TRENDS OF THE DETERMINISTIC ROUTE APOLLO2.8 / JEFF-3.1.1 OF CRISTAL V2 CRITICALITY PACKAGE IN ICSBEP BENCHMARKS

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Outlook

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2. Deterministic schemes in Criticality Package CRISTAL V2
3. Experimental validation process of the Design Route « APOLLO2 Sn »
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   - Improvements due to the European JEFF-3.1.1 evaluation
   - Criticality calculation of thermal lattices
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1. Introduction

- Purpose : multigroup deterministic route in the criticality package CRISTAL V2
- Features
  - A Design Route including the accurate **JEFF-3.1.1 / 281-G [SHEM] Library** ,
    The major version **APOLLO2.8** with new capabilities in the domain of cross section self-shielding : resonance overlap treatment, transfer matrix self-shielding, new or improved flux solvers.
  - Specific procedures : self-shielding, homogenization and collapsing of self-shielded cross sections, treatment of space, angular and energy variables in the Boltzmann equation solving by the Discrete Ordinate Method (**Sn**).
  - A Standard Route including new capabilities in the deterministic schemes and in the procedures of CRISTAL V2.0 (Sn bias estimation).

15 years feedback of LWR studies in neutronics codes and evaluation, extensively used in the French industry (AREVA, EDF) and fully integrated in the reference JEFF-3.1.1 evaluation.

- Experimental validation object
  - Evaluating **biases and uncertainties** associated to the multi-group treatment,
  - Collecting an extensive feedback from **representative benchmarks of criticality – safety studies**.

2. Deterministic schemes

Components used in the multigroup « APOLLO2 Sn » Route

- Transport code APOLLO2.8 / resonant mixture model
  - Handles the resonance overlap between 33 - 66 eV of the main actinides (^{238}U, ^{240}Pu, ^{239}Pu) as well as absorbers ($^{176\text{-}180}$Hf),
  - Specific options implemented for the multigroup scattering cross sections treatment of intermediate mass isotopes (^{56}Fe) in thick reflectors.

  Avoid self-shielding models for the whole resonances of major and minor actinides, main Fission Products and LWR absorbers which are explicitly described
- CEAV5.1 libraries

  Consistent multigroup / pointwise JEFF-3.1.1 libraries (CEAV5.1 for APOLLO2.8 and TRIPOLI-4.8)
- CRISTAL V2.0 Procedures

  Include **recommended schemes (Pij – Sn)** adapted to each configuration :
  - Self-shielding in fissile (from H/X = 0), structure (metallic reflectors) and absorbent (Hf), 20-G collapsing of 281-G self-shielded cross sections, validated against TRIPOLI-4.8 & the reference “SHEM MOC” in LWR applications.
  - Specific homogenization for lattices.

JEFF-3.1.1 / SHEM

Creation of **medium**

Creation of Self-shielding & Flux calculation **geometry**

Self-shielding

Geometric boundary conditions definition **Flux calculation**

Creation of an equivalent geometry with **spatial homogenization** of the reference geometry ; **20-Group collapsing** (energy homogenization)

Pij step

MORET 5 keff

APOLLO2 Sn keff

ICSBEP 2011

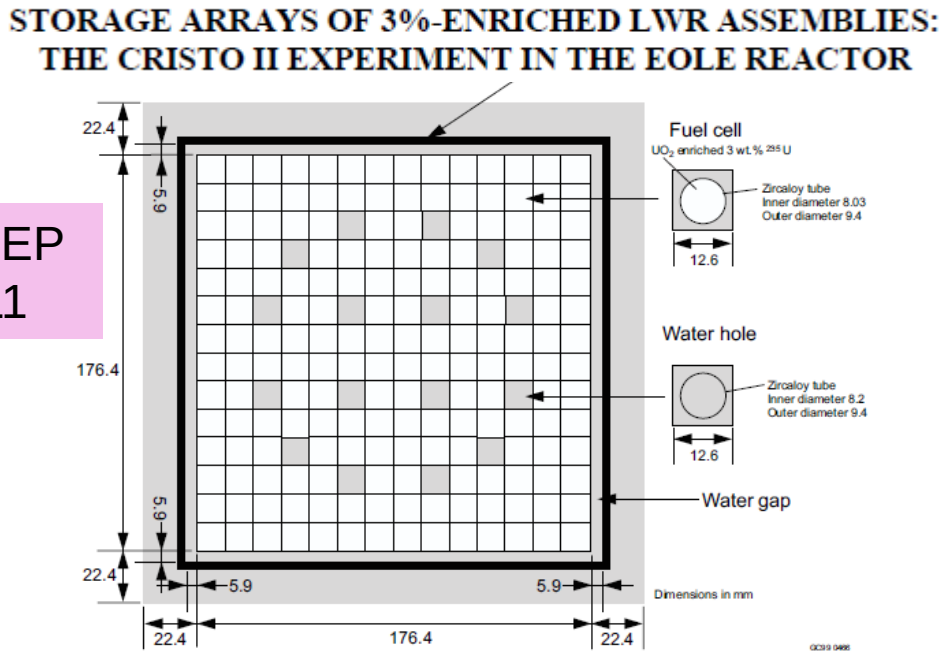
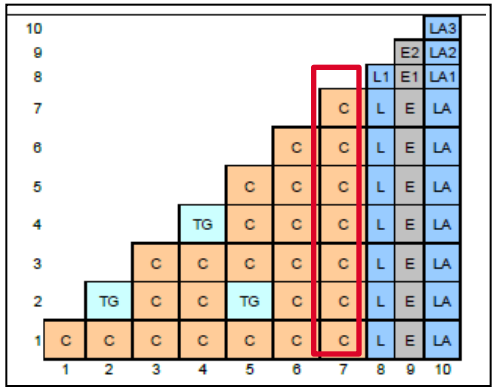


Figure 19. CRISTO II Assembly with Absorber Plates (Configurations B, C, D, E) for the Benchmark Model. (reflecting boundaries on all sides)



14x14 CRISTO II

PWR transport

- 4 rings in the pellet description, all cells differentiated
- Homogenization : outer peripheral cells differentiated
- 20-G collapsing effect < 50 pcm, time 20G / 281G = 1/200
- Code to code validation APOLLO2 / TRI-4 : **+350** ± 50 pcm

Main principles of the experimental validation process of the multigroup « APOLLO2 Sn » Route of CRISTAL V2.0

- Selection of benchmarks
  - Quality
  - Representativity / industrial application
  - Modelization in 2 or « pseudo » 3-D with the Sn solver of APOLLO2
  - CRISTAL V1.2 experimental Database fully re-interpreted
  - Additional experiments (GEN IV)

- Feedback
  - C/E Comparison of CRISTAL V2.0 and CRISTAL V1.2
  - CRISTAL V2.0 contribution in the reduction of criticality margins in industrial applications
    - Ex : reduction of the former overestimation of steal reflected metal systems

[J.M. Gomit et al., ICNC 2011]

- Experimental validation results
  - Detailed results provided and exploited in CEA/DER/SPRC tools DIANE and RIB
    - Integral Experiment Methodology for the validation of criticality studies
  - Average tendencies to be published
  - Specific results of private programs dedicated to Burnup Credit applications with the French BUC Route

[C. Carmouze et al., NCSD 2013]

Experimental Database retained for the « APOLLO2 Sn » Route

- 701 cases of 147 series are available in the current Validation Report, from **ICSBEP** Handbook 2011

(CRISTAL V1 configurations) :

PU (metallic, solution)	136 cases
HEU (metal, solution, compound)	217 cases
LEU (miscellaneous, solution, compound)	170 cases
MIX (solution, compound, miscellaneous, metal)	172 cases
IEU (metal)	6 cases

- Specific programs in CEA/Cadarache dedicated to Burnup Credit (MINERVE) and low-moderated MOX lattices validation (ERASME-S, integrated in ICSBEP)

MINERVE (Cadarache) separated FPs

[A. Chambon et al., NCSD 2013]

ZPR EOLE (Cadarache)

- Covered domain

  - Unreflected / reflected configurations : steal, concrete, beryllium, tungsten carbide, aluminium, light and heavy water, graphite, nickel, lead, polyethylene, uranium
  - Poisoned benchmarks : boron, gadolinium, cadmium
  - Moderation ratios :

Uranium systems : homog. fiss. H/U [0 – 2100], heterog. fiss. Vm/Vf [0.5 – 21], *Plutonium systems* H/Pu [0 – 2800].

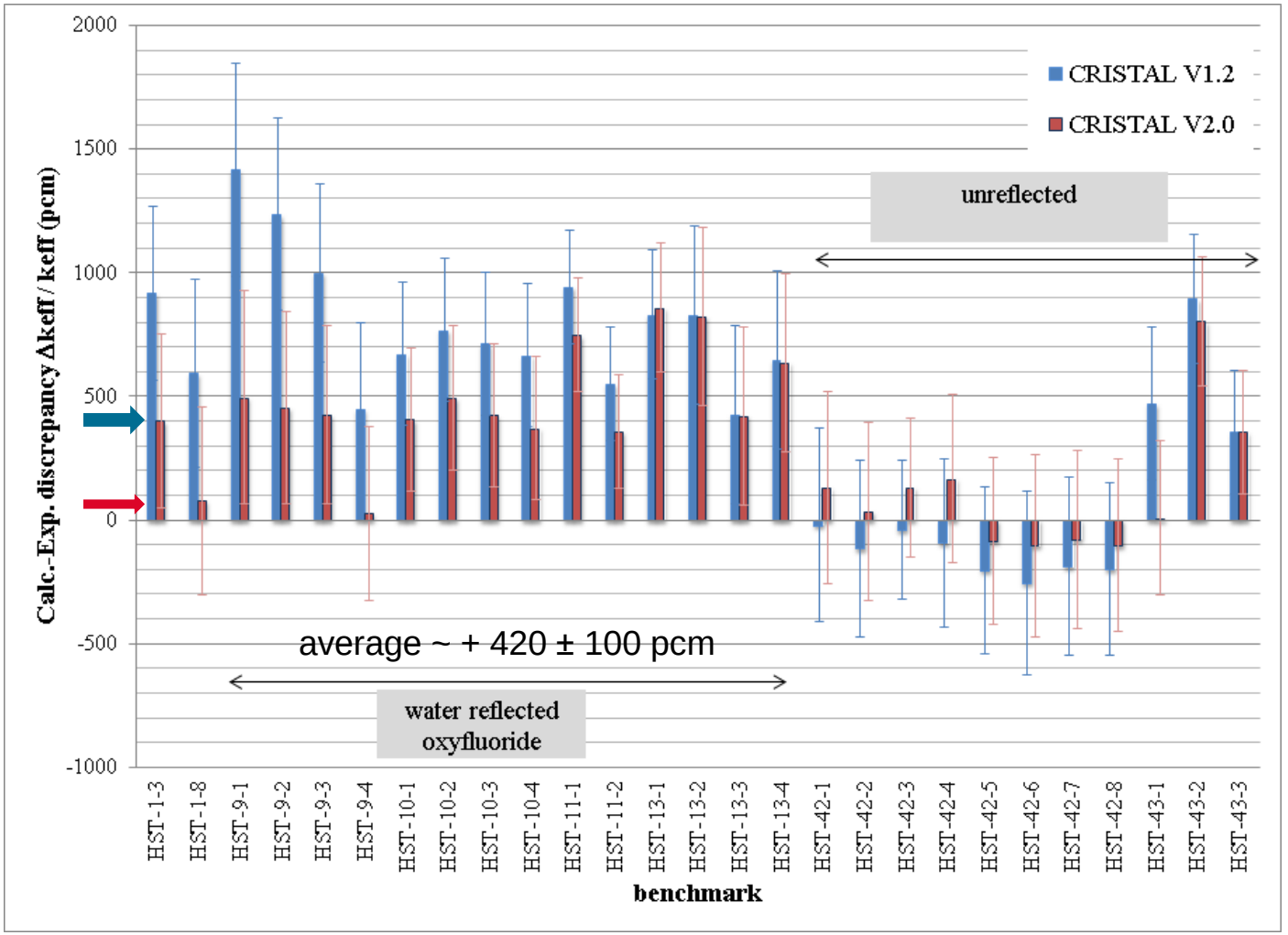
HIGH ENRICHED URANIUM SYSTEMS (SOLUTIONS)

^{235}U new evaluation of capture resonance width $<\Gamma\gamma>$ = 40 meV, instead of 35 meV in JEF2

[A. Santamarina, ICNC 2011]

Water-moderated benchmarks : average of +20 pcm with a standard deviation of 620 pcm (1σ) (~ - 400 pcm / JEF2.2)

Slight reduction of the well mastered average bias in LEU-SOL benchmarks.



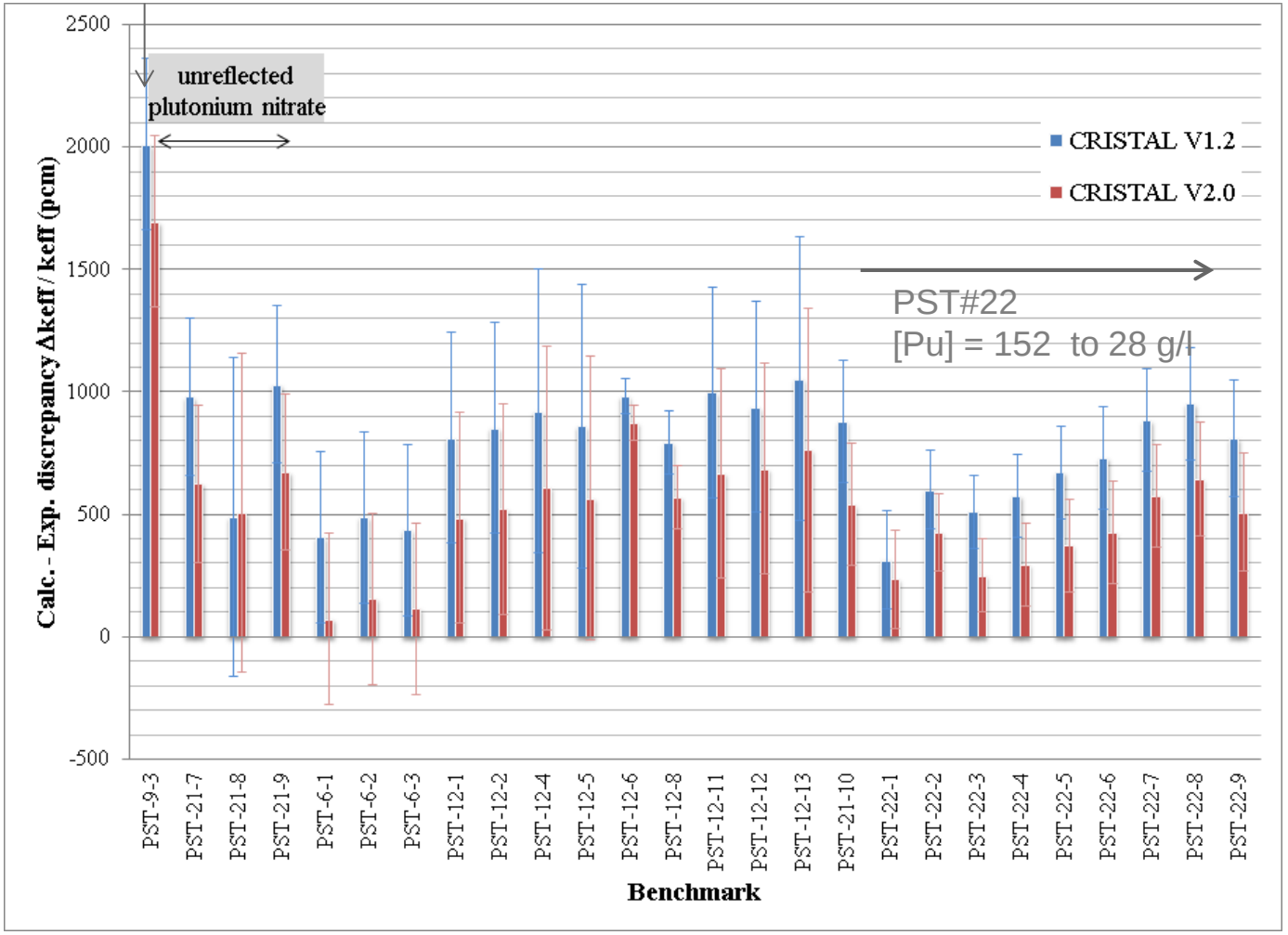
PLUTONIUM SOLUTIONS

[Pu] < 10 g/l

^{239}Pu new evaluation of ν, checked with measurement of a ^{239}Pu sample oscillated in the OSMOSE program; reduction of the former overestimation of low concentrated Pu solutions

[A. Santamarina, ICNC 2011]

water-reflected benchmarks : Average bias +440 ± 40 pcm with a standard deviation of 270 pcm
(~ -360 pcm / JEF2.2)

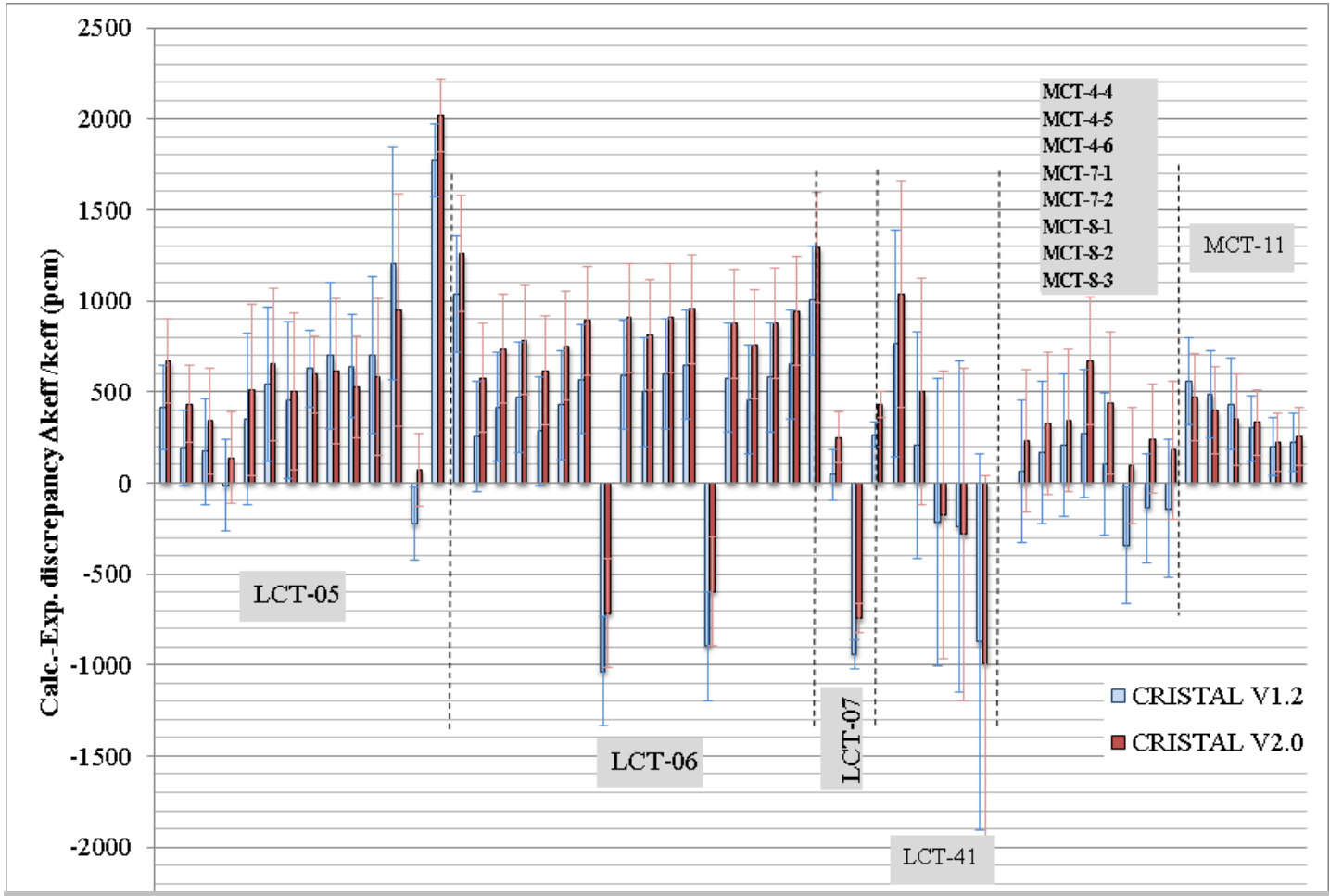


LATTICES IN THERMAL SPECTRUM

$^{239,241}Pu$, ^{238}U, ^{235}U new evaluations in JEFF-3.1.1driven by feedback on ND from EOLE, ICSBEP and french PIE : <u>reduction of the former underestimation (-500 pcm) of LCT benchmarks</u>

[A. Santamarina, ICNC 2011]

<u>Average Biases</u>
LEU-COMP-THERM : 580 ± 30 pcm
MIX-COMP-THERM : 450 ± 50 pcm
APOLLO2 Sn scheme effect : ~ 350 pcm



Combination of ND (+500) and specific « Sn » schemes effects in the general overestimation of thermal lattices, consistent with CRISTAL V1.2.

Calculation - Experiment comparison using the "APOLLO2 Sn" calculation route of CRISTAL V2.0

Main Components of CRISTAL V2.0 drive the experimental validation of the CRISTAL V2 package.

- JEFF-3.1.1 / SHEM library

  New ^{235}U evaluation in JEFF-3.1.1 is particularly highlighted in Highly Enriched Uranium Thermal and Fast systems, showing a reduction of the former overestimation of the keff.

  ^{239}Pu improvement in JEFF-3.1.1 is confirmed by an increased accuracy in calculating plutonium solution benchmarks.

- APOLLO2 Sn schemes and specific procedures based on APOLLO2.8 major version

  "APOLLO2 Pij"

  Improvements in metal-reflected configurations, due to the new multigroup cross section treatment of intermediate mass isotopes (self –shielded ^{56}Fe).

  "APOLLO2 Sn"

  Well mastered Sn biases (energetic collapsing and homogeneization) in thermal lattices.

➢ Improved accuracy and ergonomy of the multigroup "APOLLO2 Sn" Route of CRISTAL V2.0.