# USE OF FISSION PRODUCT EXPERIMENTS FOR BURNUP CREDIT VALIDATION

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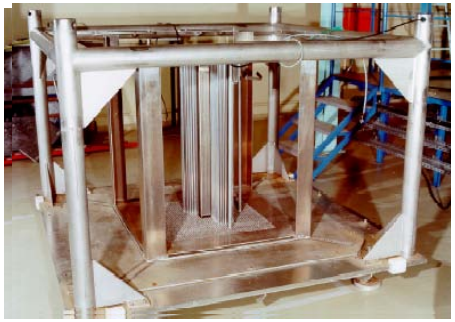
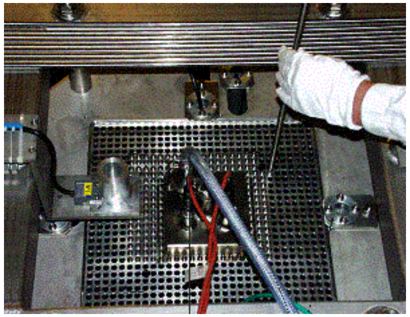
# Outline

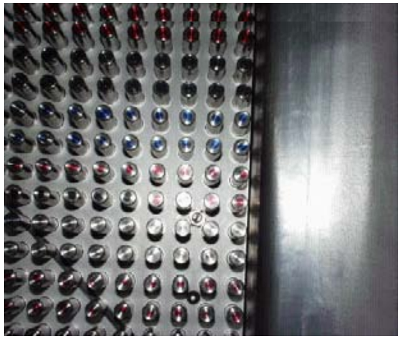
- French Fission Product (FP) Experimental Program
- Modification to the adjustment technique to establish bias and bias uncertainty due to FPs
- FP credit validation for application systems of the present and future fuel cycle
- Summary

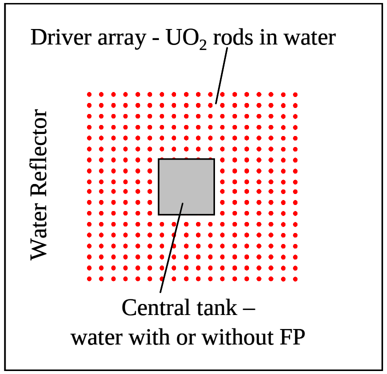
# French FP Experimental Program

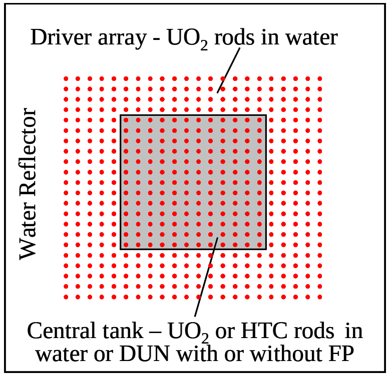
Series of 145 critical experiments referred to as the FP Experimental Program was performed in the Valduc facility (CEA, France) in 1998-2004 [Ref.] with Cs-133, Sm-149, Sm-152, Gd-155, Ph-103, and Nd-143 in solutions

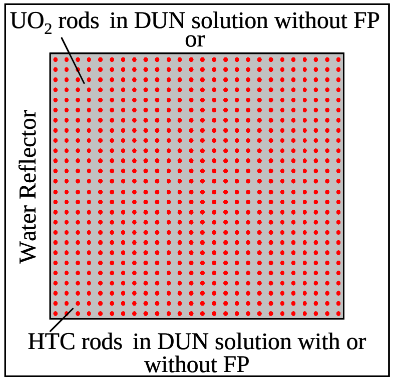








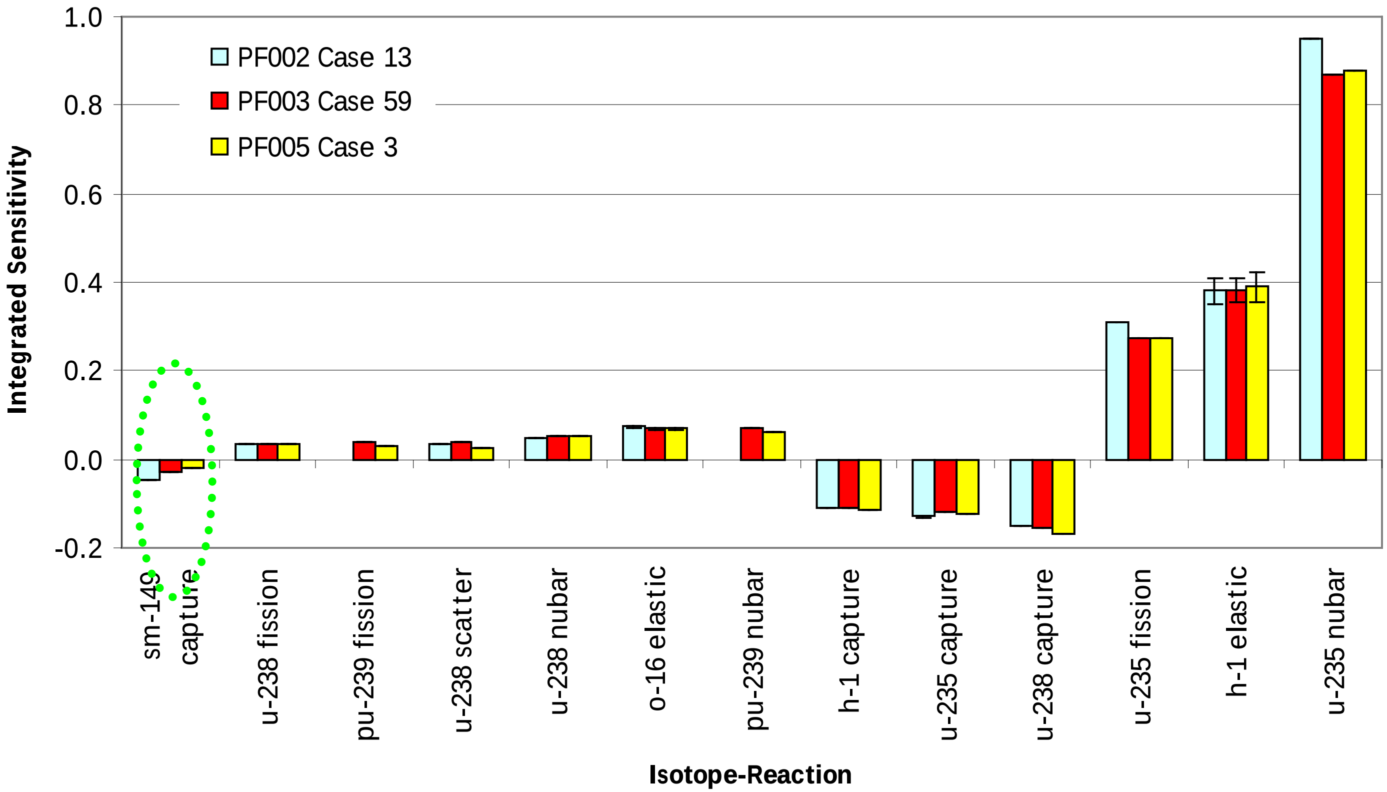




**a)** "Physical" **b)** "Elementary Dissolution" **c)** "Global Dissolution"

[Ref.] N. Leclaire et al., "Fission Products Experimental Programme: Validation and Computational Analysis", *Nucl. Sci. Eng.*, **161**, 2, pp. 188-215 (2009)

# 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

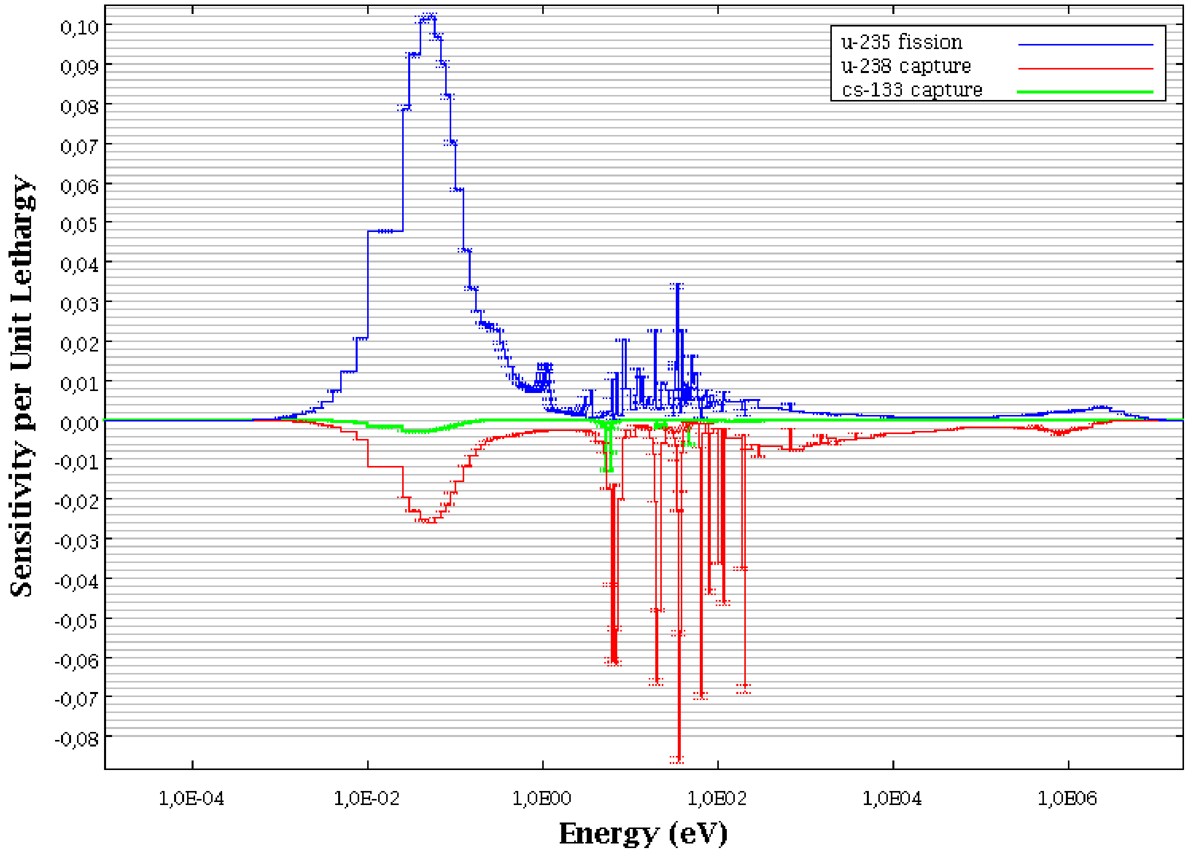
# Analysis of the FP Experiments: an Example (1/3)

## Some Physical Type Configurations

| Exp. | No. | FP | C(FP) g/l | r (g/cm$^3$) | $H^+$ (N) | Array | Number of rods | Number of rods removed | °C | Hc (mm) |
|---|---|---|---|---|---|---|---|---|---|---|
| 2834 | 2 | $^{103}$Rh | 40 | 1.0916 | 0.97 | 25x25-25 | 600 | 0 | 19.9 | 600 |
| 2835 | 3 | $^{103}$Rh | 20 | 1.0454 | 0.49 | 25x25-25 | 600 | 0 | 20.3 | 530 |
| 2811 | 8 | $^{133}$Cs | 130 | 1.1383 | 0.014 | 25x25-25 | 600 | 0 | 20 | 540 |
| 2809 | 11 | $^{133}$Cs | 80 | 1.0809 | 0.014 | 25x25-25 | 600 | 0 | 20 | 520 |
| 2812 | 13 | $^{133}$Cs | 80 | 1.1483 | 2.04 | 25x25-25 | 600 | 0 | 19.5 | 521 |
| 2817 | 14 | $^{133}$Cs | 78 | 1.1463 | 2 | 25x25-25 | 600 | 0 | 19 | 521 |
| 2821 | 16 | Ndnat | 120 | 1.2224 | 0.023 | 25x25-25 | 600 | 0 | 19 | 540 |
| 2823 | 18 | $^{152}$Sm | 50 | 1.088 | 0.011 | 25x25-25 | 600 | 0 | 19 | 700 |
| 2844 | 28 | Mixt. | | 1.0989 | 0.21 | 25x25-25 | 600 | 0 | 20 | 600 |
| 2803 | 35 | Water | | 0.9986 | 0.014 | 25x25-25 | 600 | 0 | 19.4 | 460 |
| 2813 | 37 | Water | | 0.9986 | 0.014 | 25x25-25 | 600 | 0 | 19.4 | 460 |

# Analysis of the FP Experiments: an Example (2/3)

Some $k_{eff}$ sensitivity profiles for configuration #2809 with $^{133}$Cs



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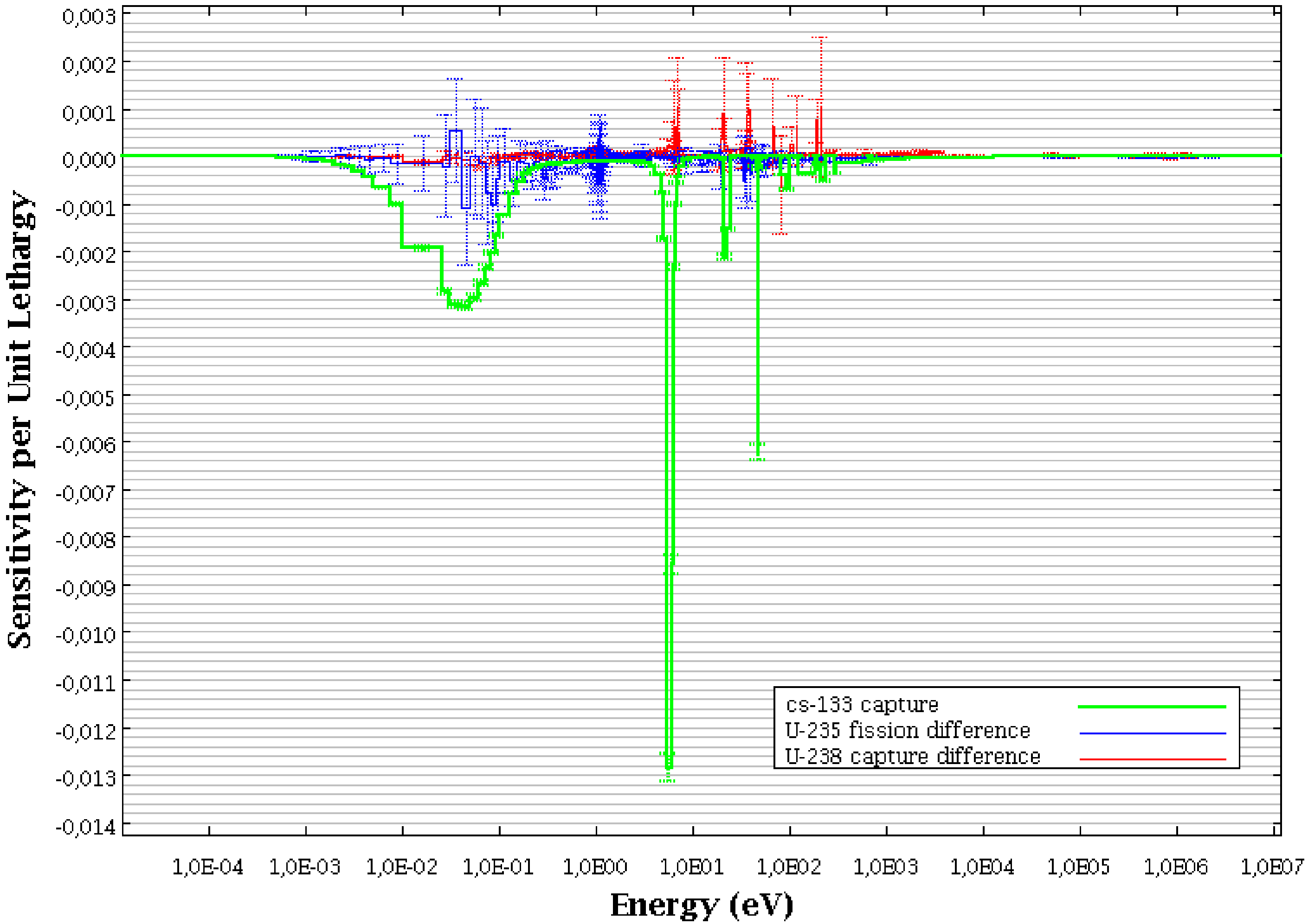
# Analysis of the FP Experiments: an Example (3/3)

*Some* $k_{eff}$ difference sensitivity for configurations with (#2809) and without (#2803) $^{133}$Cs



# Basic Equations for the "Adjustment" Method

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

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

$$W' = (W^{-1} + H^t U^{-1} H)^{-1}$$

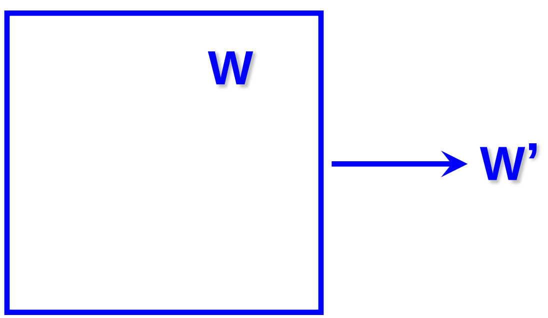
**Bias for Application System = DP**

**Bias Uncertainty for Application System = DW'D$^t$**

W – ND covariances
U – Experimental uncertainty correlation
H – $k_{eff}$ Sensitivities for experiments
D - $k_{eff}$ Sensitivities for application systems
P – vector of corrections to cross sections
$\Delta K = k_c - k_e$

# Modification to the "Adjustment" Method

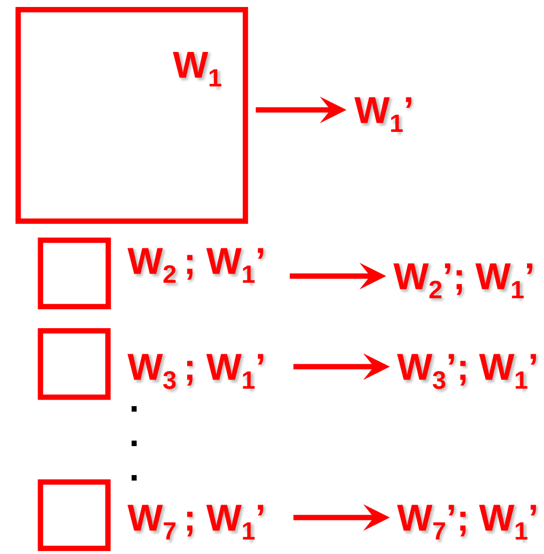
## Standard Approach




W: covariance data for

U-235, U-238, H, O, FPs

## Modified Approach




$W_1$: covariance data for

U-235, U-238, H, O

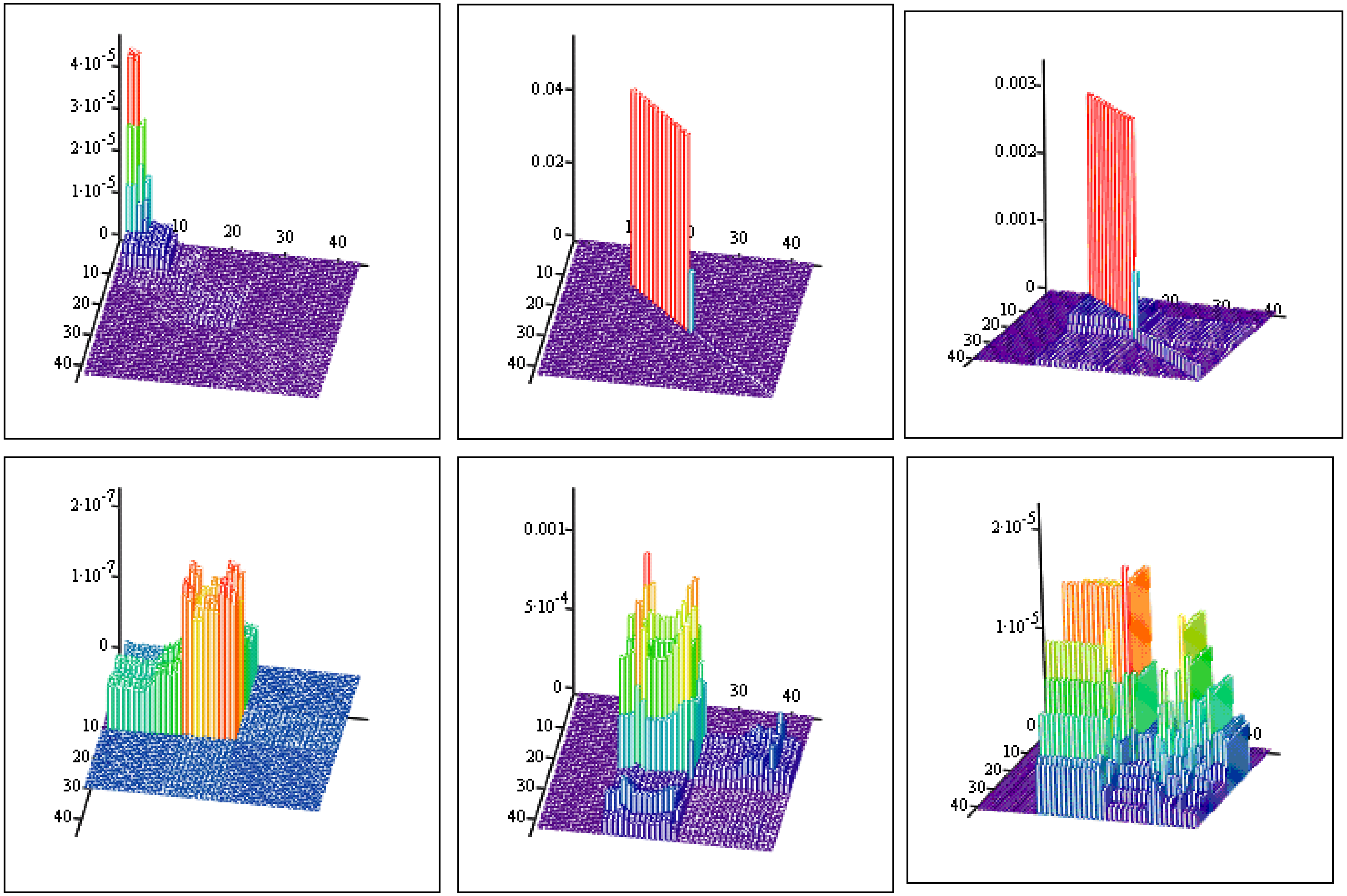
$W_2$ : covariance data for FP-1,

$W_3$: covariance data for FP-2…

# Some ND Covariance Before/After the "Adjustment"

**Before**

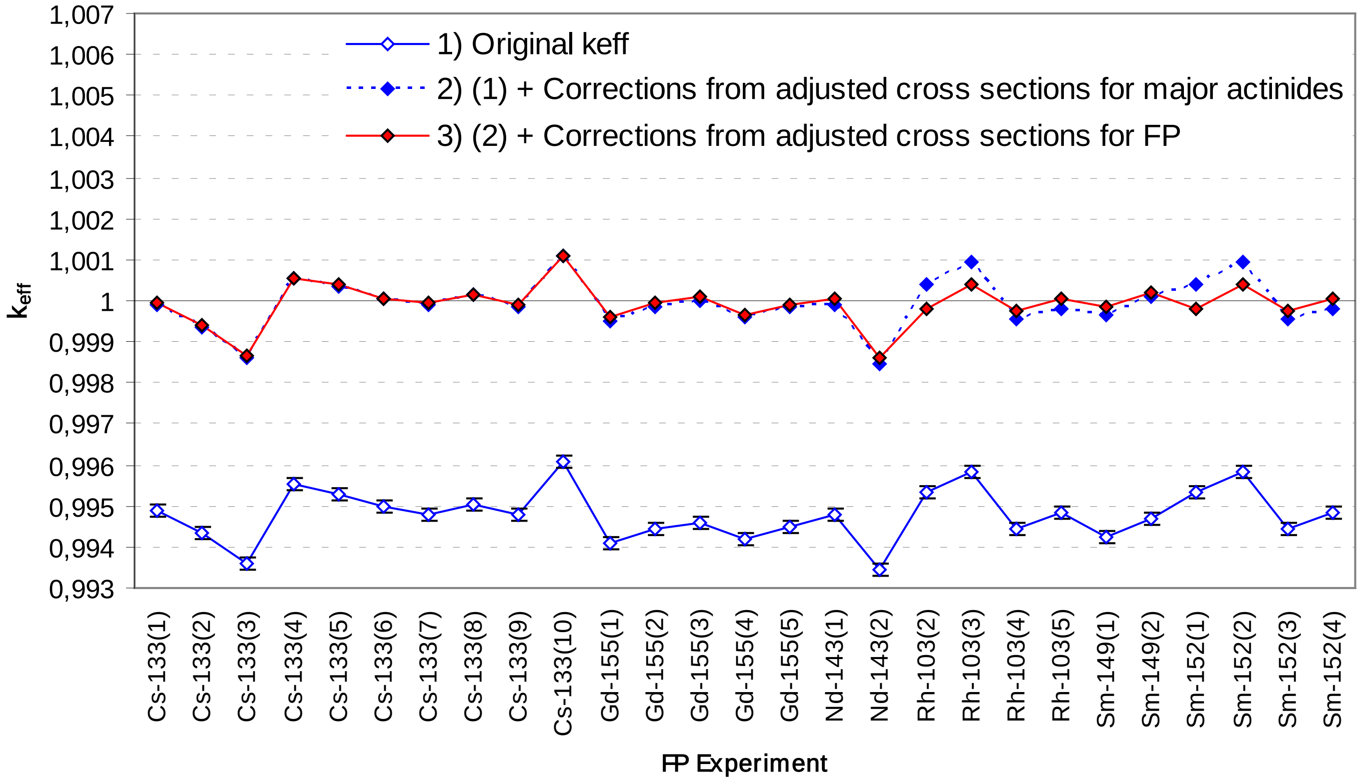
**After**




**U-238 Capture** **Nd-143 Capture** **Rh-103 Capture**

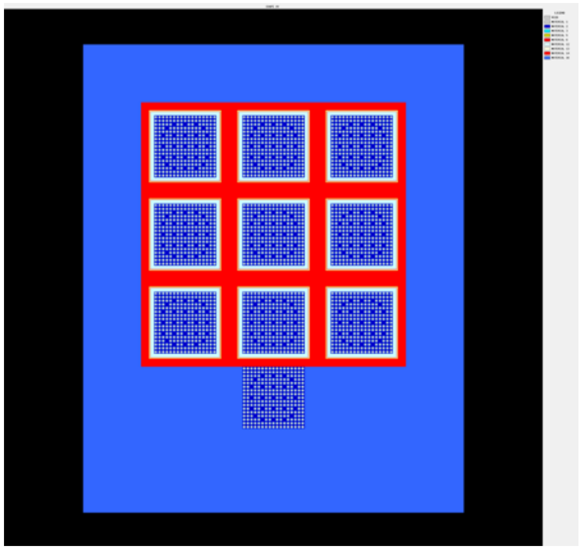
44-group ND covariance data for Cs-133, Sm-149, Sm-152, Gd-155, Ph-103, Nd-143 from ENDF/B-V.rec (SCALE5.1)

# $k_{eff}$ Bias for the FP Configurations

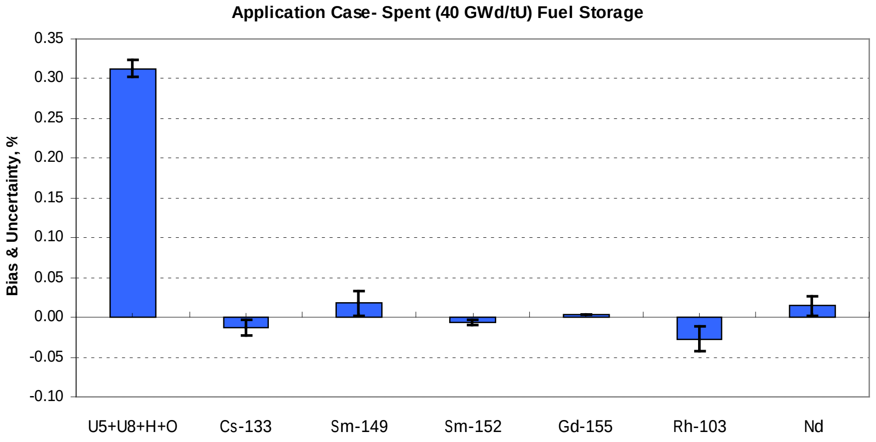


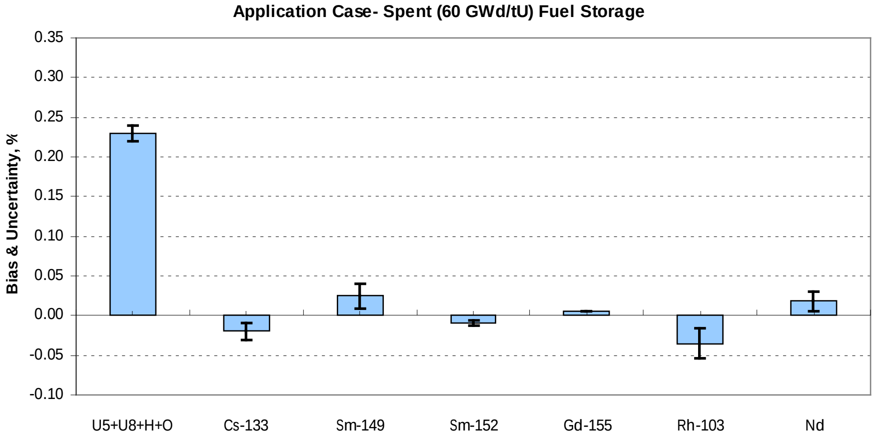
# Uncertainty Assessment for Typical Application System

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



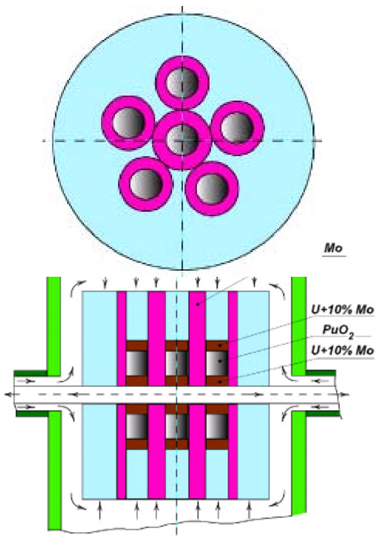
The composition of the spent fuel was calculated by CESAR4 code

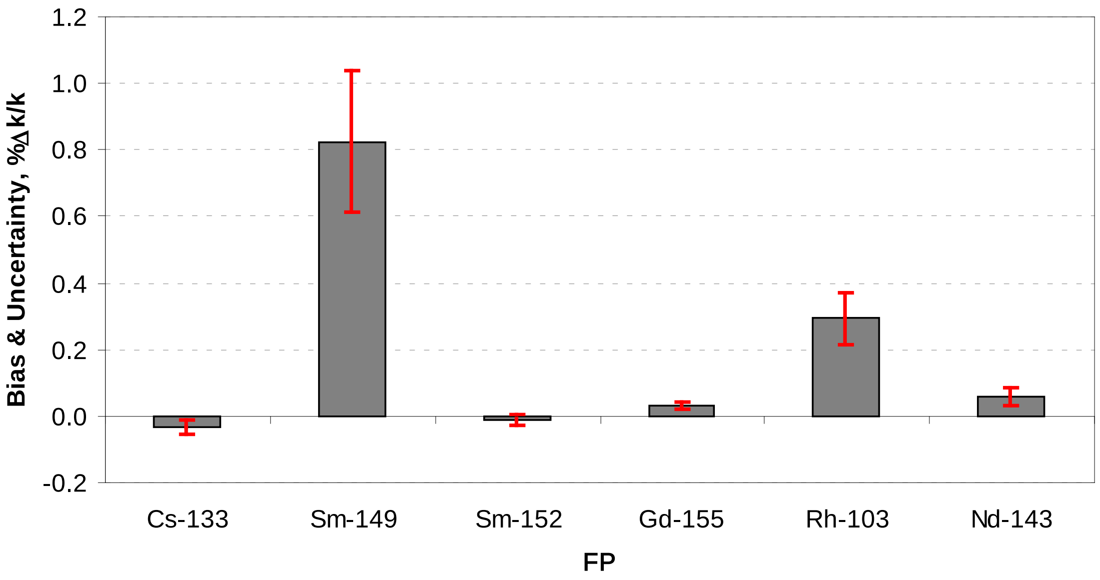


# Uncertainty Assessment for Future Application System

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

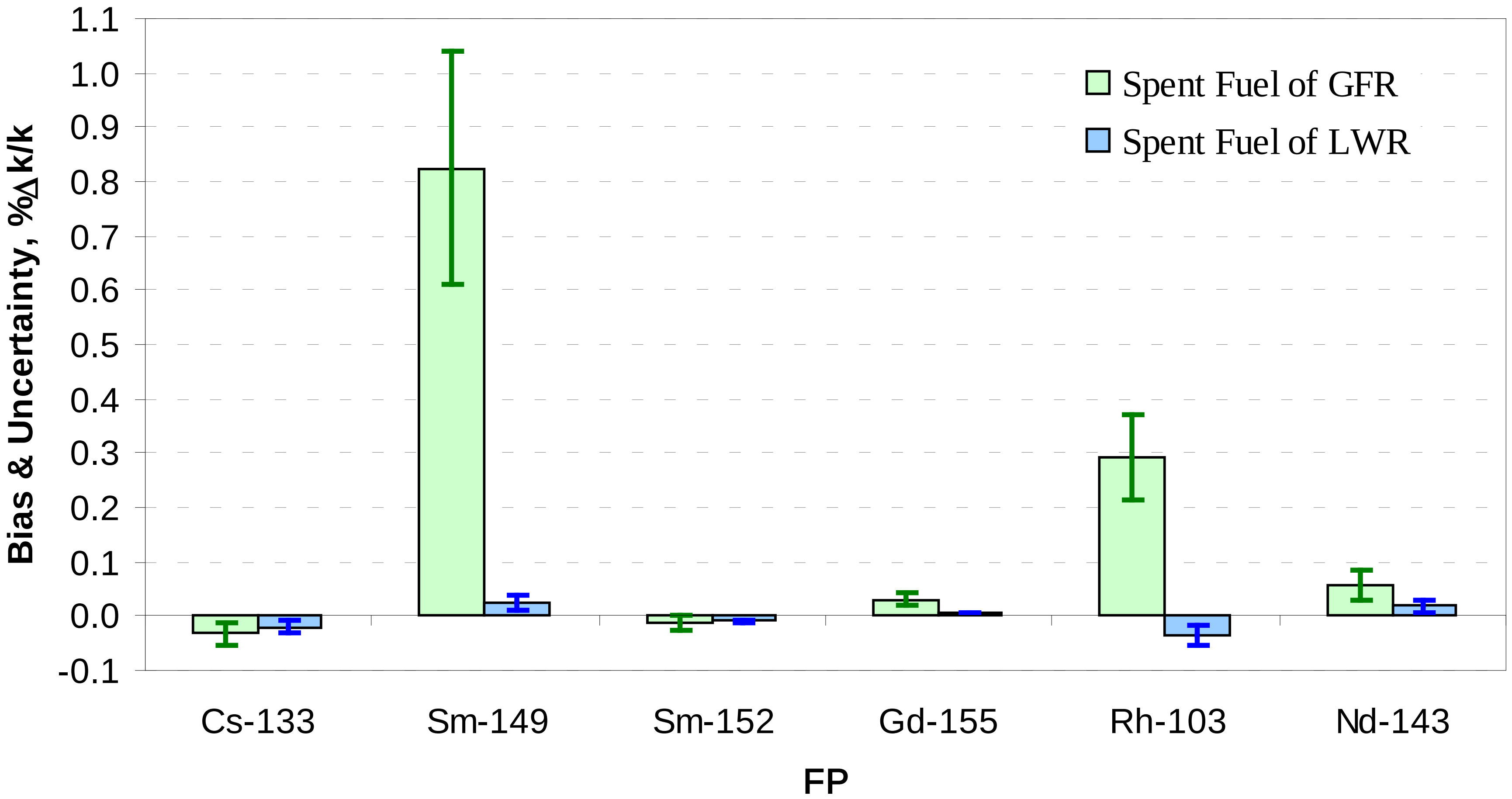



The composition of the spent fuel was calculated by ORIGEN code

[Ref.] P. N. Alekseev et al., Nuclear facility with the gas cooled fast reactor BGR-1000 using coated particles and technologies of light water reactors, Proc. of International Congress on Advances in Nuclear Power Plants (ICAPP 2007) "The Nuclear Renaissance at Work", Volume 3, pp.1657-1663 (2008)

# From Present to Future Fuel Cycle Applications



# 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.