JEFF-3.3 covariance application to ICSBEP using SANDY and NDaST

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Outline

- Comparison of two state-of-the-art tools for nuclear data uncertainty propagation
  - NDaST
  - SANDY
- JEFF-3.3 covariance propagation
- Comparison of results for ICSBEP criticality benchmarks
  - Effect of angular distribution covariance data
  - Effect of energy distribution covariance data
NDaST

- Java-based software
- NEA sensitivity tool
- Linear perturbation theory
- User friendly GUI

\[ COV_{k_{eff}} = S \ COV_{ND} \ S^T \]

SANDY

- Python3 package
- Sampling of nuclear data
- Whole phase-space of the problem
- Production of *perturbed* files for brute force uncertainty propagation

\[
x_1^{(1)}, x_2^{(1)}, \ldots, x_3^{(1)} \rightarrow f(x_1^{(1)}, x_2^{(1)}, \ldots, x_3^{(1)}) \rightarrow y^{(1)}
\]
\[
x_1^{(2)}, x_2^{(2)}, \ldots, x_3^{(2)} \rightarrow f(x_1^{(2)}, x_2^{(2)}, \ldots, x_3^{(2)}) \rightarrow y^{(2)}
\]
\[
x_1^{(N)}, x_2^{(N)}, \ldots, x_3^{(N)} \rightarrow f(x_1^{(N)}, x_2^{(N)}, \ldots, x_3^{(N)}) \rightarrow y^{(N)}
\]

\[ COV_y \]
Sensitivities from DICE

\[ COV_{keff} = S COV_{ND} S^T \]
Covariances from JANIS

\[ COV_{\text{keff}} = S \text{COV}_{\text{ND}} S^T \]
NDaST

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- NEA sensitivity tool
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\[ COV_{keff} = S \ COV_{ND} \ S^T \]

SANDY

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\[
\begin{align*}
    x_1^{(1)}, x_2^{(1)}, \ldots, x_3^{(1)} &\rightarrow f(x_1^{(1)}, x_2^{(1)}, \ldots, x_3^{(1)}) &\rightarrow y^{(1)} \\
    x_1^{(2)}, x_2^{(2)}, \ldots, x_3^{(2)} &\rightarrow f(x_1^{(2)}, x_2^{(2)}, \ldots, x_3^{(2)}) &\rightarrow y^{(2)} \\
    x_1^{(N)}, x_2^{(N)}, \ldots, x_3^{(N)} &\rightarrow f(x_1^{(N)}, x_2^{(N)}, \ldots, x_3^{(N)}) &\rightarrow y^{(N)}
\end{align*}
\]

\[ COV_y \]
Why SANDY?

- It samples from the covariances in the file
- It can perturb all nuclear data for which covariances are given
- It can be used with any code (provided that you can process the perturbed files)
- It is open-source
Sampling method

Extract covariances from ENDF-6 evaluated file

Multivariate normal distribution

$M$ variables
Sampling method

Draw $N$ sets of perturbations

$\begin{pmatrix} p_1 & p_2 & \ldots & p_M \end{pmatrix}^{(1)}$

$\begin{pmatrix} p_1 & p_2 & \ldots & p_M \end{pmatrix}^{(2)}$

$\vdots$

$\begin{pmatrix} p_1 & p_2 & \ldots & p_M \end{pmatrix}^{(N)}$
Apply perturbations to original data

\[(p_1, p_2, \ldots, p_M)^{(1)}\]

- xs
- nubar
- PFNS
- ang. distr.
- ...

perturbed file
Apply perturbations to original data

\[(p_1 \quad p_2 \quad \ldots \quad p_M)^{(1)}\]
\[(p_1 \quad p_2 \quad \ldots \quad p_M)^{(2)}\]
\[(p_1 \quad p_2 \quad \ldots \quad p_M)^{(N)}\]
Multigroup perturbations
Comparison NDaST / SANDY

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<thead>
<tr>
<th>Covariance type</th>
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<th>JEFF-3.2</th>
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- **Mosteller’s suite**
  - Jezebel
  - Plutonium benchmarks
  - PMF6
Jezebel

- Comparison NDaST / SANDY for Pu239
- No covariances for angular distributions

![Graph showing comparison between NDaST and SANDY]

- Total
-XS
-Nubar
-Chi

1000 samples

Uncertainty (pcm)
Comparison NDaST / SANDY

Discrepancy for PFNS

1000 samples
Covariances for PFNS are given in blocks for few incident energy ranges
Covariances for PFNS are given in blocks for few incident energy ranges.
Energy distributions

- Covariances for PFNS are given in blocks for few incident energy ranges
NDaST results can be reproduced by SANDY sampling from only one covariance matrix.

The chart shows the uncertainty in pcm for different categories:
- **Total**
- **xs**
- **nubar**
- **chi**

Each bar compares NDaST and SANDY results, with 1000 samples indicated.
PU-MET-FAST (uncertainties)
### PU-MET-FAST (correlations)

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PU-MET-FAST (correlations)

U238 reflector
U238-reflected Pu sphere

Sensitivity PMF6

sensitivity to P1 elastic

stdev SANDY = 2056 ± 555 pcm
stdev NDaST = 1382 pcm
$E_n = 1.8\ MeV$
\[ E_n = 1.8 \text{ MeV} \]
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\[ E_n = 1.8 \text{ MeV} \]
NDaST results can be reproduced by SANDY sampling from only P1

\[ E_n = 1.8 \text{ MeV} \]
Sensitivity to P1-P2 coefficients

- 10% std dev over all neutron energies
- Strong non-linearity (mean shift, non-Normal PDF)
- Null-hypothesis of Normal distribution is rejected
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Conclusions

- JEFF-3.3 covariances were processed and included into JANIS
- 300 perturbed suites were created for JEFF-3.3 in ACE format (293.6 K) for criticality studies
- SANDY validates NDAST results for PMF
- Energy distribution covariances should be weighed on the fission rate
- Covariances for P>1 can be significant for systems such as PMF6
- The format for angular distribution covariances should be addressed to avoid non-physical correlations