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Nuclear Safety of RBMK Storage Pool under Seismic Impact

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Abstract. Nuclear safety of RBMK storage pool of spent fuel during of the maximum design earthquake is evaluated. The lower ends of the fuel assemblies are not fixed and they can deviate from the vertical position. The seismic action may be one of the reasons for such deviations. 3D model of fuel assemblies movements caused by seismic impact is used. The simulation of the dynamics of a fuel assemblies group under seismic impacts allows to find the dangerous configuration of closest approach of the fuel assemblies. Three-dimensional neutron program STEPAN calculates the Keff of the most dangerous systems. The maximum design earthquake is the design basis accident. In this case according to the regulatory documents the fuel is considered with zero burn-up. Nuclear safety of RBMK storage pool under considered conditions is provided.

1.Introduction

The RBMK spent fuel pool is located directly in the reactor hall. The pool consists of two concrete compartments. Each compartment is covered with corrosion-resistant steel plates and is 10.3 m long, 4.2 m wide and of 17.3 m deep. The compartment is filled with water up to 16.6 m and closed with caps. Fuel assemblies are hanged on the 2 m long cantilever beams. The distance between the centers of the beams is 0.25 m. There is a canyon in the middle of the compartment between the ends of the beams. The canyon is used to transport fuel assemblies under water to their place of storage.
In the initial project it was planned to put the fuel assemblies into steel pipes. But to increase the capacity of the pool 2.2 times the fuel assemblies are placed now without the pipes by a triangular lattice. The lower ends of the fuel assemblies are not fixed and they can deviate from the vertical position. The seismic action may be one of the reasons for such deviations.

According to the regulations nuclear safety during storage and transportation of nuclear fuel is provided when the neutron multiplication factor Keff is less than 0.95 in normal operation, in case of violations of normal operations and in case of design basis accidents. The Keff≤0.95 criterion is not required for beyond design basis accidents. It is sufficient to show that a self-sustaining fission chain reaction is impossible. For beyond design basis accidents regulatory documents require a realistic (non-conservative) analysis. This means that the actual fuel burn-up should be considered in the calculations.

The maximum design earthquake is the design basis accident. In this case the burn-up credit can be used if a special device for the measurement of fuel burn-up is available. Otherwise, all of the fuel in the pool should be considered as fresh (with zero burn-up). The conservative static analysis has shown that if a lot of assemblies with fresh fuel deviate from the vertical and their lower ends are in contact, the criterion Keff≤0.95 may be violated. That brought up the task of modeling of the actual behavior of a fuel assemblies group during an earthquake.

2. Fuel assemblies motion simulation

The problem can be divided into two parts. The first part is the simulation of the dynamics of a fuel assemblies group under seismic impacts with regard to their collisions and water resistance. This simulation allows to find the dangerous configuration of closest approach of the fuel assemblies (FA). In the second phase the three-dimensional neutron program calculates the Keff of the most dangerous systems.

Seismic action moves the pool with cantilever beams. Since the FA fixed only at the top, they start to oscillate like a pendulum relative to the walls and bottom of the pool due to the inertia.

When the horizontal oscillations occur, the lower part of the water at the depth of more than ¾ of the pool width is considered to be rigidly connected with the walls, i.e. it moves the same way as the pool itself [1]. Above the level of ¾ of the pool width there is a complex movement of water, including the possibility of wave oscillations of liquid free surface. Water that moves together with the pool walls resists the movement of the FA. Fuel assemblies are fixed to the beams by the thin hangers. Resistance of water to hangers can be neglected. To simplify the task the bending of the fuel assemblies is not considered.

Figure 1 shows a scheme of the fuel assembly with the hanger. The hanger consists of two parts 14 and 36 mm diameter.

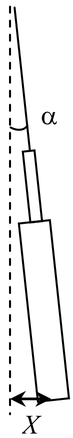

Figure 1. Scheme of fuel assembly.

As a result of the seismic action assembly deviates from the vertical by an angle α, which leads to displacement of the lower part of FA by a distance X. Water resistance (force) for dz element of moving fuel assembly at a height z is determined by the formula:

$$F_c(z) = \frac{1}{2} C_x(z) \rho u^2(z) D dz + \frac{\mu}{L} a(z) dz \quad (1)$$

where $C_x(z)$ - drag coefficient; ρ – water density; μ - added mass of water; $u(z)$, and $a(z)$ – velocity and acceleration at the height z; D, L - diameter and length of the fuel assembly or hanger. The drag coefficient is determined according to the formula $C_x = cRe^{-b} k$ [2], where c - constant depending on the geometry; Re - Reynolds number; b - exponent, k - correction factor that takes into account the non-uniformity of movement and the mutual influence of the fuel assembly.

From dynamic equation considering the moments of all the forces, one can get an equation that describes the behavior of a harmonic oscillator with a nonlinear damping and external disturbing force f (force of inertia):

$$\ddot{X} + \beta \, \dot{X}^{2-b} + \omega_0^2 X = -f(t) \quad (2)$$

where X - deviation of lower part of FA from of the vertical axis; β - coefficient determined by the geometry of the assembly and the viscosity of water; ω_0 - the natural frequency of the assembly with added mass of water.

The movement of the lower part of each assembly, composed of the oscillation in X and Y directions, is described by equation (2). All assemblies move in the same way before the collision with the walls or other assemblies. Distance between them is almost constant. The collision of the FA lower parts with the wall and its reflection cause a chain reaction of mutual collisions. As a result regular lattice is broken. In some places the lower parts of fuel assemblies form a compact group with a reduced lattice pitch that leads to an increase of the neutron multiplication factor.

3. Evaluation of the neutron multiplication factor

STEPAN-БВ code is used for the analysis of nuclear safety. This code is a modification of a well-known STEPAN code [3] that is certified for calculations of RBMK. Changing lattice pitch in the horizontal direction for the layers with different heights allows to simulate the FA deviation from the vertical axis in emergency situations. Two-group system of constants has been prepared for the three-dimensional calculations. The constants depend on fuel burn-up, lattice pitch, water density and temperature. Calculation model was verified by comparison with the precision calculations by the Monte Carlo MCNP code [4]. Keff calculation example for different types of lattice is shown in the table 1.

Table 1. Neutron multiplication factor in the RBMK pool (fresh 2.6% enriched fuel).

Lattice type	MCNP	STEPAN-БВ	Δ(STEPAN – MCNP)
Square 8x8 cm	1.2069 ±0.0003	1.2105	0.0036
Triangle 12,5 cm	0.7974 ±0.0003	0.8018	0.0044
Rectangle 8x12,5 cm	0.9954 ±0.0003	1.0055	0.0101

4. The results of the maximum design earthquake simulation

FA dynamics in a fragment of the pool of the 1st unit of Kursk NPP caused by the maximum design earthquake of 7 points was considered. Accelerogram (acceleration g) during an earthquake in a horizontal direction is shown in figure 2.

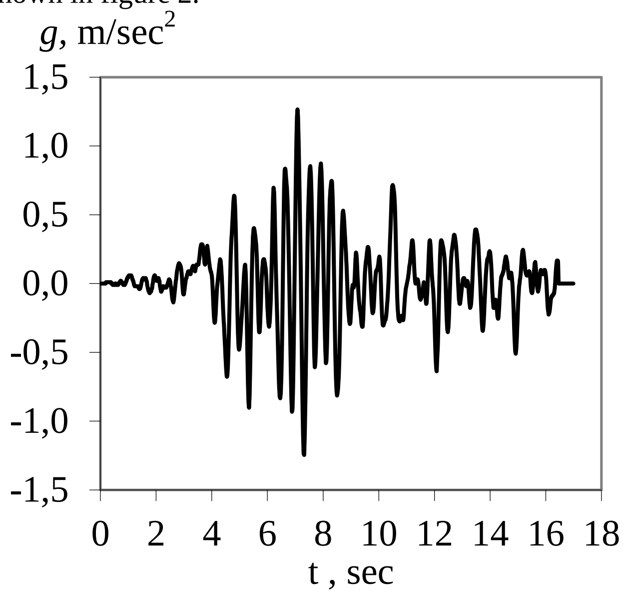

Figure 2. Accelerogram of the 7 points earthquake.

Pool fragment 20x14 FA is shown in figure 3. The pool walls are to the left and at the bottom of the scheme. Canyon is at the top of scheme. The figure 3 shows the moment of closest approach of the FA lower parts.

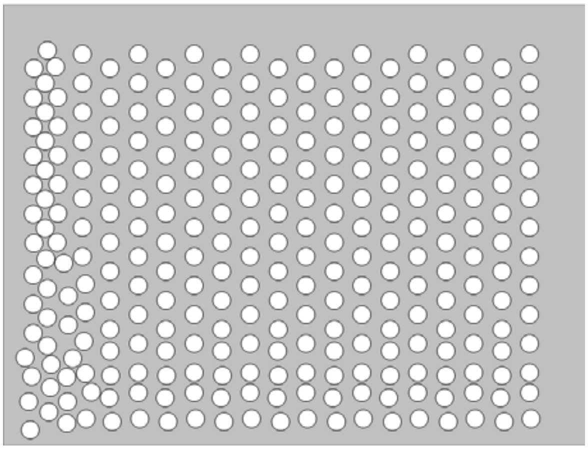

Figure 3. Horizontal section of pool fragment (lower parts of FA).

In the initial state before the earthquake Keff=0.790 for 2.6% enrichment fuel with a zero burn-up. For the configuration shown in figure 3 Keff=0. 937. Nuclear safety criterion is ensured. Safety can be improved by leaving the left row empty (free of fuel assemblies). In this case Keff=0.823.

5. Conclusion

Presented calculations have shown that nuclear safety of storage pool RBMK in the maximum design earthquake of 7 points is provided.

References

[1] Birbraer A N 1988 Calculation of Structures for Seismic Stability (St. Petersburg: Nauka) (in Russian).
[2] Batchelor G K 1970 An Introduction to Fluid Dynamics (Cambridge at the University Press)
[3] Babaytsev M N, Fedosov A M, Glembotsky A V, Krayushkin A V, Kubarev A V, Romanenko V S 1993 The STEPAN Code for RBMK Reactor Calculation Preprint IAE-5660/5
[4] MCNP – A General Monte Carlo N-Particle Transport Code Version 4B 1997 Los Alamos National Laboratory Report LA-12625-M