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IMPROVING THE VVER-440 FUEL DESIGN AND TECHNOLOGY

Prepared by:

P.M. Aksenov, Y.N. Bondar, V.G. Kolosovsky,
V.M. Kochergin, Y.V. Luzan, A.A. Malakhov
OAO MSZ, Elektrostal, Russia

V.G.Krapivtsev
N. E. Bauman MGTU, Moscow, Russia

A.I. Shumeev
OAO “OKB “Gidropress”, Podolsk, Russia

V.R. Filippov
OAO TVEL, Moscow, Russia

Abstract

1. Operational performance of VVER-440 fuel has long been demonstrating good reliability of the fuel. However, assembly failures occur, and fuel suppliers should always take measures to maintain its reliability. For several years, OAO MSZ has been fabricating working assemblies with detachable shrouds and removable fuel rods.
The next step is the supply of demountable assemblies to allow inspection or repair of fuel rods after removal of the shroud.
With the help of corresponding program the Russian organizations have carried out research and development work to advance and study operational features of demountable VVER-440 CFAs. The main engineering solutions are consistent with the working assemblies.
The pilot demountable CFAs are running in the Kola-4 core.
The obtained results can be used when deciding on the demountable CFAs delivery issues.
2. The experiment-calculated research results of coolant mixing in the present design VVER-440 have been analysed.
It has been found out that coolant mixing in the WA head is incomplete and that is why leading to conservatism when determining the reactor operational limits.
The proposed WA head design includes an upgraded bumper grid with additional planes intensifying coolant mixing in the head.
The bumper grid drawing and a pilot model is available. The thermohydraulics and rigidity features of the proposed design have been studied by experiment-calculated methods.

I

The 1st generation VVER-440 TVS ARKs (*TVS ARK stands for Emergency Control Fuel Assembly or Control Fuel Assembly, further on* CFA) include a hexagonal shroud, which is made of 2mm sheet and is permanently attached to the headpiece/tailpiece by M10 screws fixed by welded pins. The operational experience of standard assemblies show that leakages in CFAs are much more rare than in the Working Assemblies (WA). This is true for the leakages with the exceeded failure criterion, also. The leakages, meanwhile, tend to be caused not by the CFA design, but, rather, by some operational conditions (corrosion on the surface of the primary coolant circuit equipment and debris in the coolant) and CFA lifetime.

The second generation fuel comes with the reduced CFA shroud thickness of 1.5mm. Today, the WAs and CFAs for VVER-440 B-213 are used in Kola (3, 4), Dukovany, Mohovce and Bohunice power plants. Besides, the second generation WAs are demountable – thanks to detachable shroud and elastic fastening of the fuel rods to support grid – allowing inspection (or repair) of structural elements, when the inspection bench is available.

The existing trend of designing demountable fuel assemblies together with customers' demands propelled development and verification of the second generation CFAs with detachable shroud. In 2008, six demountable CFAs of the second generation started their five-year cycle in Kola 4 (2 years in control group, and 3 years in the scram system).

In 2006-2008, a development program, based on the design by OAO MSZ and OKB Gidropress, was launched to build and license demountable VVER-440 CFAs. The program is still under way.

The report describes the demountable CFA design and offers a new WA headpiece design with a modified bumper grid.

1.2 Engineering Design of Demountable CFA

1.2.1 Features

The 2nd generation CFAs come with 1.5mm thick shroud, 12.3mm fuel rod spacing in a bundle and modified spacer grids of the 2nd generation WAs. Table 1 compares the requirements of different CFAs designs.

Table 1. Comparison of different CFA designs

Feature	1st generation CFA	2nd generation CFA	Demountable CFA of the 2nd generation
“Width across flats” dimension, mm	144.2	145	
Shroud thickness, mm	2.0	1.5	
Number of grids (spacer + upper grids), pcs	10		
Spacer Grid cell height, mm	10	10 and 20 3 lower spacer grids are 20mm, 6 spacer and upper grids are 10mm	
Upper Grid fixture to the shroud	No fixture (distance is guaranteed by the dimples on the shroud)	No fixture (distance from the shroud is guaranteed by the dimples on the outer strip of the spacer grid)	
Gap size for temperature and radiation increase, mm, not less than	25	30	
Shroud fixture to the end parts (headpiece/tailpiece): – fixture method – number of fixture points, pcs – fixture method – number of fixing points, pcs	<u>Headpiece and tailpiece:</u> – M10 screw (fixed by welds) – 12 points (2 per each edge)	<u>Headpiece and tailpiece:</u> – M10 screw (fixed by welds) – 12 points (2 per each edge)	<u>Headpiece:</u> – M10 screw (fixed by welds) – 12 points (2 per each edge) <u>Tailpiece:</u> – M14 screws (fixed by punching) – 6 points (one per edge)
Fuel rod fixture to support grid	Splint wire	Elastic tip	

The main distinctive feature of demountable CFA as compared to non-demountable lies in the fixing of the shroud to the tailpiece.

The general view of demountable CFA is given in Fig.1. The shroud fixed on the headpiece and tailpiece is in Figures 2 and 3 correspondingly. The tailpiece with the detached shroud is in Fig.4.

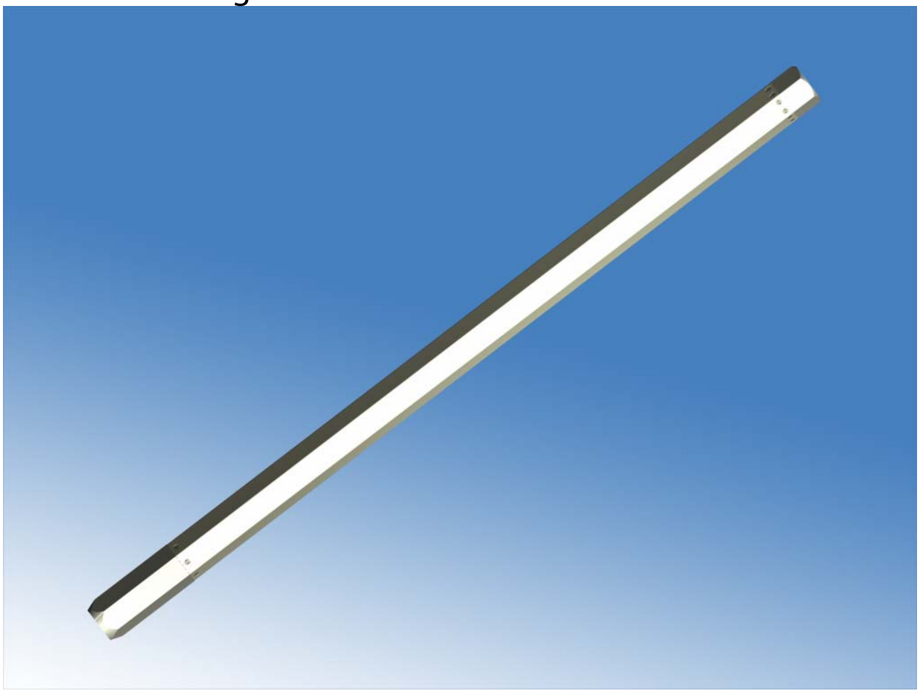


Figure 1. General view of the demountable CFA

Figure 2. Shroud-to-tailpiece fixture unit

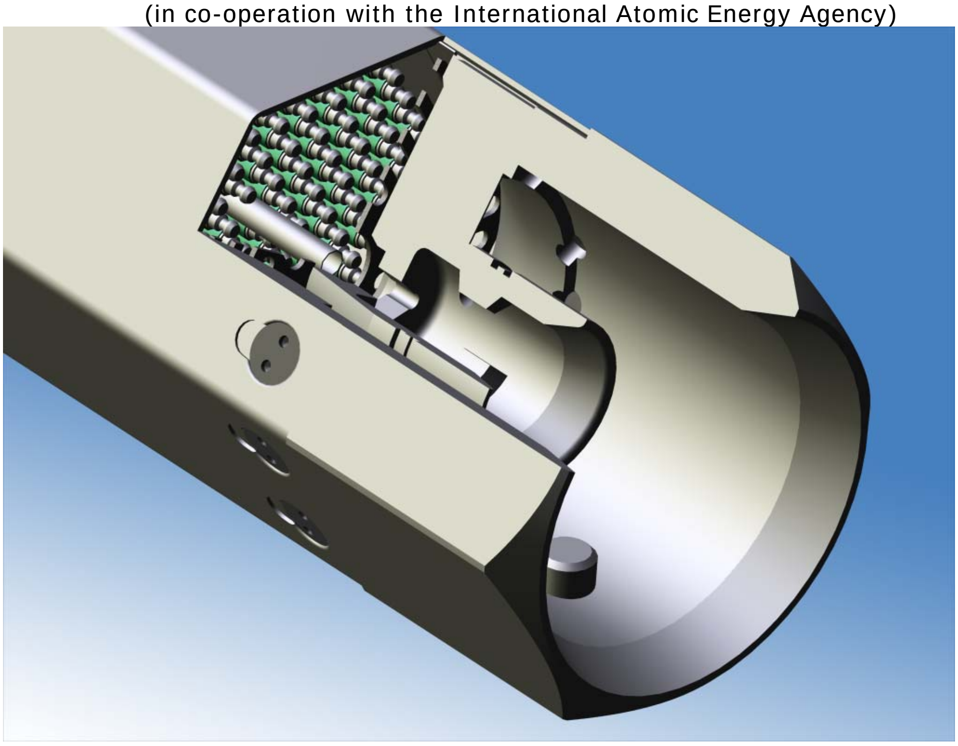


Figure 3. Shroud-to-headpiece fixture unit

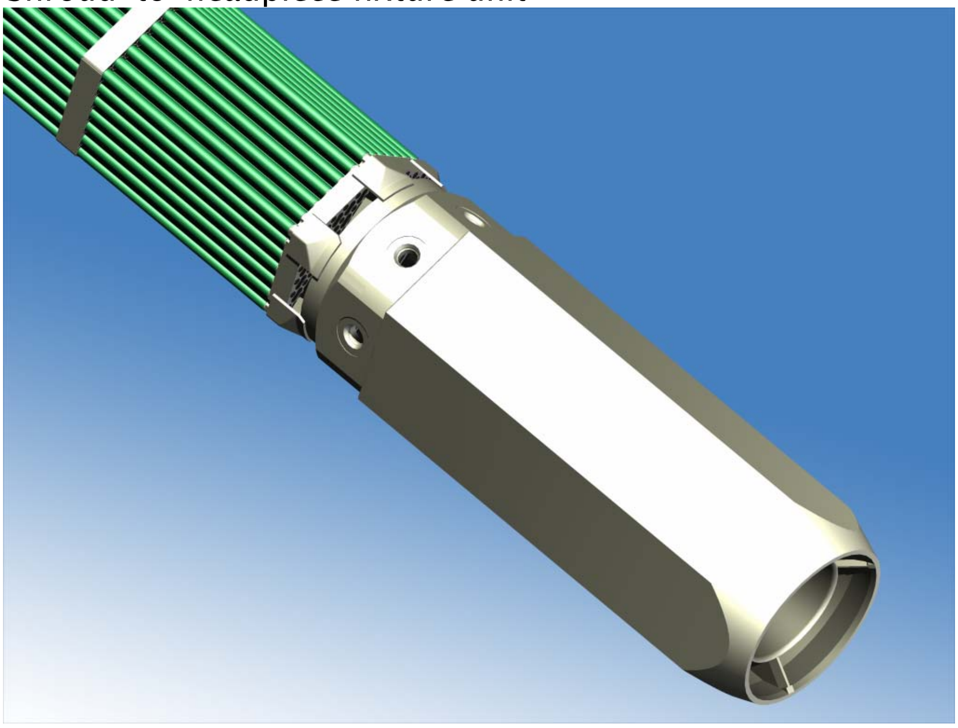


Figure 4. The tailpiece with the detached shroud

1.2.2 Fuel Assembly Mount/Demount

Fixing the shroud on the tailpiece:

- Force the shroud, having special dimples around screw holes, on the tailpiece with corresponding grooves;

- Fix the shroud on the tailpiece by M14 screws;
- Punch the screws with circular grooves on the head against any rotation.

Removing the shroud from the tailpiece:

- Unscrew the shroud by the tool for coping with the punched fixtures.
- Remove the shroud with the headpiece from the bundle surmounting the starting force and components weight.

You can apply a reversed order of mounting the FA with spare screws to be punched by a special tool.
The described operations have been tested in real life situation at Loviisa 1 with running pilot WAs having similar design of shroud-to-tailpiece fixture.

1.3 Design verification

1.3.1 Structural strength evaluation

To evaluate the structural strength :

- the strength of shroud-to-tailpiece unit is analysed by calculation;
- the starting point force and the screw torque is measured.

1.3.1.1 The following calculations are performed to verify the strength and stability of the thinner shroud and the shroud-to-tailpiece unit :

- static tensile load of the bundle with tailpiece during operation (2000N roughly);
- maximum static tensile load (19620 N), compressing (5890 N) and torsional load (98 N·m) of the refueling machine during assembly handling;
- dynamic compressing load during the CFA fall as a result of emergency protection (speed – 0.216 m/sec, weight – 137 kg roughly (extension+headpiece with shroud), temperature – 300°C roughly).

Calculation results has proved the conformance of the structural strength parameters.

1.3.1.2 The torque of the dummy CFA screws is 25 N·m when fitting the shroud to the bundle.

The torque of unscrewing the dummy tailpiece is:

- 19 – 23 N·m – from initial position;

- 27 – 39 N·m – from the very start of unscrewing.

The initial torque increase during unscrewing is caused by rubbing of the punched metal against the conical edge of the shroud hole.

The axial force during shroud dismantle from the dummy bundle is:

- 475 N – from initial position;
- 335 – 300 N – while moving the shroud along the bundle length.

All the steps have been performed in the open air.

1.3.2 Experimental justification

To experimentally justify the design, we have accomplished the following:

- fabrication and assemblying process of the Shroud–Tailpiece unit;
- fabrication of the advanced 2nd generation dummy FA with detachable shroud for justification;
- CFA hydraulic tests for hydraulic resistance ratio determination;
- the CFA dummy life test. The 1500–hour test of mechanical durability of CFA dummy in thermohydrodynamic conditions similar to real–life;
- CFA dummy drop from the working height to prove the shroud's durability and stability in specific operational CFA environment of heavy dynamic loads;
- vibrostability tests of CFA dummy (durability proof and evaluation of the units interacting with the structure as a whole);
- static durability tests of CFA dummy (stretching tests to verify structural durability).

The data obtained by experiments correspond or close to the design data. All the results confirm positive influence of the advanced demountable CFA on the reliability indices.

1.4 Pilot CFAs in Fabrication

In April 2008, OAO MSZ fabricated six pilot demountable CFAs, developed working design documentation, manufactured process tooling and redesigned tailpieces. After acceptance tests the pilot CFAs were confirmed as serviceable.

1.5 Running the Pilot Demountable Fuel Assemblies

The six pilot demountable assemblies were installed in Kola 4 during 2008 shutdown. The fuel assemblies were operated according to the pilot operation program. The program, in particular, requires inspection of demountable FAs during reloads.

1.6 Conclusions

The results that have been achieved by the Russian organizations allow to develop and install the demountable CFAs for pilot operation. This will, undoubtedly, increase operational flexibility of the VVER-440 fuel.

II

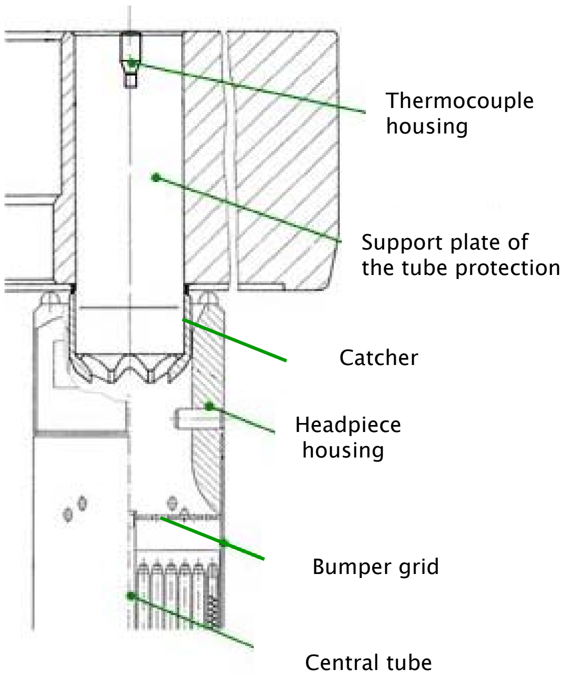
2.1 Introduction

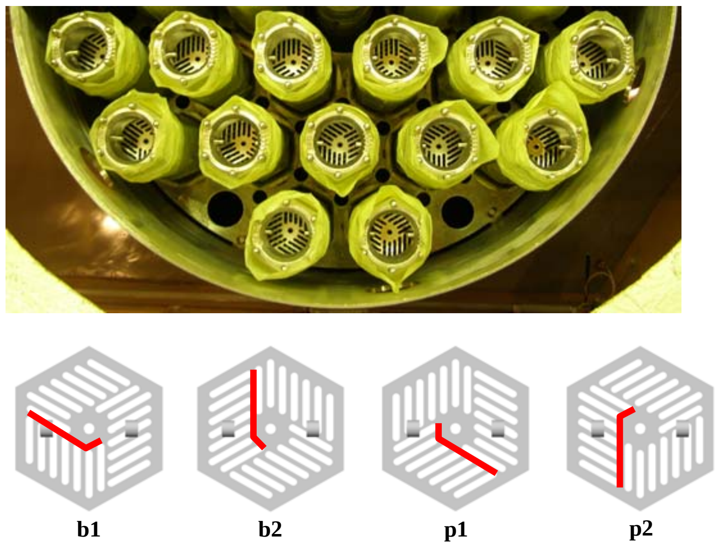
The core outlet temperature of the VVER-440 reactors is measured by the in-core thermocouple, installed above the WA's headpiece (See Fig. 5).
The thermocouple measurements allow to determine radial distribution of neutron flux and assembly power, playing a significant role in determining the reactor operational limits.
Formerly, it was believed that these values were equal to the average WA outlet temperature. However, recent experiment-calculated researches /2-4/ show that the thermocouple readings are slightly different from the average temperature due to incomplete mixing of the coolant in the WA outlet. According to these calculations the difference between the absolute temperature values of the coolant at thermocouple level reaches 5°C.
The maximum difference between the outlet temperature and the thermocouple readings is about 0.63°C making 2.7% of the coolant heating. This is because of the influence of relatively colder flow from the Central Tube and, consequently, lower coolant temperature near the CT outlet.

The difference, of course, does not bring any noticeable problems thanks to special programs processing the data of the in-core temperature measurements. Nonetheless, as the new WA designs are being implemented and the researches in VVER power increase are being held, the question of improving coolant mixing in the headpiece is very much in the foreground.

2.2 WA Head & Bumper Grid Design

VVER-440 headpiece design is given in Fig. 5. The headpiece consists of a housing, springs, elements of insertion-removal of the WA and a bumper grid. The bumper grid is welded to the lower part of the headpiece in three corners.





Bumper grid positions in the WA headpiece

Figure 5. VVER-440 Headpiece, Bumper grid and WA in a container of the fresh fuel unit at NPP

The bumper grid serves the purpose of preventing the fuel rods or their parts from leaving the core at emergencies, limiting radial movement of CT, and, also, partial mixing of the coolant in the WA headpiece.

As Figure 5 shows, there are 4 possible azimuthal orientations or positions of bumper grid in the WA headpiece, all of them influencing the in-core thermocouple readings. The temperature difference between these grid positions can reach 0.8°C /3/.

The existing standard bumper grid is a hexagonal 2mm thick plate with 21 slots for the coolant (slot width - 7 mm, slot gap - 4.5 mm) and a central hole 26 mm maximum. Standard grid material - rolled stainless steel 08X18H10T.

To improve the coolant mixing in the head it has been proposed to complement the spilling slots with mixing planes that make the coolant curl at 15…20° to longitudinal axis of WA towards coolant outlet (See fig. 6).

The number of slots and planes thickness has remained as with the standard grid. The width of the slot has increased to 8…9 mm to make up for hydraulic resistance increase due to flow curl.

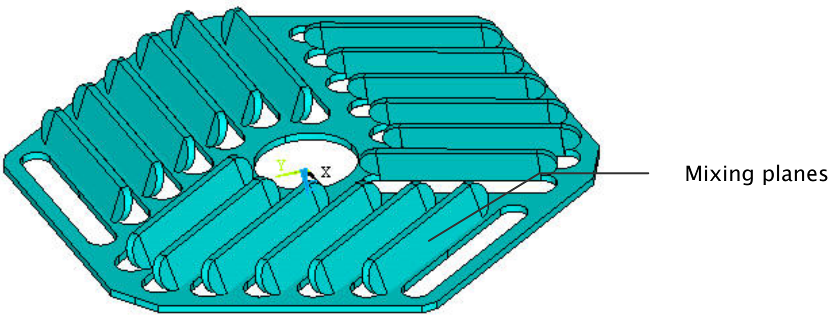


Figure 6. The Proposed Bumper Grid Configuration

2.3 Research Results Analysis

The research required manufacturing of a short outlet sector of VVER-440 WA dummy placed in a hexagonal transparent channel with the “width across flats” dimension of 140 mm. The channel was situated in an open vertical aerodynamic tester with even air inlet to the bundle.

The investigated sector of the WA was a 500 mm long bundle of 126 fuel rods, a central tube, 2 spacer grids and one upper grid with welded bumper grid.

The experiments were carried out with the standard bumper grid and the proposed pilot grid for comparison purposes. And, also, the head without any grid was investigated.

To assess mixing properties of the proposed grid, the flow after the grid was investigated and the flow diffusion results on the bundle outlet were obtained.

Program of experiments included measurements of pressure, flow speed after the grid, temperature distribution after heaters installed on the dummy outlet.

The results show the proposed VVER-440 bumper design ensures twofold decrease of temperature variation in the catcher region as compared to the standard bumper grid. The fact proves the efficiency of the proposed configuration of the bumper grid. Besides, the additional planes reduce the influence of the grid position on the coolant mixing.

The experiment-calculated investigation of the proposed grid strength shows the following:

The existing and the proposed grids are equally rigid. A somewhat bigger (by 19%) values of the design stress of the proposed grid in comparison to the standard grid can be explained by the used approach – equal pressure drop was applied to both the grids. In reality, the proposed grid pressure drop will be less because of its smaller (by 24%) hydraulic resistance. Bearing this in mind, the proposed and the standard grids will, in fact, be equally rigid and strong.

Calculation results demonstrate that the maximum equivalent stress of the standard and proposed grids during operation is much lower than it is allowed.

Thus, it can be noted that the proposed grid design meets the rigidity requirements, while the additional planes facilitate better coolant mixing in the assembly outlet and improve operational performance of VVER-440 reactors.

2.4 Conclusions

2.4.1 The proposed WA head design includes an upgraded bumper grid with additional planes intensifying coolant mixing in the head. The Design Documentation, the fabrication process and a pilot model are available for the bumper grid.

2.4.2 The thermal-hydraulic research has been carried out for the proposed grid. The results show the proposed design guarantees twofold decrease of temperature variation in the catcher region as compared to the standard bumper grid.

2.4.3 The proposed bumper grid design meets rigidity requirements, while the additional planes help to reduce the influence of the grid position on the coolant mixing and facilitate better mixing in the WA outlet, improving, consequently, the VVER-440 operational performance.

REFERENCES

1. A. Ivanov, et al. "Experience of designing a demountable VVER-440 assembly, prereactor and postreactor tests". The 7th conference on reactor materials report. Dimitrovgrag, September 8-12, 2003.
2. L.L. Kobzar and D. A. Oleksyuk, *Experiments on Simulation of Coolant Mixing in Fuel Assembly Head and Core Exit Channel of VVER-440 Reactor*, 16th Symposium of AER on VVER Reactor Physics and Reactor Safety, Bratislava, Slovakia, 2006.
3. S. Tóth, A. Aszódi. Detailed Analysis of Mixing in VVER-440 Fuel Assembly Heads. Budapest University of Technology and Economics Institute of Nuclear Techniques, 2008.
4. S. Tóth, A. Aszódi, *Detailed Analysis of Coolant Flow in VVER-440 Fuel Rod Bundle*, 16th Symposium of AER on VVER Reactor Physics and Reactor Safety, Bratislava, Slovakia, 2006.