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NEUTRONICS BENCHMARK OF CEFR START-UP TESTS: *REACTION RATES AND INTEGRAL REACTIVITY COEFFICIENTS*

T. K. Kim

Argonne National Laboratory (ANL)

U.S.A

P. Sciora

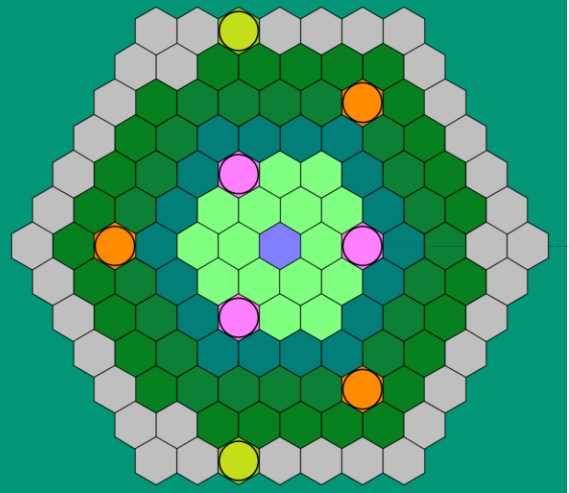
French Alternative Energies and Atomic Energy Commission (CEA)

France

K. Devan

Indira Gandhi Centre for Atomic Research (IGCAR)

India



Author List

T. K. Kim, M. Jarrett
Argonne National Laboratory
Argonne, IL. U.S.A

P. Sciora
French Alternative Energies and Atomic Energy Commission (CEA), France

K. Devan, S. V. Vedharathinam
Indira Gandhi Centre for Atomic Research (IGCAR)
India

C. Batra, V. Kriventsev
International Atomic Energy Agency
Vienna, Austria

J. Bodi, K. Mikityuk
Paul Scherrer Institute , Switzerland

Youqi Zheng, Xianan Du
School of Nuclear Science and Technology, Xi'an Jiaotong University, Xi'an, China

Deokjung Lee, Tuan Quoc Tran, Jiwon Choe
Ulsan National Institute of Science and Technology
Republic of Korea

H. Taninaka
Japan Atomic Energy Agency
Japan

A. Gómez-Torres, R. López-Solís, J. Galicia-Aragon, E. del Valle-Gallegos
National Institute of Nuclear Research, Mexico

S. Di Pasquale, V. Giusti, A. Petruzzi
Nuclear and Industrial Engineering and University of Pisa
Italy

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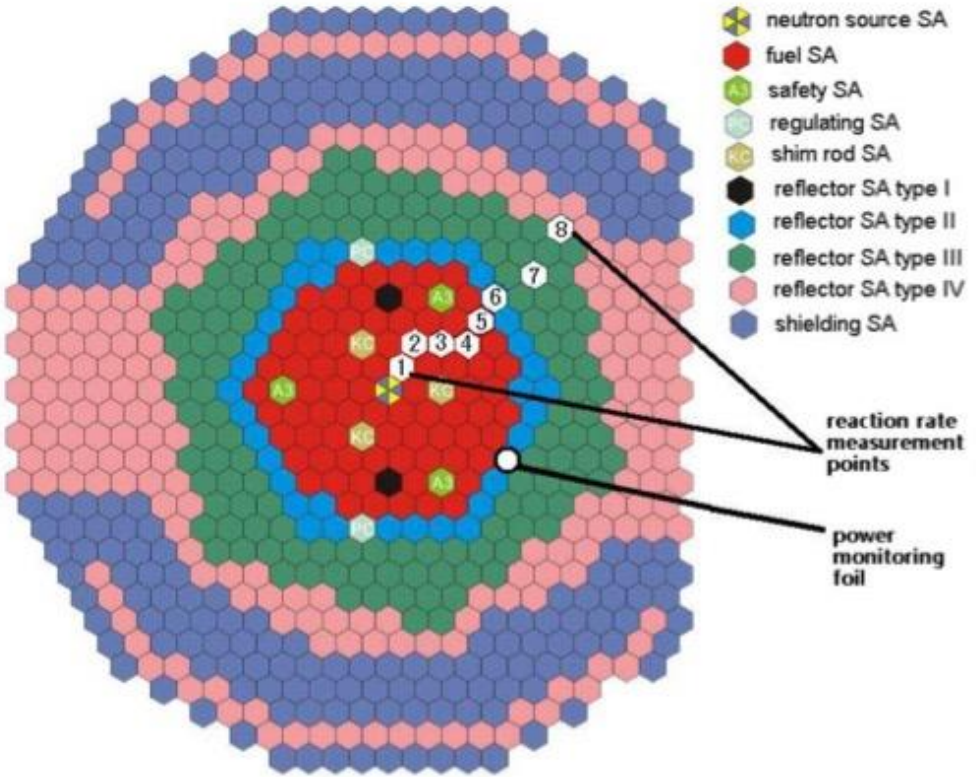
Introduction

- **International Atomic Energy Agency launched a Coordinated Research Project (CRP) entitled "Neutronics Benchmark of CEFR Start-up Tests"**
  - See previous presentations for detailed information on the CEFR and benchmark specifications
  - About 30 organizations from 17 countries/international organizations participated for eight benchmarks
  - Benchmark consists of two phases
    - First blind phase – analysis without the knowledge of measurement values
    - Second refined phase – refine analysis with blind phase results and measurement values
- **Among eight benchmarks, following two benchmarks obtained from second refined phase are compared in this work**
  - Reaction rate measurements from foil activations
  - Integral reactivity coefficients

- **Benchmark Description and Participants**

Reaction Rate Measurements

- **Reaction rates of $^{235}U(n,f)$, $^{238}U(n,f)$, $^{237}Np(n,f)$, $^{197}Au(n,\gamma)$, $^{58}Ni(n, p)$, and $^{27}Al(n, \alpha)$ were measured using foil activation**
- **Radial reaction rate measured in eight positions**
  - five in fissile zone and three in reflectors
- **Axial reaction rates measured in central position (2-2)**
  - 13 to 14 axial positions from lower blanket to top of sodium plenum zone
- **Measure activities of irradiated foils were measured using high purity germanium detector**
- **Experimental uncertainties: 15-20%**
- **Normalized distributions were reported**



Integral Reactivity Coefficients

- **In kick-off meeting in 2018, participants agreed on numerical benchmark of integral reactivity coefficients for understanding CEFR's safety features**
  - Axial and radial thermal expansion coefficients
  - Fuel, steel, and sodium density coefficients
  - Doppler constants at normal and voided conditions
  - Control rod expansion coefficients
- **Integral reactivity coefficients were defined by perturbating parameters**

$$\Delta\rho^{parameter}\left(\frac{pcm}{\%}\right) = \frac{k^{perturbed.} - k^{normal}}{\%\ perturbation}$$

  - Detailed perturbed conditions were defined by participants
- **Numerical results were compared between participants**

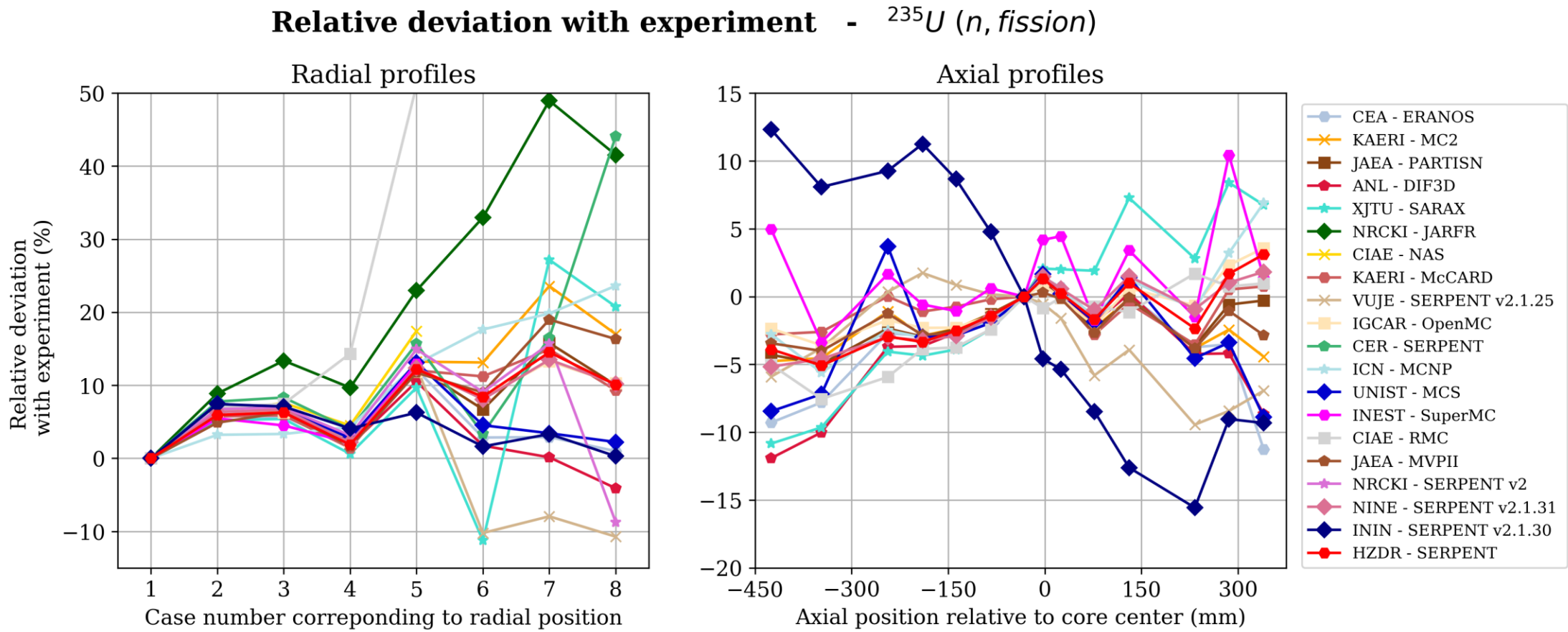
Participants

Country	Organization	Code	Library	Deterministic	Stochastic
China	INEST	SuperMC	HENDL-3.0		X
China	CIAE	NAS, RMC	ENDF/B-VIII.0	X	X
China	XJTU	SARAX	ENDF/B-VIII.0	X	
France	CEA	ERANOS [2]	JEFF 3.1 [3]	X	X
Germany	HZDR	Sepent	JEFF 3.1		X
Hungary	MTA / CER	Sepent	ENDF/B-VIII.0		X
India	IGCAR	OpenMC [4]	ENDF/B-VIII.0		X
Italy	NINE/UNIPI	Serpent	ENDF/B-VIII.0		X
Japan	JAEA	PARTISN, MVP	JENDL-4.0	X	X
Korea	UNIST	MCS	ENDF/B-VII.1		X
Korea	KAERI	DIF3D, McCARD	ENDF/B-VII.0 and VII.1	X	X
Mexico	ININ	Sepent, Aznhex	ENDF/B-VIII.0	X	X
Romania	RATEN (ICN)	MCNP	ENDF/B-VIII.0		X
Russia	NRCKI	JARFR, Sepent	ABBN-93,JEFF 3.3	X	X
Slovakia	VUJE	Sepent	ENDF/B-VII.0		X
U.S.A	ANL	DIF3D	ENDF/B-VII.0	X	

- **16 organizations from 13 countries participated with various deterministic and stochastic codes and neutron libraries**

Reaction Rate Measurements

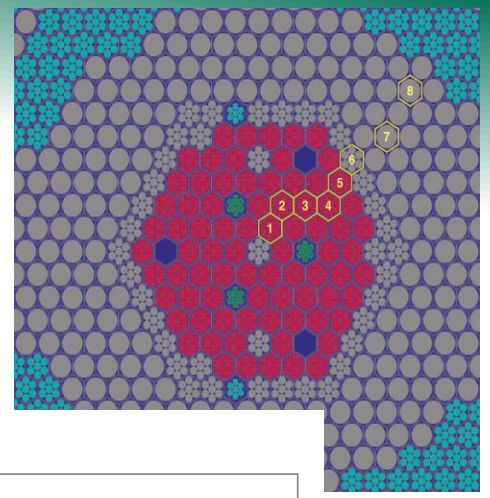
Reaction Rate (I) - ^{235}U(n,f)

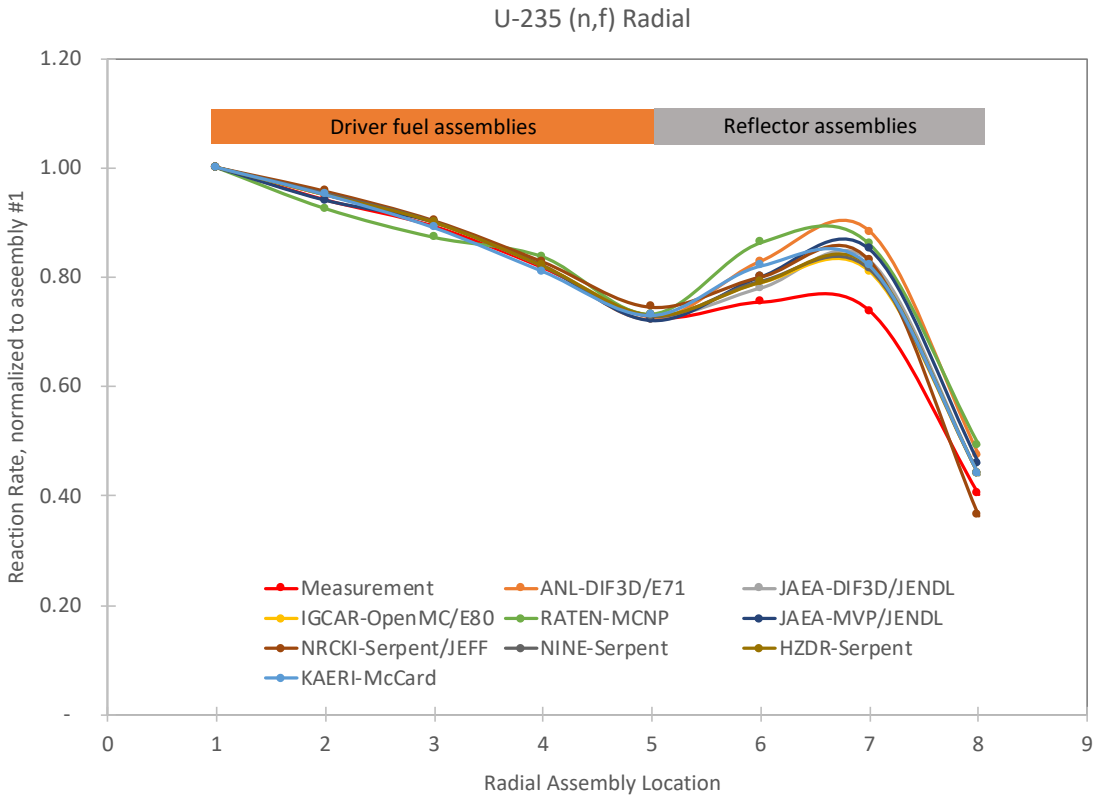


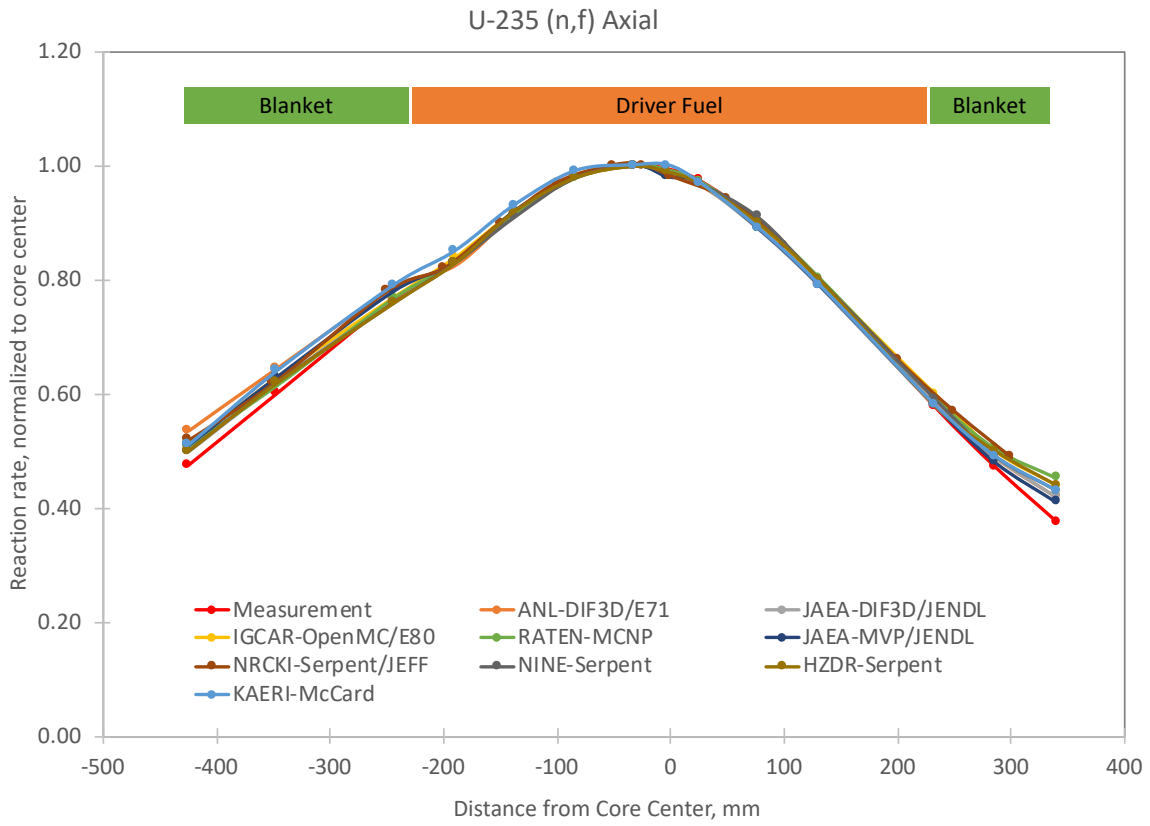
- **Generally, ^{235}U(n,f) results of participants are within experimental uncertainty in fissile zone, while disagreement increases in non-fissile zone**
- **Similar trends observed for results of ^{238}U(n,f), ^{237}Np(n,f), and ^{58}Ni(n, p)**

Reaction Rate (II) - ^{235}U(n,f)

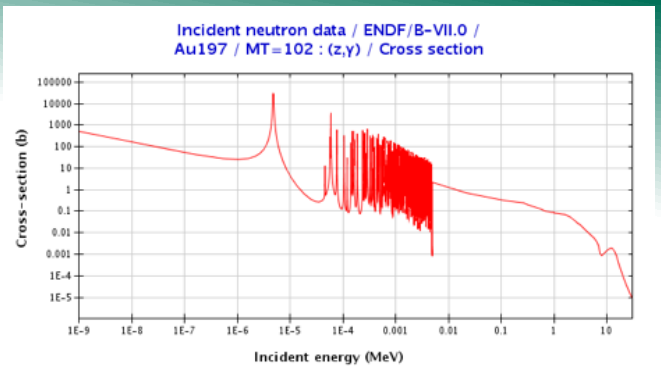
- **Good agreement in core region, but difference increased in blanket/reflector**

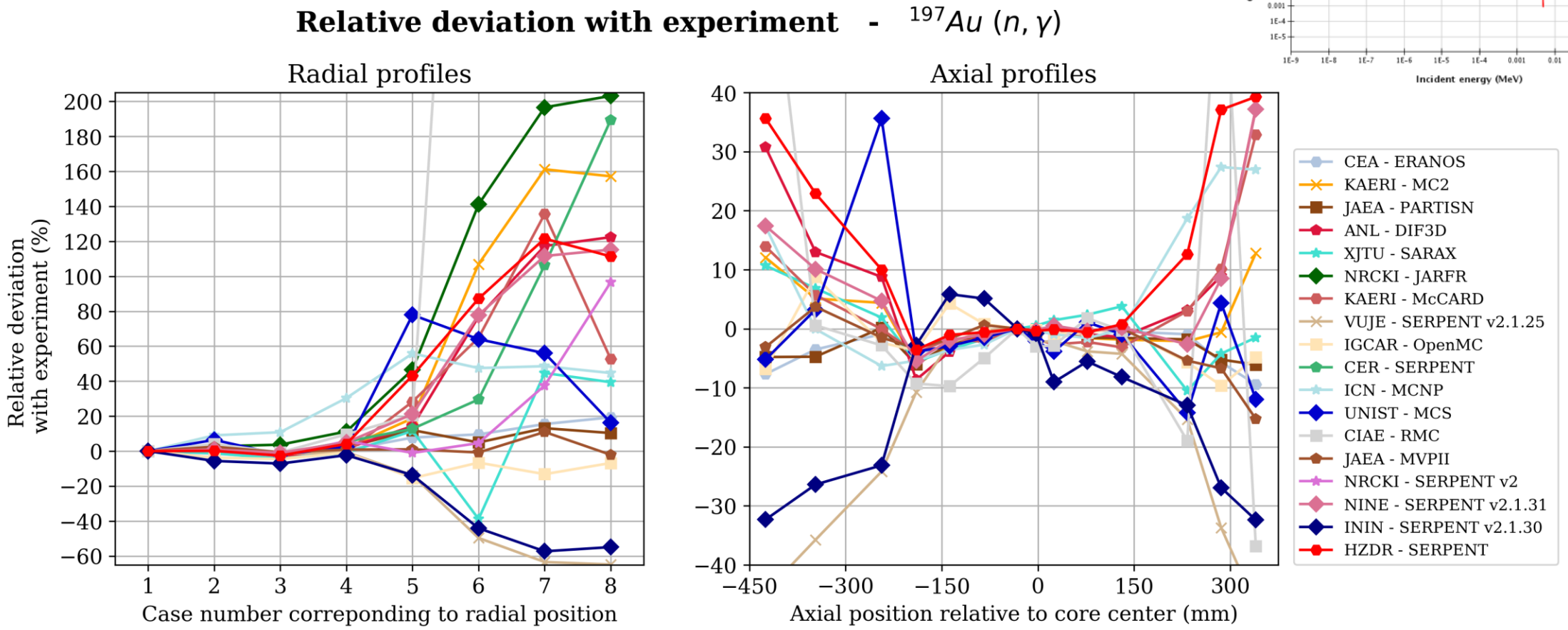






Reaction Rate (III) - ^{197}Au(n,γ)

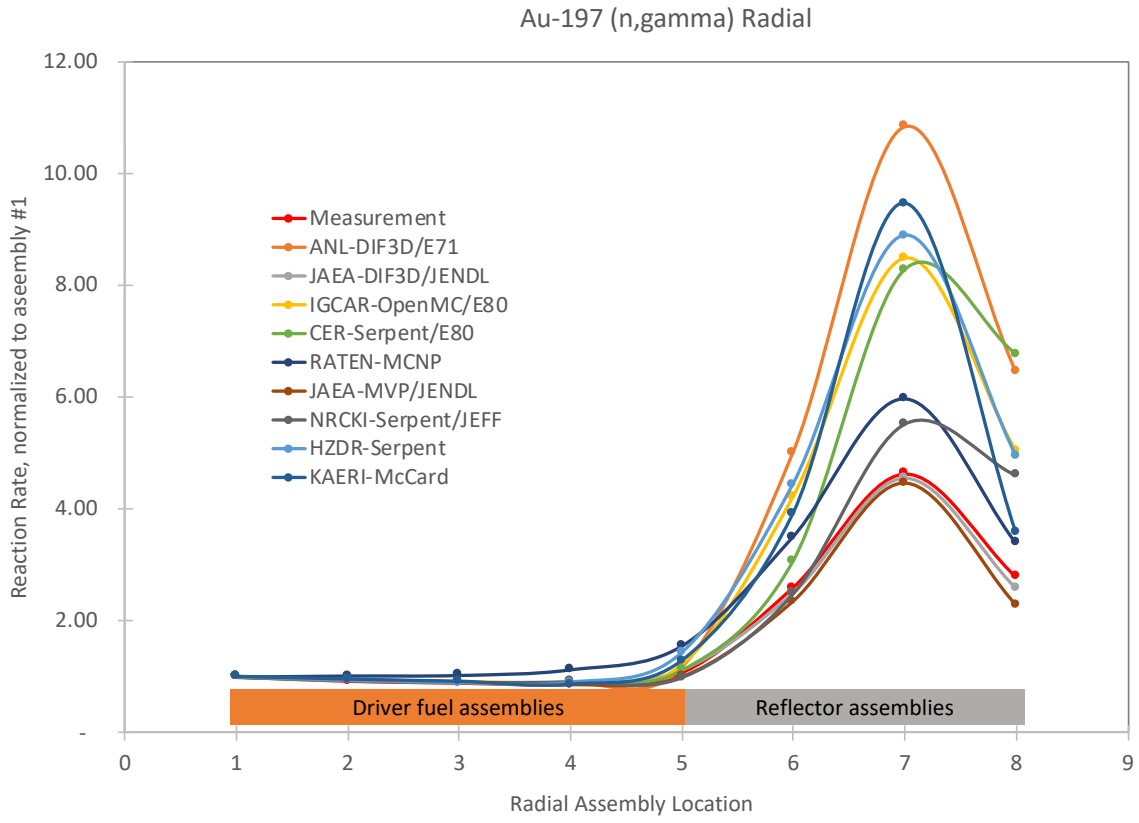


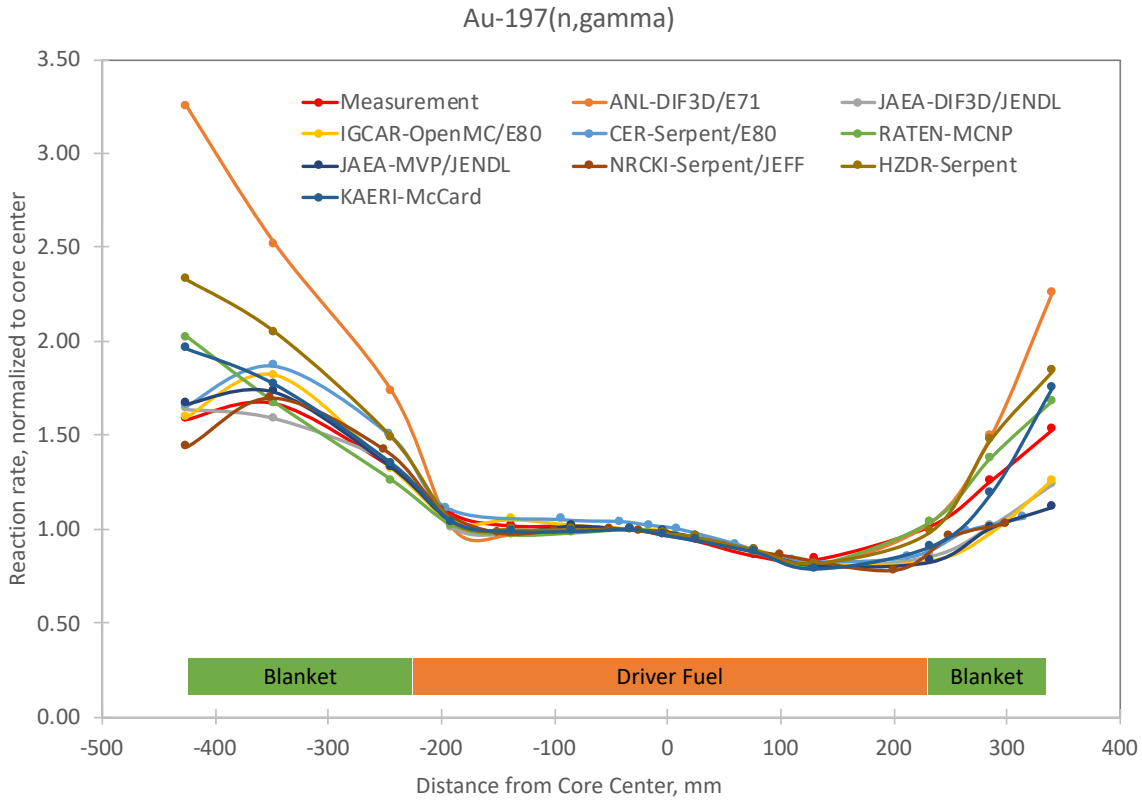


- **Large deviations in reflector zone (#6, 7, and 8) because of self-shielding effect from a large resonance at 4.9 eV**

Reaction Rate (III) - ^{197}Au(n,g)

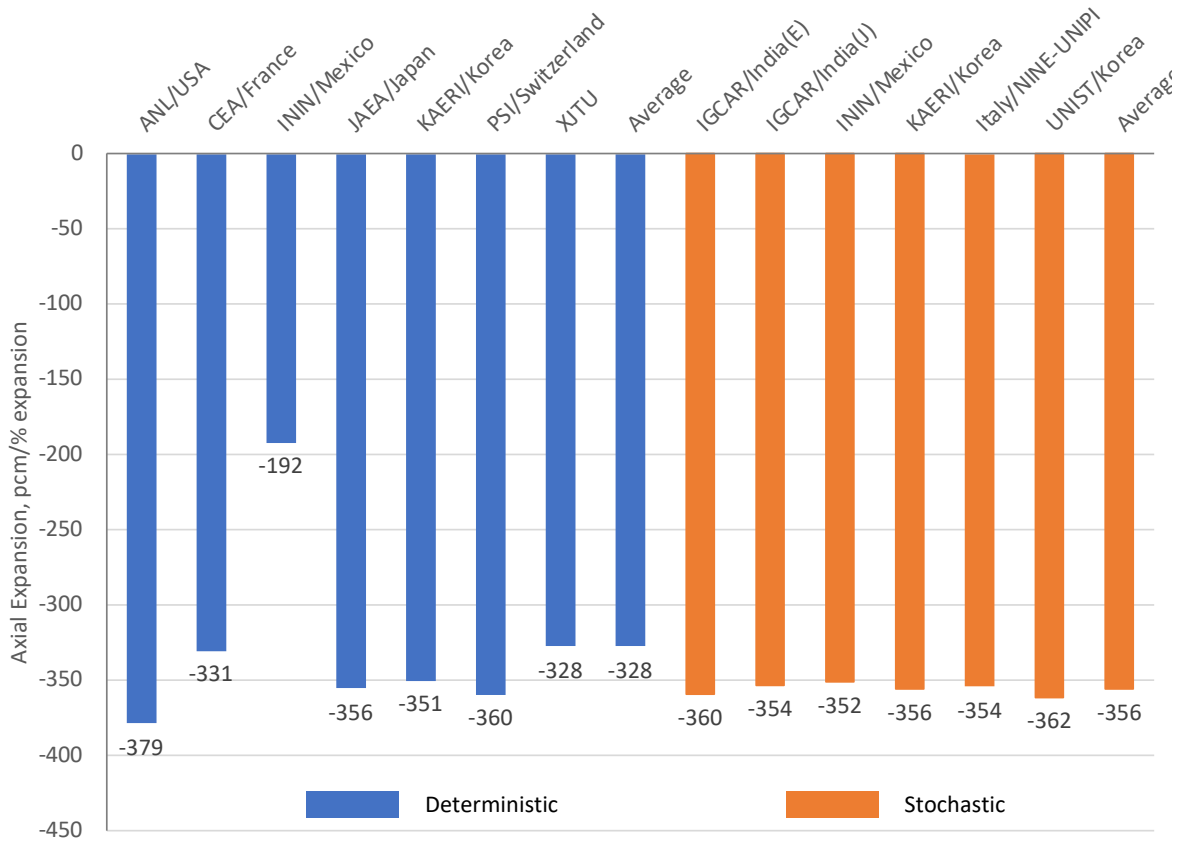
- **Due to resonance at 4.89 eV, Au-197 has high (n,γ) reaction in blanket and reflector**

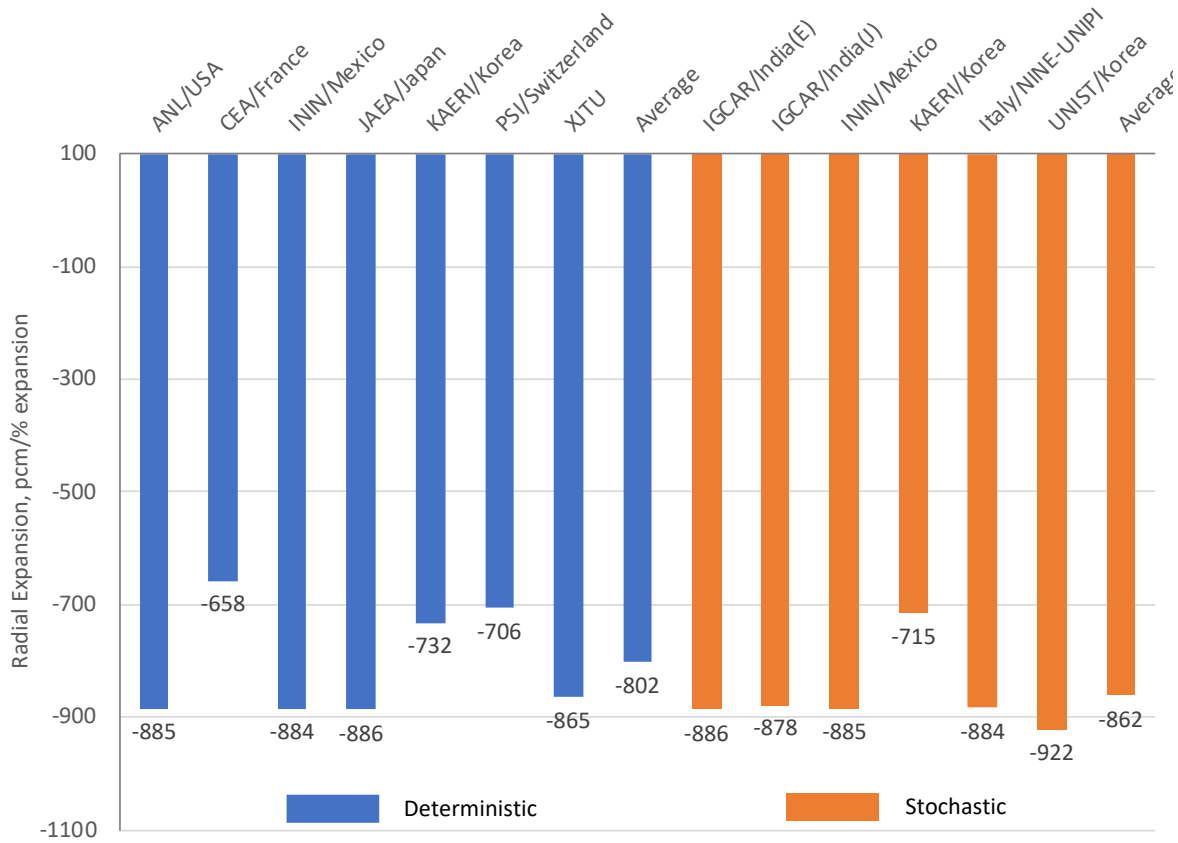




Integral Reactivity Coefficients

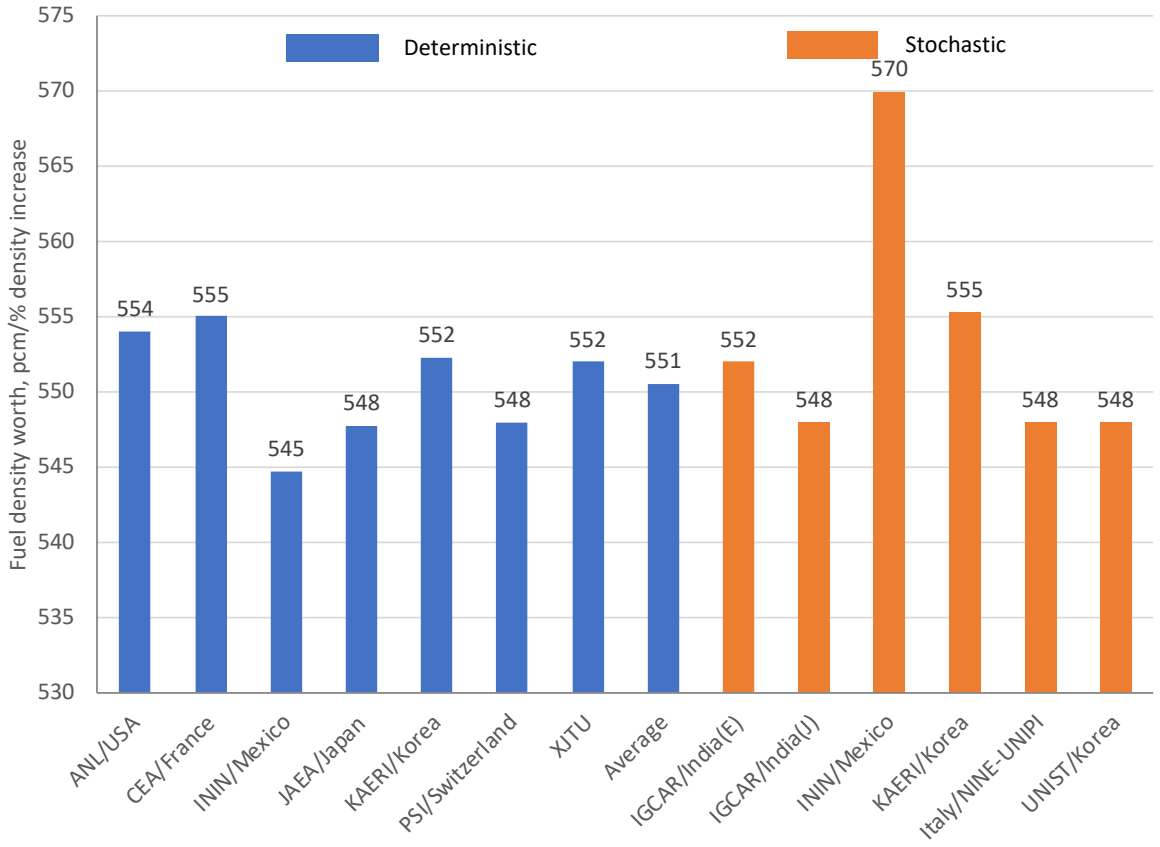
Integral Reactivity Coefficients (I) - Expansion

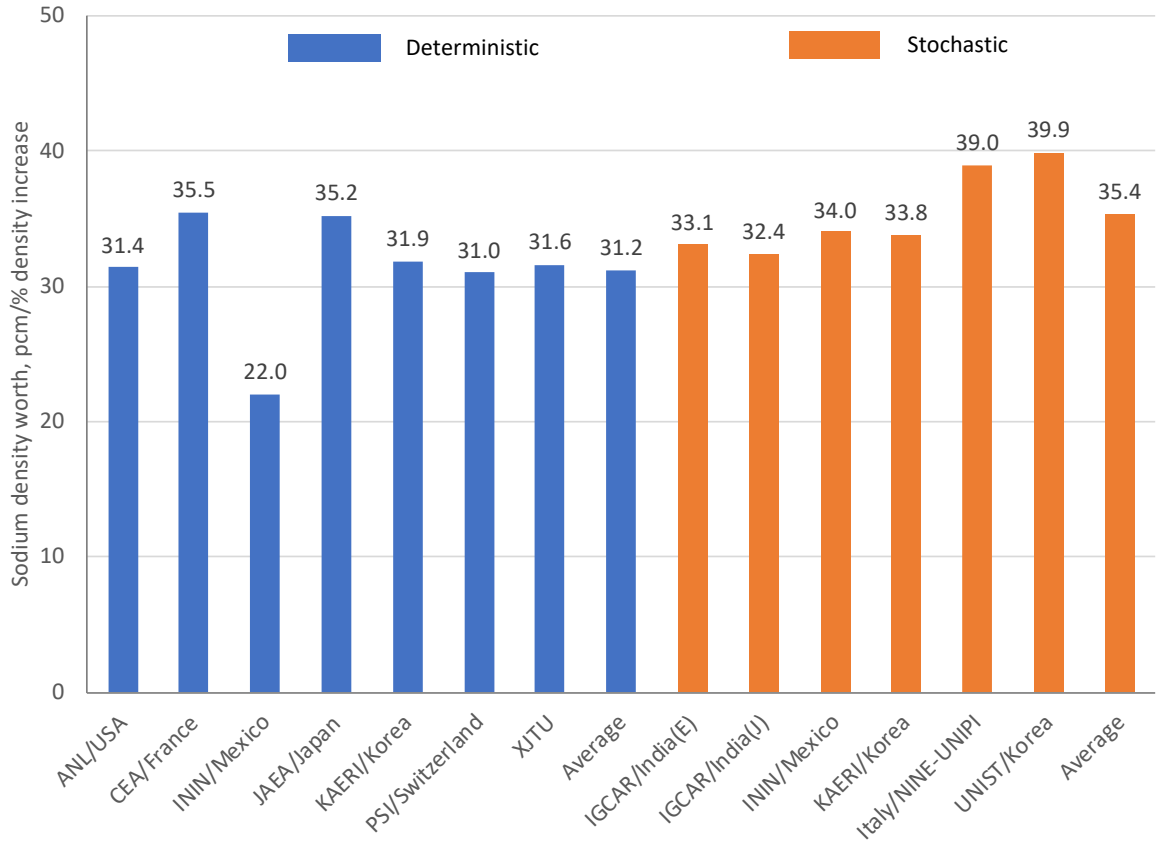




- **CEFR has negative expansion coefficients, and most probable axial (left) and radial (right) expansion coefficients are about -355 pcm/%-expansion and -885 pcm/%-expansion, respectively.**

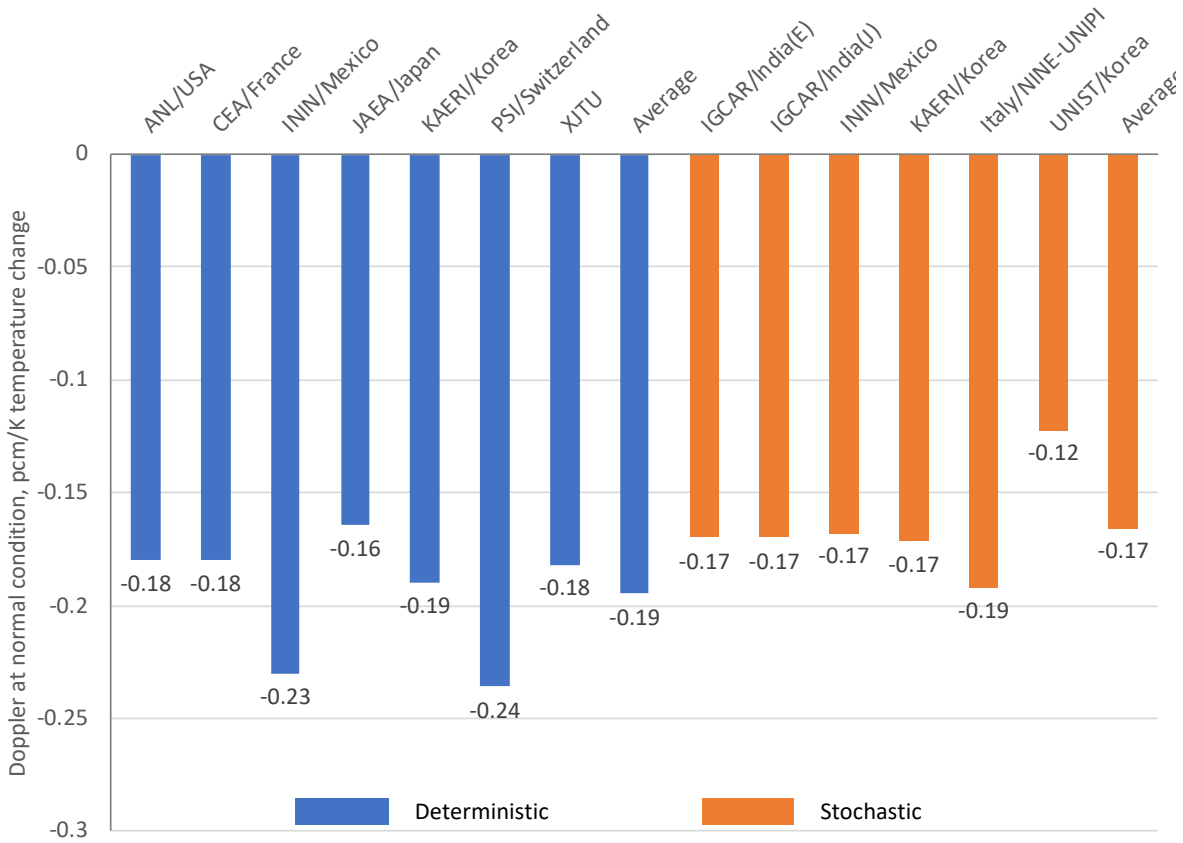
Integral Reactivity Coefficients (II) - Density

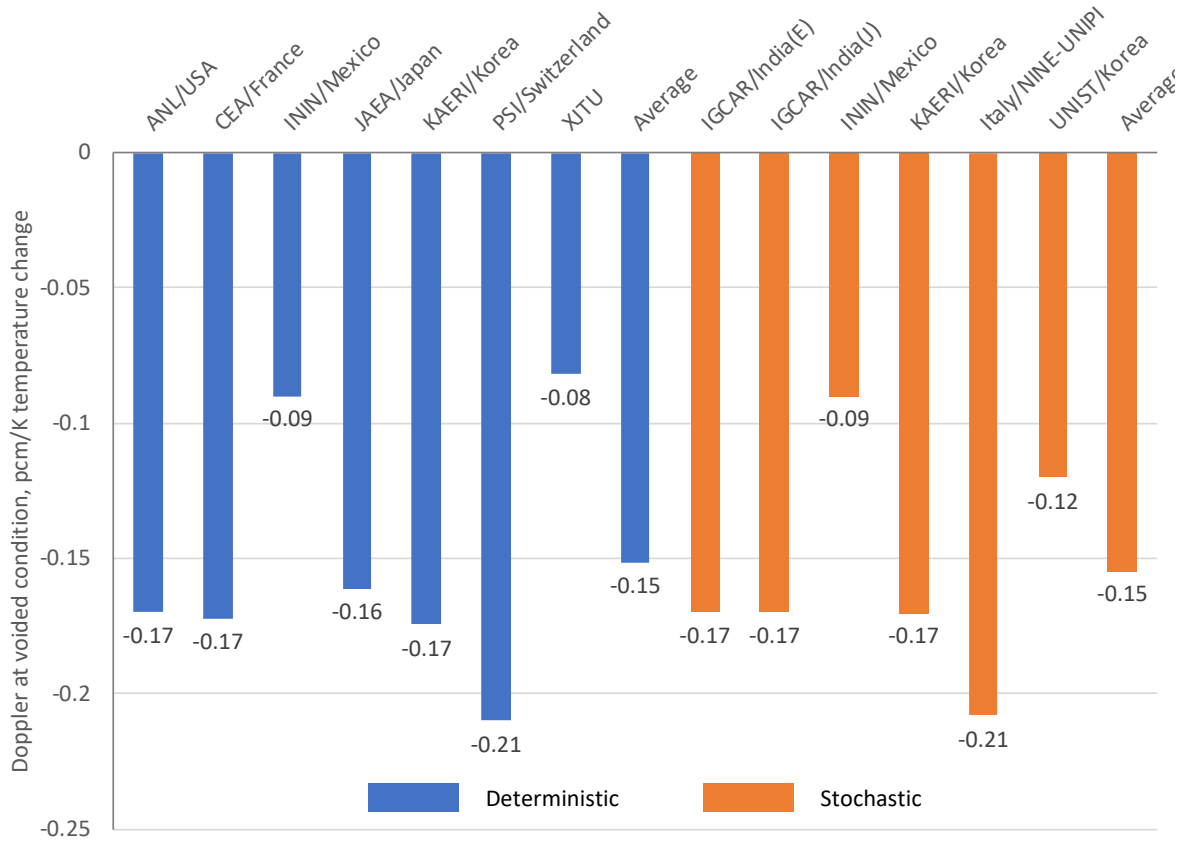




- **CEFR has positive fuel (left) and sodium (right, negative void) density coefficients**

Integral Reactivity Coefficients (III) – Doppler Constant





- **CEFR has negative Doppler constant at normal (left) and voided (right) conditions**

Conclusions

- **IAEA/CRP on "Neutronics Benchmark of CEFR Start-up Tests" gave good opportunities for validation of fast reactor tools of member countries**
  - Comparison with measured values in clean CEFR core
  - Inter-comparison between participants, neutron libraries, and computation methods (Monte Carlo vs. Deterministic)
- **Reaction rate measurements**
  - Generally, both deterministic and stochastic results give good agreement in fissile zone, but disagreement between participants and deviation from measured values increase in non-fissile zones
  - Extra attention is needed in simulation for following cases:
    - reactions with low cross section (^{27}Al).
    - reactions far from the fissile zone, if the reaction rate is a threshold one (^{237}Np or ^{238}U).
    - reactions with strong thermal resonance (^{197}Au).
- **Integral reactivity coefficients**
  - Except for several outlier results, predicted integral reactivity coefficients by participants are generally comparable regardless of deterministic and stochastic calculations
  - Deterministic results have relatively larger standard deviations compared to stochastic results due to wide diversity of deterministic methods (approximations of angular dependency, condensation of cross section, homogenization, etc.)

Thank you!

Contact information: tkkim@anl.gov