

# POSSIBLE SHIFTS IN MARIA REACTOR REACTIVITY AND POWER CHANGES CAUSED BY THE SEISMIC EVENT

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## Abstract

The paper is investigating the possible impact of seismic events on the change of reactivity and Power of the MARIA research reactor in Poland, caused by potentially occurring vertical oscillations of control rods. Using the measurements of the actual vibrations of the reactor, a calculation model was developed and was used to determine the scale of the threat. Data used to calculate the problem were actual waveforms of earthquakes registered in Poland, upscaled to meet international recommendations of reactor . They were scaled to the peak ground acceleration, recommended for the calculation of nuclear reactors safe shutdown earthquake limits.

## 1. Introduction

Poland is generally considered to be aseismic zone, with Peak Ground Acceleration (PGA) lower than  $1.6 \text{ m/s}^2$ . The MARIA reactor is situated in even safer area, with predicted max PGA =  $0.5 \text{ m/s}^2$  [1] Because of the low earthquake risk, there is no existing seismic code in Poland. For this reason, for calculations, the values recommended by International Atomic Energy Agency (IAEA) were taken. The IAEA recommends the for aseismic zones calculations the value PGA =  $0.1 \text{ g}$  [2], where  $g=9.81 \text{ m/s}^2$ . Calculation was carried out on the basis of the real seismic events time series registered in Belsk, Poland (Jarocin, Poland 2012 seismic event) and Warszawa (Kaliningrad, Russia 2004 earthquake). The monitoring stations are located 50 and 25 kilometers from MARIA reactor site, respectively.

## 2. Methodology

Initially, the waveforms of ground displacement in three directions, obtained from the Institute of Geophysics, Polish Academy of Sciences, were differentiated twice to get ground accelerations as the result. For this purpose, the central differencing scheme was used. The next step was to strenghten the derived accelerations to PGA=0.1 g in the potentially most damaging direction (vertical), and the other two directions proportionally. Then by Runge-Kutta 4<sup>th</sup> order method they were integrated to get dislocations of ground to which reactor foundations are constrained. After the integration, the results had large systematic error caused by the high sensitivity of accelerometers, that were used to record the waveforms. To get correct values, certain correction scheme, taken from [3] and [4] was introduced. Earthquakes time series, upscaled to PGA =  $0.1 \text{ g}$  are presented in *Figures 1 and 2*

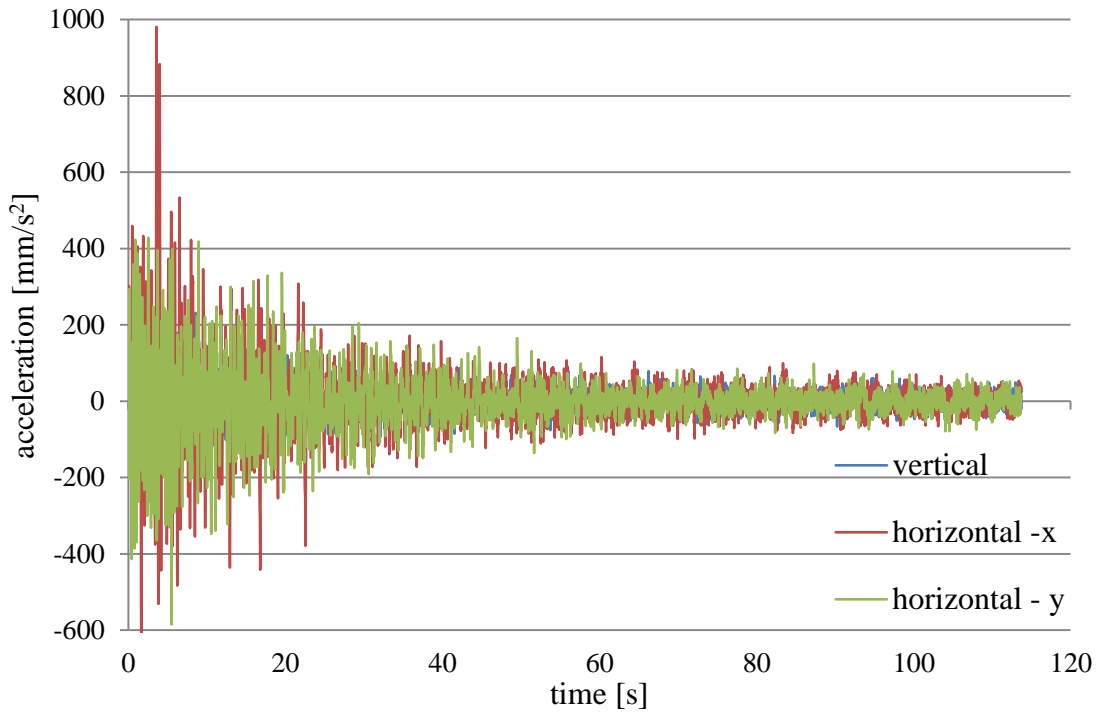


Figure 1: Belsk registered seismic event ground accelerations scaled to  $PGA=0.1$  g.

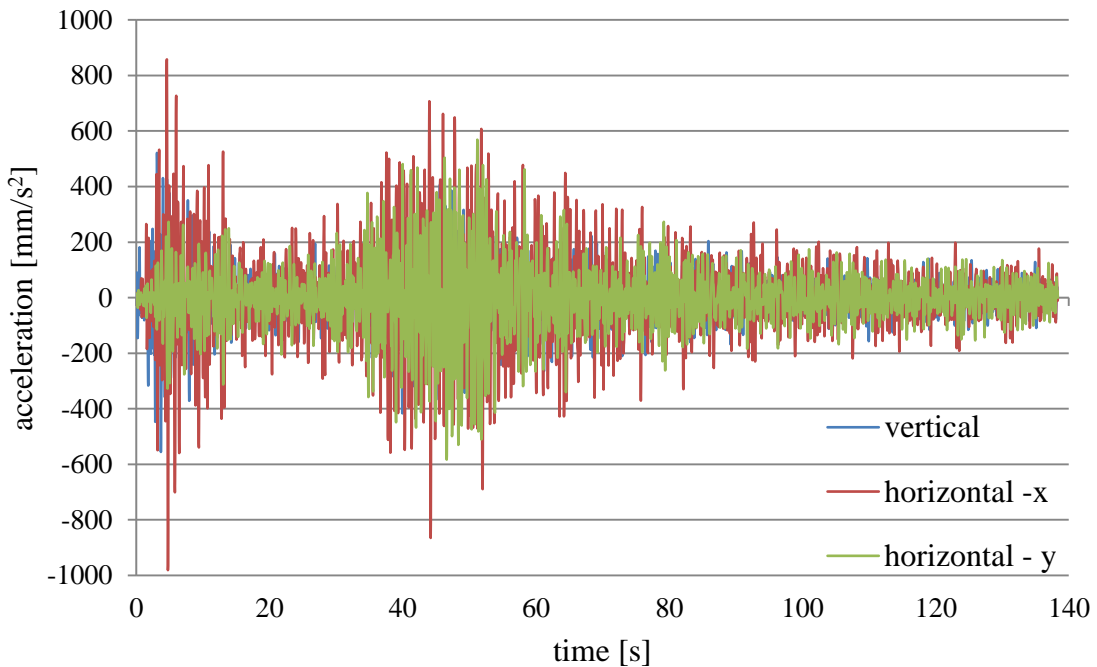


Figure 2: Warszawa registered seismic event ground accelerations scaled to  $PGA=0.1$  g.

After initial corrections, the data were appropriate to be used in the numerical simulation of an earthquake impact on the MARIA reactor reactivity and power changes. Due to many possible uncertainties, the conservative approach was used at all of the steps, so the results show worst case scenario.

It was assumed that in MARIA reactor the control rods can move in the two ways: vertically or horizontally along with the trolley that carries control rods moving mechanism, as shown in the Figure 3.

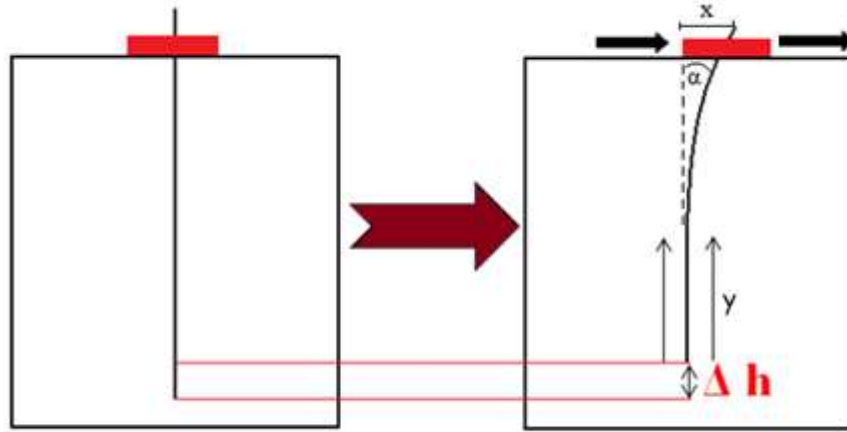


Figure 3: Control rods possible movement.

The locations of reactor elements valid in the calculations are shortly presented in the Figure 4. The significant numbers are summarized in the Table I.

TABLE I: Results obtained from the calculations.

| Parameter                     | Value     |
|-------------------------------|-----------|
| Reactor nominal power         | 30 [MWth] |
| Control rods total weight     | 8 [\$]    |
| Single control length         | 1.1 [m]   |
| Distance from core to trolley | 7 [m]     |

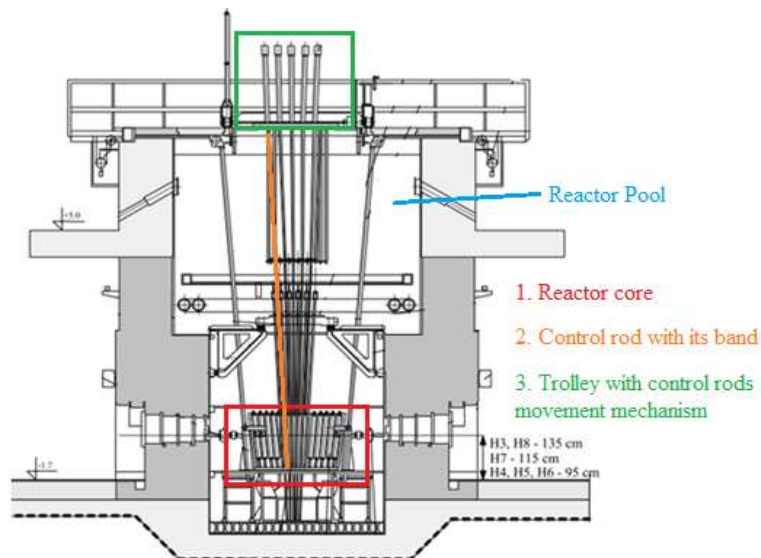


Figure 4: MARIA reactor scheme.

The vertical motion was described by a simple Newtonian correlation as the combination of motion of a material point and elastic collision. During an earthquake, there are two possibilities of control rods displacement in relation to the reactor core:

1. When the movement of the reactor corpse caused by an earthquake is changing its direction from "up" to "down". In that case the control rods have initial velocity caused

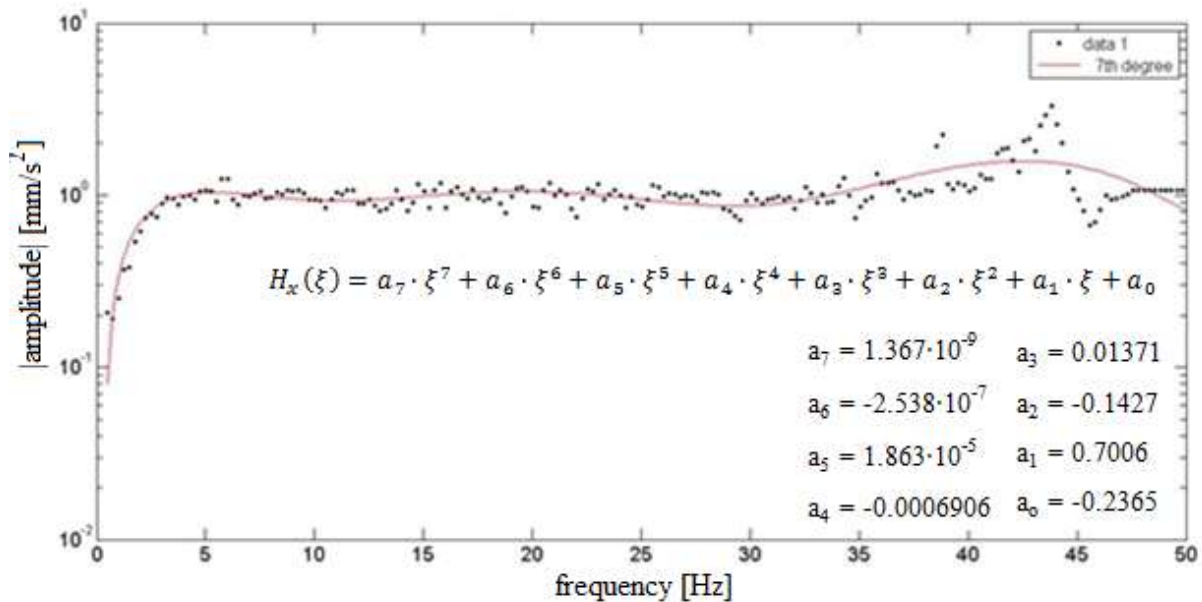
by inertia force. If that velocity is higher than negative velocity vector caused by gravity force, control rods can move along the reactor core.

2. After the situation described in the previous case, the control rod is eventually going down and hitting the reactor corpse. The elastic collision happens.

The control rod can also change its position in the reactor core by retraction caused by horizontal movement of the trolley that contains control rods mechanism. The trolley can move freely along rails and due to construction constraints  $\pm$  perpendicularly to them, as shown in *Figure 3*.

To determine the possible trolley movement caused by foundations movement, the vibration transfer function was determined. Initially the accelerations of reactor foundations and trolley were measured. Then the time series was transformed into frequency series, using Fast Fourier Transform algorithm (FFT).

Then the vibration transfer function was obtained by division of Trolley and Reactor Corpse's Fourier Transformations.

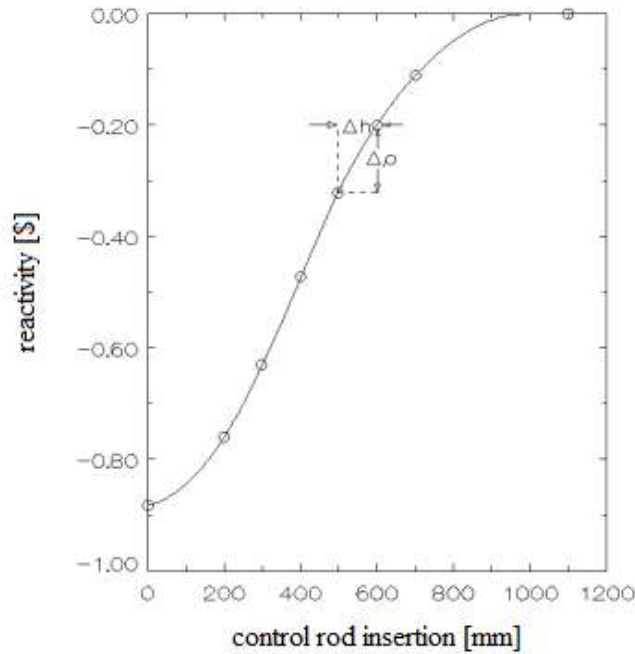


*Figure 5: Transfer function between ground and control rods motion.*

The waveforms of accelerations were transformed into frequency spectrum using FFT and multiplied by transfer function presented in *Figure 5*. Then the Inverse Fast Fourier Transform was used. Finally the trolley absolute accelerations were obtained and the data were integrated twice using Runge-Kutta 4<sup>th</sup> order algorithm, and the correction scheme taken from [3] was applied. Displacement of the reactor corpse was subtracted from the displacement movement of the trolley, thereby obtaining a displacement of the trolley relative to the foundations. From these values the total length of displacement vector  $D$  for each time step was calculated. To calculate how horizontal displacement of the trolley (stretching from the core) changes control rods immersion into core, simple trigonometric were used.

With known vertical displacement of the control rods in relation to the reactor core, their impact on reactivity changes can be calculated. As it can be seen from the reactivity  $S$ -curve presented

in *Figure 6*, the biggest change in reactivity occur when the rod is depressed halfway in the core. Therefore in accordance with accepted principle of conservative approach, this situation was assumed for the purposes of the model, and described as  $\Delta\rho = \frac{2 \cdot \rho_{\max}}{H}$



*Figure 6: Control rod S-curve.*

Due to impossibility of measuring individual control rods vibrations transfer function, all of the control rods were treated as one with total reactivity weight of 8\$

Calculated reactivity changes were used to derive reactor power changes, with Point Reactor Kinetic equations taken from [7]. The existence of fifteen delayed neutron groups was assumed. Runge - Kutta 4<sup>th</sup> order algorithm was used for integration. After the final integration of Point Kinetics Equation, the reactor power fluctuations caused by an earthquake based control rods vibrations were obtained.

### 3. Results

Results of the calculation showed that in worst case scenario reactivity of the reactor could increase for  $2.36 \times 10^{-4}$  \$ resulting in 0.650 ‰ power change. Time series of reactivity and power changes are presented in *Figure 7* and *Figure 8* respectively. showing time related changes of the most important parameters. Maximal values of parameters that were calculated during the simulation are gathered in TABLE II.

TABLE II: Results obtained from the calculations.

| Parameter                              | Result from Belsk data series | Result from Warszawa data series |
|--|-------------------------------|----------------------------------|
| PGA                                    | 0.1 [g]                       | 0.1 [g]                          |
| Trolley vertical displacement          | 0 [mm]                        | 0 [mm]                           |
| Trolley horizontal displacement x-axis | 12.9 [mm]                     | 2.1 [mm]                         |
| Trolley horizontal displacement y-axis | 10 [mm]                       | 2.6 [mm]                         |
| Control rod vertical displacement      | $1.6 \times 10^{-2}$ [mm]     | $5.7 \times 10^{-5}$ [mm]        |
| Reactivity change                      | $2.36 \times 10^{-4}$ [\$]    | $8.2 \times 10^{-6}$ [\$]        |
| Power relative change                  | 0.650 [‰]                     | 0.014 [‰]                        |

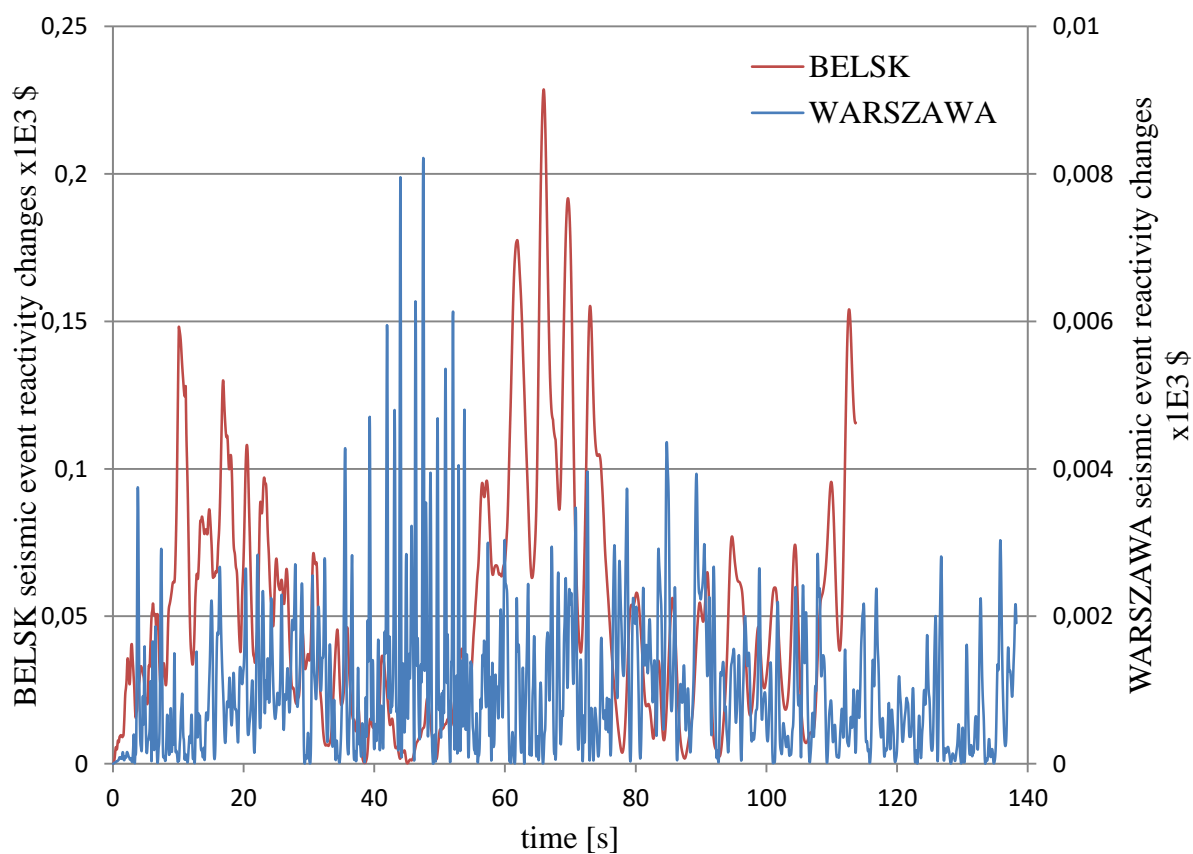


Figure 7: Reactivity changes time series.

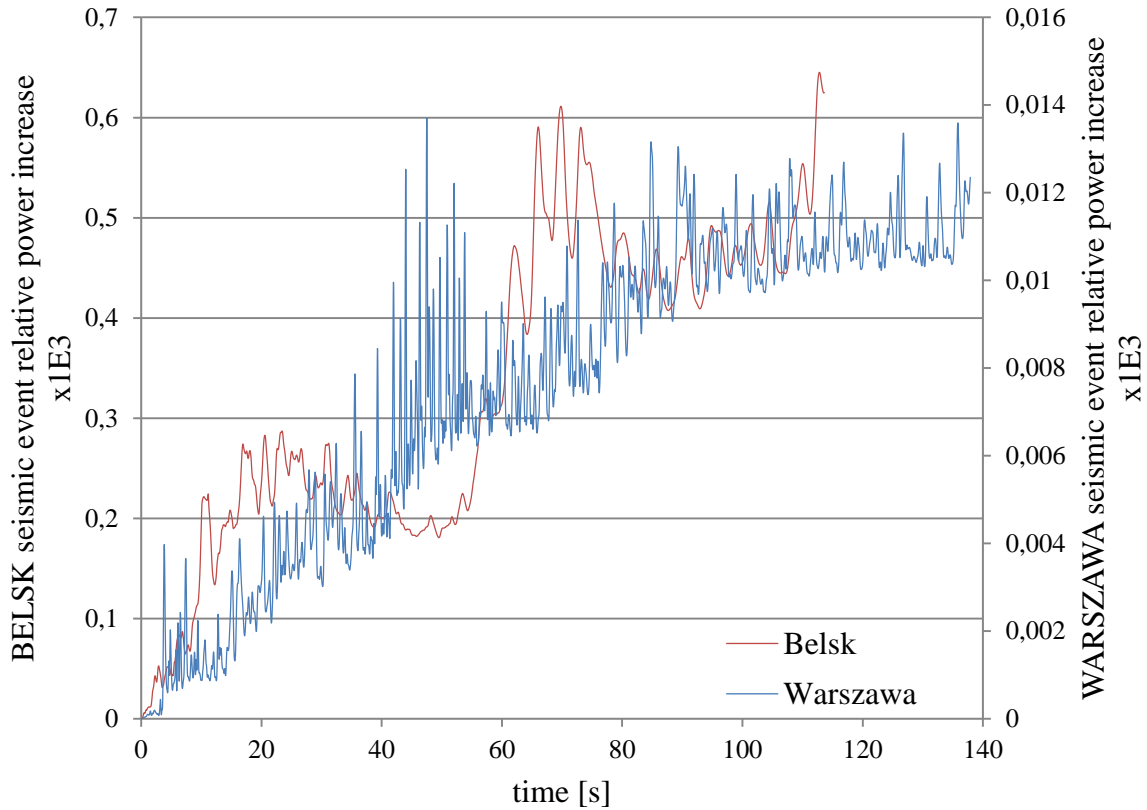


Figure 8: Relative power changes time series.

#### 4. Conclusions

The obtained results show reactivity and power fluctuations of the MARIA nuclear reactor caused by the earthquake based control rods movement. Despite the high values of ground acceleration adopted for the calculation,  $PGA = 0.1g$ , vertical movements of control rods in relation to the core, and the resulting changes of reactivity and nuclear reactor power were vanishingly small. That is because of the vibrations damping by the reactor foundations. In the *Figure 5* it can be seen that for earthquake frequency lower than c.a. 5 Hz, ground motion can be damped even by an order of magnitude.

Changes of the reactor reactivity and power are within the range of noise and are impossible to measure during normal operation of the reactor and definitely will not cause deviations from the normal operation regime. Even during the seismic event many times stronger that is possible to happen in Poland, power fluctuations are within the range of natural noise of the reactor, which is of the order of  $\pm 1\%$ .

#### 6. Acknowledgements

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