UFMG UNIVERSIDADE FEDERAL DE MINAS GERAIS
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Thermal-hydraulic Modeling of a Small Modular Reactor Core Using RELAP5

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1. Introduction - Small Modular Reactors (SMRs)

- Up to 300 MWth
- Reduced size
- Modularization
- Improved safety

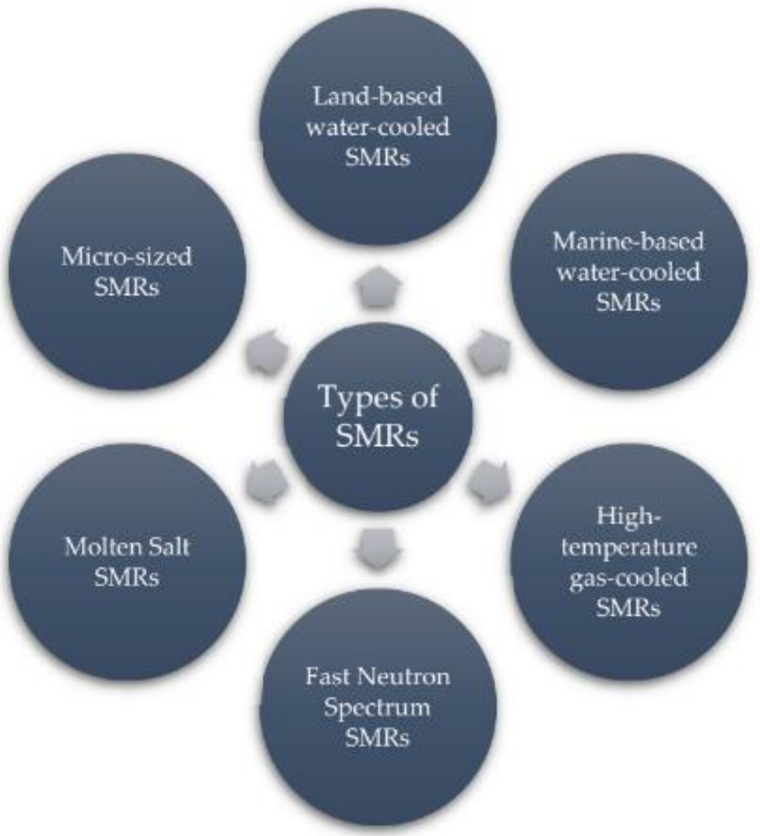

Figure 1: Classification of SMRs according to the IAEA [1].

1. Introduction - System-integrated Modular Advanced Reactor (SMART)

- Pressurized Water Reactor (PWR)
- 330 MWt
- Four coolant pumps
- 12 steam generators
- 57 fuel assemblies (17x17)
- 264 fuel rods per fuel assembly

  (8.05 mm *D* / 2.0m *L*)
- UO_2 (4.95%)
- No soluble boron

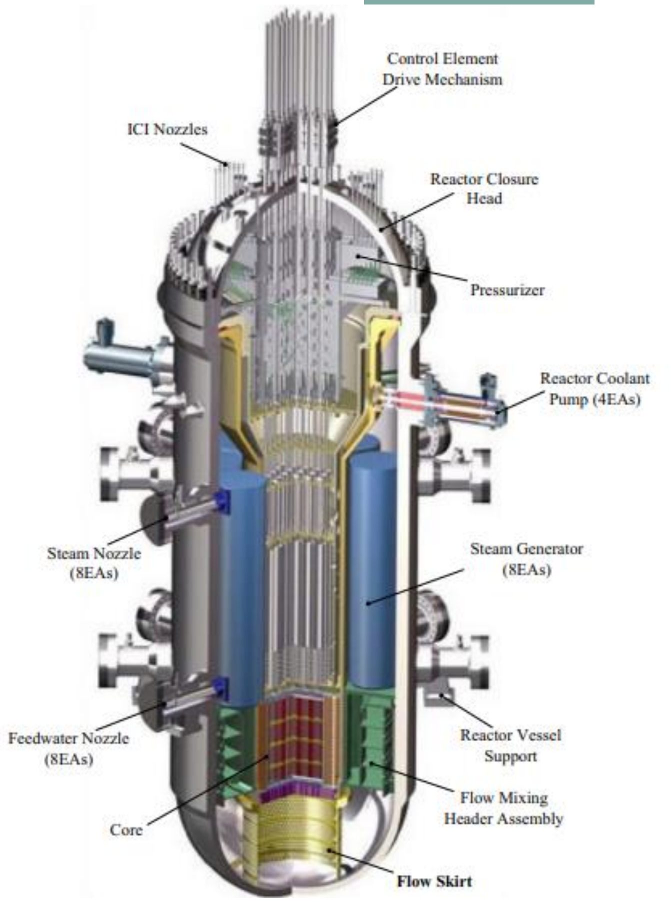

Figure 2: Pressure vessel of SMART [2].

1. Introduction - SMART

Table I: General characteristics of fuel assemblies used on SMART [1].

Fuel Assemblies				
Type	Total Number	Number of Fuel Rods	Number of Al_2O_3-B_4C rods	Number of Gd_2O_3-UO_2 rods
A	20	240	24	0
B	16	244	20	0
C	1	236	24	4
D	20	228	24	12

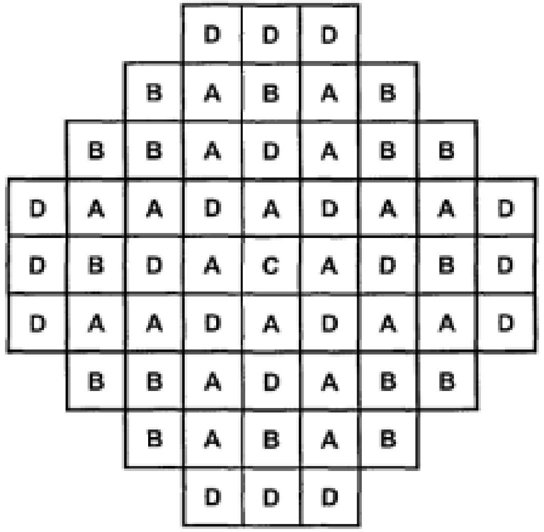

Figura 3: Core loading pattern of SMART [3].

2. Motivations

- Available literature;
- Modeling experience on SMRs;
- Parallel studies in development on the Nuclear Engineering Department (UFMG) – STHIRP and OpenFOAM;
- Part of the INCT (National Institute of Science and Technology) project involving SMRs;
- Optimization potential.

3. Objectives

- Model the components of a SMART core on steady-state operation condition using the RELAP5 MOD3.3 code;
- Verify the nodalization;
- Perform transient calculations on the verified model to assess the system's safety.

4. Methodology

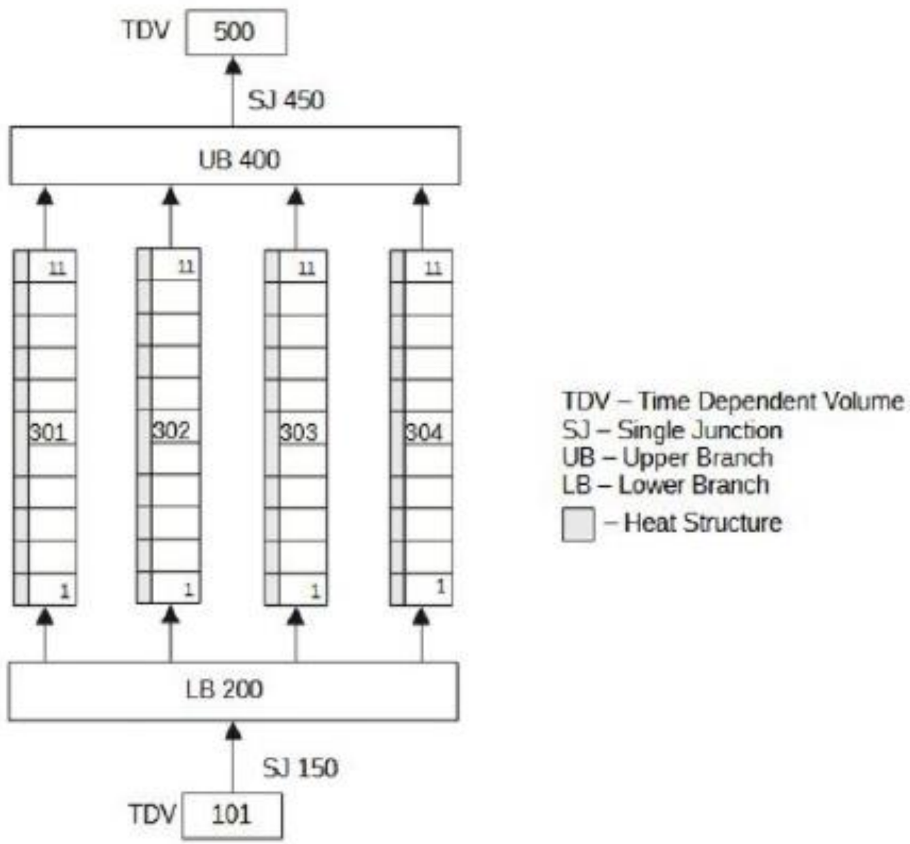

Figure 4: Nodalization of SMART core components.

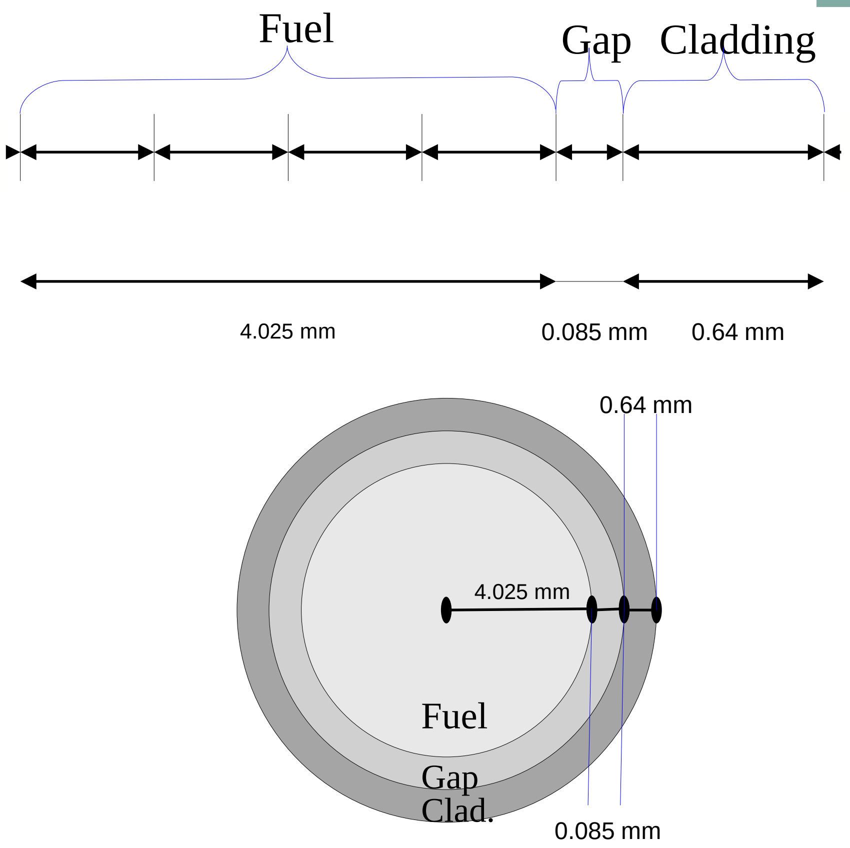

Figure 5: Heat structures mesh point distribution.

4. Methodology

Table II: Entry data for the RELAP5 SMART model [2].

Thermal Hydraulic Channel	Model Identification	Coolant Mass Flow Rate (kg/s)	Number of fuel assemblies/type	Channel Flow Area (m^2)
1	301	733.33	1/C	0.0246
2	302	586.67	20/A	0.4912
3	303	36.67	16/B	0.3930
4	304	733.33	20/D	0.4912

Table III: General entry data for the RELAP5 SMART model [2].

Parameter	**Value**
Pressure	15 MPa
Coolant Mass Flow Rate	2090 kg/s
Coolant Inlet Temperature	543 K
Total flow area	1.4 m^2

5. Results and Discussion

Table IV: Comparison between reference data and RELAP5 calculations [1].

Parameter	Reference data	RELAP5	Error*(%)	Suggested (%) [6]
Power (MW)	330	330	0	2.0
Average outlet coolant temp. (ºC)	310	310.23	0.07	0.5
Core coolant temp. increase (ºC)	40	40.38	0.07	0.5
Core Pressure drop (kPa)	400	359.65	0.28	10
Outlet core mass flow (kg/s)	2090	2090	0	2

*Error = (Reference – Calculated)/Reference

**List or requirements for the steady state qualification of a nodalization [6]

5. Results and Discussion

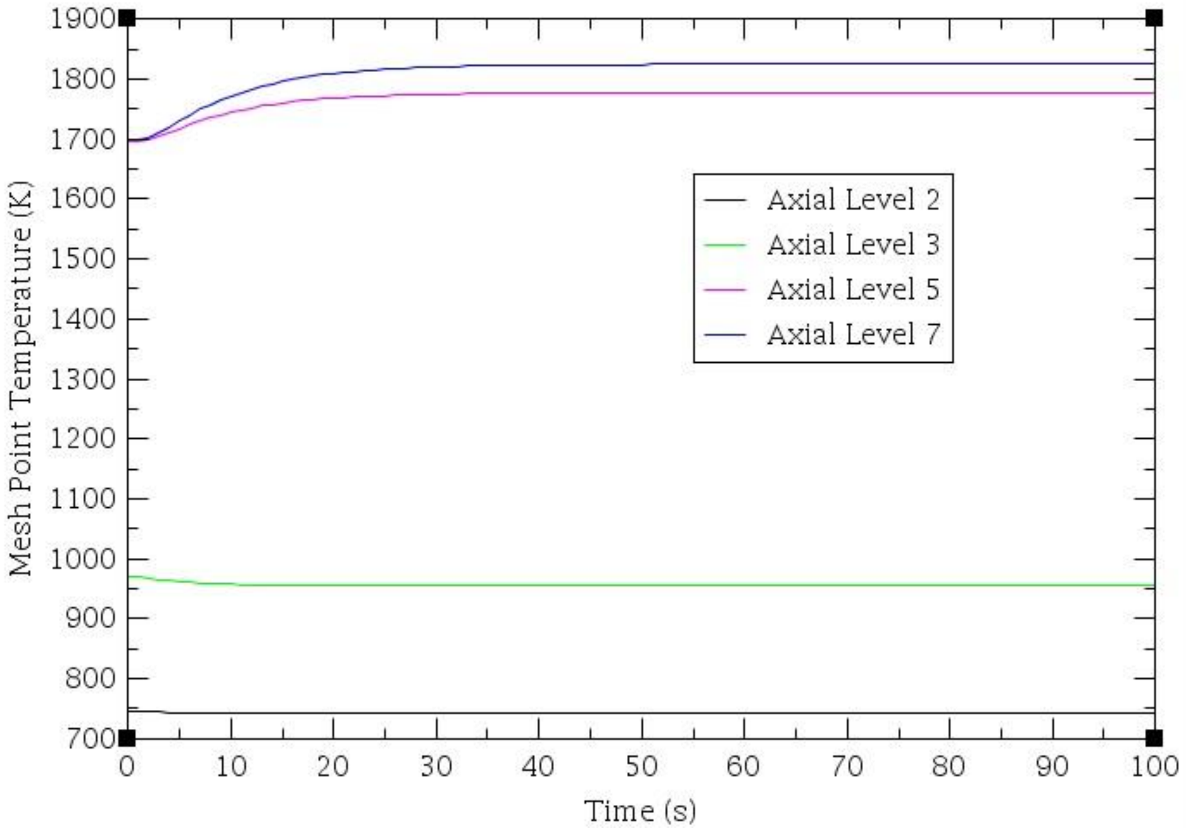

Figure 7: Central fuel temperature for TH channel 303.

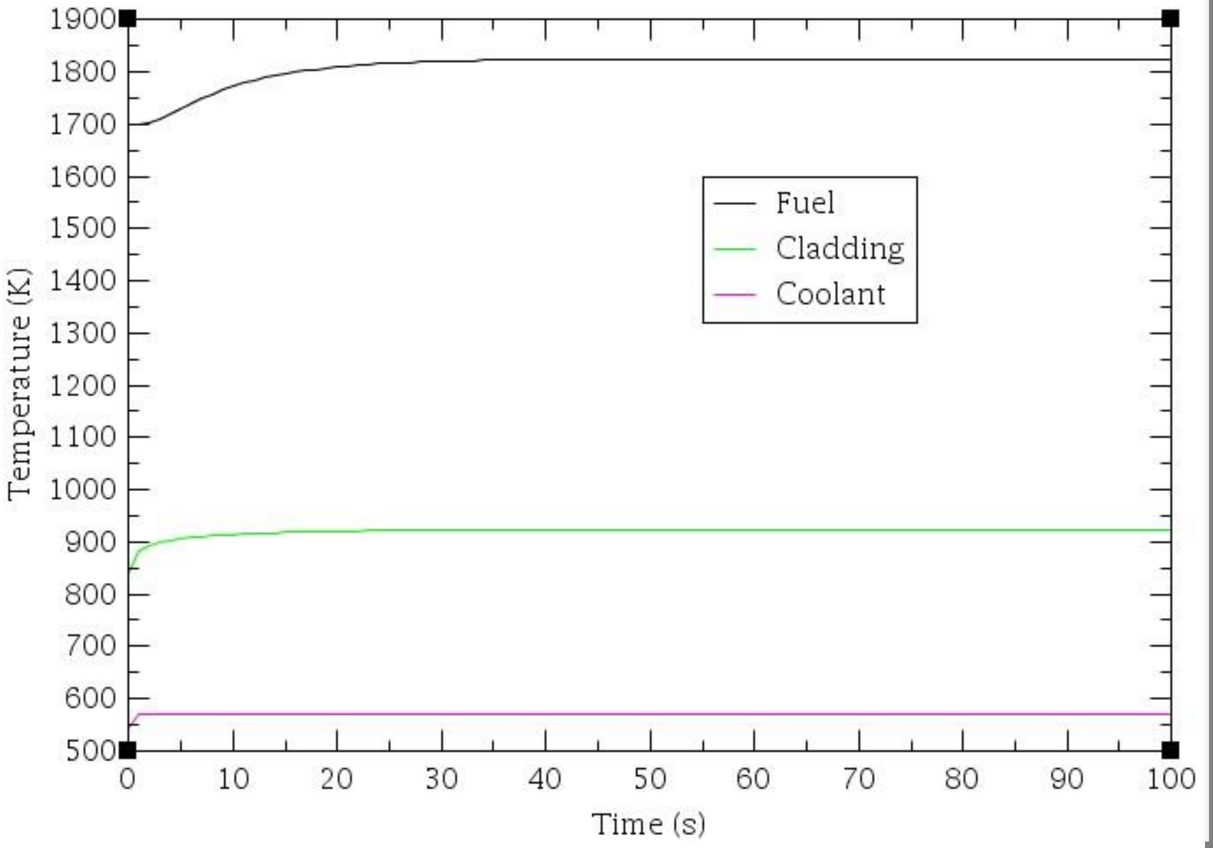

Figure 8: Fuel, cladding and coolant temperatures for axial level 7 of TH channel 303.

5. Results and Discussion

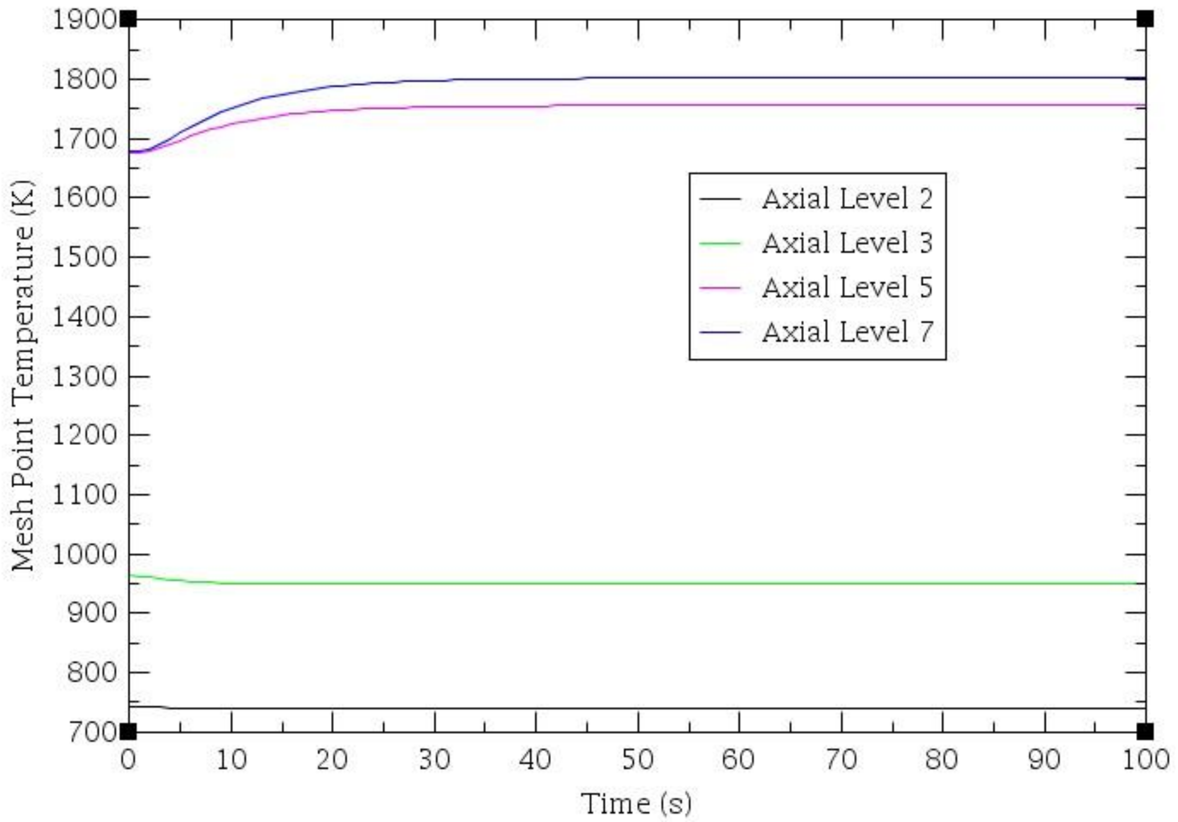

Figure 9: Central fuel temperature for TH channel 304.

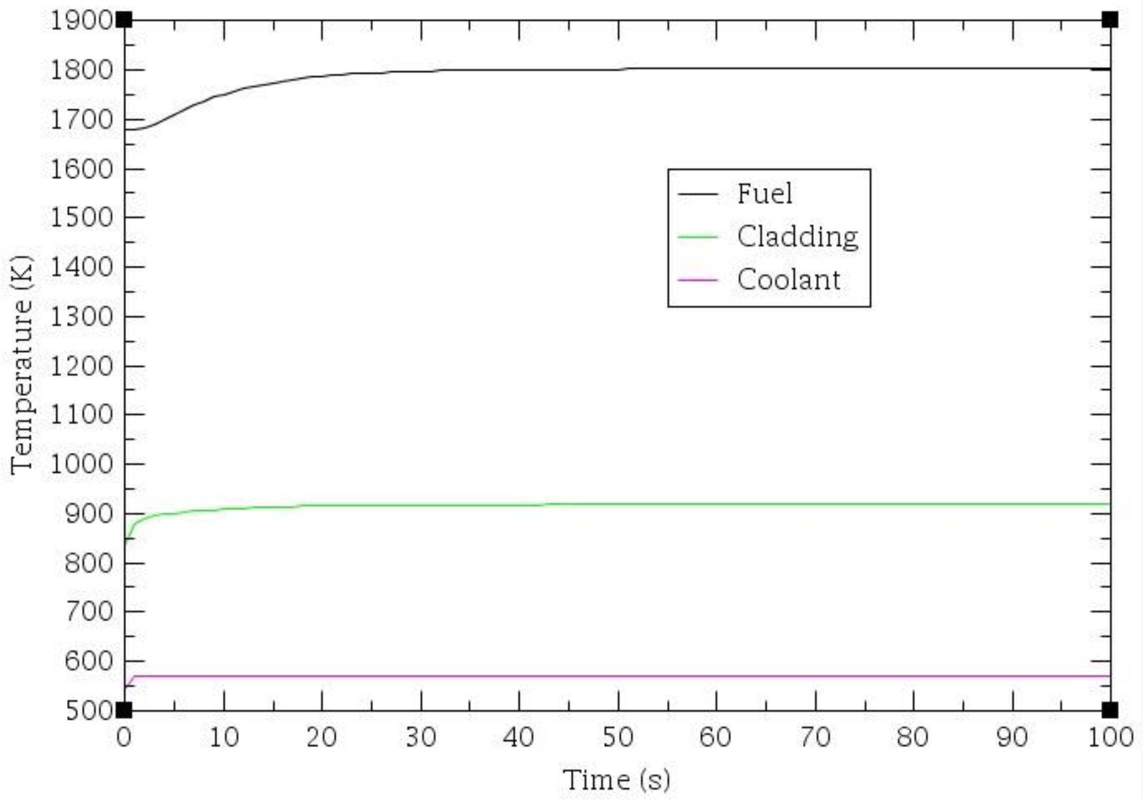

Figure 10: Fuel, cladding and coolant temperatures for axial level 7 of TH channel 304.

Expanded Model

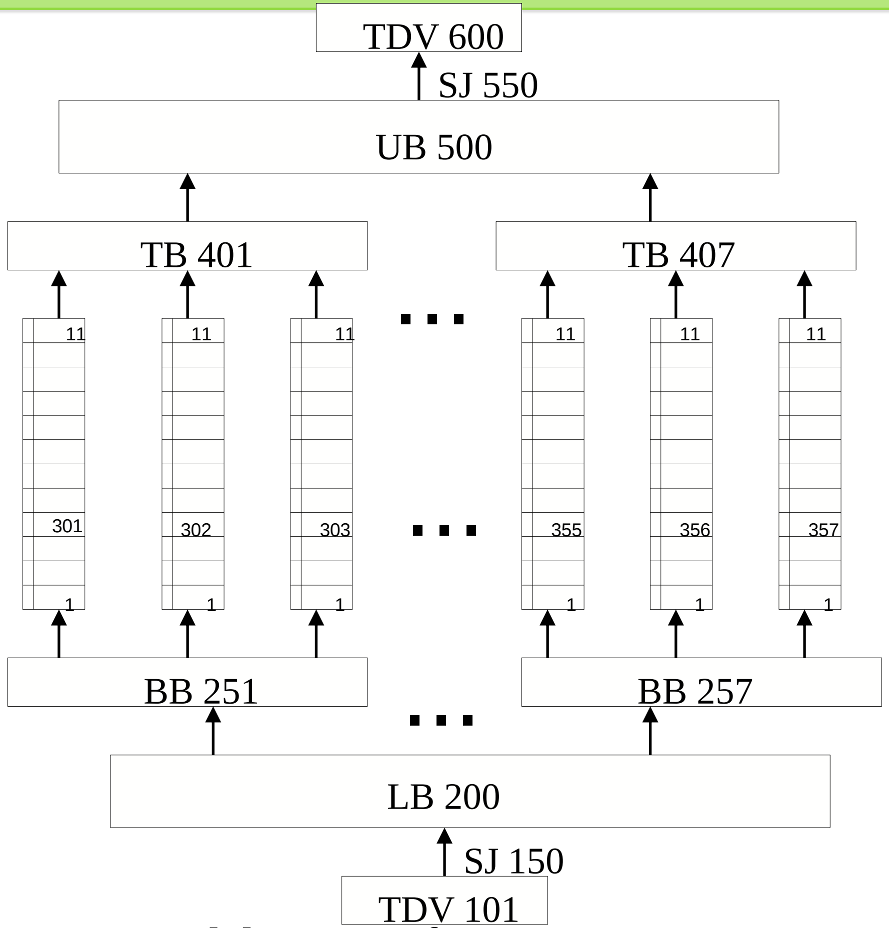

Figure 6: Nodalization of SMART core components.

- 57 TH channels
- Channel Flow Area = 0.0246 m²
- Mass Flow Rate/THC = 36.67 kg/s

6. Conclusions and future goals

- Good approximation for steady state conditions;
- Coolant, fuel and cladding temperatures within reference range;
- Inclusion of pumps, pressurizer and steam generators;
- Transient calculations.

7. Acknowledgements

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8. References

[1] C. L. Vinoya et al. “State-of-the-Art Review of Small Modular Reactors”. In: Energies 16.7 (2023), p. 3224.

[2] U. S. Nuclear Regulatory Commission, 2001. RELAP5/MOD3.3 Beta Code Manual, Vol. IV – Models and Correlations. Nuclear Safety Analysis Division, NUREG/CR-5535/Rev 1-Vol IV, Washington, DC.

[3] C. C. Lee, et al. "Nuclear and thermal hydraulic design characteristics of the SMART core."*International Conference on Global Environment and Advanced Nuclear Power Plants Kyoto Japan* (2003).

[4] S. Y. Park et al. Nuclear characteristics analysis report for system-integrated modular advanced reactor. 1998.

[5] H. C. Kim et al. “Safety analysis of SMART”. Em: Proc. of Int. Conf. on Global Environment and Advanced Nuclear Power Plants: GENES4/ANP2003, Kyoto, Japan. 2003.

[6] A. Petruzzi and F. D'Auria, 2008. Thermal hydraulic System Codes in Nuclear Reactor Safety and Qualification Procedures. Science and Technology of Nuclear Installations, 2008, 460795.

[7] N. E. Todreas and M. S. Kazimi. Nuclear systems volume I: Thermal hydraulic fundamentals. CRC press, 2021.