IRSN

REPRESENTATIVITY STUDY OF THE FRENCH HTC AND FP EXPERIMENTS FOR BURNUP CREDIT APPLICATION TO THE TN® 24 E TRANSPORT/STORAGE CASK

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Looking to the future
PATRAM 2010

LOGISTICS

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Introduction

▶ **Objective**

Demonstration of the similarity between a selected set of critical experiments and a transport/storage cask containing irradiated fuel assemblies in order to support validation of the criticality code used for burnup credit calculations and associated nuclear data

▶ **Demonstration of similarity can be done by:**

◆ Comparison of global and specific spectral parameters (e.g. energy of average lethargy causing fission EALF, moderator to fuel ratio V_m/V_f, reaction rates etc.)

◆ Sensitivity /uncertainty (S/U) analysis

◆ S/U analysis can be used in order to consolidate the results obtained by the analysis of the global spectral parameters and reaction rates
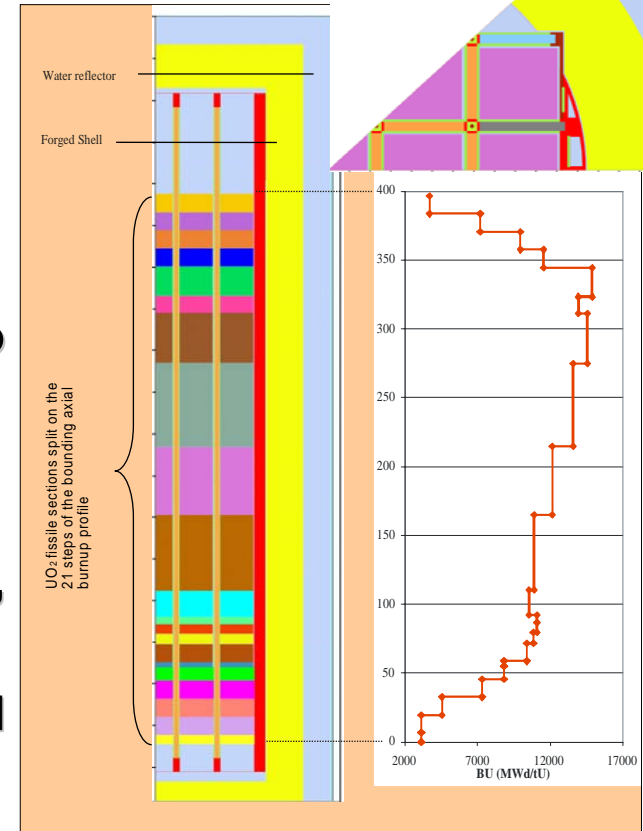
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Cask model and BUC calculations

▶ ## Cask model TN® 24 E:

- ◆ **Transport/storage cask loaded with 21 PWR UO$_2$ spent fuel assemblies**

- ◆ **18 different axial burnup zones**

- ◆ **Minimum average burnup of 12 GWd/t$_U$**

- ◆ **Cooling time of 2 years**

- ◆ **Cask filled with water**

- ◆ **Fuel assemblies separated by two borated aluminium plates**

▶ ## BUC calculations:

- ◆ **9 Actinides:** ^{235}U, ^{236}U, ^{238}U, ^{238}Pu, ^{239}Pu, ^{240}Pu, ^{241}Pu, ^{242}Pu and ^{241}Am

- ◆ **6 FP:** ^{103}Rh, ^{133}Cs, ^{143}Nd, ^{149}Sm, ^{152}Sm and ^{155}Gd

Water reflector

Forged Shell

UO₂ fissile sections split on the 21 steps of the bounding axial burnup profile

BU (MWd/tU)

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French experiments description

✓__One array__

Critical parameter: array dimension and water height

HTC Rod lattice

HTC001/ HTC002

18 exp./41exp.

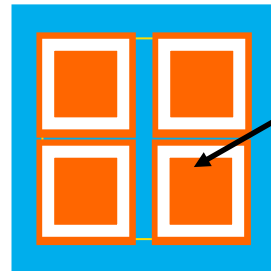HTC rods cluster
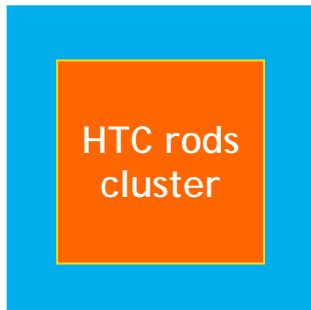
pitch varying between 1.3 and 2.3 cm

✓__4 assemblies in water (pitch 1.6 cm)__

Critical parameter: assembly dimension, distance between assemblies and water height
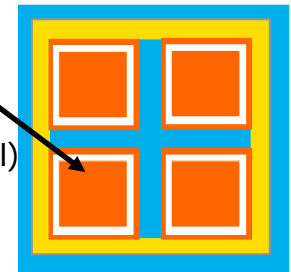
Pool storage

HTC003

26 exp.

Transport

HTC004 / HTC005

71 exp. / 49 exp.

Assemblies with canisters
(borated steel, Cd or boral)

Lead reflector or steel reflector
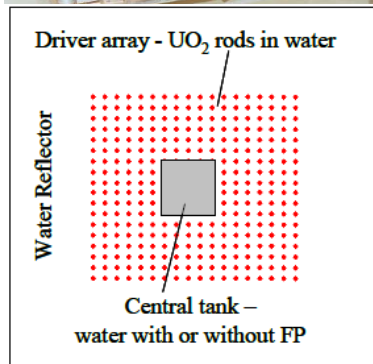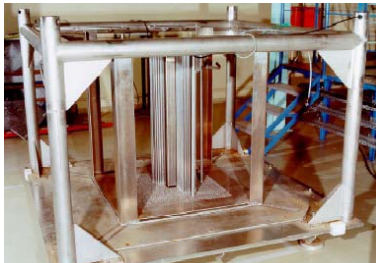
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<u>Objectives</u> : **Validation of FP cross sections**

Six FP stable, non volatile dissolved in slightly acidic solution:

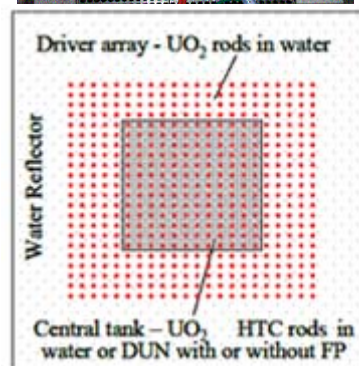⇨ ^{103}**Rh,** ^{133}**Cs,** ^{143}**Nd,** ^{149}**Sm,** ^{152}**Sm and** ^{155}**Gd**

<u>148 experiments</u> performed in Valduc from 1998 to 2004

(Common Interest Program IRSN/COGEMA under disclosure agreement)

Driver array - UO$_2$ rods in water
Water Reflector
Central tank – water with or without FP

Physical *(45 exp.)*

Driver array - UO$_2$ rods in water
Water Reflector
Central tank – UO$_2$ HTC rods in water or DUN with or without FP
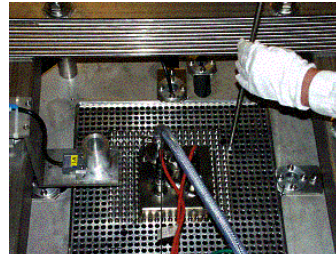
Elementary Dissolution *(89 exp.)*

UO$_2$ rods in DUN solution without FP or
Water Reflector
HTC rods in DUN solution with or without FP
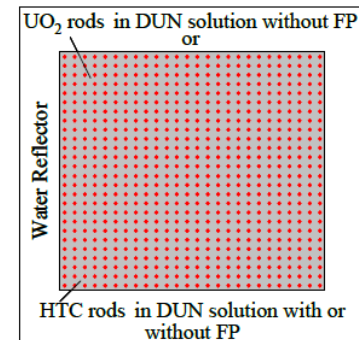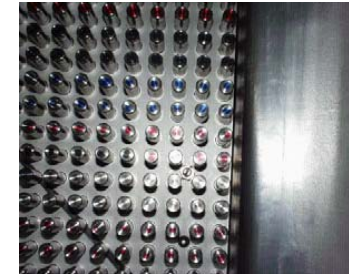
Global Dissolution *(14 exp.)*

LOGISTICS

Similarity study

▶ **Selection of adequate cases of HTC and FP experiments**

 ◆ **Useless experiments discarded:**

  • *Experiments with gadolinium in water*
  • *Experiments with cadmium as absorber material*

111 cases from HTC and FP experiments selected for the validation of the criticality code

▶ **Similarity of the selected integral experiments and the cask application is analysed using the following criteria:**

 ◆ **Global parameters: main neutron spectrum indicators for the TN® 24 E cask and experiments**

 ◆ **Specific parameters: isotopic reaction rates for relevant isotopes in energy groups and media**

Similarity study

▶ **Main global spectral parameter comparison**

TN® 24 E	Lattice type	Pu/(U+Pu)	EALF	V_m/V_f
UOX PWR 18×18 (av. BU 12 GWd/t_{HM})	Nominal	0.54	0.35	2.034
Experiment	**Number of selected cases**	**Pu/(U+Pu)**	**EALF**	**V_m/V_f**
MCT-HTC001	18	1.104	0.07 – 0.26	1.98 – 4.41
MCT-HTC003	6	1.104	0.14 – 0.15	3.74
MCT-HTC004	29	1.104	0.13 – 0.16	3.74
MCT-HTC005	7	1.104	0.23	3.74
LCT-PF002	28	0	0.23 – 0.25	2.01
MCT-PF003	14	0.183	0.23 – 0.24	2.01/1.83
MCT-PF005	5	0.183	0.23 – 0.24	2.01/1.83
MCT-PF007	4	1.104	0.14	3.74

The global spectral parameter values of the selected experiments cover the TN® 24 E cask configuration or are near to the application (EALF)

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Similarity study

▶ **Isotopic reaction rates**

◆ **Comparison of fission and capture rates** was performed for the main isotopes in the fissile media
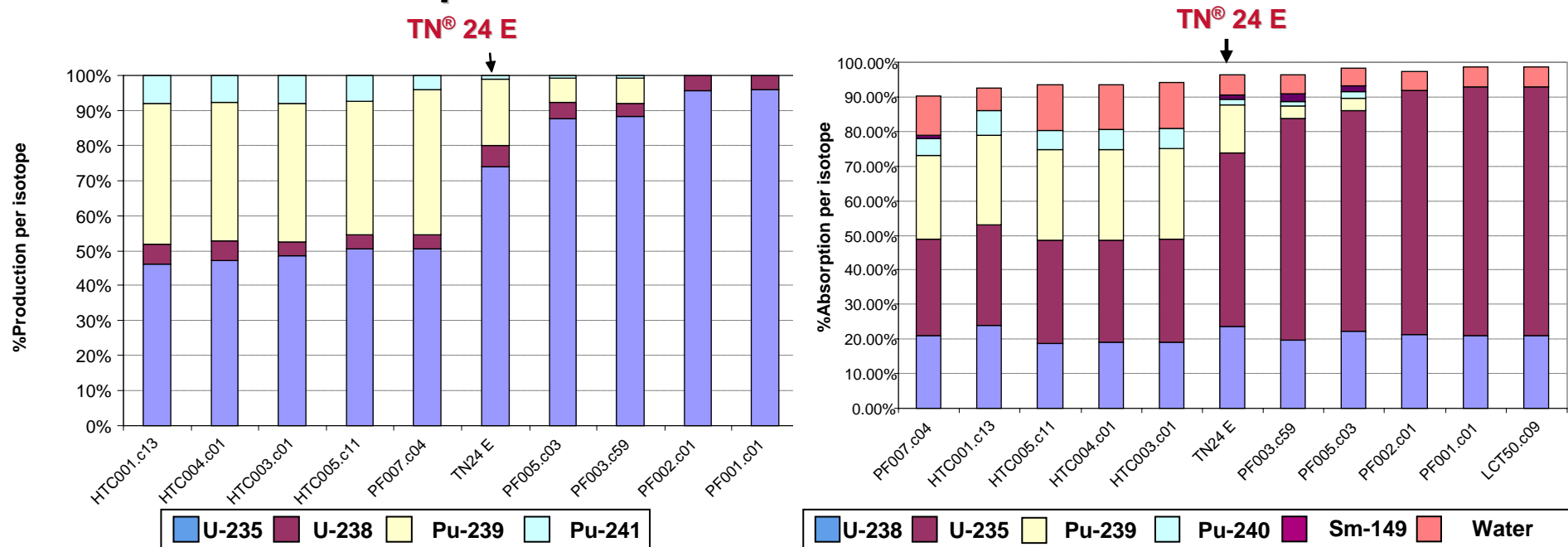
**TN® 24 E cask configuration between
MCT-PF003, -PF005, -PF007,
and MCT-HTC001, -HTC003, -HTC004, -HTC005**

Similarity study

▶ **S/U Analysis**

◆ **Calculations for experiments and TN® 24 E performed with :**

> **KENO Va under SCALE 5.1 – 238 group ENDF/B-V library**
> ↳ **TSUNAMI–3D to compute sensitivities (S/U)**
> ↳ **TSUNAMI-IP to compute correlations (c_k)**
> ↳ **Covariance data: 44groupv5rec**

◆ **Methodology of S/U analysis :**

- *Checking sensitivity coefficients of integral values* with two KENO-V.a direct perturbations calculations for actinides and main FPs
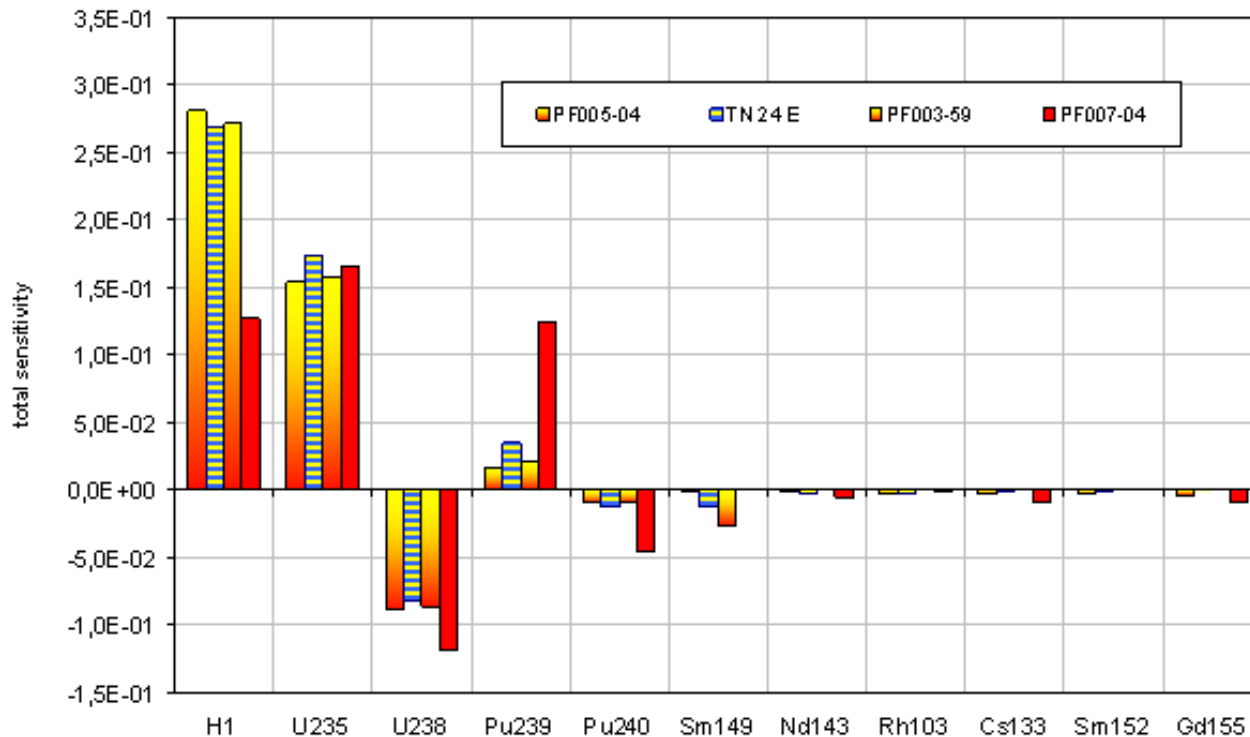
$$S_{k,\alpha} = \frac{\alpha}{k} \times \frac{k_{\alpha^+} - k_{\alpha^-}}{\alpha^+ - \alpha^-},$$

- *Optimization of direct and adjoint flux parameters* (msh)

- *Comparison of sensitivity profiles* for major actinides and FPs (integral value, shape and magnitude)

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Similarity study

▶ **S/U Analysis**

◆ *Integrated total sensitivity by isotope for some FP experiments and the TN® 24 E*
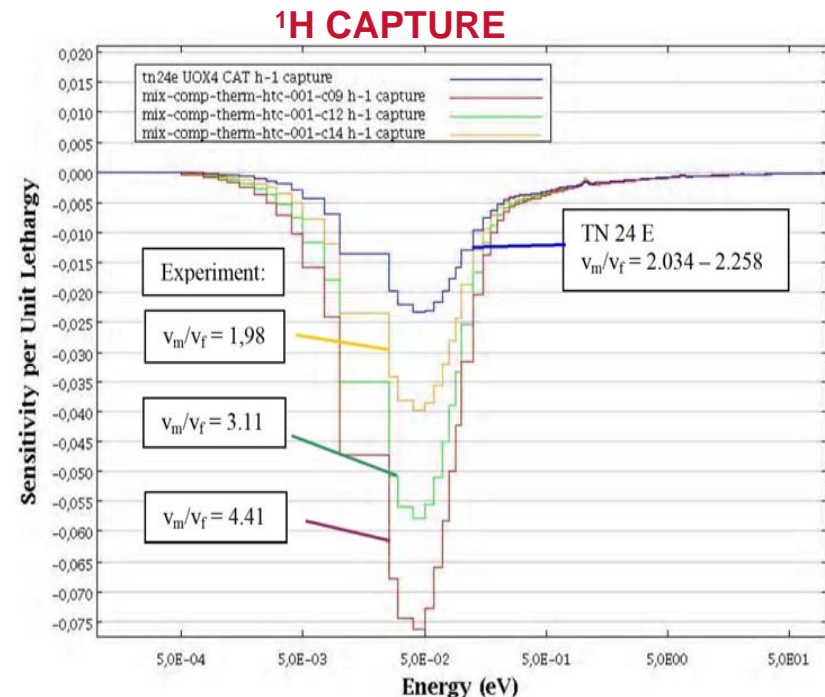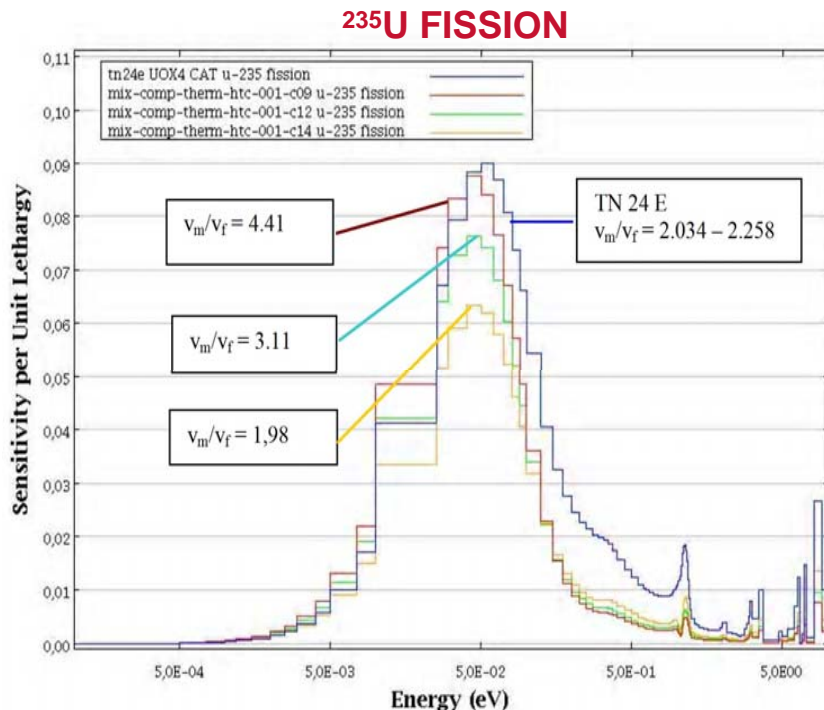

Sensitivities to FPs are a magnitude smaller than sensitivities to major actinides and hydrogen

Similarity study

▶ **S/U Analysis**

   ◆ *Comparison of* ^{235}U fission *and* ^{1}H capture *sensitivity profiles TN$^®$24 E vs*

   MCT-HTC001 cases experiments :

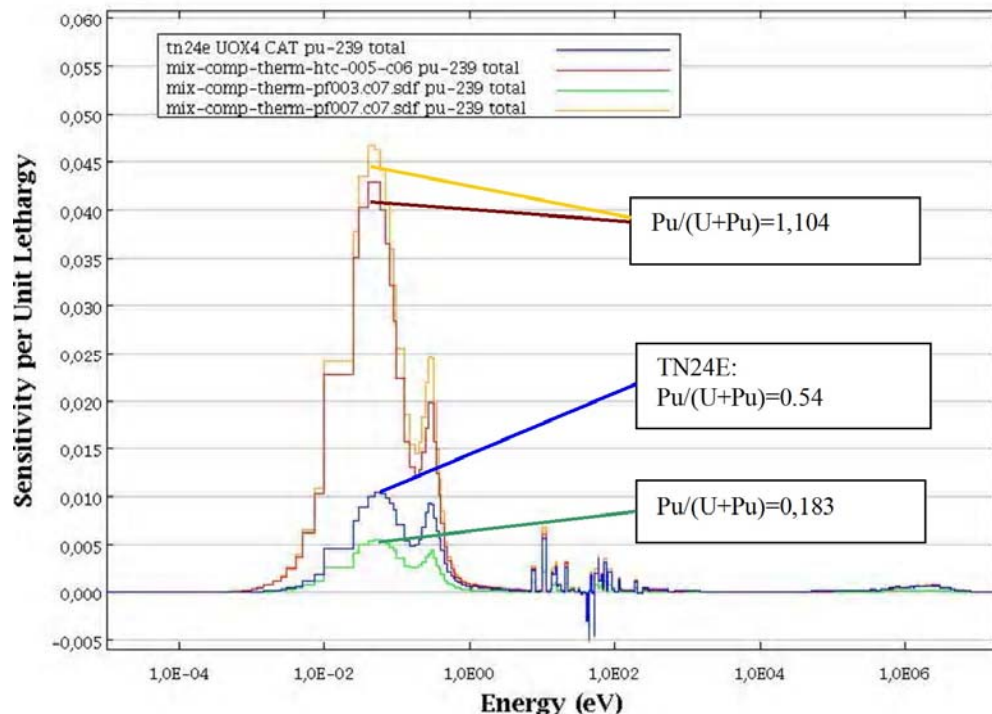**^{235}U FISSION** **^{1}H CAPTURE**

Sensitivity profiles for TN$^®$ 24 E and selected cases of the HTC001 cases match very well (same sensitivity and similar profile shape)

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Similarity study

▶ **S/U Analysis**

◆ *Comparison of ^{239}Pu fission sensitivity profiles TN$^®$ 24 E vs experiments with different Pu content (MCT-HTC 005, MCT- PF003 and MCT-PF007)*
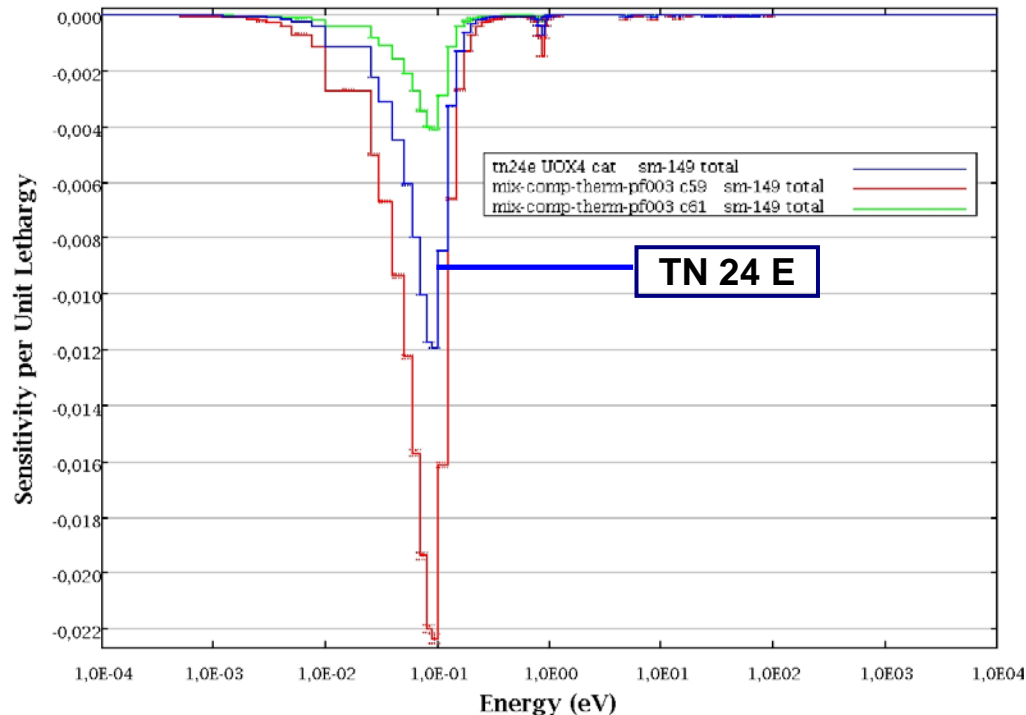

- **Similar shape between experiments and TN$^®$ 24 E**
- **FP experiments and TN$^®$ 24 E have same sensitivity to ^{239}Pu (fission)**

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Similarity study

▶ **S/U Analysis**

◆ *Comparison of ^{149}Sm sensitivity profiles TN® 24 E vs FPs experiments :*

Similar shapes of the sensitivity profiles but magnitude depends on the concentrations of the fission products in the FP experimental configurations

Similarity study

▶ **Correlation Experiments vs TN® 24 E**

Series	Case	c_k value
TN® 24 E	Nominal lattice	1.0000±0.0006
MCT-HTC-001	Case 12	0.8639±0.0029
	Case 14	0.8891±0.0029
MCT-HTC003	Case 4	0.8676±0.0018
MCT-HTC004	Case 4	0.8716±0.0019
MCT-HTC005	Case 11	0.8622±0.0030
MCT-PF003	Case 5	0.9134±0.0032
MCT-PF005	Case 4	0.9158±0.0032
MCT-PF007	Case 7	0.8885±0.0018

- c_k > 0.85 for experiments with HTC rods including MCT-PF007
- c_k > 0.90 for experiments with a combination of UO_2 and HTC fuel rods
  (experiments with a low average Pu content close to the TN® 24 E)

Presence of the FP experiments does not significantly contribute to the c_k values due to small K_{eff} sensitivities to fission product cross sections, compared with actinides

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Summary

▶ Similarity analysis based on global spectral parameter and reaction rate comparisons consistent with S/U analysis

▶ c_k values show good correlation between HTC and FP Experiments and TN® 24 E cask configuration

▶ Reaction rates analysis and sensitivity comparisons demonstrate that the actinides fuel composition along with the degree of neutron moderation are the dominant characteristics that determine the similarity between spent fuel systems

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Thank you for your attention

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