Calculation of critical parameters of the experimental stand «FKBN»

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Abstract. The experimental stand «FKBN» (physical fast-neutron boiler) is a critical assembly in which the vertical lift mechanism is used. With the help of such stands, in the second half of the 20th century, experiments were conducted on the effect of various materials in various designs on the kinetic characteristics of a system with fissile material. Mostly, such works were conducted in Los Alamos National Laboratory (USA), Oak Ridge Laboratory (USA), VNIIEF (Russia), VNIITF (Russia). On such installations, there were often accidents with the emergence of a self-sustaining chain reaction. One of these occurred on April 5, 1968 in VNIITF in Chelyabinsk-70 (now Snezhinsk). In this paper, the critical state of the stand is calculated for different distances of the reflector from the core under the conditions of the presence and absence of solid polyethylene inside the core. The configurations in which $K_{\text{eff}}=1.00$ and $K_{\text{eff}}=1.00+\beta_{\text{eff}}$ are of interest are of interest. As a tool, the CSAS6 sequence of the SCALE-6.2.1 software package was used.

1. Introduction

In the past, the exclusion of the possibility of the emergence of SCR was considered to be the main and the only noteworthy problem of nuclear safety. However, experience has shown that it is impossible to achieve absolute reliability of measures to prevent SCR, since economic indicators of production cannot be ignored. On the sum of potential consequences, the SCR is among the serious accidents: external exposure of personnel, release of radioactive substances and the possibility of external and internal exposure to a wider range of people, environmental pollution, equipment failure, deterioration and loss of valuable materials. However, the probability of an accident with such a sum of consequences is insignificant.

The need to obtain data on the course and consequences of SCR required special experiments. So, in the USA a number of critical assemblies were tested in conditions of instantaneous supercriticality (Godiva, Triga, KEWB, SPEPT, TREAT, etc.). However, the most significant was the French CRAC program, during which (1968–1972), more than 60 experiments were carried out with active zones from solutions of $^{235}\text{U}$ with enrichment of 93%. Similar Soviet works also provided valuable information on the SCR kinetics and allowed the creation of a series of pulse reactors of self-extinguishing action.

It is now established that at the SCR is not a phenomenon that cannot be foreseen. Therefore, the analysis of the consequences must be done at the design stage of production processes and equipment. The most important measures are measures to counteract the radiation consequences of the SCR,
which, as a rule, are reduced to the design of an emergency alarm system, optimal evacuation routes, the use of protective equipment, emergency dosimetry and etc.

2. Accident with the emergence of SCR in Chelyabinsk-70, April 5, 1968

The accident occurred on April 5, 1968 in the Russian Federal Nuclear Center VNIITF (RFNC-VNIITF), located in the southern part of the Ural Mountains between Yekaterinburg and Chelyabinsk. Experiments with critical assemblies using the vertical lift mechanism at the FKBN facility began at VNIITF in 1957. The FKBN, in particular, implemented a number of critical configurations with a thick reflector and a large internal cavity providing operation in the pulsed mode and in a static mode at power several kW.

Stand BKBN consisted of a support, which housed the central hollow sphere, in fact is as. Above and below were hemispherical reflectors that were attached to the rods of mechanical drives. Changing with their help the distance and measuring the count of neutrons, it was possible to determine the degree of subcriticality of the system.

In the present case, the effect of the presence of a polyethylene spherical sample on the kinetic characteristics of the reactor system was investigated.

![Figure 1. Schematic representation of the configuration of the vertical lift assembly and the FCSN core during the accident.](image)

At the first stage of the experiments, inside the cavity of the core was empty, and critical assembly parameters were defined. In the second stage, a polyethylene sphere was placed inside the cavity and again the critical state was measured. To speed up the work (it was the 2nd evening shift on the eve of the weekend), it was decided to quickly lower the upper reflector to the core, and then use a fine calibration to raise the lower reflector until a critical condition arrived.

From the manual control panel, the responsible work supervisor began operating the upper hoist to lower the upper half of the reflector and bring it into contact with the core. The operator, standing next to the FKBN, guided a descending reflector with his hand. The accident occurred when the upper half of the reflector fell towards the core and almost came in contact with it. After the power of the ejection reached a kilowatt level, a high-speed emergency protection triggered and the lower half of the reflector was dropped, which was enough to bring the system into a deeply subcritical state and stop the chain reaction. The emergency release led to the death of two specialists standing next to the
assembly during the release. The criticality alarm system was installed, but did not work during the experiment.

3. Description of the calculation model
Based on the description of the critical assembly, a calculation model was constructed. Its 3D image is shown in figure 2.

Parameters of the calculation model:
- Central hollow sphere with radii: 5.15 cm 9.15 cm
- Hollow hemispherical reflector (2 halves) with radii: 9.15 cm and 20.00 cm
- The central sphere consists of highly enriched uranium metal (90% of $^{235}$U)
- Reflector consists of metallic uranium with natural enrichment (0.71% of $^{235}$U)

![Figure 2. Critical stand model.](image)

The calculation is performed using the CSAS6 module of the SCALE-6.2.1 software package, which uses the KENO-VI Monte Carlo code. ENDF / B-VII.1 is used as a nuclear data library.

4. Calculation
At the first stage, we determine the critical parameters of the system, namely the distance between the reflectors and the az. in the absence of materials in the cavity of the central sphere.

First we will change the distance between the core and the upper reflector, leaving the lower reflector in the initial position. The results of measuring the effective multiplication factor are shown in table 1.

| №  | Distance R (cm) | Calculated value of $K_{eff}$ | Estimated accuracy ($\Delta K/K$) |
|----|----------------|------------------------------|----------------------------------|
| 1.1| 2,00           | 0.8875                       | 0.0003                           |
| 1.2| 1,50           | 0.9007                       | 0.0003                           |
| 1.3| 1,00           | 0.9153                       | 0.0003                           |
| 1.4| 0,50           | 0.9311                       | 0.0003                           |
| 1.5| 0,00           | 0.9484                       | 0.0003                           |
Thus it can be seen that even a complete approach of the upper reflector and core does not lead to criticality. Therefore, in the following calculation, we will vary the distance between the core and the lower reflector, with the upper reflector completely lowered.

The results of the calculations are shown in table 2, and are also graphically shown in figure 4.

**Figure 3.** Dependence $K_{\text{eff}}(R)$ for the upper reflector.

Table 2. Effective reproduction rate and distance for the lower reflector.

| №  | Distance R (cm) | Calculated value of $K_{\text{eff}}$ | Estimated accuracy ($\Delta K/K$) |
|----|----------------|-------------------------------------|---------------------------------|
| 2.1| 4.00           | 0.9280                              | 0.0003                          |
| 2.2| 3.50           | 0.9381                              | 0.0003                          |
| 2.3| 3.00           | 0.9484                              | 0.0003                          |
| 2.4| 2.50           | 0.9597                              | 0.0003                          |
| 2.5| 2.00           | 0.9725                              | 0.0003                          |
| 2.6| 1.50           | 0.9854                              | 0.0003                          |
| 2.7| 1.00           | 0.9996                              | 0.0003                          |
Figure 4. Dependence $K_{\text{eff}}(R)$ for the lower reflector.

From these results it is evident that in the absence of materials in the cavity of the core. Criticality will arise only when the upper reflector is completely lowered and when the lower reflector approaches a distance of 1 cm from the core.

At the next stage of the calculations, we place inside the cavity of the core the solid polyethylene. Just as in the previous case, we will change the distance between the core and the upper reflector, leaving the lower reflector in the initial position.

The results of the calculations are shown in table 3, and are also graphically shown in figure 5.

| №  | Distance R (cm) | Calculated value of $K_{\text{eff}}$ | Estimated accuracy $(\Delta K/K)$ |
|----|-----------------|-------------------------------------|----------------------------------|
| 3.1| 2,00            | 0.9771                              | 0.0003                           |
| 3.2| 1,60            | 0.9873                              | 0.0003                           |
| 3.3| 1,20            | 0.9971                              | 0.0003                           |
| 3.4| 0,80            | 1.0083                              | 0.0003                           |
| 3.5| 0,40            | 1.0202                              | 0.0003                           |
| 3.6| 0,00            | 1.0332                              | 0.0003                           |
Figure 5. Dependence $K_{\text{eff}}(R)$ for the upper reflector.

It can be seen from the graph that even at a distance of 1.10 cm between the core and the upper reflector is critical. It is clear that further convergence of a core with the upper reflector will lead to a large supercriticality, and consequently to acceleration on the instant neutrons, even if the initial position of the lower reflector is preserved.

5. Conclusions
In the course of the work, the description of the accident with the emergence of the SCR occurred in VNIITF was studied. A computational model was constructed for calculating the critical parameters.

In analysing the results obtained, we can say that in the case of an empty core the criticality arises when the core with, the upper reflector and the lower reflector are completely approaching at a distance of 1.00 cm.

When installing polyethylene inside the core criticality occurs at a distance of 1.10 cm from the lower reflector to the core.

The initial placement of the lower reflector just below indicates the insurance of the experimenters. However, the blunder of the responsible manager is to underestimate the positive effect of polyethylene on the criticality of the stand. From the calculations, we obtain an additive of positive reactivity when adding polyethylene, which is equal to 10.33%.

Reference
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