Modeling of the FFTF isothermal physics tests with Serpent and DYN3D

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HZDR
HELMHOLTZ
ZENTRUM DRESDEN
ROSSENDORF

DYN3D code

- 3D multi-group nodal diffusion + T-H feedback + dynamics
- Rectangular and hexagonal geometries
- Developed at HZDR for VVERs and LWRs

Extending DYN3D to SFR application

- Serpent-based few-group XS generation
- T-H module updated with Na properties
- Thermal expansion models for in-core structures
  - Axial fuel rod expansion
  - Radial diagrid expansion
- Coupling with a system code ATHLET

Related V&V activities

- Serpent-DYN3D successfully verified vs. **full core Serpent solution**
  - Various SFR cores: OECD-SFR, ESFR, ABR, ASTRID, Phenix, Superphenix

- Serpent-DYN3D validation vs. **experiments**
  - Neutronics: Phenix EOL control rod shift tests
  - Transient: Initial stage of Phenix EOL natural convection test

- Ongoing validation activates:
  - Neutronics: IAEA CRP on CEFR start-up tests
  - Transients: Superphenix start-up tests (within EU H2020 project ESFR-SMART)
  - Transients: IAEA CRP on FFTF loss of flow without scram tests

Fast Flux Test Facility (FFTF)

- FFTF – 400-MW sodium-cooled research and test reactor
- First criticality on February 9, 1980
- Followed by isothermal physics tests

FFTF, Hanford Site, Washington

FFTF Isothermal Physics Measurements

- Experimental data evaluated and summarized by INL (Bess, 2019*)
- MCNP input and results are available
- Part of the "International Handbook of Evaluated Reactor Physics Benchmark Experiments"

– *Bess, J.D., 2019. Evaluation of the Initial Isothermal Physics Measurements at the Fast Flux Test Facility, a Prototypic Liquid Metal Fast Breeder Reactor, in: International Handbook of Evaluated Reactor Physics Benchmark Experiments. NEA/NSC/DOC(2006)1, FFTF-LMFR-RESR-001, revision 2, OECD/NEA

– Bess, J.D., 2012. Development of a HEX-Z Partially Homogenized Benchmark Model for the FFTF Isothermal Physics Measurements. Nucl. Sci. Eng. 171, 32–40. https://doi.org/10.13182/NSE10-100

– Bess, J.D., 2010. Benchmark evaluation of the initial isothermal physics measurements at the fast flux test facility, in: International Conference on the Physics of Reactors 2010, PHYSOR 2010. Pittsburgh, Pennsylvania, USA.

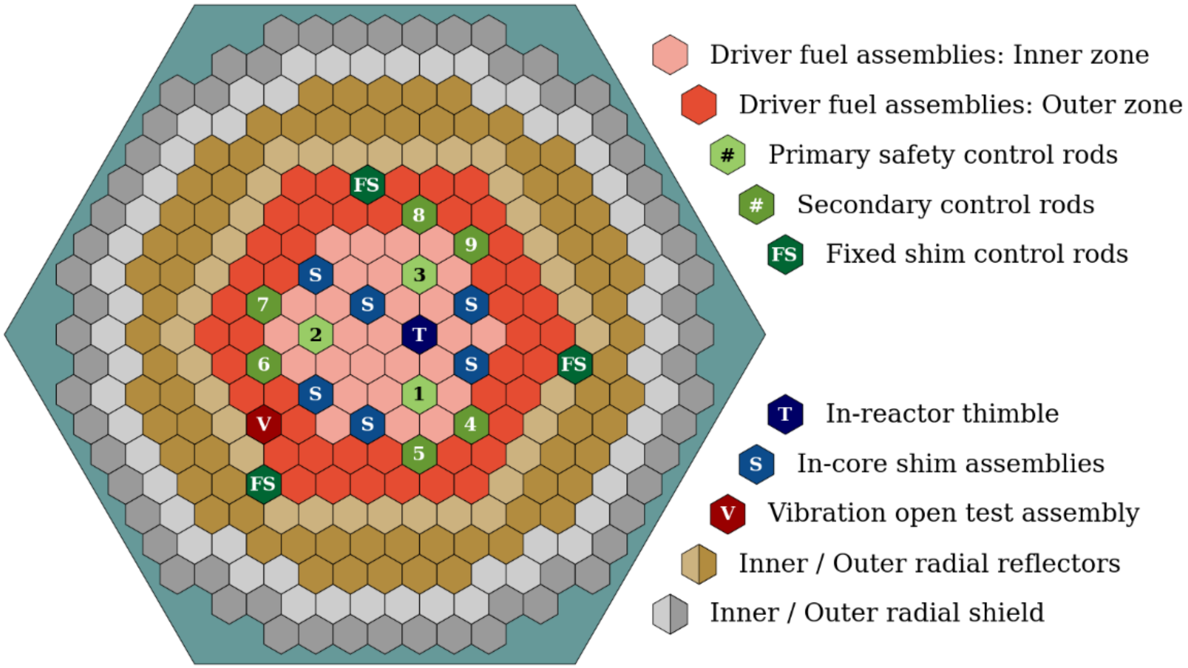
Motivation and objectives

- Father assessment of XS generation methodology

- Validation of Serpent-DYN3D vs. SFR experiments

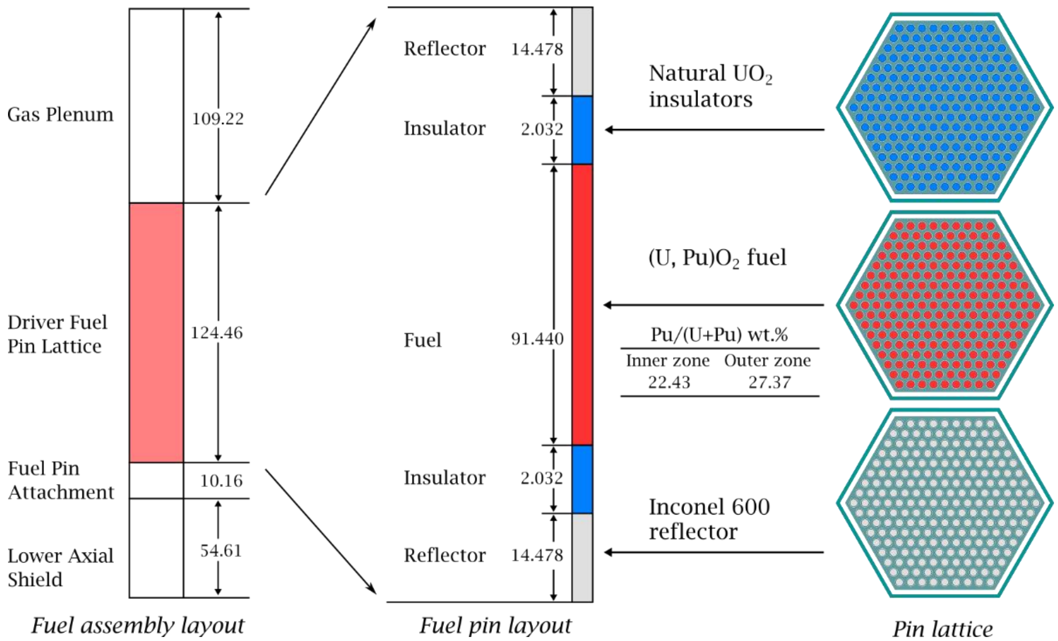
- Preparation for future transient analysis of unprotected LOFA in FFTF

FFTF core data



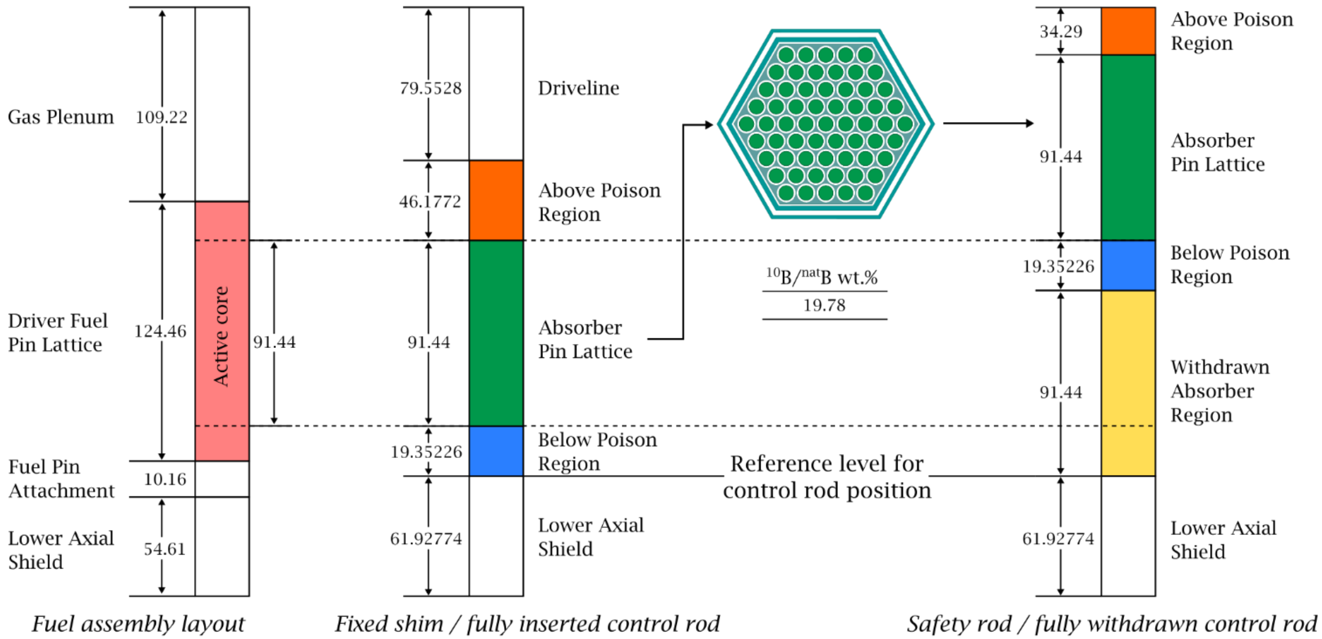
- 27 MOX assemblies in inner zone (19.8 wt.% Pu)
- 46 MOX assemblies in outer zone (24.4 wt.% Pu)
- 12 identical CR assemblies with three different roles:
  - 3 primary safety rods / 6 secondary control rods / 3 fixed absorber rods
- Isothermal state corresponding to ~204°C (400°F)

FFTF fuel assembly data



- Detailed geometry is only for the pin region (fuel and CR)
- The rest are homogenized by regions
- 217 MOX pins

FFTF control assembly data



- Detailed geometry is only for the pin region (fuel and CR)
- The rest are homogenized by regions
- 61 B4C pins

Compared parameters

- K-eff
- Isothermal temperature coefficient
- Control rod related reactivity measurements
  - Rod worth
  - Differential rod worth for six secondary control rods
  - Rod bank worth
  - Shutdown margin
  - Excess reactivity

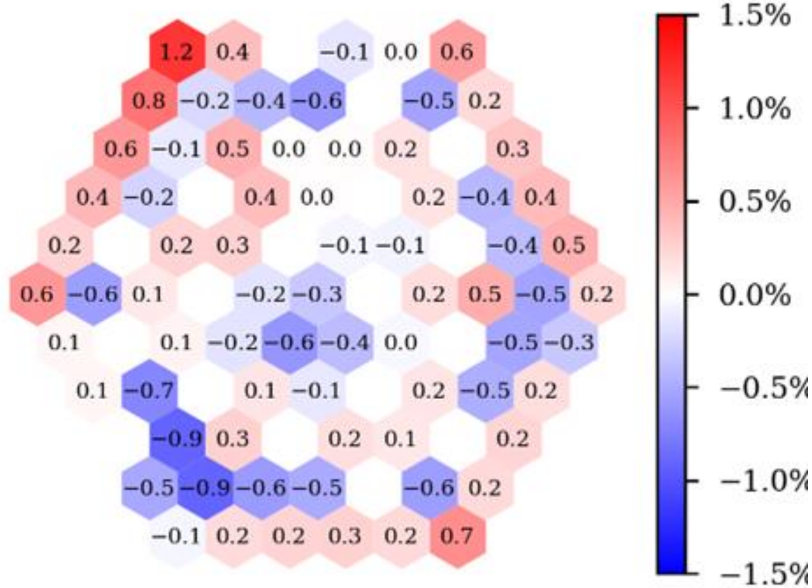
Results

K-eff critical core

Experiment	Calculated			Δρ, pcm		
	INL/MCNP	Serpent	DYN3D	INL/MCNP	Serpent	DYN3D
0.99927 ± 0.00211	1.0030 ± 0.0001	1.00284 ± 0.00003	1.00132	370	357	205

- Excellent agreement between MCNP and Serpent (< 20 pcm)
- Very good agreement between DYN3D and Serpent (< 160 pcm)

Radial power distribution, DYN3D vs. Serpent



- Max. difference < 1.2%
- RMS difference = 0.4%

Isothermal temperature coefficients

Isothermal temperature coefficient, $\Delta\rho \pm \sigma$ (¢/K)			
Experiment	INL/MCNP	Serpent	DYN3D
-1.26 ± 0.19	-1.17 ± 0.18	-1.19 ± 0.02	-1.50

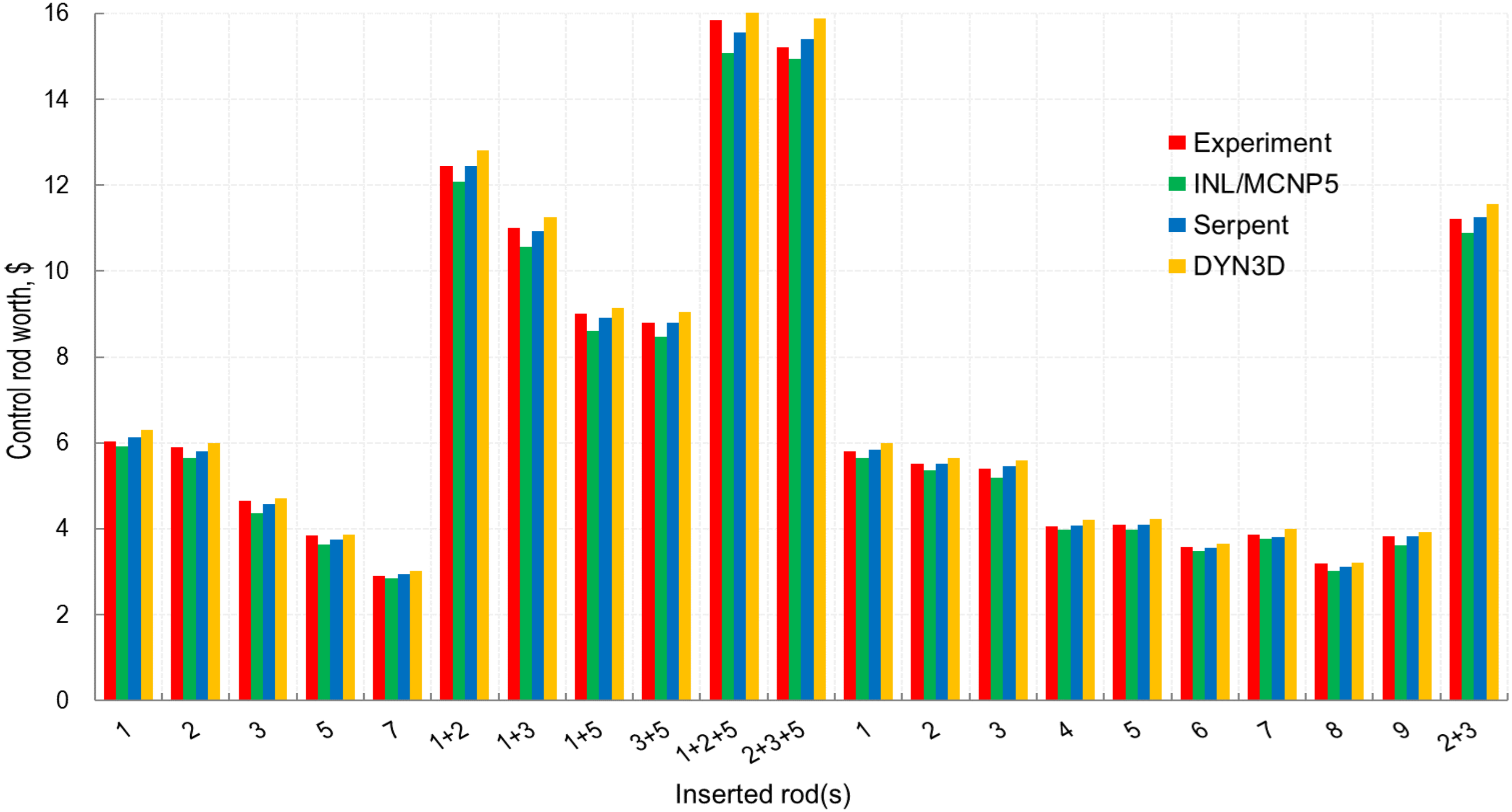
- Temperature adjustment by ±25 K
- Doppler + uniform thermal expansion are accounted for
- Excellent agreement between MCNP and Serpent
- MCNP and Serpent results are within 1σ measurement uncertainty
- DYN3D result is within 2σ measurement uncertainty

CR worth: measured rods and related reference states

Reference	R0	R1	R2	R3	R4	R5	R6	R7	R8	R9	R10
1 (Safety)	91.4	91.4	91.4	91.4	91.4	91.4	91.4	91.4	91.4	91.4	91.4
2 (Safety)	91.4	91.4	91.4	91.4	91.4	91.4	91.4	91.4	91.4	91.4	91.4
3 (Safety)	91.4	91.4	91.4	91.4	91.4	91.4	91.4	91.4	91.4	91.4	91.4
4 (Control)	36.1	0.0	35.3	91.4	24.4	26.4	25.4	27.7	25.7	35.1	34.8
5 (Control)	35.6	91.4	35.3	24.6	91.4	26.4	25.4	27.7	25.7	35.1	34.8
6 (Control)	35.6	0.0	35.3	24.6	24.4	91.4	25.4	27.7	25.7	35.1	34.8
7 (Control)	35.6	71.1	35.3	24.6	24.4	26.4	91.4	27.7	25.7	35.1	34.8
8 (Control)	35.6	0.0	35.3	24.6	24.4	26.4	25.4	91.4	25.7	35.1	34.8
9 (Control)	35.6	0.0	35.3	24.6	24.4	26.4	25.1	27.7	91.4	35.1	34.8

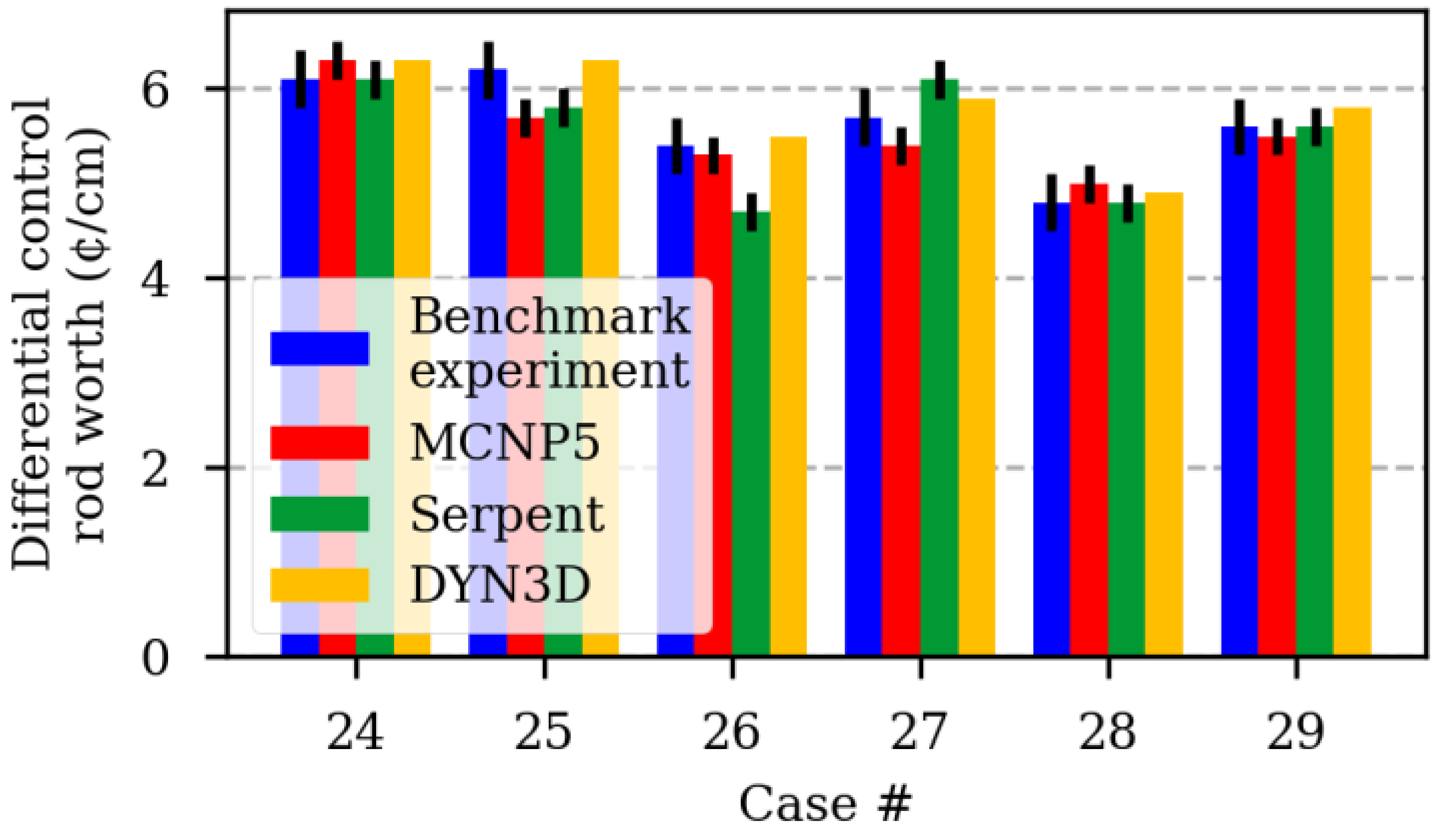
Case #	Reference	Inserted rod(s)		Case #	Reference	Inserted rod(s)
1	R1	1		12	R2	1
2	R1	2		13	R2	2
3	R1	3		14	R2	3
4	R1	5		15	R3	4
5	R1	7		16	R4	5
6	R1	1+2		17	R5	6
7	R1	1+3		18	R6	7
8	R1	1+5		19	R7	8
9	R1	3+5		20	R8	9
10	R1	1+2+5		21	R9	2+3
11	R1	2+3+5				

CR worth



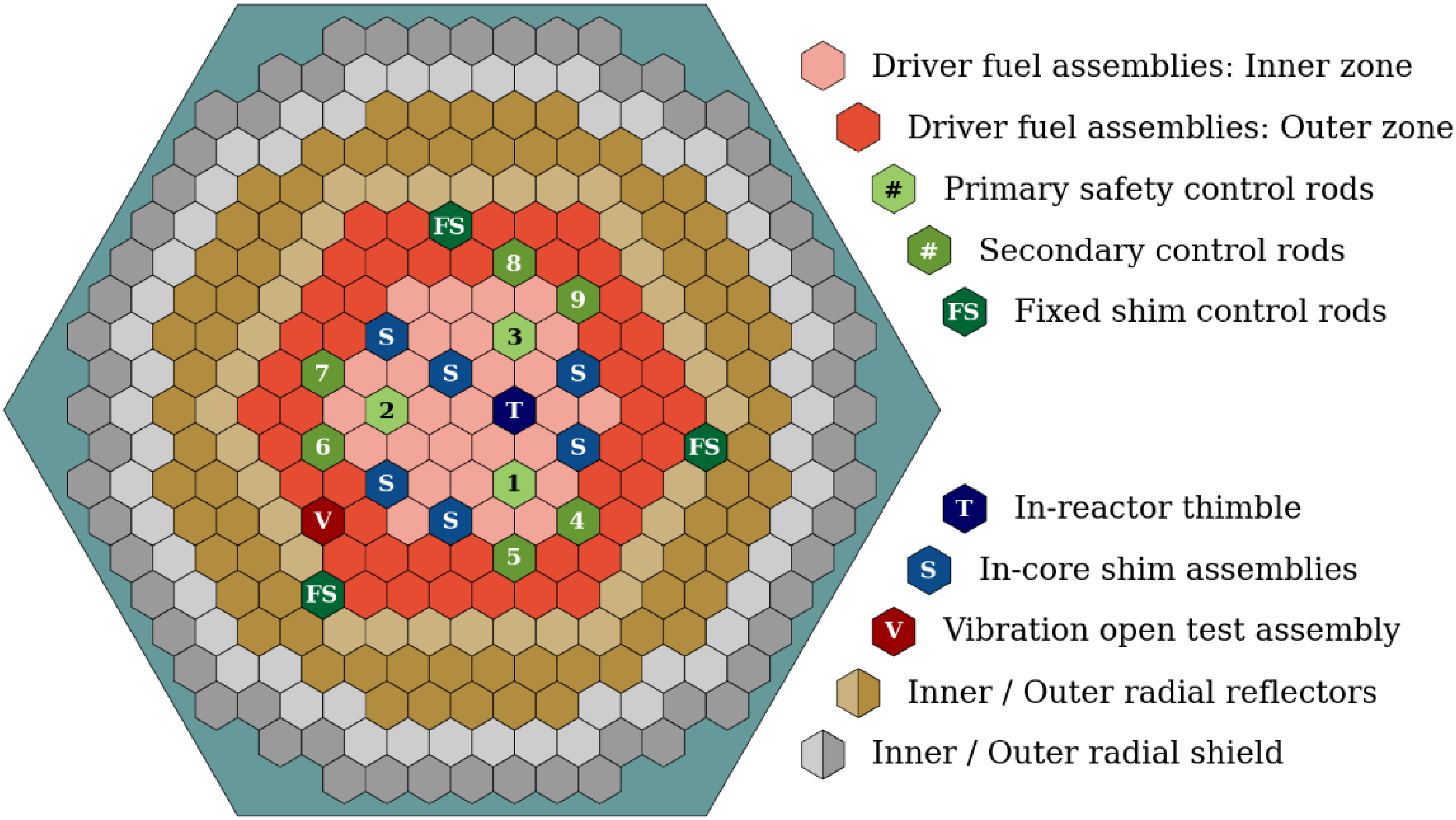
- Full insertion of CR (s) from different reference states
- Serpent and DYN3D are within exp. uncertainty of 5-6%
  - 1σ experimental uncertainty

Differential worth of 6 secondary control rods

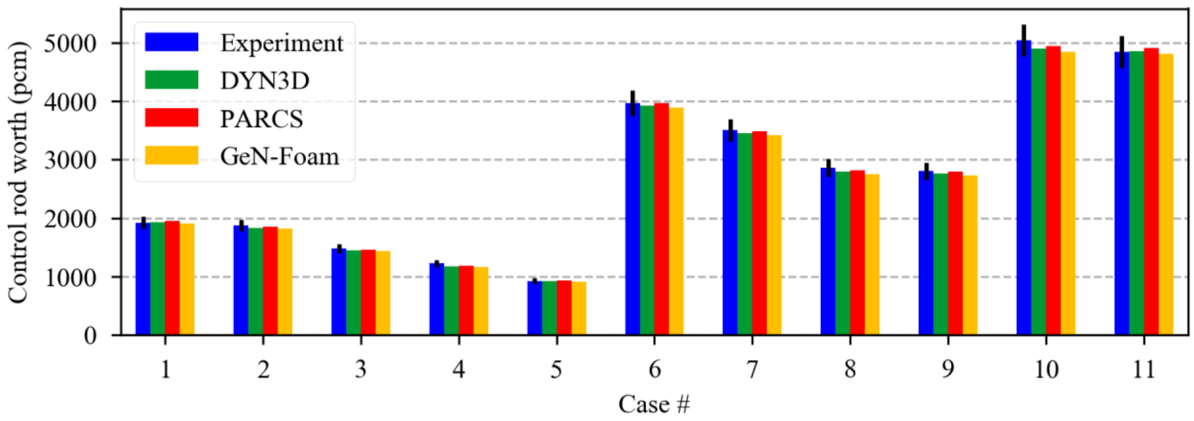


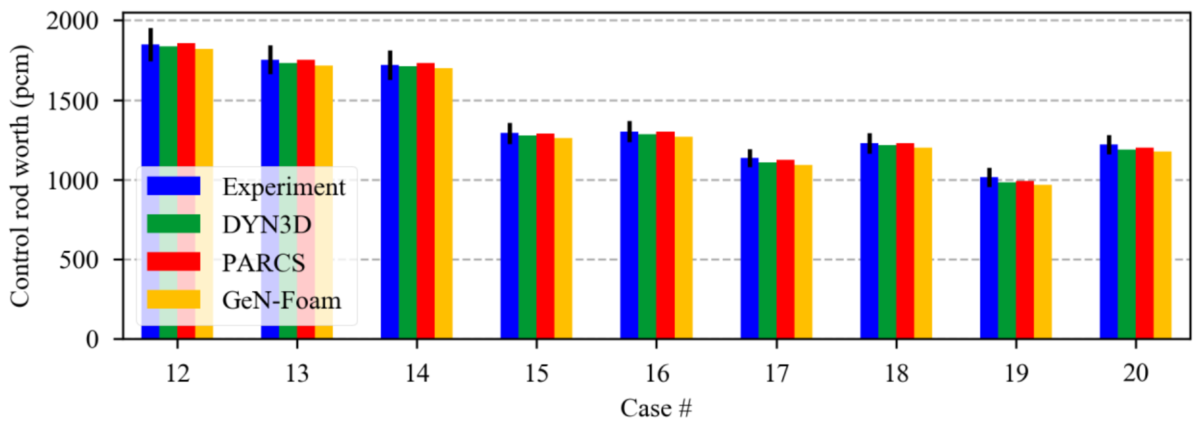
- CR shift by ±2.54 cm from reference state R10
- Serpent and DYN3D agree with measurements within 0.6 ¢/cm
  - 2σ experimental uncertainty

FFTF core


FS
8
9
3
S
S
S
7
2
T
6
S
FS
S
1
V
S
4
5
FS
Driver fuel assemblies: Inner zone
Driver fuel assemblies: Outer zone
Primary safety control rods
Secondary control rods
Fixed shim control rods
In-reactor thimble
In-core shim assemblies
Vibration open test assembly
Inner / Outer radial reflectors
Inner / Outer radial shield

CR worth - comparison with other diffusion codes





Summary

- FFTF isothermal physics tests were analyzed with Serpent and DYN3D
  - Compared: k-eff, isothermal temperature coefficient, control rod related reactivities

- C/E for Serpent and DYN3D is typically within 1σ of expr. uncertainty

- Exceptions (C/E within 2σ):
  - Serpent: differential control rod worth
  - DYN3D: differential control rod worth and Isothermal temperature coefficients

- Nodal diffusion and reference MC results show very good agreement

- More details:

  E. Nikitin, E. Fridman,Modeling of the FFTF isothermal physics tests with the Serpent and DYN3D codes, Annals of Nuclear Energy, 132, 2019.

Thank you for your attentions