USE OF FISSION PRODUCT EXPERIMENTS FOR BURNUP CREDIT VALIDATION

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Outline

• French Fission Product (FP) Experimental Program

• Modification to the adjustment technique to establish bias and bias uncertainty due to FPs

• FP credit validation for application systems of the present and future fuel cycle

• Summary
French FP Experimental Program

Series of 145 critical experiments referred to as the FP Experimental Program was performed in the Valduc facility (CEA, France) in 1998-2004 [Ref.] with Cs-133, Sm-149, Sm-152, Gd-155, Ph-103, and Nd-143 in solutions.


**a)** “Physical”   **b)** “Elementary Dissolution”   **c)** “Global Dissolution”
Sensitivity Comparison: an Example

$k_{eff}$ sensitivity* to FP are significantly smaller than sensitivities for major actinides and moderator materials

*Sensitivity coefficients calculated by TSUNAMI-3D code/ 44-group ENDF/B-V based library
## Analysis of the FP Experiments: an Example (1/3)

### Some Physical Type Configurations

<table>
<thead>
<tr>
<th>Exp.</th>
<th>No.</th>
<th>FP</th>
<th>C(FP) g/l</th>
<th>r (g/cm³)</th>
<th>H⁺ (N)</th>
<th>Array</th>
<th>Number of rods</th>
<th>Number of rods removed</th>
<th>°C</th>
<th>Hc (mm)</th>
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<tbody>
<tr>
<td>2834</td>
<td>2</td>
<td>¹⁰³Rh</td>
<td>40</td>
<td>1.0916</td>
<td>0.97</td>
<td>25x25-25</td>
<td>600</td>
<td>0</td>
<td>19.9</td>
<td>600</td>
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<td>3</td>
<td>¹⁰³Rh</td>
<td>20</td>
<td>1.0454</td>
<td>0.49</td>
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<td>1.1383</td>
<td>0.014</td>
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<td>0</td>
<td>20</td>
<td>540</td>
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<td>530</td>
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<td>Ndnat</td>
<td>120</td>
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<td>0</td>
<td>19</td>
<td>540</td>
</tr>
<tr>
<td>2823</td>
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<td>¹⁵²Sm</td>
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<td>1.088</td>
<td>0.011</td>
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<td>0</td>
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<td>600</td>
<td>0</td>
<td>19.4</td>
<td>460</td>
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</tbody>
</table>
Some $k_{eff}$ sensitivity profiles for configuration #2809 with $^{133}$Cs
Some $k_{\text{eff}}$ difference sensitivity for configurations with (#2809) and without (#2803) $^{133}$Cs.
Basic Equations for the “Adjustment” Method

\[ S^2 = P^t W^{-1} P + (\Delta k - HP)^t U^{-1} (\Delta k - HP) \]

\[ P = (W^{-1} + H^t U^{-1} H)^{-1} H^t U^{-1} \Delta k \]

\[ W' = (W^{-1} + H^t U^{-1} H)^{-1} \]

Bias for Application System = DP
Bias Uncertainty for Application System = DW'D^t

W - ND covariances
U - Experimental uncertainty correlation
H - \( k_{\text{eff}} \) Sensitivities for experiments
D - \( k_{\text{eff}} \) Sensitivities for application systems
P - vector of corrections to cross sections
\( \Delta K = k_c - k_e \)
Modification to the "Adjustment" Method

Standard Approach

Modified Approach

W: covariance data for
U-235, U-238, H, O, FPs

$W_1$: covariance data for
U-235, U-238, H, O

$W_2$: covariance data for FP-1,
$W_3$: covariance data for FP-2...
Some ND Covariance Before/After the “Adjustment”

Before

After

U-238 Capture

Nd-143 Capture

Rh-103 Capture

44-group ND covariance data for Cs-133, Sm-149, Sm-152, Gd-155, Ph-103, Nd-143 from ENDF/B-V.rec (SCALE5.1)
**k_{eff} Bias for the FP Configurations**

![Graph showing k_{eff} bias for different FP configurations.](graph.png)
Uncertainty Assessment for Typical Application System

Simplified models of storage in accidental condition for UO$_2$ fuel with initial enrichment of 5% burned to 40 GWd/MTU and 60 GWd/MTU

The composition of the spent fuel was calculated by CESAR4 code.
Uncertainty Assessment for Future Application System

Simplified model of MOX fuel for GFR burned to ~120 GWd/MTU and flooded by water [Ref.]

The composition of the spent fuel was calculated by ORIGEN code

From Present to Future Fuel Cycle Applications

![Graph showing bias and uncertainty for various isotopes in spent fuel of GFR and LWR](image)

- Cs-133, Sm-149, Sm-152, Gd-155, Rh-103, Nd-143

- Spent Fuel of GFR
- Spent Fuel of LWR
Summary

- The methodology is proposed and tested to establish bias and bias uncertainty for FPs;

- FP validation study is performed for typical and innovative application systems;

- For the present test application the FP biases are small, as expected, and comparable with the bias uncertainties;

- The significant bias for Sm-149 is established for the innovative (FR) application system;

- The presented results show that the proposed method is useful in design and safety studies for innovative systems;

- The FP experiments provide valuable information to assess FP credit for configurations containing fuel of both the present LWR and the future FR.