SVETRUM

Kalibracija in analiza Cherenkov pulzov

Nuclear power plants are crucial for modern society due to their ability to generate large-scale, reliable, and low-carbon energy, along with their applications in medicine, industry, and scientific research. The usage of nuclear energy is particularly important for Slovenia due to its energy independence. The nuclear plant Krsko stands as pillar of the energy production in these region, since it provides 35% of Slovenia's electricity together with 20% of Crotian's needs due to joint ownership. Therefore comes the importance of analysis, research and development of this process, which we did here today to some degree.

With the help of Cerenkov pulse, which is the burst of light produced when a charged particle moves through a media faster than light can travel in, we did some analysis of the work of the given reactor. As a data, we were given the voltage and time for three different measurement of the pulse numbered 696, 701 and 702, as well as the peak power and the prompt reactivity over time of each measurement. With the help of some programming in Phyton we did all the calculations and measurements. Link to GitHub repository:

https://github.com/evgenijahahah/MacGyver16.0.git

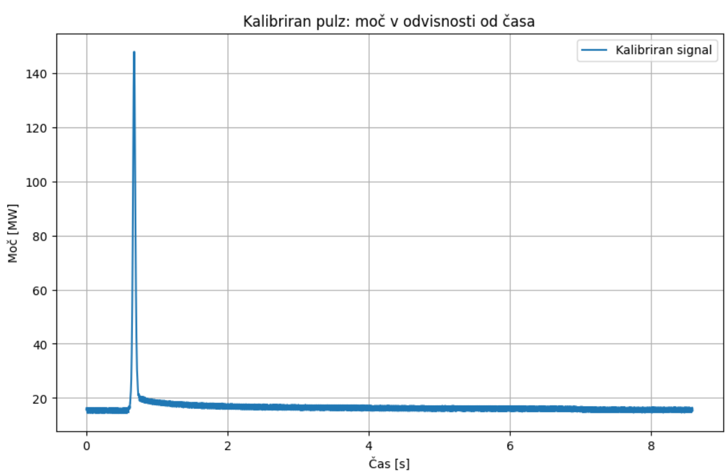
Firstly we calculated the calibration coefficient by dividing the maximal voltage measured by the peak maximum power and got the following numbers:

calibration_coefficient_696=1342

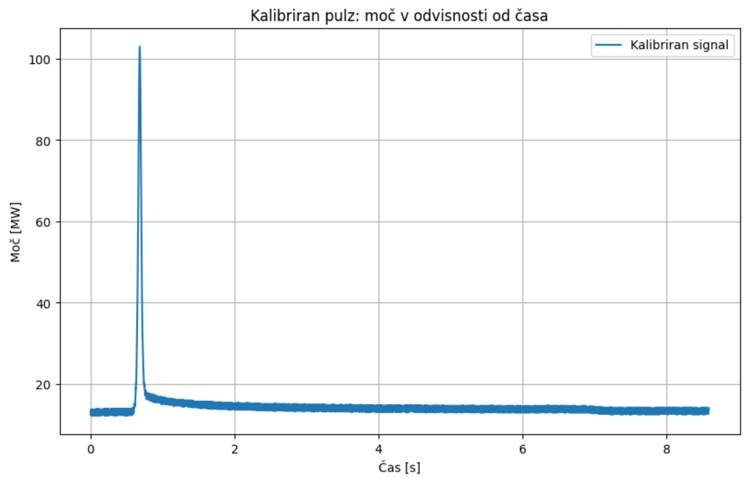
calibration_coefficient_701=1140

calibration_coefficient_702=1191

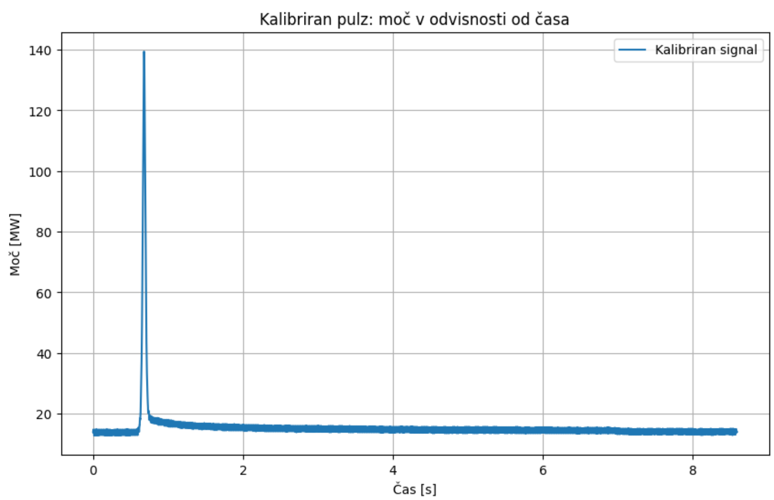
With the help of these coefficients, we calibrated the given voltage determined the change of power by time, which is shown in the following graphs:



Sl. 1 – Kalibriran pulz 696: Moč v odvisnosti od časa



Sl. 2 – Kalibriran pulz 701: Moč v odvisnosti od časa



Sl. 3 – Kalibriran pulz 702: Moč v odvisnosti od časa

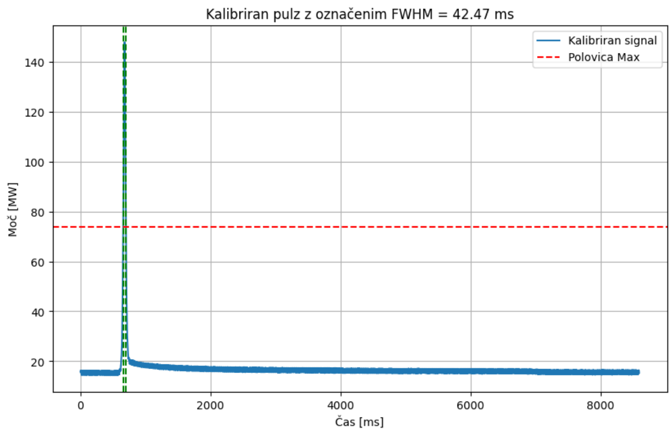
The next task we dealt with was finding the Full Width of Half Maximum (FWHM) with the help of our code. We found the two points that equal half of the given peak power and their x coordinates that is the time difference and calculated the difference between them. The results that we got are:

FWHM_699=42.47 ms (med 656.45 ms in 698.92 ms)

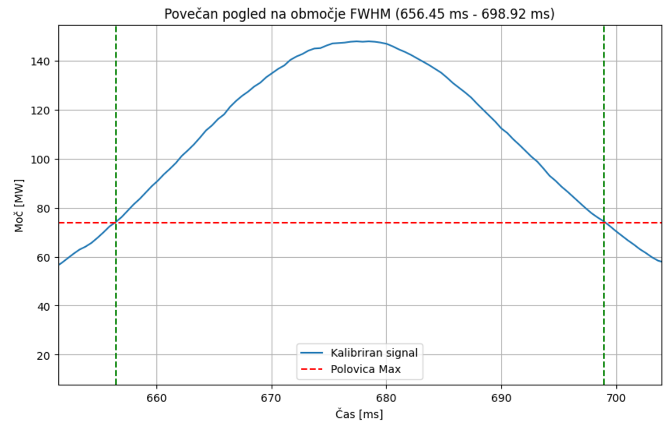
FWHM_701=51.91 ms (med 658.02 ms in 709.93 ms)

FWHM_702=43.52 ms (med 658.02 ms in 701.54 ms)

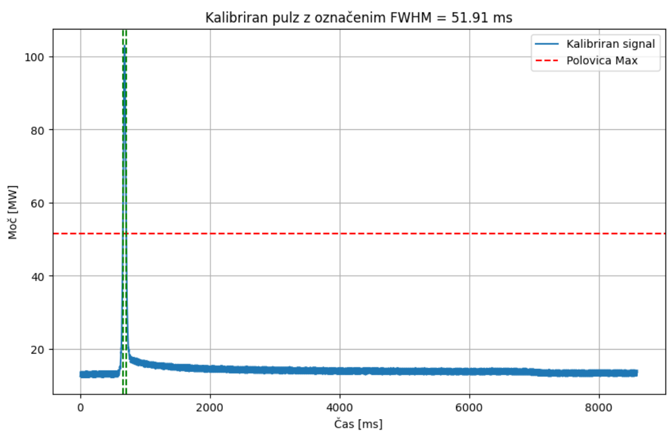
Accordingly we showed the results on the graphs below. For each measurement, we have two graphs, one that shows for the whole time period measured and one zoomed in, where you can clearly see the calculated value.



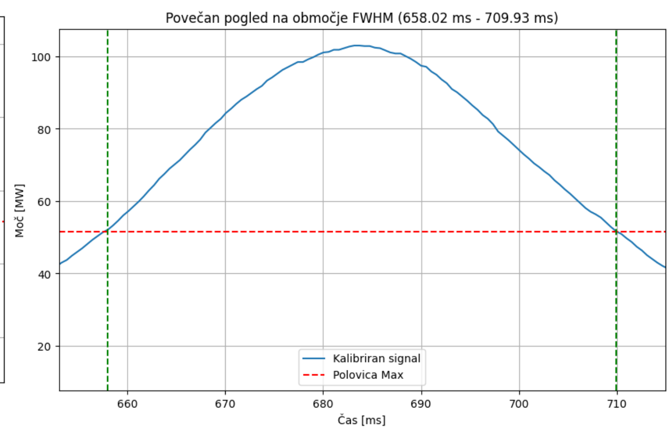
Sl. 4 – Kalibriran pulz 696 z označenim FWHM



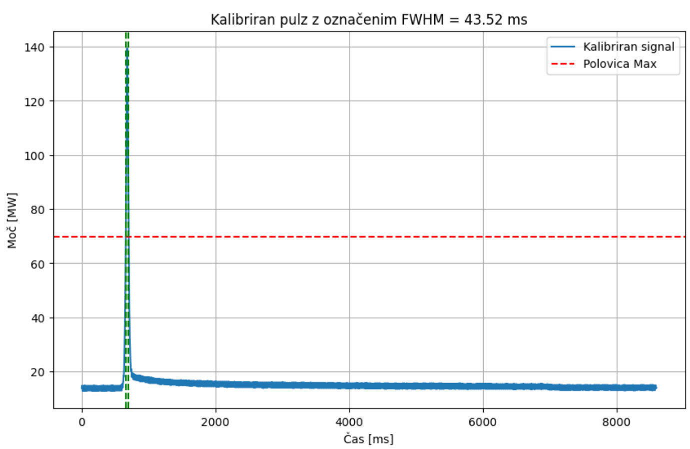
Sl. 5 – Povečan pogled kalibriranega pulza 696 z označenim FWHM



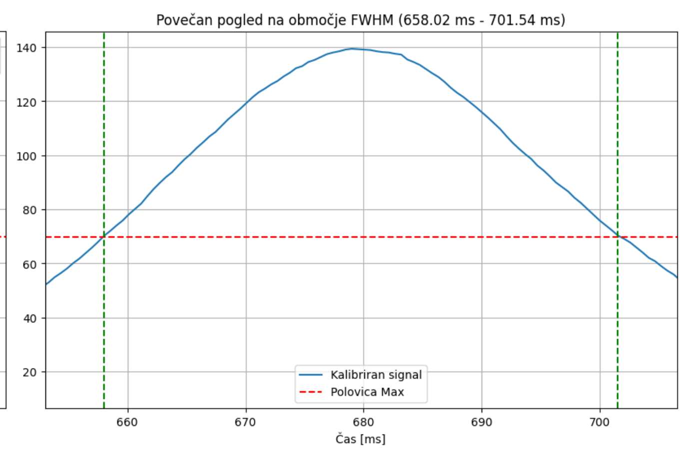
Sl. 6 – Kalibriran pulz 701 z označenim FWHM



Sl. 7 – Povečan pogled kalibriranega pulza 701 z označenim FWHM

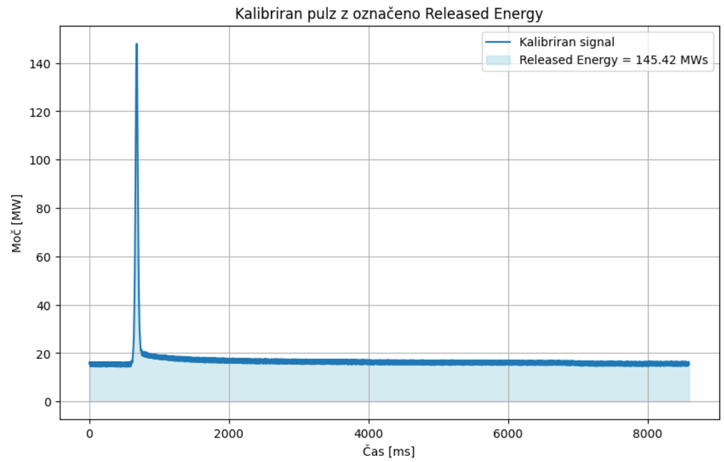


Sl. 8 – Kalibriran pulz 702 z označenim FWHM

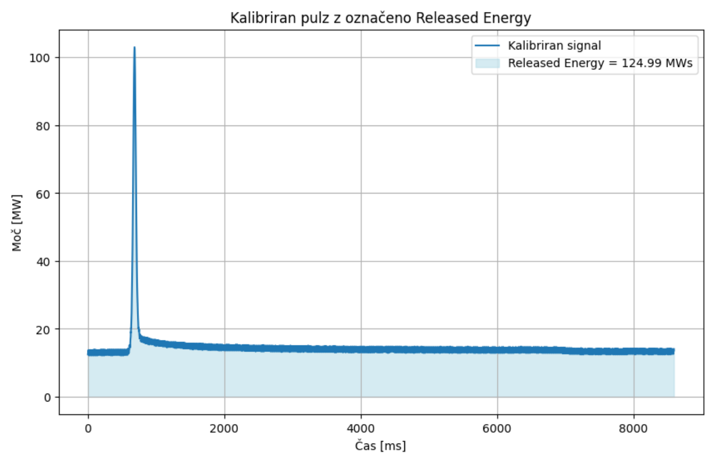


Sl. 9 – Povečan pogled kalibriranega pulza 702 z označenim FWHM

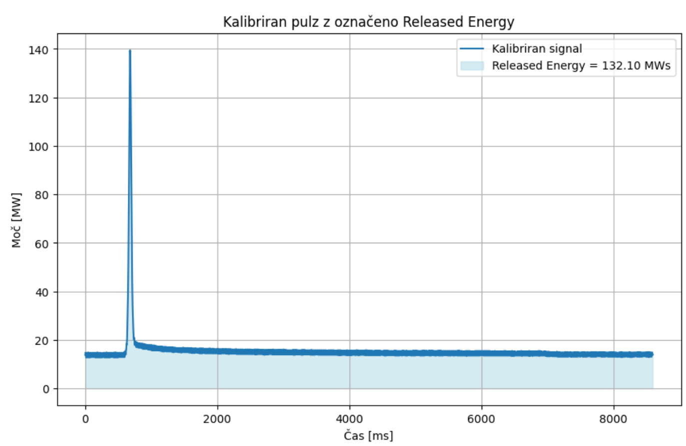
Calculating the area under the power-time curve using integration we determined the released energy of the process.



Sl. 10 – Released Energy Pulse 696



Sl. 11 – Released Energy Pulse 701



Sl. 12 – Released Energy Pulse 702

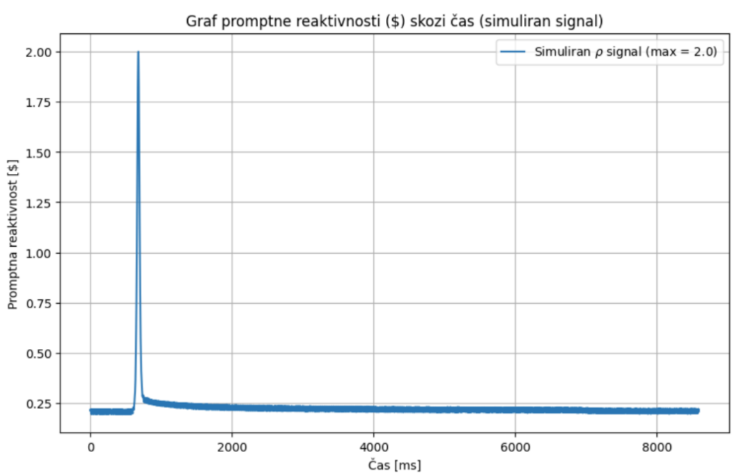
The energy released in a nuclear reactor is the fundamental driver of its operation, with major implications for power generation, safety, and efficiency. Based on our measurements, we received the following results:

$$E\_released\_696 = 145.4223\ MWs$$

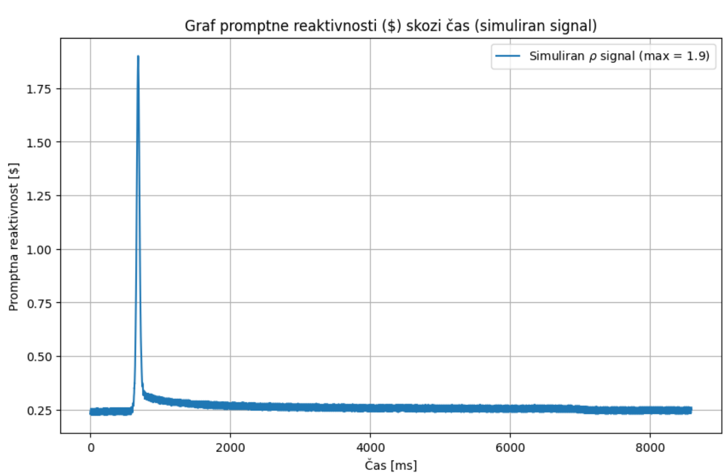
$$E\_released\_701 = 124.9923\ MWs$$

$$E\_released\_702 = 132.1043\ MWs$$

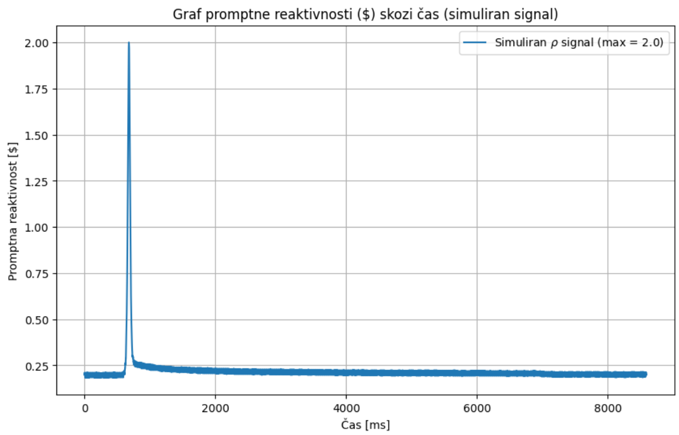
And lastly with the same method we evaluated the prompt reactivity. Prompt reactivity refers to immediate changes in nuclear chain reaction power caused by fast neutrons (as opposed to "delayed neutrons," which are emitted later during fission product decay). Again we used graphs, shown below, to show the calculated results, as the most visually pleasing and suitable way to present the results.



Sl. 13 – Prompt reactivity - Pulse 696



Sl. 14 – Prompt reactivity - Pulse 701



Sl. 15 – Prompt reactivity - Pulse 702

The second task for today was finding the best and most optimal way to measure the temperature of the fuel rods. Measuring the temperature of the fuel rods is a complex procedure because of the extreme conditions, such as the high temperature, which exceeds 300 degrees Celsius. However it is also very important cause it helps us prevent fuel damage and meltdowns, on top of that maintaining optimal reactor performance.

To begin with we started with doing as much research as we could in the given time and find all of the different options for solving this problem. Some of the solutions we looked into were measuring the temperature of the cooling water around the rods using measuring strips or optical fibers. We opted for the optical fibers solution specifically FBG - Fiber Bragg Grating temperature sensors.

We plan to place the FBG optical fiber sensor along the fuel rod to measure temperature distribution along its length. This technology allows us to remain within the constraints of size, radiation tolerance, and temperature resistance, without requiring any modifications to the fuel rod. Fiber Bragg Grating (FBG) temperature sensors are devices integrated into optical fibers with a unique grating structure that alters with temperature variations. This change affects the reflected light, enabling precise temperature measurements. Typically constructed from silica or glass fibers, these sensors offer reliable temperature monitoring in demanding environments.

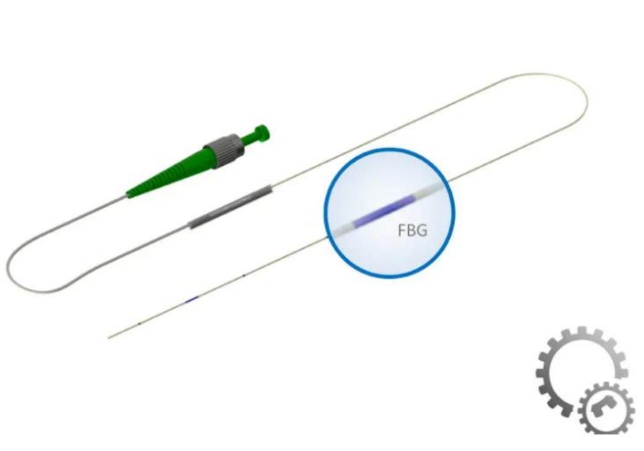
Specifications of the FBG optical fiber sensor:

- **Optical Fiber:** Length - approximately 55 cm with a diameter of approximately 1 mm.
- **Model**: HT500 High Temperature - up to 500°C
- **Material:** Optical fibers made from specialized glass materials, such as aluminum oxide, along with protective coatings. Specific material details for this sensor are not provided.
- **Response Time:** Approximately 100 ms.
- **Applications:** Suitable for electromagnetic, radioactive, and humid environments.

- High sensitivity and fast responsiveness to temperature changes
- Robust design and high physical stability
- **Function:** Allows accurate and distributed temperature profiling in real-time.

Common Usage: Often utilized in power plant monitoring.

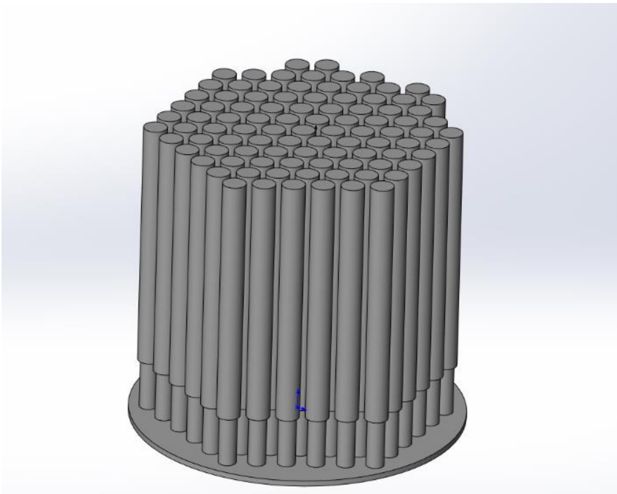
Sl. 16 – FBG fiber sensor



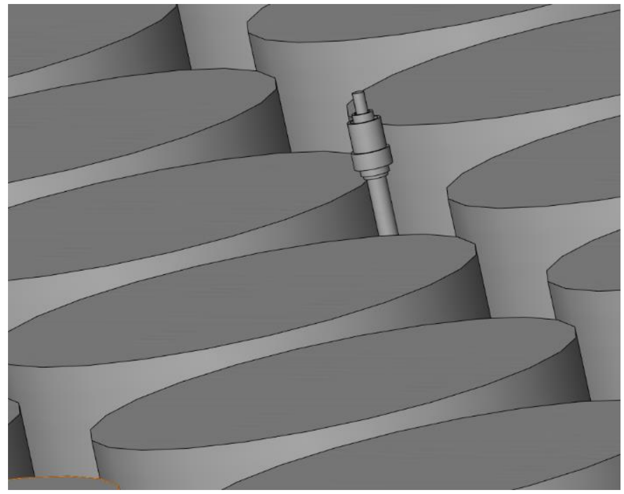
Sl. 17 – FBG fiber sensor on the optical fiber

The next step we did was found the pricing and expenses for the solution we worked on. Exact prices vary based on specifications and order quantities; these sensors typically range from €500 to €2,000 per unit.

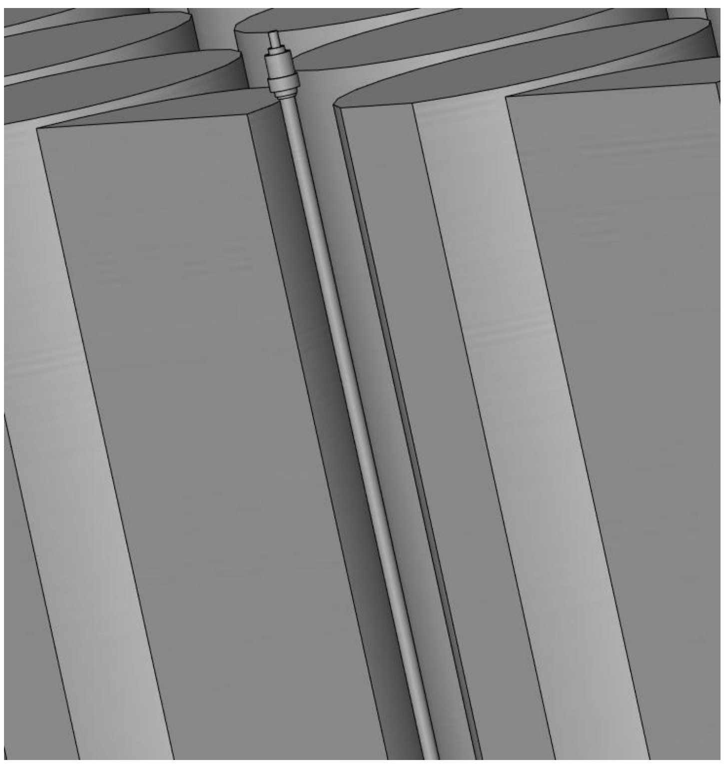
We also created a model of the fiber installation on the rods, which looks as shown in the images below.



Sl. 18 – Model of the fiber installation on the rods



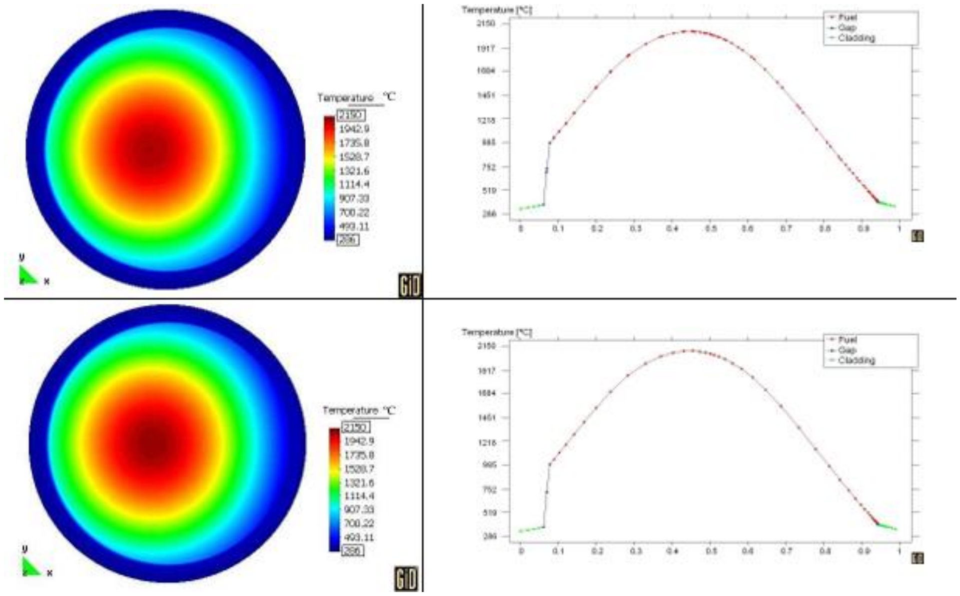
Sl. 19 – Model of the fiber installation on the rods



Sl. 20 – Model of the fiber installation on the rods

Additionally below is shown a picture of the temperature gradient that can be calculated with getting the measured temperatures and using finite element method. Link to the resource:

https://arhiv.djs.si/proc/nene2011/pdf/814.pdf



Sl. 21 – Temperature gradient of the fuel rod

As this is a highly relevant topic among engineers, we were eager to dive into the research and calculations for this challenge. Using Python and Jupyter Notebook, we calibrated three voltage signals and determined how power and released energy evolve over time. We also familiarized ourselves with the concept of prompt reactivity and plotted its progression. In addition, we explored the complex and demanding environment of a nuclear reactor and searched for innovative solutions to measure the temperatures of fuel rods. Through this project, we not only broadened our knowledge in the field of nuclear physics but also significantly improved our teamwork and problem-solving skills.