Results of neutron physics calculations for benchmark of SFR ASTRID core of ESNII+ project

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Outline

- Benchmark input data
- Calculation tool
- Modelling assumptions
- Results

Input data

- **Benchmark input data**
  - ***Deliverable D6.1.1-1 ASTRID Core Specifications*** (CEA)
  - **xls**-data file ***ASTRIDCoreSpecificationTemplate_v6b*** (PSI)
- provide:
  - core structures design and nominal operating conditions
  - temperature dependent material and atomic densities
  - temperature dependent structure geometry
- and equations defining their mutual changes for different core states

Calculation tool

- **KANEXT code system** (deterministic) used with two-step calculation procedure:

- 1st step - XS:
  - 350-group JEFF3.1.1-based ("in-house" library)
    collapsed to 33 groups (ERANOS-like)
  - homogeneous unit cell representation, resonance self-shielding done by the Bondarenko method and the narrow resonance approximation

- 2nd step - 3D core:
  - VARIANT (included as a module), SP33 and P33 options

- applied successfully for SFR projects during more than 5 years
- well approved and tested calculation route for SFRs

Modeling assumptions

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- Core model with 19 mixtures (homogenized)

- EOEC core state (no burnup modeling)

- Based on xls-file input values and “build-in” equations the n.ph.model is prepared for every core state of interest characterized by
  - specific region dimensions and arrangement
  - material temperatures
  - corresponding materials volumetric fractions
  - corresponding atomic densities

- the influence of calculation mesh is neglected while keeping similar mesh
- power fraction in non-fuel region is neglected (up to 2% of total)

Results (1/9)

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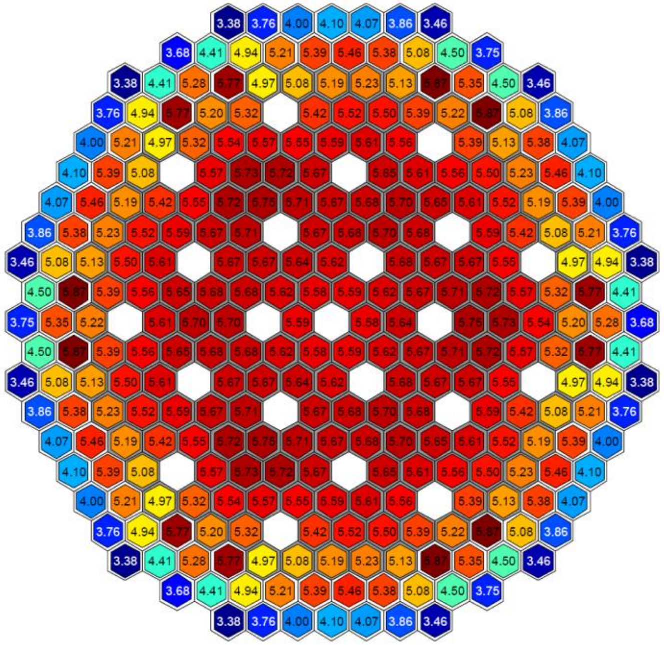
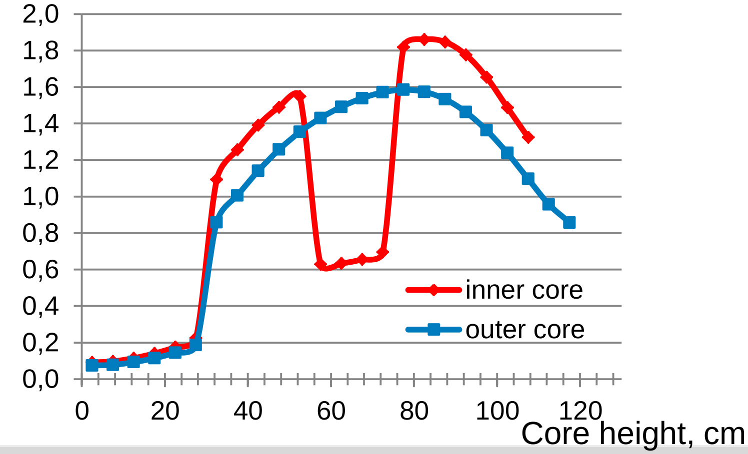
- **Initial core state** (at n.o.c.):

Parameter	Value IC	Value OC
Total core power, MW	1500.00	
Subcore powers, MW	973.98	526.02
SA number in subcores	177	114
Subcore volumes, m3	5.27	3.70
Total core volume, ccm	8.97	
Average SA power in subcores, MW	5.503	4.614
Maximum SA power in subcores, MW	5.750	5.874
Minimum SA power in subcores, MW	4.974	3.377
Subcore radial peak.factor (for SA)	1.045	1.273
Maximum power density in core, W/ccm	360.4	
Average power density, W/ccm	167.2	
Volumetric peak.factor	2.156	
Maximum power density, ccm	360.4	287.5
Average power density in subcores, W/ccm	184.8	142.1
Minimum power density in subcores, W/ccm	12.9	9.5
Volumetric peak.factors in subcores	1.950	2.024
Maximum linear power, W/cm	446.1	355.9
Average linear power, W/cm	228.8	175.9
Maximum power density in av.SA, W/ccm	343.9	225.2

SA power map, MW

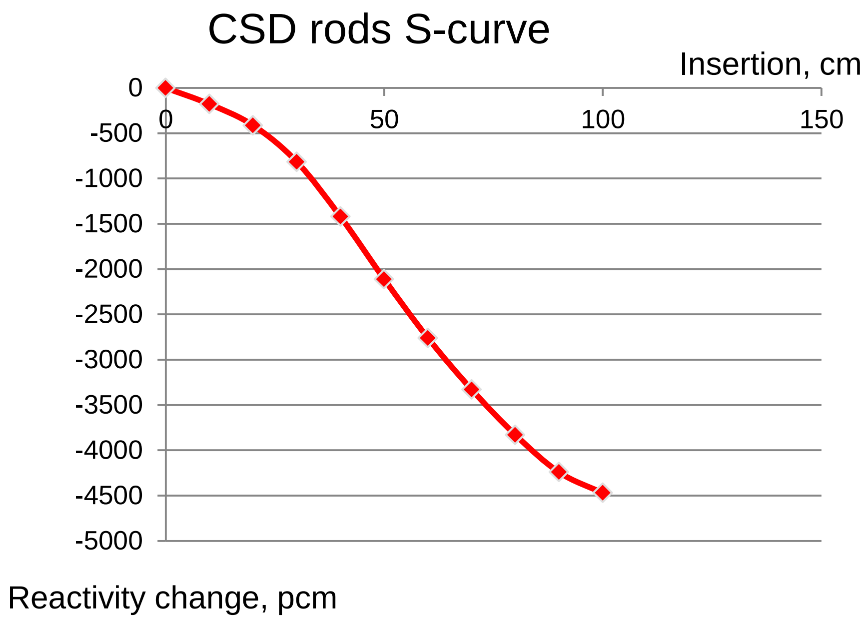


Normalized power at av.SA



Results (2/9)

- **Control rods worth and S-curve:**
  - initial core reactivity: very close to criticality (-34pcm)
  - SP33 -> P33 gives +200 pcm
  - CSD rods worth: -4472 pcm
  - SCRAM 1 (CSD+DSD): -6418 pcm
    - initial state to „all CRs inserted“
  - SCRAM 2 (CSD+DSD): -6127 pcm
    - initial state to „all CRs inserted+COLD“



Results (3/9)

- **Doppler effect:**
  - Doppler effect is due to XS change as result temperature change for all fuel isotopes
  - core geometry and material compositions are as at initial core state
  - 4 cases:
    - fissile fuel, both inner and outer: +300K and -300K (1800K and 1200K)
    - fertile fuel, both inner and lower breeders: +300K and -300K (600K and 1200K)

Case	Reactivity change, pcm	Doppler constant, pcm
1 Fissile fuel -300K	+139	-623
2 Fissile fuel +300K	-110	-606
3 Fertile fuel -300K	+128	-314
4 Fertile fuel +300K	-88	-305

Results (4/9)

- **Sodium void effect:**
  - calculated with P33 option of VARIANT
  - removal of “inner” sodium (82% of total for pin bundle, 94% for sodium plenum)
  - heterogeneity effect is neglected (rather small)

Case	SVE, pcm
S1 – Above IF	-1395
S2 – Upper IF	+479
S3 – IB	+355
S4 – Lower IF	+228
S5 – Above OF	-259
S6 – OF	+205
S7 – (Above IF) + (Above OF)	**-1625**
S8 – (IF+LF+IB+OF)	**+1272**
S9 – whole core (incl. interassembly gap)	-318
S9.1 – whole core (only within SA)	-440
S7 = S1+S5*	*-1654 (-29)*
S8 = S2+S3+S4+S6*	*+1267 (-5)*
S9.1 = (S1+S5)+(S2+S3+S4+S6)*	*-387 (+53)*

Results (5/9)

- **Fuel rod expansion effect** defined as a reactivity change due to change of cladding temperature:
  - pins expand in axial direction; the active core height increases with consideration of fuel mass conservation ("linked")
  - cladding and fuel density decrease
  - pin diameter increases, leading to decrease of "inner" sodium fraction in the core cross-section; the cladding fraction increases

    - Doppler effect on clad steel isotopes is not accounted

Case	Reactivity change, pcm	Effect, pcm/K
1 Clad +200K	-32	-0.16
2 Clad +400K	-64	-0.16

Results (6/9)

- **Coolant expansion effect** defined as a reactivity change due to change of coolant (sodium) temperature:
  - for active core height (initially at core average temperature of 750K)
  - for upper regions like upper gas expansion zone, sodium plenum and upper shielding (initially at outlet temperature of 820K)

Case	Reactivity change, pcm	Effect, pcm/K
1 Coolant +200K	+18	-0.09
2 Coolant +400K	+32	-0.08

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Results (7/9)

- **Diagrid expansion effect** defined as a reactivity change due to change of diagrid temperature:
  - diagrid steel density decreases
  - SA pitch in diagrid expands
  - other radial and axial dimensions of SA elements stay initial along with corresponding initial material densities
  - volumetric fractions of core materials change, in particular, the sodium fraction increases whereas all other fractions decrease

Case	Reactivity change, pcm	Effect, pcm/K
1 Diagrid +200K	-189	-0.94
2 Diagrid +400K	-384	-0.96

Results (8/9)

- **Wrapper expansion effect** defined as a reactivity change due to change of wrapper temperature:
  - wrapper steel density decreases
  - wrapper axial dimension expands leading to increase of SA height
  - pin dimensions stay intact, thus the active core height, fuel and cladding masses are conserved
  - fraction of wrapper increases along with decrease of sodium fraction whereas other core material fractions stay intact

Case	Reactivity change, pcm	Effect, pcm/K
1 Wrapper +200K	+20	0.10
2 Wrapper +400K	+40	0.10

Results (9/9)

- **Kinetics parameters**:
  - Prompt neutron lifetime: 4.54E-07 s
  - Delayed neutrons:

	1	2	3	4	5	6	7	8	total
Beta eff.	6.1	60.7	20.2	55.2	106.5	51.2	38.0	19.9	357.8
Decay constant, 1/s	1.25E-02	2.83E-02	4.25E-02	1.33E-01	2.92E-01	6.66E-01	1.63E+00	3.55E+00	

Thank you for attention!

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