THERMOHYDRAULIC ANALYSIS OF A FUEL ELEMENT OF THE AP1000 REACTOR WITH THE USE OF MIXED OXIDES OF U / Th USING THE COMPUTATIONAL FLUID DYNAMIC CODE (CFX)

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OBJECTIVES

- Develop a Three – Dimensional Model of an AP1000 Reactor Fuel Assembly Using the ANSYS – CFX Code.
- Obtain:
  - Axial and Radial Temperature Profiles.
  - Axial Density Profile and Coolant Pressure Drop Across the Fuel Assembly.
- Check the Limits of Thermal Safety Design.
- Comparison of Results with Resolutions Obtained in Simulations of Other Authors.

METHODOLOGY

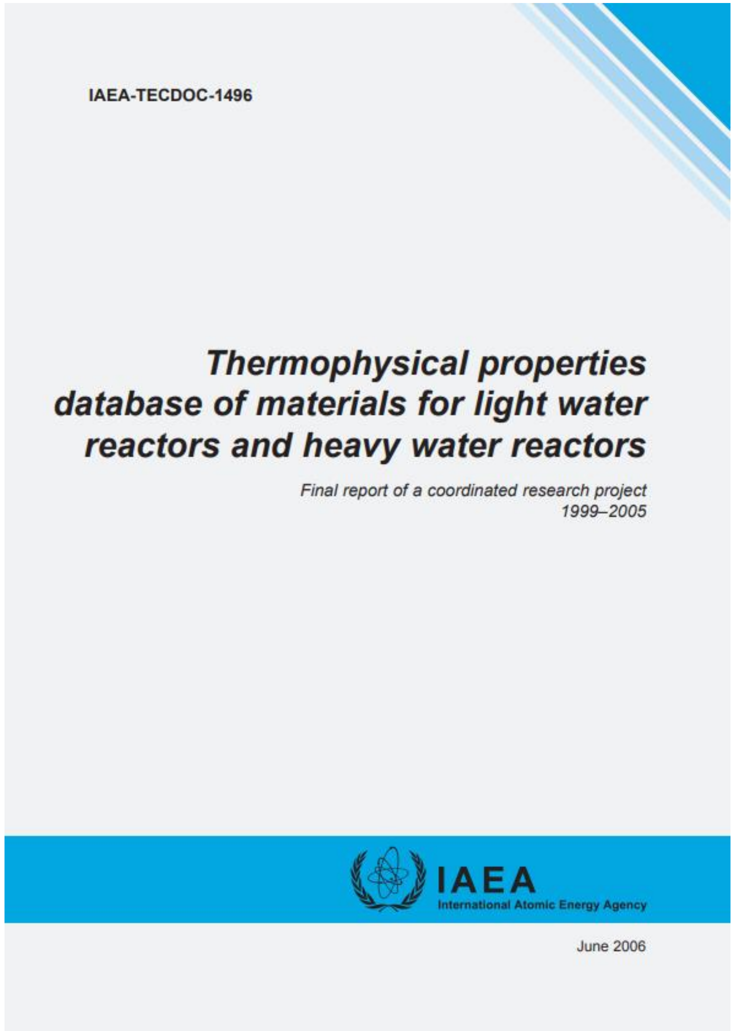
- Evaluate the Thermophysical Properties of the Fuel $(\mathrm{U}, \mathrm{Th})\mathrm{O}_2$
- Determine the Power Density Distribution in the Typical Fuel Assembly of the AP1000 Reactor;
- Establish a Computational Model for Thermohydraulic Calculations:
    - Definition of the Reactor Geometry;
    - Calculation Method;
    - Boundary Conditions;

METHODOLOGY

Thermophysical Properties of the fuel $(\mathrm{U},\mathrm{Th})\mathrm{O}_2$

- The Evaluation of the Thermophysical Properties was Made by the Use of IAEA-TECDOC-1496.

“IAEA. International Atomic Energy Agency. ***Thermophysical Properties Database of Materials for Light Water Reactors and Heavy Water Reactors****, IAEA-TECDOC-1496, Viena, 2006.”*


IAEA-TECDOC-1496

Thermophysical properties database of materials for light water reactors and heavy water reactors

Final report of a coordinated research project 1999–2005

IAEA
International Atomic Energy Agency

June 2006

METHODOLOGY

Thermophysical Properties of the fuel $(\mathrm{U,Th})\mathrm{O_2}$

- *Thermal Conductivity*

$$k_{U-Th} = [-0.0464 + 0.0034 * x + (2.5185x10^{-4} + 1.0733x10^{-7} * x)T]^{-1} \left[\frac{W}{m \cdot K}\right]$$

- *Density*

$$\rho_{UO_2} = 11063.3350 - 0.3520 * T + 5.2700 \times 10^{-5} * T^2 - 3.0300 \times 10^{-8} * T^3 \left[\frac{kg}{m^3}\right]$$

$$\rho_{ThO_2} = 10047.0285 - 0.1690 * T - 7 \times 10^{-5} * T^2 + 1 \times 10^{-8} * T^3 \left[\frac{kg}{m^3}\right]$$

$$\rho_{(U_x,Th_{1-x})O_2} = x * \rho_{UO_2} + (1 - x) * \rho_{ThO_2}$$

$$\rho_{(U_{0,24},Th_{0,76})O_2} = 10290.9204 - 0.2129 * T - 4.0552x10^{-5} * T^2 + 3.2800x10^{-10} * T^3 \quad \left[\frac{kg}{m^3}\right]$$

METHODOLOGY
Thermophysical Properties of the fuel $(\mathrm{U},\mathrm{Th})\mathrm{O}_2$

- *Specific Heat*

$$C_{p_{UO_2}} = 52.1743 + 0.08795 * T - 8.4241x10^{-5} * T^2 + 3.1542x10^{-8} * T^3 - 2.6334x10^{-12} * T^4 - 7.1391x10^5 * T^{-2} \quad \left[\frac{J}{mol \cdot K}\right]$$

$$C_{p_{ThO_2}} = 55.9620 + 0.05126 * T - 3.6802x10^{-5} * T^2 + 9.2245x10^{-9} * T^3 - 5.7403x10^5 * T^{-2} \quad \left[\frac{J}{mol \cdot K}\right]$$

$$C_{p_{(U_{\mathbf{0,24}},Th_{\mathbf{0,76}})O_2}} = 207.4842 + 0.2264 * T - 1.8161x10^{-4} * T^2 + 5.4952x10^{-8} * T^3 - 2.3819x10^{-13} * T^4 - 2.2899x10^6 * T^{-2} \quad \left[\frac{J}{kg \cdot K}\right]$$

METHODOLOGY

Power Density Distribution in the Typical Fuel Assembly of AP1000 Reactor

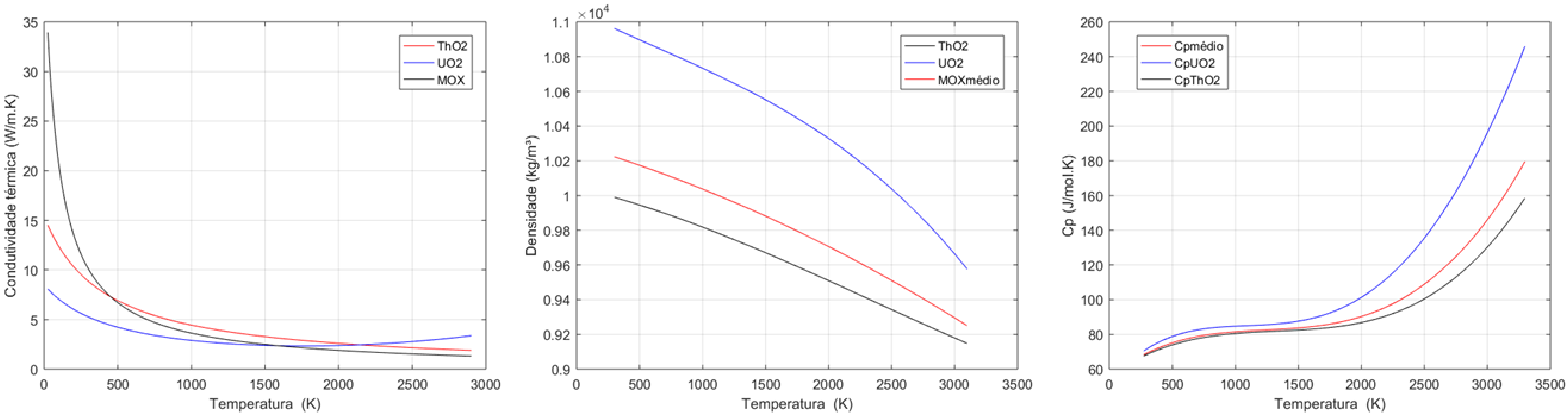


Figure 1 – Influence of Temperature on Thermophysical Properties

METHODOLOGY

Power Density Distribution in the Typical Fuel Assembly of AP1000 Reactor

- Initially a linear variation of coolant temperature was employed to give a start on the iterative process;

- The energy released at each region (11 cells) on height was determined;

- Wasn't considered any burnable poison presence (considering air);

- MCNP6 and ANSYS CFX software were used.

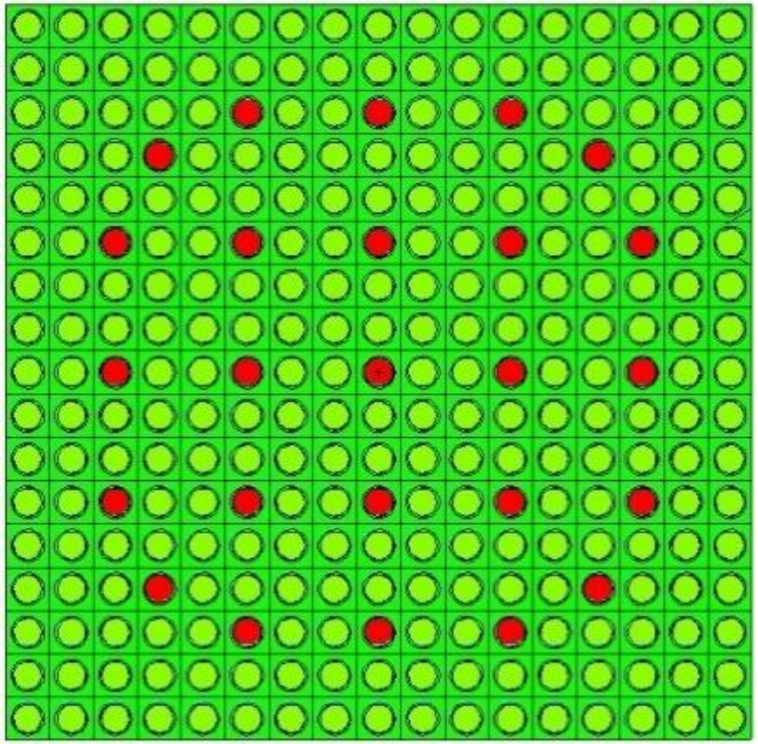


Figure 2 – Description of the Fuel Assembly Used to the Neutronic and Thermohydraulic Calculations.

METHODOLOGY

Description of the Computational Model Used for the Thermohydraulic Calculation

- Definition of the Reactor Geometry

The three-dimensional model for the AP1000 reactor were performed using the *Design Modeler* tool. Due to the symmetry characteristics of the geometry it was possible to reduce to 1/8 of the complete fuel assembly.

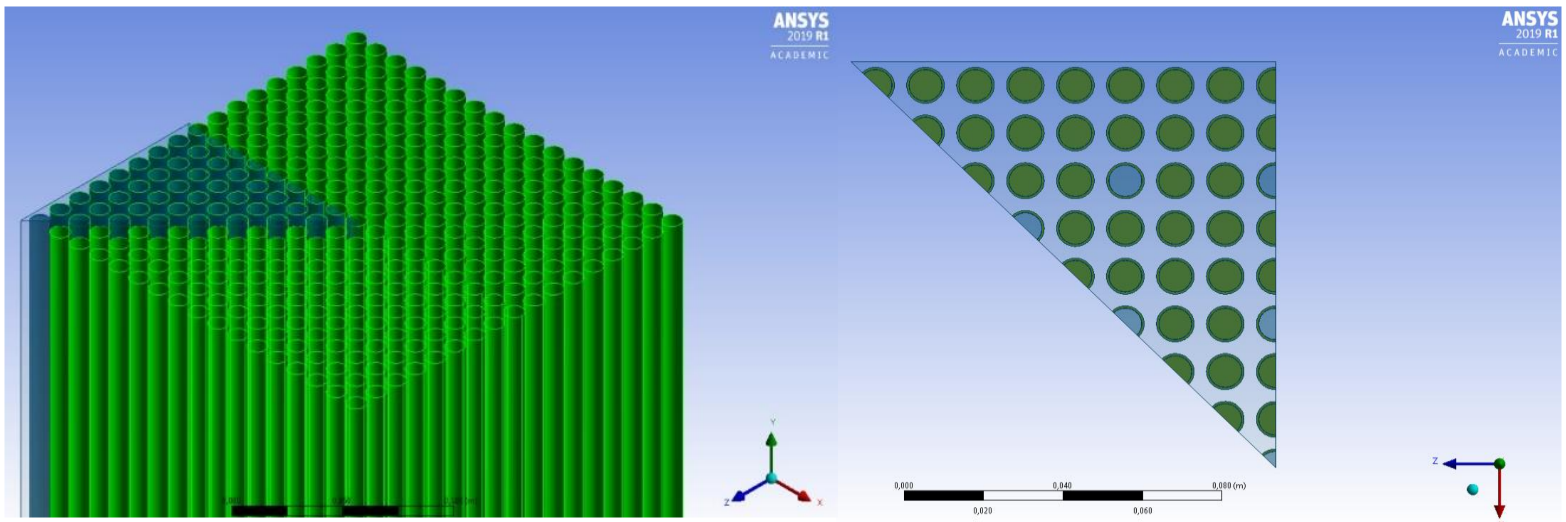


Figure 3 – Isometric and Superior View of the Geometry of the Fuel Assembly

METHODOLOGY

Description of the Computational Model Used for the Thermohydraulic Calculation

- Calculation Method
  - A structured mesh were used;
  - The Multizone method was applied;
  - Prism elements were used.

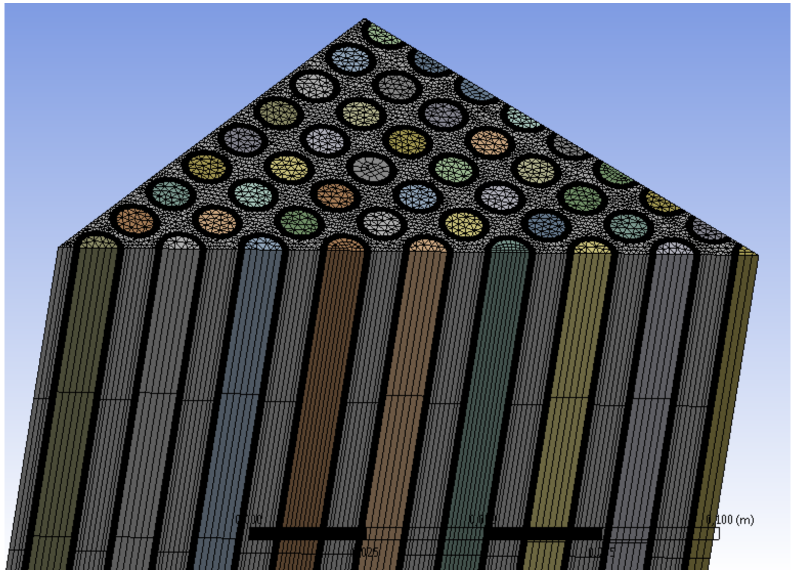


Figure 4 – Isometric View of Domain Discretization

Parameter	Minimum	Maximum	Average	Ideal Value
Ortogonal Quality	0.23675	0.99962	0.94886	1
Jacobian Ratio	0.25993	1	0.98372	1
Skewness	0.00092283	0.766325	0.1	0

Table 1 – Parameters used for the mesh quality assessment

METHODOLOGY

Description of the Computational Model Used for the Thermohydraulic Calculation

- Boundary Conditions

  - The moderator inlet temperature is assumed to be equal to the core inlet (approximation).

  - The mass flow of moderator through 1/8 of the typical fuel assembly was determined by dividing the total mass flow entering the reactor core by the total number of fuel assemblies and also divided by 8

Parâmetro	Valor
Coolant inlet temperature	288 °C
Coolant inlet flow	10.71 kg/s

Table 2 – Boundary Conditions.

RESULTS AND DISCUSSIONS

- Neutronic-Thermohydraulic Coupling

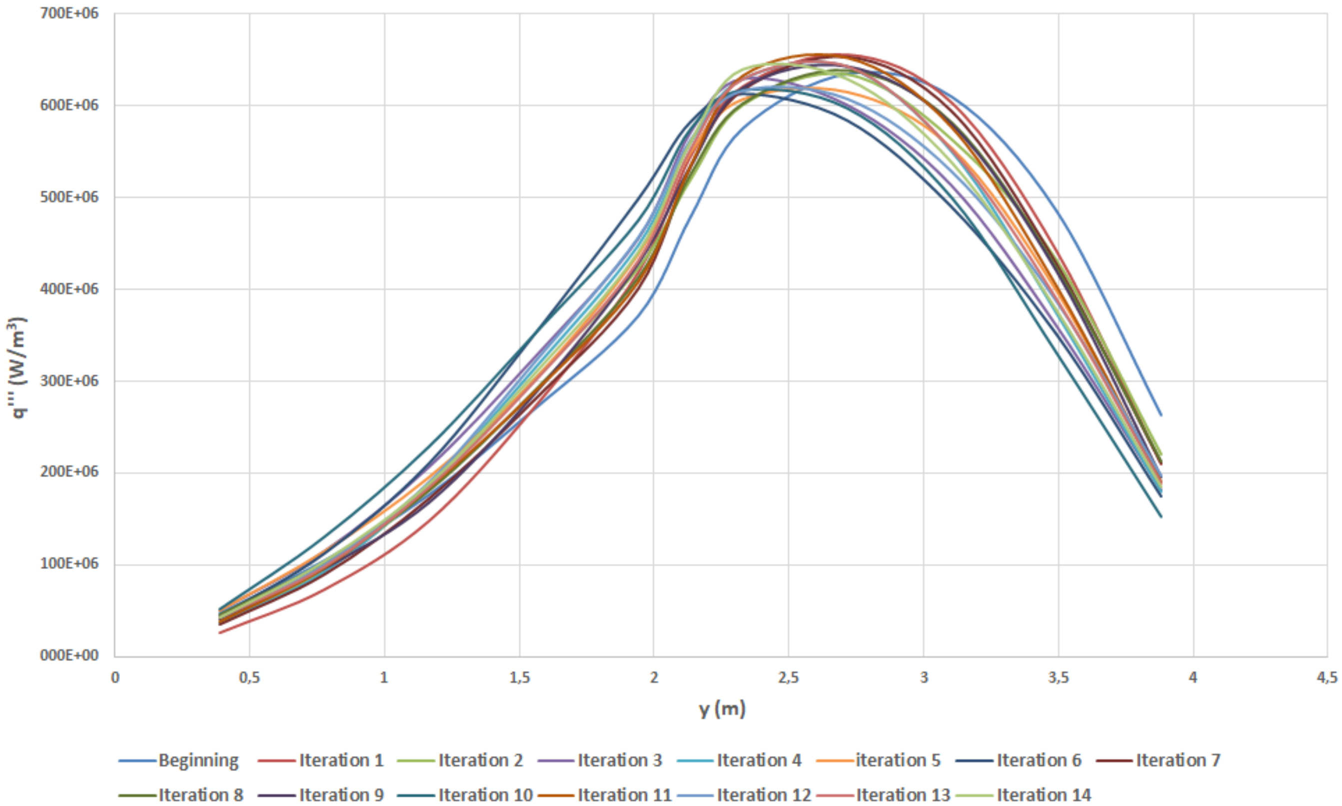


Figure 5 – Iterative Study of the Axial Distribution of Power Density.

RESULTS AND DISCUSSIONS

Neutronic-Thermohydraulic Coupling

– Beginning:

$q'''_{\text{máx}} = 634.547\text{E}{+}06\ \text{MW/m}^3$

$h = 2.71\text{m}$

– After 14 iterations:

$q'''_{\text{máx}} = 639.636\text{E}{+}06\ \text{MW/m}^3$

$h = 2.33\text{m}$

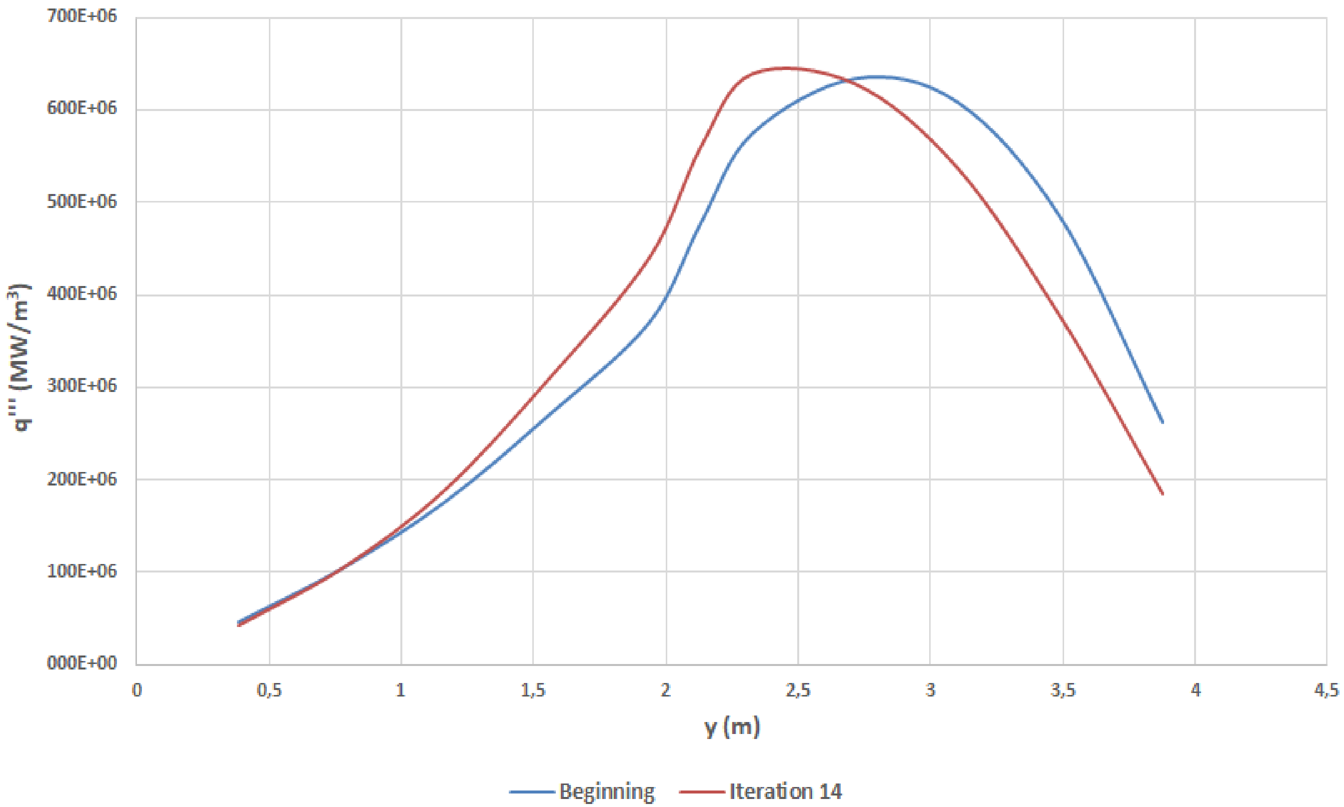


Figure 6 – Comparison of the Axial Distribution from the Power Density at Initial and Final States of the Iterative Process.

RESULTS AND DISCUSSIONS

- Thermohydraulic Analysis

The temperature field at the exit of the fuel assembly, varies from 315.6°C, for regions near the guide tubes of the control rods, up to 334.1°C for the areas adjacent to the fuel rods.

The average temperature obtained at the outlet of the fuel assembly was 325 ° C.

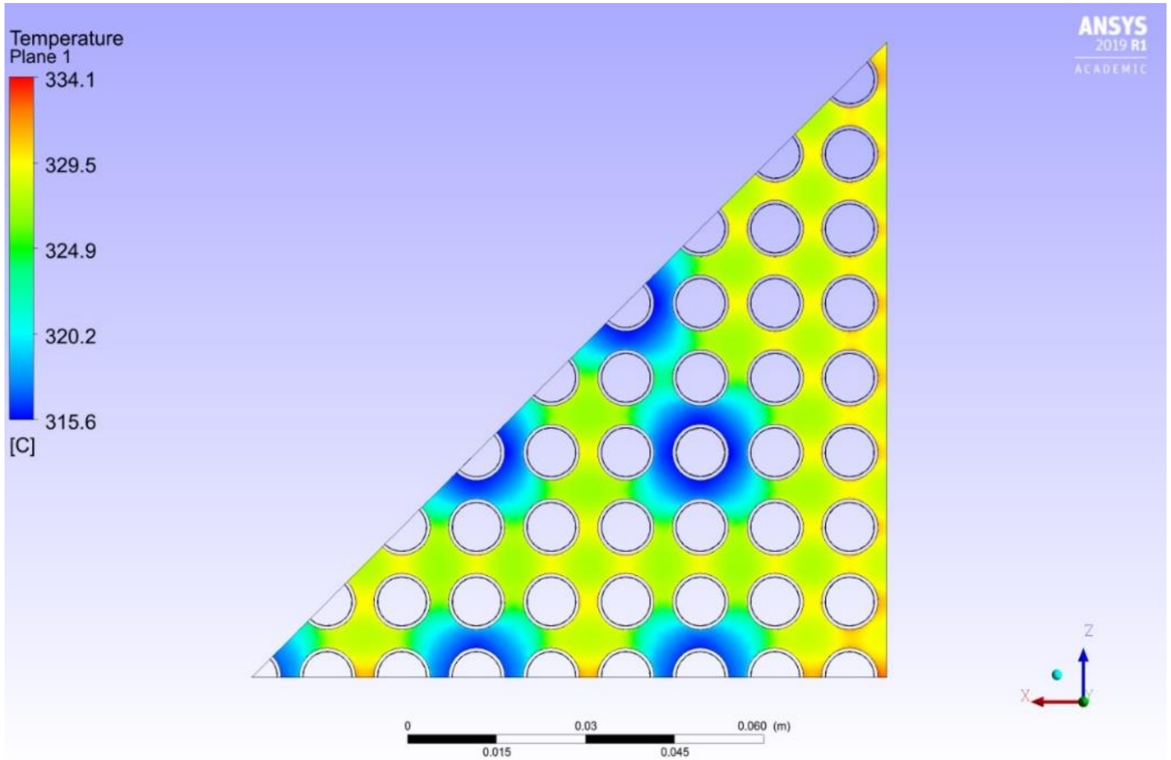


Figure 7 – Coolant Temperature Field at the Fuel Assembly Outlet

RESULTS AND DISCUSSIONS

Thermohydraulic Analysis

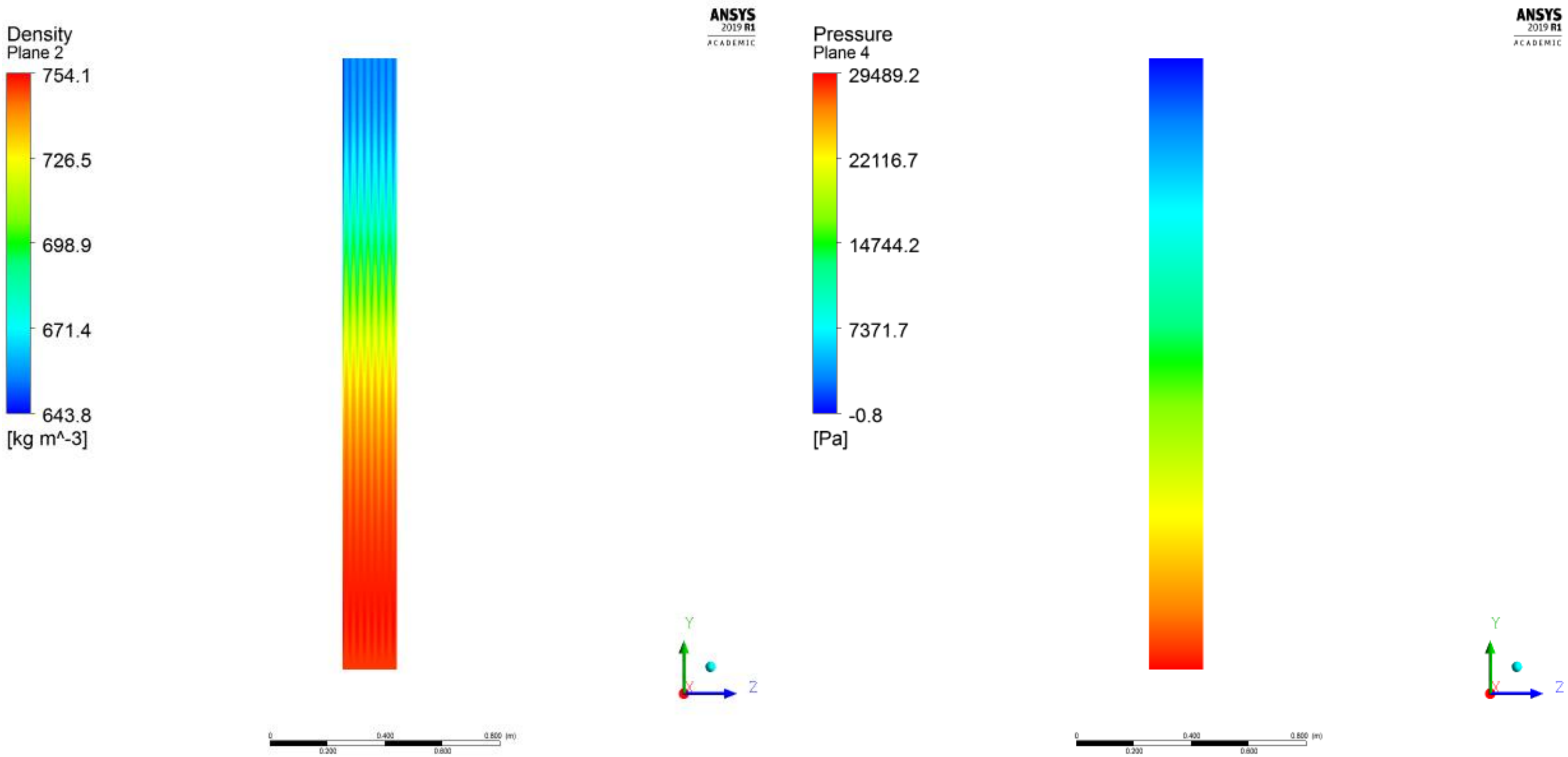


Figure 8 – Axial Distribution of Coolant Density and the Pressure Drop Along the Fuel Assembly

RESULTS AND DISCUSSIONS

Thermohydraulic Analysis

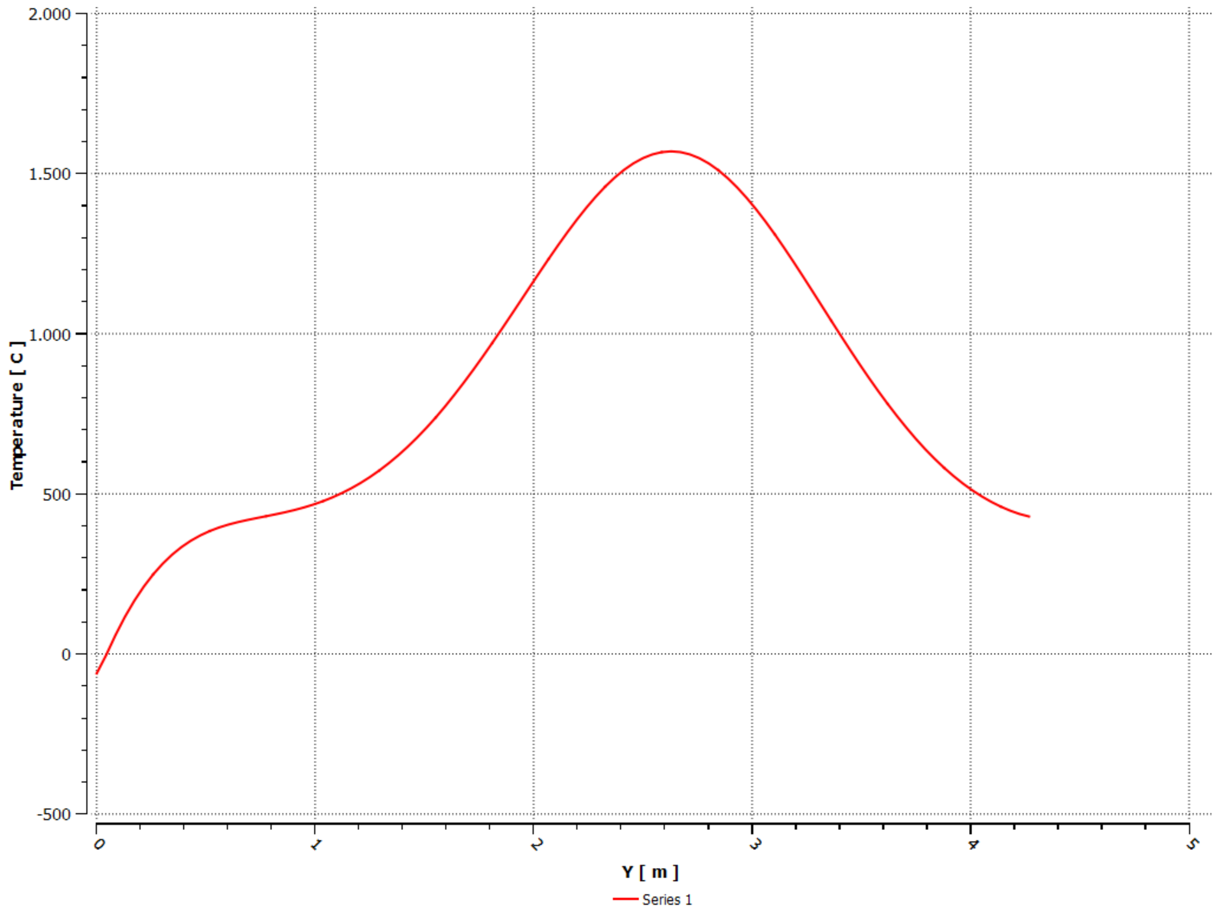


Figure 9 – Axial Temperature Distribution at the Hottest Fuel Rod

The maximum temperature reached in the fuel was 1576°C;

RESULTS AND DISCUSSIONS

Thermohydraulic Analysis

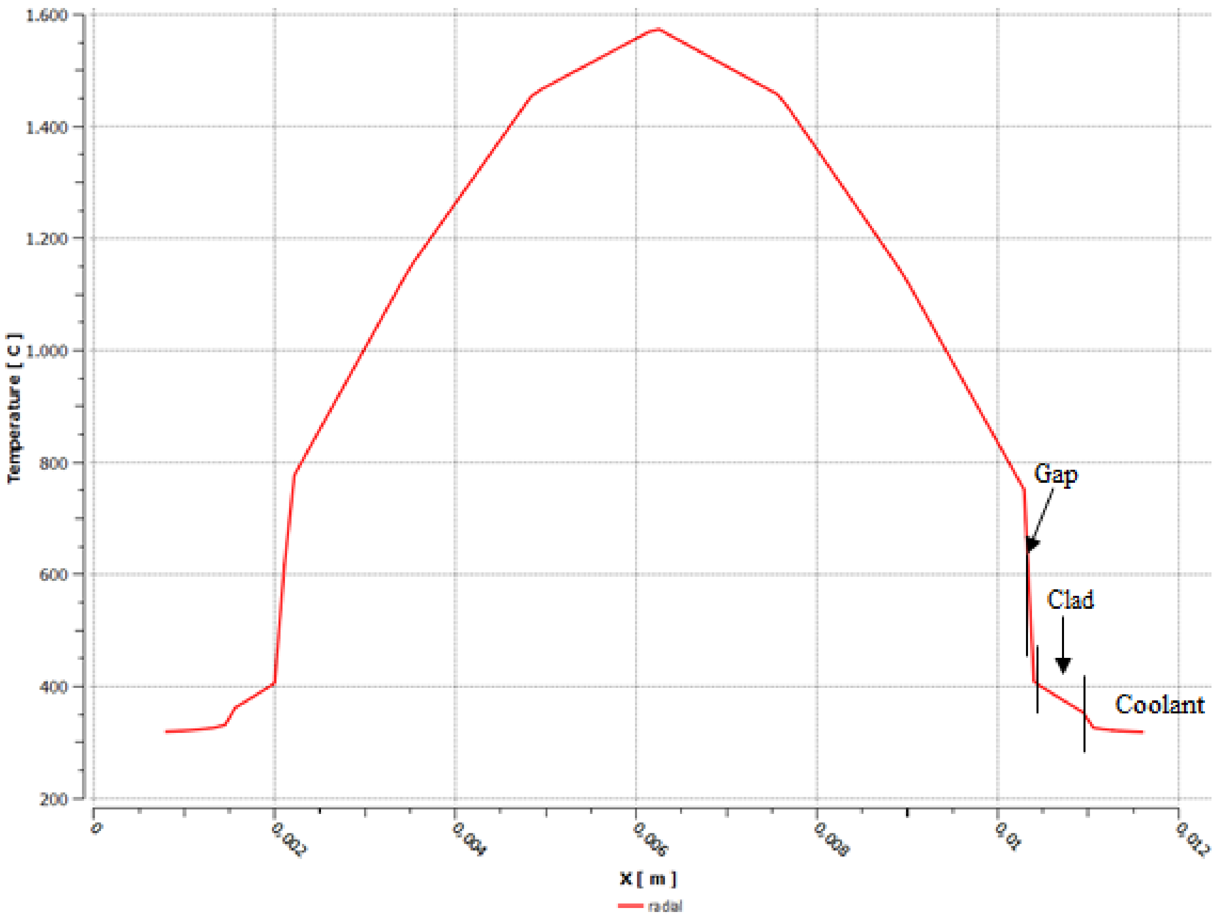


Figure 10 – Radial Distribution of the Temperature in the Hottest Bar in the Fuel Assembly

The maximum temperature reached in the cladding was 410°C;

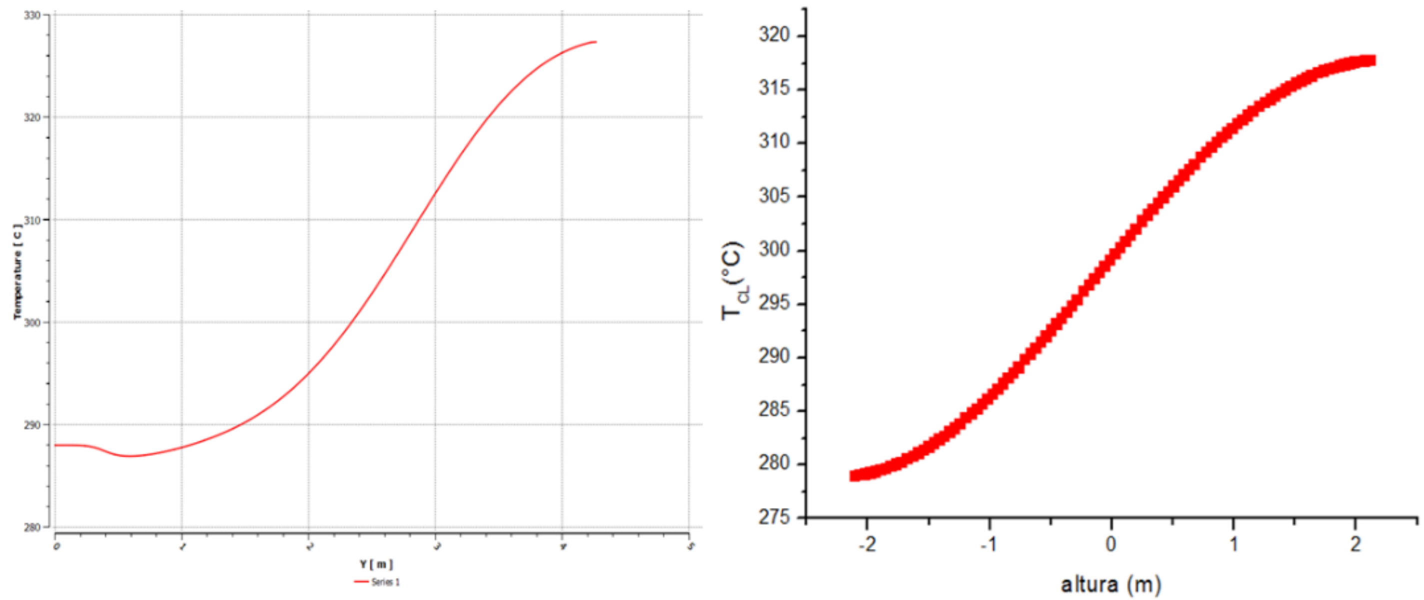
RESULTS AND DISCUSSIONS

Thermohydraulic Analysis

Water leaves the fuel assembly with a maximum average temperature of:

- 325°C for the present study (figure 11a);

- 317°C reported by Santos in 2016 (figure 11b).



(a) (b)

Figure 11 – Axial Distribution of Mean Coolant Temperature.

CONCLUSIONS

- ✓ A three-dimensional model was developed;
- ✓ The axial power distribution was obtained using the MCNP6 and Ansys CFX codes.
- ✓ The temperature profiles in the fuel assembly were determined, as well as the distribution of the coolant density and consequent the pressure drop.
- ✓ The maximum temperature reached by the cladding was also evaluated.
- ✓ The proposed model presented consistent and valid results for an initial approach.

Thank you