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Prolongation of the Terms for Irradiation of Assemblies with SS in a Reactor of the VVER-1000 (B-320) Type

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Abstract. The safe and reliable operation of a VVER-1000 type power unit is entirely determined by numerous engineering-technical, technological and other factors and requirements. The essential role in this number is a predicted change in the physical-mechanical properties of the high-responsibility components of the reactor installation. One of the most important components of the nuclear power plant is the RPV (reactor pressure vessel), the destruction of which or even its partial production is incompatible with the normal operation of the entire plant. In order to control the change in the mechanical properties of the materials of the reactor pressure vessel, a program for monitoring the RPV by means of surveillance specimens (SS) has been developed and implemented. It is world practice, after the design operational resource of a VVER-1000 power unit has expired, to carry out a detailed analysis of the condition of the main facilities of the equipment. If the results of the analysis confirm the possibility of over-design operation, a program for LTO (Long-Term Operation) is drawn up, through which the LTO process is ensured. The main emphasis of this program is a set of organizational and technical measures to ensure the necessary SS for testing and examining the condition of the irradiated material from the RV. One approach is to extend the shelf life of some SS, considering the possibility of placing them in modernized SS assemblies of a new type. The implementation of this process is preceded by numerous preliminary calculations and analyses, some of which are the subject of the present material.

Keywords: reactor pressure vessel, surveillance specimens

1 Introduction

The safe and reliable operation of a VVER-1000 type power unit is entirely determined by numerous engineering-technical, technological and other factors and requirements. An essential role in this number is the prediction of changes in the physical-mechanical properties of the high-responsibility components of the reactor installation. One of the most important components of the nuclear power plant is the RPV, the destruction of which or even its partial damage is incompatible with the normal operation of the entire plant. In order to control the change in the mechanical properties of the materials of the RPV, a program for monitoring the RPV by means of surveillance specimens (SS) has been developed and implemented [1]. It is world practice, after the design operational resource of a VVER-1000 power unit has expired, to carry out a detailed analysis of the condition of the main facilities of the equipment. If the results of the analysis confirm the possibility of over-design operation, a program for LTO (Long-Term Operation) is drawn up, through which the LTO process is ensured. The main emphasis of this program is a set of organizational and technical measures to ensure the necessary SS for testing and examining the condition of the irradiated material from the RPV.

One approach is to extend the life of certain SS, considering the possibility of placing them in modernized assemblies of a new type. The implementation of this process is preceded by numerous preliminary calculations and analyses, some of which are the subject of the present material.

The purpose of the monitoring program with SS is to track the change in the properties of the materials from which the RPV is produced as a result of neutron-radiation irradiation and temperature effects during operation. In practice, periodic testing and research of SS of different types is carried out according to established methodology, and the results of this research allow to follow the change in the properties of the materials from which the RPV was produced over time. The obtained results of the research of the materials are compared with the permissible normative dependencies for radiation and temperature embrittlement of RPV from VVER-1000.

The advantage of SS assemblies is that they are subjected to neutron radiation irradiation with a certain advance factor compared to RPV. Assemblies with SS are placed inside the RPV close to the reactor core (RC), so at a certain moment the SS “receives” radiation, which the RPV is about to receive, but after a few more fuel campaign. Thus, the research and testing of the SS basically shows the upcoming state of the RPV materials for a future period.

The main parameter used as criteria for the SS and RPV irradiation values is the neutron fluence. In order to predict the properties of the RPV, it is necessary to have clarity about the values of the accumulated neutron fluence in the SS and the RPV until the moment of operation when the SS assemblies are dismantled from the RPV. The dismantling of assemblies with SS

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from RPV is planned in advance after analyzing the values of the accumulated fluence in SS and RPV, as well as considering the maximum permissible design values of fluence in RPV.

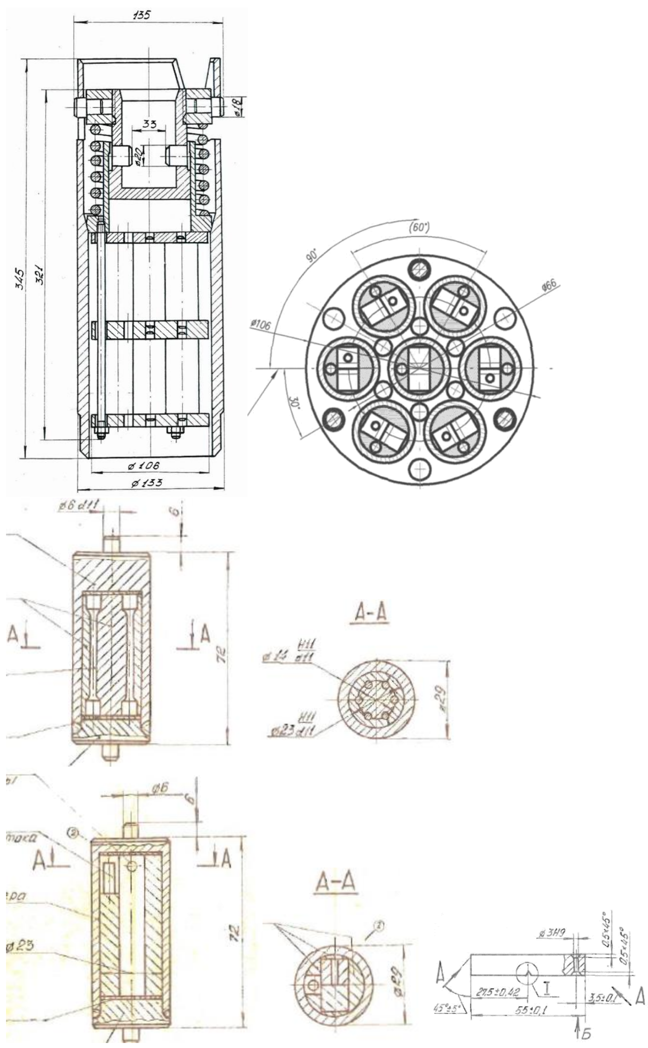
In order to determine the time of exposure (irradiation) of SS in RPV, it is important to have information about the parameters of the RC for the estimated energy campaign. Neutron fluence values for a forecast campaign are extrapolated for a future period of, for example, 5, 10, 15 and more fuel campaigns, are compared with the forecast of accumulated neutron fluence in RPV for a certain period of operation, and only then is the time for dismantling (removal) determined on the SS. It becomes clear that the activities for determining the deadlines for defending the SS in the RPV of the VVER-1000 type are predictive and preliminary. However, it is important to determine the terms in advance, and in the process of operation it is possible to refine and determine the exact required term of standing.

2 Main Objective

Justification of the possibility of extending the period of irradiation of SS from different types of assemblies for reactors of the VVER-1000 type, grouping them into four numbers of modernized assemblies, which will be irradiated in accordance with the determined terms of the LTO.

In order to fulfill the main objective described in this way, it is necessary to use the criterion value of the accumulated neutron fluence for the evaluation and selection of the necessary SS. Extension of the SS irradiation period can be performed only for those SS that have not reached values for accumulated neutron fluence above the maximum permissible values provided for the specific RPV, in the specific threatened areas.

The task boils down to the precise determination of different types of SS from an existing pre-prepared list that will be subjected to an extended period of irradiation together with RPV for the specified period of LTO. By the time the SS assemblies were dismantled from the internals (baffle), 21 fueling campaigns had passed, and from the moment of reloading the SS in a modernized assembly at the RPV internals, another 26 fueling campaigns must pass to cover the LTO period. In addition to the determination of the specific SS, for the extended period of irradiation, the task also includes the determination of specific positions in the internals for the placement of these SS. The positions for the SS assemblies are characterized by many different possible values of the distance from RC in the radial and axial directions for the different types of SS assemblies.



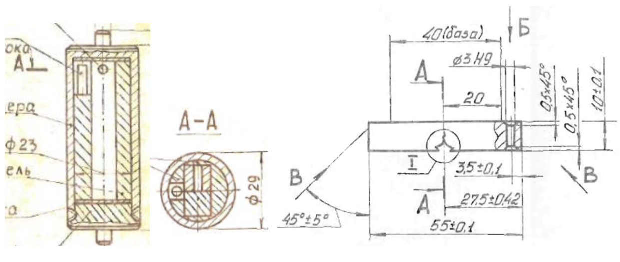


Figure 1. View of design on standard type of assemblies with SS.

3 Types of Assemblies with SS for Reactors of VVER-1000 Type [2]

The existing types of SS assemblies mainly have some structural, technological and quality differences. These differences predetermine the choice of one or another option as well as the need to use modernized assembly options.

3.1 Standard assemblies with SS placed in the sockets provided for the purpose

In Figure 1 we can view design on Standard type of assemblies with SS and in Figure 2 – positions for irradiation of assemblies with SS in RPV.

3.2 Modernized assemblies with witness samples assembled in flat containers and placed in standard irradiation sockets [3]

In Figure 3 we can view design on modernization type of assemblies with SS.

4 Evaluation of the Degree of Irradiation (Accumulated Neutron Fluence) for the Different Types of Assemblies

To predict the extended SS irradiation period in modernized assemblies, it is necessary to have available information on:

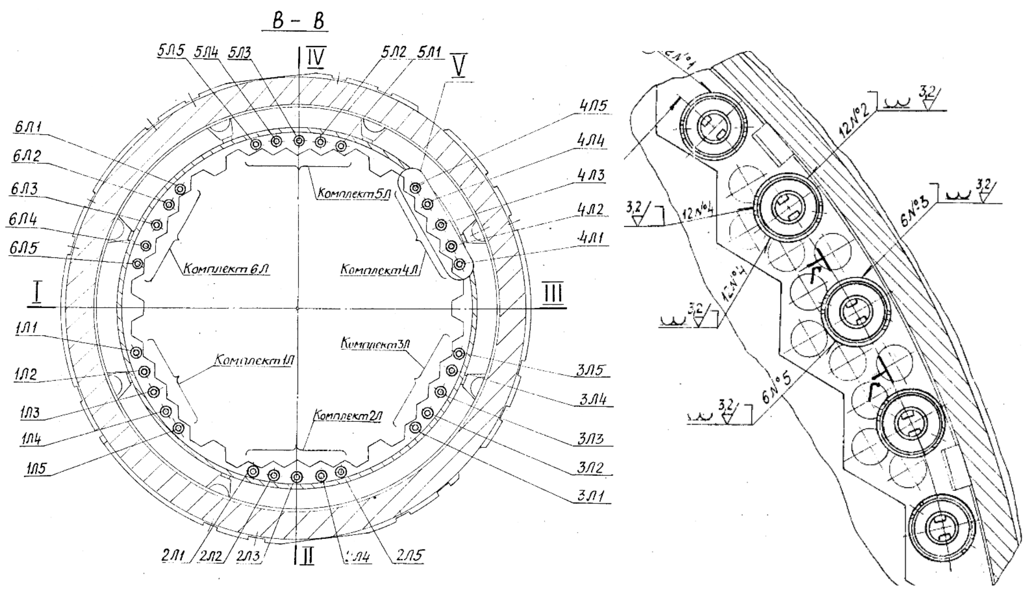


Figure 2. Positions for irradiation of assemblies with SS in RPV.

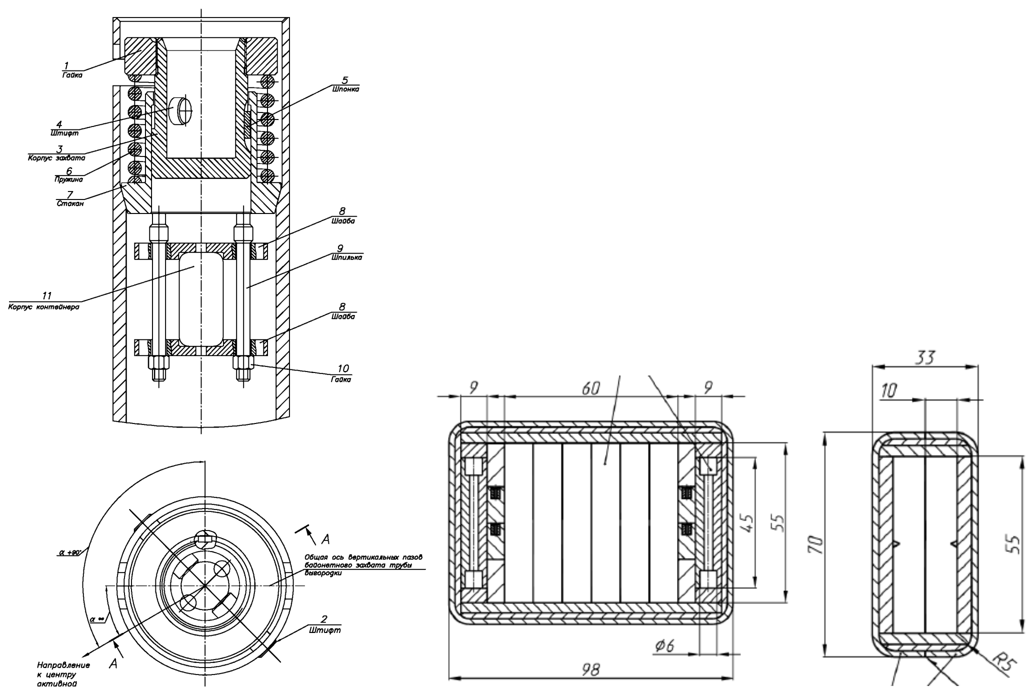


Figure 3. View of design a Modernized assembly with a flat SS container.

- the accumulated neutron fluence in the SS from the considered assembly to the moment of disassembly from the internals (21 fuel campaigns);
- detailed information on structural dimensions of the modernized assembly (Figure 3), in which we have planned to continue the irradiation of the SS through LTO;
- previously calculated estimated values of neutron fluence in SS for the extended period of operation (Table 1). In the case under consideration, this period equals 26 fuel campaigns [4]. These values differ significantly for the different positions of the assemblies in the internals. In the values presented in the table, an uncertainty of ±15% from the calculations is also provided [5].

Usually, the degree of exposure to SS from different types of assemblies varies within extremely wide limits. For the purposes of the given task, we will consider irradiated SS in a standard beam assembly (Figure 1). The accumulated neutron fluence reached by the moment of dismantling from the internals is represented by relative fluence values in %. This is a ratio between the neutron fluence reached at a given moment of operation in a specific material (point of RPV or SS) and the maximum permissible values of the neutron fluence in RPV. The graphs be-

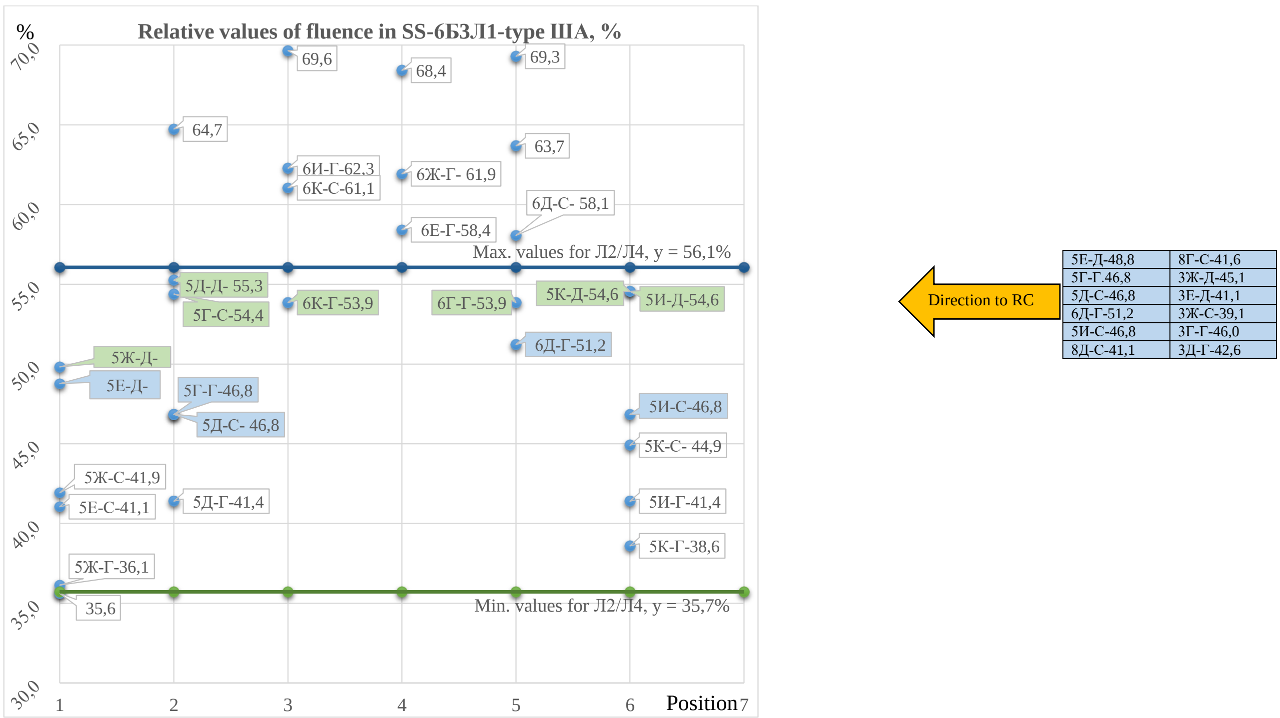


Figure 4. Flux values for SS type Ш, base metal-A. Modernized assembly for sockets L2/L4.

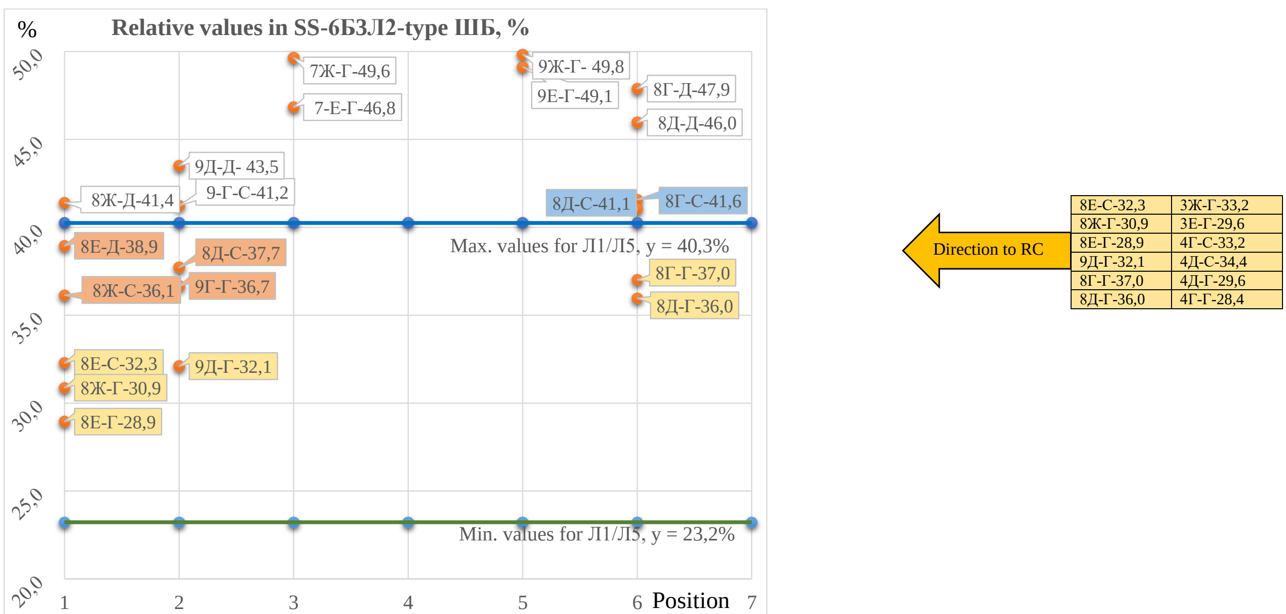


Figure 5. Flux values for SS type Ш, welding seam-Б. Modernized assembly for sockets L1/L5.

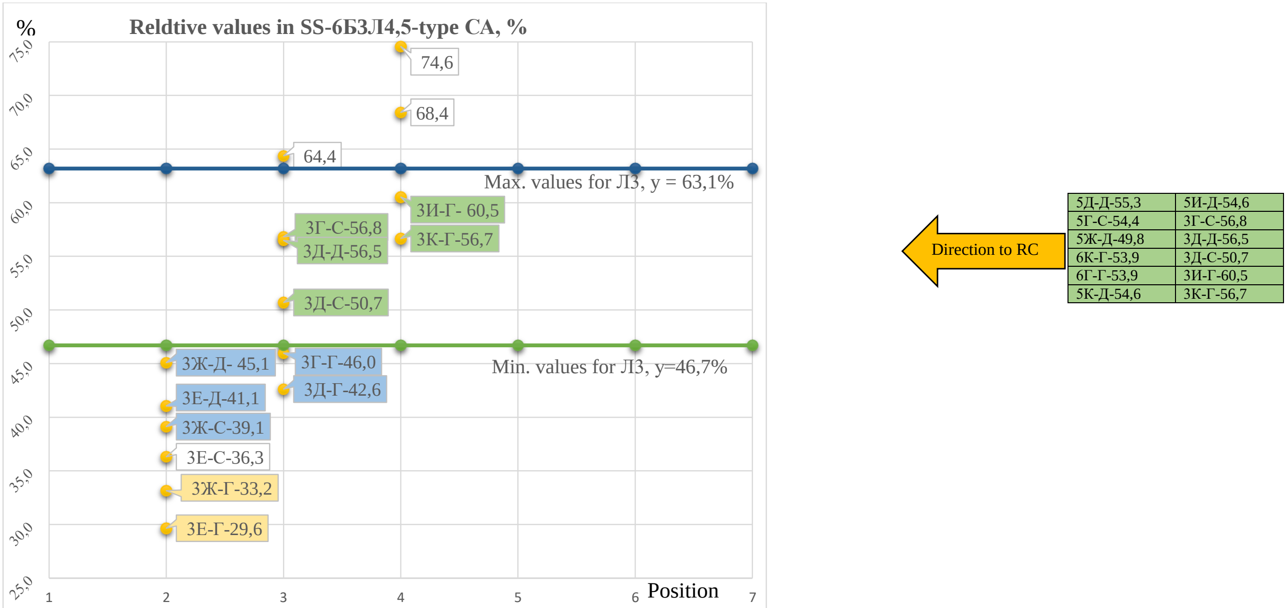


Figure 6. Flux values for SS type C, base metal-A. Upgraded assembly for socket L3.

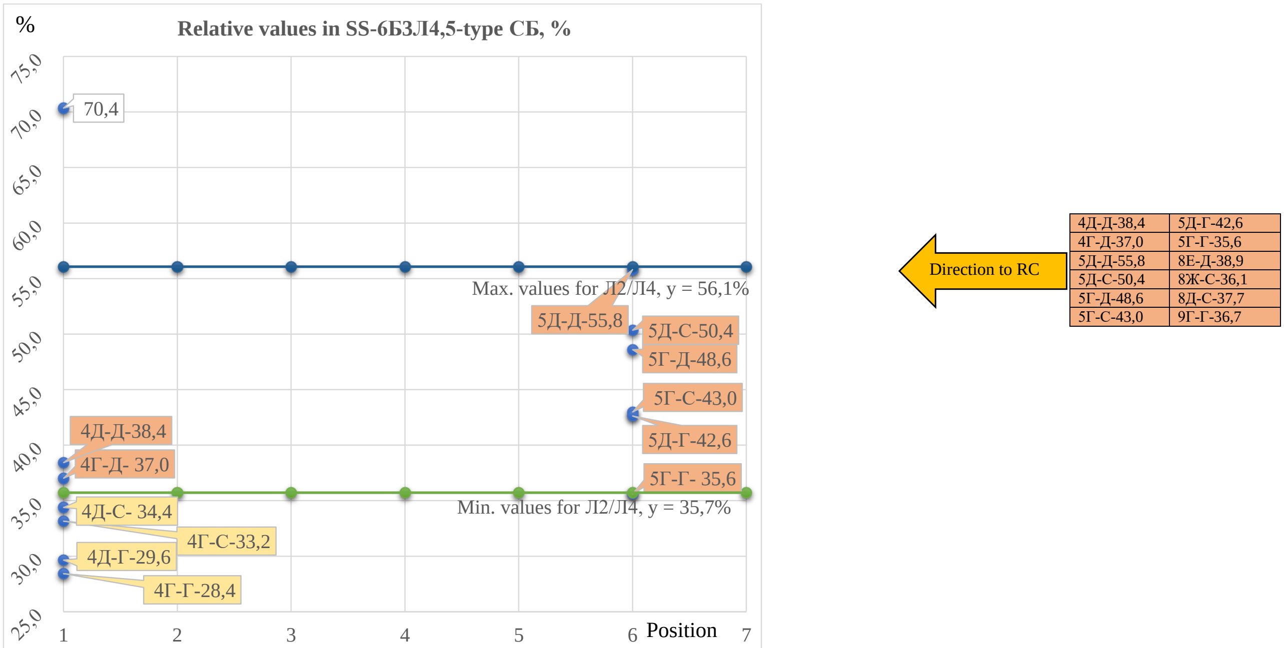


Figure 7. Flux values for SS type C, weld seam-Б. Modernized assembly for sockets L2/L4.

low (Figures 4, 5, 6, 7) show exemplary relative SS fluence values (calculated for 21 fuel campaigns) intended to be placed in retrofitted assemblies subsequently for extended irradiation in the RPV of the VVER-1000 type for the LTO period.

Table 1. Relative values of fluence in internals positions for a modernized assembly corresponding to 26 fuel campaigns

	Position in internals		
Relative values of fluence, %	Л1/Л5	Л2/Л4	Л3
Maximum	40.3	56.1	63.1
Minimal	23.2	35.7	46.7
Average	31.7	45.9	55.0

5 Conclusions

The thus determined groups of 12 SS for the planned four modernized assemblies meet the requirements that they can be irradiated throughout the LTO period and that the deviation of the neutron fluence values of each SS from the average ones for the group is no more than ±15%. For the entire period of LTO, it is expected that the SS from the modernized assemblies will reach an accumulated neutron fluence no more than the maximum permissible fluence in the RPV. In this way, the task of justifying the possibility of extending the period of irradiation of SS from already dismantled assemblies for reactors of the VVER-1000 type and grouping them into four numbers of modernized assemblies for re-irradiation in RPV for the period of LTO has been fulfilled.

Grouping requirements (neutron fluence values) determine the need for OS of different types of material and intended for different types of tests to be placed together in a specific modernized assembly. This means that at the time of their dismantling by the internals of the RPV for the purpose of testing and research, SS from all four numbers of modernized assemblies must be used to form a test series of a specific material and a specific test.

It is noticed that with an increase in the values of the neutron fluence, the process for selecting the SS for a test series becomes more complicated and it becomes impossible at particularly high values. The execution of the task will not be possible with less than five builds of SS available. The differences in the values of the accumulated neutron fluence in SS from standard assemblies are too significant.

References

[1] Long-term operation program for researching the condition of the metal of the reactor housings of units 5 and 6 of the Kozloduy NPP EAD, using SS for a period of 60 years of operation. №30.PP.00.RP.046

[2] Surveillance specimens. Technical description and operating instructions. 1152.75.00.000 TO

[3] Requirements for substantiating the possibility of extending the design life of equipment used in nuclear installations.

[4] Calculation-experimental determination of the neutron fluence in SS from assemblies 3L1-5 of unit 6 of the Kozloduy NPP, Contract No. 282000009/07/09/2018

[5] Methodology for determining resistance to destruction based on SS test results for calculating the strength and resource of reactor pressure vessel of the VVER-1000 type.