Numerical Analysis of Flow and Heat Transfer in a Fuel Subassembly of SFRs with Porous Model

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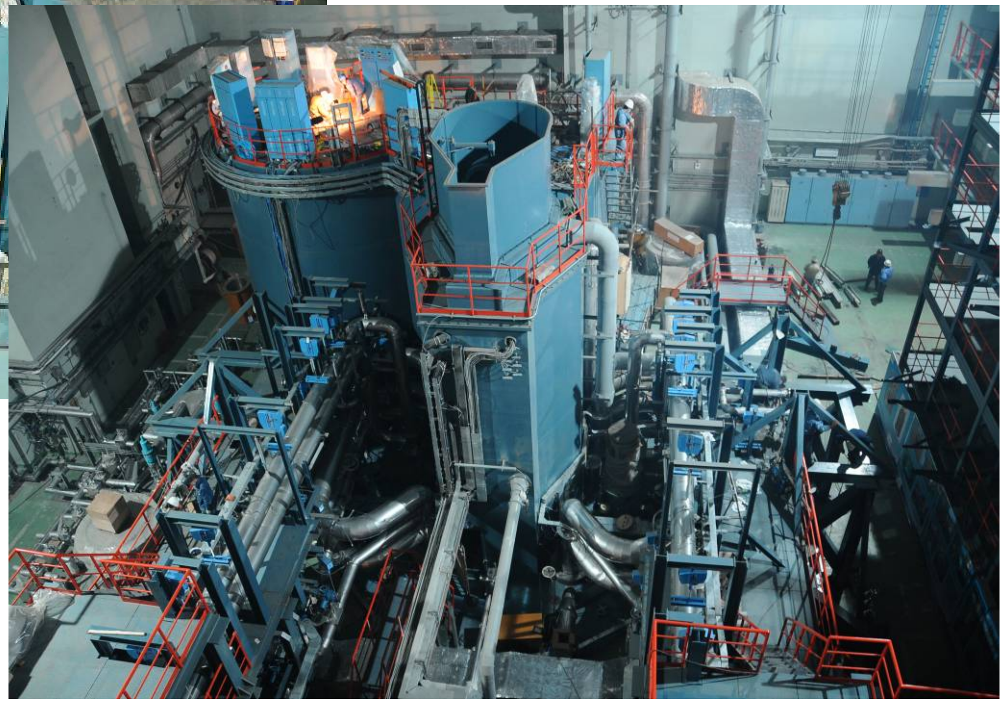
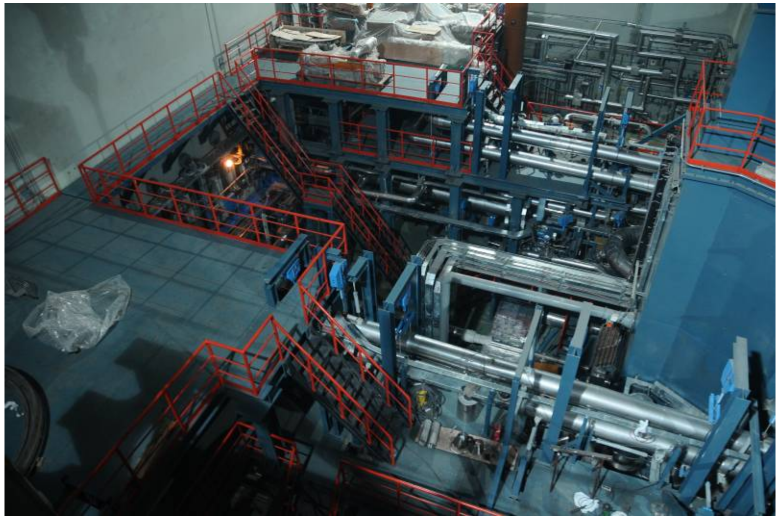
Current status of the CEFR



Reactor Hall



Piping line of secondary circuit

Main control room

I&C system room

Milestones

- ✓ **1995.12.09, project approved;**
- ✓ **1997.11.13, primary design approved;**
- ✓ **2000.05.30, first pot concrete;**
- ✓ **2004.11.30, detail design finished;**
- ✓ **2009.05.30, start primary circuit commissioning.**

Numerical Analysis of Flow and Heat Transfer in a Fuel Subassembly of SFRs with Porous Model

- N-S formula and porous model
- Pressure drop model and heat transfer model
- Numerical simulation results

System analysis code

More accurate

More detailed

One dimensional ⇨ Three dimensional

OASIS

SASSYS

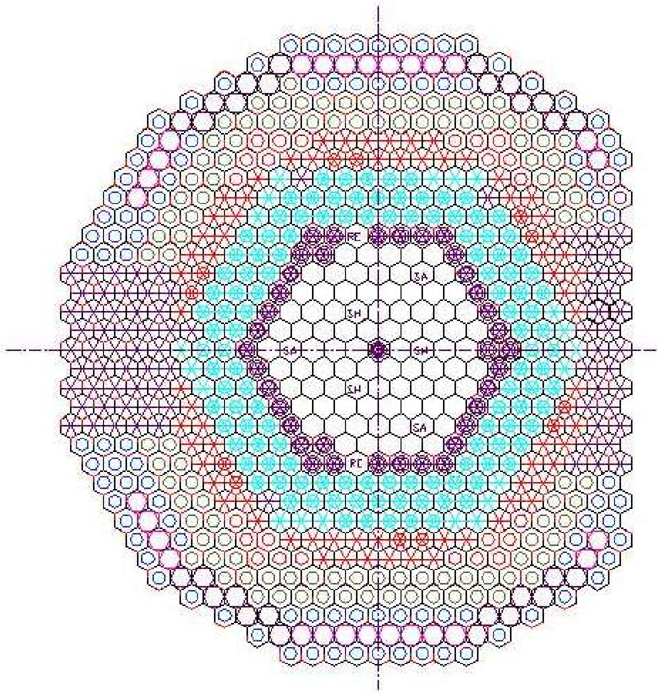
Relap

⇧

CFD method

⇧

Experimental data



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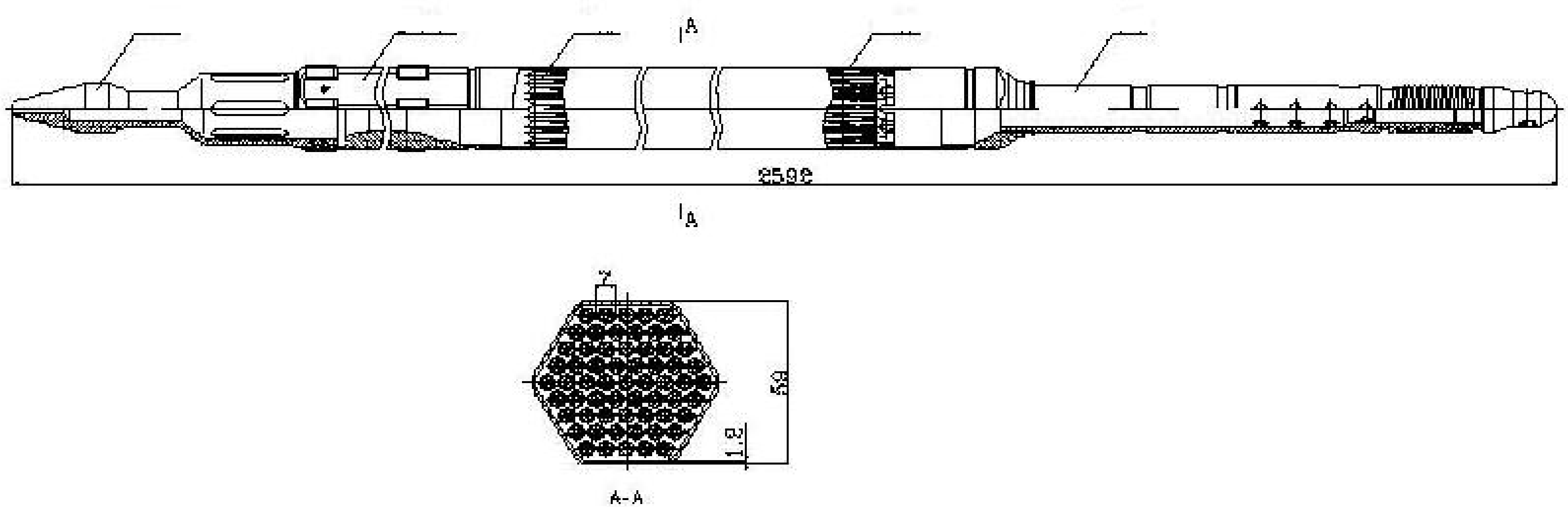
- Safety subassembly
- Regulation subassembly
- Compensation subassembly

CEFR Core Configuration

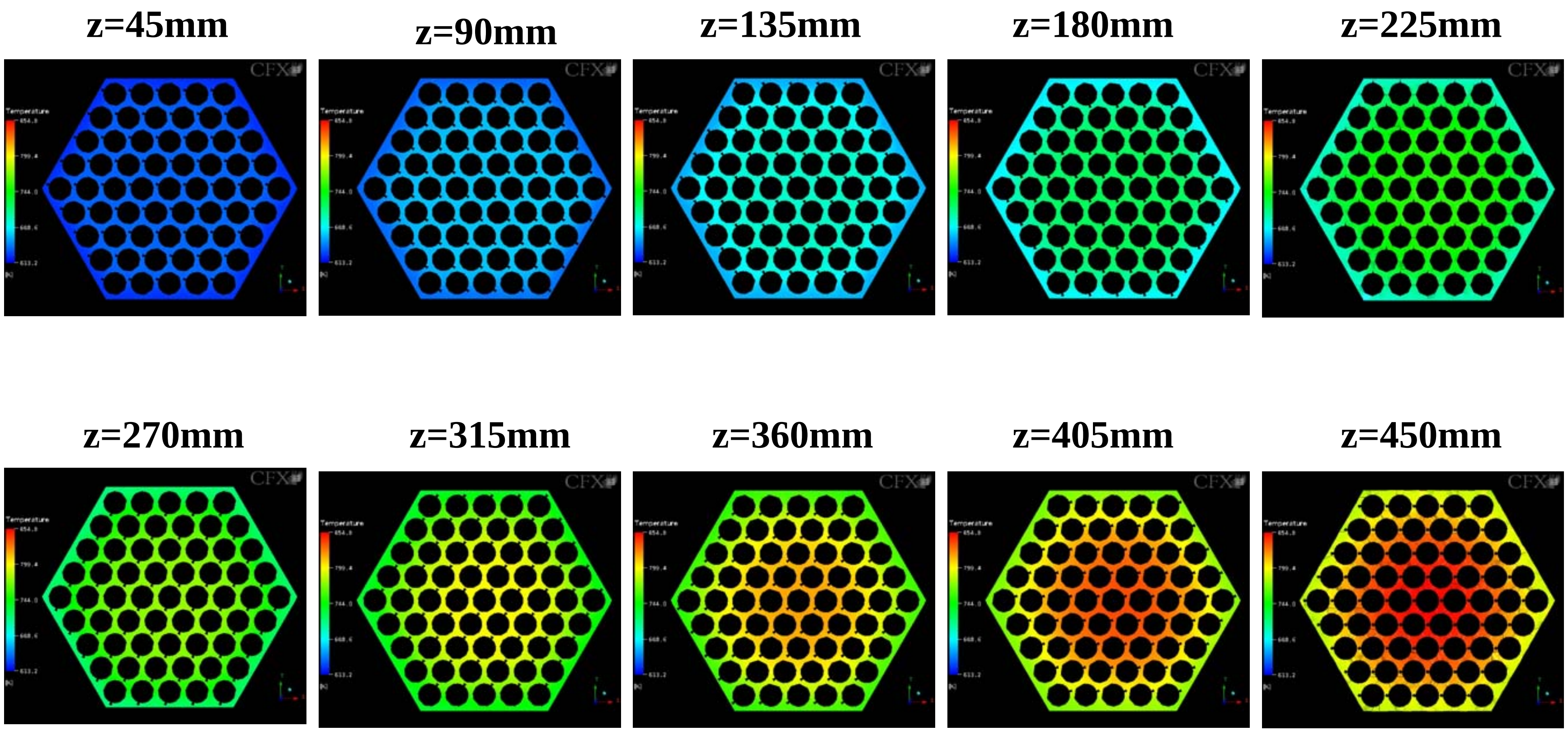


Layout of Fuel Subassembly

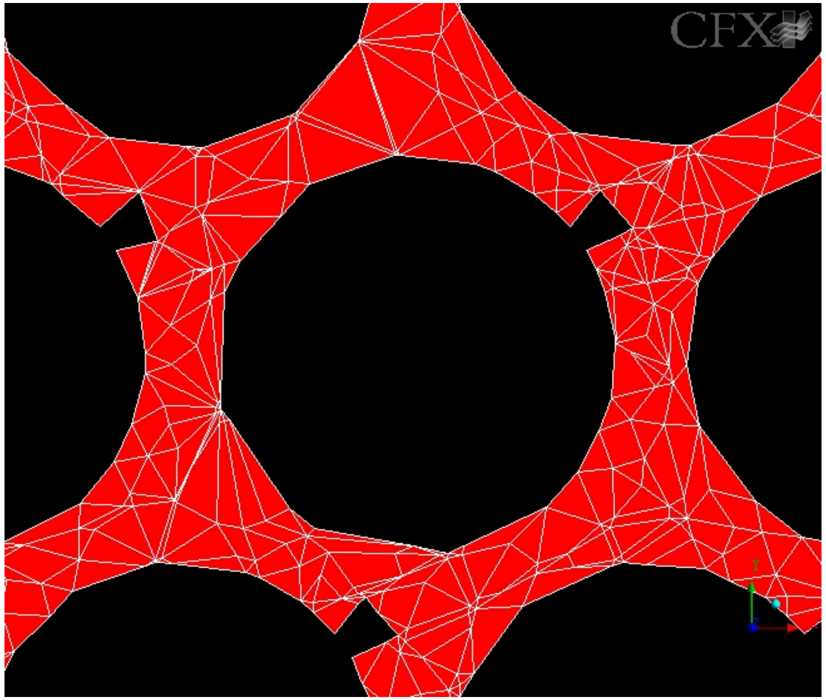
P–Pitch
D–Pin Diameter
s–Wire Diameter
H–Lead
L–Pin Length

Rod Bundle

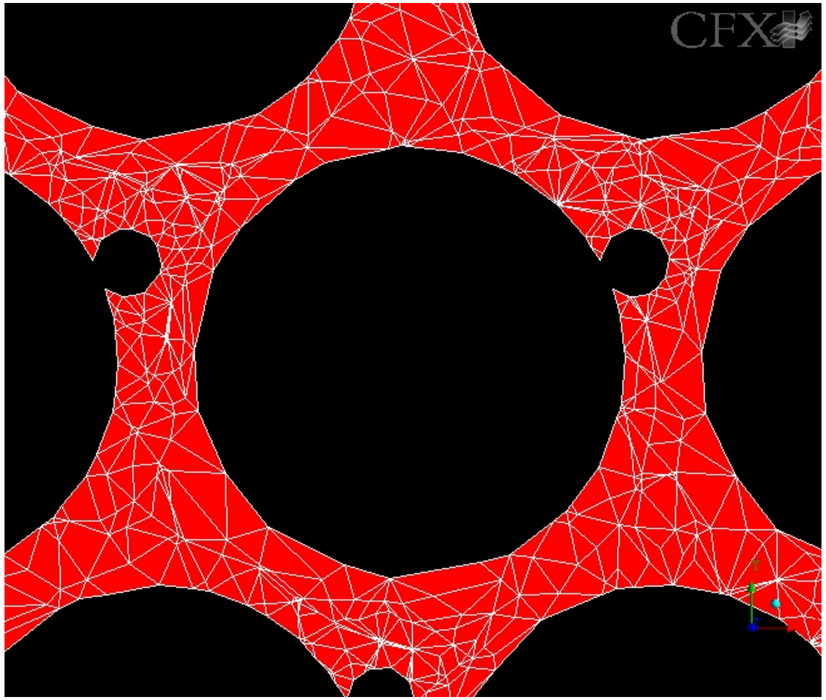
Rod wrapped by helical wire



Temperature Distribution at 10 Cross Sections

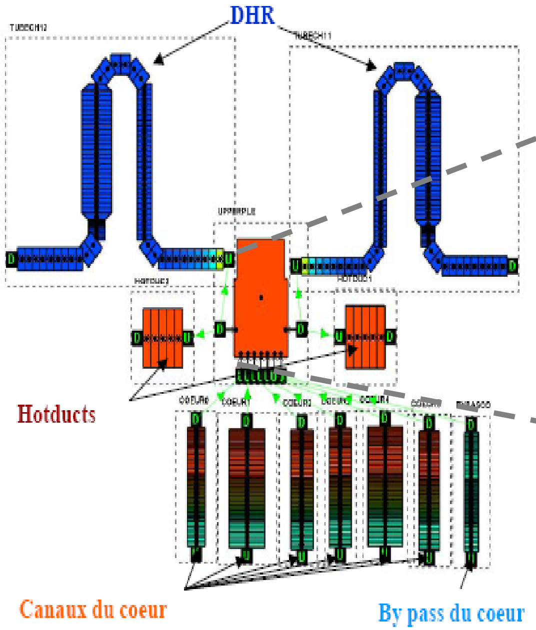


2.4 million meshes
1 CPU, 3 hours

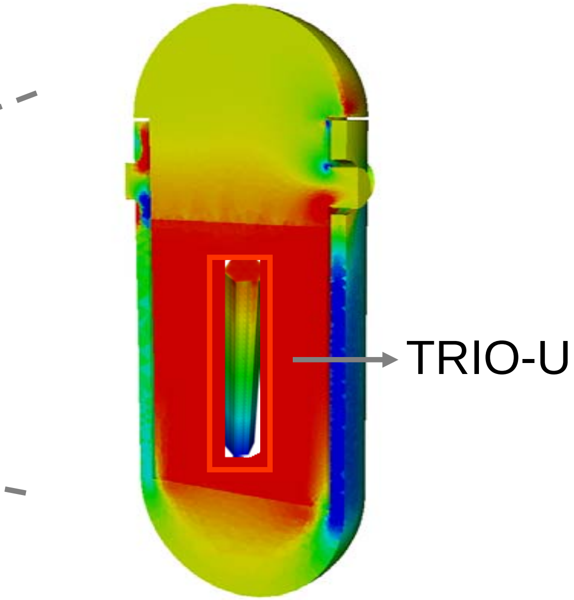


20 million meshes
10CPU, Several days
Better

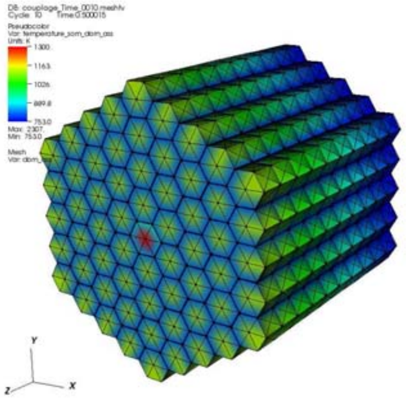
Comparison of Mesh Quality

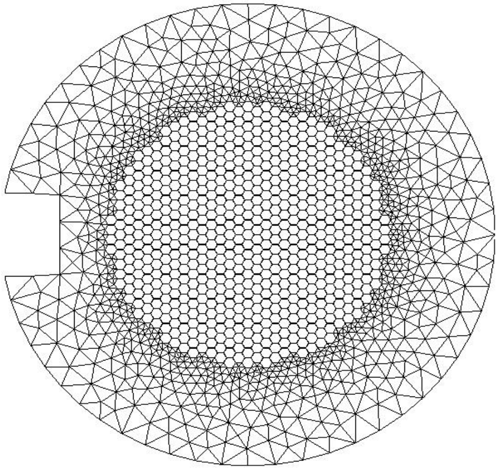


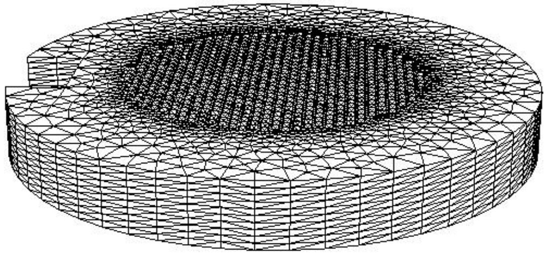
CATHARE-ML



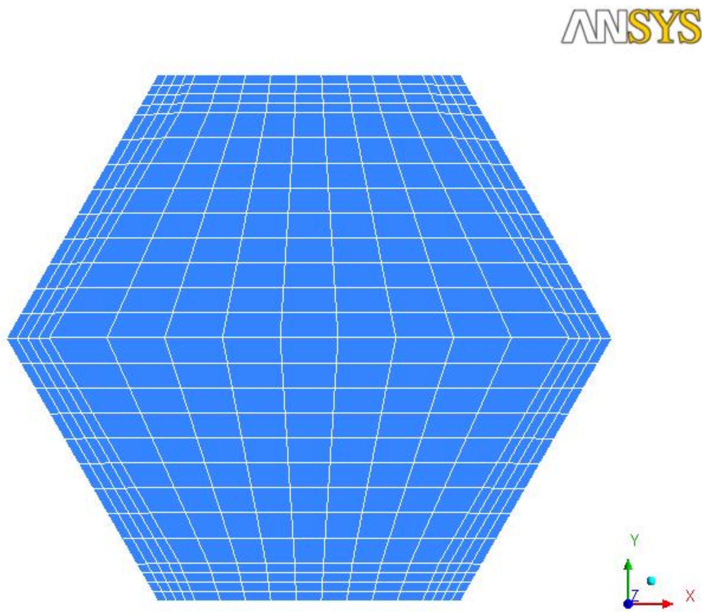
New system code program in France



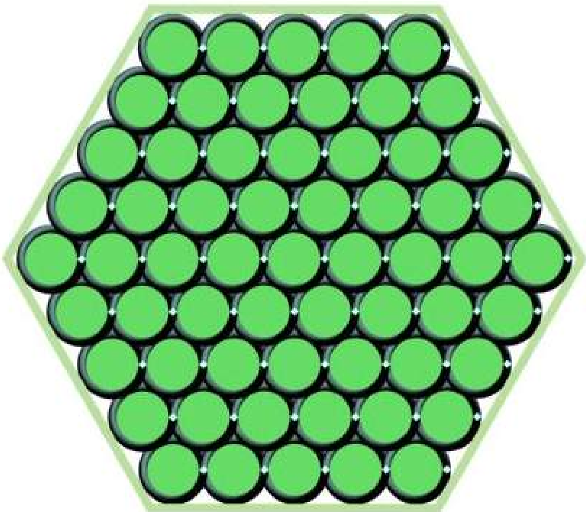


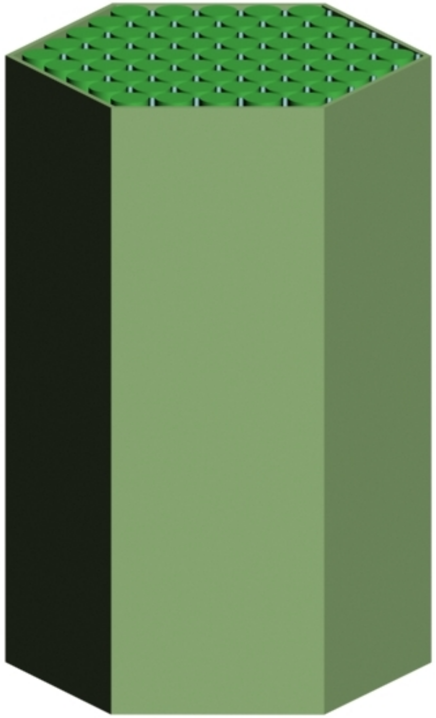


Porous model consideration



Meshes of the SA active part





Volume porosity and surface porosity

Governing Equations in Code

Darcy's law

$$-\frac{\partial p}{\partial x_i} = \frac{\mu}{K_{perm}} U_i + K_{loss} \frac{\rho}{2} \left| U \right| U_i$$

Advection-diffusion equation

$$\frac{\partial}{\partial t}(\gamma \rho \Phi) + \nabla \bullet (\rho K \bullet U \Phi) - \nabla \bullet (\Gamma K \bullet \nabla \Phi) = \gamma S$$

Equations for conservation of mass and momentum

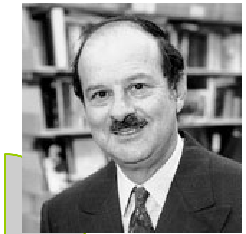
$$\frac{\partial}{\partial t} \gamma \rho + \nabla \bullet (\rho K \bullet U) = 0$$

Pressure Drop In Rod Bundle

Sangster (1968) → Novendstern (1972)

Rehme (1965) → Novendstern (1972)

Novendstern (1972) → CRT (1978)



Neil E. Todreas

$$\Delta p = M f_{光滑} \frac{L}{D_{e1}} \frac{\rho V_1^2}{2}$$

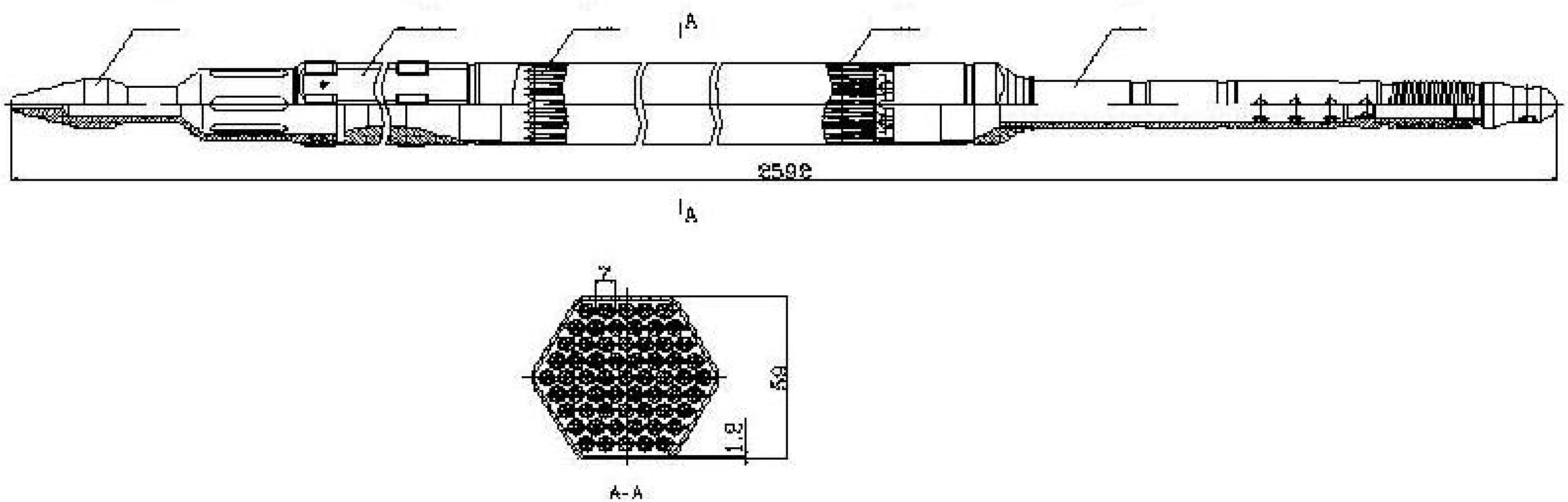
$$\Delta p_1 = f_{s1} \frac{L}{D_{e1}} \frac{\rho V_1^2}{2} \left[1 + C_1 \frac{A_{r1}}{A_1'} \frac{D_{e1}}{H} \frac{P^2}{(\pi P)^2 + H^2} \right]$$

$$\Delta p_2 = f_{s2} \frac{L}{D_{e2}} \frac{\rho V_2^2}{2} \left\{ 1 + \left[C_2 n \left(\frac{V_T}{V_2} \right)_{间隙} \right]^2 \right\}^{1.375}$$

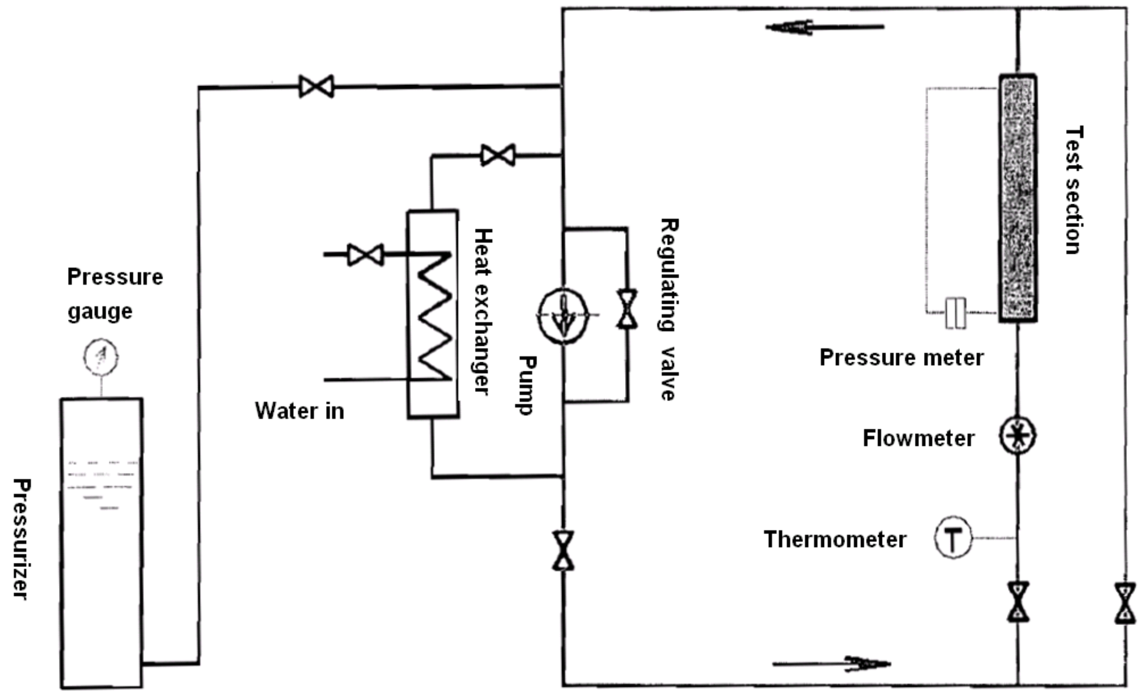
$$\Delta p = \frac{N_1 A_1}{N_1 A_1 + N_2 A_2} \Delta p_1 + \frac{N_2 A_2}{N_1 A_1 + N_2 A_2} \Delta p_2$$

Colebrook Formula:

$$\frac{1}{f^{0.5}} = -4 \lg \left[\frac{(\varepsilon / D)}{3.7} + \frac{1.255}{\left(R_e f^{0.5} \right)} \right]$$



Layout of Test Subassembly

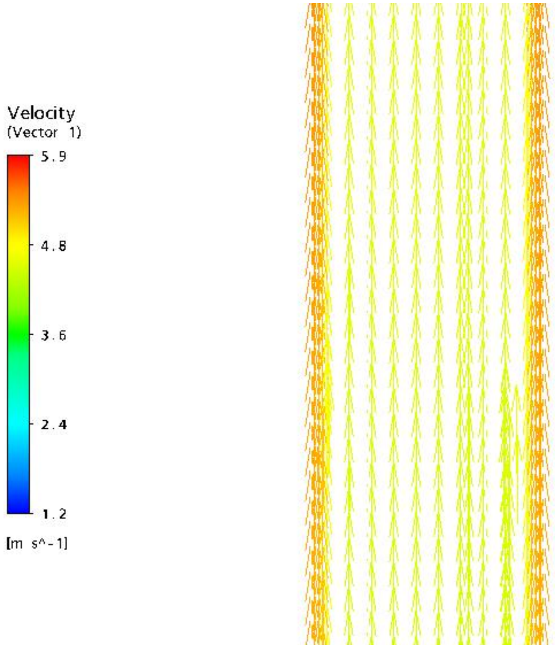


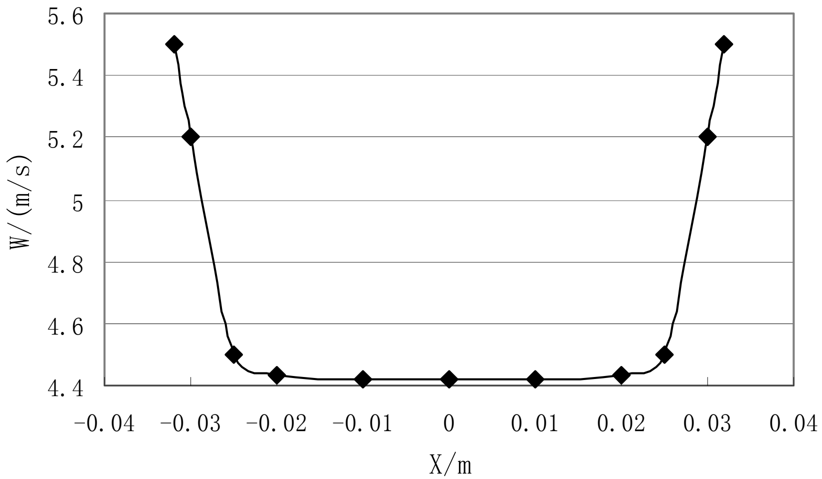
Test rig for pressure drop of SA

Heat transfer model

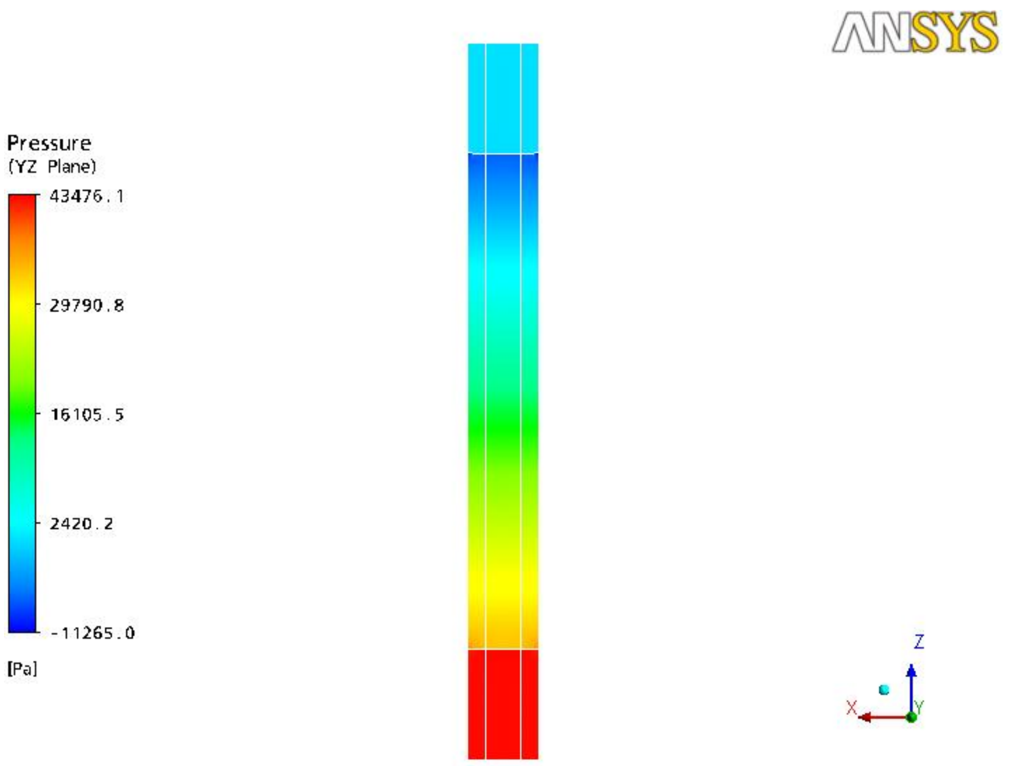
$$\frac{\partial}{\partial t}(\gamma\rho H)+\nabla\bullet(\rho K\bullet UH)-\nabla\bullet\left(\left(\rho C_p\varepsilon+\Gamma_e K\right)\bullet\nabla H\right)=\gamma S^H$$

$$\varepsilon=\left(\frac{D}{H}\right)\left[0.85-12.8\left(\left|\frac{P}{D}-1.25\right|\right)^{1.424}\right]\frac{\overline{\lambda}_a}{\lambda_{LI}}$$

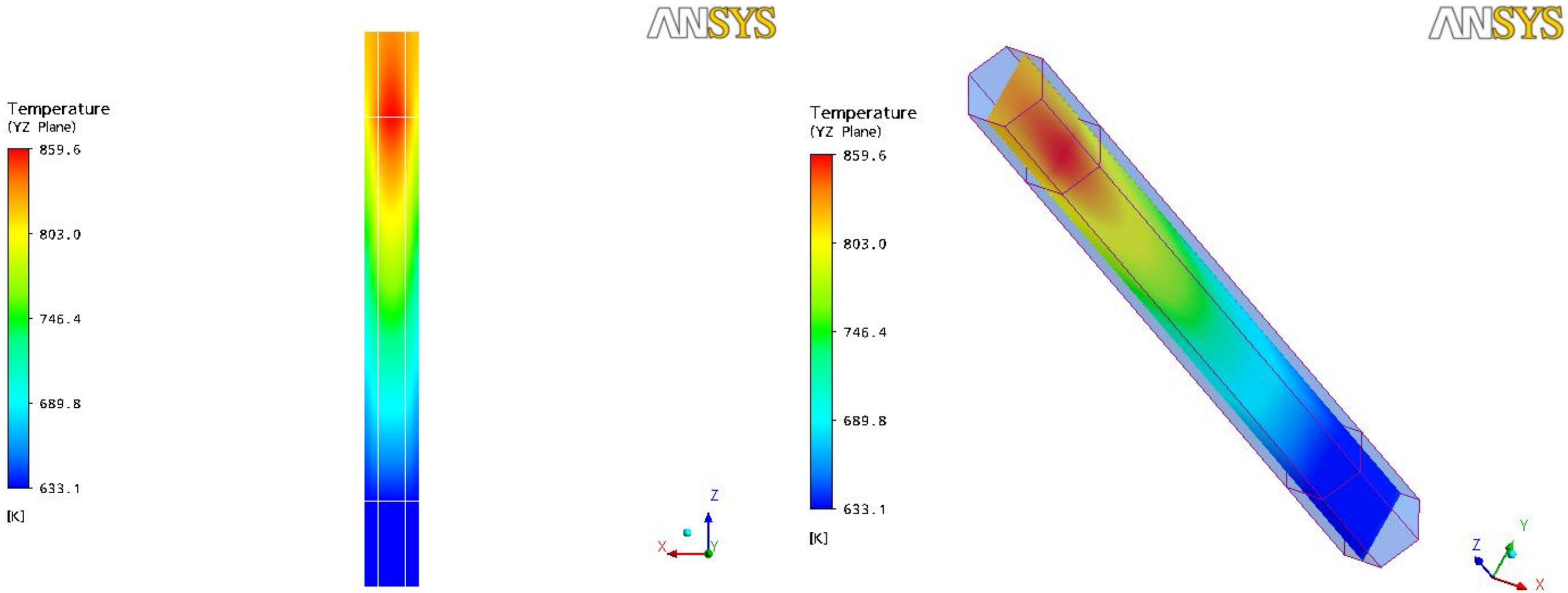




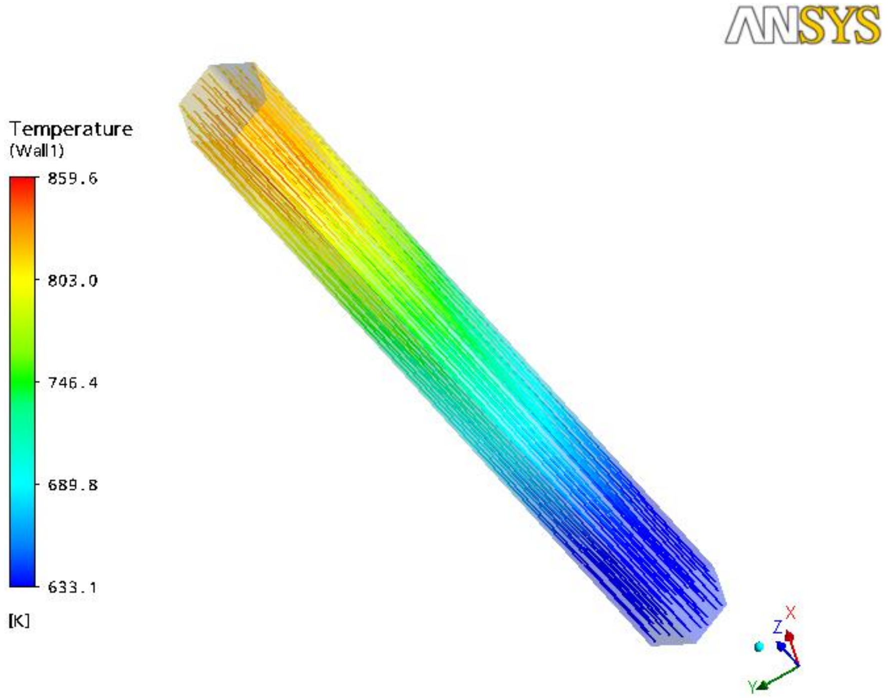
Axial velocity distribution

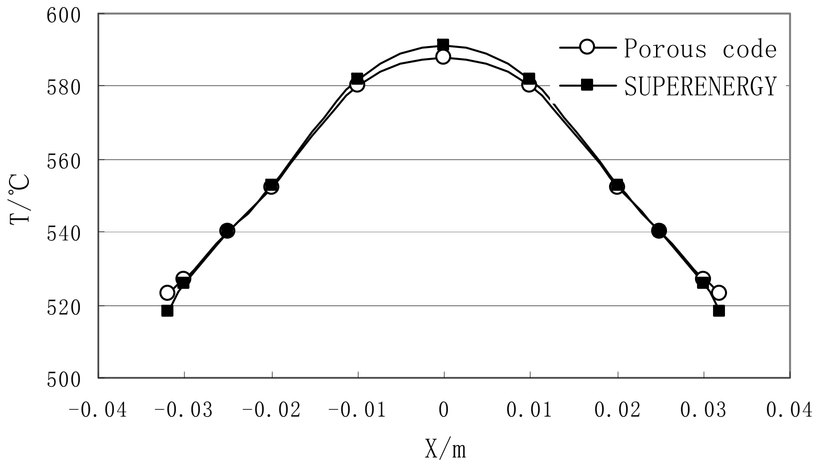


Pressure drop in the active part



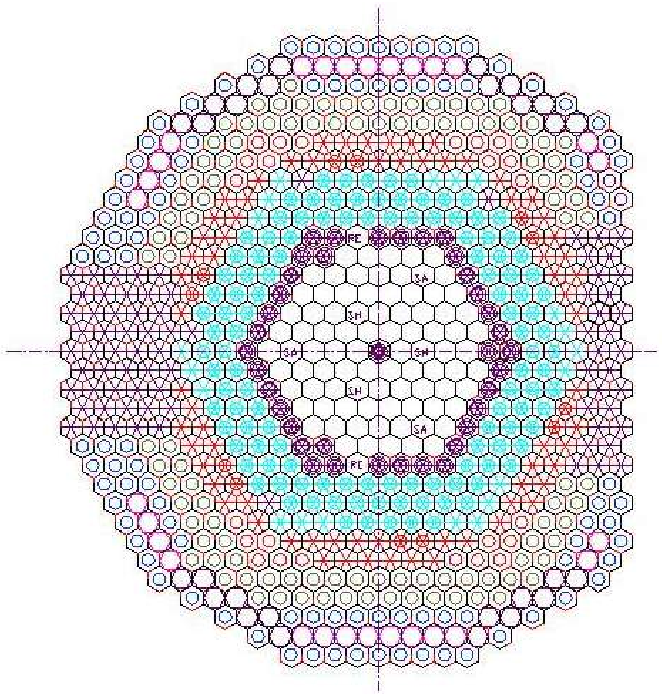
Axial temperature distribution





Axial temperature distribution

Whole core flowrate distribution test in CEFR



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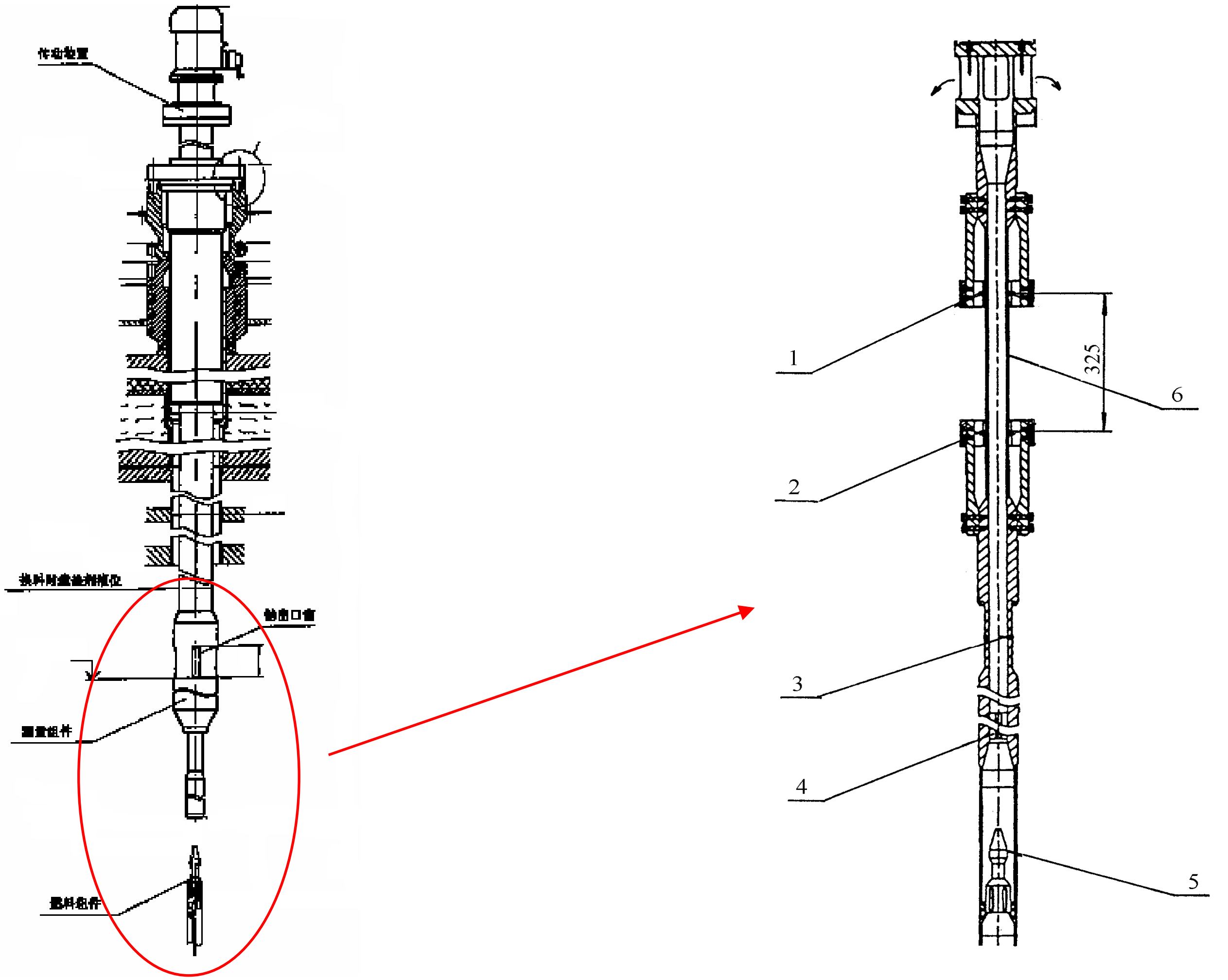
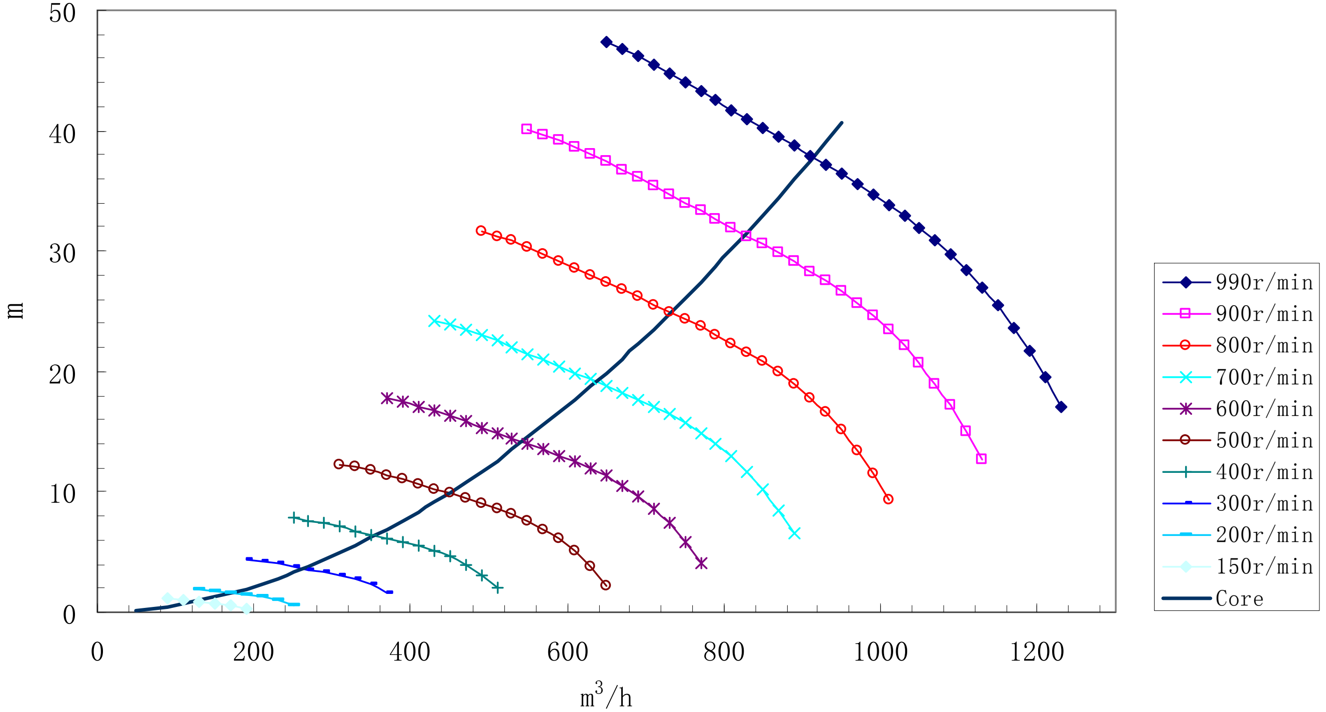
CEFR Core Configuration



Permanent-magnet sodium flowmeter

Reactor block model

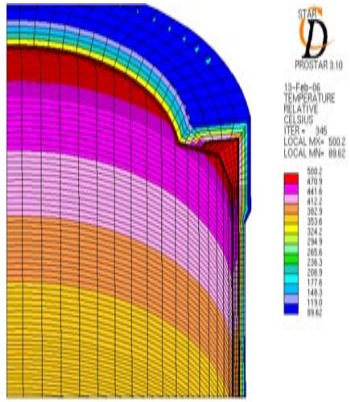


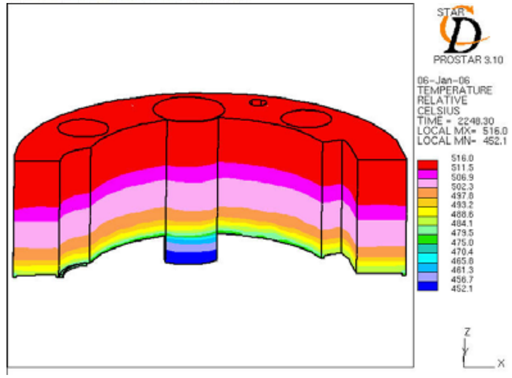
Hydraulic characteristics of the core

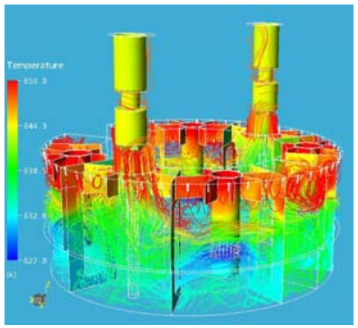
Issues requiring further research and development:

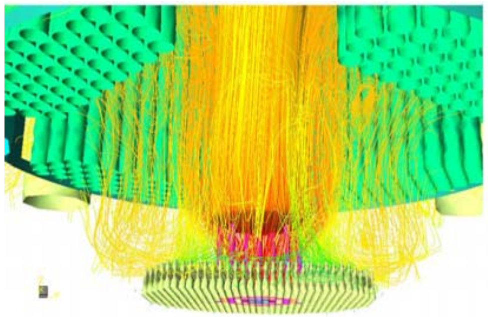
- Flowrate distribution results.
- Experimental database for DHRS.
- Thermal-hydraulics coupling with physics.

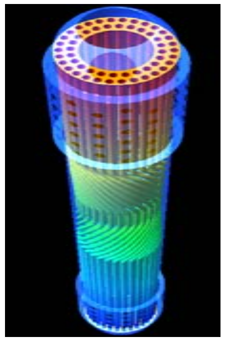
New system code to optimize design and guide reactor operation.

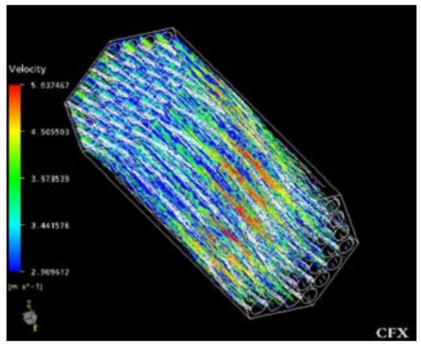













2009
Welcome to CEFR!

- Thank you!