Joint ICTP-IAEA Workshop on Physics and Technology of Innovative Nuclear Energy Systems

Group 2 – B B I M U

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Overview

1. The main objectives of the group activity
2. Phénix reactor core thermohydraulic calculation
3. BREST-300-OD reactor core thermohydraulic calculation
4. The calculation results comparison
5. Map of the module topics
6. Conclusions

THE MAIN OBJECTIVES OF THE GROUP ACTIVITY

- The main objectives of the group activity are:

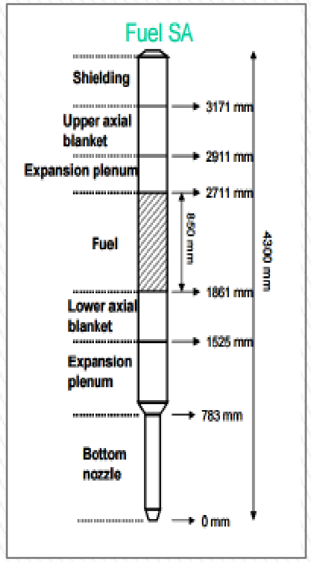
1. To understand the basic thermal hydraulic characteristics of the sodium and lead cooled fast reactors.
2. To calculate the power profile, temperature profile etc. to understand the reactors behavior.
3. To compare obtained calculation results.
4. To describe the needs for technological and institutional innovations and improvements in nuclear energy systems with the goal to achieve sustainable development and deployment.

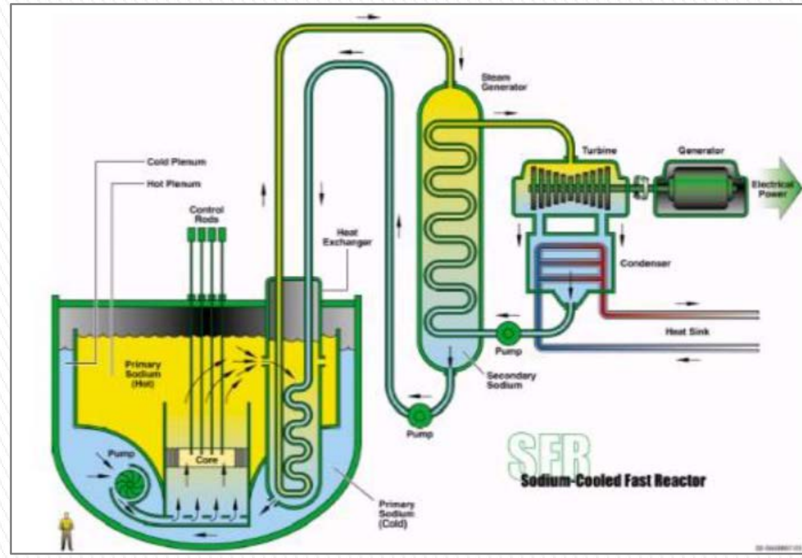
Phénix reactor core thermohydraulic calculation

- Input data:

Number of pins in SA:	217
Pitch of pins (P):	7,773 mm
Inner diameter of fuel clad:	5,65 mm
Outer diameter of fuel clad (D):	6,55 mm
Diameter of fuel pellet:	5,42 mm
Width across flat of SA:	116,9 mm
SA length:	4300 mm
Active core portion length:	850 mm

Specific Heat Capacity C_p (J/Kg.K)	1268
Thermal Conductivity λ_{Na} (W/m.K)	66
Viscosity η (Pa.s)	2.410^{-4}
Density ρ_{Na}	$830 kg m^{-3}$



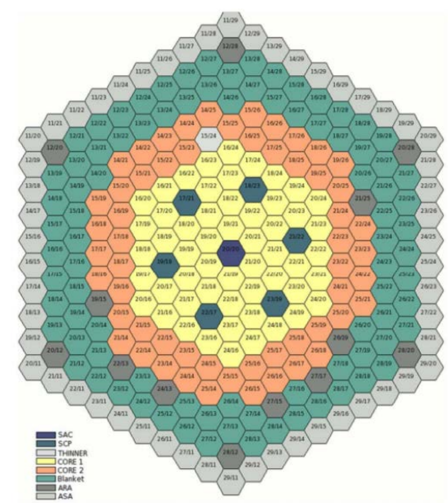


Parameter	563 MW regime (1974-1993)
Thermal power (MW)	563
Gross electrical power (MW)	250
Net electrical power (MW)	233
Neutron flux at core centerline (n/cm2.s)	7×10^{15}
Primary sodium core outlet temperature (°C)	560
Primary sodium core inlet temperature (°C)	400
Secondary sodium SG inlet temperature (°C)	550
Superheated steam temperature (°C)	512

$Peaking Factor\, K = K_z \times K_r = 1.62$
where, K_z is the axial peaking factor and K_r is the radial peaking factor

Thermal Conductivity Clad- λ_{cl} (W/m.K)	22
Thermal Conductivity Gap- $\lambda_g (W/m.K)$	0.5
Thermal Conductivity Fuel- $\lambda_f (W/m.K)$	3.2

Thermal Power (MW)	6.037971
Mass Flow $\dot{m}$(kg/s)	25.1147
Inlet Temperature T_{in} (°C)	400



Phénix reactor core thermohydraulic calculation

1. The total mass flow of the reactor:

$$mass_{flow} := \frac{Q_{total}}{Cp \cdot \Delta T} = 2775.0394 \ \frac{kg}{s}$$

Phénix reactor core thermohydraulic calculation

2. The axial and radial peaking factors:

$$q_{FA\_avg} := \frac{Q_{total}}{N_{FA}} = 5.1182\ \mathrm{MW}$$

$$K_r := \frac{q_{FA\_max}}{q_{FA\_avg}} = 1.1797$$

$$K_z := \frac{PeakingFactor}{K_r} = 1.3732$$

$$K_r \cdot K_z = 1.62$$

Phénix reactor core thermohydraulic calculation

3. The effective height of the active core:

$$q_{pin\_max\_peak} := K_z \cdot q_{pin\_max} = 0.0382\ \mathrm{MW}$$

(Peak power in hottest pin, used in cos distribution)

$$q_{max} := K_z \cdot q_{FA\_max} = 8.2915\ \mathrm{MW}$$

(Peak power in hottest FA, used in cos power distribution)

$$q'_{max} := \frac{q_{max}}{L_{active}} = 9.75465\ \frac{\mathrm{MW}}{\mathrm{m}}$$

(peak linear power in hottest FA, used in cos distribution)

Phénix reactor core thermohydraulic calculation

3. The effective height of the active core:

$$q'(z) := q'_{max} \cdot \cos\left(\frac{\pi \cdot z}{h_{eff}}\right)$$

$$q_{FA\_max} = \int_{-\frac{L_{active}}{2}}^{\frac{L_{active}}{2}} q'(z)\,dz \qquad q_{FA\_max} = 6.037971\ \text{MW}$$

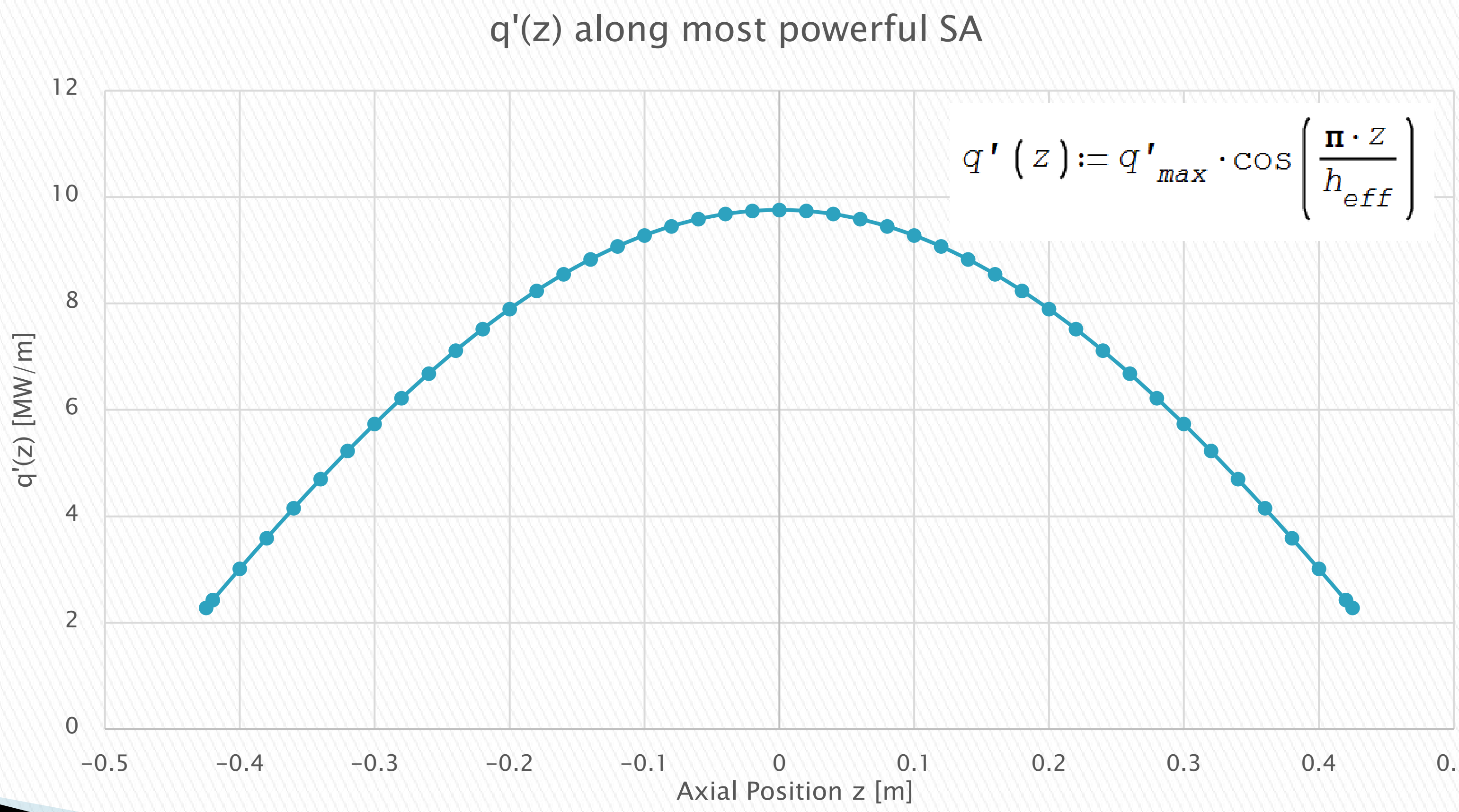
$$\int_{-\frac{L_{active}}{2}}^{\frac{L_{active}}{2}} q'(z)\,dz = 6.0379292584\ \text{MW}$$

$$h_{eff} := 0.99988\ \text{m}$$

$$h_{eff} := 1\ \text{m}$$

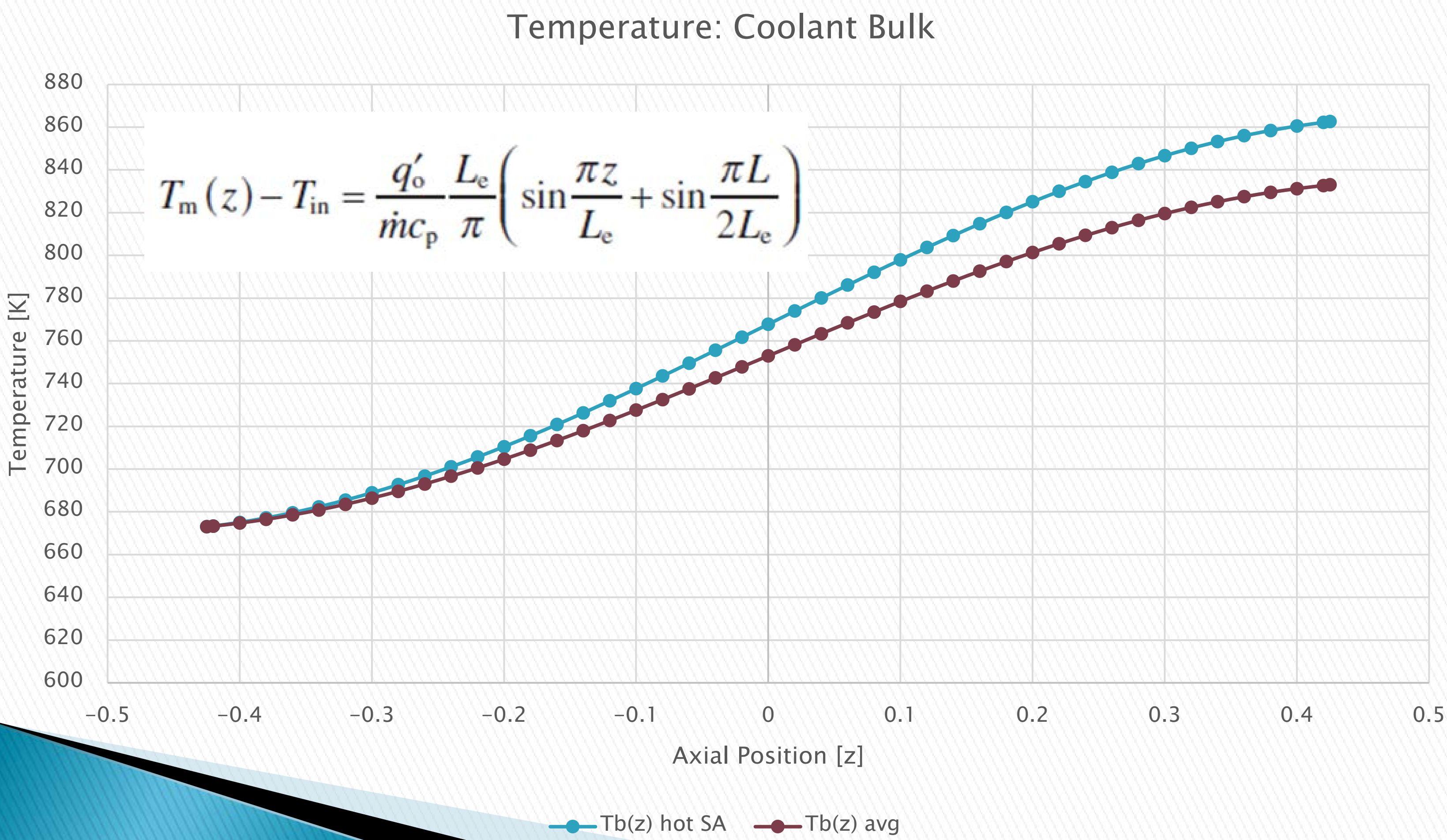
Phénix reactor core thermohydraulic calculation

4. Axial linear power distribution across the most powerful subassembly (q’ vs z) :



Phénix reactor core thermohydraulic calculation

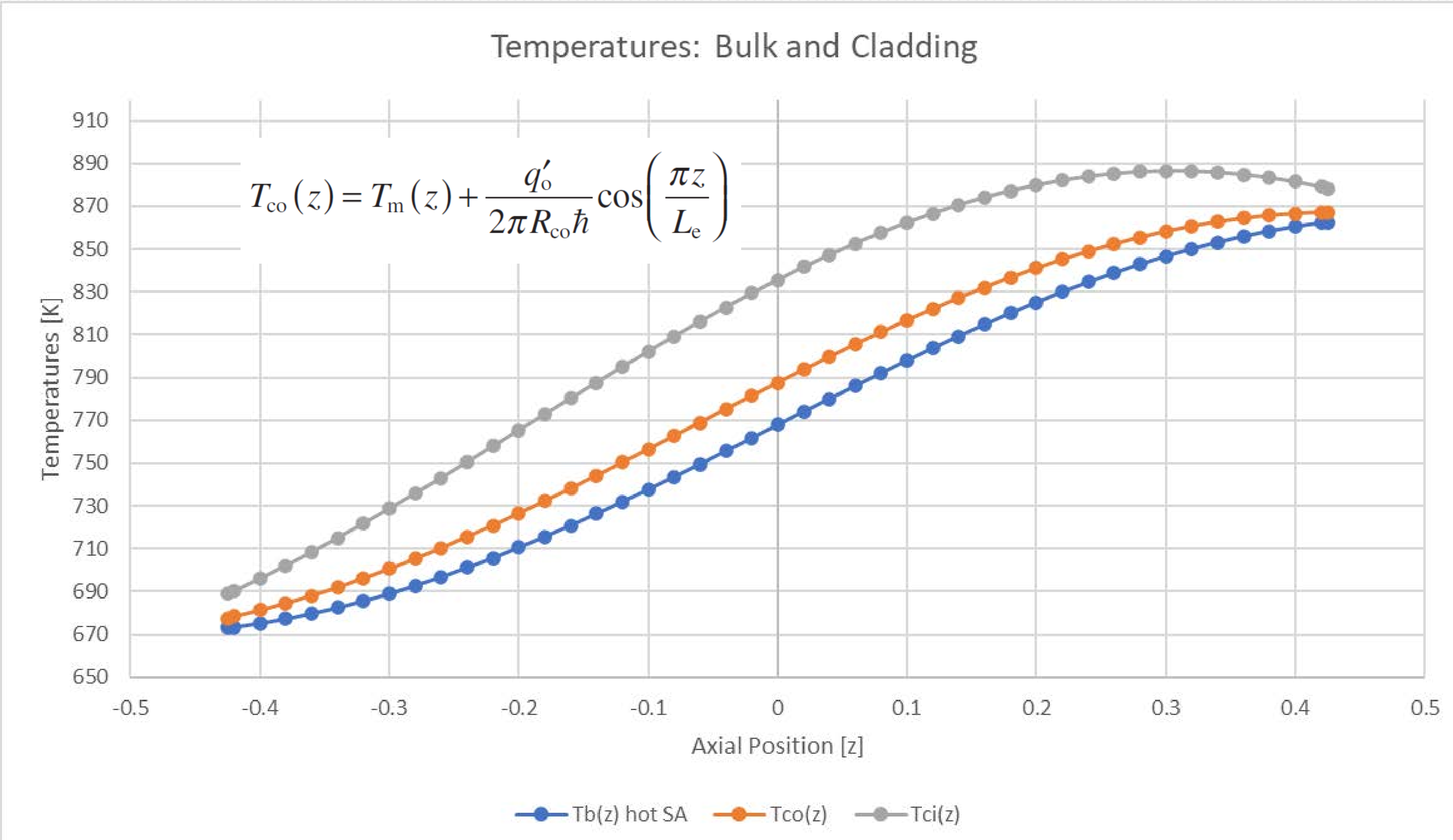
5. Axial temperature distribution profile across the most powerful subassembly (T vs z):



$$T_m(z) - T_{in} = \frac{q_o'}{\dot{m} c_p} \frac{L_e}{\pi} \left(\sin \frac{\pi z}{L_e} + \sin \frac{\pi L}{2 L_e} \right)$$

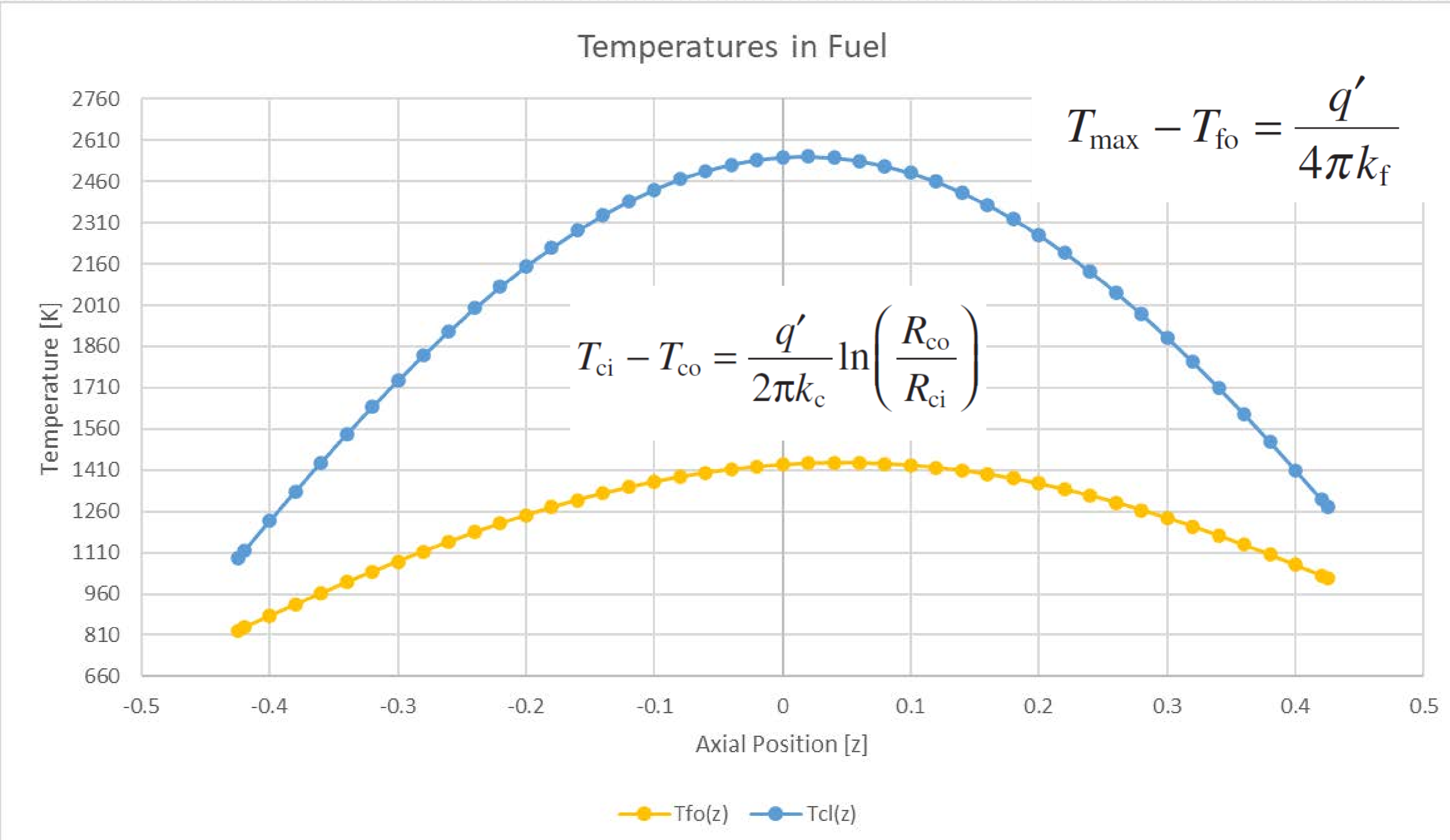
Phénix reactor core thermohydraulic calculation

6. Axial temperature distribution of bulk, clad outer surface and clad inner surface (T vs z):



Phénix reactor core thermohydraulic calculation

6. Axial temperature distribution of fuel outer surface and centerline (T vs z):

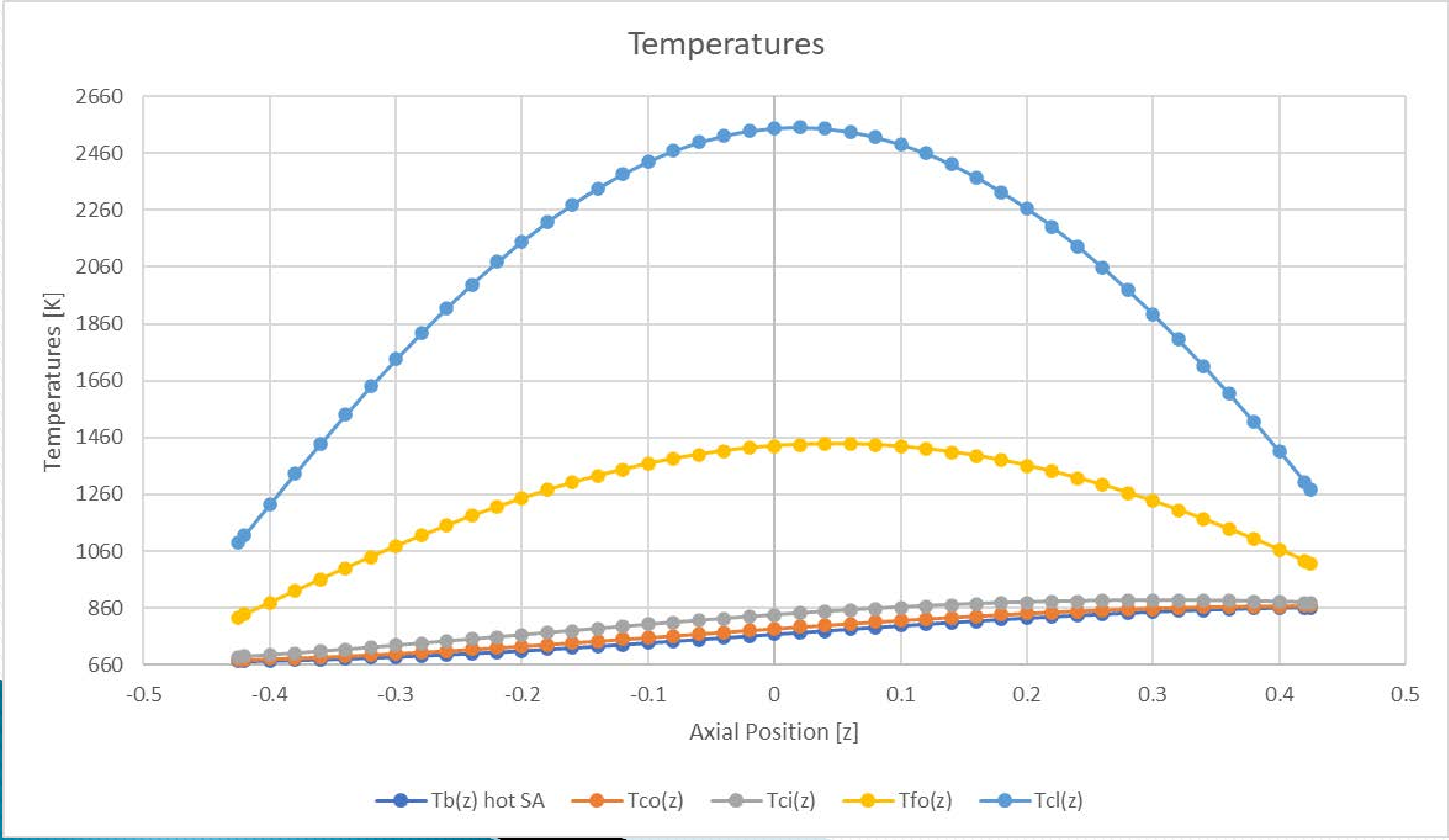


$$T_{max} - T_{fo} = \frac{q'}{4\pi k_f}$$

$$T_{ci} - T_{co} = \frac{q'}{2\pi k_c} \ln\left(\frac{R_{co}}{R_{ci}}\right)$$

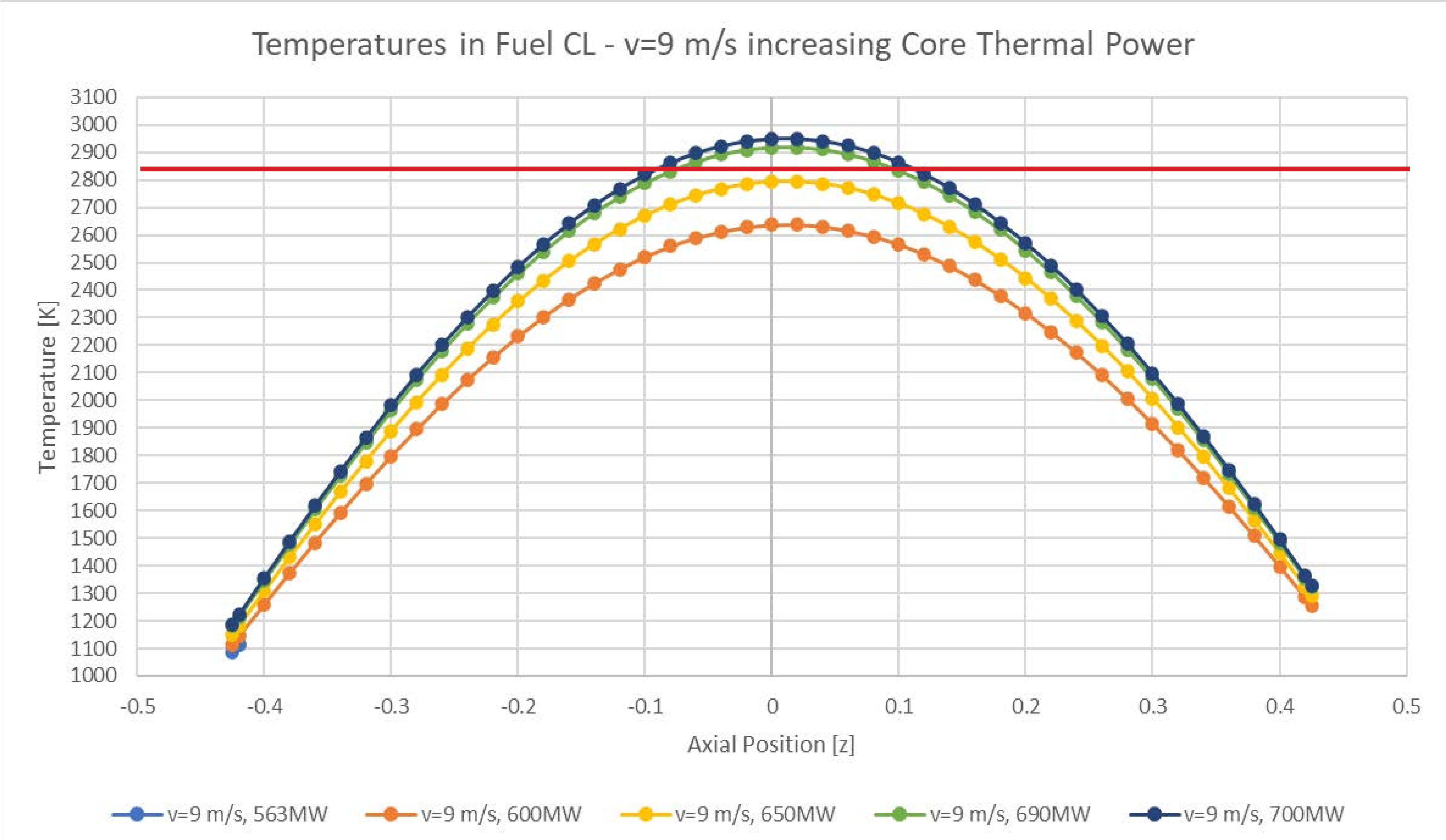
Phénix reactor core thermohydraulic calculation

6. Axial temperature distribution of bulk, clad inner and outer surfaces, fuel outer surface and centerline (T vs z):



Phénix reactor core thermohydraulic calculation

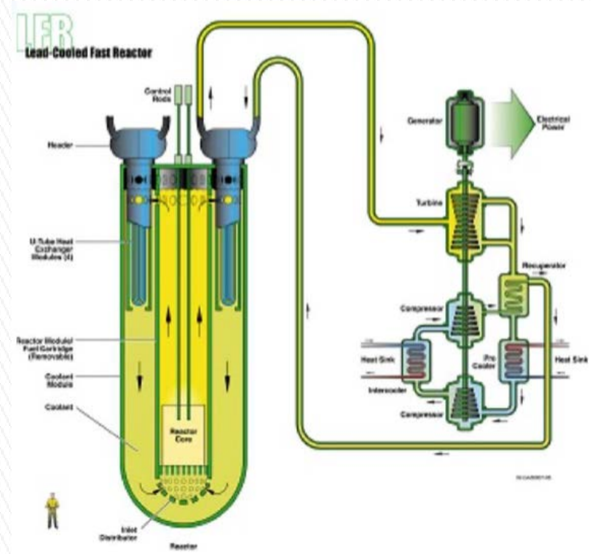
6. Optional Exercise

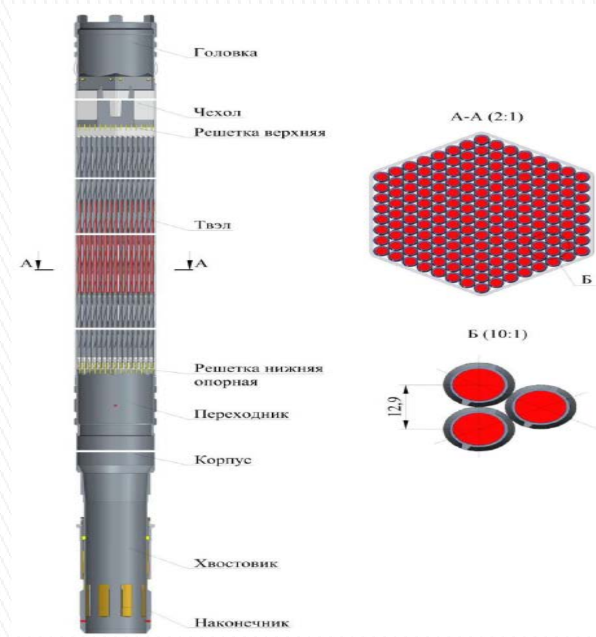


BREST-300-OD reactor core thermohydraulic calculation

- Input data:

Reactor Power (th), *N*	700 MW
Number of FAs, *nFA*	168
Pins/FAs, *nPIns*	169
Fissile Core Height, *H*	1.1 m
Inlet Temperature, *Tin*	420 C
Total Flowrate in Primary Circuit, *Gtot*	40000 kg/s
Nominal Flowrate in FA, *Gfa*	115 kg/s
FA Hex inner flat size, *h*	17 cm
Fuel Pin Diameter, *D*	9.7 mm
Fuel Pellet central hole, *d*	-
Cladding Wall Thickness, *wall*	0.5 mm
Fuel Pellet Diameter (assuming no gap), *gap*	8.7 mm
Pitch-to-Diameter Ratio, *P/D*	1.33
Radial Peaking Factor, *Kr*	1.09
Axial Peaking Factor, *Kz*	1.25





BREST-300-OD reactor core thermohydraulic calculation

1-2. Were given in the exercise input data

3. The effective height of the active core

4. Axial linear power distribution across the most powerful subassembly (q' vs z)

5. Axial temperature distribution profile across the most powerful subassembly (T vs z)

6. Axial temperature distribution of clad outer surface, clad inner surface, fuel pellet outer surface and fuel pellet centerline (T vs z)

7. T_{bulk}, T_{ci} and T_{cl} with variation of coolant velocity

BREST-300-OD reactor core thermohydraulic calculation

3. The effective height of the active core:

$$q_{pin\_hot} := \frac{Q_{total}}{N_{FA} \cdot N_{pins\_per\_FA}} = 0,0247 \text{ MW}$$

$$q_{pin\_hot\_peak} := K_z \cdot q_{pin\_hot} = 0,0308 \text{ MW}$$

$$q'_{pin\_hot\_peak} := \frac{q_{pin\_hot\_peak}}{L_{active}} = 0,028 \frac{\text{MW}}{\text{m}}$$

BREST-300-OD reactor core thermohydraulic calculation

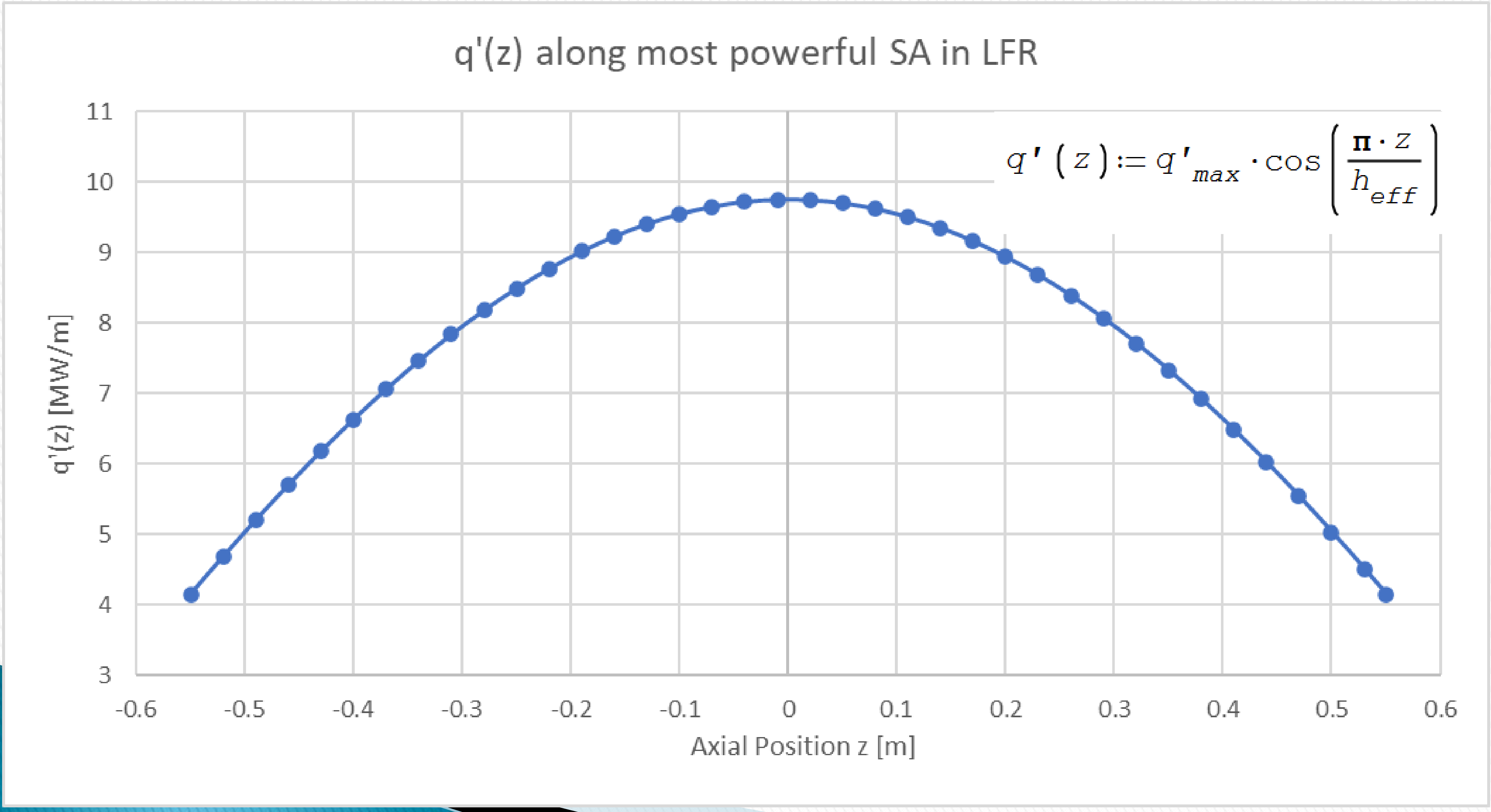
3. The effective height of the active core:

$$q_{pin\_hot} = \int_{-\frac{L_{active}}{2}}^{\frac{L_{active}}{2}} q'_{pin}(z)\,dz \qquad q_{pin\_hot} = 24.65483235\ \text{kW}$$

$$\int_{-\frac{L_{active}}{2}}^{\frac{L_{active}}{2}} q'_{pin}(z)\,dz = 24{,}6540527045\ \text{kW} \qquad h_{eff} := 1{,}5275\ \text{m}$$

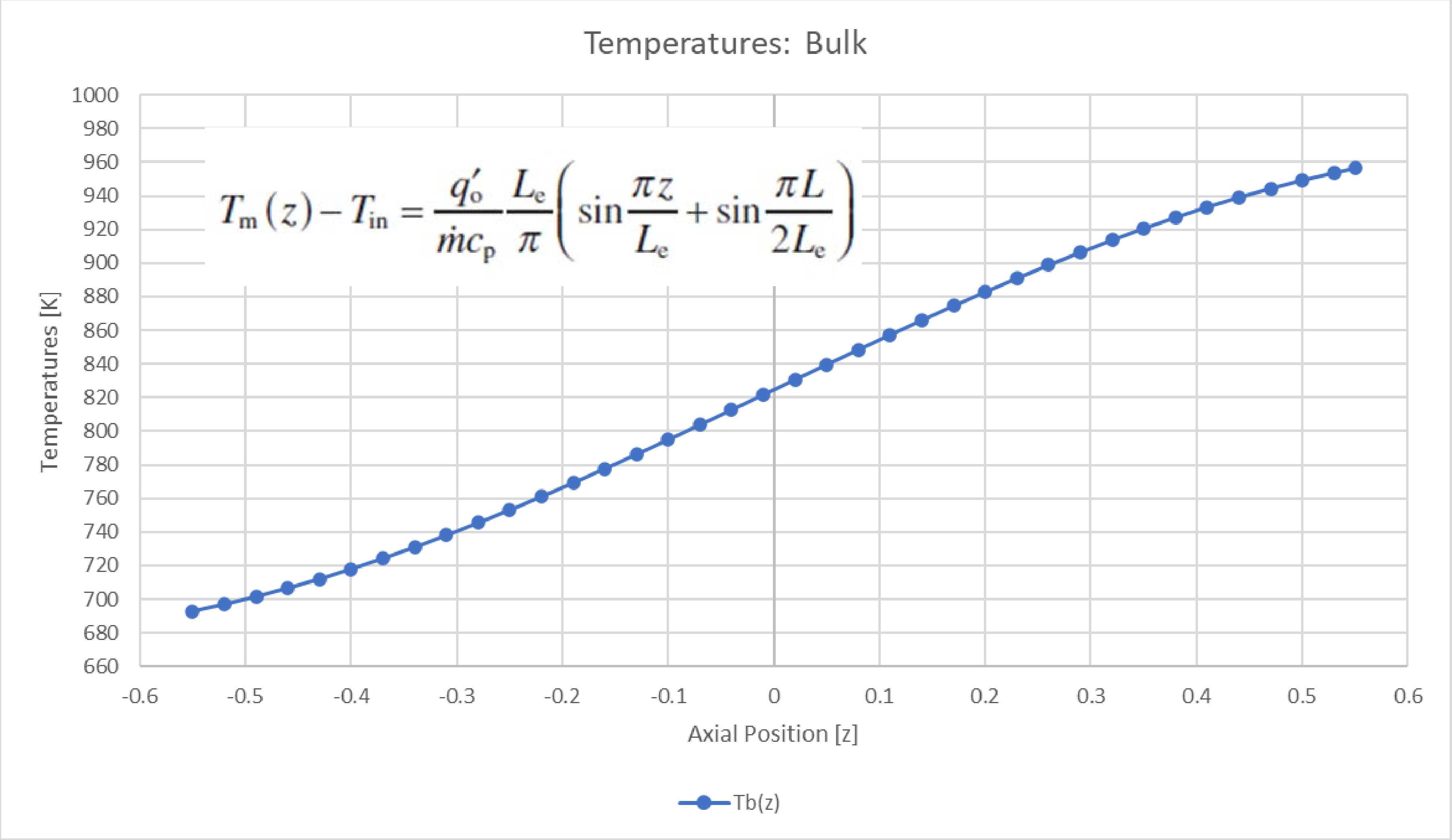
BREST-300-OD reactor core thermohydraulic calculation

4. Axial linear power distribution across the most powerful subassembly (q’ vs z) :



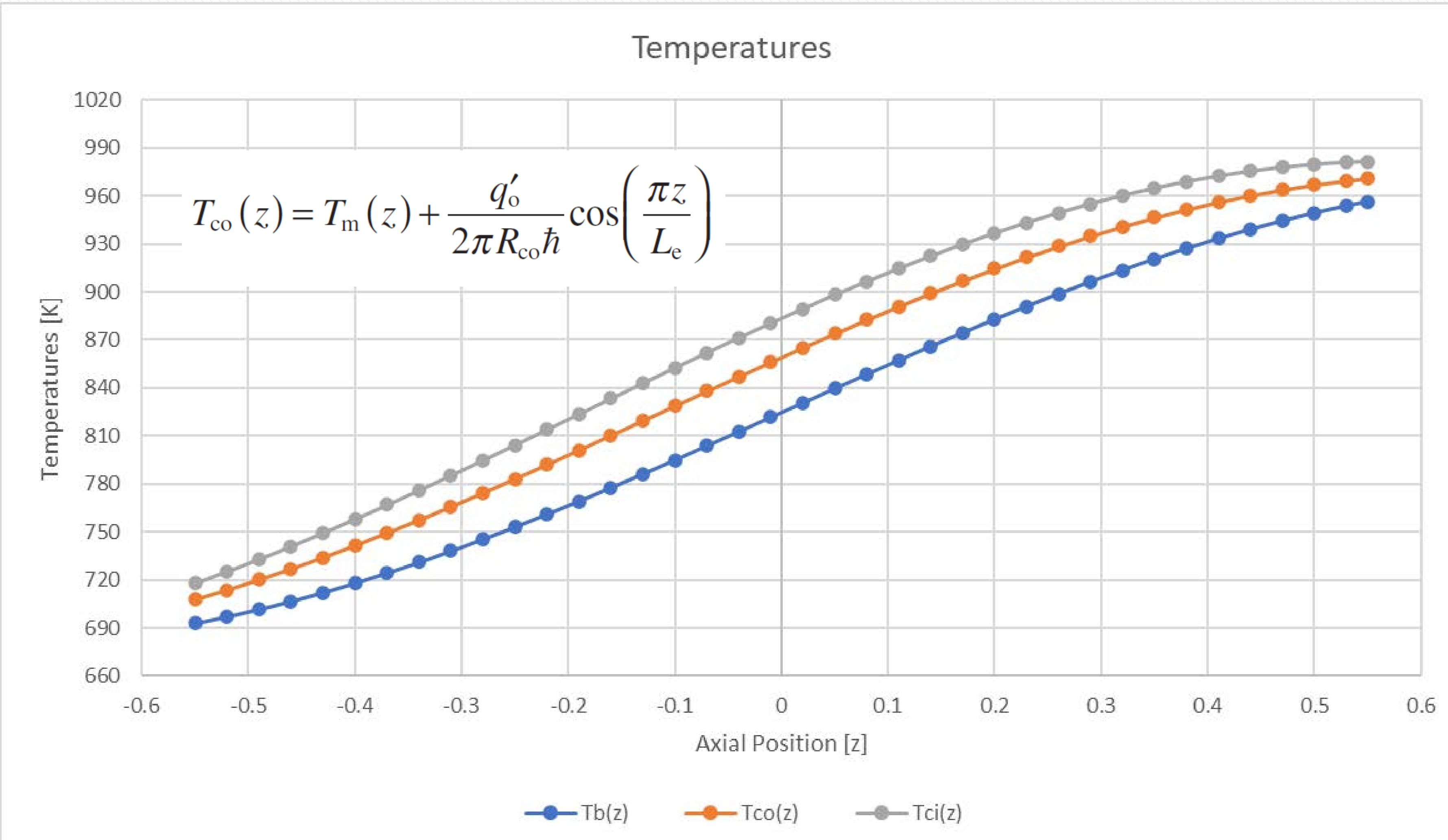
BREST-300-OD reactor core thermohydraulic calculation

5. Axial temperature distribution profile across the most powerful subassembly (T vs z):



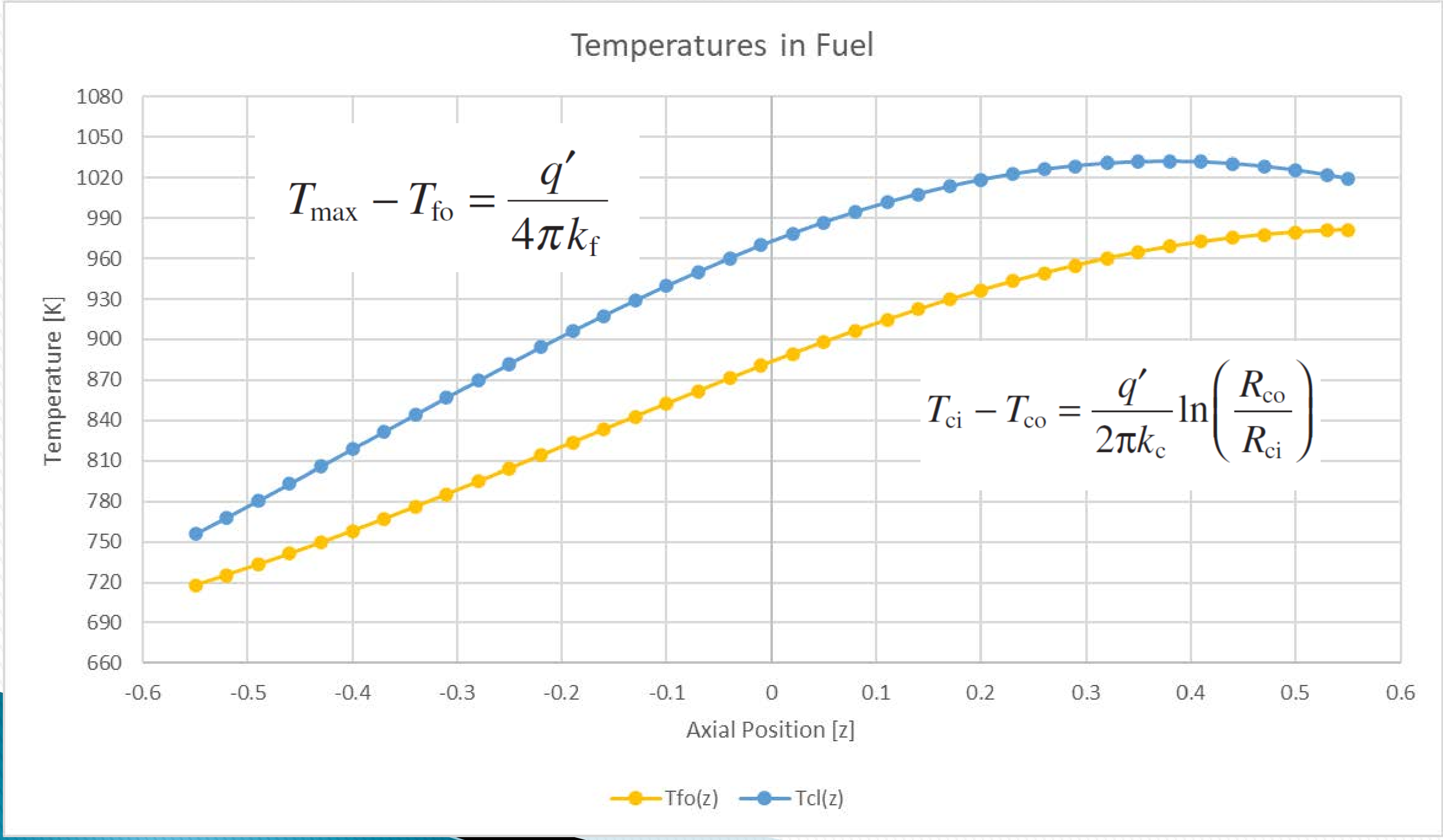
BREST-300-OD reactor core thermohydraulic calculation

6. Axial temperature distribution of bulk, clad outer surface and clad inner surface (T vs z):



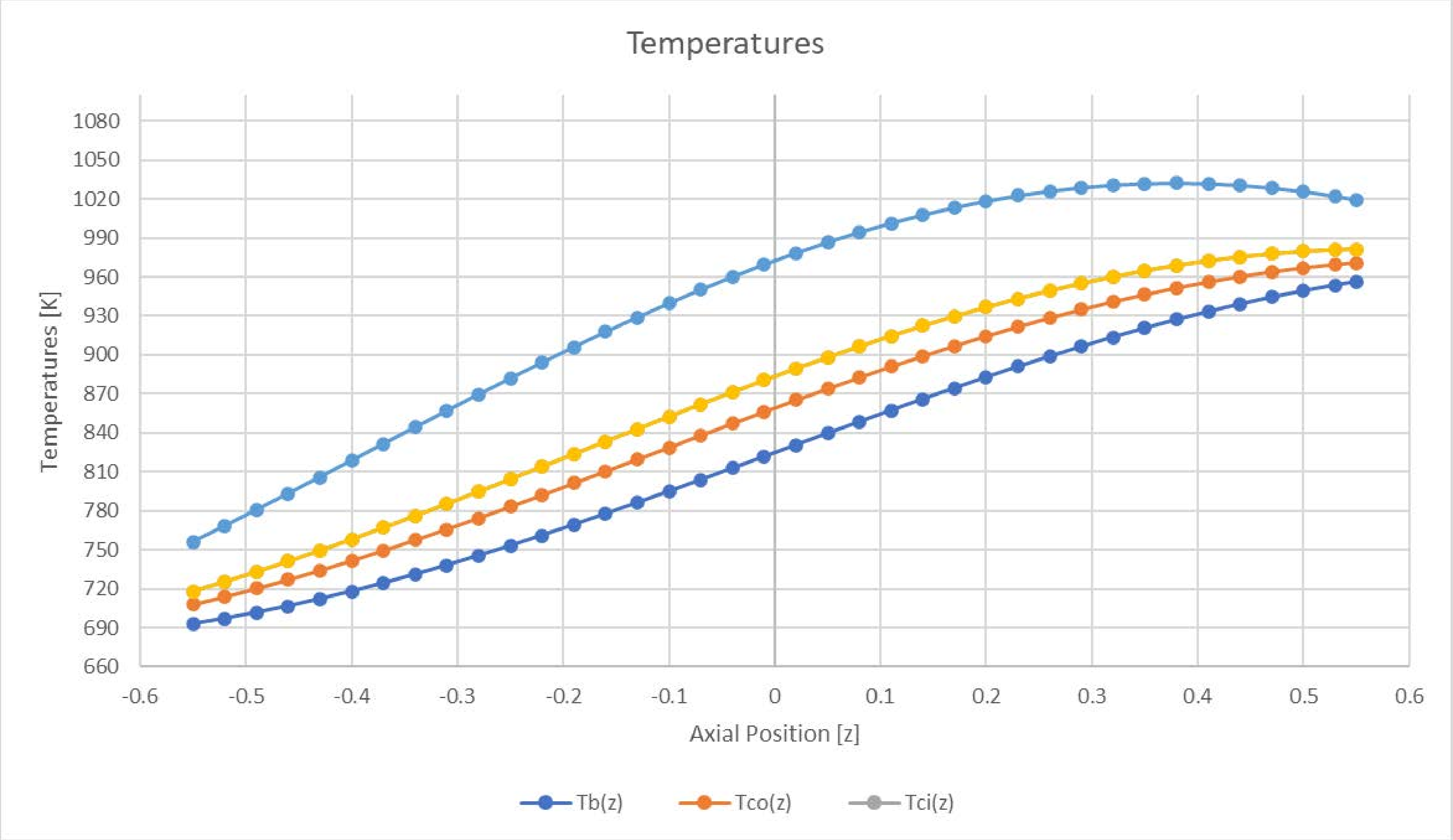
BREST-300-OD reactor core thermohydraulic calculation

6. Axial temperature distribution of fuel outer surface and centerline (T vs z):



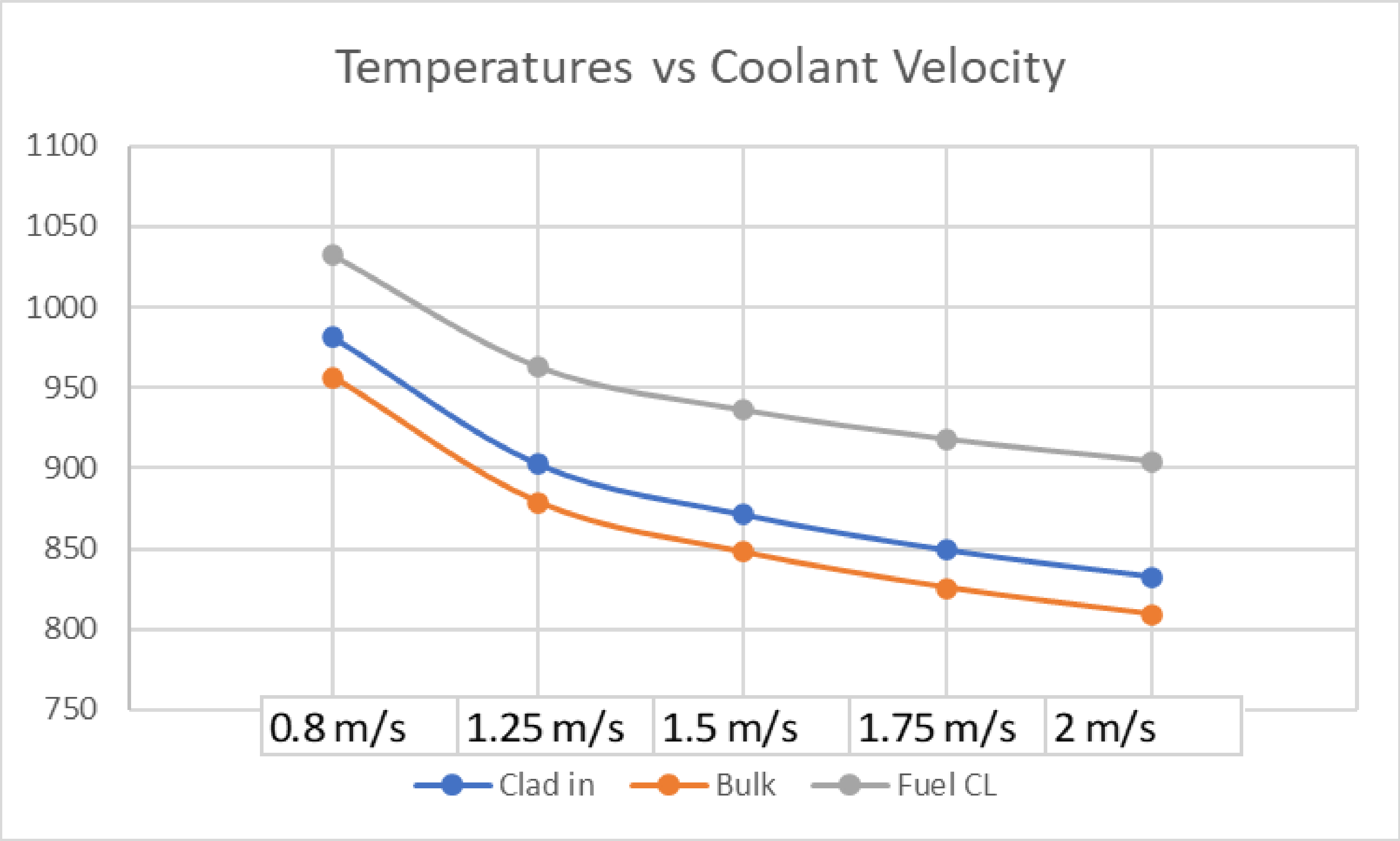
BREST-300-OD reactor core thermohydraulic calculation

6. Axial temperature distribution of bulk, clad inner and outer surfaces, fuel outer surface and centerline (T vs z):



BREST-300-OD reactor core thermohydraulic calculation

7. T_{bulk}, T_{ci} and T_{cl} with variation of coolant velocity:



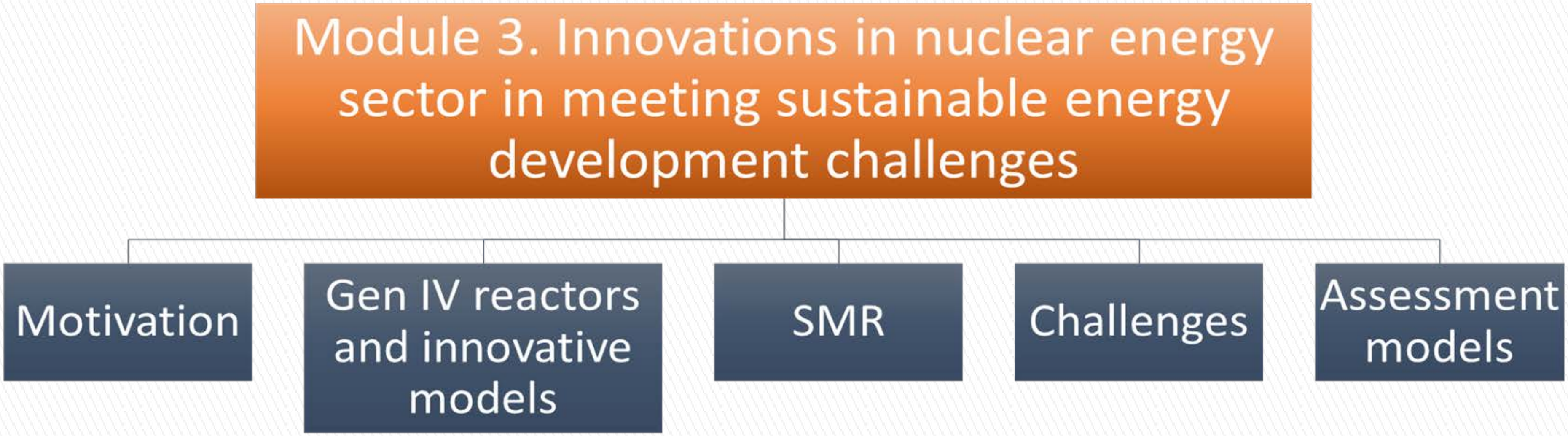
The calculation results comparison

#	The parameter	Phénix	BREST-300-OD
1	Total termal power [MW]	563	700
2	Active height [m]	0.85	1.1
3	Effective height [m]	1	1.5
4	Bulk Delta T in Hottest FA [K]	190	263
5	q’ in the hottest pin [kW/m]	32.735	22.4135
6	Highest Fuel CL Temperature [K]	2550	1032

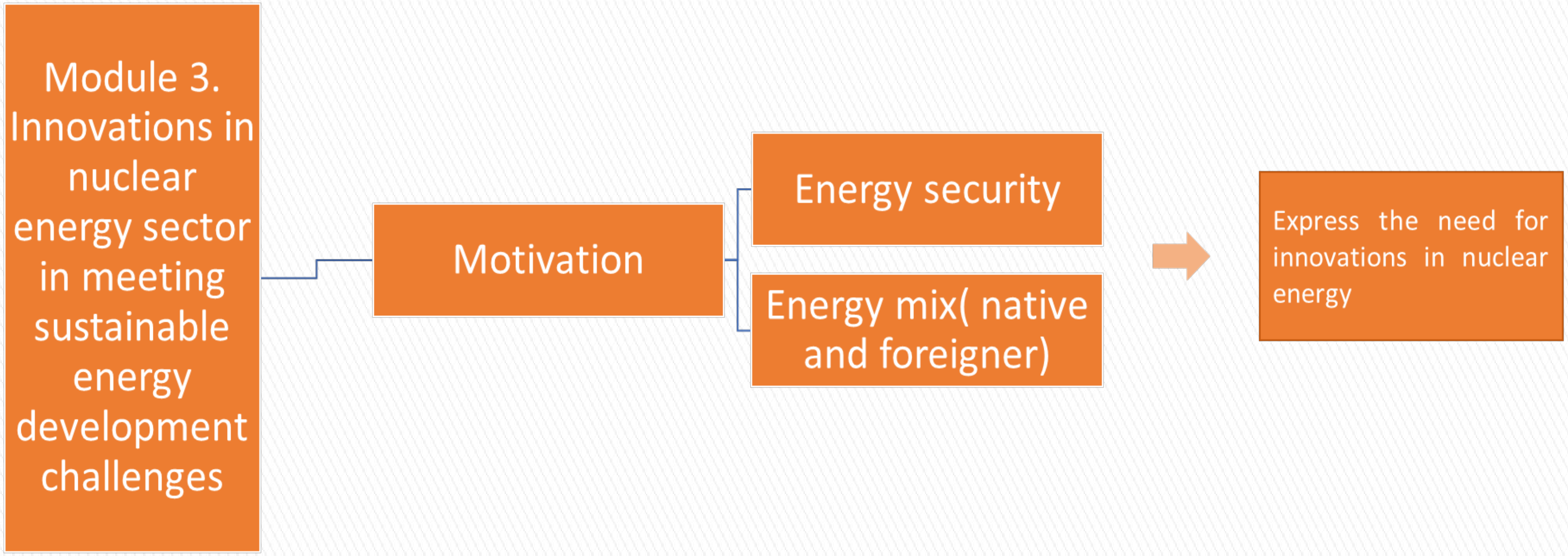
Conclusion Ex 1

- The TH calculations were carried out successfully
- Phenix maximum temperatures do not pass the limiting conditions for fuel nor cladding
- To reach Phenix fuel temperature limit, it would have to be operated up to 690 MW at 9 m/s coolant velocity
- The differences in BREST-300-OD temperatures were lower than in Phenix
- The BREST presents significant lower temperatures during operation at limit velocity of 2 m/s,

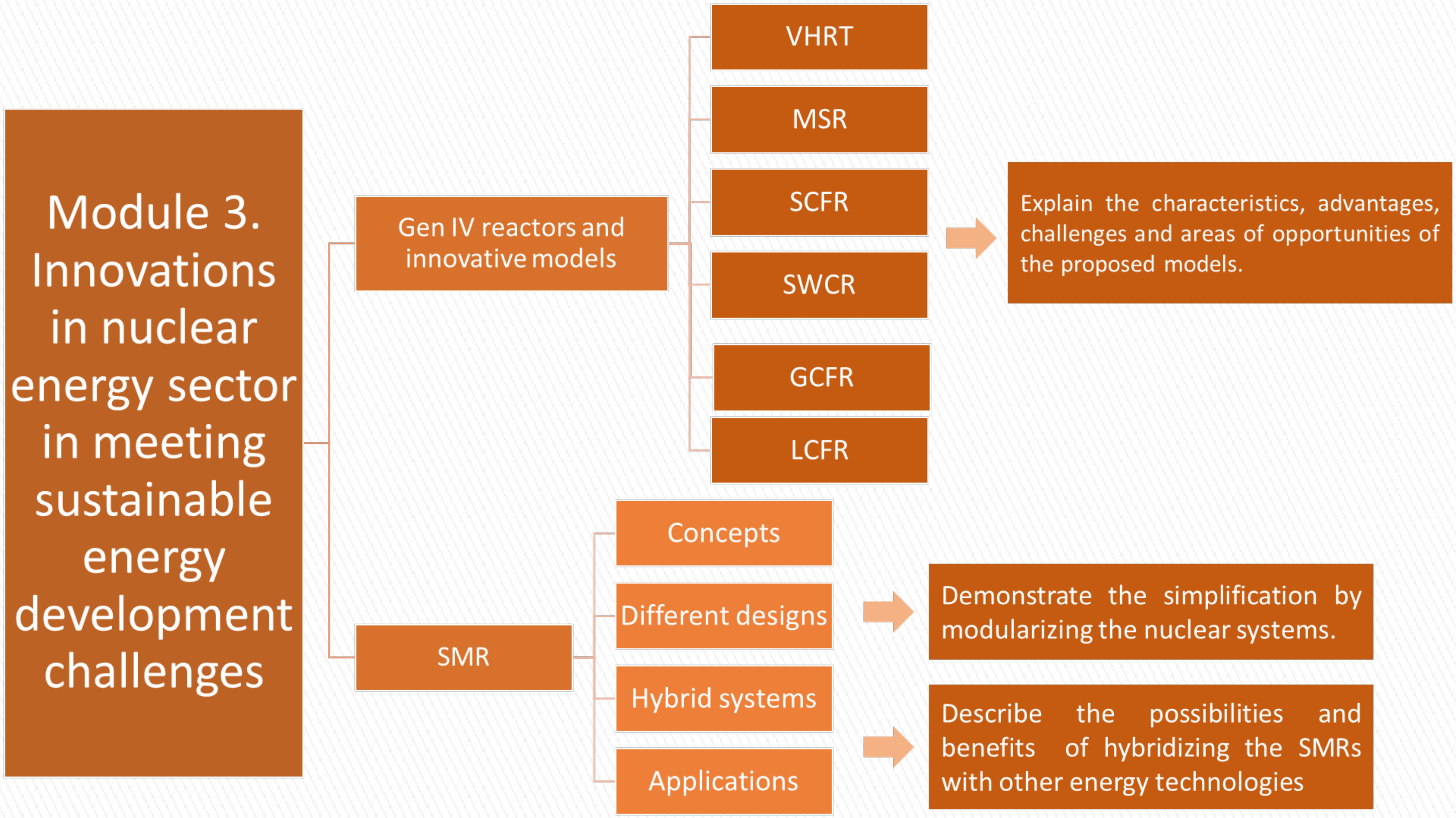
Map of the module topics



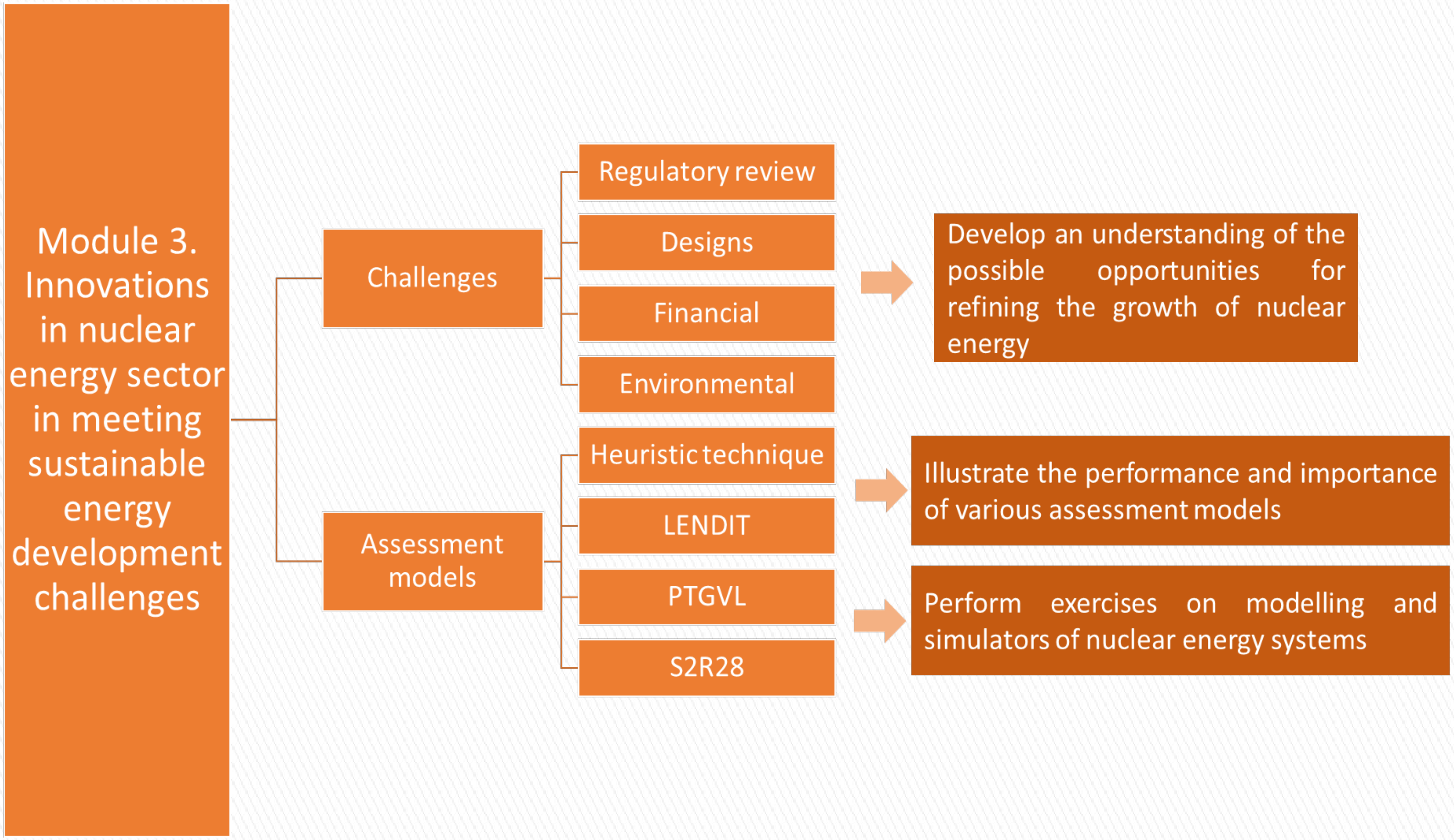
Map of the module topics



Map of the module topics



Map of the module topics



Map of the module topics

Main objective

Familiarize the students with innovative approaches to reach the goal of sustainability in nuclear systems with the understanding of the models and teach them the ways to put the knowledge in practice

Prerequisites

- Require the basic knowledge on maths and physics of nuclear science; design and analytical engineering background

Conclusion Ex 2

- Educational system is very important to motivate the students to find innovative solutions for the current nuclear systems.
- The practical knowledge of Gen-IV reactors would help the students to build better models for the future of nuclear energy system.

“No matter what we choose, our unwavering stance is to enhance the safety of nuclear power generation…”

Sean Chen

We're BBIMU and we're researching for YOU!

Thank you for your attention!