Nuclear Data Adjustment and Impact on Applications

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Introduction to Nuclear Data Adjustment

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What is adjustment?

- Adjustment refers to the inclusion of integral data in a differential evaluation.
- Adjustment requires prior knowledge of the differential evaluation, and realistic nuclear data for all materials the integral system is sensitive to.
- Integral data often has smaller uncertainties than differential data, so adjustment can reduce uncertainties in an application specific way.
The adjustment process

- Differential Data
- Nuclear Theory
- Integral Data
- Integral Sensitivities

General Purpose Library

Integral Validation

Adjustment

Adjustment Tools

Application Specific Library
Simplest example of integral data

- There are many differential fission measurements with systematic uncertainty of 1-2%.
- Integral measurements with $^{252}$Cf(sf) neutrons require shape information, but also have uncertainties of 1%.
- There is a 2.4% discrepancy between ENDF and these $^{252}$Cf(sf) neutron measurements, so adjustment may have a large impact on actinide nuclear data.
A more complex example of integral data

- Critical assembly fission ratio measurements are sensitive to fission cross sections and the assembly neutron spectrum.
- Criticality data is considered here along with fission ratios to ensure PFNS and scattering properties that are consistent with the critical assembly.
- The variety of fission cross section thresholds available also constrain the neutron spectrum.
  - One concern about these measurements is the need for modeling corrections due to the presence of the fission chamber.
  - Otherwise, the measurements were quick, which allowed for multiple fission chambers and foil thicknesses.
The ENDF/B-VIII.0 Spectral Indices Validation Data


<table>
<thead>
<tr>
<th>Assembly</th>
<th>Quantity</th>
<th>$U_{238}/U_{235}$</th>
<th>$Np_{237}/U_{235}$</th>
<th>$U_{233}/U_{235}$</th>
<th>$Pu_{239}/U_{235}$</th>
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<tr>
<td>Godiva</td>
<td>Calc</td>
<td>0.1583</td>
<td>0.8318</td>
<td>1.5793</td>
<td>1.3846</td>
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<td>Exp-B</td>
<td>0.1643 ± 0.0018</td>
<td>0.8516 ± 0.012</td>
<td>1.4152 ± 0.014</td>
<td>1.4020 ± 0.025</td>
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<td>Exp-A</td>
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<td>Jezebel</td>
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<td>1.4273</td>
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<td>Exp-B</td>
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<td>Exp</td>
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<td>1.198 ± 0.028</td>
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<td>C/E=0.9920</td>
<td>C/E=0.9920</td>
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</table>

- Assembly letters indicate main actinide.
- For many assemblies, reaction rates systematically low by ~2%; all are ratios to $^{235}$U(n,f).
- Some relevant fission ratios claim 1% uncertainty.

What can you do when validation data fails to validate? Adjust!
Adjustment with many integral data

- Adjustment includes $k_{eff}$ and reaction rates, so resulting evaluation consistent with both.

- This set of integral data from the ENDF spectral indices table has enough statistical significance to cause substantial changes in differential evaluation.
Impact on major actinide nuclear data

- Adjustment indicates a change in the $^{235}$U(n,f) cross section.
- Adjusted fission and inelastic scattering uncertainties are reduced, resulting from combination of fission data, spectral sensitivity, and criticality data.
- Impact not sensitive to $k_{eff}$ uncertainty; just as significant when all are set to 0.3%.
Who would be impacted by adjustment?

Several programs rely on actinide and other nuclear data:

- Nuclear Energy
- Criticality Safety
- Stockpile Stewardship
- Nuclear Forensics
- Incident Response
- Nuclear Threat Reduction
Correlations between isotopes

Reaction order from lower left to upper right:
- (n,tot)
- (n,el)
- (n,n’)
- (n,2n)
- (n,3n)
- (n,f)
- (n,g)
- nubar
- pfns

Adjusting with several integral data requires tracking correlations between all materials.
Adjustment with pulsed spheres

- Pulsed sphere nToF spectra are very sensitive to inelastic and prompt fission neutron spectra.
- Due to 14 MeV source, fission-relevant nuclear data only impacted if critical assembly constraint included.
- As shown below, result is very sensitive to efficiency and uncertainty assumptions.
Takeaways About Adjustment

- Adjustment is a useful tool for adding integral data to a differential evaluation.

- The small uncertainties of many integral experiments make it extremely impactful when it can be used.

- Adjustment relies on realistic uncertainties for all relevant materials.

- It provides a method for dealing with problems found in validation data.

- There is a diverse set of historical integral data that could impact many programs but would require a careful understanding of uncertainties.
Adjustment method

- There are several methods for adjustment, but we have used a hybrid of Monte Carlo sampling and sensitivity analysis for the regression (GLS).
  - Covariance matrices generated from ENDF/B-VIII.0 using NJOY.
  - Monte Carlo sample phases are decorrelated, which requires covariance rank + 1 samples.
  - Variations include PFNS covariance, but not elastic angular or inelastic spectral covariances.

- Assembly and foil nuclear data varied together, to account for uncertainty in assembly neutron spectrum.

![Godiva spectrum confidence bands](image1)

![Change in Godiva spectrum](image2)

Results from change in $^{235}$U(n,n')