Joint ICTP-IAEA workshop on physics and technology of innovative nuclear energy systems

The Abdus Salam International Centre for Theoretical Physics

12-16 December 2022

02

Group 1

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Group activity

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Activity 1

Temperature field in a fuel pin of SFR and LFR

Used formulas:

$$ql = ql\,max \times \cos\left(\pi \times \frac{z}{Heff}\right)$$

$$\langle ql \rangle = \frac{ql\,max}{Kz}$$

$$K = Kz \times Kr$$

$$\langle ql \rangle = \frac{1}{H}\int_{-\frac{h}{2}}^{\frac{h}{2}} ql\,(z)dz$$

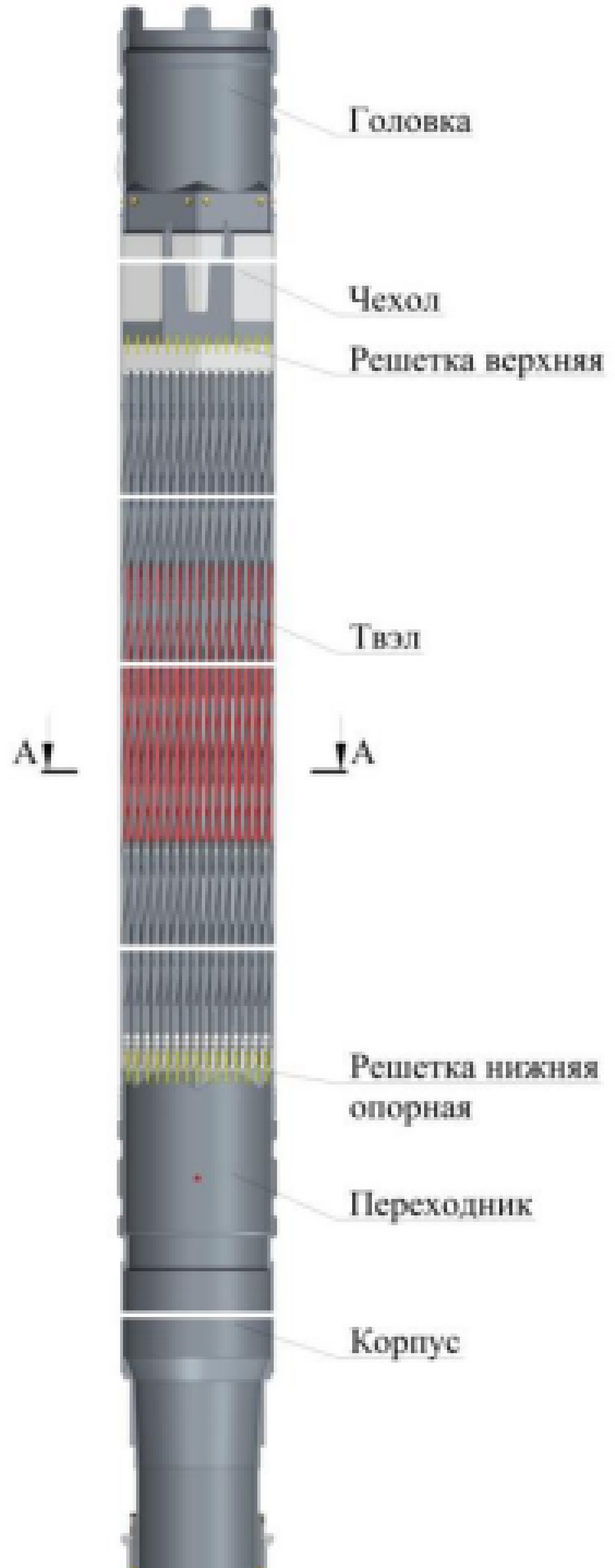
$$\dot{m}\,total = \frac{Q}{Cp \times \delta t}$$

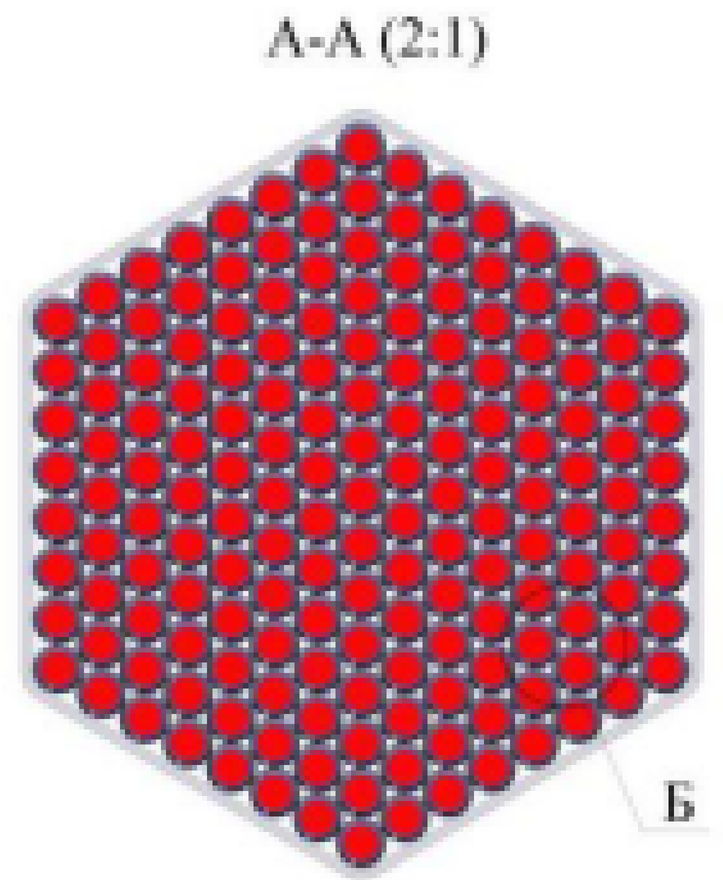
Group activity

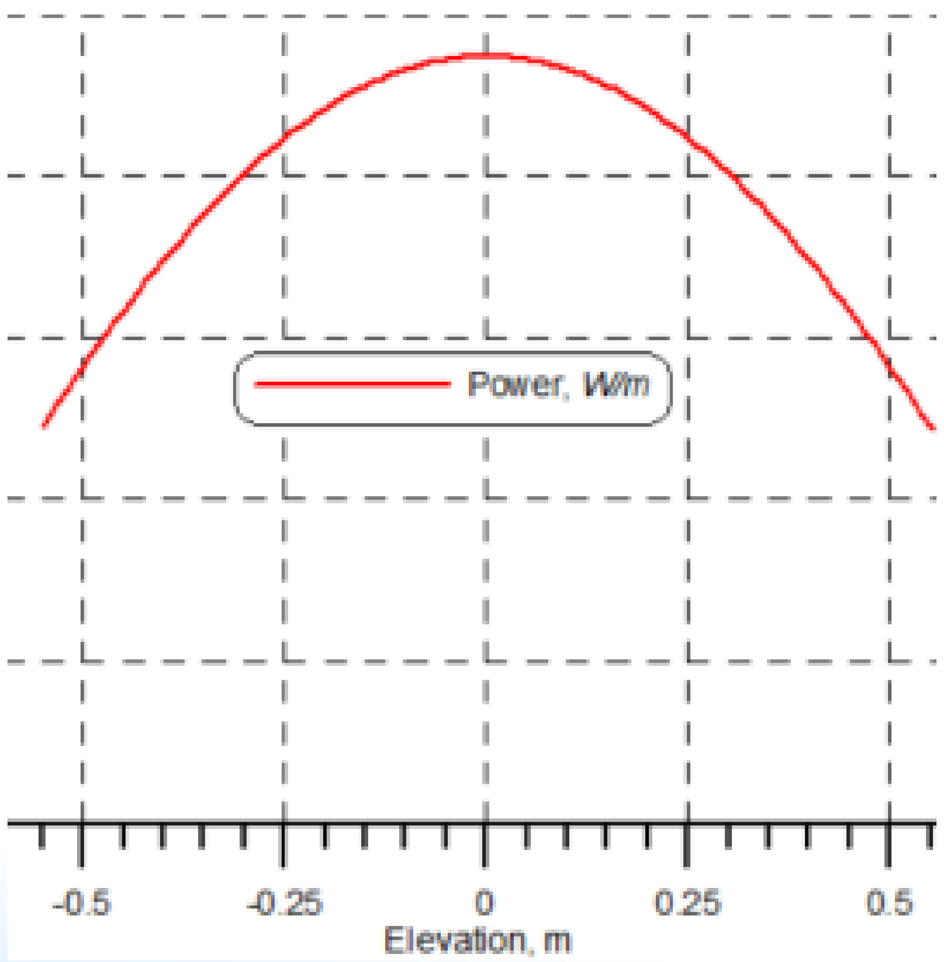
04 BREST-OD-300 LFR reactor parameters

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
H_{eff} in $q = q_{max}*cos(\pi*z/H_{eff})$	? m

Group activity







Calculation

05

3. The effective height of the active core :he f f

$$<ql> = \frac{ql\,max}{Kz}$$

$$<ql> = \frac{1}{H}\int_{-\frac{h}{2}}^{\frac{h}{2}} ql\,(z)dz = q_{lmax} \times \frac{Heff \times Kz}{\pi H} \times 2\sin\left(\frac{\pi H}{2Heff}\right)$$

$$1 = \frac{2Heff \times Kz}{\pi H} \times \sin(\frac{\pi H}{2Heff})$$ =>

$$y1 = \frac{2Heff \times Kz}{\pi H}$$

$$y2 = \frac{1}{\sin(\frac{\pi H}{2Heff})}$$

Calculation

$$\frac{dq}{dz} = q'_{max} \, cos\left(\frac{\pi z}{h_{eff}}\right)$$

$$\int dq' = \int q'_{max} \, cos\left(\frac{\pi z}{h_{eff}}\right) dz$$

$$\int_{q_o}^{q} dq' = \int_{-z/_2}^{z/2} q'_{max} \, cos\left(\frac{\pi z'}{h_{eff}}\right) dz'$$

$$q - q_o = q'_{max} \int_{-z/_2}^{z/2} cos\left(\frac{\pi z'}{h_{eff}}\right) dz'$$

$$q - q_o = \frac{q'_{max} \, h_{eff}}{\pi} \sin\left(\frac{\pi z'}{h_{eff}}\right)\Bigg|_{-z/2}^{z/2}$$

$$if \; q_o = 0$$

$$q = \frac{q'_{max} \, h_{eff}}{\pi}\left(\sin\left(\frac{\pi z}{2h_{eff}}\right) + \sin\left(\frac{\pi z}{2h_{eff}}\right)\right)$$

$$\therefore \boxed{q = \frac{2 \, q'_{max} \, h_{eff}}{\pi} \sin\left(\frac{\pi z}{2h_{eff}}\right)}$$

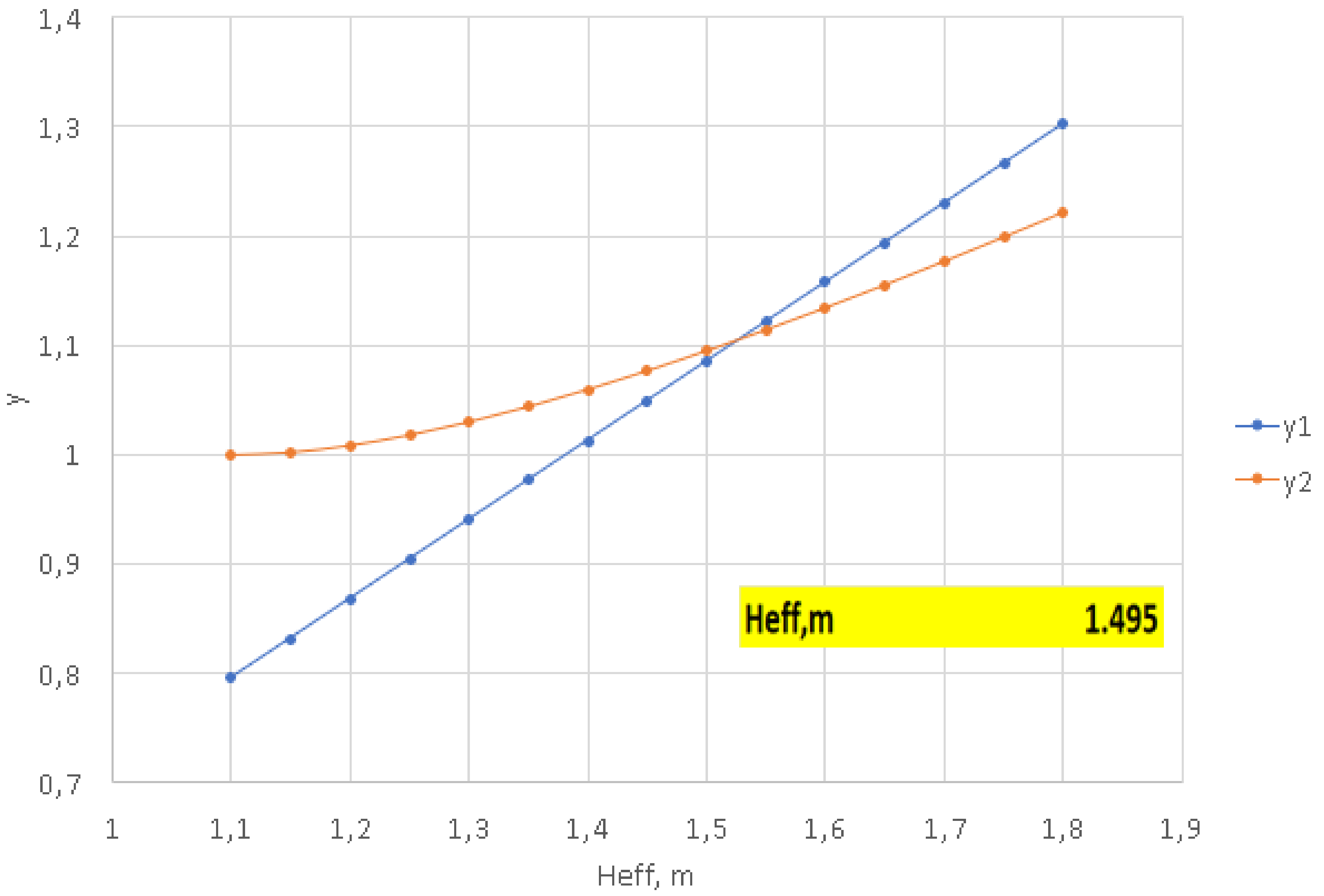
Calculation

07

3. The effective height of the active core :he f f

$$y1 = \frac{2Heff \times Kz}{\pi H}$$

$$y2 = \frac{1}{\sin(\frac{\pi H}{2Heff})}$$

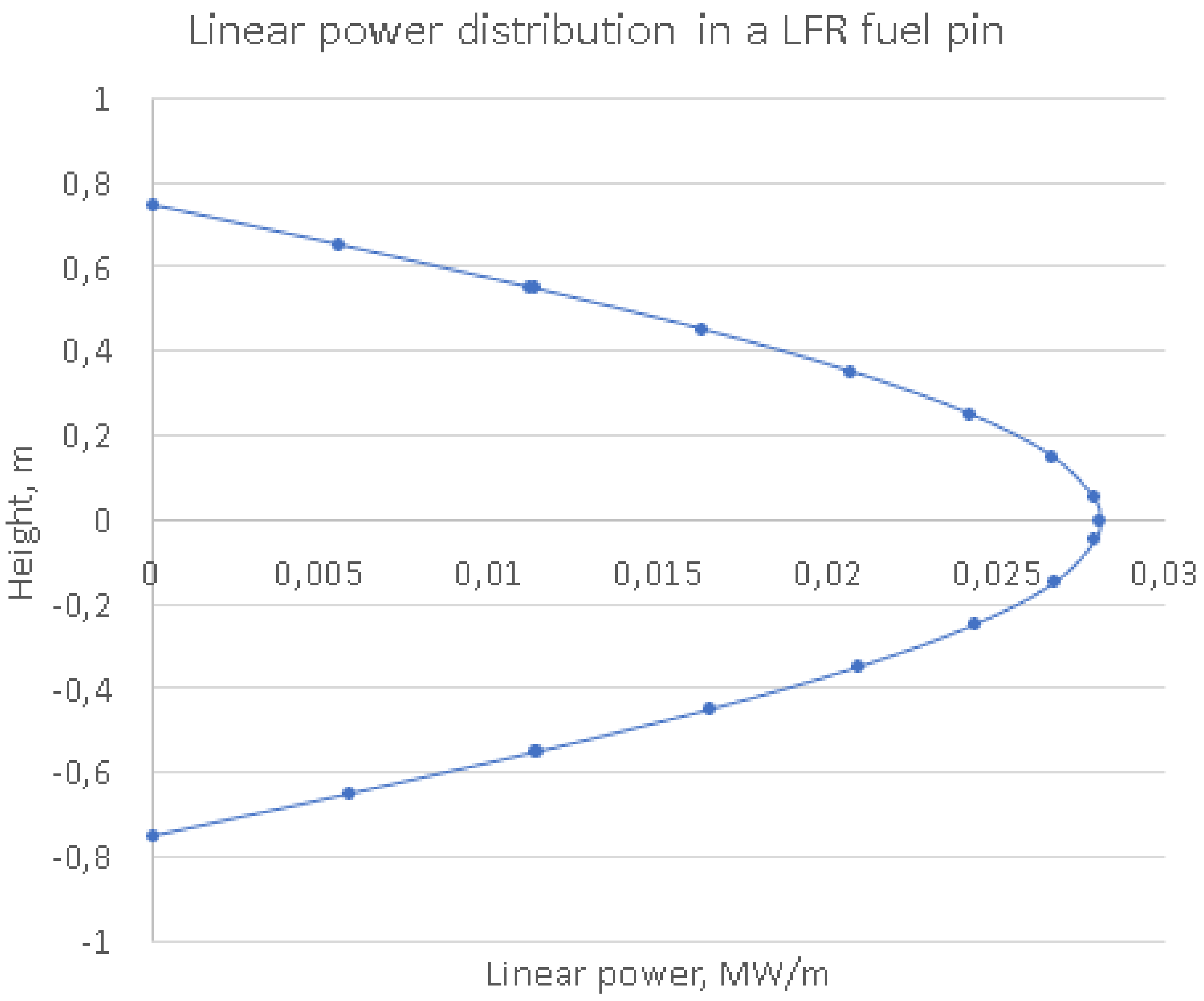


Calculation

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

average linear power-->	Power/(#FA*#FR/FA*H)	
<q_L>, MW/m	0.022413484	
max.linear power-->	Kz*<q_L>	
qmax_L, MW/m	0.028016855	

q_L(z)=qmax_L*cos(PI*z/Heff)



Calculation

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

$$t_{\max}(z) = t_{coolant}(z) + \Delta t_{colant} + \Delta t_{clad} + \Delta t_{gap} + \Delta t_{fuel}$$

$$t_{coolant}(z) = t_{inlet} \int_{-h/2}^{z} c_p G_i q_l(z) dz$$

$$\Delta t_{coolant} = \frac{q_l(z)}{\alpha \pi d_{pin}} \qquad \Delta t_{clad} = \frac{q(z)\Delta_{clad}}{\lambda_{clad}}$$

$$\Delta t_{gap} = \frac{q(z)\Delta_{gap}}{\lambda_{gap}} \qquad \Delta t_{fuel} = \frac{q_v(z) d_{fuel}^2}{16\lambda_{fuel}}$$

$$t_{coolant}(z) = t_{in} + \int_{-\frac{H_{active}}{2}}^{z} \frac{q_l(z)\,dz}{c_p G_i} = t_{in} + \int_{-\frac{H_{active}}{2}}^{z} \frac{q_l^{max} \cos\left(\frac{\pi z}{H_{eff}}\right) dz}{c_p G_i} \; t_{coolant}(z) \rightarrow$$

$$t_{coolant}(z) = t_{in} + \frac{q_l^{max} H_{eff}}{c_p G_i \pi}\left[\sin\left(\frac{\pi z}{H_{eff}}\right) + \sin\left(\frac{\pi H_{active}}{2 H_{eff}}\right)\right]$$

Calculation

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

$$t_{coolant}(z) = Tm = t_{in} + \frac{q_l^{max} H_{eff}}{c_p G_i \pi}\left[\sin\left(\frac{\pi z}{H_{eff}}\right) + \sin\left(\frac{\pi H_{active}}{2 H_{eff}}\right)\right]$$

From ***Nuclear systems*** *– I textbook by N. E. Todreas & M. S. Kazimi:*

$$T_{co} - T_m = \frac{q'}{2\pi R_{co} h}$$

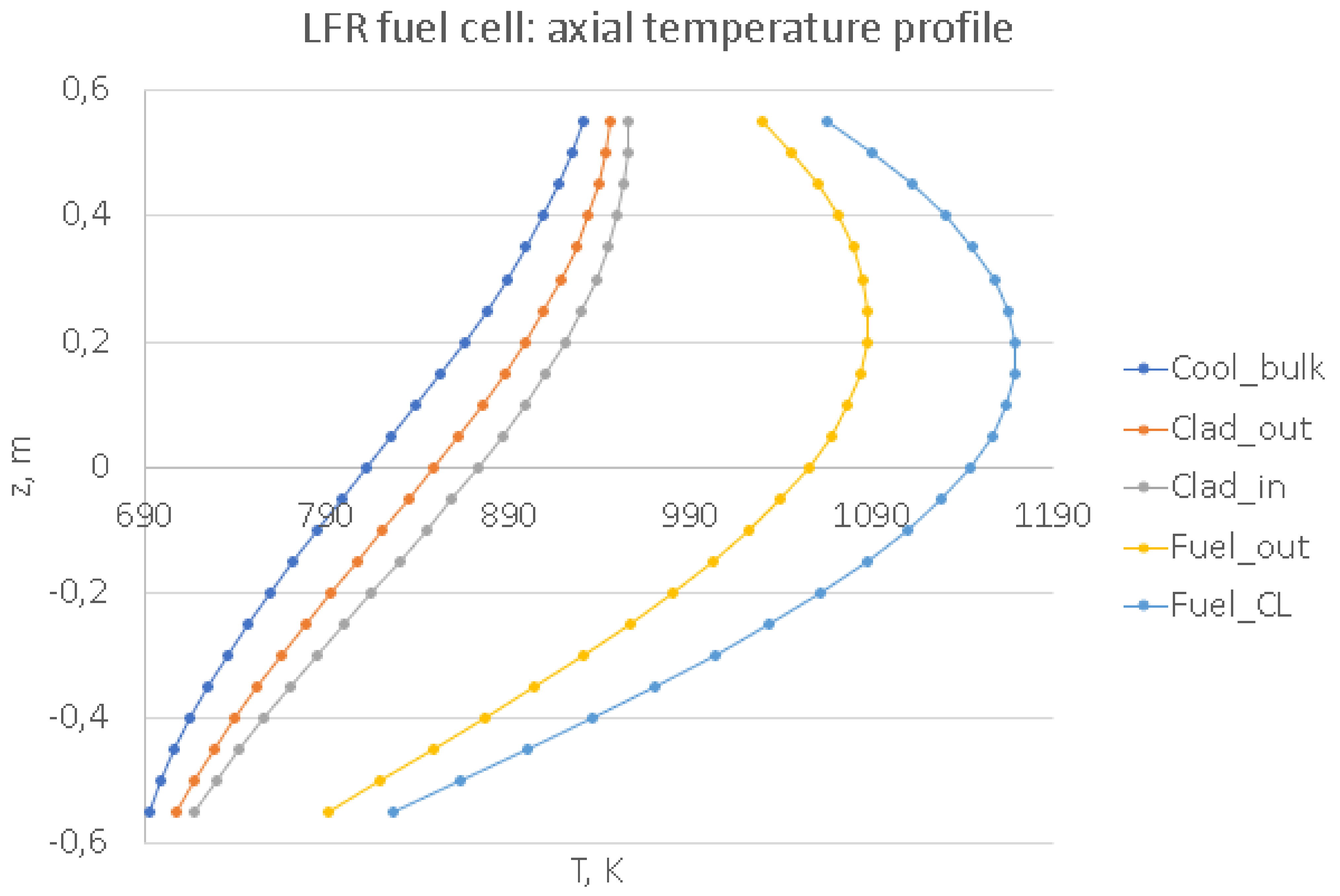
$$T_{ci} - T_{co} = \frac{q'}{2\pi k_c} \ell n \left(\frac{R_{co}}{R_{ci}}\right)$$

$$T_{fo} - T_{ci} = \frac{q''_g}{h_g} = \frac{2\pi R_g q''_g}{2\pi R_g h_g} = \frac{q'}{2\pi R_g h_g}$$

$$T_{max} - T_{fo} = \frac{q'}{4\pi \bar{k}_f}$$

Results: Graphs

Assuming 0.1 *mm gap with* 0.5 $\frac{W}{mK}$ *of thermal conductivity as same for SFR*



12 Phenix fast reactor parameters

2.2 Geometrical Data for the Fuel Subassembly

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

2.3 Reactor Parameters

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

$PeakingFactor K = K_z \times K_r = 1.62$

2.4 Most Powerful Subassembly

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

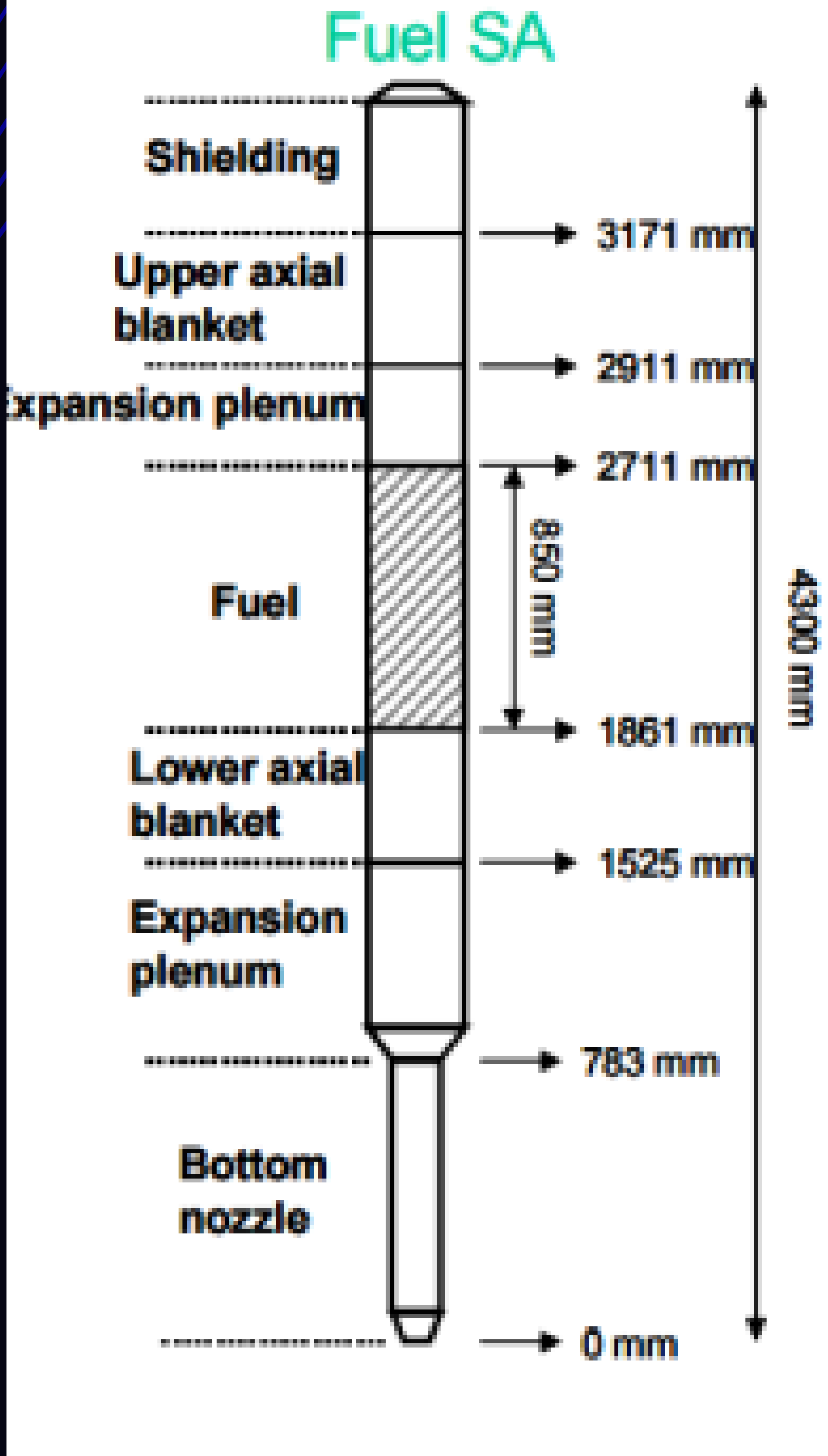
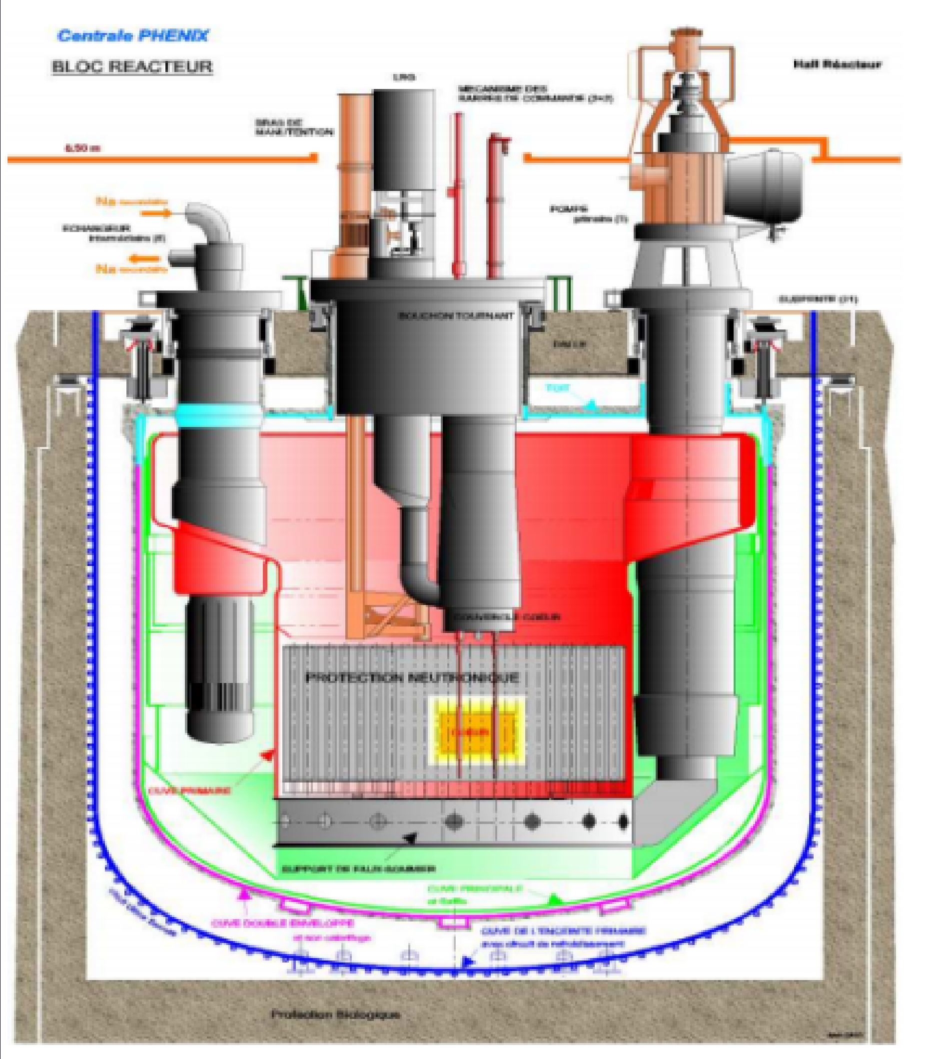
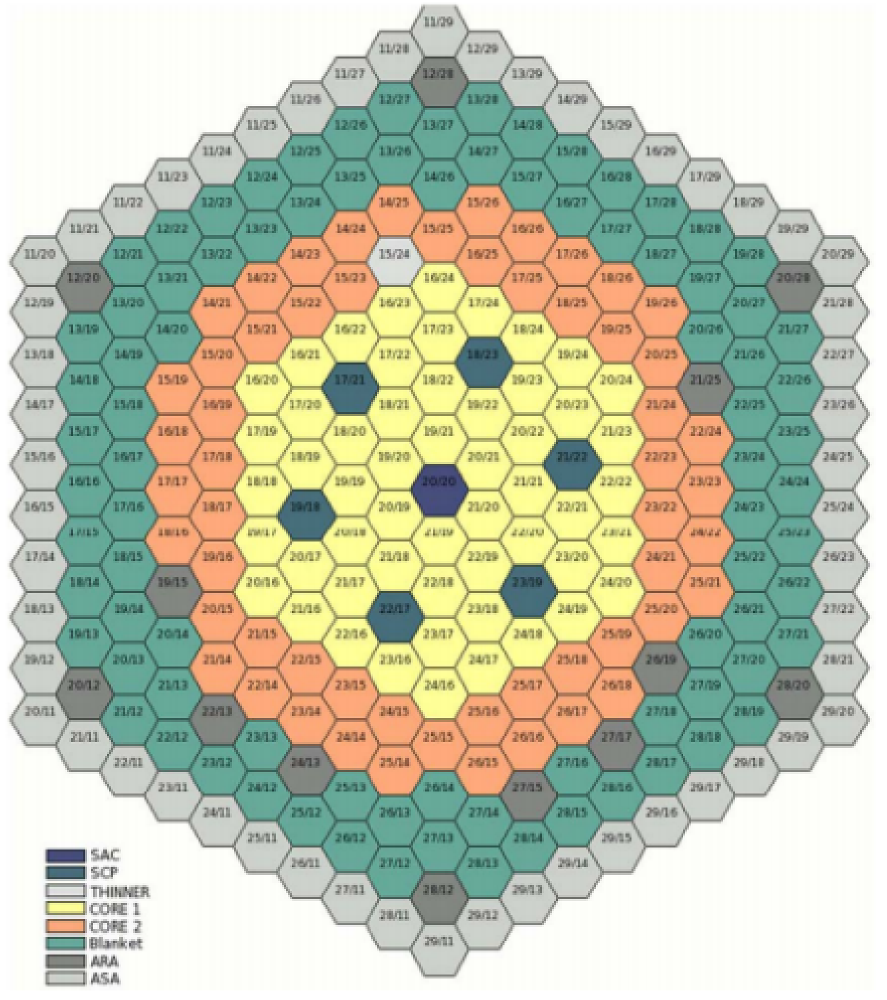


Figure 2.2: Fuel Sub Assembly





Group activity

Calculation

1. The total mass flow of the reactor:

Considering the mass flow for the most powerful subassembly equal to 25.1147 kg/s, we have that the total mass flow of the reactor is given by

$$\dot{m}_{total} = 25.1147 \times \#N_{SA}$$

$$\therefore \dot{m}_{total} = 25.1147 \times 110 = 2{,}762.617\ kg/s$$

Calculation

2. The axial (Kz) and radial (Kr) peaking factors:

The radial peak factor K_r is obtained by the relation $K_r = {}^{q_{max}}/_{q_{avg}}$. Knowing that $q_{avg} = {}^{q_{core}}/_{\#N_{FA}}$, we then have

$$K_r = \frac{q_{max}\#N_{SA}}{q_{core}} = \frac{6.037971\ MW \times 110}{563\ MW} \approx 1.18$$

and therefore K_z is

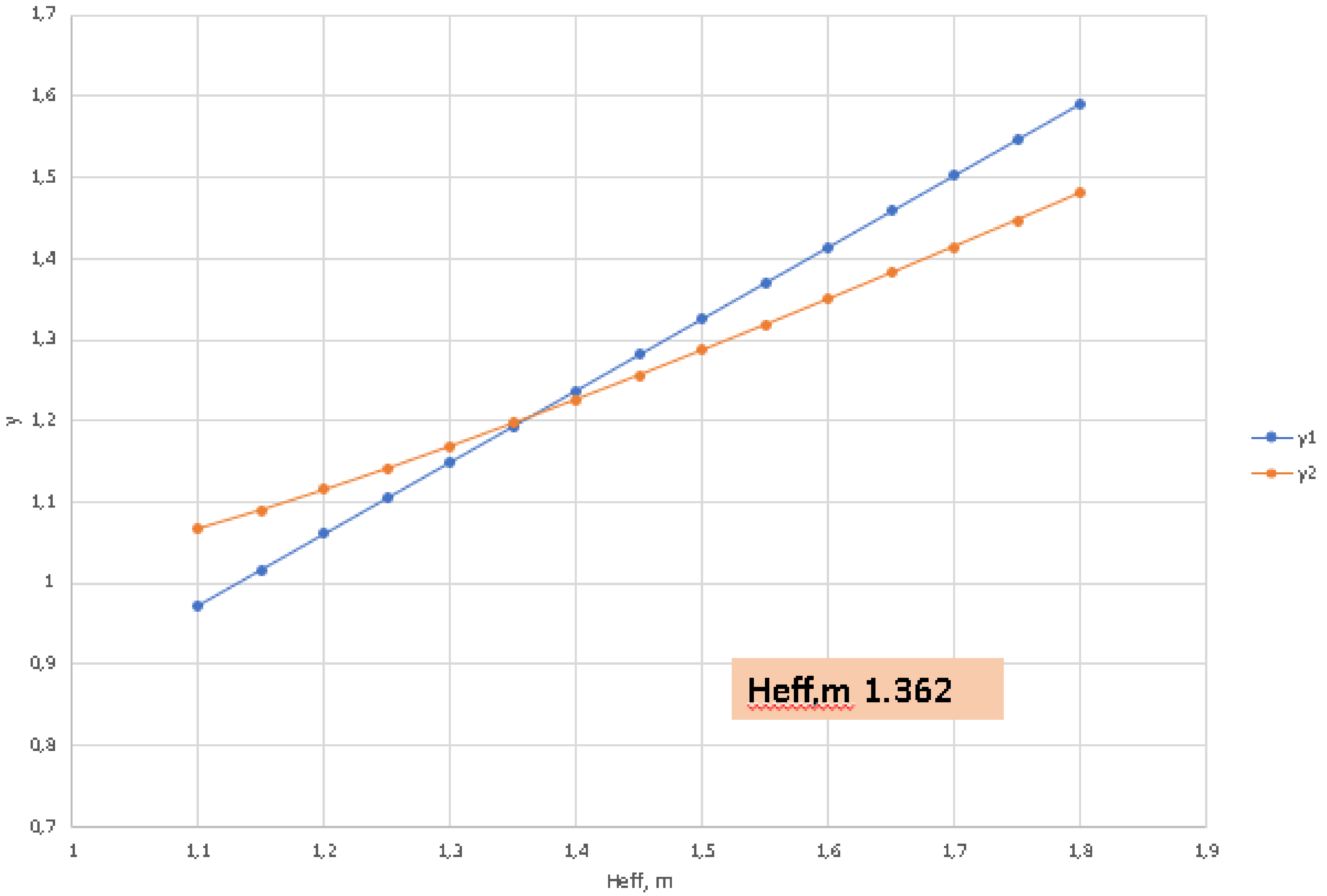
$$K_z = \frac{K}{K_r} = \frac{1.62}{1.18} \approx 1.37$$

Calculation

3. The effective height of the active core :he f f

$$y1 = \frac{2Heff \times Kz}{\pi H}$$

$$y2 = \frac{1}{\sin(\frac{\pi H}{2Heff})}$$

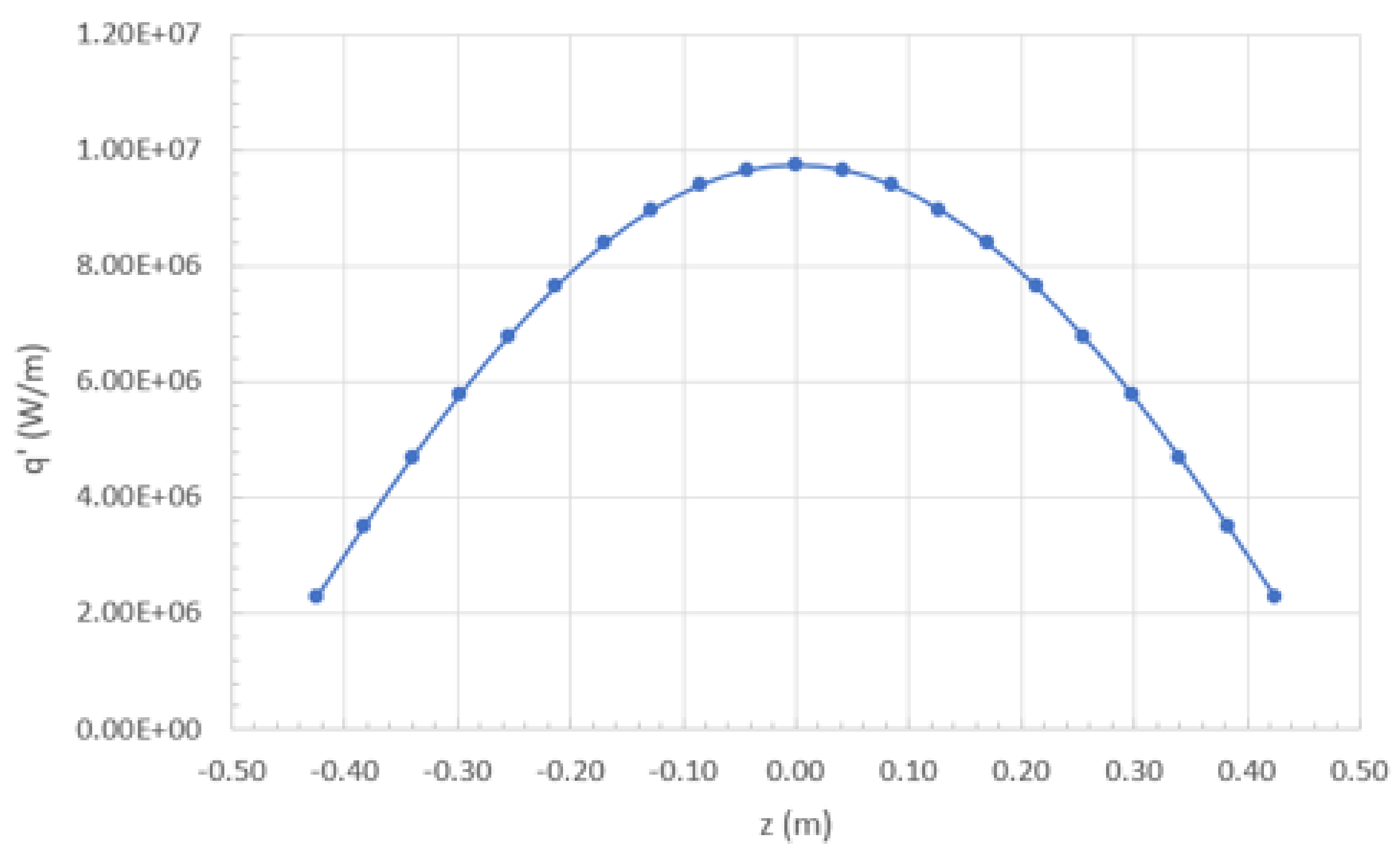


Calculation

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

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

$z\ (m)$	$q'\ (W/m)$
-0.4250	2.2772E+06
-0.3825	3.5196E+06
-0.3400	4.6993E+06
-0.2975	5.7954E+06
-0.2550	6.7884E+06
-0.2125	7.6605E+06
-0.1700	8.3962E+06
-0.1275	8.9825E+06
-0.0850	9.4089E+06
-0.0425	9.6678E+06
0.0000	9.7547E+06
0.0425	9.6678E+06
0.0850	9.4089E+06
0.1275	8.9825E+06
0.1700	8.3962E+06
0.2125	7.6605E+06
0.2550	6.7884E+06
0.2975	5.7954E+06
0.3400	4.6993E+06
0.3825	3.5196E+06
0.4250	2.2772E+06



Calculation

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

Starting from the energy balance equation:

$$\dot{m}C_p dT = q'(z)dz$$

$$\dot{m}C_p dT = q'_{max} cos\left(\frac{\pi z}{h_{eff}}\right)dz$$

$$\dot{m}C_p \int_{T_{in}}^{T} dT' = \int_{-z/2}^{z/2} q'_{max}\, cos\left(\frac{\pi z'}{h_{eff}}\right)dz'$$

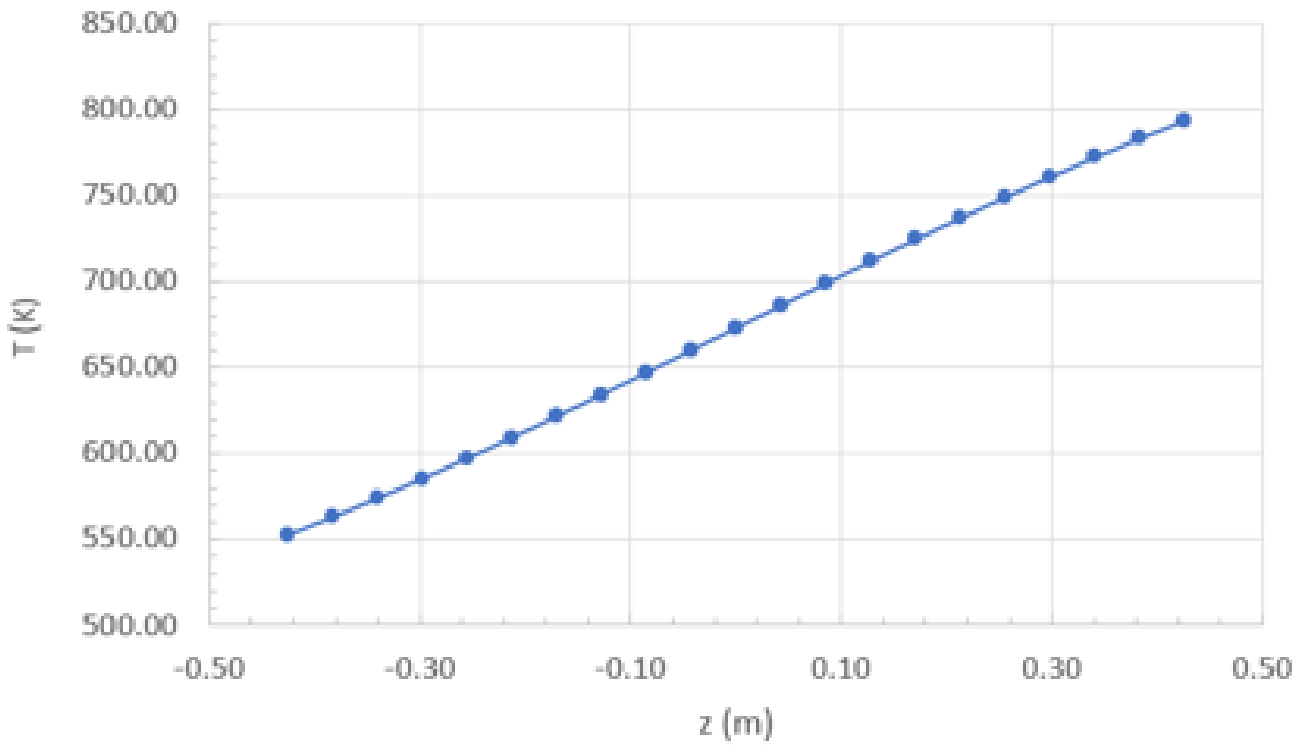
$$T - T_{in} = \frac{q'_{max}}{\dot{m}C_p}\int_{-z/2}^{z/2} cos\left(\frac{\pi z'}{h_{eff}}\right)dz'$$

$$T - T_{in} = \frac{q'_{max}}{\dot{m}C_p}\frac{h_{eff}}{\pi}\sin\left(\frac{\pi z'}{h_{eff}}\right)\Bigg|_{-z/2}^{z/2}$$

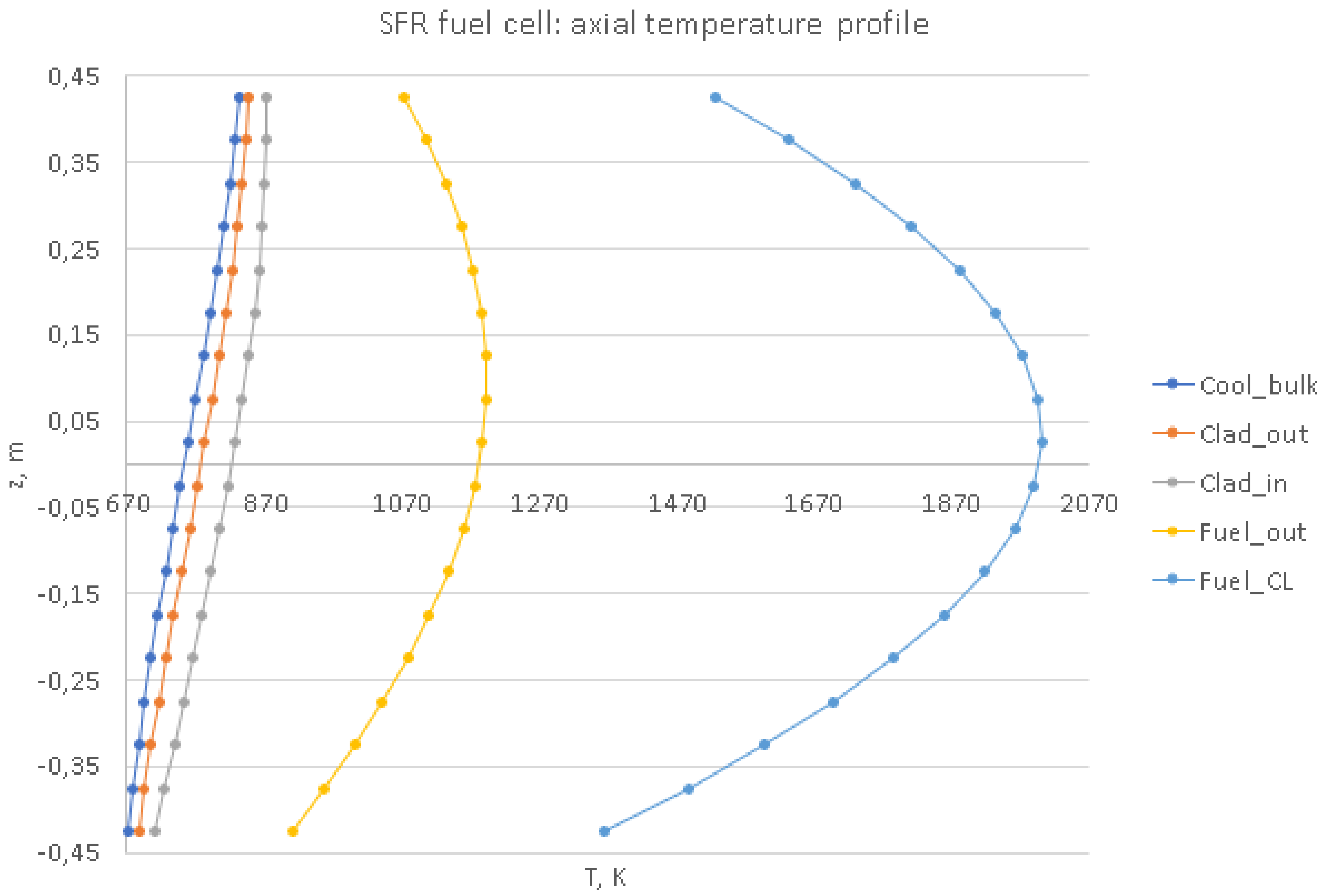
$$T - T_{in} = \frac{2\, q'_{max}\, h_{eff}}{\pi\, \dot{m}\, C_p}\sin\left(\frac{\pi z}{2\, h_{eff}}\right)$$

$$\therefore \boxed{T = \frac{2\, q'_{max}\, h_{eff}}{\pi\, \dot{m}\, C_p}\sin\left(\frac{\pi z}{2h_{eff}}\right) + T_{in}}$$

$z\ (m)$	$T\ (K)$
-0.4250	552.42
-0.3825	562.91
-0.3400	573.88
-0.2975	585.30
-0.2550	597.11
-0.2125	609.26
-0.1700	621.69
-0.1275	634.36
-0.0850	647.19
-0.0425	660.14
0.0000	673.15
0.0425	686.16
0.0850	699.11
0.1275	711.94
0.1700	724.61
0.2125	737.04
0.2550	749.19
0.2975	761.00
0.3400	772.42
0.3825	783.39
0.4250	793.88



Results: Graphs



Activity 2

Learning objectives:

•To describe the needs for technological and institutional innovations and improvements in nuclear energy systems with the goal to achieve sustainable development and deployment.

•To Provide knowledge and practical skills about nuclear energy as part of environment of sustainable development with planning and modelling scenarios.

•To train nuclear personnel (masters and doctoral students, professors and technicians) to adequately present to the public and policy makers innovations in the nuclear sector that contribute to the development of a sustainable world.

Module 3: Innovations in Nuclear Energy Sector in Meeting Sustainable Energy Development Challenges

Nuclear and renewables for carbon neutral future

- Life cycle assessment: comparing the sustainability of energy technologies → Tracing sustainable energy paths
- Sustainable development goals (SDG) → To present Sustainable Development Goals (SDGs) of the UN, which include a dedicated goal on energy (SDG 7): "Ensure access to affordable, reliable, sustainable and modern energy for all"
- To archive green hydrogen production to reduce carbon foot print

Environmental and developmental impact

- Reviving growth
- Merging environment and economics in decision making → To show how nuclear power can help to provide electricity access to growing urban populations worldwide
- Development that is Conserving and Enhancing the Resource Base to sustain large number of people living in poverty.

Economic growth

- Meeting basic human needs
- Intergenerational challenges of nuclear Power, safety and non-proliferation → Nuclear power must not only be safe but also used exclusively for peaceful purposes supported through safeguards measures (including activities of the IAEA and others) to build confidence and foster technical co-operation.
- Economic and social development can and should be mutually reinforcing. Money spent on education and health can raise human productivity. Economic developments can accelerate social development by providing opportunities for underprivileged groups or by spreading education more rapidly.

News technologies development in nuclear area

- New classes of advanced reactors and fuels

Prerequisites:

- Possess a basic knowledge of mathematics, physics, and nuclear power technologies; an engineering background (including a bachelor's degree in nuclear engineering) is advantageous.

- Successful completion of core module 1 “Energy planning and strategies for sustainable development” and 2 ‘Planning for Nuclear Energy Sustainability’ of the model curriculum or a module or course with similar content.

Learning Outcome:

- Explain the concept of Innovations in Nuclear Energy Sector in Meeting Sustainable Energy Development Challenges as developed by INPRO and presented in relevant IAEA publications.

- Relate the INPRO concept of sustainable energy systems to meet the sustainable energy development for achieving Sustainable Development Goals (SDGs).

- To present Sustainable Development Goals (SDGs) of the UN, which include a dedicated goal on energy (SDG 7)“Ensure access to affordable, reliable, sustainable and modern energy for all”

- Meeting basic essential needs in part and achieving full growth potential, and sustainable development to require economic growth in places where such needs are not being met.

Joint ICTP-IAEA Workshop on Physics and Technology of Innovative Nuclear Energy Systems | (smr 3700)

THANK YOU FOR YOUR ATTENTION!