NSC KIPT	ES Group LLC	STC, JSC “NNEGC “Energoatom”	Atomenergomash, JSC “NNEGC“Energoatom”	STC “E.O. Paton EWI”

APPROACHES TO SUPPLY UKRAINIAN NPPs WITH CORE COMPONENTS

Valeriy Zuyok[1] , *Oleksandr Mazurok*[2] , Oleg Zelenyy[3] , Sergiy Lavrov[4] , Oleg Godun[3] , Anton Makarenko[5]

[1]National Science Center “Kharkov Institute of Physics and Technology”, Ukraine, Kharkiv
[2]ES Group LLC, Ukraine, Kyiv
[3]Scientific and Technical Center, JSC “NNEGC "Energoatom”, Ukraine, Kyiv
[4]Atomenergomash, JSC “NNEGC “Energoatom”, Ukraine, Kyiv,
[5]Scientific and Technical Complex "E.O. Paton Electric Welding Institute", Ukraine, Kyiv

1st International Conference on LWR Fuel Performance, Modelling and Experimental Support
September 14-19, 2025, Nessebar, Bulgaria

Need of Ukrainian NPPs for core components from an alternative manufacturer

ENERGY SAFETY GROUP

Ukraine operates **15 power units** with soviet-designed VVER reactors:

- 2 power units with VVER-440 reactors,
- 13 power units with VVER-1000 reactors,

located at four operating NPPs (6 power units on ZNPP are occupied by russia now). The total installed capacity of the operating power units is 13,835 MW.

Ukranian nuclear operator Energoatom has completely abandoned russian fuel and is implementing a **diversification program**. But besides the fuel in the core, there are other components that require diversification, since they are produced only in russia: rod cluster control assemblies (RCCA) for reactor VVER-1000, the absorber extension assemblies and the shielding assemblies for reactor VVER-440.

Therefore, Ukraine faced an acute issue and Energoatom chose the path of **independent production of these components**, for which it developed its own design.

Diversification strategy for core components

VVER-1000

Fuel. Replacement with Westinghouse assemblies and preparation for production at the Energoatom plant.

RCCA. Since the lifetime was ending, a decision was to extend lifetime for several years and gain time for licensing and organizing our own Energoatom production in Ukraine. The new assemblies were licensed and put into pilot operation in 2024.

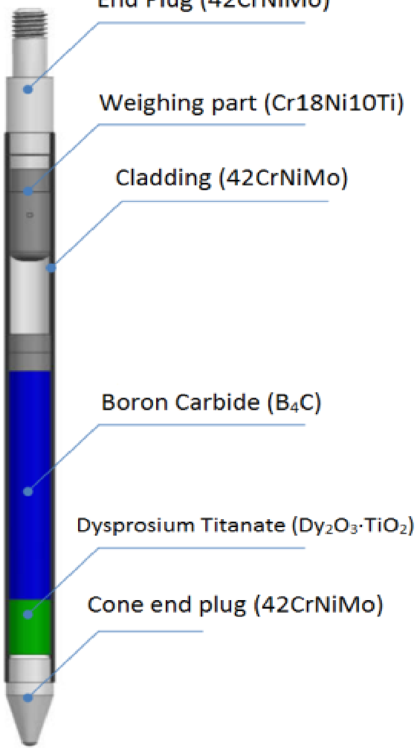
VVER-440

Fuel. Replacement to Westinghouse fuel assemblies.

Absorber extension assembly. Lifetime has already been extended to the maximum and a gradual replacement with new ones is required. Energoatom has started production of its own design at its plant. The implementation SAR has been approved. Pilot operation will begin in 2026.

Shielding assemblies. Lifetime of the assemblies cannot be extended, only replaced with new ones. Energoatom has started production of its own design at its plant. The implementation SAR has been approved. Pilot operation will begin in 2027.

VVER-1000 RCCA and control rod design



RCCAs perform protective and control functions and are designed to quickly stop a nuclear reaction, maintain reactor power at the required level, transfer power from one level to another, and smoothing the energy release field by core height.

Structural materials:

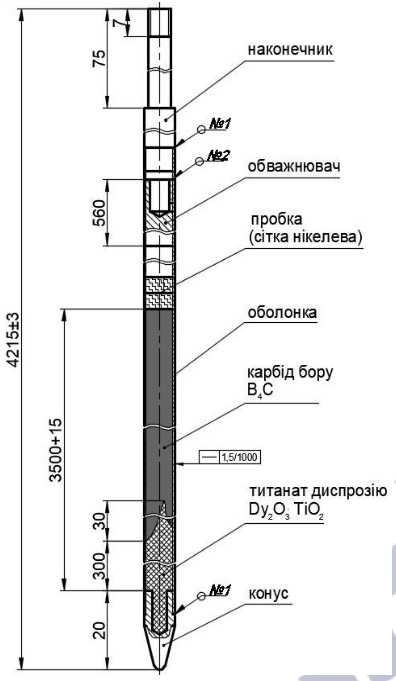
- chromium-nickel alloy (42CrNiMo);
- stainless steel (Cr18Ni10Ti).

Neutron-absorbing materials:

- titanium dysprosium ($Dy_2 . O_3 . TiO_2$);
- boron carbide ($B_4 C$).

Comparison of the original and Ukrainian absorber rods

The external geometry, overall and connection dimensions, including the functional parameters of absorber rods and RCCA, as well as the original ones, are comparable.

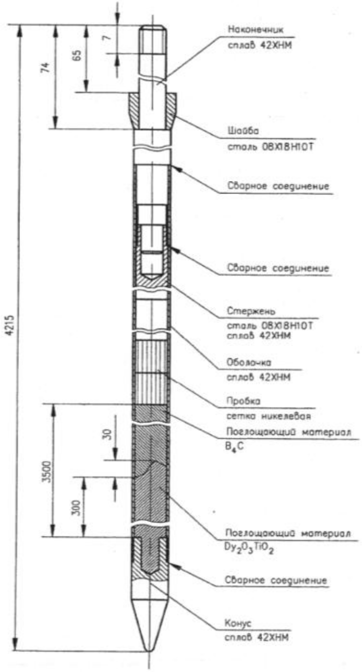


(Ukraine)

The structural and neutron-absorbing materials in both designs are similar.

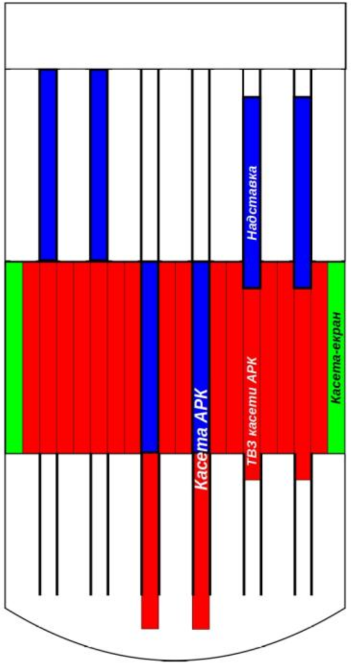
The mass, chemical and phase composition, and filling density of absorber rods cladding with neutron-absorbing materials are comparable.

Only materials whose manufacturing technology has been developed and mastered at Ukrainian enterprises are used in the manufacturing process.



(Original)

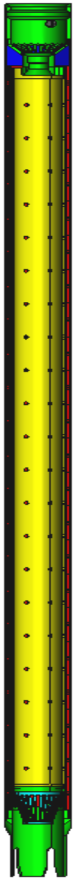
VVER-440 absorber extension assemblies design

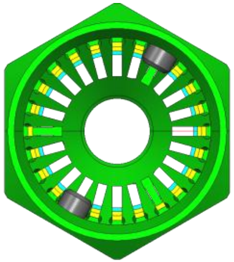


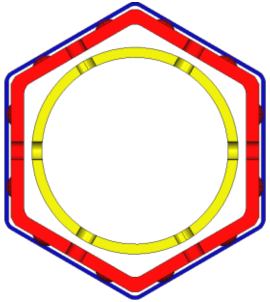
Regulating fuel assemblies consist of a fuel part and an absorber extension part. The absorber part is a working body that affects the reactivity of the reactor control and protection system.

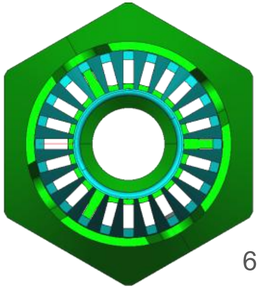
The main structural material is chromium-nickel stainless steel. The insert material is stainless steel with a boron additive of 1.6-2.0%.

The impact on the reactivity of the absorber extension is comparable to the impact of the original absorber extension.

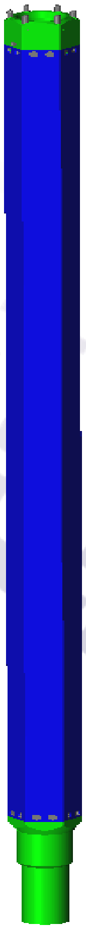






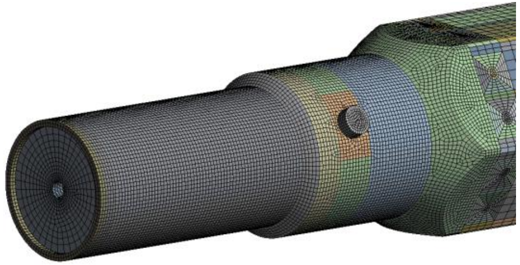


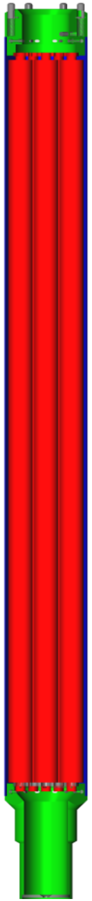
VVER-440 shielding assemblies design

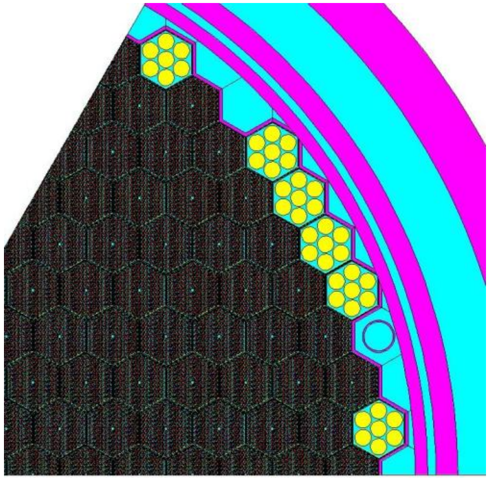


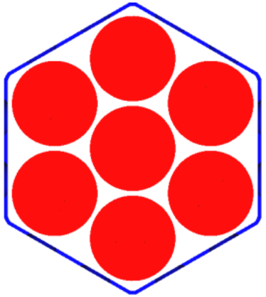
Shielding assemblies is part of the reactor core that reduce neutron flux and the induced activity of the RPV itself, thereby enhancing safety and the operational lifespan of the reactor components. Shielding assemblies is located within the core’s 36 peripheral cells.

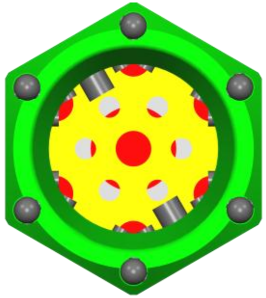
The main structural material is chromium-nickel stainless steel. The effect on reducing the neutron flux to the reactor pressure vessel and redistributing the coolant flow is comparable to original assembly.











Licensing

Licensing of new core elements required the development of preliminary safety analysis reports for pilot operation with various types of **calculations and assessments** performed:

- Mechanical, strength (static strength, vibration resistance, cyclic strength, etc.) and seismic calculations;
- Strength calculations for welded joints;
- Thermal-hydraulic calculations;
- Neutron-physical calculations;
- Assessment of the impact on the plant safety level (probabilistic calculations etc).

The same scope of justification was performed for lifetime extension of RCCA which are operated at NPPs. **This will be briefly shown in the following slides**.

Its was done **with scientific and technical support by ES Group, Kharkiv Institute of Physics and Technology and Paton Welding Institute.** All developed calculations and assessments was agreed by the Ukrainian Regulator Body.

Lifetime extension of RCCAs

ENERGY SAFETY GROUP

The total lifetime of standard RCCAs is 10 years, comprising 3 years in automatic control mode and 7 years in emergency protection mode. Lifetime of some RCCAs at Ukrainian NPPs ended in 2024.

One way to temporarily cover the needs of NPPs for RCCAs is to extend the lifetime of those RCCAs that are already in operation. This allowed additional time for development, justification, and implementation of RCCAs produced in Ukraine.

Lifetime extention is based on **determination and justification of the criteria** for maintaining the integrity of RCCA structural elements and the protective cladding of absorbing rods (taking into account changes in the characteristics of their structural materials over the previous operational period in the reactor core); thermal characteristics of the absorbing rods; compliance with the design criteria for the control rod effectiveness in the reactor; and determination of the remaining lifetime of RCCAs already in operation at Ukrainian NPPs.

Phenomena that could potentially lifetime limit

Given the RCCA operating conditions in the reactor core during at-power operation, the parameters that characterize their technical condition can be divided into **3 categories**: 1) those that **depend on the operating time**: corrosion of 42CrNiMo chromium-nickel alloy (rods cladding and end elements) and corrosion of the Cr18Ni10Ti alloy (crossbar, nut, spring); 2) **on fast neutron fluence:** the mechanical characteristics of structural materials, and 3) **on thermal neutron fluence:** change in the absorber's isotopic composition, change in neutron absorption efficiency, and boron carbide swelling (B_4C).

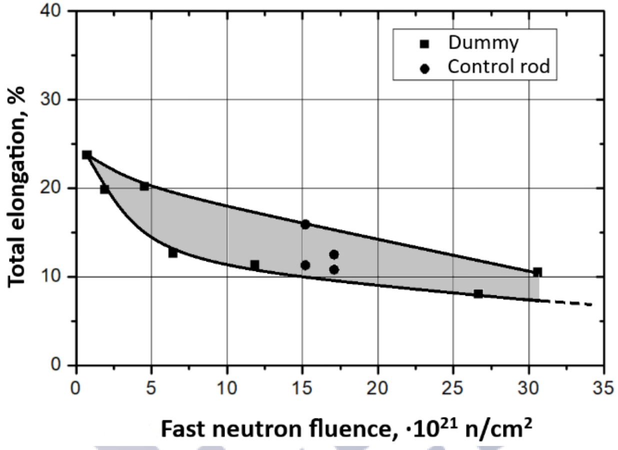
Phenomena that could potentially bring structural elements closer to their limit state or limit the rods and RCCAs lifetime in general include:

- material compatibility (42CrNiMo, B_4C, Dy_2O_3 TiO_2);
- corrosion resistance of structural materials (reduction in the rods cladding wall thickness);
- radiation resistance of structural materials (42CrNiMo, Cr18Ni10Ti);
- radiation resistance of neutron-absorbing materials (B_4C, $Dy_2O_3 \cdot TiO_2$);
- degradation of the elastic characteristics of the rods spring;
- decrease in neutron absorption efficiency.

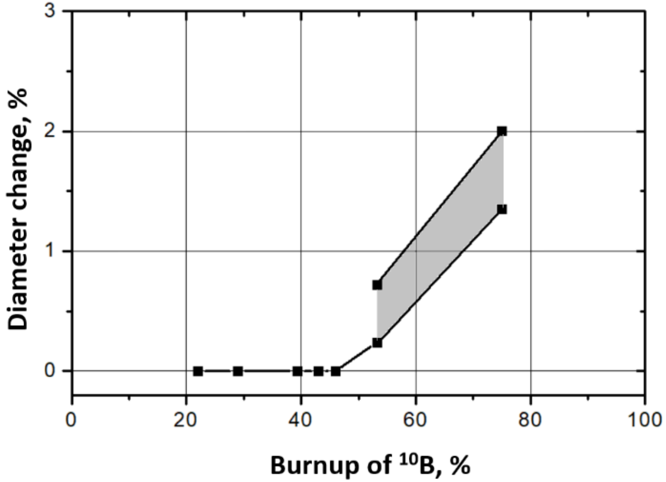
Potentially dangerous phenomena

This analysis [*] identified two main factors that could lead to a loss of integrity of the absorbing rods protective cladding under the loads experienced by the RCCAs during operation:

- **reduction in the plasticity of the absorbing rods cladding material (42CrNiMo) due to neutron irradiation;**
- **mechanical contact between the absorbing rods cladding and the neutron-absorbing column when the ^{10}B isotope burns out by more than 45-50%.**



Generalized data on dependence of the total elongation of the absorbing rods cladding material made of 42XHM alloy on neutron fluence



Generalized data on change in the maximum diameter of absorbing rods cladding from the maximum burnup depth of ^{10}B isotope

* V. Zuyok, O. Mazurok, O. Godun, M. Chaikovskyi, M. Tretyakov. Material Science Analysis of RCCA Structural Materials and Calculations for Lifetime Extension. Nuclear and Radiation Safety, vol. 101 (1), 2024, p. 38-48. https://doi.org/10.32918/nrs.2024.1(101).04

Justified criteria for the RCCA operability

ENERGY SAFETY GROUP

Based on the results of RCCA absorbing rods post-reactor studies, as well as calculations of static, cyclic, vibration, and seismic strength and a set of neutron calculations, the following limit values [*] have been established, which can be used as criteria for absorbing rods performance:

- **maximum fluence of fast neutrons** in the lower, most loaded part of the absorbing rods cladding (in the area of the weld of the end plug and the absorbing rods cladding) should **not exceed $3.4 \cdot 10^{22}$ n/cm^2** ;
- **maximum burnup** of the 10B isotope shall **not exceed 45%.**

When these two criteria are met, the probability of other phenomena occurring that could affect the integrity of the absorbing rods or RCCA structural elements is low.

Strength calculations have shown that the material has sufficient mechanical characteristics to ensure the integrity of the absorbing rods shell and RCCA structural elements.

Neutron-physical calculations have shown that neutron-absorbing materials are sufficiently effective to meet the physical efficiency criteria for the RCCA.

The RCCA absorbing rods with a "burned-up" absorber (by 45% for ^{10}B) will be reliably cooled in the conditions of the VVER-1000 core.

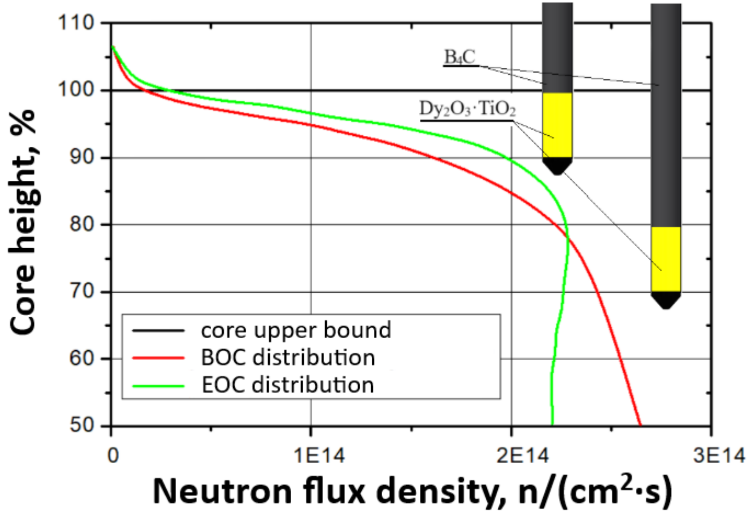
* Valeriy Zuyok, Oleksandr Mazurok, Oleg Godun, Mykola Chaikovskyi, Anton Makarenko, Vadym Ivanov, Valodymyr Zigunov, Mykhaylo Tretyakov. Justification of RCCAs lifetime extension at operating Ukrainian NPPs. Summary calculations. Nuclear Engineering and Design. Volume 437, June 2025, 114008. https://doi.org/10.1016/j.nucengdes.2025.114008

Evaluation of the residual lifetime of the operating RCCAs

In the presence of justified criteria for the RCCA operational capability, a justification for extending their lifetime was carried out by determining their residual lifetime. For this purpose, an approach was employed that takes into account the RCCA actual position during all fuel campaigns in which they were operated.

Excessive conservatism was assumed based on the assumption that the **immersion** of the 10th working group in the core during all fuel campaigns is 70%, while the actual position is 85-90%.

The higher position of the lower part of the absorbing rods results in a decrease in the fast neutron flux density on the lower, most loaded part of the absorbing rods cladding and a decrease in the burnup rate of ^{10}B.



Axial distribution of fast neutron flux density over the core height

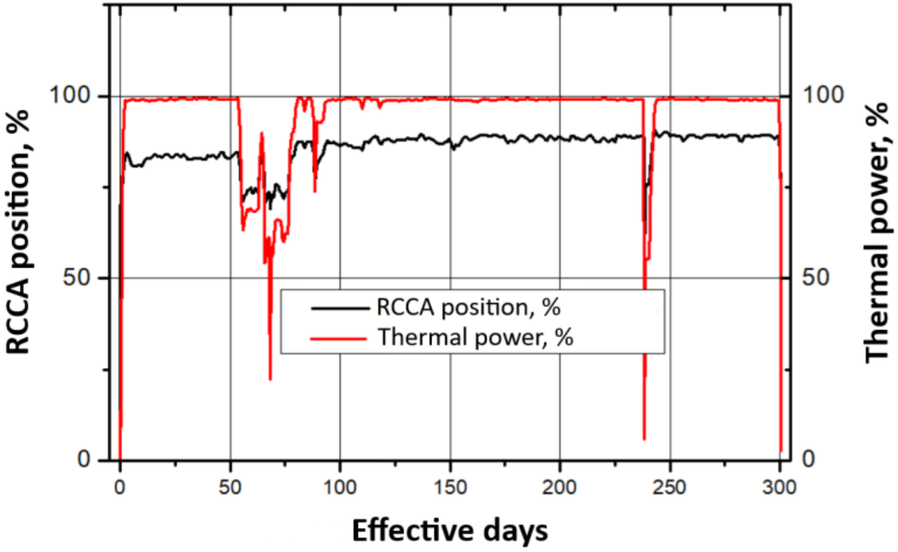
Evaluation of the residual lifetime of the operating RCCAs

The methodology and criteria for operational integrity were applied to extend the RCCA lifetime already in operation at Ukrainian NPPs.

The justification for extending the lifetime of RCCAs was carried out by detailed modeling of the individual history of each RCCA using available operational data.

During the research, operational data (location of RCCAs and power unit capacity) for each of the 61 RCCAs at all power units over the last 10 years **were processed and systematized**.

For each RCCA, the **maximum fast neutron flux and burnup of ^{10}B were calculated**, and the margin before reaching the limit values was determined.



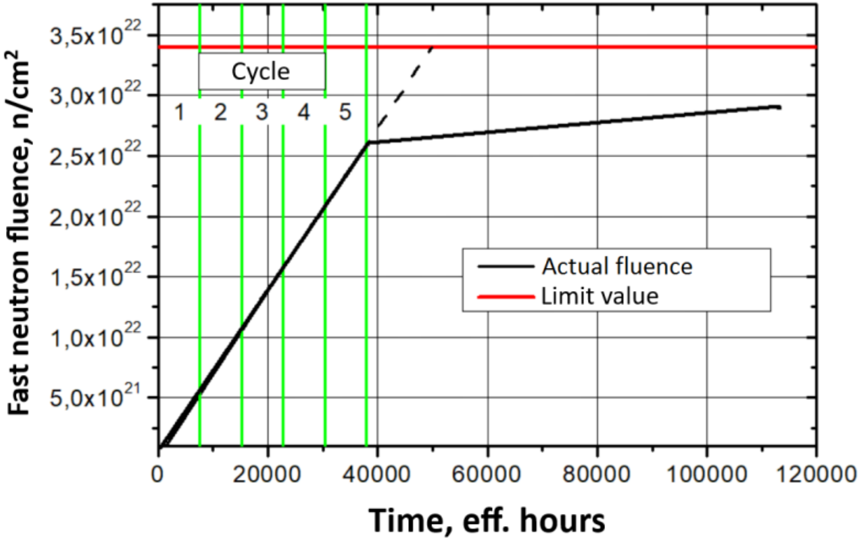
Graphic diagram of changes in the RCCA position and thermal power during one fuel cycle

Evaluation of the residual lifetime of the operating RCCAs

ENERGY SAFETY GROUP

Based on the initial data of neutron flux distribution over the core height and the position of the RCCA in it, one can determine that the increase in **fast neutron fluence** for one fuel cycle with RCCA operation in control group **will be ~ $5.2 \cdot 10^{21}$ n/cm^2**.

Based on the assumption that the maximum fast neutron fluence in the lower part of the fuel cladding should **not exceed $3.4 \cdot 10^{22}$ n/cm^2**, the lifetime of the RCCAs can be more than 6 years in the control group under the initial operating conditions (80-90% immersion depth). Or 5 years in the control group and further operation in the scram groups, which is characterized by a lower neutron flux.



Calculated data on changes in fast neutron fluence in the lower part of the control rod cladding over the period of operation in the VVER-1000 core

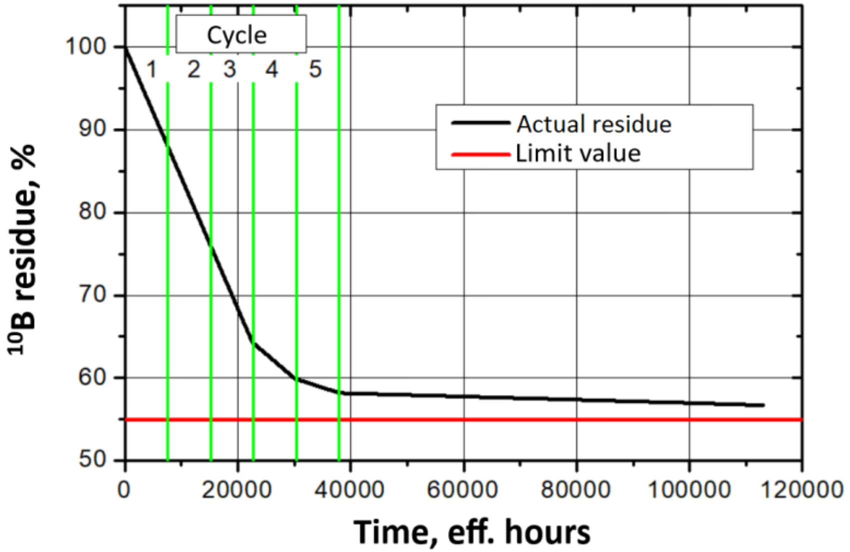
Evaluation of the residual lifetime of the operating RCCAs

ENERGY SAFETY GROUP

There is a criterion for the **maximum burnup** of the only neutron-absorbing isotope ^{10}B in B_4C in order to reduce the absorbing effect on the RCCA rod cladding and to retain the required neutron absorption efficiency. The maximum ^{10}B isotope burnup **should not exceed 45% (55% residue).**

Operation of the RCCAs in the control group for 3 design years, with the actual core height position, results in a ^{10}B burnup of 37.6% (62.4% residue). Such a low ^{10}B burnup rate extends RCCA lifetime for another 2 years in the control group, which will result in a 42% burnup of ^{10}B (58% residue).

The residual ^{10}B content provides for further operation of the RCCAs also in the scram groups, which are characterized by a much lower ^{10}B burnup rate.



Calculated data on changes in ^{10}B isotope content over the period of operation in the VVER-1000 core

Lifetime extension result

The results of the work performed allowed for an extension of the lifetime of nearly all RCCAs in VVER-1000 reactors at Ukrainian NPPs **from 3 to 5 years** for the control group and **from 10 to 15 years** for the scram groups, with the exception of 12 RCCAs from RNPP-4 and 6 RCCAs from SUNPP-1.

For these RCCAs, an individual lifetime assessment was carried out, during which the acceptability criterion will be met for the maximum value of fast neutron fluence in the lower part of the absorbing rod cladding and burnup of ^{10}B.

RCCA manufactured in Ukraine

The additional time gained by extending the lifetime of the RCCAs already in operation allowed **to begin producing new RCCAs** of its own design. Work on developing the RCCA manufacturing technology started earlier. Additional time was necessary to conduct a series of tests, substantiate and implement the RCCA of its own design.

The design of domestically manufactured RCCA was developed taking into account that it **must be fully compatible** (including mechanically) with the design of the original RCCA, fuel assemblies of all fuel suppliers, core components, and existing reloading equipment, as well as have comparable neutron absorption efficiency and change over time of operation.

Preliminary tests and analytical justifications confirmed the absorbing rods full mechanical compatibility with fuel assemblies from all fuel suppliers, and existing reloading equipment.

These justifications use the properties of structural and neutron-absorbing materials that were obtained through a series of preliminary laboratory tests.

New RCCA pilot operation

The first samples of Ukrainian RCCA were manufactured in 2023. The first batch of 12 RCCAs **was delivered for pilot operation in 2024**. All RCCAs **successfully passed the initial inspection** at the NPP site and tests to confirm their mechanical compatibility with the power unit equipment and their effectiveness as part of the scram group.

After the first year of pilot operation of 12 RCCAs in the scram groups, visual inspection, and successful post-reactor testing, pilot operation of RCCAs in the 10th control group began.

In addition to visual inspection and mechanical testing, the reactor testing program provides for:

- Continuous determination of the effectiveness of scram group as part of the 61st control rod;
- Continuous determination of the integral and differential effectiveness of individual control rods;
- Determination of the differential and integral effectiveness of individual experimental RCCA at power;
- Monitoring the energy release of fuel assemblies in which the RCCAs of the control group are immersed during operation at power.

Conclusion

ENERGY SAFETY GROUP

- Energoatom is working to ensure a timely supply of alternative design core components, such as RCCA (VVER-1000), absorber extension assembly and shielding assembly (VVER-440). These components are being developed as replacement for components that were previously supplied solely from the russia. The design and manufacture of elements is performed by Energoatom with the involvement of Ukrainian companies and scientific institutes.
- The lifetime for the current RCCAs has been extended. The results of the performed work have made it possible to extend the operating life of almost all RCCAs in VVER-1000 reactors at Ukrainian from 3 to 5 years for the control group and from 10 to 15 years in the scram groups. This provided additional time for the implementation of the new degign RCCAs.
- All required justifications and assessments have been completed and agreed upon by the nuclear regulator for Ukrainian-made equipment.
- Pilot operation has begun for VVER-1000 elements and is planned for VVER-440 elements in the near future.
- This is done with the support of Ukrainian organizations ES Group, Kharkiv Institute of Physics and Technology and Paton Welding Institute. The cooperation of Energoatom and these organizations turned out to be very effective. This is a good experience for future projects.
- Ukraine received unique experience and this experience can be extended to European NPPs that operate VVER reactors and want to diversify the core components.

ENERGY SAFETY GROUP

THANK YOU FOR YOUR ATTENTION!

mazurok@e-s-group.com.ua