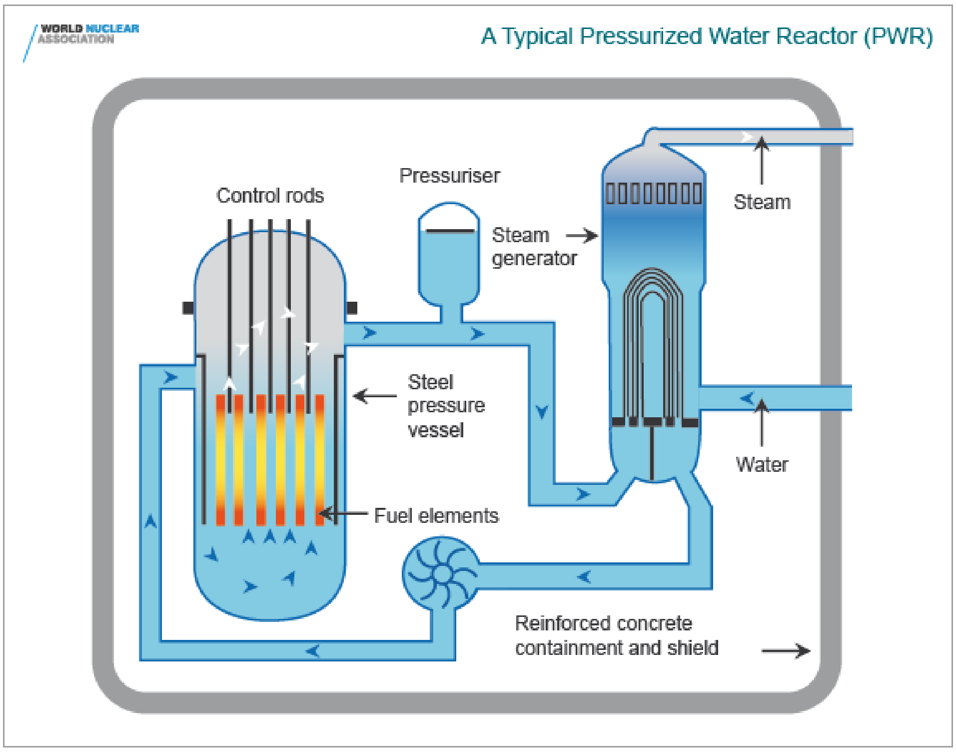
Nuclear reactor cooling model

Jan Witczak (131396), Przemysław Woźniak (145423), Jakub Wróbel (145188)

1. Description



As the result of nuclear reactions occurring in the reactor, the fuel produces heat according to the following formula:

$$P = RR \cdot E_r \cdot V \tag{1}$$

Where: P – power of the reaction in an unit of volume, RR (reaction rate) – average number of reacions in an unit of volume , E_r – average amount of energy from a single reaction, V – fuel volume

The reaction rate is calculated using the formula:

$$RR = \phi \cdot \Sigma \tag{2}$$

Where: ϕ – neutron flux, Σ – macroscopic cross section of an atom

The macroscopic cross section of uranium atoms is calculated using the formula:

$$\Sigma = \sigma \cdot N \tag{3}$$

Gdzie: σ – microscopic cross section of an atom, N – number density

The value of N is calculated using the formula:

$$N = \frac{\rho \cdot N_A}{M} \tag{4}$$

Where: ρ – density , N_A – Avogadro constana, M – molar mass

Neutron flux has a direct impact on the amount of produced energy. Value of the neutron flux can be regulated by lowering the control rods into the reactor core. Control rods are made out of boron. They partially absorb the neutrons created as a result of nuclear reactions, preventing the rise of the reaction rate.

Inside the reactor there is a number of control rods. In order to control the number of occurring reactions, control rods are lowered into or removed from the core.

Macroscopis cross section of boron atoms of the control rods are calculated in the same way as the cross section of uranium atoms.

Probability of the neutron getting absorbed by the control rod or the fuel rod is equal to the ratio of boron and uranium cross sections.

Fission reaction of uranium produces 2.5 neutrons on average; to sustain the reaction rate, one neutron should start the next reaction.

Changes of the reactor's temperature, when the generated energy, mass and the specific heat capacity of the fuel are known are calculated using the following formula:

$$\Delta T = \frac{Q}{m \cdot c_w} \tag{5}$$

Heat is transferred from the reactor using water circulation. High pressure water flows through the reactor transfering heat from the core. Next, the water transfers the heat to the water stored in a separate container, and then returns into the core after it has cooled down.

Strumień ciepła, czyli ilość ciepła przepływającego przez materiał, w tym przypadku przez ścianę pręta paliwowego wykonanego ze stopu cyrkonu (Zircaloy), obliczymy ze wzoru:

Heat flux, which is the amount of heat transferred through the material, in this case walls of the fuel rod made out of Zircaloy is calculated using the formula:

$$P = \frac{k \cdot A \cdot \Delta T}{l} \tag{6}$$

Where: P – heat flux, k – thermal conductivity, A – total surface area of the rods, ΔT – difference between fuel and water temparatures, l – rod wall thickness

Thermal conductivity of Zircaloy is **21.5 W/mK**.

2. Program description

User sets the temperature of the reactor. The system’s task is to automatically adjust the fuel temperature to the desired temperature by regulating the position of control rods. It is also possible to change the temperature of water.

3. Screenshots

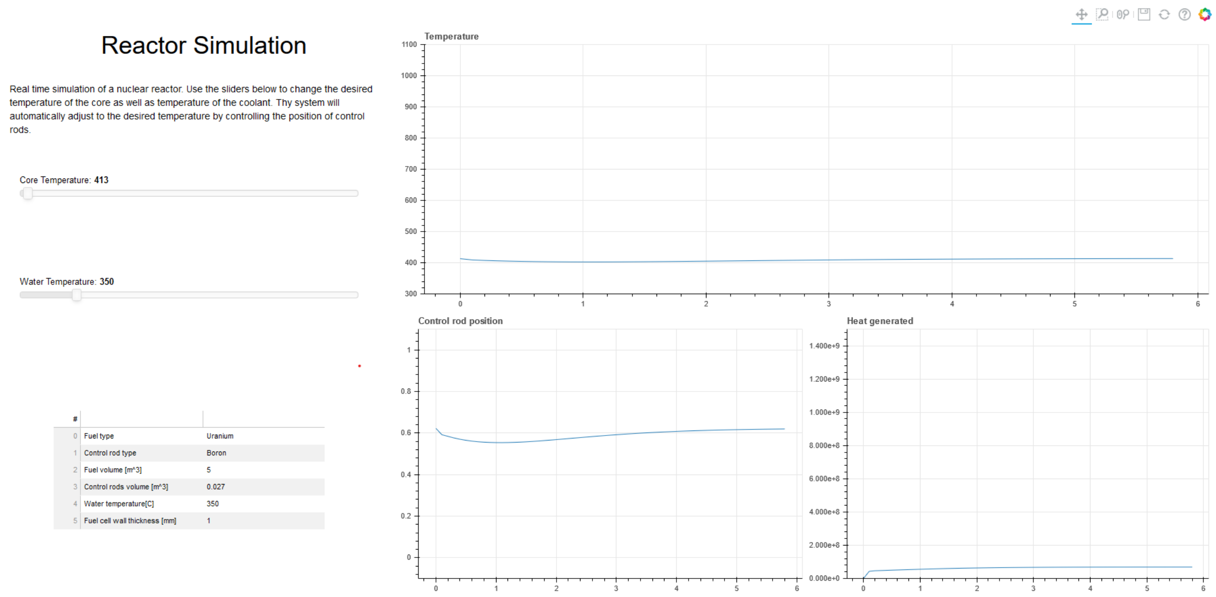
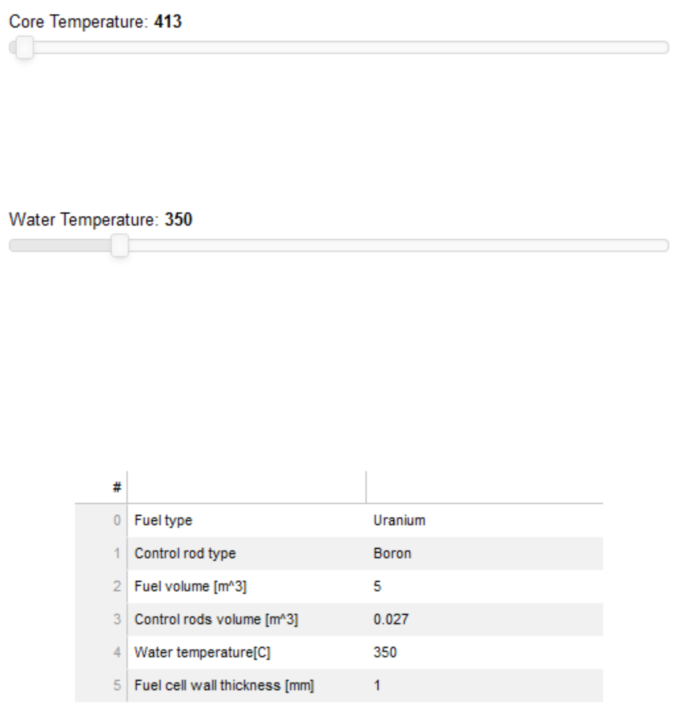


Figure 1: Interface created using Bokeh



#		
0	Fuel type	Uranium
1	Control rod type	Boron
2	Fuel volume [m^3]	5
3	Control rods volume [m^3]	0.027
4	Water temperature[C]	350
5	Fuel cell wall thickness [mm]	1

Figure 2:Sliders used to control the reactor and a table containing the reactor’s parameters

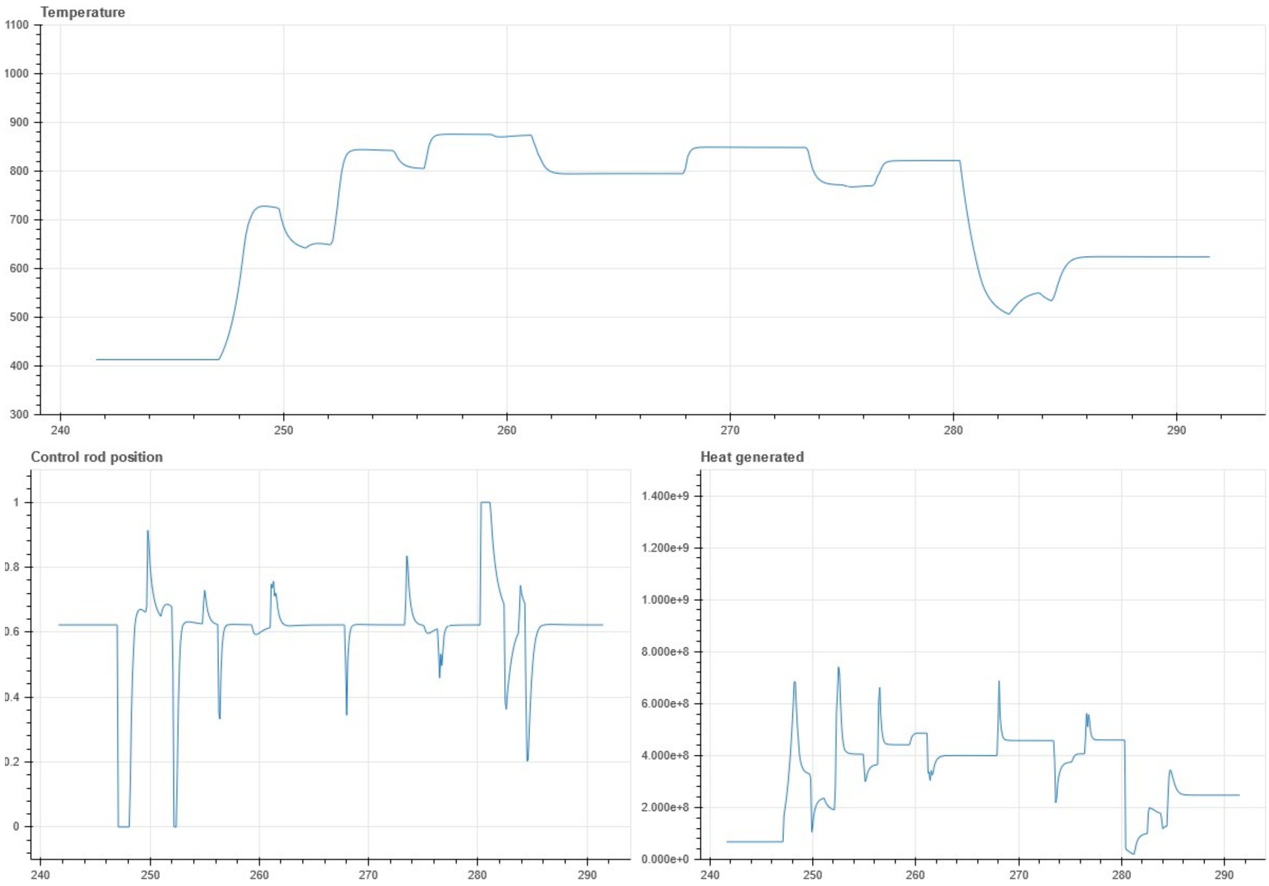


Figure 3: Graph section

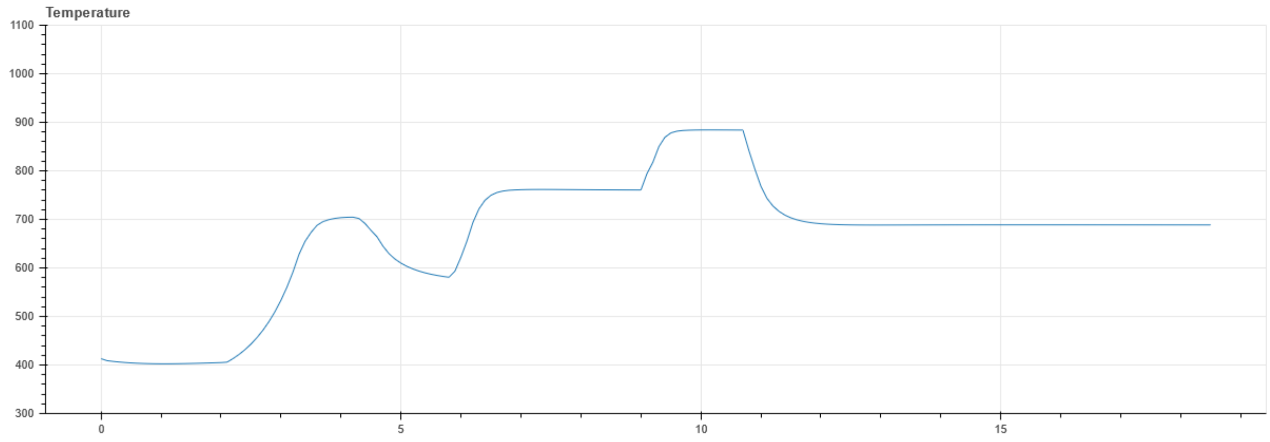


Figure 4: Temperature graph

Temperature is controlled by the control rods position and temperature of the cooling water.

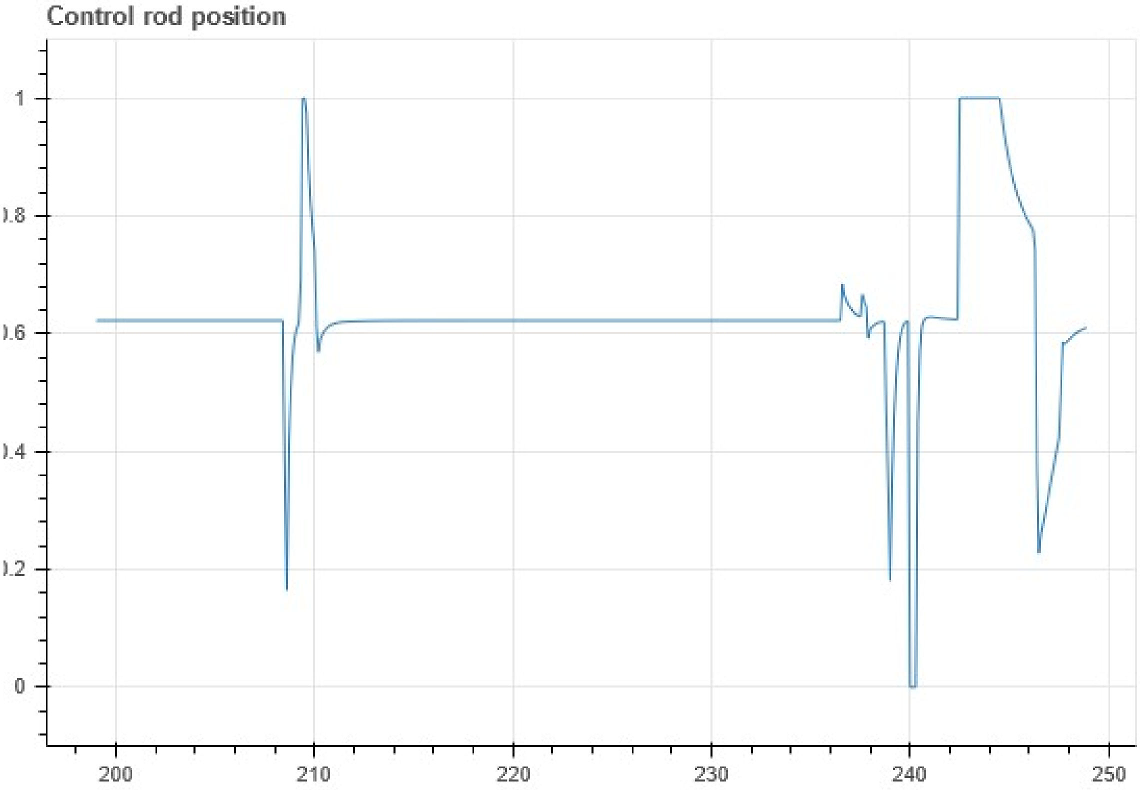


Figure 5: Control rod position graph

A PID controller controls the position of control rods. When the percentage of control rods inside the core is lower, temperature rises quicker.

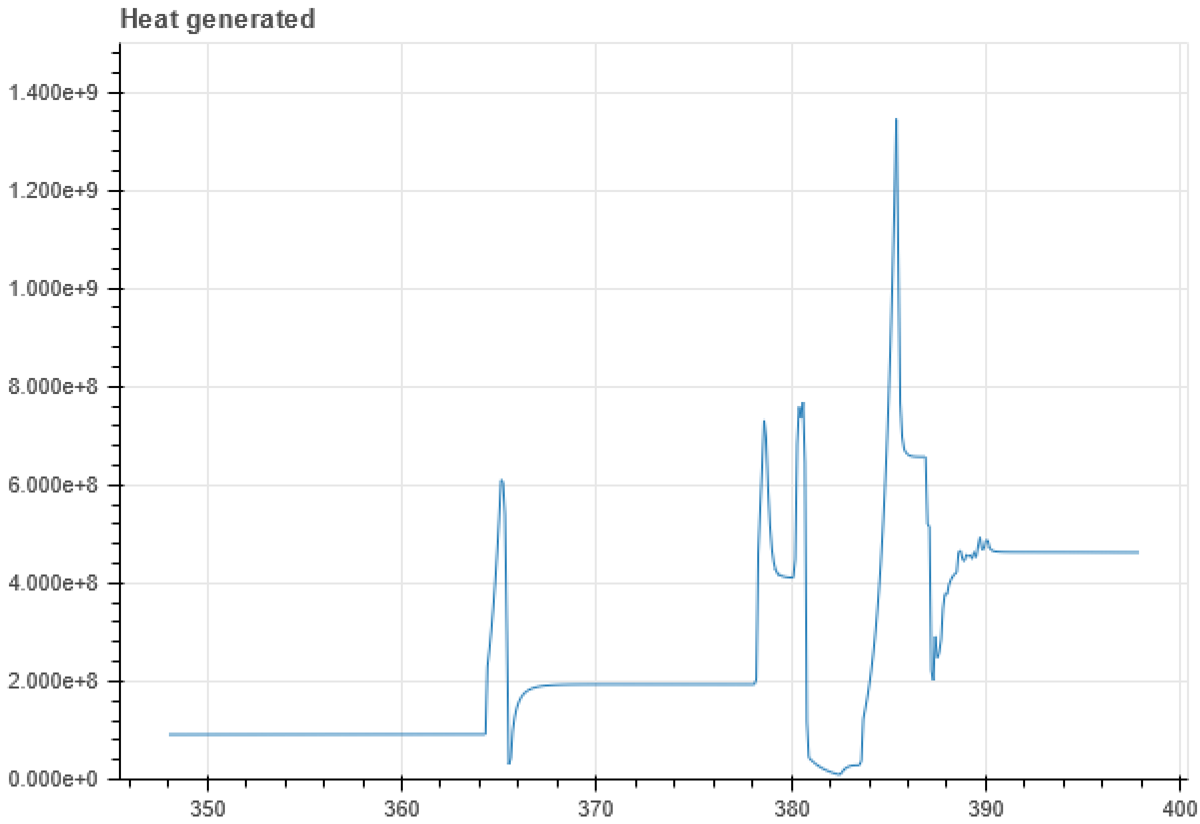


Figure 6: Heat generated graph