Results of Trial Operation of the WWER Advanced Fuel Assemblies

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1. Features of the WWER-1000 Advanced Fuel Assemblies

Pilot operation of the advanced fuel at WWER-1000 has been finalized. Advanced fuel is deemed here as fuel assemblies developed according to the concept of standard WWER-1000 – jacket-free with new features, which can be broken down into the following groups:

- Zirconium guiding channels (alloys Э-635 and Э-110) and spacing grids (alloy Э-110);
- Integrated burnable absorber - Gadolinium;
- Extended service life of FA and absorber rods (possibility of repair of fuel assemblies);
- Improved adaptation to reactor conditions.

Detailed design is described in [1].

2. Dynamics of Introduction of WWER-1000 AFA

The dynamics of introduction of WWER-1000 AFA is shown in Table 1. Till 1998 at Balakovo NPP, Unit 1, other 54 pieces of prototypes of advanced fuel assemblies were in pilot operation.

3. Results of AFA Pilot Operation

The following is highlighted by the results of a three-year operation:

- All fuel assemblies are leak-tight;
- Burnup obtained – 42.7 MWd/kgU;
- Scram time <3 s;
- Representativeness of thermal control is increased;
- Stability of operation of the CPS CRDM is increased.

In the course of pilot operation of prototypes and the first batches of advanced fuel assemblies, separate shortcomings were revealed and the following types of retrofitting were performed in the next batches.

High-temperature relaxation stability:

- New material of springs of high-temperature steel is applied, therefore, relaxation stability is achieved;
- Restrictive sleeves on the central tube and safeguard sleeves on the guiding channels preventing from SG displacement above permissible limits are integrated;
- Gadolinium oxide content is reduced from 8% up to 5%;
- Value of the central hole in the pellets is reduced.

Originally, pilot operation was planned to take place during three effective years, however, their operation will be continued in a new 4-year cycle (using a part of fuel assemblies during 3 years).

One of the prototypes of the advanced fuel assembly, with residence time of 5 calendar years in the reactor, has passed post-reactor studies. The results are positive.

The results specified make possible to transfer to AFA commercial operation and at the same time to begin elaboration of the design of the core structure for 4-5 year fuel cycle with burnup of 55-60 MWd/kgU.

Table 1. Dynamics of Introduction of WWER-1000 AFA

Unit	The number of the installed AFAs, [pcs]			
	1998	1999	2000	2001
Bal 1	48	48	-	52
Bal 2			55	48
Bal 3		42	49	54
Bal 4			49	48
Rost.1			163	

4. Analysis of Effectiveness of Introduction of Improvements

4.1. Application of Zirconium Channels and Grids

- Makes possible to realize fuel cycle approximately equal, in terms of duration, to that achieved in the former structure but with medium enrichment ~3.77 instead of ~4.31 in ^{235}U;
- Makes possible to decrease quantity of active corrosion products in the reactor and to improve radiation situation upon the whole;
- To reduce axial load to the fuel assemblies in reactor hot state ~ by 40%. It makes possible to accept maximum inter-assembly gap estab-

lished for stainless steel cores by the results of direct measurements and calculations;
- Conditions for prevention of fretting-wear of fuel rod clad in the spacing grid have been improved.

4.2. Application of the Integrated Burnable Absorber

- Makes possible to realize a 4-year fuel cycle with saving of specific consumption of uranium ~15%;
- Decreases maximum fast neutron fluence to the reactor vessel;
- Enhances nuclear safety during storage and transportation of fresh FA;
- Excludes procedures with transportation, storage and disposal of burnable absorber rods.

4.3. Extension of FA and Absorbing Rod Service Life (Including Repairability)

- Duration of operation in reactor – 30000 eff. days with possibility to have a 5-year residence time in the reactor has been established for a new construction;
- Fuel charging in the fuel assembly is increased by 7% due to reduction of central hole diameter in the pellets;
- Service life of new absorbing rods – 10 years;
- Average burnup ~55 MWd/kgU is reached in two test assemblies with uranium-gadolinium fuel;
- Possibility for FA to be repaired is checked in case of their unprovided failure (Design project of inspection rig is developed in parallel);
- Fuel operation with interval of 350 days between refuellings is provided at Balakovo NPP, Unit 1, for increase in load factor (usage factor of the established power).

4.4. The Improved Adaptation to Reactor Conditions

- Homogeneity of materials is provided in the core, and, respectively, minimum relative displacements of fuel rod bundle and the channel components;
- Elimination of superfluous margin of spring forces under decrease in pressure differential on FA in hot state. As a result, there is no spring relaxation, stable position of fuel assembly caps in the reactor is provided;
- Full damping under control rod dropping in case of scram.

5. Advanced Design of WWER-440 Fuel Assemblies

Design of fuel assemblies of new generation for WWER-440 reactors has been developed which involves the following key changes:
- Fuel inventory is increased due to lengthening of fuel stack and reducing diameter of the central hole;
- Vibration stability is enhanced as a result of:
  - No-play junction of the fuel rod with the lower grid;
  - Change of SG arrangement;
  - Strengthening of the lower grid unit;
  - Securing of the central tube in the cap;
- Water-uranium ratio is increased (return to FA jacket thickness 1.5 mm is considered to be meaningful);
- Knock-down structure of operating fuel assemblies;
- ERC joint unit is modernized.

Introduction of all these kinds of modernization in a 5-year fuel cycle will reduce fuel component of energy cost by 7%.

Isolated solutions are introduced into operation at the Units with WWER-440.

Comprehensive tests of fuel assemblies of new design will begin at Kola NPP, Unit 3, since 2002.

6. Conclusion

Five units of NPP with WWER-1000 have been transferred to operation with the advanced fuel in Russia. This fuel has confirmed the declared advantages in spite of isolated shortcomings revealed, basically, at the early stage of operation. These advantages manifest themselves in providing design requirements in the course of fuel handling and during operation of the units.

Structure of WWER-440 fuel assemblies of a new generation has been developed and is being integrated. This structure involves improved technical and economic characteristics. The urgency of this operation increases in connection with extension of service life of WWER-440 reactors.

Reference

[1] Yu. Dragunov, et al. Fuel Assembly Structure as a Result of Improvement and Basis for Perspective WWER. Report at the Conference WWER – Technical Innovations in the 21-st Century, Prague, 17-20 April, 2000.