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 present, 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 the leading manufacturer of the nuclear fuel for such reactors.

2. RELIABILITY INDICATORS FOR THE VVER-440 FUEL
The VVER-440 fuel guarantees a rather reliable performance. The V-230 reactors (VVER-440 1-st generation) account for the most of the leaks at Novovoronezh NPP, Kola NPP, Kozloduy NPP and Bohunice NPP.

The situation with V-213 (2-nd generation) is much better, especially in Finland, Hungary and the Czech Republic, where the average leak rate of 6.6E-7 has been one the lowest in the world over the last 5 years.

There have been no leaks at Metsamor NPP in Armenia recently.

3. FURTHER DEVELOPMENT OF VVER-440 FUEL DESIGN AND FUTURE PROSPECTS
3.1 Uranium/gadolinium fuel, profiling, dismountability
The fuel of a new profiled design has been implemented to provide continuous fuel cycles. The fuel's composition included gadolinium oxide integrated into uranium dioxide. This type of fuel makes it possible to utilize pellets of higher enrichment that ensure the required cycle time and operational safety. The first uranium-gadolinium assemblies were manufactured and delivered to Kola NPP, Russia in 1998.

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. In 1995 the first working fuel assemblies with 3.82 % enrichment were manufactured for Novovoronezh NPP, Russia.

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 top nozzle,
- To remove individual fuel rods and mount fuel rods or dummies in the bundle;
- To place shroud and top 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, third and fourth year of operation and loaded back into the reactor.

3.2 Regenerated uranium

The implementation of the closed fuel cycle will improve the nuclear business and bring the increase in the amount of regenerated uranium. In order to assess the usage possibilities of regenerated uranium within the fuel cycles of water-moderated water-cooled power reactors, the first fuel assemblies of 2, 4 % enrichment were manufactured for Kola NPP, Russia, in 1992.

Since 2002, the fuel assemblies of 3.82 % enrichment, containing fuel rods with regenerated uranium, are loaded into Unit 2 of Kola NPP on a regular basis.

3.3 Hafnium plates

With the purpose of suppressing power peaks in working fuel assemblies surrounding control fuel assemblies, there are six hafnium plates (one per each side) located on the inner surface of the shroud tube.

This has particular importance for those NPPs that operate in power tracking mode, when the control fuel assemblies are in constant motion.

The first fuel assemblies with hafnium plates were delivered to Novovoronezh NPP, Russia, in 2001.

3.4 The second generation fuel for VVER-440

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.
A number of features characterize the working fuel assemblies of the second generation, 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 is down to 1.2 mm);
- Fuel rods distance is increased up to 12.3 mm;
- Radially profiled fuel rod bundle with integrated burnable absorber;
- Design improvements to enhance fuel assembly rigidity and vibration stability.

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

Implementation of the above-mentioned improvements has 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;
- Increased water-to-uranium ratio;
- Increased fuel weight;
- Enhanced vibration stability;
- Reduced thermal loads on fuel rods;
- Possibility of fuel assembly repairs.

The second generation assemblies are designed for the V-213 project.

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 2005 this fuel is delivered to Dukovany, Bohunice and Mochovce NPPs. The year 2008 will see the deliveries to Loviisa NPP, and from 2009 to Paks NPP.

### 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 mm used before), fuel rod attachment to the lower lattice by means of a resilient 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 now, these fuel assemblies have successfully operated for 1 year and continue operation. New anti-debris filter designs are under consideration at the present moment.

3.7 The 3-rd generation fuel for VVER-440

From the year 2006, OAO MSZ has been running the development of the 3-rd generation fuel. The future assemblies will follow the best characteristics of the second generation with the following design features:

- Shroudless fuel assembly;
- Bigger fuel rods distance;
- Larger inner diameter of the rods;
- Use of pellets without a central hole;
- High-precision grids
- Smaller number of spacer grids: 9 instead of 10
- Dismountable design thanks to removable top nozzle

All the improvements will bring the following positive results:

- Less steel inside the core to increase the amount of neutrons absorbed
- Better coolant mixture inside/between assemblies
- Increase in fuel weight
- Increase in water-to-uranium ratio

At provisional estimates, the 3-rd generation fuel can give a 5-7% boost to the fuel cycle economy.

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 being 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 the leading manufacturer and supplier of the nuclear fuel.