Fuel Improvement and WWER-1000 FA Main Operational Results

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1. Introduction

At present 21 WWER-1000 power units are in operation at 9 NPPs in Russia, Ukraine and Bulgaria. For the period of 1980-2002, the total time of WWER-1000 FAs operation at NPPs is 326 reactor years.

For the period of 1980-2002, more than 17 500 FAs (more than 5 mln. FEs) have been manufactured at JSC NCCP, delivered to WWER-1000 NPPs and successfully operated there.

Many-year operational experience of WWER-1000 FAs manufactured at JSC NCCP which first were in operation in 2-year cycle and then in 3-4-year cycle confirmed a considerable margin of all parameters characterizing operating reliability. This makes it possible constantly to develop and improve fuel for WWER-1000 reactors.

2. Main Lines of Activities Aimed at WWER-1000 Fuel Improvement

In accordance with a comprehensive program for development and improvement of WWER-1000 fuel the main objectives and tasks of activities aimed at WWER-1000 fuel improvement are as follows:

1. Improvement of operating safety and reliability;
2. Improvement of economic indicators:
   - Enhancement of efficiency of fuel use (decrease of specific consumption of natural uranium);
   - Increase of operating life (transition to 5 year fuel cycle);
   - Increase of average burnup (up to 65-70 MWd/kg(U);
   - Improvement of installed power utilization factor up to 90%;
3. Guarantee of fuel performances under flexible operating conditions.

3. WWER-1000 Fuel Evolution

To achieve the a.m. objectives and tasks, during the whole period of WWER-1000 FAs fabrication at JSC NCCP in cooperation with DB Gidropress, RRC Kurchatov Institute, FSUE All-Russian Research Institute of Inorganic Materials the work on fuel improvement for WWER-1000 reactors is carried out and it is under progress now. All WWER-1000 FAs manufactured at JSC NCCP till the present time can be conventionally divided into 6 generations:

- First generation: Shroud WWER-1000 FA manufactured for Novovoronezh NPP, Unit 5.
- Second generation: FA without shroud designed for operation in 2-year cycle, with a skeleton consisting of stainless-steel spacer grids (SG) and guide thimbles (GTh);
- Third generation: FA without shroud with a stainless steel skeleton designed for operation in 3 year cycle;
- Fourth generation: FA-M – FA without shroud with a stainless steel skeleton, a detachable head, removable FEs, designed for operation in 3-4 year cycle;
- Fifth generation: Advanced FA – FA without shroud with a zirconium alloy skeleton, a detachable head, removable FEs, with Uranium-Gadolinium fuel (UGF), designed for operation in 3-4 year cycle;

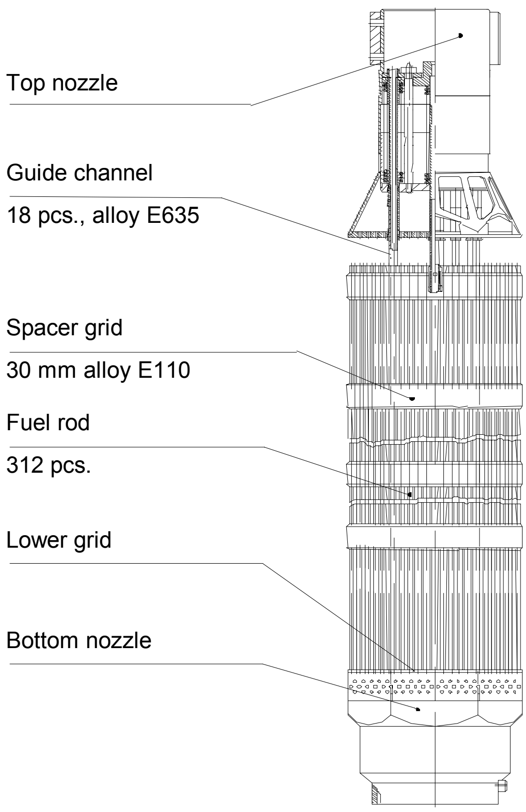

Figure 1. WWER-1000 TVS-2

- Sixth generation: TVS-2, advanced FA – FA without shroud with a rigid zirconium alloy skeleton (formed by channels welded to SG in TVS-2 and by angles welded to SG in alternative FA, a detachable head, removable FEs, with UGF, designed for operation in 4-5 year cycle.

Design of advanced FA of the fifth generation for operation in 4-year cycle, developed for full-scale production and commercial operation was finally licensed in July 2001. At present advanced FAs of the mentioned design are delivered and in successful operation in Balakovo NPP and Volgodonsk NPP. Advanced FAs are produced for first fuellings at Bushehr NPP (Iran) and Tianwan NPP (China).

In Figure 1 TVS-2 design is presented. The design has all the best features of advanced FA of the fifth generation and is characterized by higher flexural rigidity owing to a welded construction of a skeleton. TVS-2 has increased strain stability during in-core operation. At present the first TVS-2 batch (54 pcs.) is in operation in unit 1 at Balakov NPP. No remarks upon TVS-2 have been recorded up to this date.

Alternative FA the design of which is developed by FSUE OKBM in cooperation with JSC MSZ is presented In Figure 2. Alternative FA pilot operation began in 1998 at Kalinin NPP, Unit 1.

Under technical support of JSC TVEL, JSC MSZ and FSUE OKBM, at JSC NCCP the mentioned FA production was mastered and alternative FA simulators were fabricated, in order to conduct start-up and adjustment works at Kalinin NPP, Unit 3. 48 alternative FAs were fabricated for Zaporozhye NPP, Unit 3.

Introduction of TVS-2 of the sixth generation made it possible to implement the most cost effective fuel cycles at WWER-1000 NPPs. At the same time specific consumption of natural uranium was decreased from 0.240 kgU/MWd (FA of the third generation) up to 0.196 kgU/MWd (FA of the fifth and sixth generations).

The design of TVS-2 and alternative FA provides for capabilities of their further modernization (use of anti-debris filter, MOX-fuel etc.) that will make it possible to satisfy the requirements of nuclear fuel Users (NPPs with WWER reactors) to the full extent.

4. WWER-1000 operational results for the period of 1990-2002

For the period of 1992-2002, 2257 FAs manufactured at JSC NCCP have been in operation for 4 fuel cycles. During 2002-2003 fuel campaign 306 FAs in 15 NPP units in Russia, Ukraine and Bulgaria were left for the 4-th fuel cycle.

The number of FAs which have completed 4 fuel cycles within the period of 1992-2002 is given in Figure 3. The number of FAs, which have completed 4 fuel cycles and the number of NPP units where the mentioned FAs are in successful operation are constantly growing.

Analysis of statistical data on WWER-1000 FAs operation within the period of 1990-2002 shows that average burnup of FAs, which have completed 4 fuel cycles is 44.66 MWd/kgU, maximum FA burnup is 55.44 MWd/kgU.

In Figure 4 average burnup of WWER-1000 FAs which completed 4 fuel cycles and discharged within the period of preventive maintenance in 2002 is presented. Average burnup is within a wide range which is indicative of a considerable margin for optimization of parameters of fuel use at WWER-1000 NPPs.

One of the main operating characteristics is total specific iodine isotopes activity of the primary coolant. Analysis of WWER-1000 FA operational results for the period of 1990-2002 shows that total specific iodine isotopes activity of the primary coolant at WWER-1000 units is within a wide range – from $1{\cdot}10^{-7}$ Ci/kg to $1.9{\cdot}10^{-3}$ Ci/kg.

High total specific iodine isotopes activity of the primary coolant recorded at some WWER-1000 units, such as Rovno NPP, Unit 3 is caused by abnormal operating conditions of reactor plant which are connected with availability of alien objects in the primary coolant.

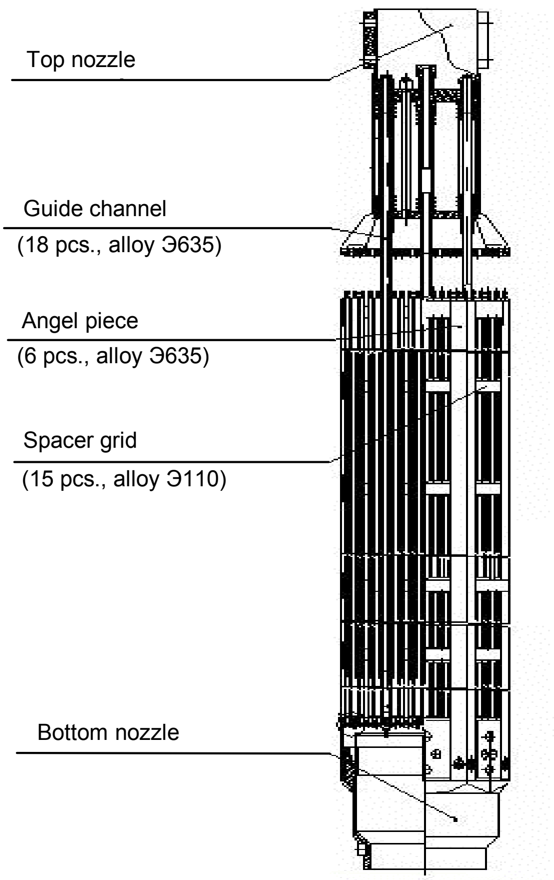

Figure 2. WWER-1000 alternative FA

But, now some WWER-1000 units, such as at Zaporozhie NPP, Units 1, 3, Volgodonsk NPP, Unit 1 are in operation with relatively low total specific Iodine isotopes activity of the primary coolant, equal to $1 \cdot 10^{-6}$-10^{-7} Ci/kg.

Criterion of ahead of schedule shutdown of reactor based on total specific activity of $^{131-135}I$ radionuclides in the primary coolant through the fault of fuel manufactured at JSC NCCP was achieved by no one of WWER-1000 units during their operation period.

5. Brief Information on Advanced FA Operation

To improve economic indicators and fuel use efficiency, advanced FAs of the fifth generation with zirconium skeleton (ZSG and ZGTh) and uranium-gadolinium fuel have been put in operation at WWER-1000 NPPs since 1992. Total number of advanced FAs manufactured at JSC NCCP and delivered to NPPs in Russia and Ukraine during the period of 1992-2002 is 939, at present 782 of them are still in operation.

As on 01.01.2003, 157 advanced FAs have finished operation, 2 of them have completed 4 fuel cycles (30550 eff. hours) in Balakovo NPP, Unit 3 and achieved burnup of 55.44 MWd/kgU.

In Figure 5 the commissioning dynamics of advanced WWER-1000 FAs manufactured at JSC NCCP in 1993-2003 is shown.

Post-irradiation examination (in Russian Research Institute of Atomic Reactors) of advanced FA, which has been in operation for 3 fuel cycles in Balakov NPP, Unit 1 proved advanced FA design efficiency.

6. Results of WWER-1000 FE Leak-Proofness Control

Analysis of results of WWER-1000 FE cladding leak-proofness control (CLPC) over the whole operational period shows that FAs considered as leaky have a sufficiently wide range of specific activity of reference radionuclide ^{131}I: 10^{-8}-10^{-5} Ci/kg, and FE depressurization is of gas leakage nature.

We have to point out that during the whole operational period no one FA after 4 fuel cycles has reached failure criterion based on CLPC results. In all 6 units at Zaporozhie NPP where the majority of such FAs have been in operation, as on 01.01.2003 no one leaky FA has been found out after 4 years of operation.

Analysis of leaky FAs operation results shows that increase of FE damage rate in several years in some NPP units is caused by operational factors (abnormal operating conditions, availability of alien objects in the primary coolant, non-observance of water chemistry conditions, FAs damage during loading-unloading, etc.).

For the whole operational period of 1980-2002, no cases of FE depressurization caused by non-observance of WWER-1000 FE production process have been recorded.

Analysis of results of FAs operation, inspection at NPPs and test in hot chamber in Russian Research Institute of Atomic Reactors showed that the main reason of WWER-1000 FE depressurization is cladding damage by alien objects (debris).

We have to point out that reactor plant, main equipment aging and resulted increase of repair volume can lead to increase of the number of alien objects in the core and FE damage rate during the operation process. Actions aimed at decrease (elimination) of alien objects in the core can be considered as a partial solution of this difficulty. Making such actions at some NPPs (for example, Rovno NPP, Unit 3) has already resulted in decrease of the number of leaky FAs. Introduction of FAs with anti-debris grids provides for giving a partial solution of the problem of elimination of alien objects in the core.

In Figure 6 distribution of WWER-1000 FAs as per depressurization causes for the period of 1990-2002 is presented.

In Figure 7 distribution of leaky FAs as per NPP units for the period of 1996-2002 is presented.

Analysis of operational results shows that the most significant contribution to the total number of leaky FAs for the last years is made by Rovno NPP, Unit 3. The number of leaky FAs detected in any unit at Rovno NPP is greater than the total number of leaky FAs in six units at Zaporozhie NPP. At the same time, in some units, such as Zaporozhie NPP, Units 1, 3, 4, Balakov NPP, Unit 3 during the last years (1996-2002) there were almost no leaky FAs. This confirms operational causes of WWER-1000 FE depressurization.

In Figure 8 distribution of WWER-1000 units with zero damage rate is presented. Based on CLPC results no one leaky FA has been detected there. Analysis of operational results shows that the number of units wit zero damage rate has a rising tendency, during last year in comparison with the year before the last one the number of units with zero damage rate increased by 80%.

7. Conclusions

JSC NCCP experience of WWER-1000 FAs fabrication and operation confirms the adequate feasibility and efficiency of fuel operation in 3-4-x fuel cycles, high operating reliability and competitive capacity as compared with foreign analogues.

Work on fuel improvement is aimed at improvement of operating reliability and enhancement of fuel use efficiency in WWER-1000 advanced FAs.

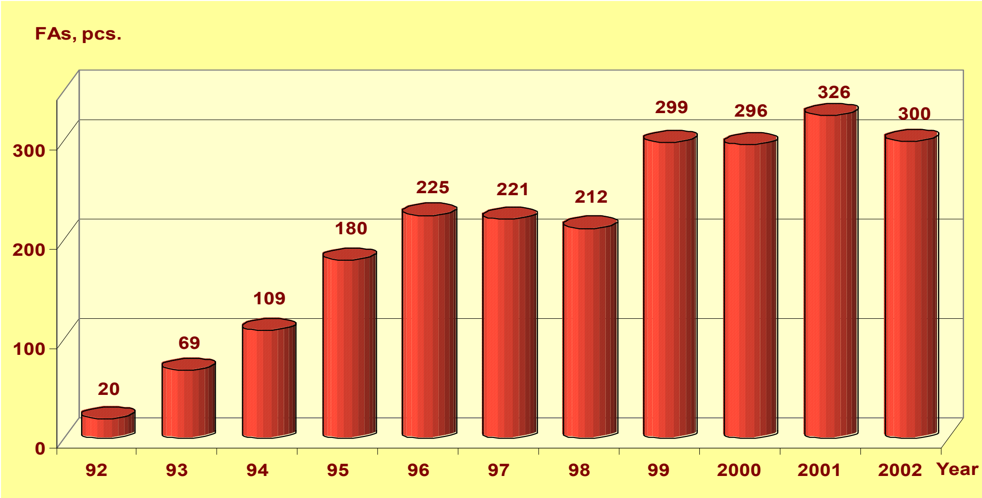

Figure 3. Number of WWER-1000 FAs, which have been in operation 4 fuel cycles within the period of 1992-2002

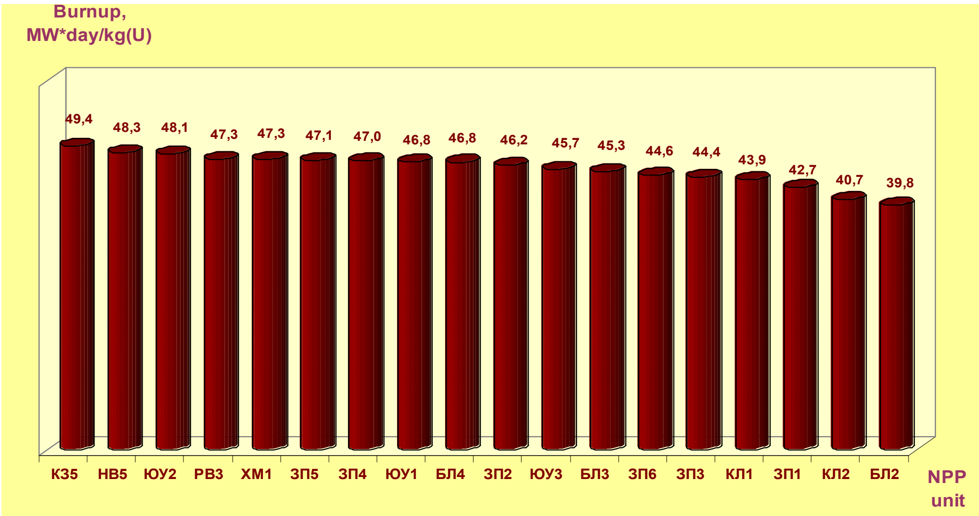

Figure 4. Average burnup of WWER-1000 FAs discharged in 2002 after completion of 4 fuel cycles

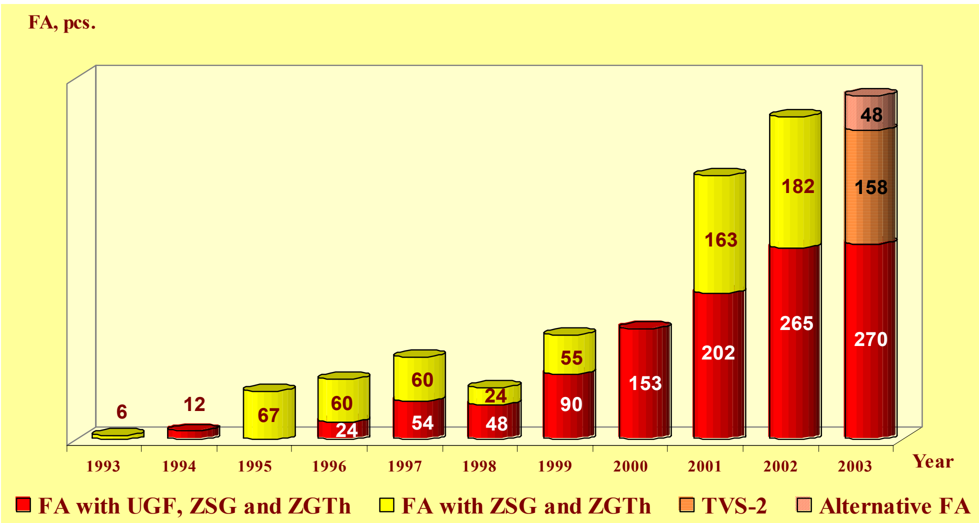

Figure 5. Dynamics of advanced WWER-1000 FAs commissioning

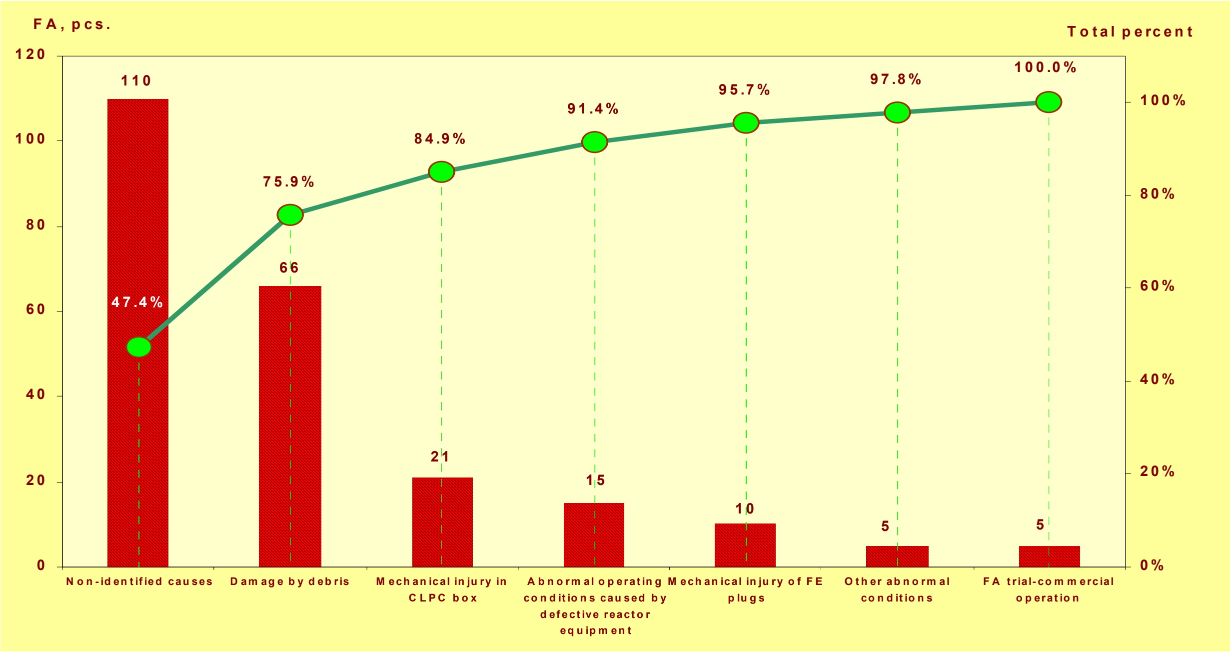

Figure 6. WWER-1000 FAs distribution as per depressurization causes within the period of 1990-2002

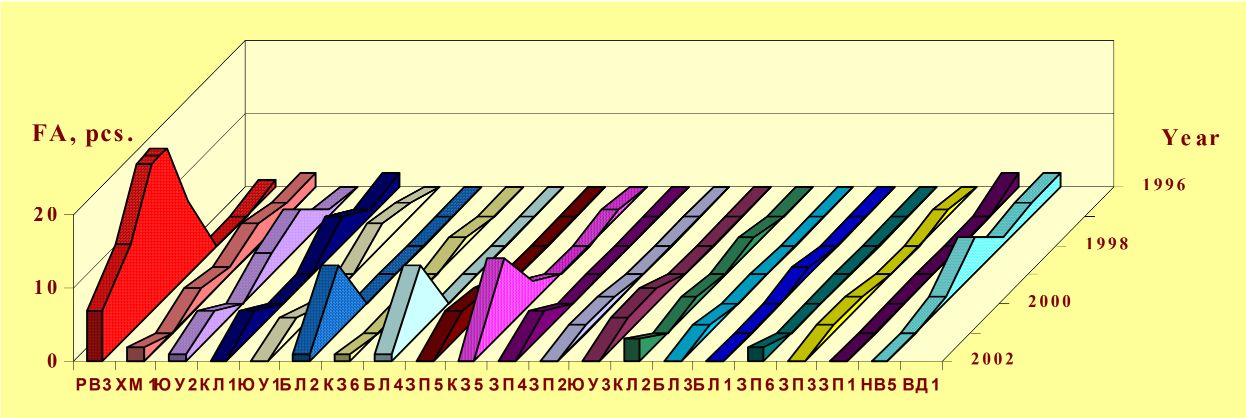

Figure 7. Leaky WWER-1000 FAs distribution as per NPP units

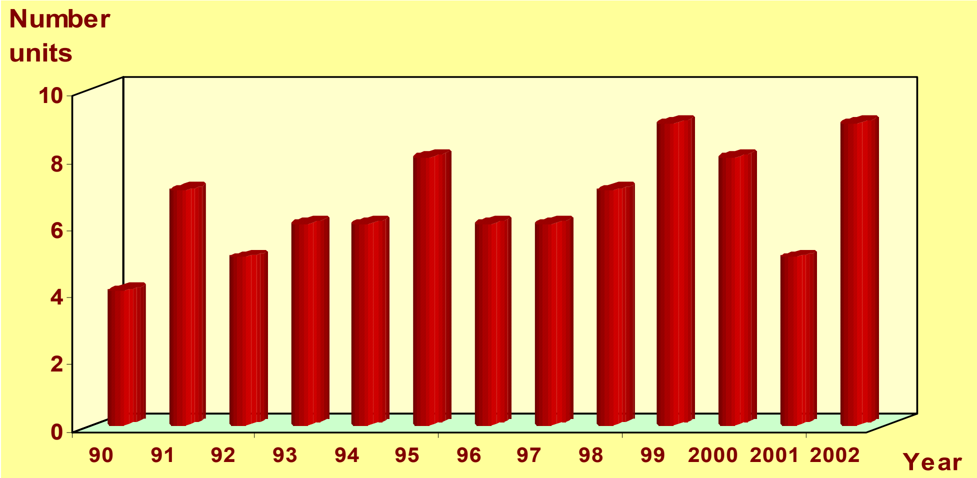

Figure 8. Number of WWER-1000 units with zero damage rates over the period of 1990-2002