VVER-440 NUCLEAR FUEL MANUFACTURED BY
OAO “MASHINOSTROITELNY ZAVOD”.
RELIABILITY, DEVELOPMENT AND PROSPECTS.

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1. INTRODUCTION

Unit 1 of Novovoronezh NPP with VVER-440 reactor was commissioned in the Soviet Union in 1964. At the present moment 27 nuclear power reactors of VVER-440 types are being in operation worldwide. These reactors are installed at Novovoronezh NPP, Kola NPP, Rovno NPP (Ukraine), Metsamor NPP (Armenia), Kozloduy NPP (Bulgaria), Paks NPP (Hungary), Dukovany NPP (Czech Republic), Bohunice NPP, Mochovce NPP (Slovakia), Loviisa NPP (Finland). OAO “Mashinostroitelny zavod” is a leader in manufacturing of a nuclear fuel for such types of reactors.

2. RELIABILITY INDICATORS FOR VVER-440 NUCLEAR FUEL

The analysis of operational results has been performed separately for the 1st generation and 2nd generation of reactors. Moreover, due to significant differences in operational results and conditions all the power units were divided into 5 groups:

Group I-A
6 reactors of the first generation: Units 1&2 of Kola NPP, Units 3&4 of Kozloduy NPP, Units 3&4 of Novovoronezh NPP;

Group I-B
2 reactors of the first generation: Unit 1&2 of Bohunice NPP;

Group I-C
1 reactor of the first generation: Unit 2 of Metsamor NPP (Metsamor NPP was placed into an individual group because on one hand, the unit was restarted after a long-time shutdown period, on the other hand, no leaking fuel assemblies have been unloaded from the reactor during the last 6 years).

Group II-A
14 reactors of the second generation: Units 1-4 of Paks NPP, Units 1-4 of Dukovany NPP, Units 1&2 of Loviisa NPP, Units 3&4 of Bohunice NPP, Units 1&2 of Mochovce NPP;

Group II-B
4 reactors of the second generation: Units 3&4 of Kola NPP, Units 1&2 of Rovno NPP.

Average and maximum burn-up values for all the fuel assemblies unloaded in the year 2004 made:
The leakage rates for VVER-440 reactor groups are as follows:

- **Group I-A**: the leak rate in 2004 remained high and made 2.3 x 10^-4. The average leak rate for the last 5 years accounts for 2.1 x 10^-4.
- **Group I-B**: 5 leaking fuel assemblies were found at Bohunice NPP in 2004. The leak rate in 2004 made 6.3 x 10^-5. The average leak level for the last 5 years makes 2.5 x 10^-5;
- **Group I-C**: it has been already mentioned that the leak rate at Metsamor NPP was at zero level during all the recent years;
- **Group II-A**: no leaking fuel assemblies were found in power units outside the CIS territory in 2004. The average leak rate during the last 5 years made 7 x 10^-7, being in full compliance with the best international results;
- **Group II-B**: the leak rate at power units of the second generation located in Russia and Ukraine (Kola NPP-3, 4 and Rovno NPP-1, 2) decreased in 2004 compared to the previous year and made 2.4 x 10^-5; average leak rate during the last 5 years accounted for 4.7 x 10^-5.

3. EVOLUTION OF VVER-440 FUEL DESIGN AND PROSPECTS FOR FURTHER DEVELOPMENT

3.1 Fuel profiling and dismountable design

Profiled fuel design containing fuel integrated burnable gadolinium oxide has been implemented with the purpose of increasing fuel cycle length. This fuel contemplates loading fuel pellets with higher enrichments guaranteeing required fuel cycle length and reactor safety. The first U-Gd fuel assemblies were manufactured in 1998 and delivered to Kola NPP, Russia. In 1999 the large-scale commercial production of U-Gd fuel pellets was started. Different enrichment profiling patterns of the working assembly cross-section were considered and developed to reduce non-uniform power density distribution in the fuel assembly cross-section. The enrichment range of fuel pellets and rods manufactured by the company was significantly extended and resulted in obtaining average calculated enrichment within wide tolerance limits. In 1995 the first working fuel assemblies with 3.82 % enrichment were manufactured for Novovoronezh NPP. In 1998 profiled fuel assemblies were delivered to...
Dukovany NPP. Average enrichments manufactured by the company include 3.82%, 4.21%, 4.25%, 4.38%, 4.4% by U-235.

The dismountable fuel assembly design was developed with the purpose of having a possibility of remote examination of the fuel bundle and removal of irradiated fuel rods without cutting fuel assembly components.

Such a dismountable design provides for the possibility of performing the following operations remotely:

- To loosen the screws fixing the shroud on the bottom nozzle,
- To remove shroud and bottom nozzle,
- To remove individual fuel rods and mount fuel rods or dummies in the bundle;
- To place shroud and bottom nozzle back on the bundle
- To tighten screws on the shroud and bottom nozzle,
- To load fuel assemblies into the reactor to continue in-pile operation.

The first 6 dismountable fuel assemblies were loaded in Loviisa NPP (Finland). Some assemblies from that batch were visually inspected after the first, second and third year of operation and loaded back into the reactor.

In 2002 several fuel rods were removed from dismountable fuel assemblies after a 3-year irradiation at Loviisa NPP and inserted back into the bundle after inspections and measurements.

Since 2002 dismountable profiled U-Gd working fuel assemblies have been delivered to Dukovany NPP (Czech Republic).

3.2 Regenerated uranium

Regenerated uranium is accumulated throughout the plant operation life. The first fuel assemblies of 2.4% enrichment for water-moderated water-cooled power reactors containing regenerated uranium were manufactured for Kola NPP, Russia, in 1992. Since 2002 fuel assemblies of 3.82% enrichment and containing fuel rods with regenerated uranium are loaded into Unit 2 of Kola NPP on a regular basis.

In our opinion, this issue should be given more attention due to the reduction of natural uranium reserves. It is high time that the negotiations should be started with our foreign partners regarding the transition to the delivery of fuel containing regenerated uranium.

3.3 Hafnium plates

With the purpose of suppressing power peaking in working fuel assemblies surrounding control fuel assemblies there are 6 hafnium plates (one plate on each side) located on the external surface of the fuel assembly.
The first fuel assemblies containing hafnium plates were delivered to Novovoronezh NPP, Russia, in 2001.

3.4 VVER-440 fuel of the second generation

In 2001-2002 a great amount of work was performed regarding further improvements of assembly design. This fuel is known as the fuel of the second generation.

Working fuel assemblies of the second generation are characterized by a number of specific features, viz.:

- Dismountable fuel assembly design (fuel rods are fixed in the lower lattice by means of mouth-pieces);
- Lower hafnium content (less than 0.01 %) is used for fuel rod claddings;
- Increased fuel weight due to the extension of the fuel zone and change of the pellet geometry (central hole diameter 1.2 ± 0.3 mm);
- Radially profiled fuel rod bundle with integrated burnable absorber;
- Design improvements (optimization of the spacer grid location along the bundle height, bushing in the top nozzle to be used for central tube attachment, stiffening rib under the lower lattice) aimed at enhancing fuel assembly rigidity and vibration stability.

There are 6 hafnium plates located on the shroud of the second-generation VVER-440 fuel assembly.

The first batch of the second-generation working fuel assemblies and fuel follower of control rods was manufactured in 2002 for Unit 3 of Kola NPP. Starting from the year 2005 this fuel will be delivered to Dukovany, Bohunice and Mochovce NPPs.

Implementation of the above-mentioned improvements have resulted in the following benefits:

- Application of the 5-year fuel cycle with the possibility of leaving a group of fuel assemblies for the sixth year of operation;
- Water to uranium ratio has increased;
- Increased fuel weight;
- Enhanced vibration stability;
- Reduced thermal loads on fuel rods;
- Possibility of fuel assembly repairs

3.5 Vibration resistant fuel assemblies

As the above statistics shows most leaking VVER-440 fuel rods are found in V-230 reactors of the first generation. The main reason for fuel rod failures is the increased
vibration of reactor internals. Vibration resistant design has been developed in order to enhance fuel resistance against vibrations. First fuel assemblies of this design were loaded in 2004 in Unit 2 of Kola NPP. The availability of 3 lower spacer grids of a 20-mm height (instead of 10 used before), fuel rod attachment to the lower lattice by means of a mouthpiece instead of pin wire and presence of a stiffening rib under the lower lattice are among the specific design features of these fuel assemblies.

3.6 Anti-debris filter
In 2004 six working fuel assemblies equipped with anti-debris filters were loaded in Unit 2 of Kola NPP. The anti-debris filter is designed to protect the fuel against debris-particles originating from the primary coolant. By the present moment these fuel assemblies have successfully operated for 1 year and continue operation now. New anti-debris filter designs are under consideration at the present moment.

3.7 Fuel assembly to be used during the sixth year of operation
Twenty fuel assemblies with 4.4 % average enrichment operated during the sixth year at Kola NPP. In 2004 these fuel assemblies were unloaded from Unit 3 of Kola NPP. Maximum fuel burn-up made 51.09 MW day/kg U. Based on the results of pilot operation and inspection performed it has been concluded that the nuclear fuel manufactured by OAO MSZ can successfully operate during 6 years.

3.8 Advanced projects for VVER-440 fuel
The following advance design developments for VVER-440 fuel assemblies can be emphasized:

- Shroudless fuel assembly;
- Enlarging of the distance between fuel rods;
- Introduction of hollow elements of design (water channels);
- Replacing of the steel rodlets in the fuel follower of control rod with low-enriched fuel pellets;
- Enrichment profiling along the working fuel assembly height;
- Decrease of the fuel rod outer diameter;
- Change of the spacer grid design;
- Use of pellets without a central hole.

4. CONCLUSION
Despite the fact that nuclear VVER-440 reactor have been operating in the nuclear market for about 40 years, the activities related to the improvement of fuel assembly design are in progress. As a result, fuel burn-up is increasing, design is optimized and fuel performance characteristics are under continuous improvement. All these characteristics offer significant opportunities for the future use of VVER-440 fuel and OAO MSZ as a leading manufacturer and supplier of this fuel.