Development of a model of critical test bench FKBN-3

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Abstract. In the course of activities there is created a calculated model of critical test bench FKBN-3 in the experimental hall. With the aid of this model for the first time by calculations there is estimated on the base of $^{235}\text{U}(36\%)$ critical system with no reflector – $K_{\text{eff}}$ effect of separate parts of FKBN-3 and supports designed to arrange multiplying system blocks on FKBN-3 bench.

1. Introduction
FKBN-3 complex meant to perform critical mass studies with different multiplying systems (MS) [1] is available at VNIIEF. With these experiments completed a calculated model of MS studied under critical state ($K_{\text{eff}} = 1$) is being formed [2]. To adequately record the MS effect of experimental equipment parts on MS multiplying parameters, one should specify an optimal degree of detailing FKBN-3 bench components in the experimental hall.

2. Development of a model
The effect of FKBN-3 parts and supports for FKBN-3 bench positioning of MS blocks on the value $K_{\text{eff}}$ is estimated for experimentally studied MS with a core made of $^{235}\text{U}(36\%)$ and no reflector [3], given symmetrical and asymmetrical decomposition into lower and upper blocks (LB and UB) (figure 1 and figure 2) in the following way:

$$\Delta K_{\text{eff}} = K_{\text{eff}} - K_{\text{base eff}},$$

where $\Delta K_{\text{eff}}$ – effect of some part of FKBN-3 or supports on the value $K_{\text{eff}}$ for spherical MS model;

$K_{\text{eff}}$ – value $K_{\text{eff}}$ for MS model when adding any FKBN-3 complex part or supports;

$K_{\text{base eff}}$ – value $K_{\text{eff}}$ for spherical MS model.

Calculations are made by Monte-Carlo method [4] using a library of neutron and physical data ENDF/B-6 [5]. Optimal quantity of randomized histories is assumed to be equal to 50000 to provide absolute calculation error $\Delta K_{\text{calc}}$ on the level 0.00005.

The value $K_{\text{base eff}} = 0.99343 \pm 0.00005$ is obtained for the spherical MS model [3]. When conducting the given calculations in models, no walls, floor, ceiling, parts of FKBN-3 complex and supports for positioning MS blocks’ are available.
In order to specify a degree of effect of walls, a floor and a ceiling of the experimental hall on the value \( K_{\text{eff}} \), the spherical MS model is placed into the calculated model of the experimental hall of the facility FKBN-3 [6]. The value \( K_{\text{eff}} = 0.99388 \pm 0.00005 \ (\Delta K_{\text{wall eff}} = 0.00045) \) is obtained as a result of calculations.

Further to the spherical MS model there are added models of the following FKBN-3 components (figure 3 and figure 4): a neutron source movement system (NSMS), a device for remote assembly and disassembly (DRAD), an electromechanical bench, a detector rack, a remote loading mechanism (RLM), enclosures, a traveler.
1 – detector rack; 2 – enclosures; 3 – NSMS; 4 – electromechanical bench; 5 – remote loading mechanism; 6 – DRAD

**Figure 3.** Critical bench FKBN-3 in the experimental hall

1 – detector rack; 2 – enclosures; 3 – NSMS; 4 – electromechanical bench; 5 – mechanism of remote loading; 6 – DRAD

**Figure 4.** Calculated of critical bench FKBN-3 in the experimental hall
Also specified are support models for locating MS blocks on FKBN-3 bench, i.e.: a support for LB ring, UB ring support, LB ring, UB ring, and a diaphragm. Composition, sizes and geometrical layout of complex’s components and supports for arranging MS blocks in the experimental hall are specified by certificates, design documentation (DD) and maintenance documentation. Besides, supports for locating of MS blocks are weighed and their density is determined, in order there are no differences in calculation and actual mass values. Geometry of MS calculated model with 235U(36%) core without reflector under symmetrical and asymmetrical decomposition into LB and UB, positioned on supports, are given in figure 5 and figure 6.

![Diagram](image)

**Figure 5.** Geometry of MS calculated model with 235U(36%) core without reflector under symmetrical decomposition into LB and UB, arranged on supports

Under different decompositions into LB and UB the values $\Delta K_{\text{eff}}$ will differ only in case of supplementing the calculated model by a gap between MS blocks and the diaphragm (figure 1 and figure 2; figure 5 and figure 6). The term addition of LB and UB gap means that MS blocks are pulled apart by a value, equaling the corresponding diaphragm thickness.

When adding FKBN-3 components and supports for MS blocks’ arrangement to MS $K_{\text{eff}}$ and $\Delta K_{\text{eff}}$ calculation results for MS with 235U(36%) core without reflector are presented in table 1.
– support for LB ring; 2 – support for UB ring; 3 – LB ring; 4 – UB ring; 5 – diaphragm; 6 – core made of 235U(36%) without reflector

**Figure 6.** Geometry of MS calculated model with 235U(36%) core without reflector under asymmetrical decomposition into LB and UB, positioned on supports

**Table 1.** $K_{\text{eff}}$ and $\Delta K_{\text{eff}}$ calculation results for MS with 235U(36%) core without reflector when adding FKBN-3 components and supports for MS blocks’ arrangement to MS

| Addition of a component of FKBN-3 or supports for placing MS blocks | $K_{\text{eff}}$ | $\Delta K_{\text{eff}}$ |
|---|---|---|
| NSMS | 0.99357 | 0.00014 |
| DRAD | 0.99354 | 0.00011 |
| Detector rack | 0.99354 | 0.00011 |
| Electromechanical bench | 0.99356 | 0.00013 |
| Bridge crane | 0.99346 | 0.00003 |
| Enclosures | 0.99351 | 0.00008 |
| RLM | 0.99362 | 0.00019 |
| Steel support for LB ring | 0.99448 | 0.00105 |
| Steel support for UB ring | 0.99424 | 0.00081 |
| LB steel ring | 0.99406 | 0.00063 |
| UB steel ring | 0.99496 | 0.00153 |
| Gap between LB and UB under symmetrical decomposition | 0.9788 | -0.01463 |
| Gap between LB and UB under asymmetrical decomposition | 0.98205 | -0.01138 |
| Steel diaphragm, used under symmetrical decomposition | 0.98132 | 0.00252 |
| Steel diaphragm, used under asymmetrical decomposition | 0.98417 | 0.00212 |
With the aid of the given calculations for the first time there is estimated the $K_{\text{eff}}$ effect of FKBN-3 components and supports for positioning MS blocks on the bench FKBN-3 for MS with $^{235}\text{U}$ (36%) core without reflector.

Table 1 shows that the greatest contribution to $K_{\text{eff}}$ is made by support constituents meant for positioning of MS blocks on the bench FKBN-3 (LB ring support, UB ring support, LB ring, UB ring and a diaphragm). Values $\Delta K_{\text{eff i}}$ obtained with walls, the floor, the ceiling and parts of complex FKBN-3 (NSMS, DRAD, a detector rack, an electromechanical bench, a bridge crane, RLM and enclosures) are by times lower than values $\Delta K_{\text{eff i}}$ with support constituents. That is why components of complex FKBN-3 can be modeled approximately, as it is implemented in the presented calculated model (figure 4), and it is reasonable to jointly calculate values $\Delta K_{\text{eff i}}$ with walls, the floor, the ceiling and FKBN-3 components, by group, in order not to overrate the resultant absolute calculation error. One should model maximally in detail supports for LB and UB rings, LB and UB rings and the diaphragm, then verifying calculated data, since support constituents’ effect on MS $K_{\text{eff}}$ turns out to be rather significant.

### 3. Verification of a calculated models

Calculated models of MS support constituents are verified by comparison of calculation and experimental values of reactivity disturbance $\Delta \rho_i$ of MS support constituents. Design values $\Delta K_{\text{eff i}}$ from table 1 $\Delta \rho_i$ are calculated by formula:

$$\Delta \rho_i = \Delta K_{\text{eff i}} / \beta_{\text{eff}} \quad (2)$$

where $\beta_{\text{eff}}$ – efficient fraction of delayed neutrons of MS model with core made of $^{235}\text{U}(36\%)$, obtained by calculations [4], $\beta_{\text{eff}} = 0,0083$.

Results of calculation and experimental data of reactivity disturbances of base MS with $^{235}\text{U}(36\%)$ core without reflector are given in table 2.

### Table 2. Results of calculation and experimental data of reactivity disturbances of base MS with $^{235}\text{U}(36\%)$ core without reflector

| Method of base MS reactivity disturbance | Symmetrical MS | Asymmetrical MS |
|------------------------------------------|----------------|-----------------|
|                                         | Calculation   | Exper.          | Calculation | Exper.          |
| Joint addition of walls, floor and ceiling of the experimental hall, NSMS, DRAD, detector rack, electromechanical bench, bridge crane and enclosures | 0,14±0,01 | - | 0,14±0,01 | - |
| Addition of LB ring steel support | 0,15±0,01 | 0,12±0,02 | 0,15±0,01 | 0,12±0,02 |
| Addition of UB ring steel support | 0,12±0,01 | - | 0,12±0,01 | - |
| Addition of steel rings | 0,30±0,01 | 0,18±0,03 | 0,30±0,01 | 0,18±0,03 |
| Reactivity disturbances versus the LB and UB gap value | -0,43±0,01 | -0,50±0,01 | -0,34±0,01 | -0,40±0,01 |
| Addition of steel diaphragm | 0,29±0,01 | 0,22±0,02 | 0,25±0,01 | 0,21±0,02 |
Basing on data presented in table 2, when performing experiment one should not neglect measuring the reactivity disturbance by UB ring support, as it has been performed earlier, since it contributes significantly to reactivity disturbance. One can see the highest divergence of calculation and experiment results for rings. In order to approach the best agreement between calculation and experiments, further the calculated model will be verified basing on experimental data, obtained with other MS.

4. Conclusion
As a result of work the calculated model of FKBN-3 critical bench in the experimental hall is developed. With the aid of this model by calculations on the example of $^{235}$U(36%) critical system without reflector for the first time there is evaluated the $K_{eff}$ effect of separate components of FKBN-3, supports designed to arrange MS blocks on FKBN-3 bench, as well as walls, floor and ceiling of the experimental hall. On the whole one can observe agreement between experimental and calculation values of MS reactivity disturbances by support constituents. Further FKBN-3 calculated model will be upgraded taking into account new experimental data for other MS.

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