interrogation of SNM using (γ,f)

Stand-off detection of SNM using high-energy photons

Target signatures: **prompt** and delayed neutrons/**photons** from (n,f) and **(γ,f)**.

ACE libraries (derive from ENDF):

- **no photon yield for (γ,f)**.

CEM:

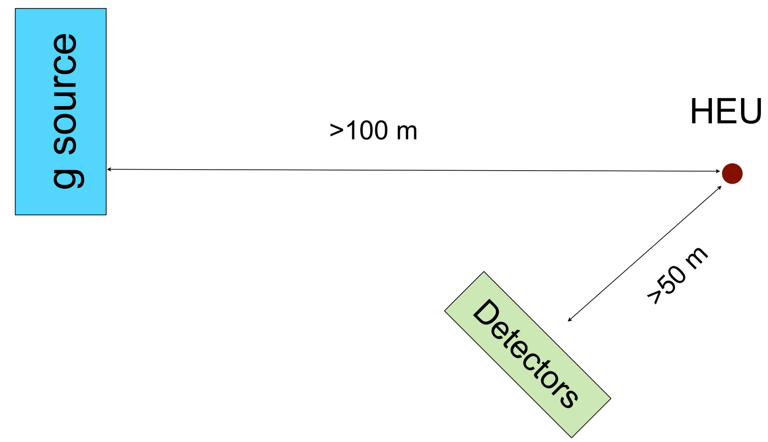
- **(γ,f) and other photonuclear lumped together.**

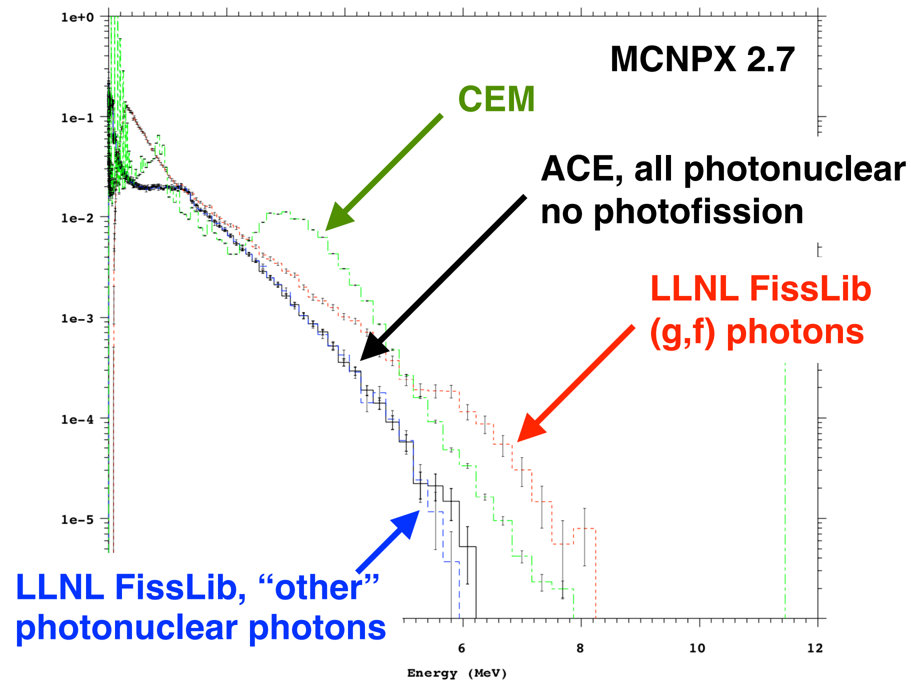
LLNL FissLib produces

- **(γ,f)-specific prompt photons** and
- “**other” photonuclear photons**

separately.

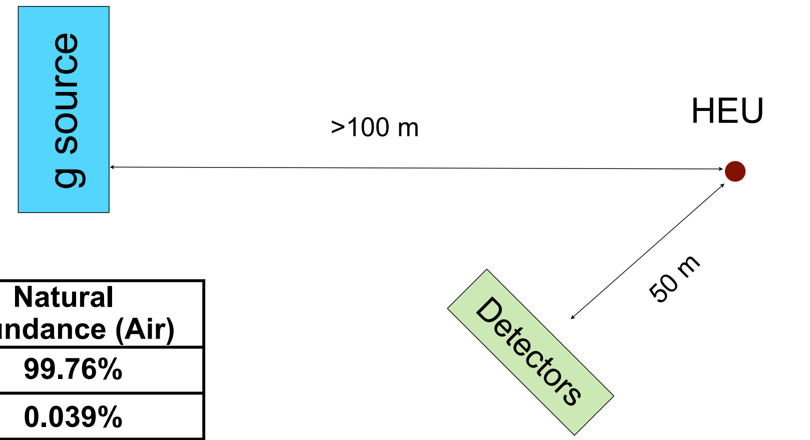
No data for prompt photon yield for (γ,f)





SNM signature: delayed neutrons from (γ,f)

Beam-induced **delayed** background due to stimulation of ^{18}O in the air, water,… produces neutrons with 4 s lifetime:



$\gamma + {}^{18}O \rightarrow {}^{17}N + p$

${}^{17}N \rightarrow {}^{17}O^* + \text{beta } (I_{1/2} = 4.173 \text{ s})$

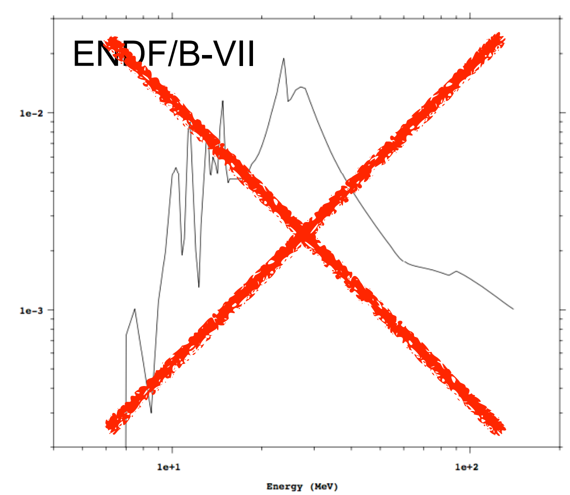
${}^{17}O^* \rightarrow {}^{16}O + n \ (95.1\%)$

	Natural abundance (Air)
^{16}O	99.76%
^{17}O	0.039%
^{18}O	0.201%

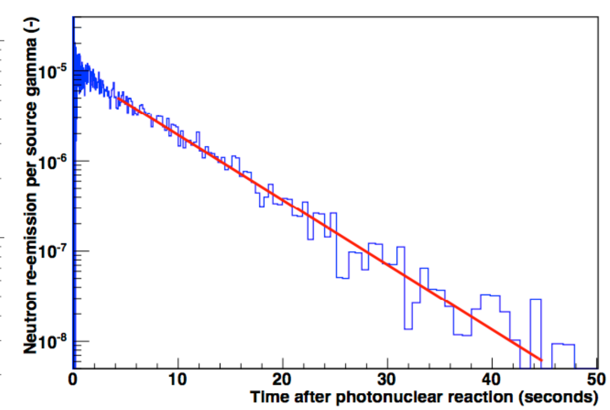
Delayed neutron production can only be simulated using **CEM model**, but the **CEM** cross sections are **off by a factor of 10**.

Unless you know **a priori** the **origin of the delayed neutron background**, your simulation will miss it.

$\gamma + {}^{18}O \rightarrow {}^{17}N + p$



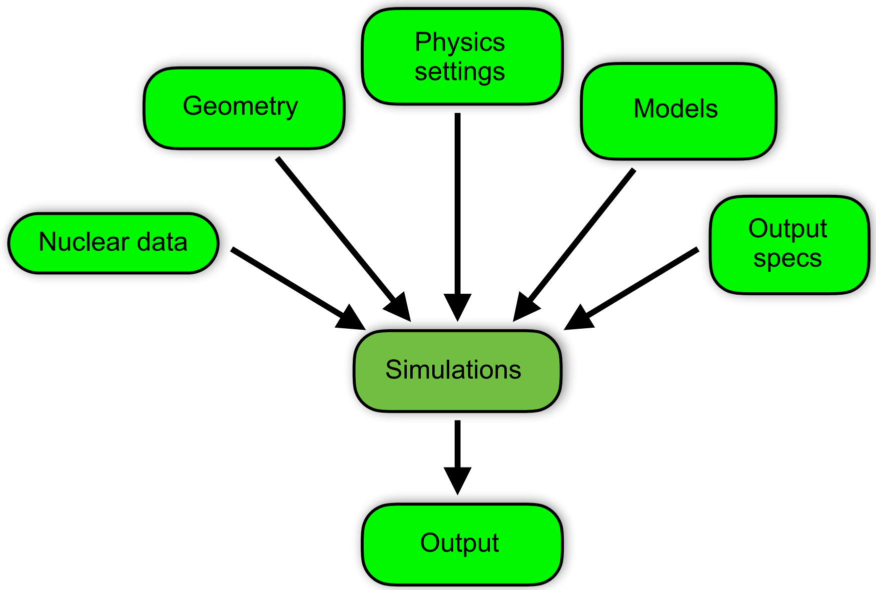
Neutrons emitted from decay of $^{17}O^*$



Nuclear data not usable in simulation

Conclusion

- **Without expertise in transport codes, physics models and data, it is very easy to come up with unrealistic modeling**
  - **Make default physics behavior correct and useful for non-proliferation applications**
  - **Describe physics settings required for simulating reactor cores, coincidence counting, backgrounds, etc.**
  - **Document these lists**



Office of Defense Nuclear Nonproliferation Research and Development

Nuclear Data Roadmapping & Enhancement Workshop (NDREW) 2018

Impact of Nuclear Data on Nuclear Explosion Particulate and Gaseous Measurements

Lori Metz
PNNL

January 23 - 25, 2018

Nuclear Explosion Debris Measurement

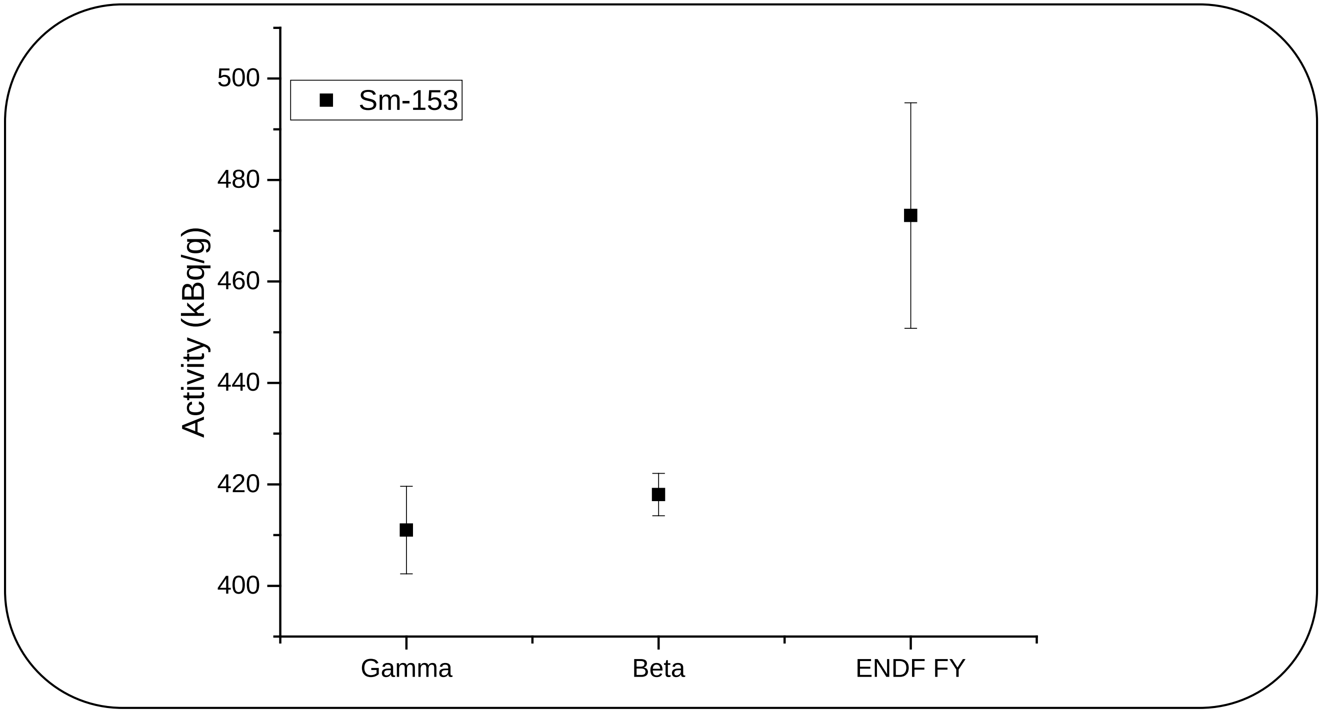
National Nuclear Security Administration

- PNNL maintains radiochemistry and nuclear physics expertise and routinely measures nuclear explosion signatures

- Methods are utilized that minimize the affect of poor nuclear data on our measurements
- As measurement methods advance, we are relying more and more on nuclear data

Pacific Northwest NATIONAL LABORATORY
Proudly Operated by Battelle Since 1965

Nuclear Data Impacts Confidence in Particulate Measurements

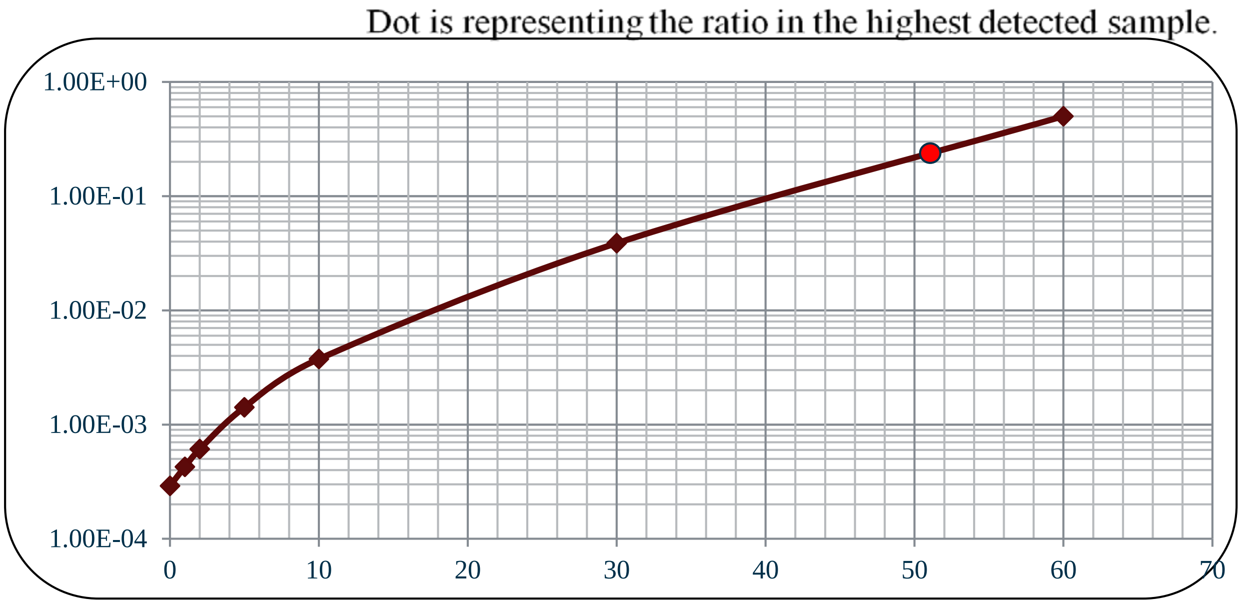


- A list of *nuclear fission yields* in ENDF and literature have been identified as questionable as they have been found to be inconsistent with modern measurements. A review of all available data needs to be completed and some new measurements need to be conducted

- Specific improvements are needed as well for a list of *gamma branching ratios*

Nuclear Data Impacts the Understanding of Nuclear Events

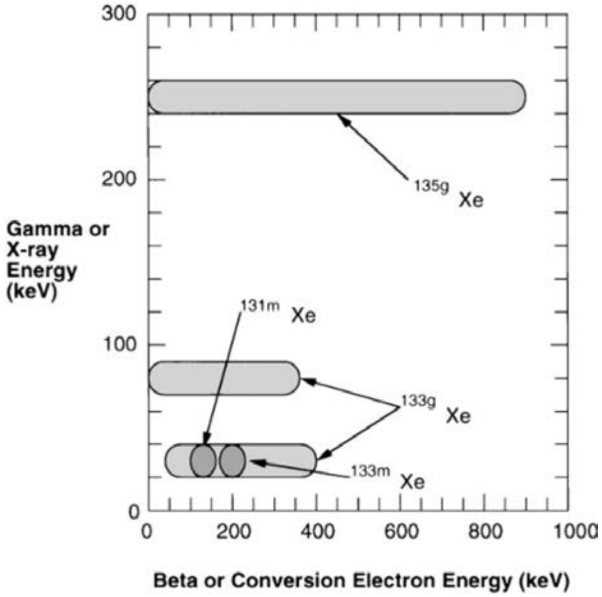
131m/133 as a function of time in days

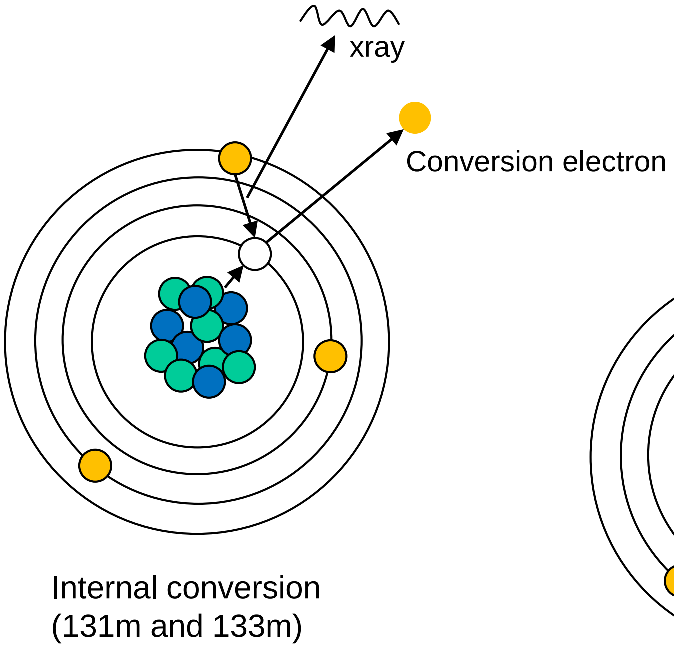


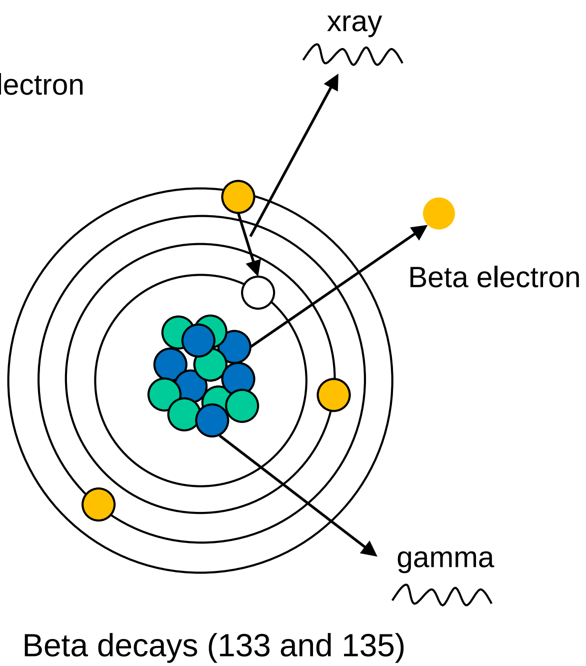
*Presentation by M. Nikkinen of the CTBTO IDC at Working Group B 41

- **A review of the *radioxenon nuclear data* is needed**
  - For example Xenon-131m half life affects interpretation of detection following announced DPRK nuclear test

Nuclear Data Impacts the Understanding of Nuclear Events



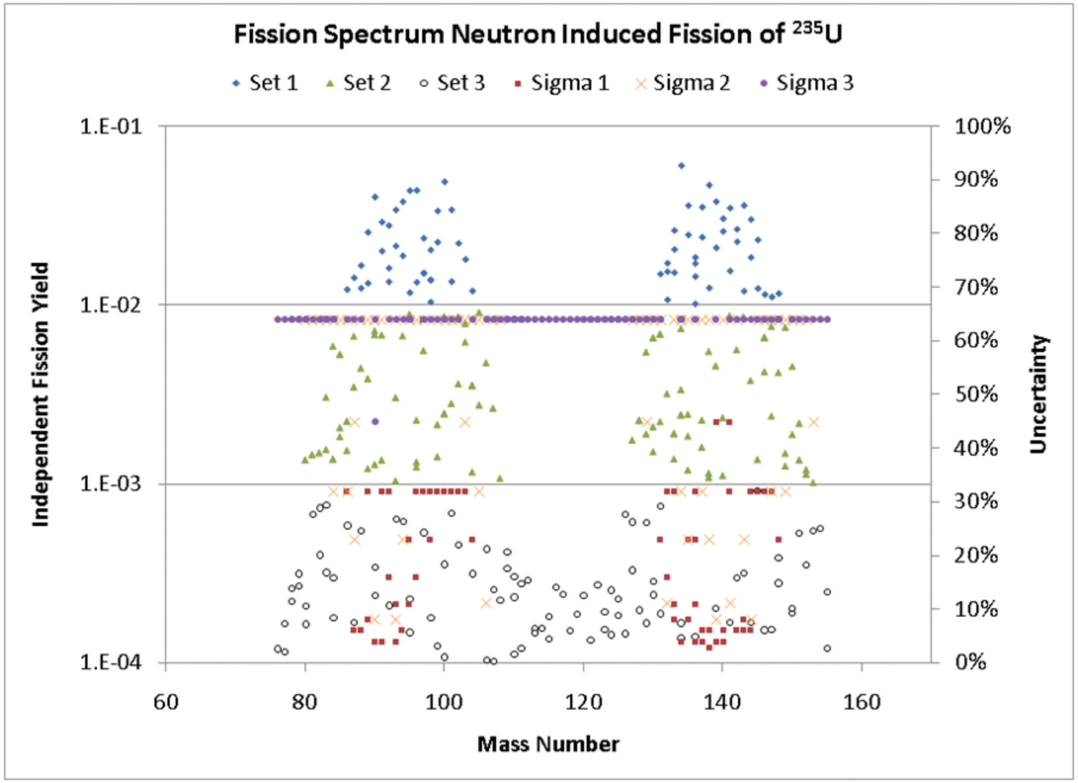




- **A review of the *radioxenon nuclear data* is needed**
  - Decay Data (Half-lives, conversion coefficients and branching ratios)
  - Fission Yield Data

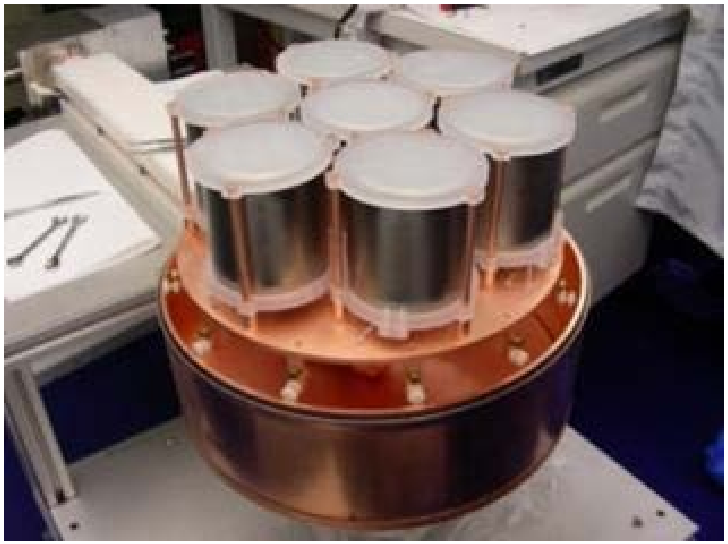
Nuclear Data Needs in the Next 10 Years

- **Improved *short-lived fission yields* are needed**
- ***Particle activation cross sections* will be needed for an identified list**
  - Branching ratios too



Fission product yields from fission spectrum neutrons and associated uncertainties versus mass number from ENDF/B-VII database.5

Nuclear Data Needs Over the Horizon



- **Need to address potential issues of *angular correlations in coincident decays* that affect designs of future systems and data interpretation**

Conclusion from a User Perspective

- Nuclear data is important to nuclear explosion particulate and gaseous measurements today and will likely become more import in the future as technology advances
- We see impacts for our current routine measurements
- We have been approaching these needs on an ad hoc basis but a more focused, prioritized effort is needed

PNNL Campus and the Hanford Site

Office of Defense Nuclear Nonproliferation Research and Development

Nuclear Data Roadmapping & Enhancement Workshop (NDREW) 2018

Use of Uncertainty Quantification to Identify Nuclear Data Needs

Bradley T. Rearden, PhD
Leader, Modeling and Simulation Integration
Ian C. Gauld
Distinguished R&D Staff

Reactor and Nuclear System Division
Oak Ridge National Laboratory

January 23 - 25, 2018

Nuclear Data Uncertainty Quantification: The Roadmap

National Nuclear Security Administration

Research goal: Identify major nuclear data needs by *quantifying the impact of existing uncertainties* on agency applications

- Supports the findings of previous qualitative data needs surveys of subject matter experts
- Provides ***objective information*** on data weakness
- ***Quantifies*** the impact of existing uncertainties for priority ranking
- A roadmap is needed by sponsors of nuclear data measurements and the measurement community

Intuition should not be the sole basis for prioritizing future data investment decisions

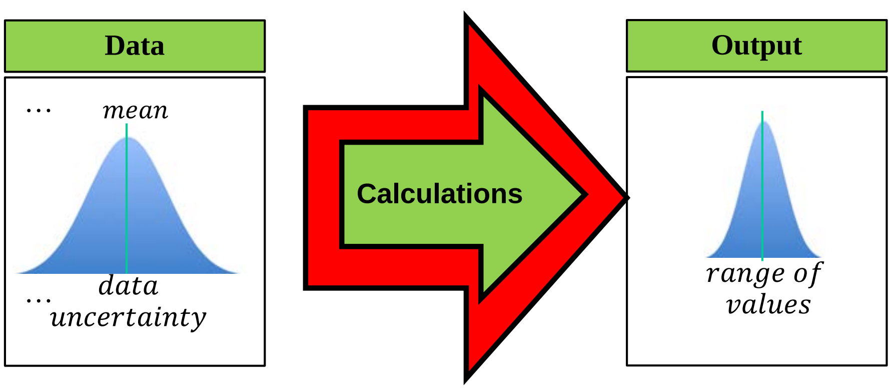
Two Approaches to Uncertainty Quantification

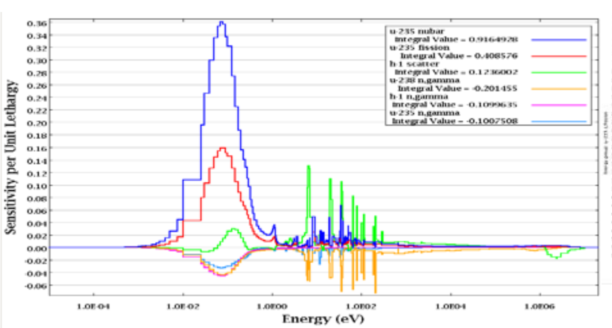
Stochastic Sampling

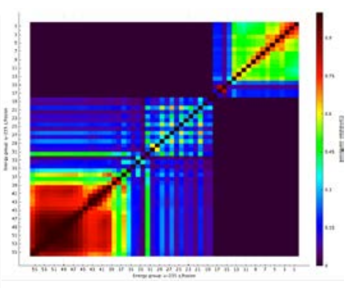
- **Covariances of input data sampled; statistical analysis of output distribution gives uncertainties**
- **Pros**
  - Typically minimally invasive to code
  - Can address complex simulations with coupled codes
- **Con:** Quantification of separate effects (sensitivity coefficients) is challenging

Sensitivity Methods

- **Sensitivities are computed and combined with covariances to obtain uncertainties**
- **Pros**
  - Quantifies uncertainty contributors
  - Obtains all data sensitivities for a single response in single calculation
- **Con:** Requires invasive implementation of adjoint or importance function in simulation codes







$$\mathrm{Var}(k) \equiv S^T C_{\alpha\alpha} S$$

sensitivity covariance

Nuclear Data Components in Defense Nuclear Nonproliferation (DNN) Applications

Previous work on passive neutron detection

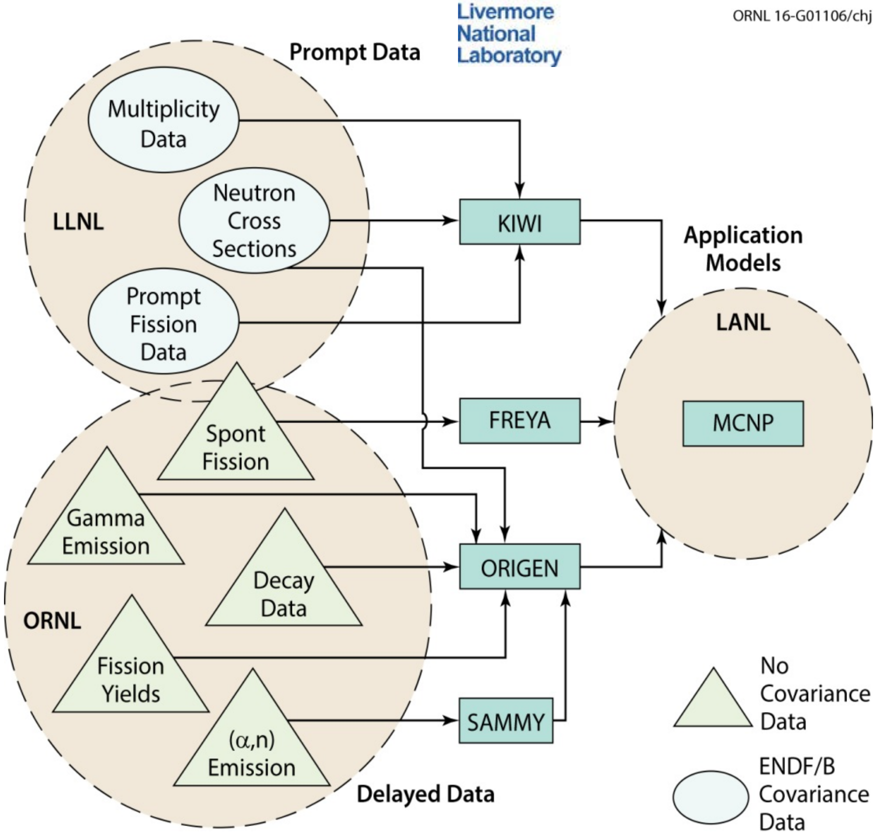
- **Neutron cross sections**
- **Neutron-induced fission neutron production, energy spectrum $\chi(E)$ and multiplicity distribution $P(\nu)$**
- **Spontaneous fission neutron production $\bar{\nu}$, $P(\nu)$ and $\chi(E)$**
- **(α,n) reaction neutron production**
- **(α,n) reaction neutron $\chi(E)$**

Other areas of focus

- **Prompt and delayed gamma ray emission**
- **Radioactive decay data**
- **Fission product yields**

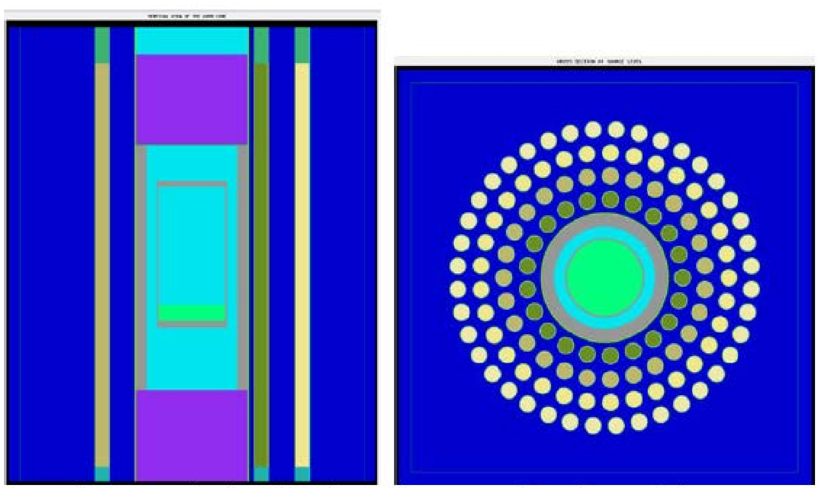
Applications

- *Passive measurement systems*
- *Active measurement systems*
- *Material production by irradiation*



Nuclear Data Uncertainty Quantification Project for Non-Destructive Assay (NDA)

- **The nuclear data uncertainty impact on the passive neutron source term was examined**
- **The ENMC detector (LANL) was used to measure the passive neutron emission of various quantities and enrichments of PuO_2**

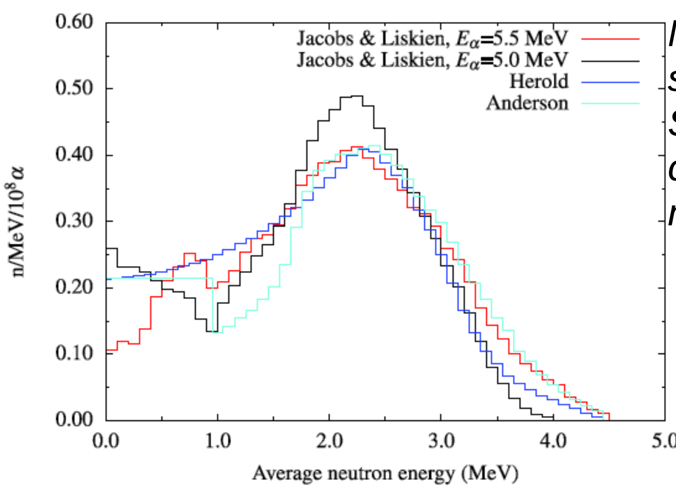


- The Kiwi (LLNL) code was used to generate 100 perturbed nuclear data libraries
- Covariance data for spontaneous fission, neutron yield, and energy spectrum do not exist. These were created for this project using the FREYA (LLNL) code
- No (alpha,n) cross sections or covariance data are available in ENDF. SOURCES4C is the code used to calculate the source term
- (alpha,n) covariance data were created using the SAMMY evaluation code

Gauld, et.al., "Systematic Approach to Nuclear Data Uncertainty Quantification for Nuclear Security Applications," *Advances in Nuclear Nonproliferation Technology and Policy Conference*, 25–30 September 2016, Santa Fe, New Mexico, USA.

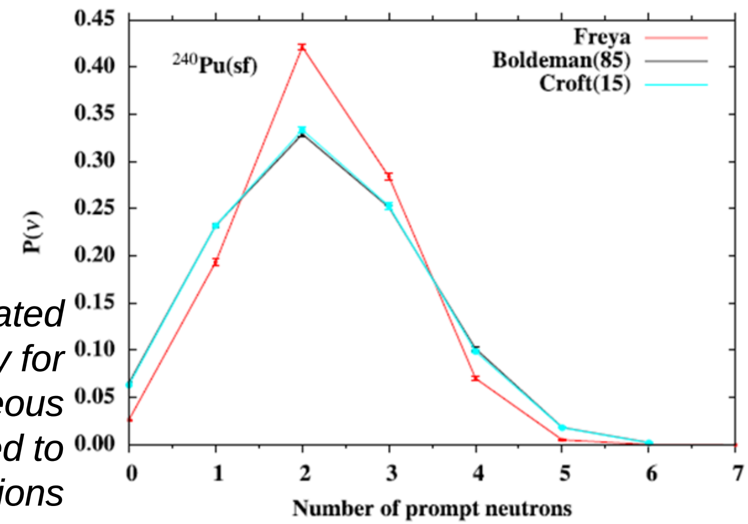
Nuclear Data Uncertainty Quantification Project for NDA

- Initial studies indicated that the dominant effect on the measured Pu mass was due to the prompt neutron fission spectrum (PNFS)
- The neutron singles, gated doubles, and gated triples are highly sensitive to changes in the ^{239}Pu PFNS and to a lesser extent to the ^{240}Pu PFNS
- The largest uncertainty contribution to the reactor-grade Pu case is the ^{240}Pu(n,γ) cross section in the energy region at around 600 keV
- The uncertainty on the (α,n) spectrum contributes to the multiplication-corrected Pu mass at a moderate level.



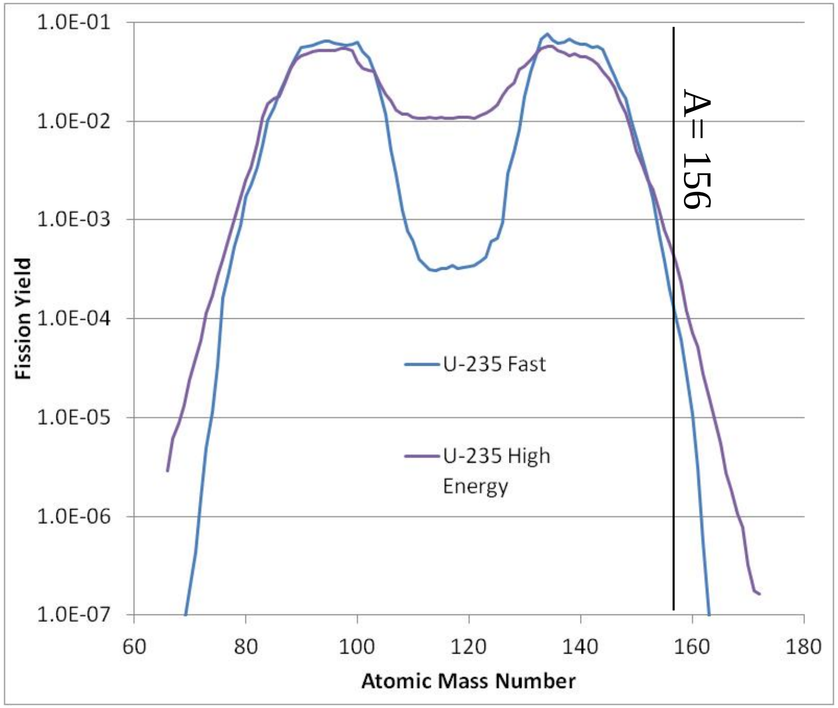
Neutron energy spectra from SOURCES4C calculations and measurements

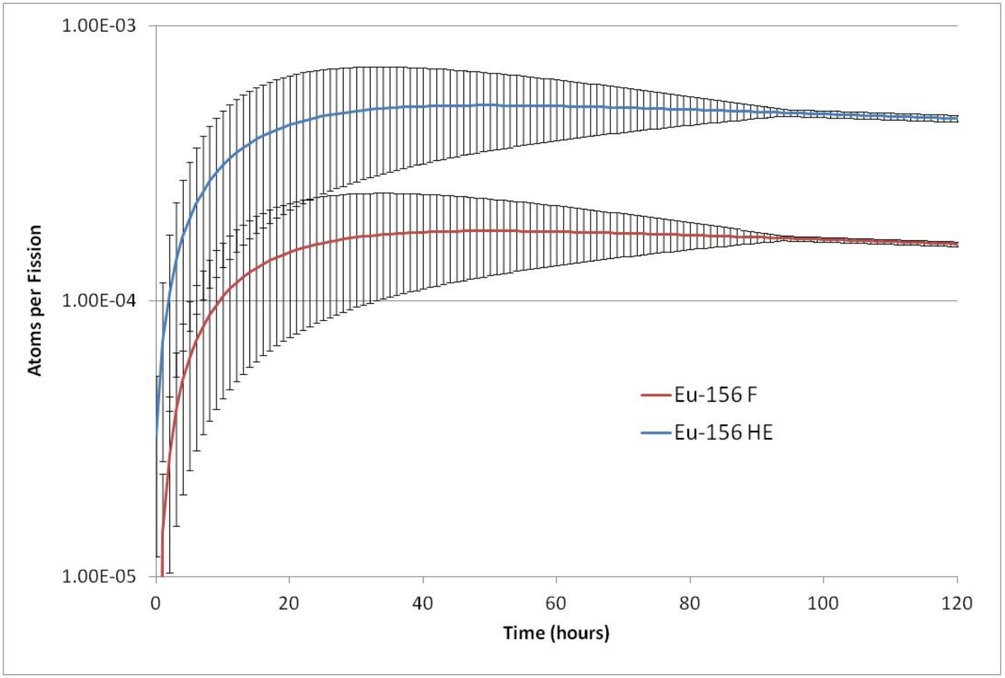
FREYA-generated neutron multiplicity for ^{240}Pu spontaneous fission compared to other evaluations



Fission Product Yield Uncertainty
^{156}Eu from ^{235}U Fast and High-Energy Fission

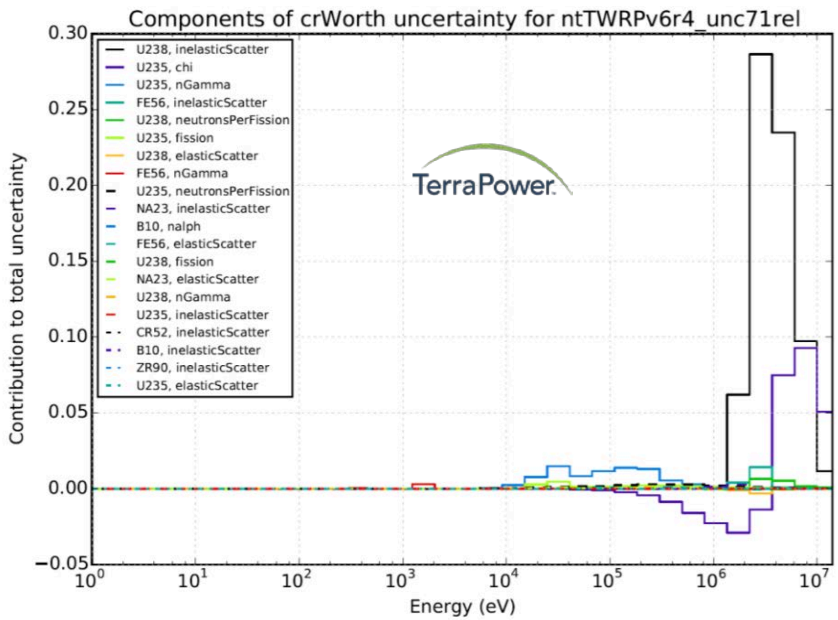
- **Stochastic sampling of uncertainties due to fission product yield and decay data indicate when it is possible to differentiate attribution**

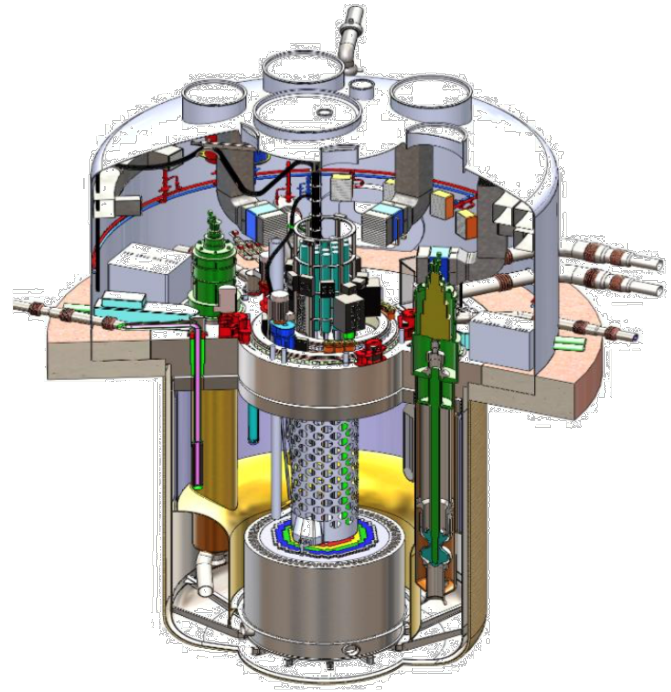




Nuclear Data Uncertainties Impact Design and Characterization of Power Reactors

TerraPower Traveling Wave Reactor



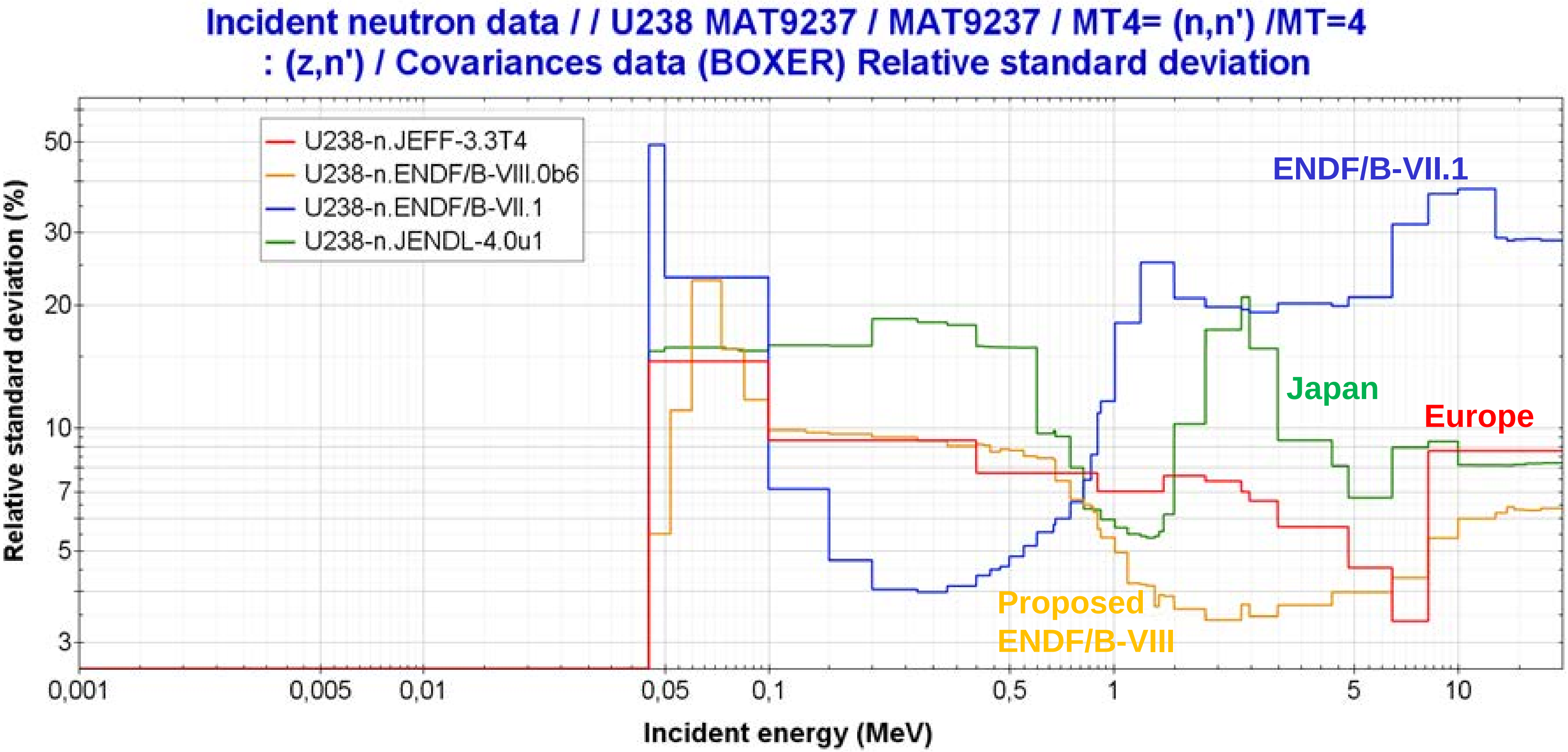


Integral Parameter		TWR-P BOL	TWR-P EOL
k_{eff}	Nominal	0.997488	0.997980
	Rel. uncertainty (pcm)	2250	1591
Coolant temperature coefficient (CTC)	Nominal (cents/K)	3.62E-03	4.90E-02
	Uncertainty	138%	11.5%
Doppler coefficient	Nominal (cents/K)	-8.27E-02	-9.43E-02
	Uncertainty	5.8%	5.1%
Void worth	Nominal ($)	2.42E-01	3.33E+00
	Uncertainty	147%	11.5%
Control rod worth	Nominal ($)	-8.31E+00	-1.30E+01
	Uncertainty	2.9%	2.6%

Nuclide-Reaction		Covariance matrix with	Nuclide-Reaction		% Δk/k Due to This Matrix
^{238}U	n,n'		^{238}U	n,n'	1.2053(9)
^{23}Na	elastic		^{23}Na	elastic	0.3242(2)
^{56}Fe	elastic		^{56}Fe	elastic	0.2590(3)
^{238}U	n,gamma		^{238}U	n,gamma	0.2435(1)
^{56}Fe	n,n'		^{56}Fe	n,n'	0.2388(1)

From: N. Touran, "Sensitivities and Uncertainties due to Nuclear Data in a Traveling Wave Reactor," NEA/OECD SG 39 Meeting 2016-05-10.

^{238}U Inelastic Scattering Cross Section Uncertainty Varies Widely among Libraries



Nuclear Data Uncertainty Quantification Lessons Learned and Recommendations

- **Modeling tools provide quantitative insight into nuclear data uncertainty impact on applications**
- **Impact of data is complex and often non-intuitive**
- **Foundational components have been demonstrated individually as research and development projects – production development and system integration is still needed**
- **Covariance data development has been demonstrated and is needed for many nuclear processes important to DNN applications (data currently incomplete)**
  - Spontaneous fission neutron emission
  - Alpha,n neutron emission
  - Neutron multiplicity
- **Consensus data of the safeguards community is in some cases different than the data in the US ENDF/B data file – better coordination is needed**
- **Nuclear data needs can vary tremendously according to the application, measurement system, nuclear material, and even the data reduction methods – need clearly identified priority APPLICATIONS**

Office of Defense Nuclear Nonproliferation
Research and Development

Nuclear Data Roadmapping & Enhancement Workshop (NDREW) 2018

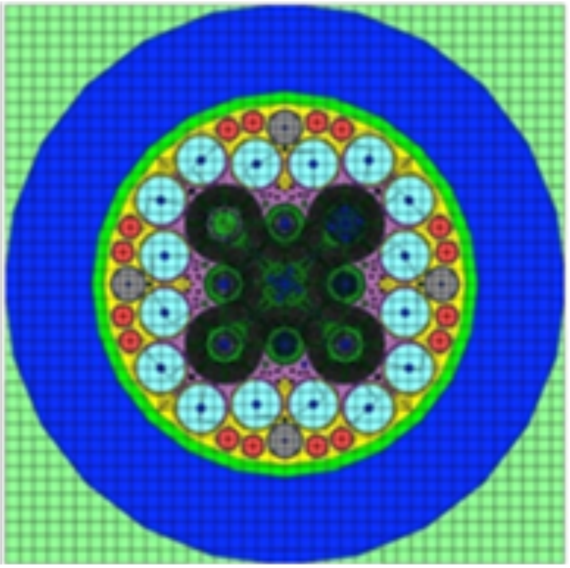
The Nuclear Data Pipeline

David Brown
National Nuclear Data Center
Brookhaven National Laboratory

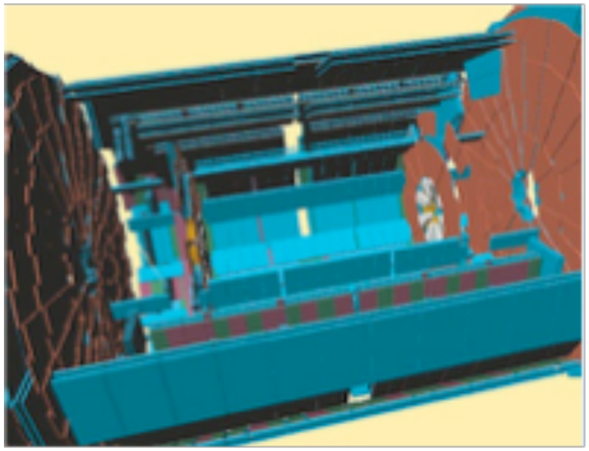
January 23 - 25, 2018

Users most likely interact with nuclear data through application codes

- **Particle transport codes (e.g. MCNP6, SCALE, & GEANT4) use transport data**
  - used for simulating nuclear energy generation
  - shielding and health physics calculations
- **Isotope burn-up codes (e.g. ORIGEN & CINDER) use cross sections and decay data**
  - nuclear waste management
  - radiochemical applications
- **All have modules that use ENDF/ENSDF data**
- **Codes switch between models and data tables based on:**
  - speed
  - fidelity to physics
- **Other code systems also use covariance data to estimate nuclear data uncertainty in application metrics (e.g. TSUNAMI, WHISPER)**



SCALE model of ATR@INL

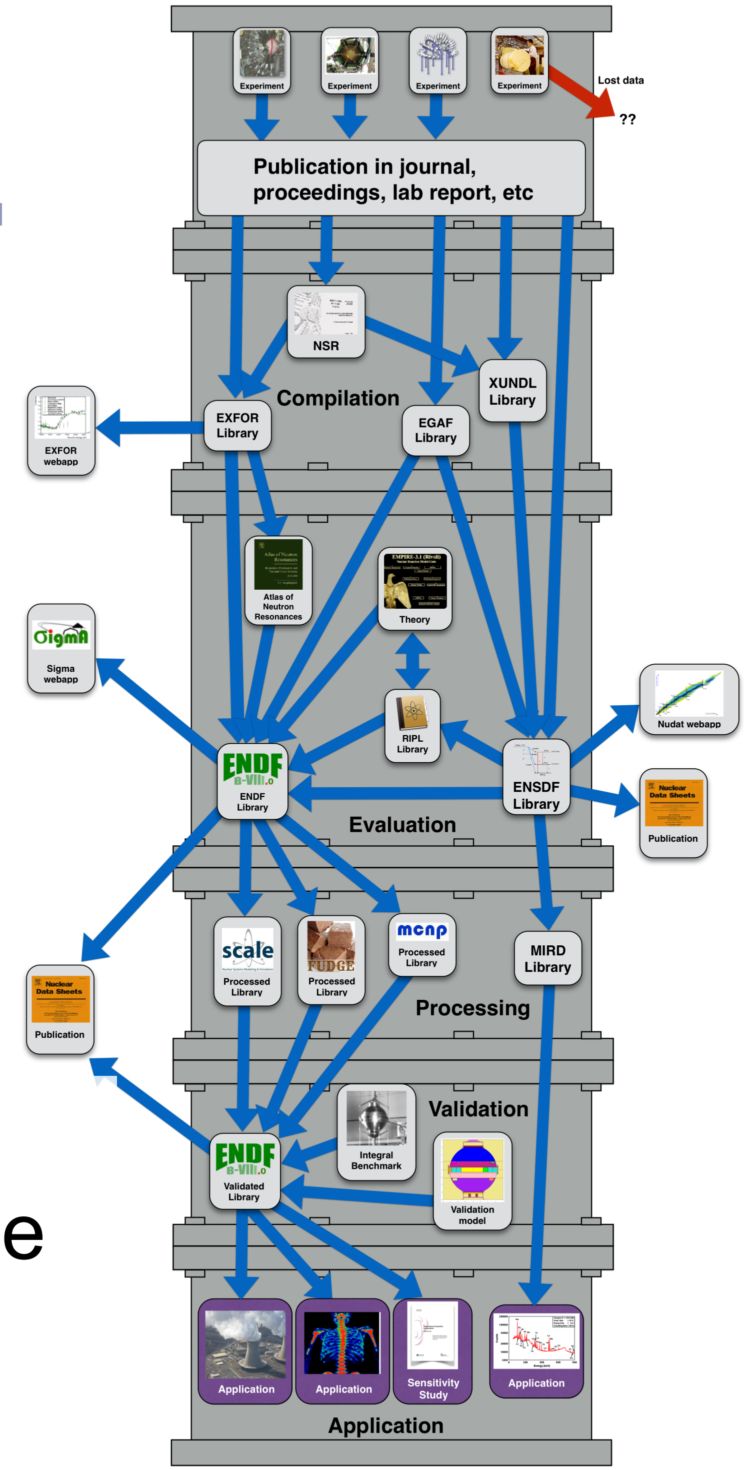


GEANT4 model of ATLAS@CERN

The Nuclear Data Pipeline

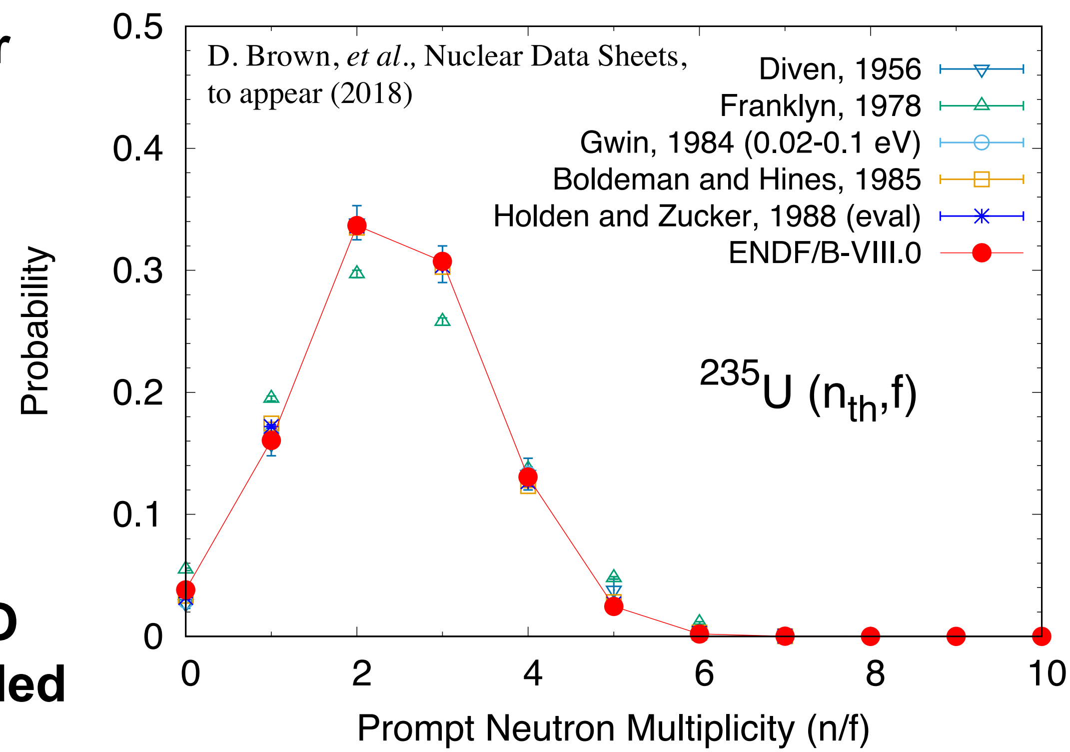
- ***Compilation:*** **collect and catalogue unevaluated data together**
- ***Evaluation:*** **combine all available information into one set of recommended <u>values</u> & <u>covariance</u>**
- ***Processing:*** **prepare data for use in an application code**
- ***Validation:*** **test data in simulation of a non-trivial but well understood nuclear system**

It can take years from the time an experiment concludes for a change to appear in an application code



Improving an application often requires holistic approach

- **Average number of neutrons per fission, nubar, is well known**
- **Knowledge of nubar often good enough**
- **New applications need details!**
- **P(nu) hard-coded in MCNP and other applications**
- **As part of ENDF/B-VIII.0 & CIELO projects, detailed P(nu) data added to ^{235}U, ^{238}U and ^{239}Pu**



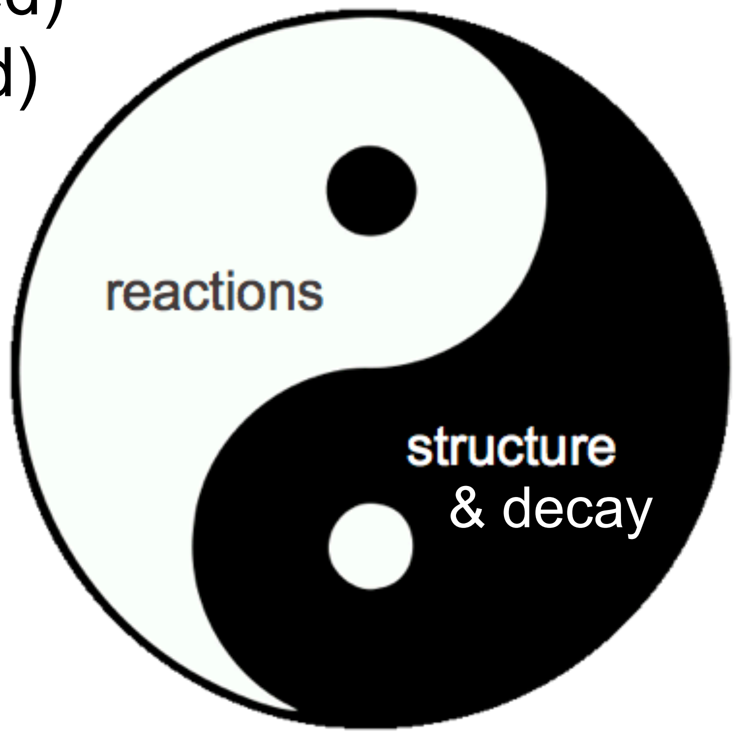
This data forced format change to ENDF-6 format, updates to NJOY & FUDGE processing codes, and we are in process of adding evaluated P(nu) to application codes

Moral: it isn't enough to take the data; someone has to ensure that the data makes it to the application

Structure and reaction data are complementary, decay data is a bit of both

Reaction data:
EXFOR (compiled)
ENDF (evaluated)

In US, USNDP is responsible for evaluated structure data libraries



In US, CSEWG is responsible for evaluated reaction data libraries

Structure & decay:
XUNDL (compiled)
ENSDF (evaluated)
RIPL (“processed”)

Note: USNDP guarantees structure data will get into ENSDF *eventually*. CSEWG *makes no such guarantee* for reaction data

Cross Section Evaluation Working Group (CSEWG)

- **CSEWG is a long running, “unofficial,” collaboration between many US programs**
  - Formed ~1966 under auspices of the Atomic Energy Commission
  - Chaired by BNL
  - Main product is ENDF/B library
  - ENDF/B-I released 1968
  - ENDF/B-VIII.0 to be released in ~ 1 week
- **This year is ENDF’s 50th anniversary**

CSEWG shepherds ENDF data through the nuclear data pipeline

Program	Measure-ment	Theory	Comp-ilation	Eval-uation	QA (V&V, IE)	Infra-structure (GForge, etc.)
DTRA	✓					
International (IAEA,NEA,…)		✓	✓	✓	✓	✓
NA-22	✓	✓		✓		
NR	✓			✓	✓	
NCSP	✓	✓		✓	✓	✓
NE					✓	
Other (NP, ICF, …)	✓	✓				
DP	✓	✓		✓	✓	✓
USNDP	✓	✓	✓	✓	✓	✓

Office of Defense Nuclear Nonproliferation Research and Development

Nuclear Data Roadmapping & Enhancement Workshop (NDREW) 2018

Group Roadmapping Session Processing and Transport Codes

Teresa Bailey
Lawrence Livermore National Laboratory

Brad Rearden
Oak Ridge National Laboratory

January 23 - 25, 2018

Cross Cutting Needs

- **Clarification of application space / benchmarks**
- **User support and training**
- **Maintenance/sustainability**
- **Continued V&V**
- **Automating the pipeline to improve testing and usability**
- **Combination and testing of data from different sources**
  - ENDF and ENDSF for integrated analysis esp. correlated detection
  - ENDF supplemented with TENDL and/or JEFF
- **Treatment of additional data uncertainties**
  - F.P. yield to decay correlation
  - Angular/energy distributions
- **Advanced architectures (GPU, etc.)**
- **New methods development (multi-band, additional particles/physics, GNDS updates, etc.)**

Brainstorming feature improvements for processing codes

- **Continue/complete modernization efforts**
  - Best practices for SQA
- **Code maintenance**
- **Additional V&V for codes and data**
- **GNDS support**

Brainstorming feature improvements for transport codes

- **Neutron thermal scatter law**
  - More temperature resolution for thermal scattering (esp. lower temperatures)
- **Transport needs**
  - Correlated treatment (leverage FREYA, CGM, and CGMF)
    - neutron/neutron
    - neutron/gamma
    - time-dependent prompt and delayed in-line w/ transport (leverage FIER)
      - (nano-second to micro-second – may need update in ENDF decay)
  - Shared library of common background sources (CRY, RADSRC)
- **Detector Response Needs**
  - Coupling transport to response function codes (common formats)
  - Access to information needed for your own response analysis
- **Inverse Problems**
  - For optimizing detector placement
  - Unknown source configurations
- **Deep shielding**
  - Possibly coupling to better tools for scoping studies
- **Sensitivity and uncertainty for all tallies**
  - (eigenvalue, fixed source, reaction rates)

Brainstorming feature improvements for transmutation codes

- **Addition gamma data with improved ENDSF implementation**
- **Shorter time scale simulations**

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Nuclear Data Roadmapping & Enhancement Workshop (NDREW) 2018

Group Roadmapping Session
Uncertainty, Sensitivity, and Covariance

Bradley T. Rearden, Ph.D.
Leader, Modeling and Simulation Integration

Reactor and Nuclear System Division
Oak Ridge National Laboratory

January 23 - 25, 2018

Uncertainty, Sensitivity, and Covariance

- **"Propagation of uncertainties is a game changer"**
- **Applications driven / need benchmarks to assess capabilities**
  - o Correlated detectors – safeguards, arms control, counter terrorism
  - o Decay chain studies
  - o Special nuclear materials – U-235, Pu-239, U-233
  - o Reactor burnup
    - – Ex. same application, different enrichment – need correlation between scenarios
- **Integration**
  - – Easy workflow and interface to make methods more accessible to community
  - – User support and training

Covariance

- **Review of quality and use of existing covariance data**
  - Covariance data generally represent uncertainty in differential measurement, not in cross section mean value provide in evaluation
  - ENDF/B-VIII recommends use of application-specific adjusted covariance library
- **Creation and testing of additional covariance data prioritized by application / sensitivity**
  - Prompt Data
    - Multiplicity data
    - Neutron cross-sections
    - Prompt fission data
  - Delayed Data
    - Spontaneous fission
    - Gamma emission
    - Decay data
    - Fission yields
    - Emission (alpha,n)

Sensitivity

- **Availability of sensitivity for every tally, every response**
  - Eigenvalue
  - Fixed source
  - Reaction rate
  - Transmutation
  - Coincidence / Detector responses
- **Use sensitivity to prioritize data and uncertainty needs**
- **Use sensitivity to quantify applicability of available benchmarks**
- **Enhance and integrate methods to apply data adjustment**

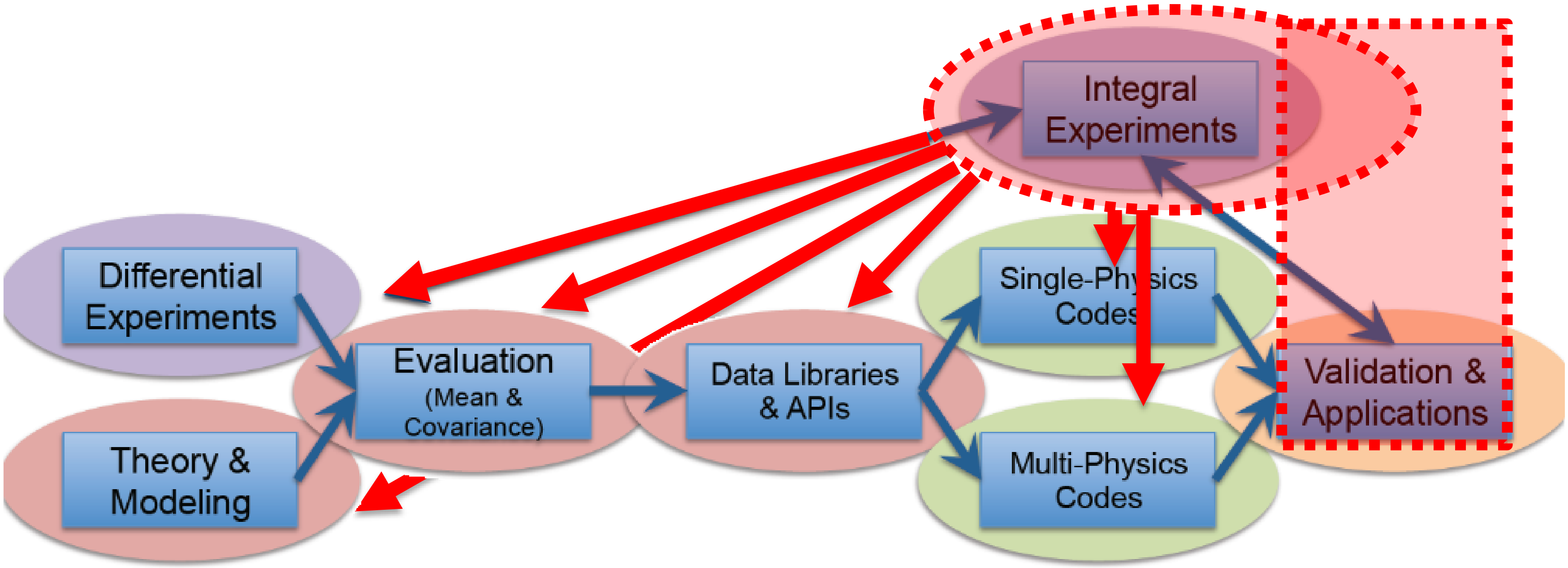
Uncertainty

- **Support for existing sampling methods**
  - Sampler, Kiwi, Dakota
- **Extend and integrate sampling methods for all data sources**
  - Prompt Data
    - Multiplicity data
    - Neutron cross-sections
    - Prompt fission data
  - Delayed Data
    - Spontaneous fission
    - Gamma emission
    - Decay data
    - Fission yields
    - Emission (alpha,n)
- **Quantify correlation between application cases with shared uncertainties**
- **Implement principle component analysis to quantify uncertainties with largest impact to feedback to data needs**

Why are benchmarks needed?

- **All application scientists want answers that often rely on <u>validated</u> modeling methodology (codes + nuclear data)**
  - Benchmarks are a major underpinning element for validation.

What do benchmarks provide?



- **Iterative validation ability (data, codes, methods)**
- **Prioritization of need (deficiency and impact)**

Progress Today

- **Agreed on categorization of types of experiments that could serve as benchmarks**
  - Integral Benchmarks, Quasi-Integral Measurements, Validation Experiments
- **Agreed on the need of a dedicated suite of nonproliferation benchmarks and validation sets, let's notionally call it the Nonproliferation Benchmark and Validation Suite Repository (NBVSR)**
  - Learning from other communities who have historically large investments for this type of effort.
- **Made progress on understanding the requirements that benchmark would need to be part of the NBVSR.**
  - Uncertainties, Sensitivities, Documentation, Accessibility, Peer-Review, Data Mgmt Plan
- **Made progress on understanding the level of effort needed to actually have an impact if this repository was to be created.**
  - Human Capital: SMEs and large effort from nonproliferation AND nuclear data communities needed.
- **Suggested a few potential future code development efforts that could complement this concerted benchmark effort**
  - Sensitivity, uncertainty and detector response
- **Discussed relevance of various candidate measurements, based on work performed by several people in the room.**
- **Many anecdotal discussions to inform various parts of how ths could evolve.**
  - Working Group model was suggested to try to make progress going forward.

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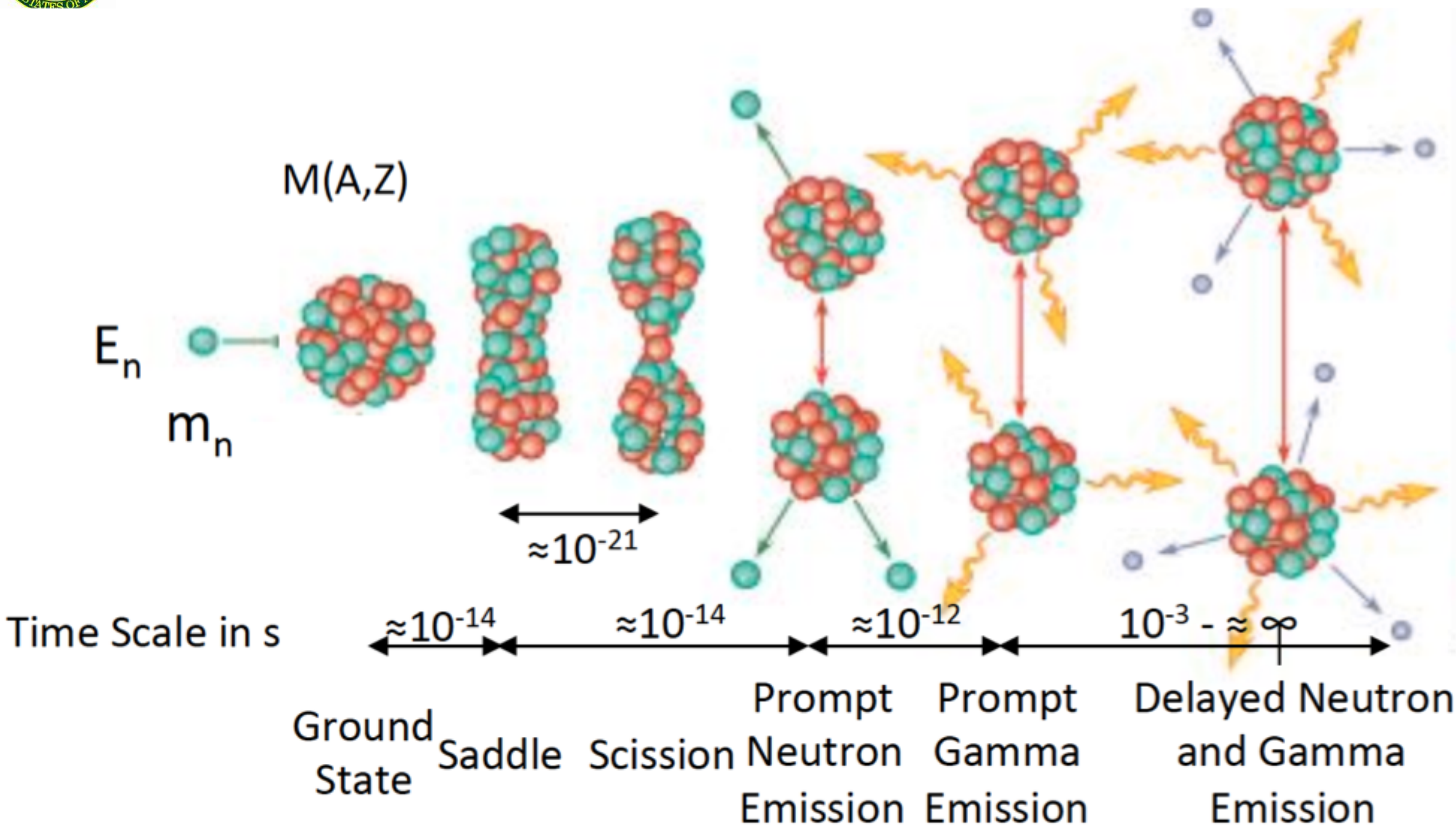
Fission Yield Breakout Session Summary

Patrick Talou
Los Alamos National Laboratory

January 23 - 25, 2018

The Fission Process



IFY (Independent Fission Yields) → **CFY** (Cumulative Fission Yields)

High Priorities & Impact

5+ Years from now

- **Evaluations**
  - New evaluations for "big three" U235, U238, Pu239 – more, if possible
  - Consistency between IFY, CFY, prompt and β-delayed neutrons and γs
  - Include uncertainties and correlations
  - Exact list of priority FPY to be finalized (Xe, Sm, Nd, …)
  - Incident energy dependence from thermal to 20 MeV, with finer energy grid
  - Develop suite of evaluation tools developed, documented and shared
  - New formats (e.g., GNDS) to better represent correlations and uncertainties
- **Experiments**
  - Finalize "2E-2v" measurements from thermal up to 20 MeV for key isotopes + SF
  - Complete and analyze CFY experiments at TUNL, MIT, NCERC
  - Newly funded (NA22-NP) measurements at CARIBU and ORNL-Tandem
  - Leverage many other efforts (SOFIA@GSI, VERDI@JRC, J-PARC)
  - Perform photofission measurements of IFY and CFY
- **Theory**
  - Large-scale calculations of fission fragment yields using phenomenological models
  - More fundamental calculations (supercomputers) to provide initial conditions of post-scission physics as a function of incident energy
  - Spontaneous fission half-lives and fragment distributions (FRIB)
- Close collaboration with the **International Community** (IAEA/CRP, WPEC, …)

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Nuclear Data Roadmapping & Enhancement Workshop (NDREW) 2018

Prompt Gamma Rays and Neutrons from Fission

Sara A. Pozzi
University of Michigan

January 23 - 25, 2018

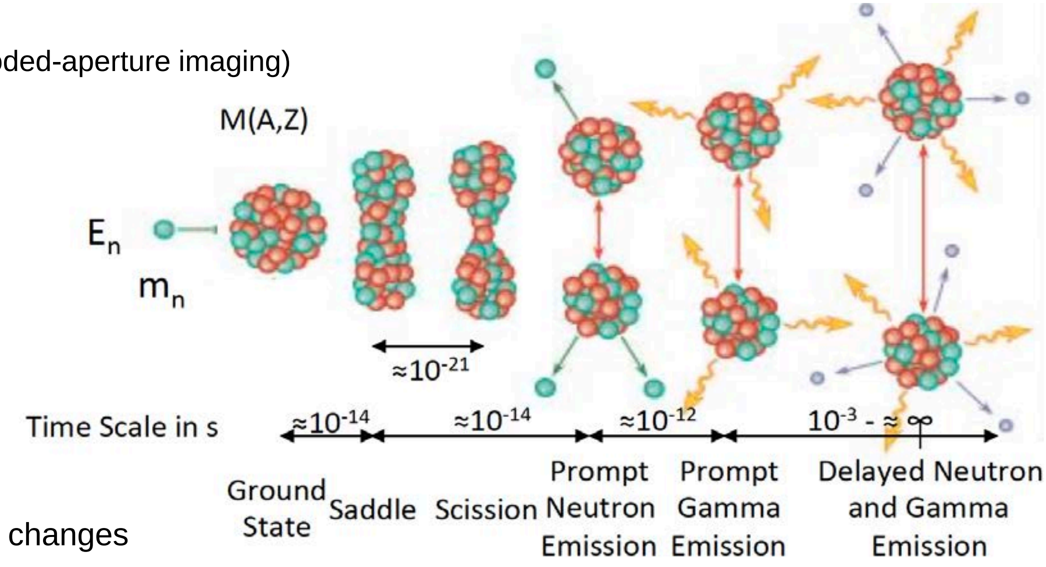
DNN Applications for Prompt Signatures

- **Safeguards**
  - Verifying declaration from operator
  - Neutron multiplicity counting – mass assay (established)
  - Gamma spectroscopy – enrichment assay, spent fuel (established)
  - Neutron differential die-away (DDSI)
  - New applications
    - o Gamma ray multiplicity
    - o Gamma ray differential die away (pulsed neutron interrogation,
    - o Joint neutron-gamma ray multiplicities
    - o Neutron angular distributions
    - o Neutron and gamma ray imaging

    (transmission tomography, scatter imaging, coded-aperture imaging)

- **Nonproliferation**
  - Multiplying vs. non-multiplying samples

  (plutonium object from Cf-252 point source ?)
  - Fissile vs. fissionable
    - o Prompt emissions from fission chains
  - Arms control
    - o Classification issues ?
  - Imaging
    - o Portability ?
  - See also safeguards topics with appropriate changes



- **Post-Detonation**
  - Active interrogation on post-det samples

Isotopes of Interest

- **Spontaneous Fission**
  - Cf-252
  - Pu-240
  - U-238
  - Cm-244 (spent nuclear fuel/safeguards)
  - Pu-238
  - Cf-250 (old Cf sources)

- **Induced Fission**
  - Neutron-induced
    - U-235
    - U-238 (fast fission)
    - Pu-239
    - U-233
    - Np
  - Photon-induced
    - U-235, U-238, Pu-239

Considerable progress made in the last few years in area of neutron-induced fission (thanks to Defense Programs), not so much in spontaneous and photon-induced

Needs: Prompt Signatures for Applications

- **Signatures (with uncertainties)**
  - There has been a big investment in DANSCE and Chi-Nu but not all of these measurable have been measured to the precision that we need yet. Needs on precision depend on the application
  - Spectra
    - Energy spectrum for both neutron and photon induced, and spontaneous fission
      - Neutron (especially the low-energy and high-energy end of the spectrum)
      - Gamma ray
  - Number distributions (multiplicities)
    - Gamma ray multiplicities
    - Gamma ray from photofission and neutron induced fission
    - Neutrons from photofission
      - Specifically for interrogating gamma rays under 10 MeV
    - Gamma ray time of emission (ns – 100 ns time scale)
    - Neutron multiplicity distributions for Pu-239, U-235, U-238
      - P(nu) as a function of inducing neutron energy
      - Effect of delayed neutrons
    - Point source vs. distributed source
    - Moments
  - Correlations
    - Neutron energy spectrum vs. number of neutrons
    - Gamma ray energy spectrum vs. number of gamma rays
    - Gamma ray total energy and multiplicity as a function of fragment mass/charge
    - Neutron angular correlations Cf-252, Pu-240
    - Neutrons, gamma rays joint multiplicity

Prompt neutron energy spectrum for important isotopes still not well-known at low- and high-energy

Neutron multiplicity distributions P(nu)
- Neutron-induced
- Photofission

Correlations
- Neutron-neutron angular correlations
- Neutron-gamma ray correlations

Needs: Modeling – Physics Transport Codes

- **Physics-based models (FREYA, CGMF) – event by event models**
  - Currently available: neutron and gamma ray decay from the fission fragment de-excitation
  - What parameters should be tuned ? Need more data (validation)
    - Need to get the neutron spectrum correct
  - Can be read-in by MCNP6, MCNPX-PoliMi, etc.
  - Photo-fission
  - Neutrons
    - Pre-scission neutrons ?
    - Angular distributions (code results agree with experiments)
    - Energy spectrum
    - Multiplicity-dependent energy spectrum (small effect in codes)
    - Beta-delayed neutrons
  - Gamma rays
    - Specific gamma ray lines (tied to a specific fragment)
    - Delayed gamma rays – Beta delayed
    - Delayed "prompt" time distributions
    - Multiplicity-dependent energy spectrum (large effect in codes)
  - Correlated events
    - Gamma rays and neutrons numbers, (small effect in both codes and experiments)
  - Speed of calculations
    - CGMF ongoing effort to make it faster

Need for models that capture these signatures accurately

Needs: Transport Codes

- **Data processing codes**
  - NJOY, Fudge, AMPX
- **Tabular data vs. models**
  - P(nu) as a function of E
- **MCNP6.2 – upcoming release (incorporation of the physics models)**
  - Better fission data (now the event-by-event emissions are not preserved)
    - Prompt neutron multiplicity distributions
    - Secondary gamma rays (including fission prompt, delayed)
    - Correlations between prompt neutrons and gamma rays in fission and other reactions (n,n')
  - CGMF, Freya modules (computation time is an issue)
  - Detector response (DRIFT)
  - Sensitivity analyses for tallies
  - PTRAC file needs improvement
- **GEANT (collaboration w/Office of Science)**
  - Open source
  - Originally for high energy physics
  - Fission models need improvement
  - Freya is working in GEANT4
  - Use of ENDF VII data
  - Comparisons w/MCNP and exp. data for neutron transport
- **OpenMC**

Need for better event by event models in Monte Carlo transport codes

Improved predictive capabilities for event-by-event fissions, including correlations

Impact

- **Improvements in the prompt emissions from fission data have the potential to impact many DNN applications, including safeguards, arms control, and nonproliferation**
  - New signatures
  - Better, more accurate measurement systems
  - Physics/transport codes for better predictive capabilities

Validation

- **Validation of physics-based codes**
- **Experimental data for validation**
  - Benchmark quality experiments
    - Need for high-quality experiments
    - Neutron multiplicity
      - Cf-252 prompt neutrons P(nu) – do we have agreement ?
      - Pu-240, Cm-244
      - P(nu) as a function of nu
    - Neutron, gamma ray multiplicity
    - Prompt fission neutron spectrum for spontaneous fission, neutron induced, and photofission (especially low-energy and high-energy (above 2-3 MeV))
      - Cf-252, Pu-240, U-235 (neutron and photon-induced)
      - LANSCE data exists
    - Shared with the community
  - Benchmark quality applications experiment
    - Neutron multiplicity counting
      - He-3 systems
      - Liquid scintillator systems
    - Integral experiments (criticality)
    - Subcritical experiments (DAF)
  - Shared with the community
    - ENDF VIII evaluations

Past and Current work

- Relevant past/present NA-22 projects
- Laboratories
  - LL11-Prompt-Fission-Sig-PD3Jb: Improved codes implementing fission physics properties
  - LA14-V-CorrData-PD3Jb: Experimental measurement of time-coincident nuclear fission data
  - LA17-V-Correlated Fission Event Sims-PD3Jb (follow-on to the previous entry): Code implementation of previously collected experimental coincident fission data
- Universities - fission experiments and detector characterization
  - NSSC – UCB
  - CNEC – NC State
  - CVT – UM

Facilities for Prompt Emission Detection
Many of these funded by Defense Programs

- **US**
  - LANSCE
    - Chi-nu (neutron energy spectrum)
    - Dance, Nuance (stilbene), low energy neutron (up to 1 MeV) induced fission FP14 -
  - Idaho State (photofission 10.5 MeV up to 40-50 MeV, plastic scintillators, TOF for n energy, small quantities of SNM, 3 g U-233, U-238)
  - RPI Prompt gamma tagging array, uses larger samples Pu-240, U-238
    - Measure PFNS, gamma ray spectrum
  - TAMU
    - Fission neutron multiplicity liquid scintillator w/Gd tank (50-80 % efficiency)
      - Measured Pu-239 induced (Pu-240 alpha,alpha')
      - Pu-241 (future)
  - Oak Ridge National Lab
    - VANDL array plastic scintillator array
  - TUNL
    - Tandem Van De Graaf tunable neutron beam (100 keV- above 10 MeV) good energy resolution (~2% energy resolution)
    - Free electron laser tunable Compton backscatter setup (HIGS)
  - Ohio University - Tandem
  - University of Michigan
    - 9MeV electron LINAC (funded by DNDO)

Experiments for Prompt Emission Detection

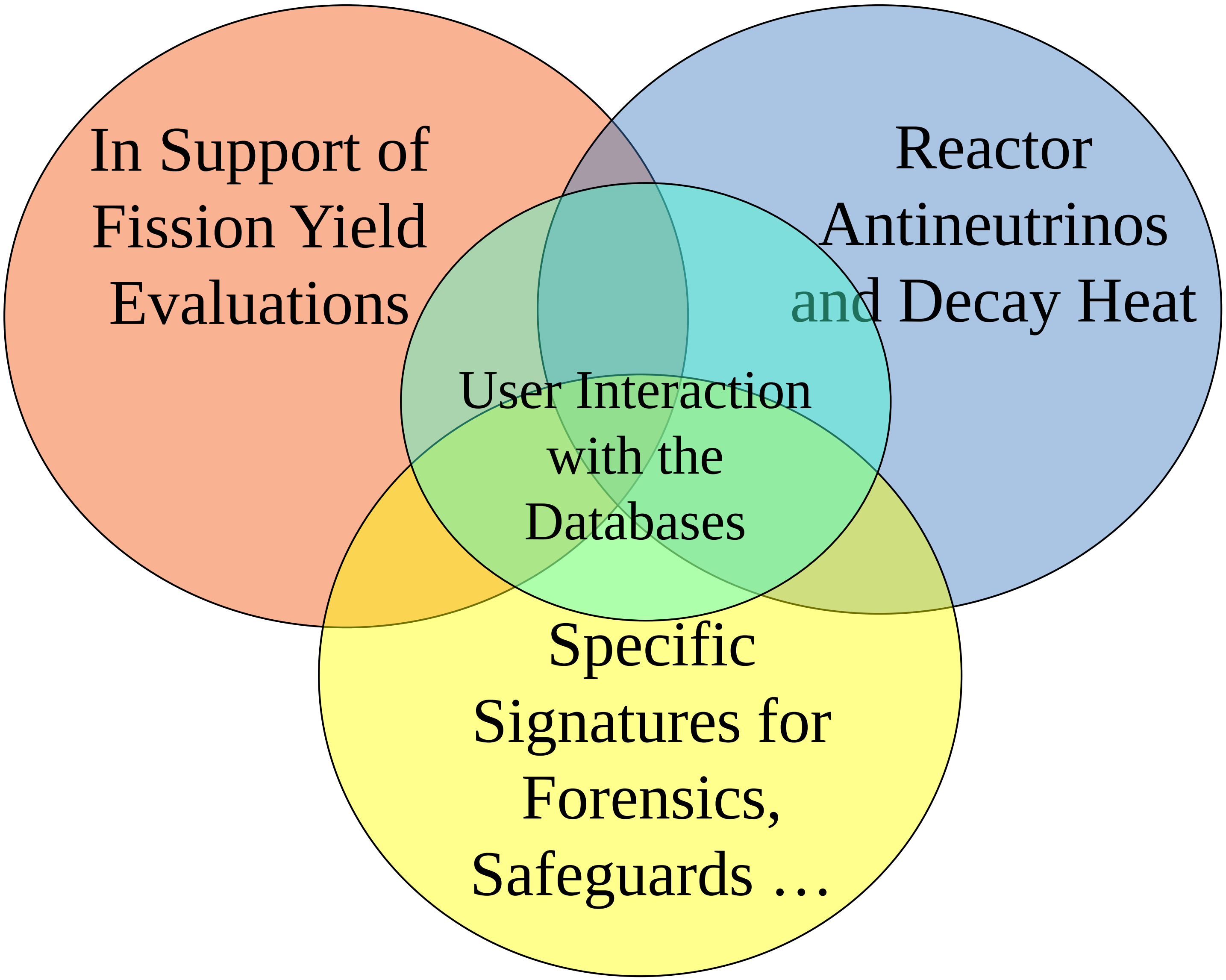
- **Detectors**
  - Stilbene
  - Liquid scintillator LAB that does not degrade over the years
  - Micro-calorimeters high resolution- low Compton background
  - High rate, high resolution gamma detectors (high rate HPGe)
  - How do we measure the spectrum as a function of multiplicity of neutrons?
    - Neutron detector that can measure the energy without TOF (CLYC ?)
    - More organic scintillator detectors ? Suffer from threshold effect
    - Li-doped glass detectors (down to 10 keV)
- **Fission chambers**
  - PPAC fission chambers (U-235, Pu-239, Cf-252) can electroplate different isotopes
  - CEA fission chamber (Pu-239, U-238)
  - TPC (simplify to bring down complexity and cost)
- **Beams**
- **Electronics**
  - Improved timing for TOF
    - SiPM readout systems for organic scintillator systems
  - FPGA
    - Commercially available CAEN
  - Time of flight

Data Analysis

- **Analysis of experimental data**

  Experiment-specific
  - Algorithms timing
  - PSD
  - Multiplicity of neutrons and gamma rays
- **Inverse problem**
  - Algorithms
    - Access to best unfolding methods sometimes an issue
    - Point-model methods
    - Iterative Baysian methods
    - Compare to known solution to see how well the unfolding method is performing
    - Library of methods that could be shared with the community
- **Uncertainty quantification**
  - Incorporating evaluators in the experiment planning
  - See separate session
  - Sources of uncertainty (statistical and systematic)

Fission III: Decay Data



Fission III: Decay Data

1) In Support of Fission Yield Evaluations

- Delayed Neutron Branching and Isomer properties are required to convert from independent to cumulative fission yields
- Recent IAEA CRP on β delayed neutrons will provide guidance
- Branching ratio data needed for future fission yield measurements

2) Specific Signatures for Forensics, Safeguards …

- Half-lives, energies, branching ratios essential for many mission relevant spaces
  - Fission fragments: Xe isotopes, Nd isotopes, ^{133}Cs, ^{141}Ce, …
  - Actinides: $^{237\text{-}239}$Np, ^{233}Pa

4) Reactor Antineutrinos and Decay Heat

- Tremendous progress studying high-priority isotopes with total gamma-spec
- Success of interagency NP, ND, NA-22 proposals
- One “lose end” is direct measurements of beta-spectra of select nuclei

3) Enhancing user interaction with the databases

- User API to parse and search ENSDF (requires code development and support)
- Improved treatment of uncertainties (e.g. Flags indicating data quality)

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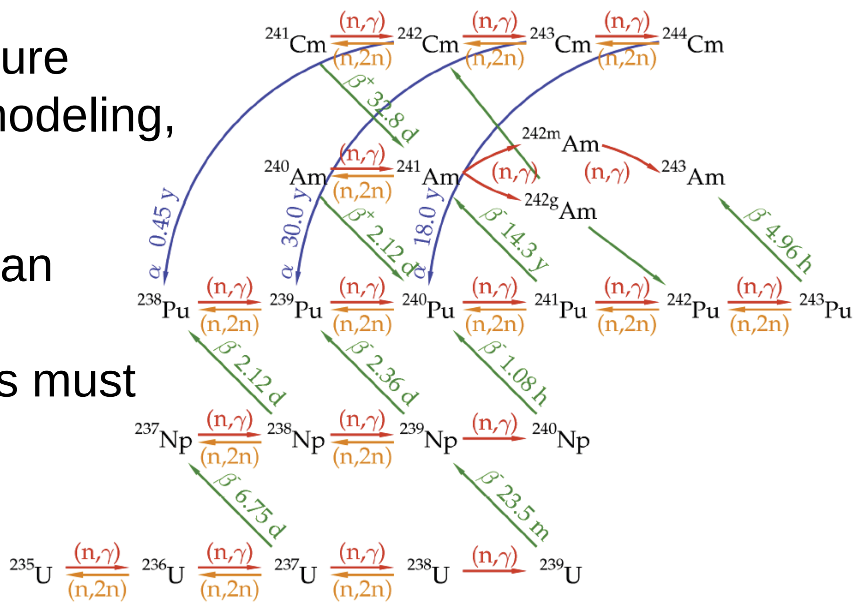
Session 4C: Actinide Cross Sections

Susan Hogle – Oak Ridge National Laboratory
Lee Bernstein – Lawrence Berkeley National Laboratory/UC Berkeley

January 23 - 25, 2018

Actinide Cross-Section Issues and Needs

- Complex web of isotopes, changes to one piece can have broad impacts throughout the network
- Solving this network requires contributions from theory, modeling, differential and integral measurements – collaborative proposals
- Isotopes that can be measured must be know very well to bound the overall network (grab low hanging fruit)
- Short lived, difficult to isolate and measure isotopes can be supported by theory, modeling, and indirect measurement
- Assessment of historical integral data can help bound the unknowns, as well as support sensitivity studies, but problems must be well characterized to minimize other contributions to uncertainty



Actinide Cross-Section Issues and Needs

- Development is needed in theory and modeling, both to support individual cross-sections and indirect measurements, as well as to tie all pieces of the web together
- Delivery of data to internal database and to EXFOR must be a project deliverable, delivery to ENDF also desired where possible
- Characterized material inventories needed for targetry needs
- Target fabrication capability needs include evaporation, ultrasonic welding and hot rolling

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Nuclear Data Roadmapping & Enhancement Workshop (NDREW) 2018

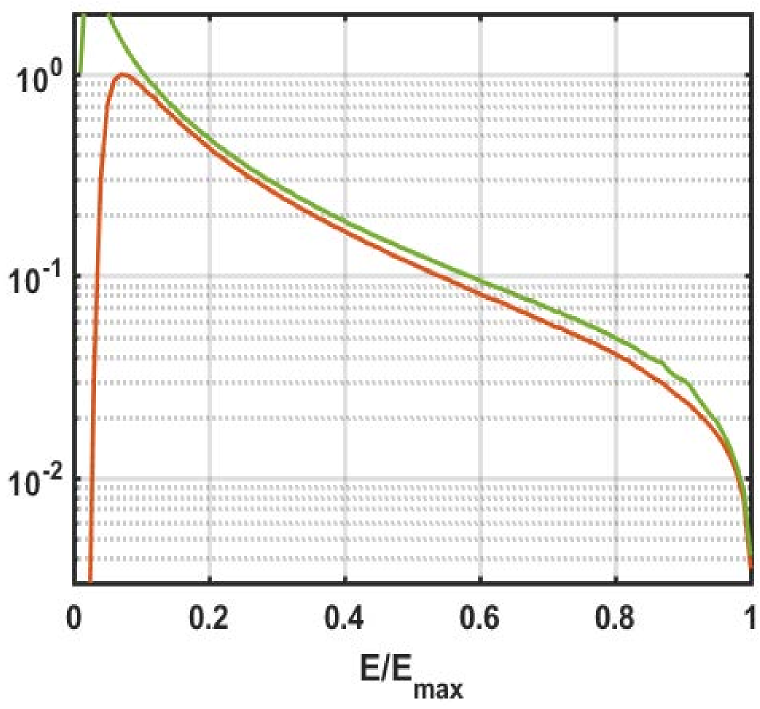
Gamma-induced Reactions

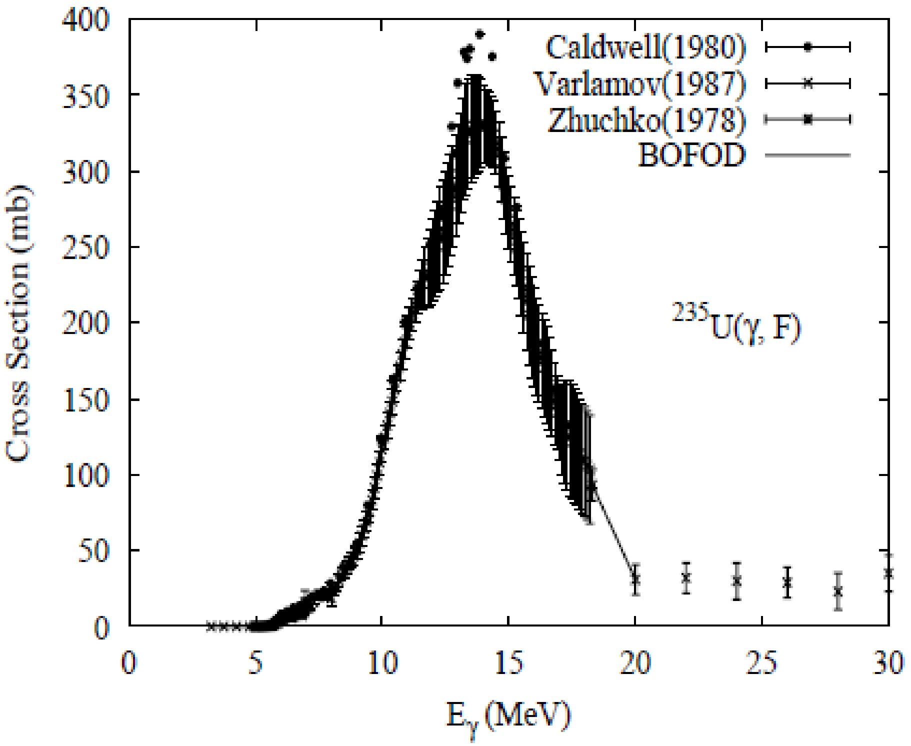
Brian Quiter
Lawrence Berkeley National Laboratory

January 23 - 25, 2018

Overview

- **Circa 2010, DNDO Photofission benchmark attempts produced signals that were up to 10x weaker than predicted by MCNP. Why did this occur?**
  - MCNP user error?
  - Need to improvement the nuclear data pipeline?
  - Bad γ,f and/or γ,xn data?
  - Bad bremsstrahlung data?





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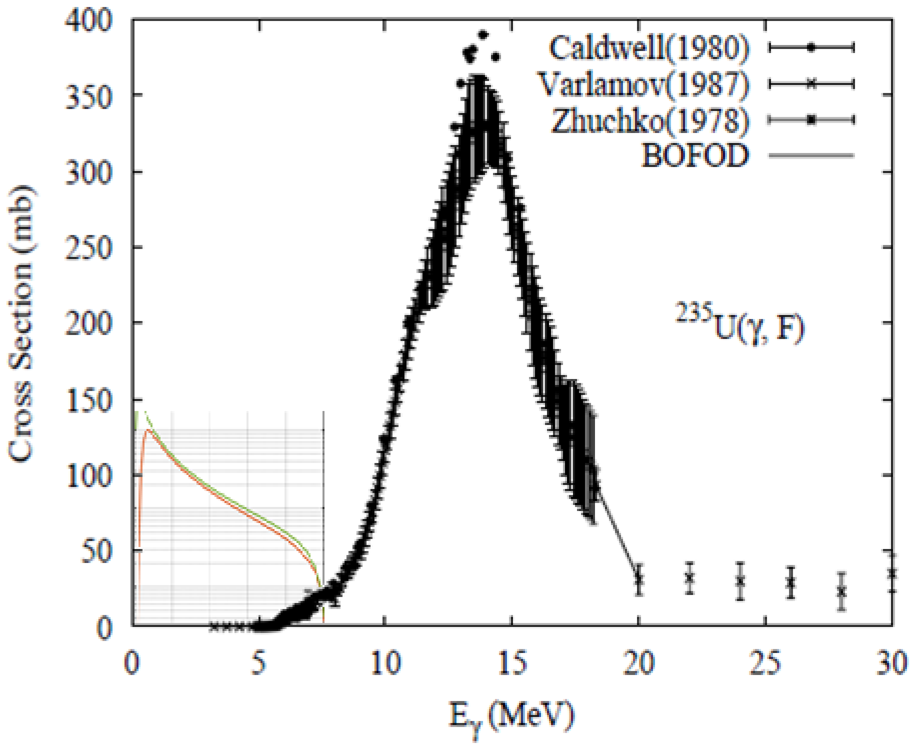
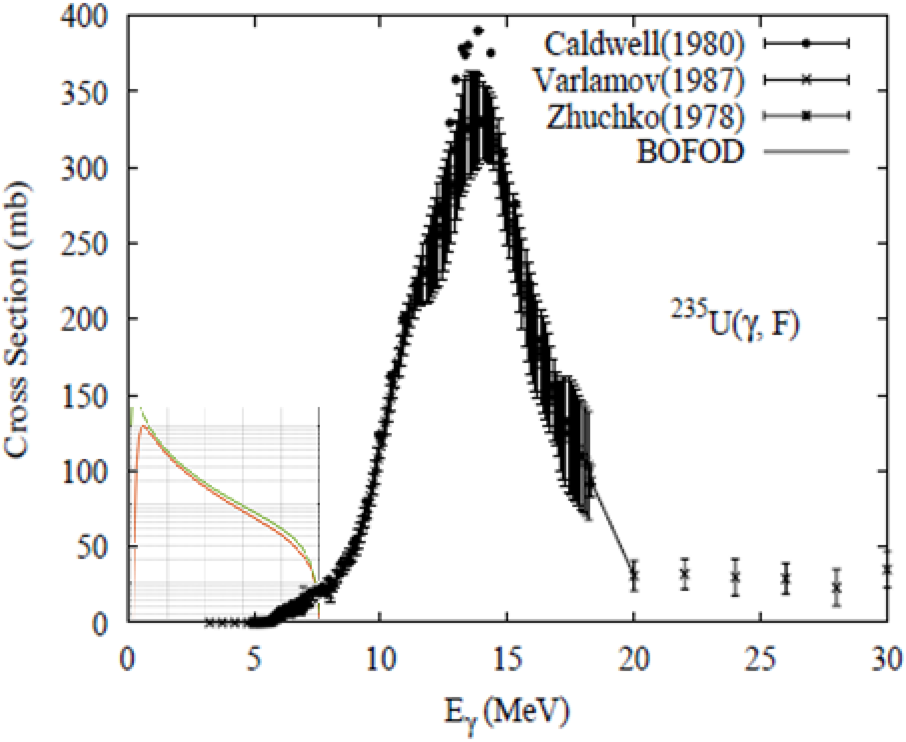


Overview

- **Circa 2010, DNDO Photofission benchmark attempts produced signals that were up to 10x weaker than predicted by MCNP. Why did this occur?**
  - MCNP user error?
  - Need to improvement the nuclear data pipeline?
  - Bad γ,f and/or γ,xn data?
  - Bad bremsstrahlung data?
- **Easy Solution:**
  - Begin with simple but **not extensible** benchmark.
- **Better solution**
  - Generate data using narrow energy-spread photon source(s)
  - Possibly piggy-backing on other measurements of data describing outgoing fission channels.



Phenomena & Applications

- **Cargo/SNM identification is primary driver for better data**
- **Subcritical assembly experiments may want photo-induced neutron sources**
  - (γ,α), (g,xn) – Cross section data <~7% except near thresholds.
  - Production multiplicities, energy dependence of fission yields, angular distributions, correlations unknown except for 6-group neutron behavior
  - **Polarized MeV photon sources are coming, but data hardly exist**
- **Photonuclear reactions to produce 'esoteric' isotopes for forensics applications – some reactions have been called out in other reports.**
  - (γ,α), (γ,p) – almost no data; reliance upon TALYS; couple to European physics priorities to better benchmark TENDL
- **Resonance fluorescence (nuclear and atomic) have NDA applications**
  - Data and/or implementation into codes lacking
- **Quality of photon attenuation data? Likely good until E > few MeV**
- **Tabulations of challenging-to-simulate photon effects?**
  - Collimation & detectors

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Nuclear Data Roadmapping & Enhancement Workshop (NDREW) 2018

Session 1B and 2B:
Neutron Capture and Associated Spectra
Inelastic Neutron Scattering and Associated Spectra

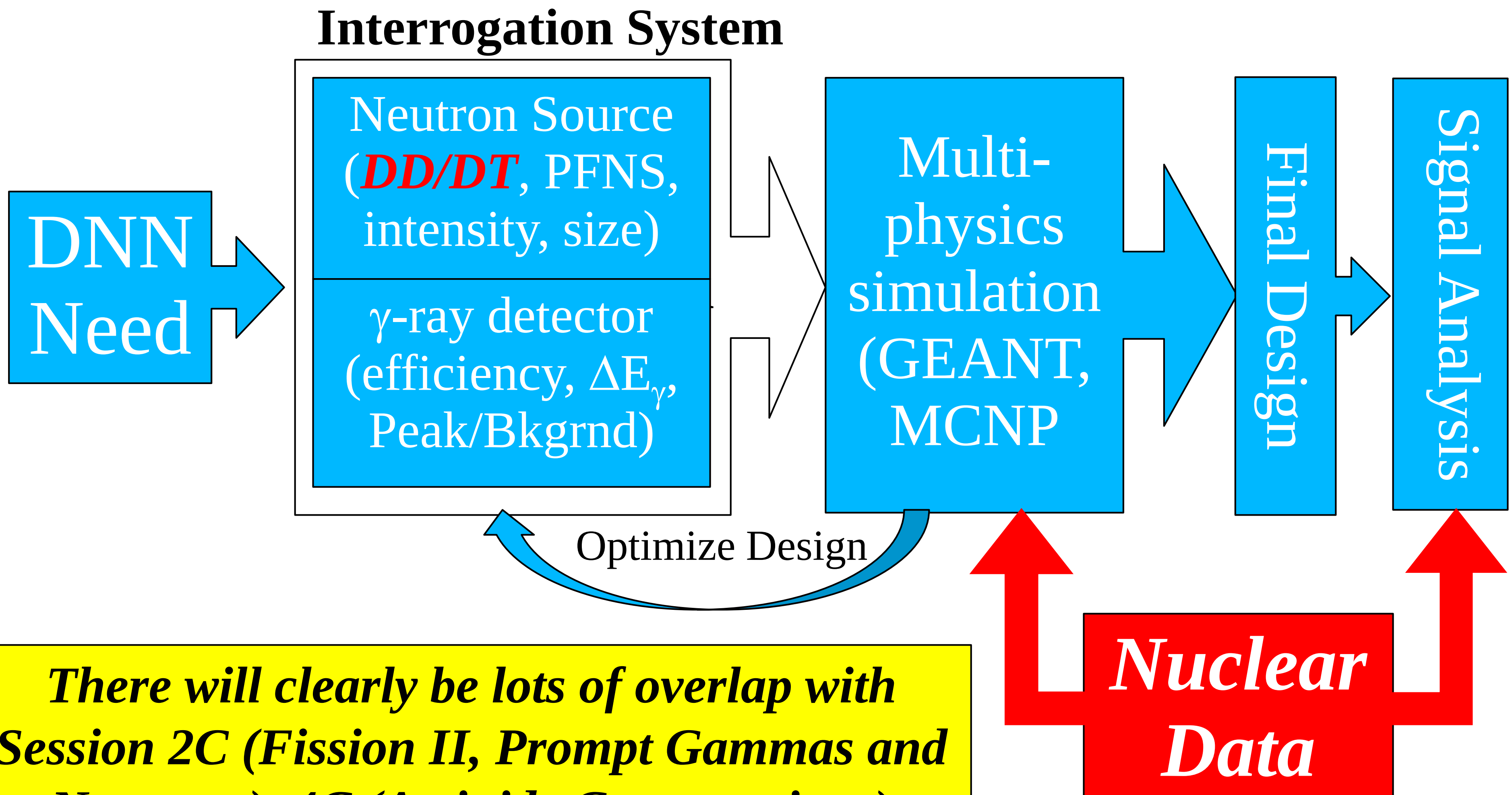
Lee Bernstein

LBNL/UC-Berkeley

January 23 - 25, 2018

UNCLASSIFIED

The driver is *Non-proliferation*
Example: Active Interrogation



There will clearly be lots of overlap with Session 2C (Fission II, Prompt Gammas and Neutrons), 4C (Actinide Cross sections)

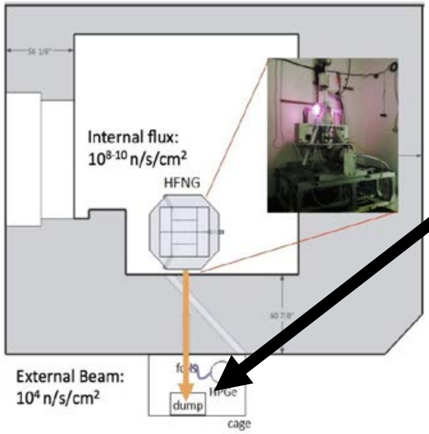
Most measurements of (n,fγ) include (n,γ) and (n,n'γ)

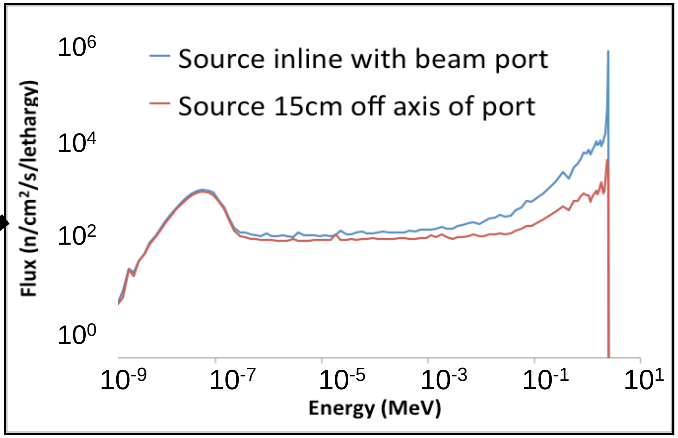
Target	$\frac{(n,n'\gamma)_{DD}}{(n,f\gamma)_{DD}}$ @ $2.45\ MeV$	$\frac{(n,n'\gamma)_{DT}}{(n,f\gamma)_{DT}}$ @ $14.1\ MeV$	$\frac{(n,\gamma)_{th}}{(n,f\gamma)_{th}}$ @ $5\ keV$
^{238}U	***5.3***	***0.41***	***>10^7***
^{235}U	***2.2***	0.20	0.31
^{239}Pu	***1.0***	0.08	***0.91***

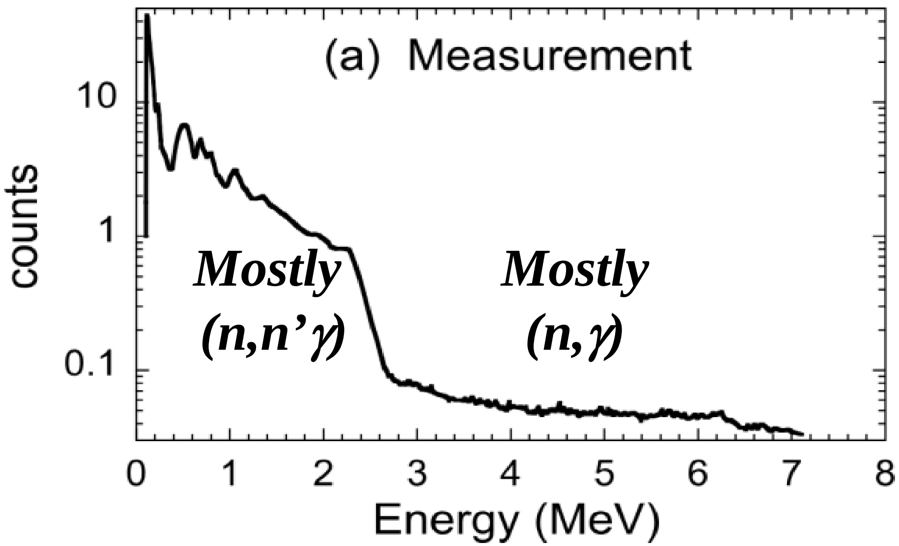
γ-multiplicity is obviously higher in (n,f) than in (n,γ) and (n,n'γ), but the energy might be higher on average.

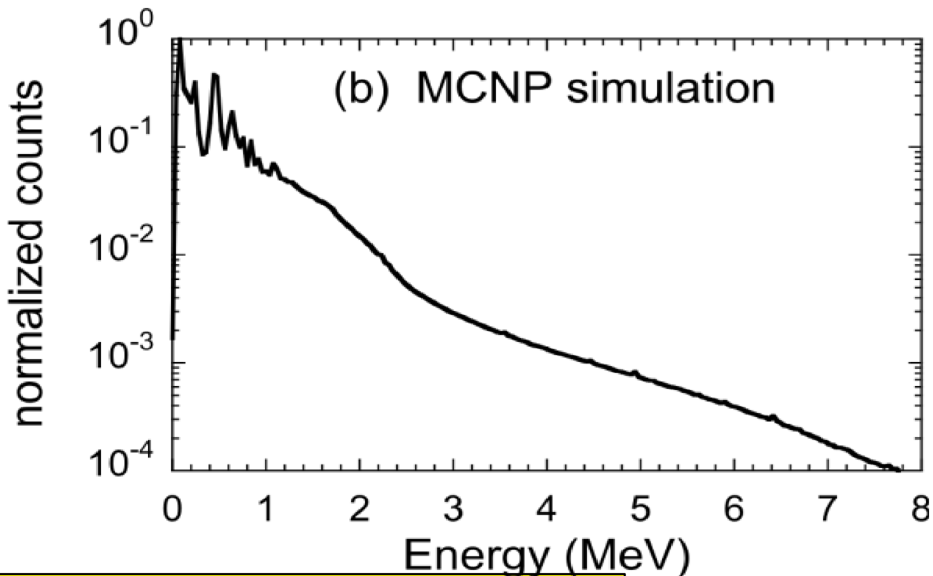
An example to kick things off: NaI(n,xγ) @ 2.45 MeV

- A NaI detector was irradiated in a DD neutron beam at UCB to benchmark modeling for a measurement of ^{239}Pu(d,pfγ)[1]
- The measured spectrum was compared to MCNP simulations









The (n,γ)/(n,n'γ) ratio is off by >10x

[1]S.G. Rose *et al.*, PRC 95, 045805 (2017). doi:10.1103a/PhysRevC.95.045805

Session 1B: Capture gamma & spectra Prioritized Plan of Action

1. The initial focus area should be on *improvement in the evaluation and post-processing of existing experimental data* for capture gamma-ray spectra.
   a) Targeted measurements *above E_n > 25 keV (Data goes from sparse to 0 as E_n goes up*)
   b) A *continuously updated inventory of experimental capabilities* would help guide these measurements.
   c) *We need data, in units of mb or per capture reaction, including quasi-continuum and discrete data*, if the capture signal is significant.
   d) The quality of data needed depends on the details of the application.
2. *A benchmark for a specific application* (e.g., prompt-γ from DD neutrons) would help define the required sensitivity.
3. We should consider *improving/expanding the methodology* used to put data in the database
   a) *Creation of data sets* for inclusion into ENDF using sophisticated modeling
   b) *Using a gamma-ray cascade event generator* (with correlations!!!) for incorporation into or use with transport codes. *(CGM and other tools exists that might fill this need)*
4. A continued program of (n,γ) activation is needed to develop and maintain capabilities and expertise. – *NCSP is addressing this area (subject to stray buses)*

There is significant overlap with this area and the (n,f) gamma session

Session 2B: (n,n'γ) & spectra Prioritized Plan of Action

1. *Develop benchmarks* for relevant applications (e.g., prompt-γ from DD, DT, PFNS) to define the approach and its required sensitivity.*
   a) Remember to include (n,n') to isomers for post-det forensics (for non-actinides).
   b) The detection system response needs to well-characterized over the entire range of measurement.
2. *Conversion of existing data* into cross sections, and the *generation of new mission relevant data*, including the nuclear data pipeline*
   a) A *continuously updated inventory of experimental capabilities* would help guide measurements.
   b) *We need data, in units of mb or per scatter reaction, including quasi-continuum and discrete data, and angular correlation if the signal is significant.*
3. A *tool to determine sensitivity* for a given system is needed for both application and benchmark analysis.
   a) Develop eigenvalue-like S/U tools to gamma-ray and neutron spectral data
   b) The SME is still essential to interpreting the output of this tool.
4. We should consider *improving/expanding the current methodology* for data inclusion into ENDF
   a) One approach is to *optimize reaction model output* relative to measured data.
   b) Another approach, appropriate for nuclei with fluctuations, is to *put measurements directly in*.
5. *Improvements in the inputs to the reaction model* (level density, pre-equilibrium, general structural inputs). This is a cross-cutting contribution to other missions.

**Coordination/collaboration with the international community is essential (GELINA, n-ELBE)*

γ-ray spectra from (n,n'γ) is inextricably linked to the energy and angle of the outgoing neutron and the

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Nuclear Data Roadmapping & Enhancement Workshop (NDREW) 2018

Matt Devlin
LANL

January 23 - 25, 2018

Current work

- **Current/past work from the Naval Nuclear Lab, indicating issues in the outgoing neutron spectrum (Michael Zerkle)**
- **Current/past funded projects (NA-22)**

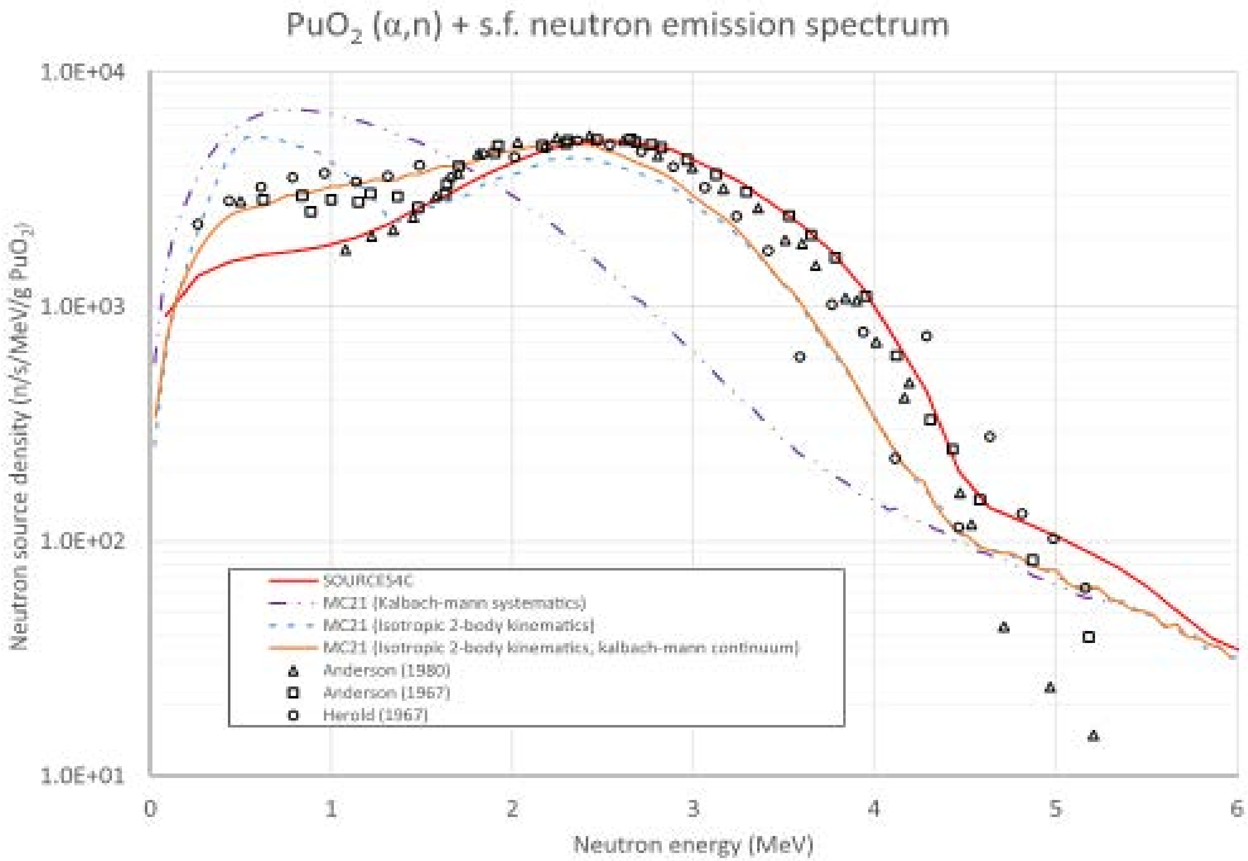
  – ORNL/INL/…. differential measurements of $^{17,18}O(\alpha,n)$ and $^{19}F(\alpha,n)$

  Using alpha beams and inverse kinematics (Michael Smith)

  – Uncertainty quantification (ORNL) with covariances using an R-Matrix formalism (Marco Pigni)

PuO_2 (α,n) Neutron Emission Spectrum

- **From Michael Zerkle**



(α,n) Reactions: Data Needs

- **High priority cross section measurements**
  - The big three isotopes: $^{17,18}O(\alpha,n)$ and $^{19}F(\alpha,n)$
  - Full energy range (<1 MeV to 9 MeV) with consistency, 2% accuracy
  - All light element isotopes; Carbon as a standard reaction
  - Theoretical calculations of other isotopes
  - Associated gamma-ray measurements
  - Measured but unanalyzed 6.7 to 8 MeV $^{19}F(\alpha,n)$: motivation?
  - Measured but unanalyzed angular distribution data
- **Outgoing neutron energy spectra**
- **Evaluations of existing data**
- **Benchmarks using well calibrated sources for validation**
  - Thick target measurements needed for validation

(α,n) Reactions: Data Needs

- **Variations in n rates from different material forms**
  – Stopping powers, energy loss in mixed materials
- **Theoretical improvements: extending R Matrix to higher energy**
- **Uncertainty quantification**
- **Improvements in methods, calculations, and simulations**
  – Improvements to SOURCES4C: active maintenance or replacement

Facilities for (α,n) Measurements

- **US**
  - Notre Dame
  - Ohio
  - TUNL
  - U Kentucky
  - LANL
- **International**
  - Geel

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Session 3B: Summary of Targetry, Facilities and Detector Arrays

Todd Bredeweg / Jason Burke
LANL / LLNL

January 23 - 25, 2018

Targetry

Targetry

- Produce and measure short-lived actinides in same location (shipping issue/co-location of detectors and production)
- Start thinking of the isotopes you will need going forward. Isotope Program will be issuing a call for needs soon. Enrichment needs.
- Identify (legacy) materials along with available details (quantity, form, isotopics…) (ORNL/LANL/LLNL/INL/PNNL/ANL/BNL/OSU/FSU/LBNL)
- Maintaining and restoring capabilities for target fabrication/characterization.

Targetry needs:

- Purchase of isotopes is taking a long time and adds costs and delay
- Lease from Isotope Program policy is difficult (no rad added is nearly impossible to guarentee)
- Separated isotopes of Uranium, Plutonium and minor actinides needed for experiments (microgram to gram quantities depending on experiment)
- PSI/LANCE/ORNL – mining and extraction of long lived isotopes produced in beam dumps and long exposures (ORNL-Mark18)

Call for isotopes coming out soon

www.isotopes.gov

Highlights – Prototype EMIS

- Daily operation
- Up to 10mA Beam Current
- Successfully separation of Xe, Ar, Kr, In, Yb, Ru, Ni
- Single Pass ^{115}In purity = 99.9975% from 95.72%
- Design is good for Pu separation

K. Dudeck (MPA-11)
C. Leibman (MPA-11)

Facilities

University and National Lab nuclear facilities need to be supported long term as they provide key capabilities that support/enable DNN activities

Facilities

- Collect a searchable list of neutron spectra and fluences from reactors/neutron sources
- Improvements of existing facilities ex: LANL target upgrade, value to all programs
- Accelerators (Cyclotron, Tandems, LINACs), mono-energetic neutron sources, reactors, critical assemblies

Facility needs:

- Neutron scattering dedicated setup
- How to interface needs with facilities, institutes, detector system access
- Rabbit at the DAF for Godiva/Flattop

Facilities: Critical Assemblies and reactors

Flattop

- Fast/Fission-spectrum
- HEU and Pu cores / Natural U reflector
- Reactivity increases as parts of spheres brought together and control rods inserted
- Samples inserted in a horizontal “traverse” or glory hole
- ~10^{11} total fissions (high power)

Godiva

- Fast/Fission-spectrum
- 65 kg of Bare U(93)
- Capable of steady-state and burst (prompt critical) operation
- Samples inserted in a vertical glory hole
- ~10^{16} total fissions

Reactors

- Numerous small research reactors in the US >25 installations
- HFIR

Detector Arrays

Gamma ray arrays

- GammaSphere, Hyperion, GRETINA, DANCE, TIGRESS, Capture calorimeter (RPI), high rate HPGe (PNNL/OSU), LaBr (BIII), MTAS

Beta decay experiment

- Ion trap and beta-gamma array at ANL run by ANL/LLNL

Neutron detector arrays

- Chi-Nu (PFNS measurements-nTOF), NeutronSTARS (3.7-ton liq. scint. eff. 80-90%), VANDLE (nTOF)

Fission detector arrays

- Parallel Plate Avalanche Counter (PPAC), fission Time Projection Chamber (fTPC), A,Z/TKE measurements SPIDER, SOFIA

Needs:

- Gamma induced fission outputs (neutron spectrum/fragments/etc…)
- Neutron scattering dedicated setup

Detector Arrays