Operation experience of the advanced fuel assemblies at Unit 1 of Volgodonsk NPP within four fuel cycles

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1. Introduction

The first commissioning of Unit 1 of Volgodonsk NPP with standard reactor WWER-1000 (project V-320) was in 2001. The reactor core, starting from the first fuel charge, was arranged completely with AFAs (figure 1). This provided for the actual possibility to obtain the experience in startup and operation of the core, completely arranged with AFAs, to get a possibility of performing the comprehensive check for justification of newly commissioned Units and justification of design solutions accepted in the design of reactor core for "Tianwan" NPP, "Bushehr" NPP and NPP "Kudankulam". The first fuel charge of Unit 1 of Volgodonsk NPP is a reference and unified for "Tianwan" NPP (V-428), "Bushehr" NPP (V-446), NPP "Kudankulam" (V-412) with small differences caused by design features of RP V-320.

The first core charge of Unit 1 of Volgodonsk NPP was arranged of 163 AFAs, comprising 61 CPS ARs and 42 BAR bundles. The subsequent fuel charges were arranged of AFAs with gadolinium oxide integrated into fuel instead of BAR.

By 2005 the AFAs operation experience has been accumulated during 4 years that confirmed their serviceability and efficiency for wide application.

By the moment of commissioning of Unit 1 of Volgodonsk NPP all measures on assurance of the emergency protection reliability have been implemented including optimization of supporting surfaces for FAs in the reactor that could be made at clean Unit only.

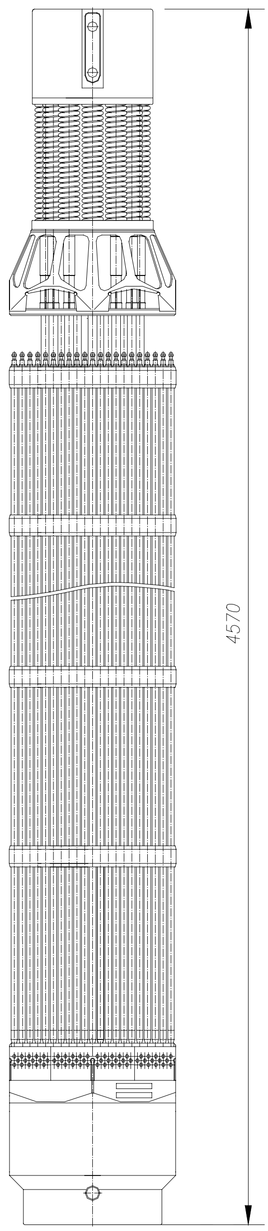
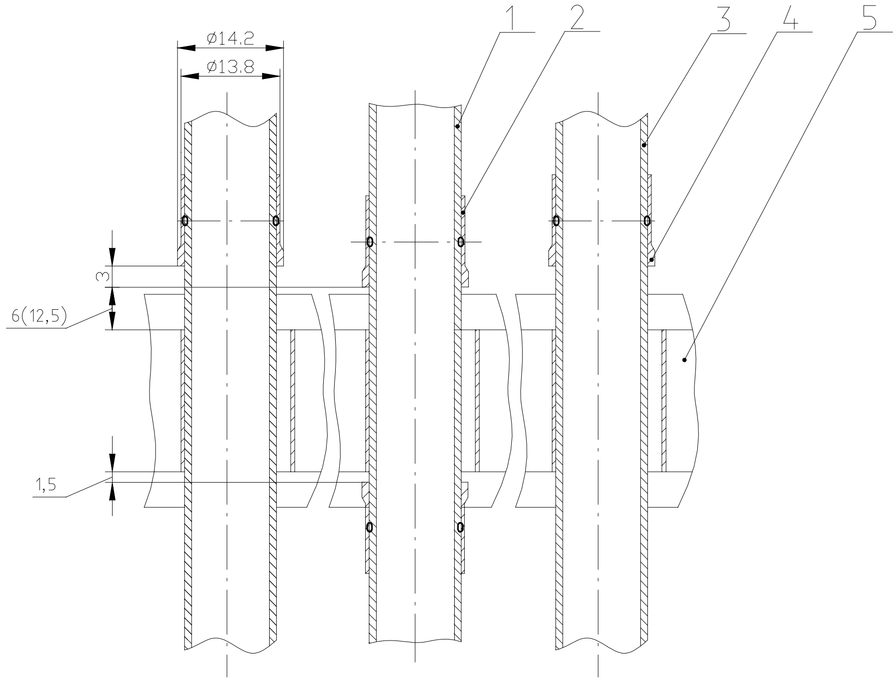


Figure 1 - AFA

2. AFA design

As to the geometry the AFA is similar to jacket-free standard FA that has been operated at RP of V-320 type since 1981. The main difference of AFA from the standard FA is using the material with decreased neutron absorption – zirconium alloy – within the assembly fuel part. Besides, in development of AFA the end pieces of the assembly – a tail-piece and a cap were improved. The tail-piece was improved to reduce metal consumption and the cap – to optimize the conditions of FA supporting frame hold-down force.

By the moment of the core loading at Unit 1 of Volgodonsk NPP the 7-year operation experience of AFAs at Balakovo NPP has been accumulated (starting from 1993). During this time the initial AFA design was upgraded in order to improve the reliability of axial fastening the spacing grids - to eliminate their displacement the restraining and safeguard sleeves (figure 2) were introduced.



1 – Central tube
2 – Restraining sleeve
3 – Guiding channel
4 – Safeguard sleeve
5 – Spacing grid

Figure 2 – Fastening of spacing grids in AFA

In the course of AFA operation at Unit 1 of Volgodonsk NPP the two main modernizations of the design were implemented:

1. To ensure more compact arrangement of FAs in the core and, accordingly, to reduce possible bowing in the course of operation, the AFA “width across flats” was increased. At the first stage the increasing was made using local projections - “bulges” – on the spacing grid rim (figure 3), and then, by increasing the statistical average “width across flats” of the spacing grid.

2. To improve indices of strength the AFA lower supporting unit was upgraded, that includes the lower tips of fuel rods, the lower supporting grid and a tail-piece.

The above-mentioned modernizations of AFA design were aimed at improving its reliability and implemented on the basis of operation experience of both AFAs, and FAs of other types, at the operating WWER-1000 Units.

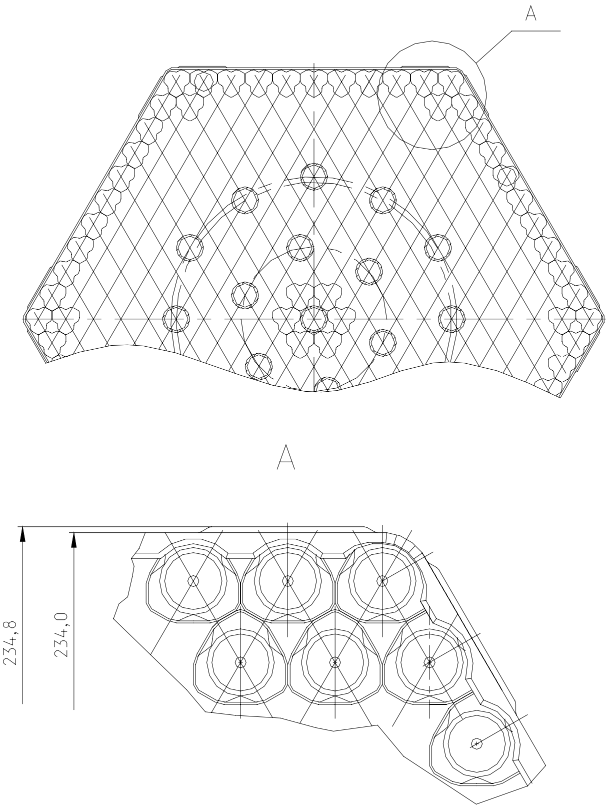


Figure 3 – “Bulges” on the spacing grid rims

3. Results of performing the preoperational work at NPP in the part concerning provision of the reactor core design state during operation

During preoperational work at NPP a set of tests and checks was performed aimed at determination of the conditions under which the core will operate. The given work included the following:

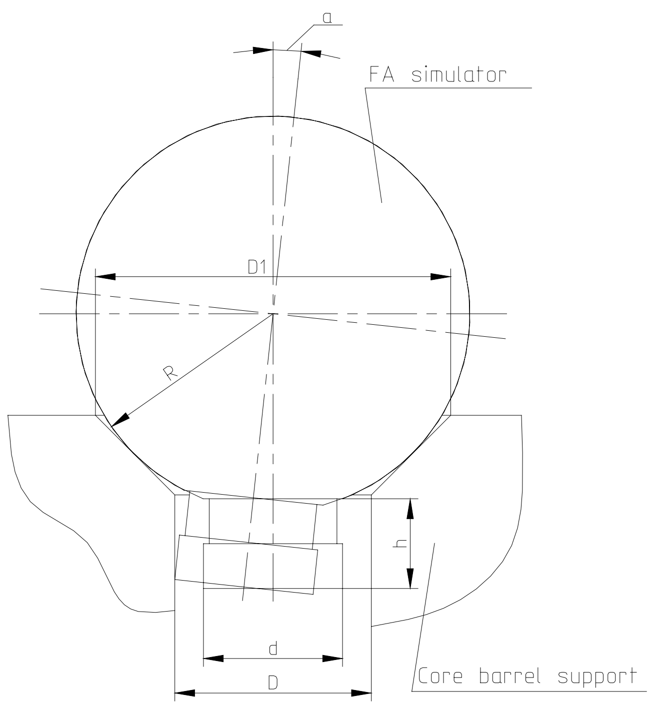
- measurement of horizontality of the core barrel supporting thimbles – during reactor test assembling;
- measurements of overall dimension for FA installing under compressed state (following sealing the reactor main joint (RMJ)) and adjustment of height elevation of PTU – during reactor test assembling;
- loading the simulated core at the stage of the reactor assembling for performing the circulation washing, hot and cold running of reactor plant (RP);
- measurements of extension of the protective tube unit (PTU) projections above RMJ following loading the simulated and actual cores;
- measurements of friction forces in upward and downward movement of CPS CRs from PTU and upper unit (UU) in performing the reactor assembling for running-in and reaching the first criticality;
- determination of thermohydraulic characteristics of the simulated core in performing the RP hot and cold running;
- determination of vibration loading of FA simulator components – a cap, a tail-piece, guiding channels, fuel rod simulators – in the course of RP cold and hot running;

- determination of coolant pulsation parameters in the region of FA simulator caps and tail-pieces in performing the reactor cold and hot running.

Preoperational work performed at Unit 1 of Volgodonsk NPP showed satisfactory results – the RP equipment state provided for the core operation under design conditions.

In loading the simulated core at the stage of the reactor assembling for performing the cold and hot running it was revealed that the state of the core barrel supports for FAs did not ensure a possibility for the vertical position of FA simulators. The given fact, according to the studies performed earlier at the test benches of OKB "Gidropress", could affect greatly the core state during operation, and namely, the core bowing.

Therefore before loading the core at Unit 1 of Volgodonsk NPP the core barrel supporting surfaces for FAs was brought to the design state. Measurements, performed with the use of specially developed gauge, simulating the FA tail-piece supporting surfaces, showed the necessity to modify 97 out of 163 supports of the core barrel. Calculational model for determination of FA deviation from vertical position in the core barrel support, is presented in figure 4. The following criteria were accepted to be the acceptance criteria in performing the given modification:



Fiqure 4 – Calculational model for determination of FA deviation in the core barrel support from vertical position

- maximum deviation of FA simulator, installed freely into the core barrel support, from the vertical position shall provide for engaging with the fuel handling machine grip and for a possibility of installing the adjacent FAs;
- a possibility shall be provided for installing the FA simulator into vertical position;
- fitting of FA simulator tail-piece spherical surface to the core barrel support taper surface shall be provided that prevents generation of moment for the tail-piece turn in the core barrel support.

Loading the first core performed after modification, as well as operation of Unit 1 of Volgodonsk NPP during 4 fuel cycles, showed the efficiency of the measures taken that is demonstrated by the operation results considered below.

Experience in the modifications made for the core barrel supports at Unit 1 of Volgodonsk NPP was used in manufacturing the in-vessel equipment for “Tianwan” NPP and NPP “Kudankulam”. That is, “adjustment” of the core barrel supports for FAs to the vertical position is implemented into this stage of test assembling of these reactors at the Manufacturer. Similar methods were applied to measurements and modification of the core barrel supports at Unit 3 of Rovno NPP before the first core loading.

4. Experience in operation of AFAs at Unit 1 of Volgodonsk NPP during four fuel cycles

Data on AFAs operation at Volgodonsk NPP are presented in Table 1. Design value of AFA-averaged fuel burnup is 41,3 MW·day/kg U, and AFA-maximum burnup is 43,4 MW·day/kg U. According to Table 1 the AFAs reached their maximum design burnup after four years of operation with regard for an error of neutron physics calculations and determination and restoration of the core power filed.

Table 1 – Data on FAs operation

No. of fuel cycle	Number of makeup FAs, pcs.	Cycle length, eff. days	Average/Maximum burnup, MW·day/kg U
1	163 AFAs	307,3	13,10 / 15,17
2	54 AFAs with UGd fuel	300,0	21,81 / 27,91
3	49 AFAs with UGd fuel	295,9	26,29 / 39,89
4	48 AFAs with UGd fuel	295,3	41,27 / 42,91

During operation of fuel cycles and preventive maintenance of 2003, 2004 and 2005 the necessary tests and measurements were performed concerning the core. The purpose of these measurements was determination of correspondence of actual operational characteristics of the core with those provided in the design.

Physical and thermohydraulic similarity was determined by the specially developed programs and methods and confirmed with sufficient reliability.

Mechanical stability of the structure was of special interest. For assessment of the core mechanical state and its prediction for the coming cycle there is a list of checks and measurements identified at the operating WWER-1000 Units. During Unit shutdown for preventive maintenance and prior to starting the refuelling procedures these checks include the following:

1. Measurement of drop time of CPS CRs under scram mode;

2. Determination of CPS CRs upward and downward movement forces from the upper unit;
3. Determination of PTU projections above the RMJ;
4. Measurement of linearity of the guiding channels of individual FAs using the special in-pile detectors.

Similar list of check was followed on completion of the core refuelling, reactor assembling and at the beginning of cycle..

Alongside with these procedures the refuelling process itself was controlled from the viewpoint of meeting the criteria established for the FAs and CPS ARs friction forces during their motion within the core. No facts of exceeding the established maximum friction forces of FAs and CPS ARs were registered within the four refuellings.

Data on operation of the core, completely loaded with AFAs, within four fuel cycles, obtained at Unit 1 of Volgodonsk NPP, were analyzed and compared to the data base available for other operating WWER Units with the fuel of similar and alternate design. The operational data presented below show evident acceptability of the obtained results for the Unit operation, as well as convincing justification of AFAs serviceability and reliability for newly commissioned Units with fuel of the given type.

<u>CPS CRs drop time under scram mode</u>

CPS CRs drop time under scram mode is the parameter governing RP safety under anticipated operational occurrences and accident situations. In design analyses of RP safety the justification is given for non-exceeding the design limits of fuel rod cladding damage providing the CPS CRs will be completely inserted of into the core under scram within 4 seconds, not more.

To confirm the given design criterion the requirement is introduced into the process guides of safe operation for each WWER-1000 Unit for its mandatory check at the beginning and end of fuel cycle with the Unit being in “hot” state, i.e. the Uni5t is at nominal parameters as to the coolant flow rate and temperature, but the core is subcritical. Results of measurements of CPS CRs drop time at Unit 1 of Volgodonsk NPP within 4 fuel cycles are presented in figure 5.

Beginning of cycle   End of cycle

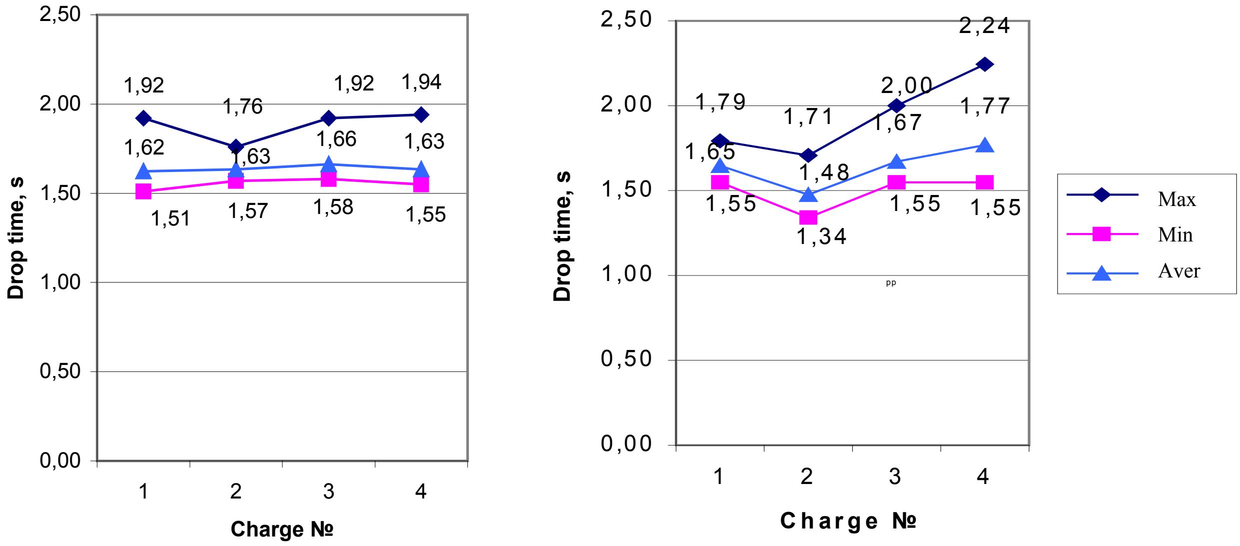


Figure 5 – CPS CRs drop time

The given results show that the CPS CRs drop time under scram mode were at the stable low level of ~1,5…2,3 s. There is a considerable margin till the design criterion of 4 seconds.

<u>Friction forces during CPS CRs upward-downward motion from the upper unit</u>

Measurements of CPS CRs upward-downward motion from the sealed upper unit are made in order to determine the friction forces of CPS AR, engaged with the CPS drive extension shaft, during its motion in the system FA-PTU. On the basis of AFA operation experience at Balakovo NPP, as well as on the basis of design analyses the criterion is accepted to be that for assurance of CPS CRs drop time of not more than 4 seconds the friction force of CPS CRs shall not exceed 10 kgf at the beginning of fuel cycle.

Results of measurements of CPS CRs friction forces at Unit 1 of Volgodonsk NPP within 4 fuel cycles are presented in figure 6.

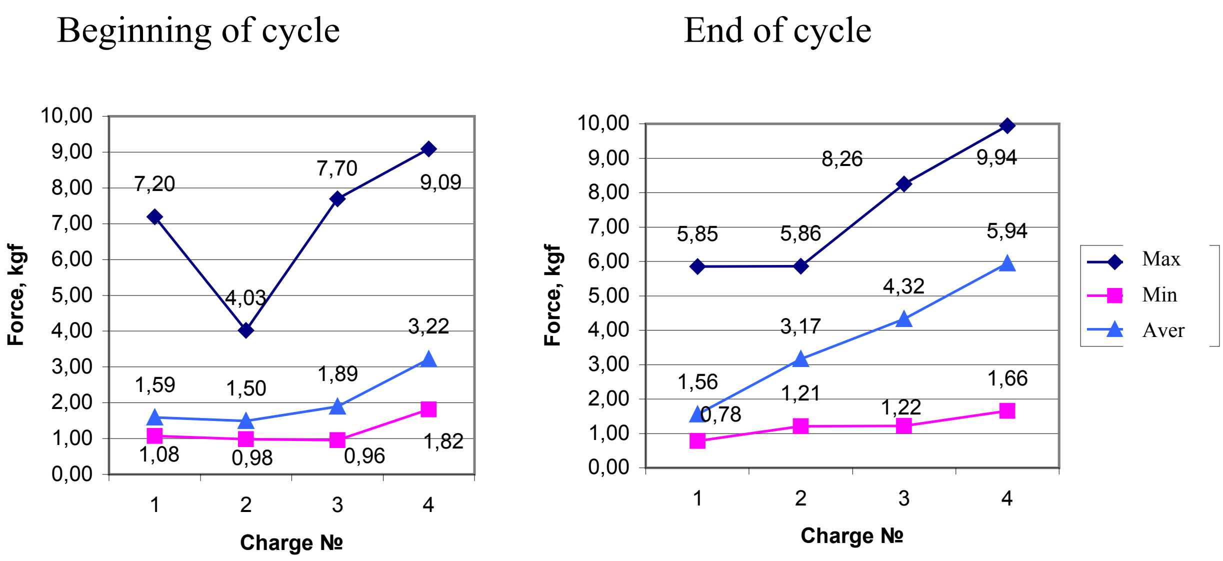


Figure 6 – Friction forces in CPS CRs upward-downward motion

The given results show that there is a tendency of rise in friction of CPS CR depending on increase in the core operation time, however all values of friction forces (before and after operation of fuel cycle) are within the design limits. AFA deformation, accumulated during four fuel cycles, doers not affect the core operational characteristics.

The important circumstance is the fact that the friction force at the end of the fourth cycle corresponds approximately to the friction force at the beginning of cycle. This is indicative of the fact that in the course of operation no considerable AFA shape variation occurs, that is, the core is stable.

<u>Measurements of linearity of AFA guiding channels</u>

Measurements of linearity of AFA guiding channels, performed at Unit 1 of Volgodonsk NPP, are supplementary to the standard checks characterizing the core mechanical state. Results of the measurement are presented in figure 7 and show that there is a tendency to stabilization of AFA bowing values.

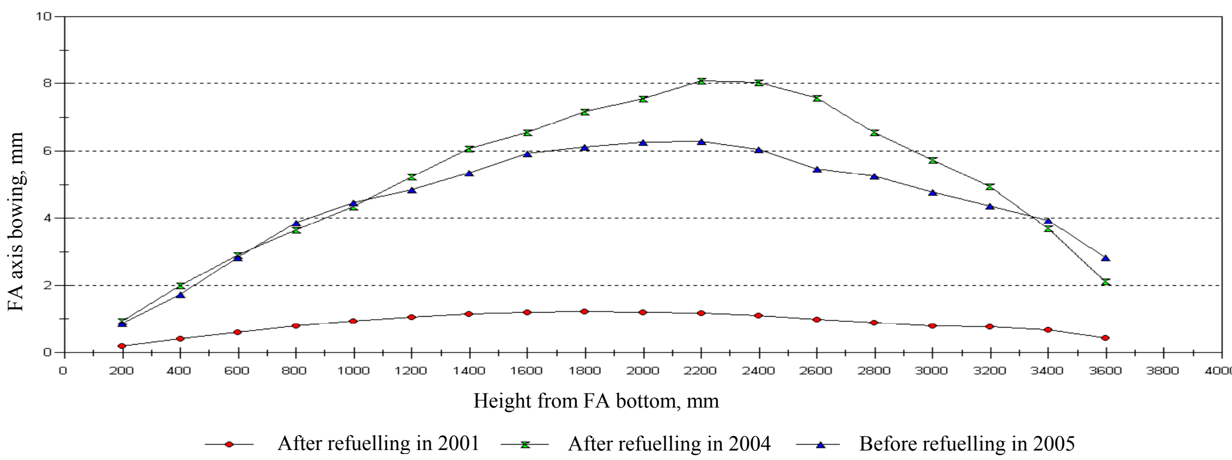


Figure 7 – Average values of AFA axes bowings

PTU projections above RMJ

The value of PTU projections above the RMJ sealing surface characterizes the minimum value of FA caps stroke with the sealing of upper unit. Results of measurement of the value of PTU projections above the RMJ sealing surface, measured at Unit 1 of Volgodonsk NPP during four fuel cycles, are presented in figure 8.

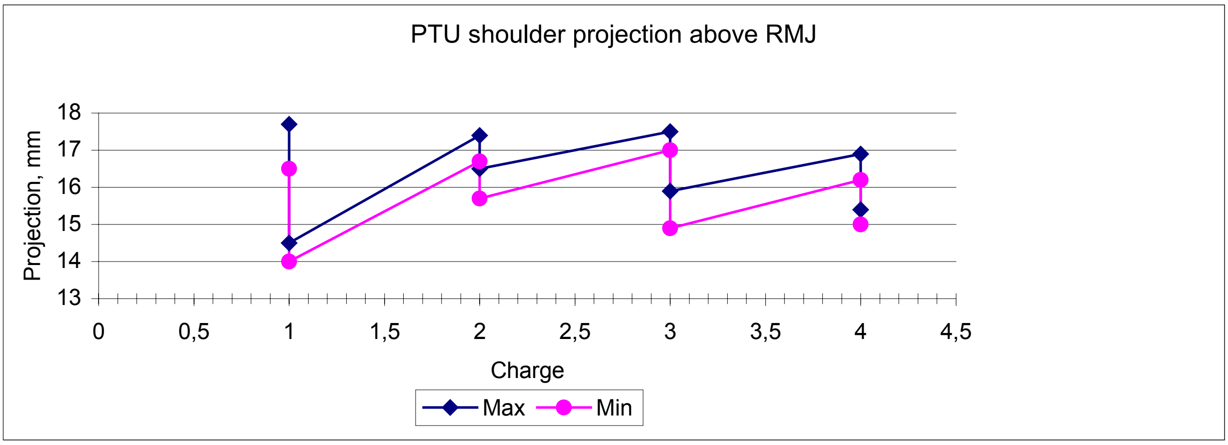


Figure 8 – PTU projections above RMJ before and after refuelling

The presented results show that spring of alloy XH77TЮР used in AFA structure provides for minimum relaxation of the cap spring unit force. Considering radiation-thermal creep of the guiding channels the value of AFA cap stroke in sealing the upper unit is within the design limits.

5. Leak tightness check of AFA fuel rod claddings

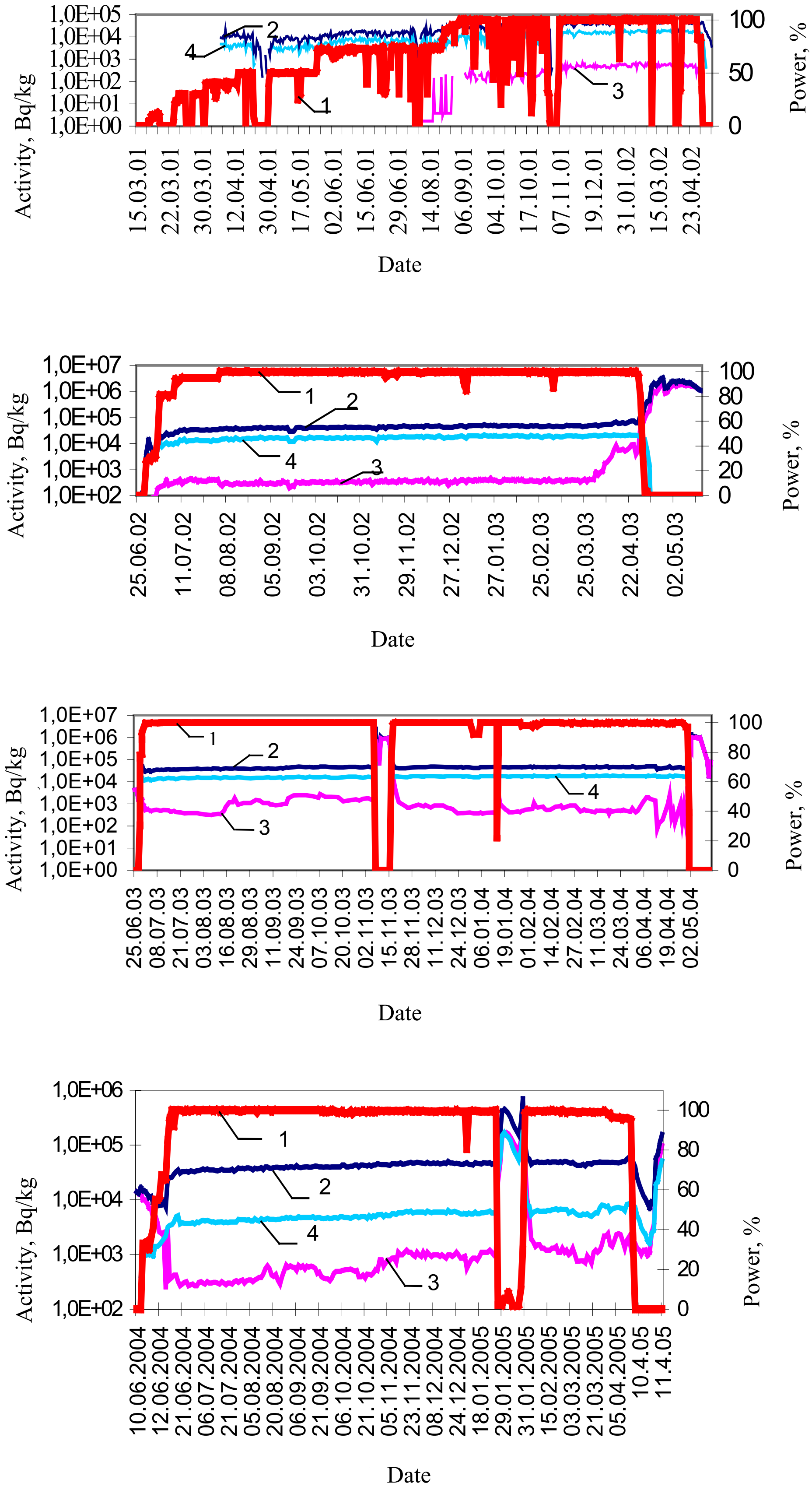
The main feature governing the core operability and reliability is a possibility to maintain the leak tightness of cladding of each fuel rod in the core within the whole service life. The given feature governs, first of all, such important indices of activities at the NPP, as a whole, as level of personnel dose commitment and level of contamination of the environment.

Results of performing the fuel rod cladding leak tightness check at the operating reactor of Unit 1 of Volgodonsk NPP are presented in figure 9.

Total activity of the primary coolant by the sum of reference iodine radionuclides was kept at stable low level, the stepwise rise in coolant activity by iodine isotopes was not observed.

Results of performing the fuel rod cladding leak tightness check at the operating reactor made it possible not to perform leak check of cladding using DADS during preventive maintenance in 2002, and during preventive maintenance of 2003, 2004 and 2005 to perform this check only on the AFA withdrawn.

Within the whole time of the core operation at Unit 1 of Volgodonsk NPP no leaky AFAs were detected.



1 – Unit power; 2 – sum of iodines; 3 – Iodine-131; 4 - Iodine -134

Figure 9 – Fuel rod cladding leak tightness check at the operating reactor

6. Conclusions

6.1 Results of operation of the core at Unit 1 of Volgodonsk NPP during four fuel cycles showed that AFA is sufficiently reliable and serviceable.

6.2 Activity of the primary coolant of Volgodonsk NPP is at stable low level. During the whole time of the core operation at Unit 1 of Volgodonsk NPP no leaky AFAs were revealed.

6.3 Modifications of the internals, made during preoperational work, are reasonable and effective to provide for fuel mechanical stability in the course of operation.

6.4 Modifications, made in AFA structure during operation at Unit 1 of Volgodonsk NPP, are aimed at improving the service and operational reliability of its components. Correctness of the solutions taken is confirmed by AFAs operation experience both at Volgodonsk NPP, and at other operating Russian NPPs.