Application of Serpent in EU FP7 project FREYA: Fast Reactor Experiments for hYbrid Applications

E. Fridman
Outline

• Overview of FREYA project

• Serpent models of VENUS-F critical cores

• Serpent vs. MCNP

• Serpent vs. experimental data

• Summary
EU/FP7 FREYA project

- FREYA - Fast Reactor Experiments for hYbrid Applications
  - EURATOM 7\textsuperscript{th} Framework Program

- Support for design and licensing of ADS and LFR systems
  - MYRRHA – Multi-purpose hYbrid Research Reactor for High-tech Applications
  - ALFRED – Advanced LFR European Demonstrator

- Sub-critical and critical experiments in VENUS-F facility
  - SCK\textcdot CEN, Mol, Belgium
VENUS-F facility

- **VENUS**: water-moderated zero power facility
  - E.g. OECD VENUS-2 MOX benchmark

- **VENUS-F**: fast zero-power facility
  - Operation in critical or sub-critical mode
  - Fuel: metallic U rodlets, 30 w% U-235
  - “Coolant”: solid lead blocks
  - Core dimensions (xyz): 97 × 97 × 60 cm
Critical core configurations in FREYA

- Several **critical** VENUS-F cores have been investigated
  - Reflect some basic features of MYRRHA and ALFRED
  - **Most** of them were **modeled with Serpent**

- **CR0** – reference critical core

- **CC5** – “clean” MYRRHA core mock-up

- **CC8** – “full” MYRRHA core mock-up
  - several MYRRHA In-Pile Sections (IPSs)
  - graphite blocks simulating MYRRHA BeO reflector

- **CC6 = CC5 core + ALFRED island**
Fuel assembly configurations: transition from CR0 to CC’s cores

CR0

U metal

Lead

Al$_2$O$_3$

CC5, CC6, CC8
Axial core channels

- Fuel assy
- Lead assy
- Safety rod
- Control rod
- Exp. Fuel assy
- Exp. assy G1
- Exp. assy G3
Considered FREYA cores

CR0 – reference critical core

CC6 – CC5 core with ALFRED siland

CC5 – clean MYRRHA mock-up

CC8 – full MYRRHA mock-up
Serpent models of VENUS-F critical cores
General setup

• Very detailed Serpent core models
  – Fully resolved fuel assemblies, control rods, and other structures
  – Based on MCNP input provided by SCK·CEN

• XS
  – Serpent JEFF3.1 library

• Neutron histories
  – ~4 billion active neutron histories
  – 1M neutron histories, 4000 active and 200 skipped cycles
  – 1σ uncertainty on k-eff is about 2-3 pcm
Serpent vs. MCNP: CR0 core
Approach to comparison

- Serpent model was built from the reference MCNP input
- Dimensions, material compositions, etc. were preserved
- Identical ACE files for Serpent and MCNP
- Identical number of neutron histories

The goals:
- To assure the consistency of the Serpent model
- To compare Serpent/MCNP performance
Serpent vs. MCNP: radial core layout

MCNP Vised plotter

Serpent plotter
## Serpent vs. MCNP: integral parameters

<table>
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<th>Difference</th>
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<tr>
<td>k-eff</td>
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<td>Gen. time, sec</td>
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<td>Beta-eff, pcm</td>
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Serpent vs. MCNP: neutron flux spectra in fuel
Serpent vs. MCNP: diff. in neutron flux spectra
Serpent vs. MCNP: Norm. power distribution

Normalized radial power

Relative difference
Serpent vs. MCNP: summary

• Very good agreement between Serpent and MCNP
  – Integral parameters, power distribution, flux spectra
  – Typically within statistics

• Consistency of the Serpent model is demonstrated

• Serpent outperforms MCNP
  – Runs 9.3 times faster
Serpent results vs. experimental data
Measured parameters calculated by Serpent

- Integral parameters
  - k-eff, β-eff, control rod worth

- Axial and radial traverses
  - Axial or radial distribution of fission rates

- Spectral indices - fission rates ratio e.g.:
  - F28 = Fission U238 / Fission U235
  - F49 = Fission Pu239 / Fission U235

- Lead void reactivity effect (CC6 core)

- **Selected** results are in the next slides
Selected results: CC5 core
Spectral indices

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<tr>
<th>Position</th>
<th>EFA-1</th>
<th>EFA-2</th>
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<tr>
<td>F28/F25</td>
<td>0.91</td>
<td>0.90</td>
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<tr>
<td>F49/F25</td>
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<td>F42/F25</td>
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<td>F37/F25</td>
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<tr>
<td>F51/F25</td>
<td>0.93</td>
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</table>
Spectral indices

- Measured in experimental fuel assemblies (EFA-1&2)
Spectral indices

- About 10% discrepancy in F28/F25
- The reasons should be further investigated
Axial traverses in EFA-1

U-235

Pu-239

Np-237
Axial traverses in EFA-2

U-235

Normalized fission rate

Distance from the bottom of the active fuel, mm

U-238

Normalized fission rate

Distance from the bottom of the active fuel, mm

Pu-239

Normalized fission rate

Distance from the bottom of the active fuel, mm

Np-237

Normalized fission rate

Distance from the bottom of the active fuel, mm
Axial traverses: fissile vs. fertile
Neutron thermalization – lower reflector

Axial core layout (X-Z)

Norm. fission rates

Thermal flux
Neutron thermalization – radial reflector

Axial core layout (Y-Z)

Thermal flux
Radial traverse

Measured positions

Graph showing radial traverse vs. distance from the core center in cm.
Selected results: CC6 core
Lead void reactivity

Estimated by “voiding” fuel assemblies in ALFRED island

Good agreement between calculations and experiment:
• C/E Case A: 0.96
• C/E Case B: 1.01
Selected results: CC8 core
Radial traverse

Measured positions

U-238 F.C.

U-235 F.C.
### C/E: spectral indexes in CC8

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<th>Position</th>
<th>EFA-1</th>
<th>EFA-2</th>
<th>EFA-2</th>
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Summary

• Serpent vs. MCNP – very good agreement (CR0 core)
  – Serpent runs much faster than MCNP (about 9 times)

• Serpent vs. experiment – generally good agreement
  – F49 and F37 spectral indexes
  – Axial and radial traverses, Lead void reactivity effect,

• But
  – Large differences in F28/F25 spectral index
  – Same trend for MCNP
Acknowledgment

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Thank you!