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ANALYSIS OF THE NUCLEAR REACTOR CORE OF CHERNOBYL POWER PLANT FOR 5 SECONDS BEFORE EXPLOSION WITH THE THREE-DIMENSIONAL SPHERICAL SPACE

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Abstracts. This research analyzed the water flow and bubble (void) of nuclear reactor core of Chernobyl Power Plant, for 5 seconds before the explosion, using a mathematical model of two-dimensional spherical coordinates. To solve the problem, we considered this phenomenon as an analogy of Newtonian gravity theory, which had been solved in Schwarzchild Solution. As a result, the calculated radius of the spherical space of water and bubble indicated the maximum limit, at which the reactor core lost the control of reactor power. And, then, a regression analysis, with exponential model, confirmed the influence of bubble and water to the reactor's power.

Keywords: nuclear power plant, Chornobyl disaster, critical operation mode, regression analysis, void and water environment.

INTRODUCTION

During a few seconds before the explosion of the reactor core of the Chernobyl Nuclear Plant in April 1986, the flow rate of the Main Circulation Pump (MCP) was reduced, and void (bubble) increased in the water flow. Our previous research [1] suggested that the water flow and void explain the process of these five seconds, while reactor's power immensely increased toward the explosion. From this previous result [1], we continued the investigation with the same data, in order to find a rule, which may explain how the water and void were related to the sudden increase of the reactor power, what resulted in an explosion.

For the further analysis, we assumed the followings: 1) the nuclear reactor core has potential to control its power; and, such a potential has an analogy from the gravity force in the space; 2) when the condition of water and void are out of the reach of the hypothetical gravity, the nuclear reactor loses its control over its power. Fig. 1 shows the scatter plots of water and void in time series. This figure shows the decreasing MCP flow rate and increasing void, over time.

METHODOLOGY

Two-dimensional spherical model

Schwarzchild solution [2] of two-dimensional rectangular coordinates is:

$$ds^2 = (1-2V)dr^2 - (1-2V)^{-1}dr^2 - r^2 d(\sin\theta)\,,$$

where ds^2 of this equation (1) is a geodesic, which indicates the status of the reactor core in hypothetical coordinates, V is potential of gravity, r is the radius, and θ is the angle of the radius in the two-dimensional spherical coordinates.

If it is applied to the Newton's gravity, V is inversely proportional to the radius, r. We take the same assumption in this analysis:

$$V = W / r,$$

where W is unknown scalar value, which is specific to the two dimensional space of this analysis.

Then $r = 2W$ is a singular point, where $ds^2 = \infty$.

In this analysis, the coordinates of Fig. 1 are converted to a two-dimensional spherical coordinate as well as the time coordinate. In this analysis, the gravity is static; therefore, time is independent from the special coordinates.

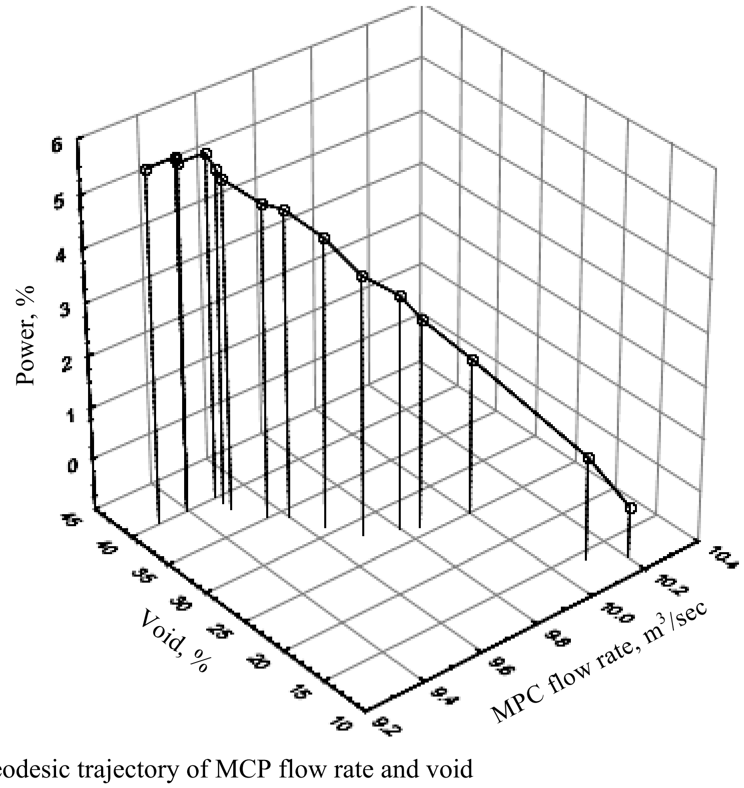

Fig. 1. Geodesic trajectory of MCP flow rate and void

Main circulation pump flow rate (x-coordinate in Fig. 1) and Void (y-coordinate in Fig.1) are converted to the two-dimensional spherical coordinates with the following equations:

$$r = \sqrt{x^2 + y^2}, \quad (1)$$

$$\theta = \tan^{-1} \frac{y}{x}.$$

In this analysis, units of MCP flow rate and void are different; therefore, the coordinates in the two-dimensional spherical space is purely hypothetical. No attempt is made to find theoretical connection to the nuclear reactor theory; but, rather, an attempt is made to find the singular point in the hypothetical space, which could lead to the explosion. Therefore, only equation (1) is considered.

Exponential model for regression analysis

After the above analysis, if a singular point of the hypothetical spherical space is identified, regression analysis of the data will be carried out, with the exponential model:

$$Y_j = a + \exp\left(b + \sum_{i=1}^{n} c_i X_{i,j}\right),$$

where a, b, c_i ($i = 1,2,3,....n$) are positive constants, and n is number of independent variables. $j = 1,2,....m$, the suffices, j, means j-th observation of the variable, $X_{i,j}$, and m is number of observations.

These coefficients, a, b, c_i ($i = 1,2,3,....,n$) are calculated numerically, which are to minimize $\frac{1}{m}\sum_{j=1}^{m} U_j^2$, where

$$U_j = Y - \left\{a + \exp\left(b + \sum_{i=1}^{n} c_i X_{i,j}\right)\right\}.$$

In this analysis, one more model is also tested:

$$Y_j = a + b\exp\left(\sum_{i=1}^{n} X_{i,j}\right), \qquad (2)$$

where a and b are positive constants, $i = 1,2,3,...,n$, and $j = 1,2,3,...,m$.

Method to test the fitting (predictability) of the exponential model with sampled data

a) calculate the predicted value of Y (i.e., $\hat{Y}$) with the following equation:

$$\hat{Y}_j = a + \exp\left(b + \sum_{i=1}^{n} c_i X_{i,j}\right).$$

b) calculate the value of R^2 by the following equation:

$$R^2 = \frac{\sum_{j=1}^{m} (\hat{Y}_j - \overline{Y})^2}{\sum_{j=1}^{m} (Y_j - \overline{Y})^2},$$

where $\overline{Y} = 1/m \sum_{j=1}^{m} Y_j$.

For the model (2), the same rule applies.

The value of R^2 represents the fitting and predictability of the given exponential model upon the given data, and when $R^2 = 1{,}0$, it is the perfect match, while the level of the matching is lower when the value of R^2 is lower. In practice, if $R^2 \geq 0{,}8 \sim 0{,}6$, the fitting of the model in the data is significant. However, the threshold value depends on the topic and the data of the concerned research question, therefore the values of R^2 need to be considered on the comparative manner.

Data

The data was taken from Martines, et.al 1989 [3], which we used in [1]. The descriptive statistics are shown in Table 1. Reactor power, MCP flow rate and void during the time period of 5 seconds before the explosion (between 01h 23 min 38 sec and 01 h 23 min 42, 71 sec on 25 April 1986) are analyzed in this research.

Table 1. Descriptive Statistics of Parameters (taken from Fig. 3 of [3])

Parameter	**Power (% nominal power)**	**MCP flow rate m^3/sec**	**Void, %**
Mean	67442,4	9,653	31,819
Median	13220	9,575	34,500
Maximum	227186,7	10,200	40,050
Minimum	0	9,3	12,000
Std, Dev.	90122,460	0,269	9,202
Skewness	0,872	0,713	−0,947
Kurtosis	2,039	2,396	2,837
Observations	16	16	16

Note: Max.: maximum value. Min.: minimum value. Std. Dev.: standard deviation. Skewness: the measure of the probability distribution leaning to one side of the mean. Kurtosis: "peakedness" of probability distributions. Observation: number of observations.

RESULT

Geodesic trajectory of MCP flow rate and void in two-dimensional spherical coordinates

Fig. 2 shows the calculated radius of the hypothetical two-dimensional spherical coordinates of MCP flow rate and void, in comparison with the reactor power. When the hypothetical radius reached the length of 40, the reactor power increased immensely[1].. We assume that this is the singular point, where $r = 2W$, and $ds^2 = \infty$.

This observation suggests that there is a potential, which is an analogy from the earth's gravity, but it is only in a hypothetical two-dimensional spherical coordinates of water and void in the reactor core. That is, when the geodesic is far from the center of the coordinates, the gravity force becomes weaker, and then, the reactor core cannot control its power.

[1] Here, the radius doesn't have unit; because, this coordinate is purely hypothetical.

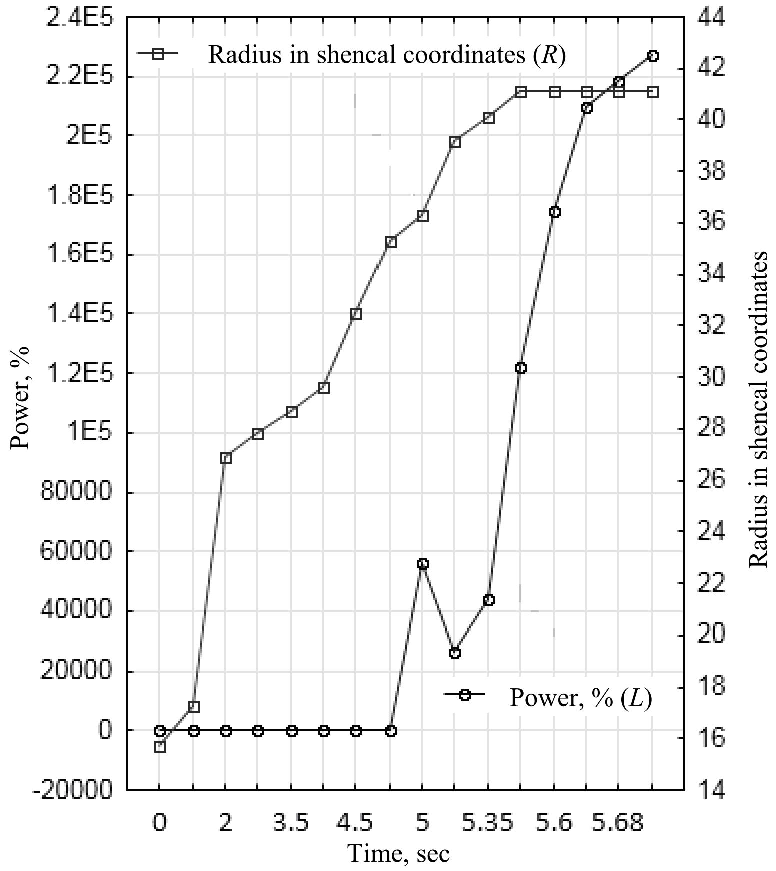

Fig. 2. Power and the radius in hypothetical spherical coordinates of water and bubble

Exponential models to explain the explosion

The next step is to describe the sudden increase of reactor power by MCP flow rate and void.

In our previous study [1], we calculated the first-order estimate with a linear model. However, upon the observation above in this research, we assumed that the reactor suddenly increased its power immensely, when the size of radius reached the singular point in the hypothetical two dimensional space of water and void of the reactor core, as if the reactor core lost its control over its power. And, then, we thought that we cannot describe the process of increasing reactor power with the standard model for the first order estimation, but with exponential models.

Table 2 shows the results of the regression analysis with two exponential models and a linear model. The fittings of the exponential models are much better than the linear model's, as indicated by the values of R^2. Fig. 3 shows the comparison between the calculated reactor power and the observed reactor power. The figure also shows that the exponential models fit well with the observed power, than the linear model.

This result shows that MCP flow rate and void can explain the increase of reactor power.

Table 2. Calculated reactor power by two exponential models and a linear model

Model	Linear models and calculated coefficients	R^2
Exponential model 1	$\text{Power} = 6353{,}2 + \exp(-14{,}561 - 2{,}2701\text{MCPflowrate} + 1{,}1997\text{void})$	0,9587
Exponential model 2	$\text{Power} = 4451{,}7 + 6{,}24 \cdot 10^{-17} \exp(\text{MCPflowrate} + \text{void})$	0,8819
Linear [1]	$\text{Power} = 4875626 - 475560{,}6 \times \text{MCPflowrate} - 6836{,}794 \times \text{void}$	0,5712

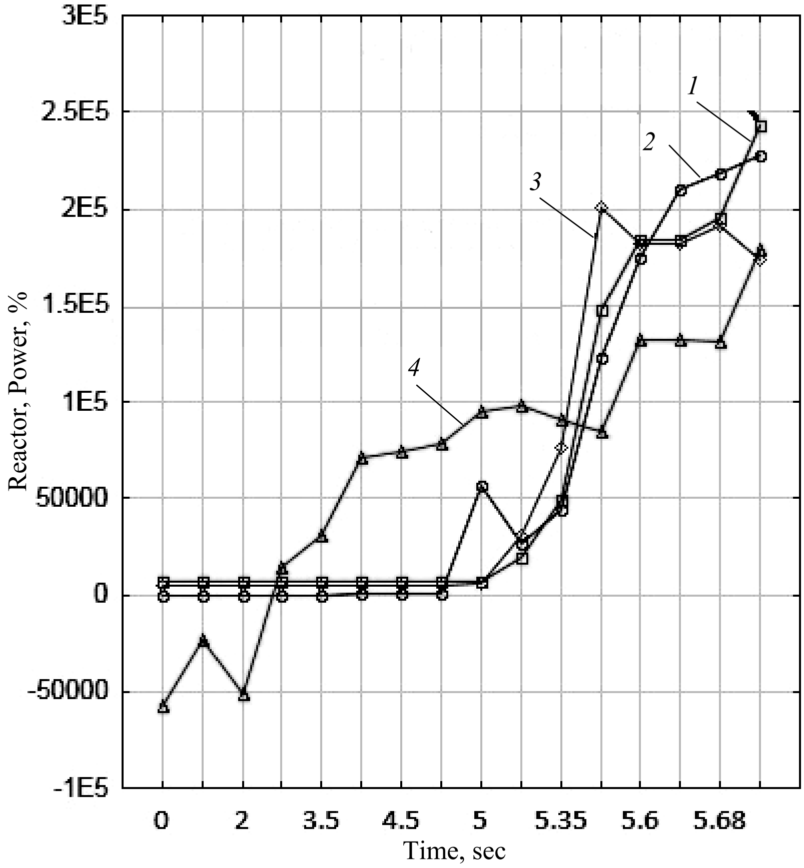

Fig. 3. Comparison of observed reactor power with calculated reactor power: *1* — calculated power by model-1, %; *2* — power, %; *3* — calculated power by model-2; *4* — calculated power by model

CONCLUSION AND RECOMMENDATION

In case of the explosion of Chernobyl nuclear reactor, both MCP flow rate and void showed unusual behaviors. And, then the reactor power increased suddenly. The exponential curve showed the immense increase of the reactor power, what resulted in an explosion.

If the reactor core had a capability to control its power, the occurrence of the explosion suggests that there is a point that led to the explosion. The result of this research also suggests that there was a limit for controlling the reactor power, and the limit existed at the singular point of the hypothetical three-dimensional spherical space of water and void in the reactor core.

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