How can a diverse set of integral and semi-integral measurements inform identification of discrepant nuclear data?

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XCP-3: Monte Carlo Codes
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Attributes of diverse measurement sets are complementary in identifying discrepant nuclear data

- Difficult to identify nuclear data contributing to bias
  - $k_{\text{eff}}$ requires $\sim 10^4$ differential nuclear data to simulate
  - Fissile core coupled with non-fissile material
  - Sensitive to specific neutron energies
- Apply machine learning to diverse set of measurements
  - LLNL pulsed sphere measurements
    - Simple geometry and composition
    - Sensitive to scattering and fission distributions
  - Subcritical benchmarks
    - Responses are integral SNM properties different from critical benchmarks
    - Sensitive to $P(\nu)$ moments

Tool for large-scale validation and identifying unconstrained physics spaces with ML (RAFIEKI)

<table>
<thead>
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<th>RAFIEKI(^{1,2,3})</th>
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<tr>
<td>Applies</td>
<td>Random forest &amp; SHAP</td>
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<tr>
<td>Input</td>
<td>Integral/differential responses and sensitivities</td>
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<td>Output</td>
<td>which nuclear data likely related to bias</td>
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<td>Tool</td>
<td>Will eventually be open-source</td>
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RAFIEKI identified F-19 (n,inl) scatter cross section as contributing >100 PCM bias in HEU-SOL-THERM benchmarks.\(^4\)

Change in $^9$Be nuclear data importance to bias: Critical benchmarks + pulsed sphere measurements

- Increased rank = increased importance
- Decreased rank = decreased importance
- “Rank a” is for critical benchmarks + pulsed sphere measurements
- “Rank b” is for critical benchmarks only

Adding pulsed sphere measurements significantly increased importance of $^9$Be nuclear data above 2 MeV.
Response sensitivities to $^9$Be nuclear data

- USI-001-012 – Uranyl-Fluoride ($^{233}$U) Solutions in Spherical Stainless-Steel Vessels with Reflectors of Be, CH2, and Be-CH2 Composites
- HMF-058-001 – Highly Enriched Uranium Metal Spheres with Beryllium Reflectors
- be0.8b – Beryllium pulsed sphere, mfp=0.8, flight path=878 cm, 26-deg

be0.8b leakage spectra (bottom) sensitivity to $^9$Be (n,2n) (top)
Change in $^{240}$Pu nuclear data importance to bias: Critical benchmarks + subcritical benchmarks

- Increased rank = increased importance
- decreased rank = decreased importance
- “Rank a” is for critical benchmarks + subcritical benchmarks
- “Rank b” is for critical benchmarks only
- Boxes highlight significant changes in importance

Adding subcritical benchmarks useful in disentangling errors in $^{240}$Pu (n,el) and (n,il) nuclear data.
Response sensitivities to $^{240}$Pu nuclear data

- PMF-002-001 – Bare Sphere of $^{239}$Pu Metal ($^{240}$Pu Jezebel)
- PST-018-001 – Water-reflected 24-inch Diameter Cylinder of Plutonium (42.9% $^{240}$Pu) Nitrate Solution
- FNPHM-002-007 – Tungsten-reflected Plutonium-metal-sphere Subcritical Measurements
Conclusions and future work

• Importance of nuclear data to bias changed significantly when including diverse measurement sets
  - LLNL pulsed sphere measurements provided information for $^9$Be nuclear data above 2 MeV
  - Subcritical benchmarks provided information for $^{240}$Pu nuclear data between 100 keV and 10 MeV

• Pulsed sphere leakage spectra and neutron noise observables are differently sensitive to nuclear data compared to critical benchmarks
  - Leakage spectra are sensitive to nuclear data above 5 MeV
  - Count rate and Feynman Y are more sensitive to nuclear data

• Change in bias can help evaluators identify discrepant nuclear data

• EUCLID plans to perform RAFIEKI analysis with additional benchmark and measurement sets\(^1,2\)
  - **Benchmarks**
    - Critical
    - Subcritical
  - **Measurements**
    - LLNL pulsed sphere
    - Beta-effective
    - Reactivity coefficient
    - Reaction rate ratio
    - Neutron leakage spectrum
    - Rossi-alpha

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2. W. Haeck et al., "Calculating the impact of nuclear data changes with Crater", Trans. of ANS (Nov. 2020)
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