The Challenges of Nuclear Data for Safeguards and Security

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Outline

- The Need for New Data
- Safeguards Motivated Nuclear Data Projects
- Nuclear Data Needs Workshop
- Nuclear Data Working Group
- Future Work

The Need for a New Emphasis on Quality Nuclear Data

- There has been little interest in Nuclear data in the U.S. since the 1980s due to:
  - The end of the cold war
  - Lack of new nuclear power development
- Nuclear data needs to be revisited due to:
  - Recent global resurgence in nuclear energy
  - New potential nuclear threats
- Modeling and Simulations capabilities have reached a level where, in many cases, nuclear data drive the total uncertainties.

Nuclear Data to Support Modeling and Simulation

- Modeling and simulation is critical to solving the inverse problem for NDA measurements.
  - Rely on nuclear data files
- Proper calibration of instruments with *well known* objects can sometimes provide a work around for poor data.

BUT

- Anomalies or unique objects require reliance on models and nuclear data for answers.

Nuclear Data Required to Support Safeguards NDA Measurements

- Active NDA directly measures the emitted neutrons and gamma rays to deduce the mass and isotopic content of the item being measured.
- This requires quality data regarding:
  - Fission cross sections – neutron/gamma induced as a function of incident particle energy
  - Fission fragment yields and their gamma decay
  - Prompt fission neutron spectrum and multiplicity
  - Prompt fission gamma multiplicity and spectrum
  - (alpha,n) cross sections - actinides, fission fragments and structural materials
  - (alpha,n) neutron spectrum and gamma emission
  - Capture cross sections and gamma decay – actinides, fission fragments and structural materials
  - Inelastic scattering cross sections and de-excitation gamma energy – actinides, fission fragments structural materials
  - Elastic scattering cross sections to ensure accurate neutron transport calculations through all materials.

Advanced Computing Capabilities Require Updated Infrastructure

- Nuclear data must be formatted for use in modern codes.
  - US in process of transitioning to GND format
- Uncertainties need to be accessible to the users of the data – available in database
  - US has been updating ENDF with covariance matrices.
- Nuclear Data uncertainties need to be propagated through the calculation so users can understand the impact.
  - Currently only limited capabilities for specific users
  - SCALE reactor models have this capability

Current Safeguards Funded Projects

- Recent funding for several nuclear data projects to support safeguards
  - Capture Gamma Decay data
  - Correlated Neutrons and Gammas from Fission
  - $^{19}F(alpha,n)^{22}Na$ Cross Section and Neutron Emission
- No comprehensive nuclear data program to address needs of safeguards and security.
- Currently, major funding sources are Defense and Criticality Safety Programs

Gamma Decay Data

- Improvements to Evaluated Gamma-Ray Activation File (EGAF)
- Cross correlated with ENSDF decay schemes
- Put into ENDF libraries for transport modeling to be in next ENDF release

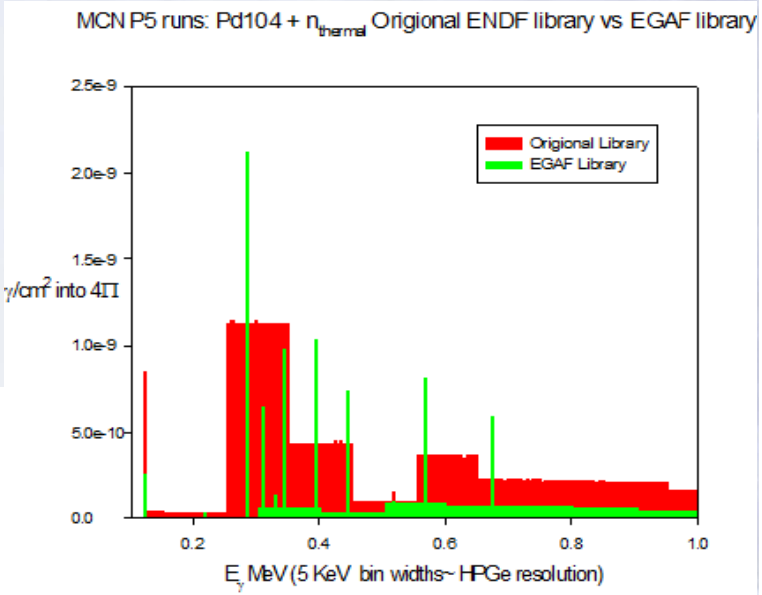
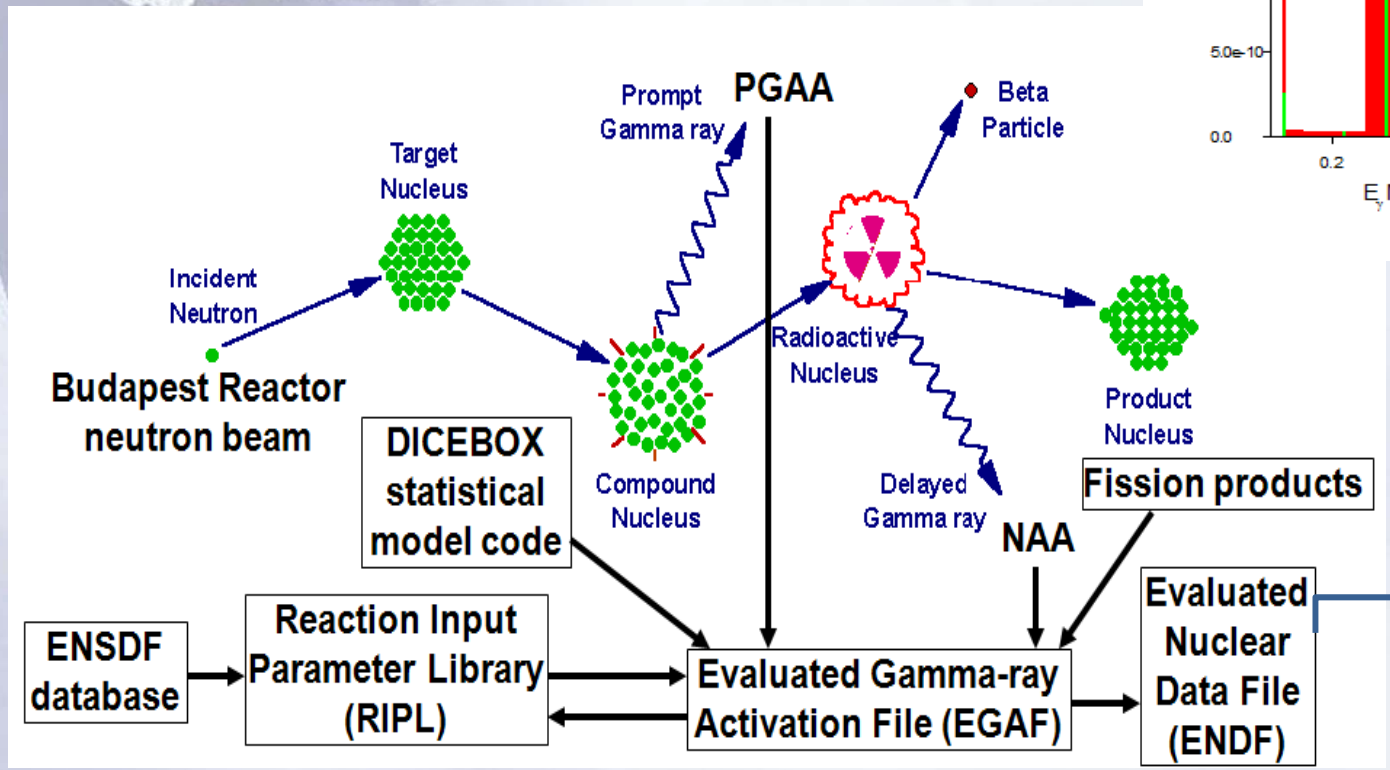


Figure 2



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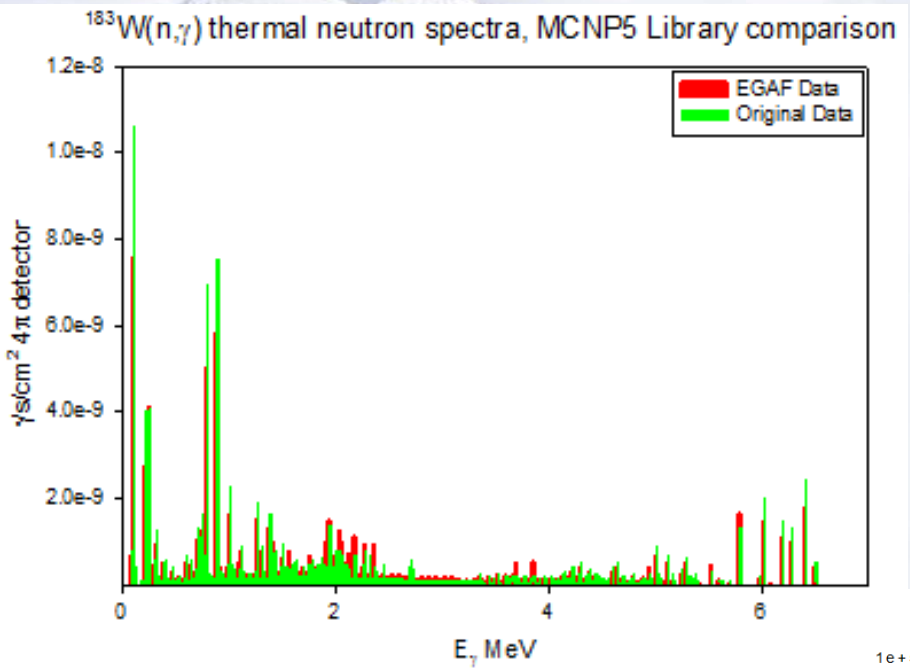
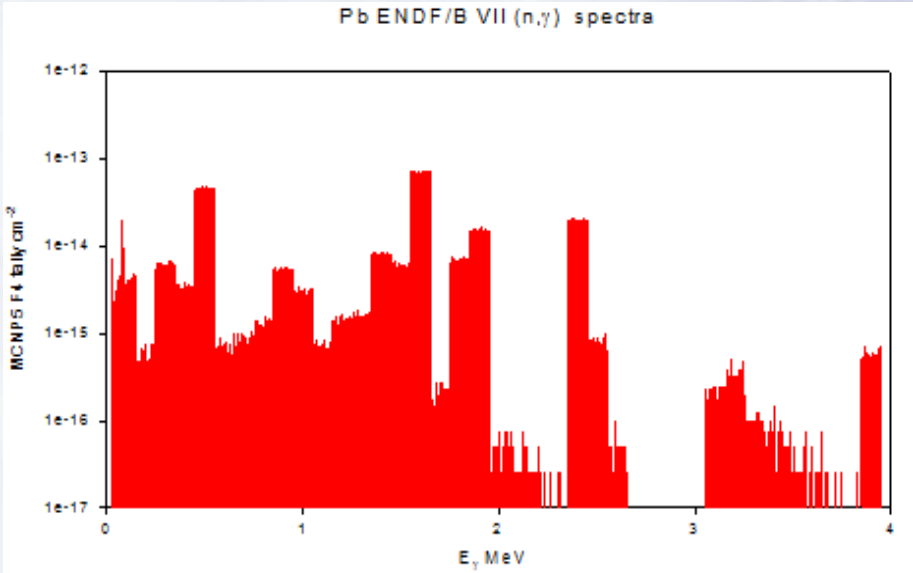
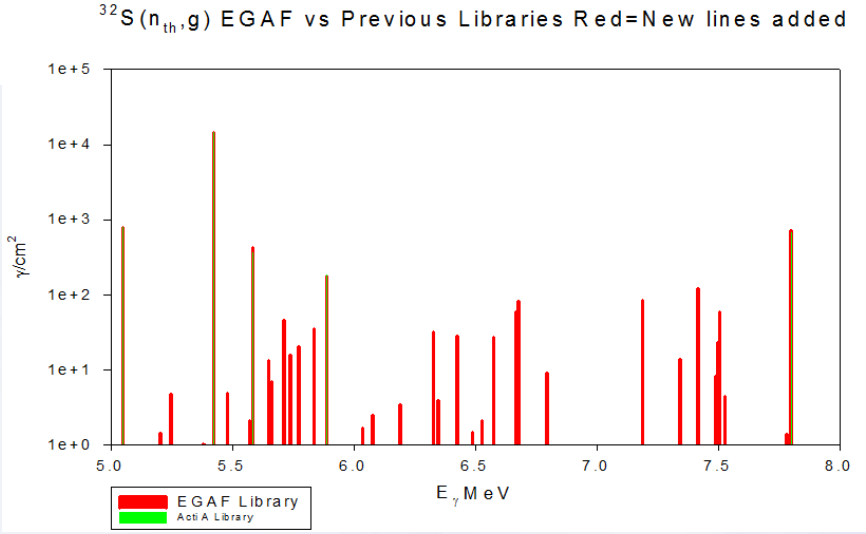
Examples of Missing Capture Data



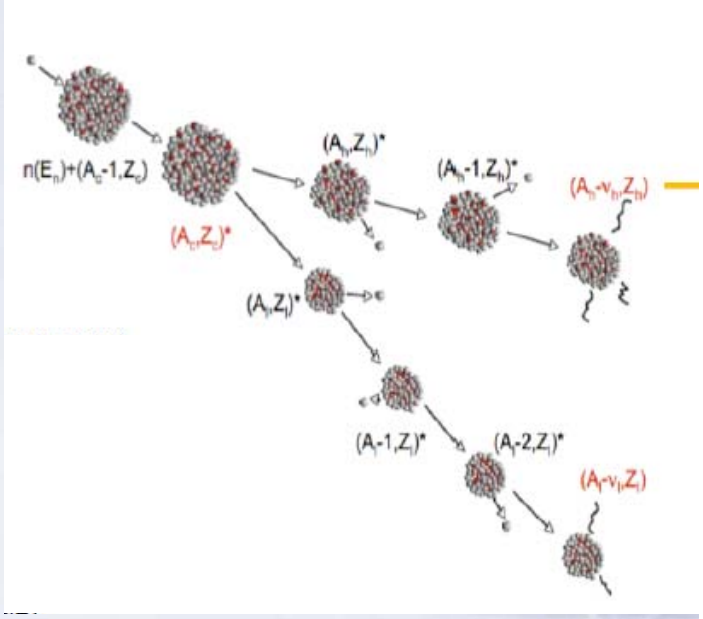


- Some libraries have no spectra,
  - Actinides
- Others have poor resolution, missing lines or incorrect intensities.



Correlated Neutron and Gamma Capabilities in MCNP6

- **Goal**: Provide a capability for prompt fission neutrons and gamma-rays in MCNP6
- Applications for detector response modeling, list mode data analysis, non-proliferation and a better understanding of the fission process.



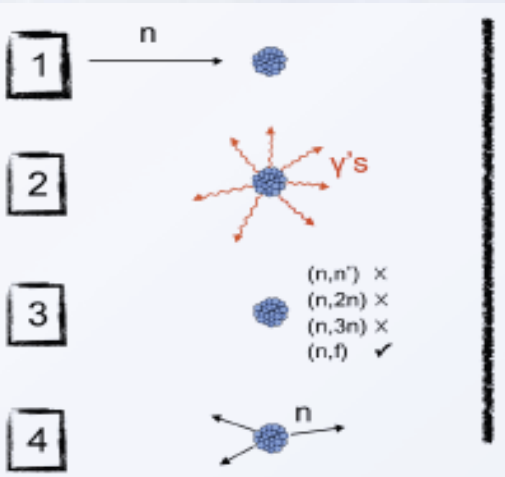
FREYA and CGMF event-by-event fission models

- Fragment Mass and TKE distributions (CGMF)
- Statistical models of neutron and gamma emission
  - multiplicity and energy spectrum
- Fission neutron angular correlations
- Conservation of energy and momentum

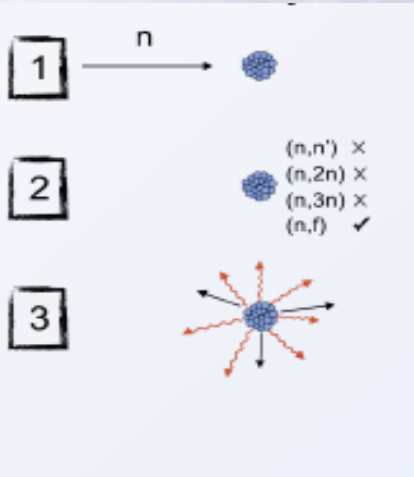
FREYA

- Current MCNP treatment:
  - Emits gamma rays
  - Determines reaction
  - Emits 2 to 3 neutrons
  - Samples an average neutron spectrum

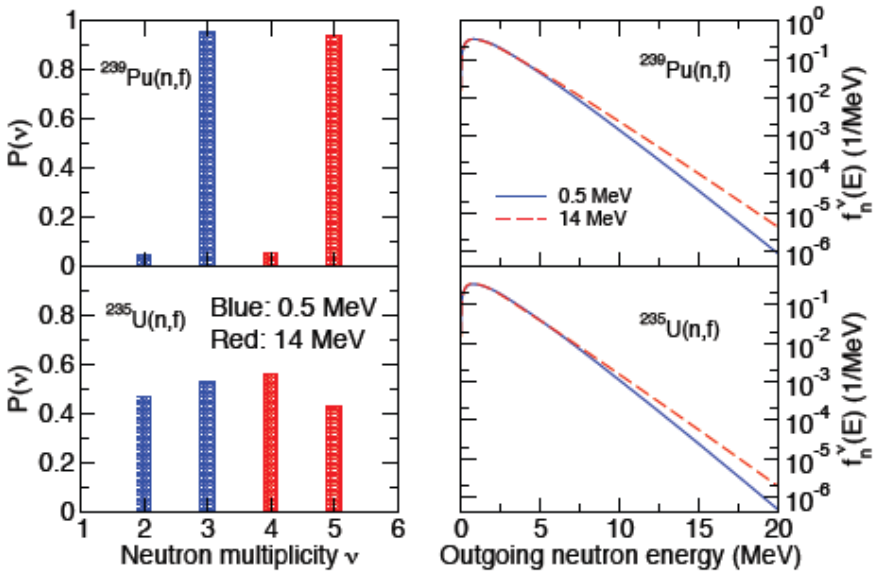
Standard model



FREYA code



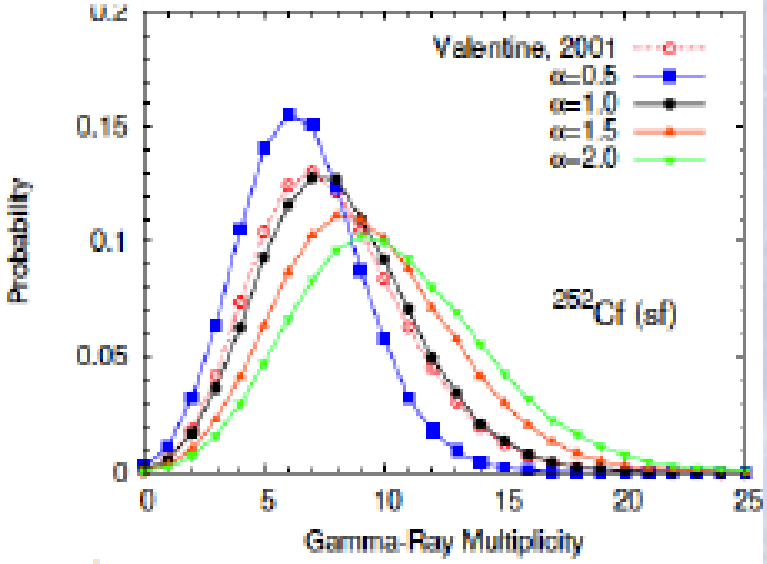
Fission model in frequently used simulation code **MCNP**:

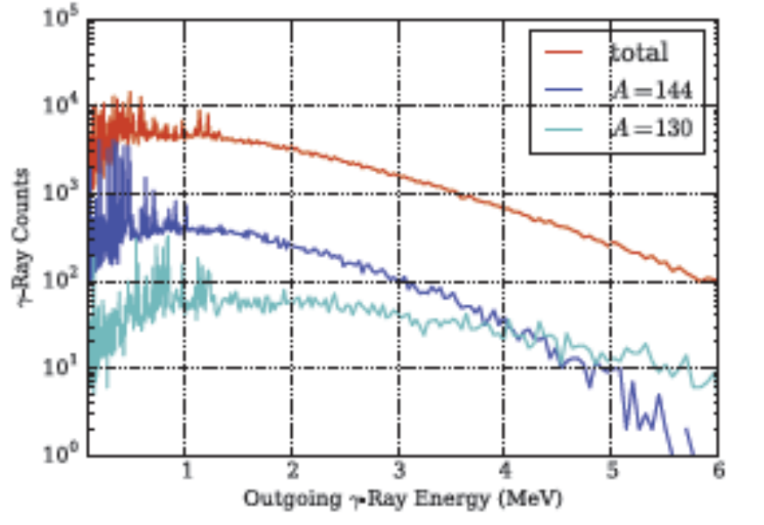


- FREYA
  - Determines reaction
  - Emits energy and angle correlated neutron and gamma-rays based on fission models and empirical data
  - Samples neutron and gamma spectrum as a function of number of neutrons and gammas emitted

CGMF Models

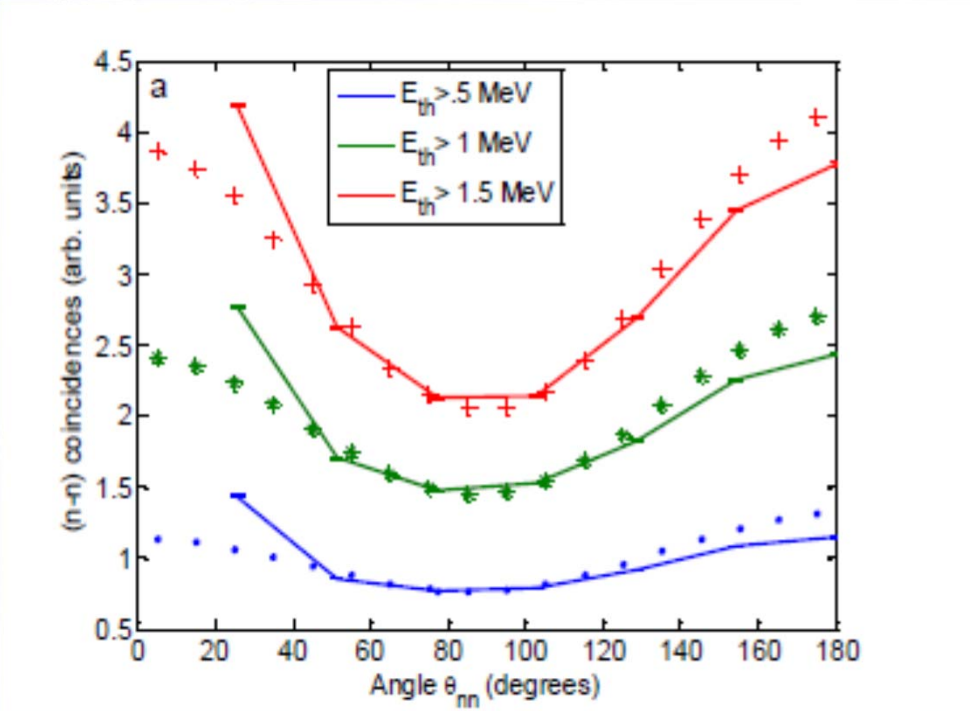
- Assumptions:
  - Prompt fission products emitted from fully accelerated fragments
  - No emission occurs during the evolution from saddle to scission
  - No emission at the neck rupture
  - Fission fragments are compound nuclei
- C++ code implementation CGMF
  - Event by event simulation of the fission fragment decay (Monte-Carlo Hauser-Feshbach formalism)
- Output
  - Average prompt fission neutron spectrum
  - Average prompt fission neutron multiplicity
  - P(ν), ν(A)
  - Prompt gamma observables
  - Correlations between gammas and neutrons



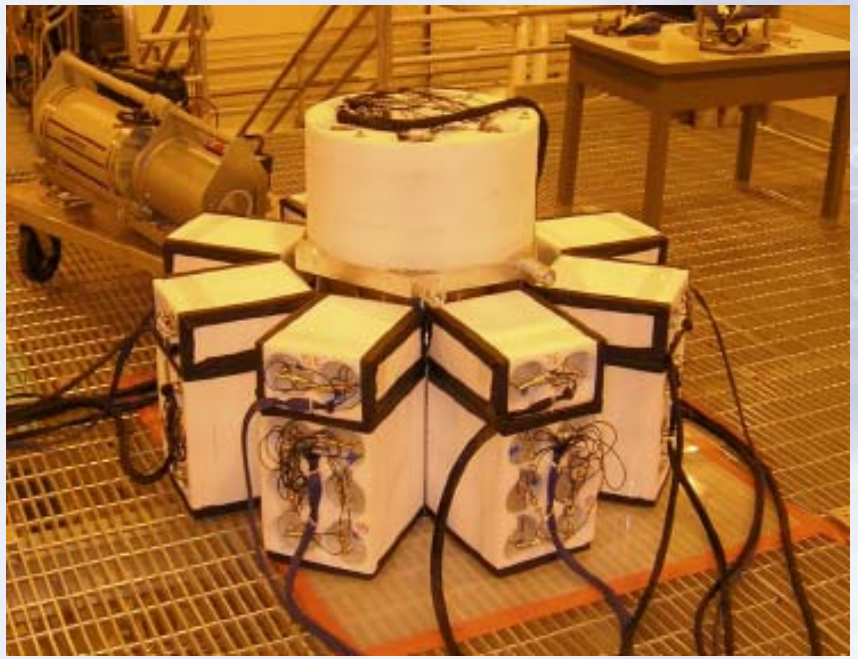


Angular Correlation Measurements

Angular correlation of fission neutrons

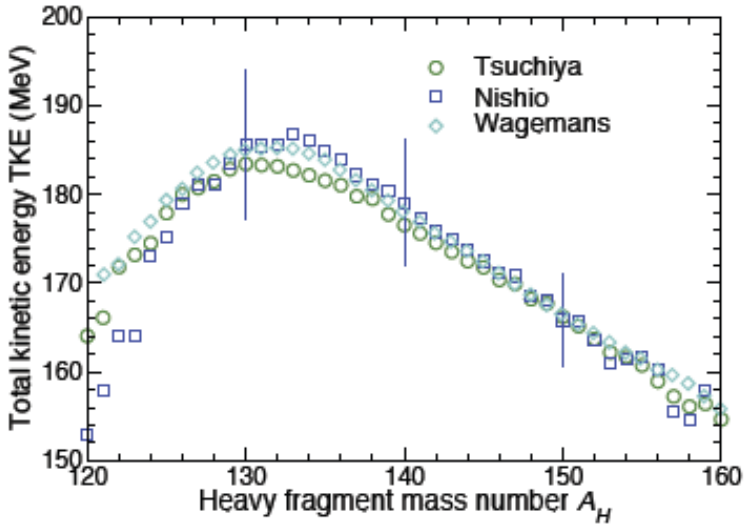


Experiment to measure correlation between ^{252}Cf spontaneous fission neutrons using 77 liquid scintillator cells at Lawrence Livermore National Laboratory

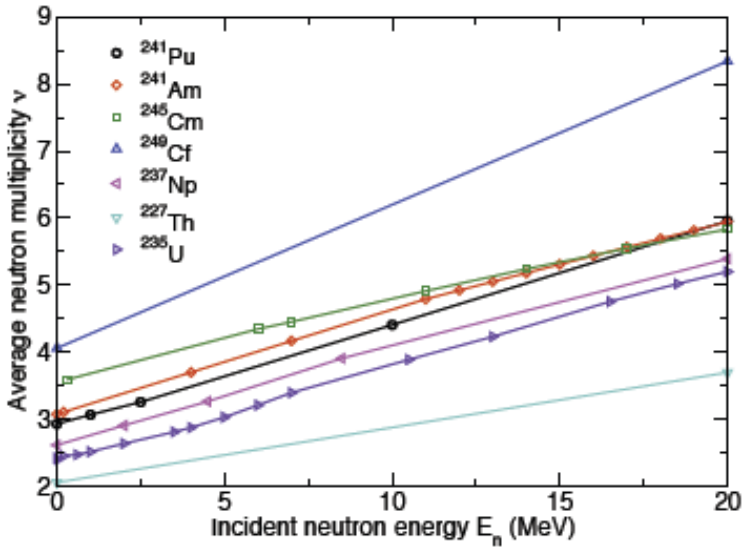


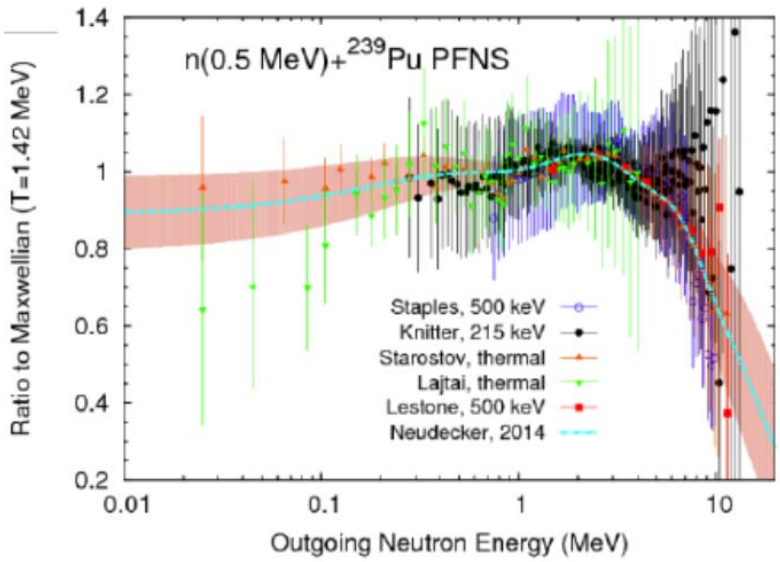
More Data Required to Support Models

Input data: Y(A), TKE(A)

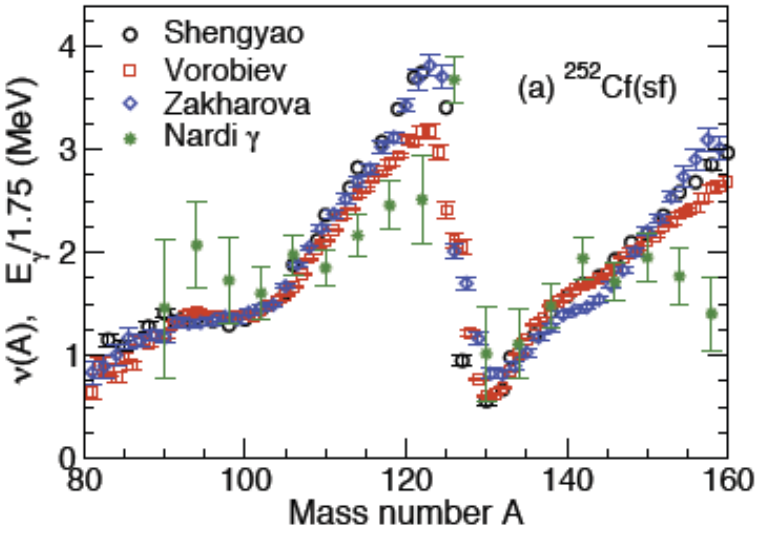


Data one fits to: neutron multiplicity





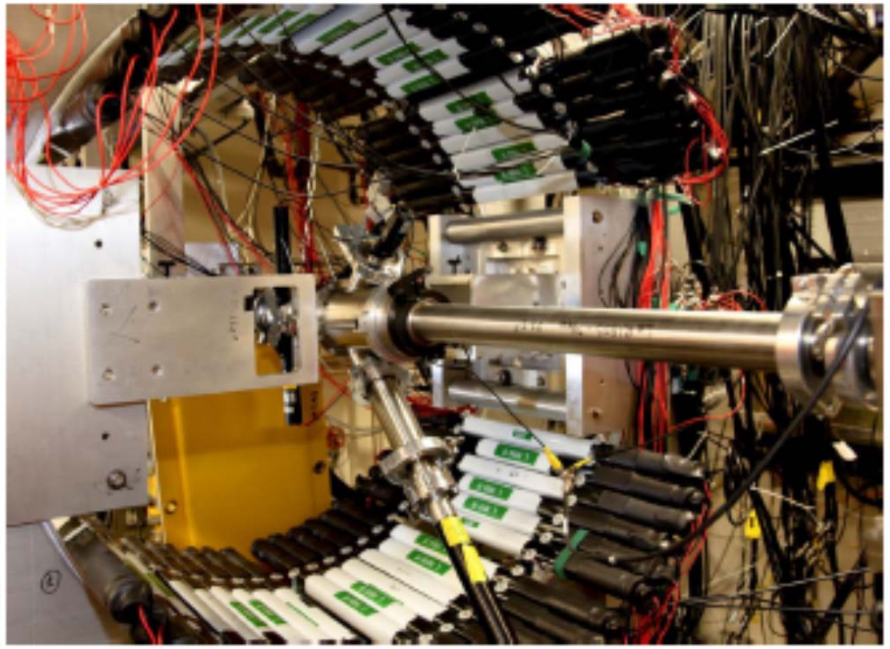
Data used to check models



D. Neudecker, P. Talou, T. Kawano et al., Nucl. Inst. Methods in Phys. Research A **791**, 80-92 (2015)

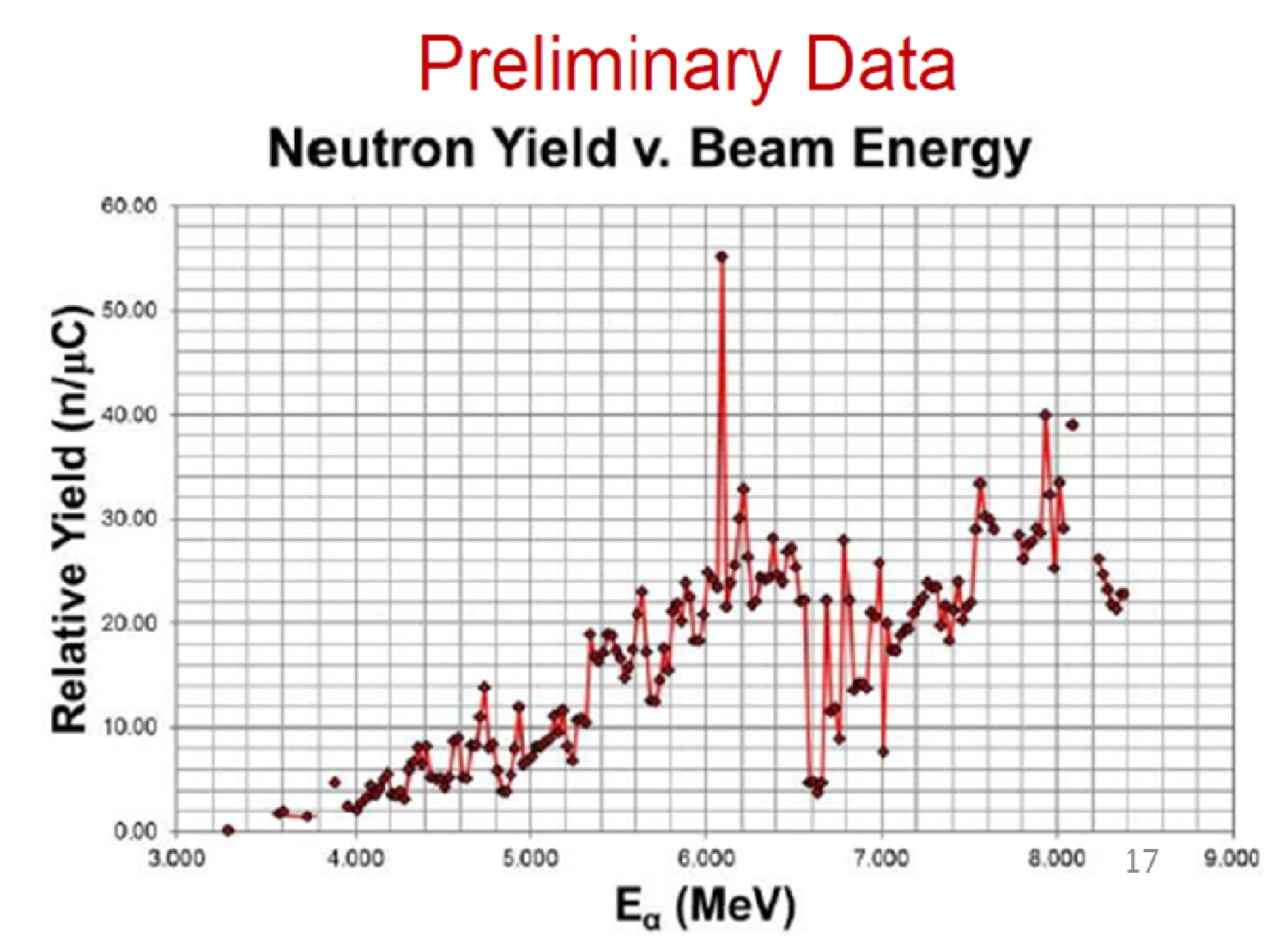
High precision $^{19}F(\alpha,n)^{22}Na$ Cross-Section for Nuclear Safeguards

- Required for verification of enrichment of UF_6 cylinders
- Measurement of
  - Cross section
  - Neutron spectrum
- Energy ranges from 3-8 MeV incident alphas
- Fine energy resolution
- Pulsed α beam with LaF_3 target
  - Notre Dame
- ^{19}F beam with He-gas target
  - Oak Ridge National Laboratory



- Versitile Array of Neutron Detectors at Low Energy (VANDLE)
- Array of 48 Neutron Detectors at the Holifield Radioactive Ion Beam Facility at Oak Ridge National Laboratory
- 700 ps resolution
- Energy range of 100 keV to 20 MeV

High precision $^{19}F(\alpha,n)^{22}Na$ Cross-Section for Nuclear Safeguards



Looking Ahead

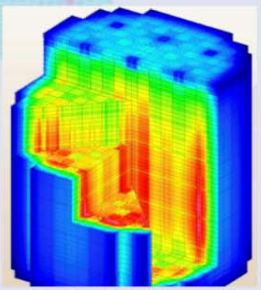
- Working towards a comprehensive nuclear data improvement plan

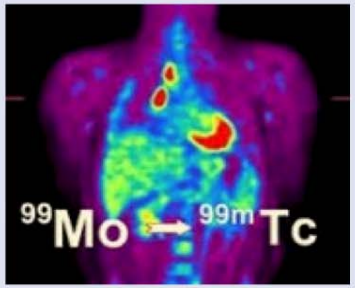
Nuclear Data Needs and Capabilities for Applications

May 27-29, 2015

Lawrence Berkeley National Laboratory,

Berkeley, CA USA





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NDNCA Workshop

- Sponsored by DOE/Office of Science and NNSA/Defense Nuclear Nonproliferation

- Application Areas
  - National Security
  - Safeguards
  - Isotope Production
  - Nuclear Energy

- Cross Cutting Needs
  - Better understanding of Fission
  - Neutron Transport – Elastic and Inelastic Scattering
  - Gamma Decay data
  - Expanded Integral Validation Experiments and Covariance Data

Nuclear Data Working Group (NDWG)

- Following the workshop, program managers that are users of nuclear data agreed that it would be beneficial to communicate and coordinate efforts.
- Each program identified a working group member to identify and prioritize opportunities to improve nuclear data.
- The NDWG is working to identify nuclear data activities where enhanced collaboration and coordination would be broadly beneficial.
- Currently creating a 5 year plan to improve nuclear data that will directly impact mission areas.
- Plan to be presented to program managers in April, 2016.

NDWG Participants

Partners	Program Area	Working Group Member
NA-22	Enabling Capabilities / Nuclear Weapons and Material Security Teams	Catherine Romano
DOE/OS/NP	Nuclear Physics	Lee Bernstein/Dave Brown
NA-22	Forensics / Post Det	Todd Bredeweg/Jason Burke
DNDO / TAR	Nuclear Detection	Doug Mayo
NA-511/ NCSP	Criticality Safety	Skip Kahler
NA-113	Defense Programs/ Research and Development	Dennis McNabb
NA-114	Defense Programs/Physics and Engineering Models	Bob Little
NE	Nuclear Energy	Phillip Finck
DNDO / NTNFC	Forensics	Richard Essex
DOE/Isotope Office	Isotope Production	Meiring Nortier

NDWG Topic Areas

- Data Evaluation, Testing and Covariance data
- Update to nuclear data base
- Better understanding of fission
  - Theoretical models and experiments
- Neutron elastic and inelastic scattering
- Gamma decay and capture cross sections
- (alpha,n) cross sections – update SOURCES4C
- Np cross sections for ^{238}Pu production

Additional NDWG Goals

- Improved communication and coordination between programs.
- Educate the user community about nuclear data uncertainties.
- Suggest best practices for nuclear data handling.
  - What happens after the experiment?
- Provide recommendations for US capabilities.
- Improve access to target materials.
  - Reduce cost, target sharing
  - Quality – create standards for characterizing targets

Thank You

Questions?