Generation of SFR few-group constants by Serpent

E. Fridman

HZDR
HELMHOLTZ
ZENTRUM DRESDEN
ROSSENDORF

Outline

- Introduction
- Description of the codes
- Description of the reference SFR cores
- Approach to few-group XS generation
- Verification of few-group XS generation methodology

Introduction

- General purpose MC codes
  - Available for a long time
    - MCNP, TRIPOLI, MVP, MCARD, …
  - “Best available” physics
  - Criticality and reaction rates
  - Can be coupled with depletion and T-H solvers
- Still too expensive for full-scale reactor calculations
  - Neutronics + TH + BU + kinetics
- Two-step procedure still dominates reactor analysis
  - Deterministic 2D lattice codes → homogenized constants
  - Deterministic 3D coarse mesh core simulators

Using MC codes for few-group XS generation

- Increasing interest in using MC for homogenization
  - Improved computer performance
  - Flexibility - not limited to any particular technology
  - Especially useful for the modeling of innovative reactor concepts

- Dedicated reactor physics MC codes
  - Serpent (2008), VTT, Finland
  - RMC (2011) Tsinghua University, China
  - OpenMC (2013) MIT, USA

Objectives

- To show the Serpent applicability to the generation of SFR few-group constants

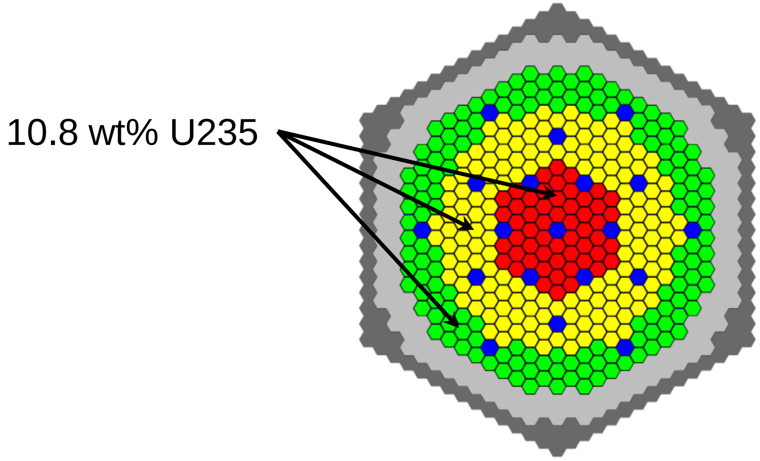
Considered nodal codes

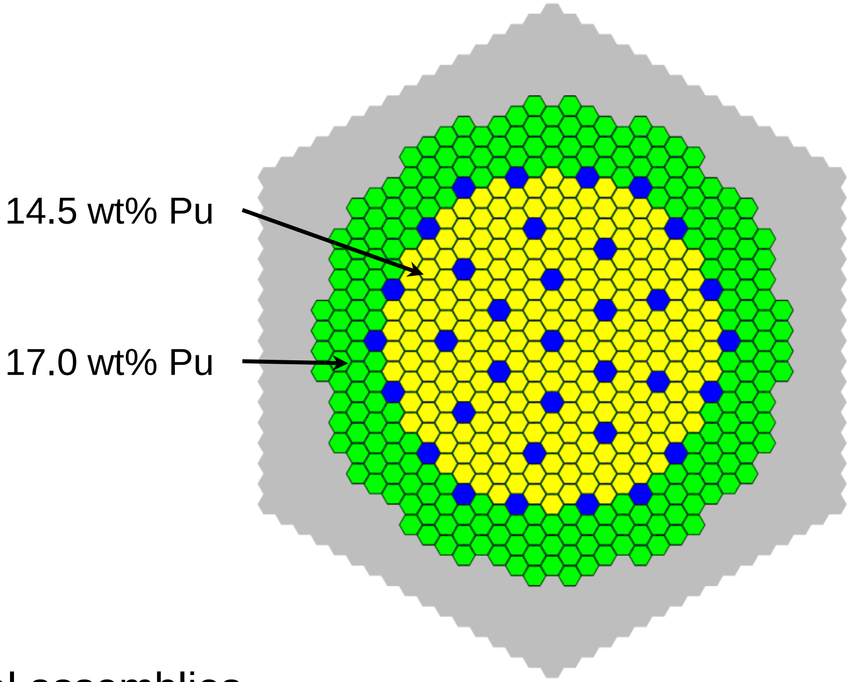
Code	DYN3D	PARCS
Developers	HZDR	Purdue/Michigan Univ.
Neutronics	• 3D multi-group diffusion and SP3 • Nodal expansion methods • Steady-state and transient	
Geometry	Square and hexagonal	
T-H	Built-in	Coupled with TRACE
Notes	• Developed for LWRs • Being extended to SFR analysis • Updated T-H module • Development of T-M module	• Part of the FAST code system for fast reactor transient analysis • Developed at PSI

Application examples:
2D simplified SFR cores

2D SFR cores

- U startup SFR (USFR)
  - 2400 MW
  - 360 UC fuel subassemblies
  - 19 control subassemblies
  - 16.14 cm lattice pitch
- European SFR (ESFR)
  - 3600 MW
  - 453 Pu MOX fuel subassemblies
  - 33 control subassemblies
  - 21.08 cm lattice pitch

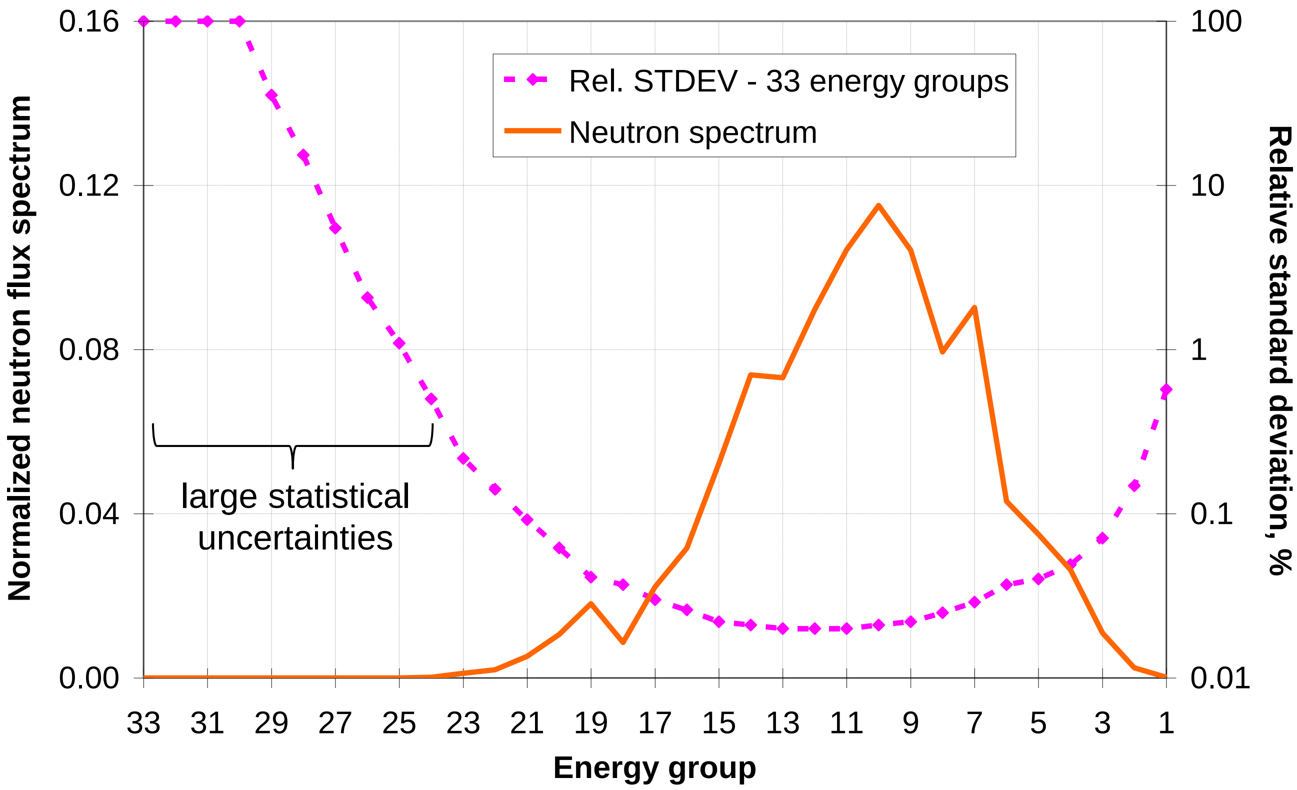




Red, ***yellow***, ***green*** – fuel assemblies,
Blue – control assemblies,
Light grey – reflector, ***dark grey*** – shield

Methodological approach for few-group XS generation

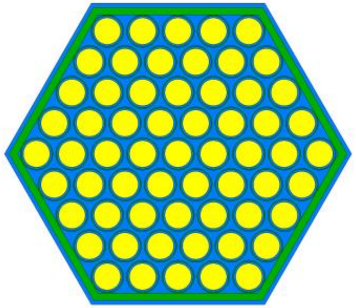
Selection of few-group energy structure



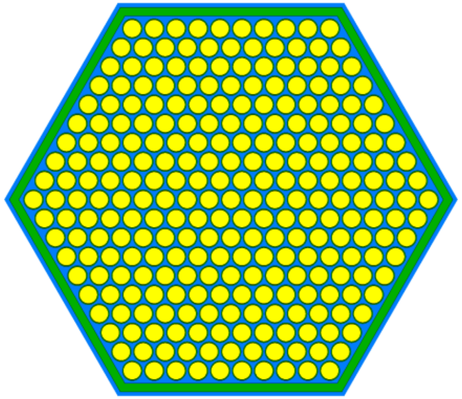
- 33 group structure is not appropriate
  - Poor statistics in thermal energy groups
- 24 group structure is selected
  - Groups 24 to 33 collapsed into a single thermal group

Few-group XS for fuel assemblies

- Generated in infinite assembly lattice calculations
- For fuel sub-assemblies not facing non-multiplying regions



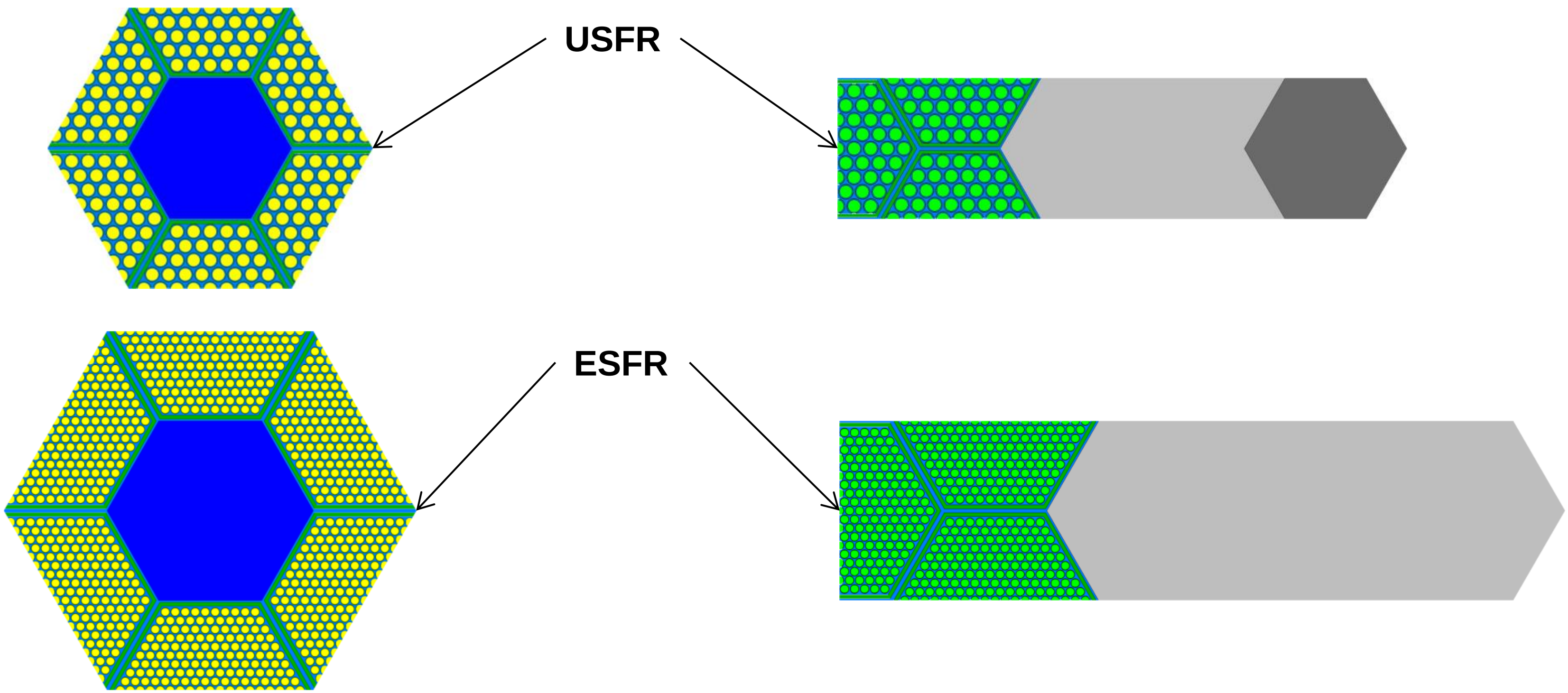
USFR fuel assembly



ESFR fuel assembly

Few-group XS for reflector and CA regions

- Generated in super-cell models
  - Fuel and non-multiplying regions are coupled in space and energy
- XS for adjacent fuel assemblies are also extracted
  - Accounting for spectral effects of non-multiplying regions



Fuel-CSD Models

Fuel-Reflector Models

Verification of few-group XS generation methodology

Verification of XS generation methodology

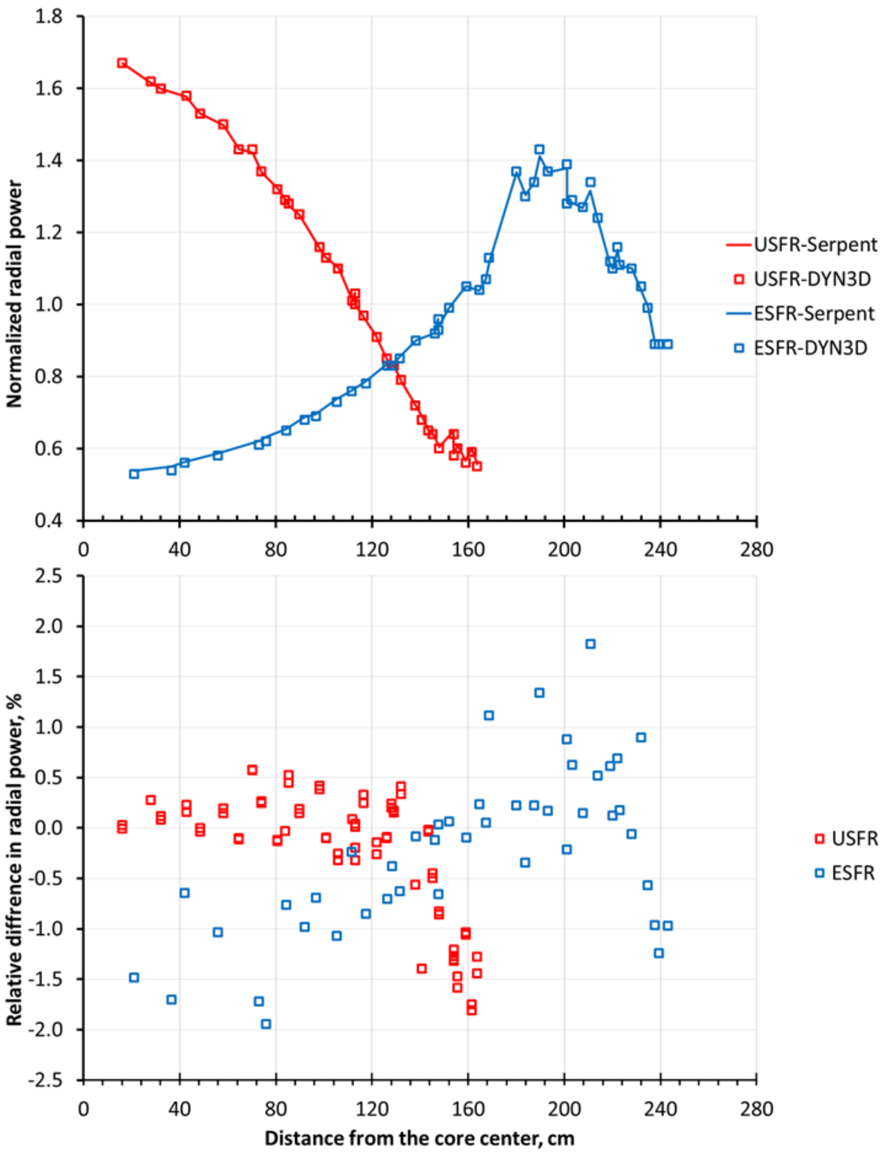
- 2D full core calculations
  - USFR and ESFR at BOL
  - Burnup calculations for ESFR

- DYN3D
  - Diffusion solution

- Serpent:
  - Reference solution
  - Few-group XS for DYN3D

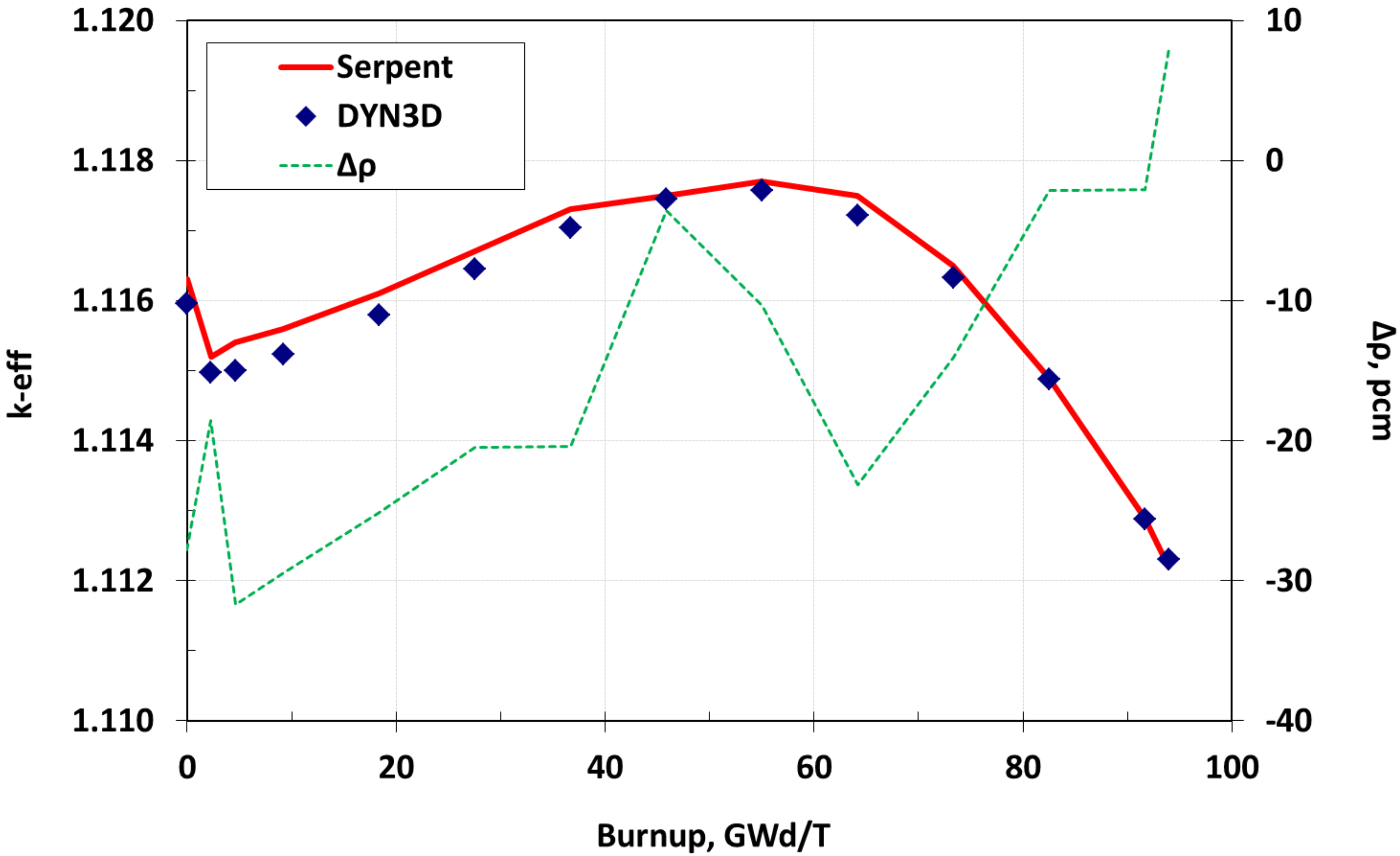
- Compared parameters:
  - k-eff
  - Doppler constant
  - Coolant void reactivity
  - Total control rod worth
  - Radial power distribution

USFR and ESFR: nominal state



- **Δρ**
  - USFR: -38 pcm
  - ESFR: -23 pcm
- **Ave. diff. in radial power**
  - USFR: 0.5%
  - ESFR: 0.6%
- **Max. diff. in radial power**
  - USFR: 1.8%
  - ESFR: 1.9%

ESFR core: k-eff vs. burnup



ESFR core: feedback parameters

Parameter	Stage	Serpent, pcm	DYN3D vs. Serpent, pcm
Doppler constant	BOL	-1062	**-10**
	EOL	-723	**0**
Na void reactivity	BOL	2821	**29**
	EOL	3654	**47**
Total CR worth	BOL	-4678	**49**

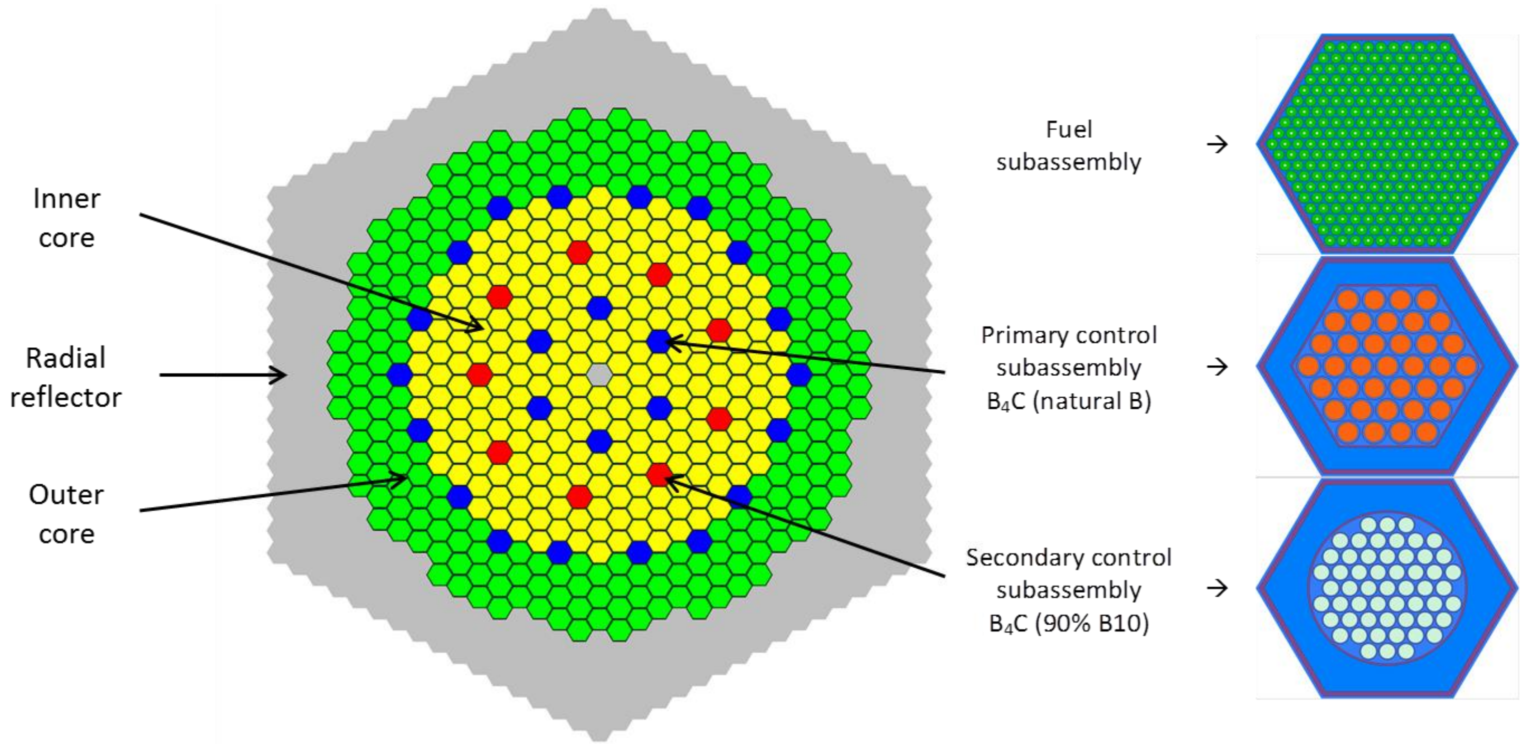
Application examples:
3D SFR core

3D SFR core

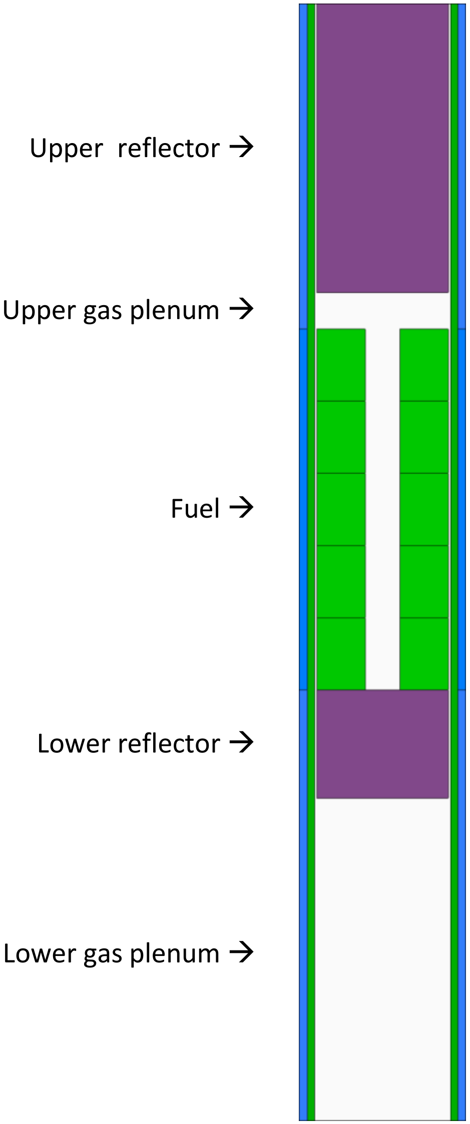
- OECD/NEA SFR Benchmark

https://www.oecd-nea.org/science/wprs/sfr-taskforce/

  - 3600 MW
  - Fuel: 225 inner and 228 outer subassemblies
  - Control: 18 primary and 9 secondary subassemblies



3D SFR core: axial layout

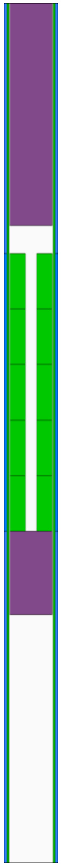


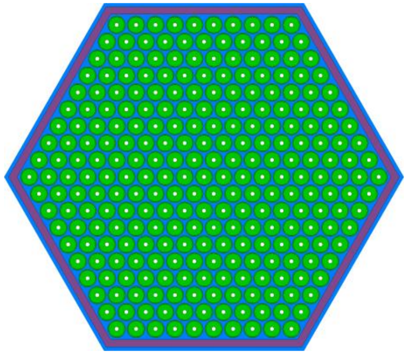
Axial Pu content

Inner core	Outer core
15.4%	17.3%
15.8%	17.5%
16.0%	17.6%
15.9%	17.6%
15.6%	17.4%

Few-group XS for fuel assemblies

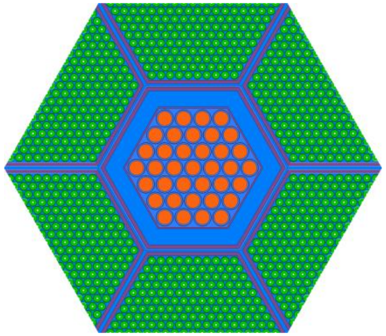
- 3D single-assembly model
  - Reflective radial and black axial boundary conditions



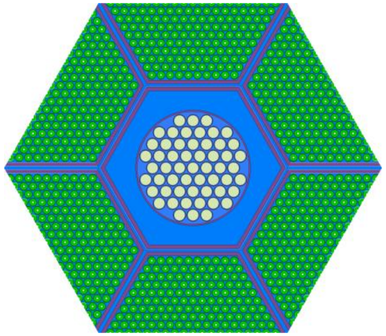


Few-group XS for non-multiplying regions

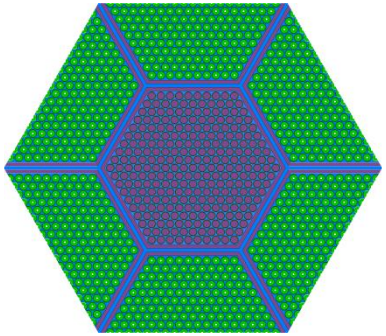
- Primarily as in 2D case
  - Super-cell models



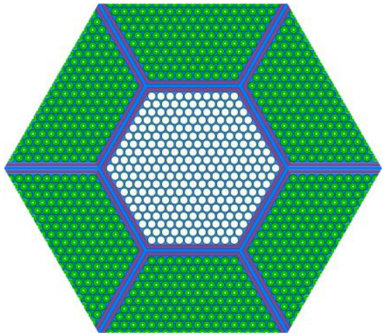
Primary control



Secondary control



Axial reflector



Gas plenum

Peripheral fuel
assemblies

Further verification of XS generation methodology

- 3D full core calculations
  - At BOL

- DYN3D and PARCS
  - Diffusion solution

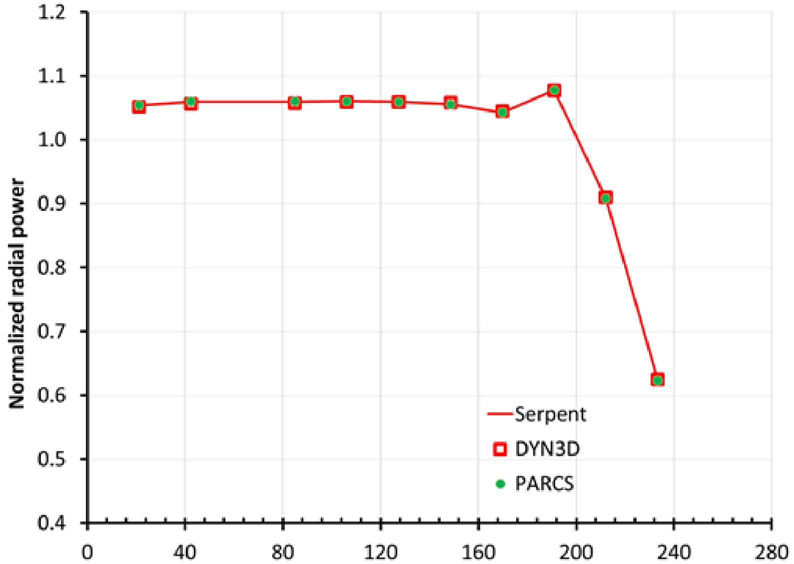
- Serpent:
  - Reference solution
  - Few-group XS for DYN3D and PARCS

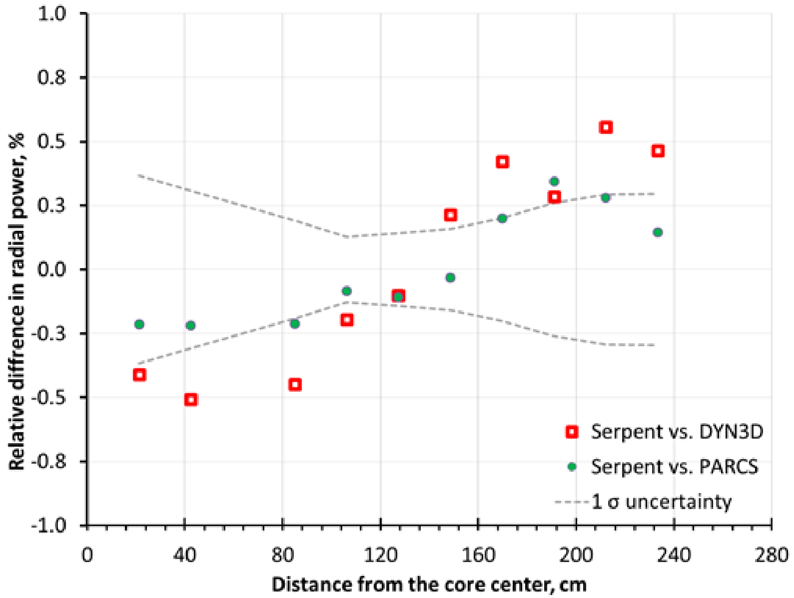
- Compared parameters:
  - k-eff
  - Doppler constant
  - Coolant void reactivity
  - Control rod worth
  - Radial power distribution

3D SFR: Nominal state

	Serpent	DYN3D	PARCS	DYN3D vs. Serpent, pcm	PARCS vs. Serpent, pcm
k-eff	1.01070	1.00940	1.00984	-128	-84

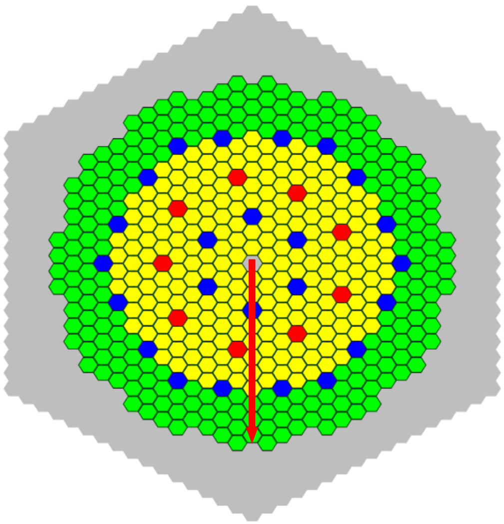
3D SFR: Nominal state





- **Δρ**
  - vs. DYN3D: 128 pcm
  - vs. PARCS: 84 pcm

- **Max. diff. in radial power**
  - vs. DYN3D: 0.56%
  - vs. PARCS: 0.34%



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3D SFR: Feedback parameters

Parameter	Serpent, pcm	DYN3D vs. Serpent, pcm	PARCS vs. Serpent, pcm
Doppler constant	-852	-15	-15
Na void reactivity	1864	87	81
Total CR worth	-6046	-127	-180

Summary and conclusions

- Serpent based few-group XS were used by nodal codes
  - DYN3D and PARCS
  - 2D and 3D nodal diffusion calculations of SFR core

- Verification of results
  - Diffusion vs. full core Serpent MC solution
  - Very good agreement between the codes

- Next steps
  - Application to the ASTRID analysis (European FP7 ESNII+ project)
  - Accounting for thermal expansion effects

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