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TECHNICAL REPORT

FUEL INTEGRITY ANALYSIS FOR BUSHEHR NPP

Moscow

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Abbreviations

NPP – Nuclear Power Plant

WWER – Water-Water Energetic Reactor

RNG – Radioactive Noble Gases

FA – Fuel Assembly

FFDS – Failed Fuel Detection System

# Fuel integrity assessment for Bushehr NPP, Unit 1, Fuel Cycle 4

## Operation parameters of Unit 1 and coolant activity during fuel campaign No.4

Operation parameters of Unit 1 and coolant activity during fuel campaign No.4 (for time interval from April 1 through October 15, 2017) are shown in figures 1-7.

Reactor thermal power [MW] and flow rate to ion-exchange filters (Q\*100) [t/h]

Iodine activity [Ci/kg]



![](data:None;base64,)

Figure 1 – Data for the 4th fuel cycle, Unit 1: reactor operation parameters and iodine activity (Ci/kg) in primary coolant during cycle 4, Bushehr-1

Relations between iodine normalized release rates



Figure 2 – Ratio of normalized release rates of iodine radionuclides during cycle 4, BNPP-1 (the left vertical axis); the right vertical axis is for reactor thermal power (MW)

![](data:None;base64,)

Cesium activity [Ci/kg]

Noble gas activity [Ci/kg]

Activated coolant and corrosion products activity [Ci/kg]

Ratio of activities Kr/Xe

Figure 3 – Activity (Ci/kg) of cesium radionuclides in primary coolant, Unit 1, cycle No.4

![](data:None;base64,)

Figure 4 – Activity (Ci/kg) of noble gases in primary coolant, Unit 1, cycle No.4

![](data:None;base64,)

Figure 5 – Activity (Ci/kg) of activated coolant and corrosion products in primary coolant, Unit 1, cycle No.4

![](data:None;base64,)

Figure 6 – Ratio of activities in pairs 85mKr/135Xe and 88Kr/135Xe, Unit 1, cycle No.4

Ratio of activities Xe/I



Figure 7 – Ratio of activities in pairs 133Xe/133I and 135Xe/135I, BNPP-1, cycle 4 (the left vertical axis); the right vertical axis is for reactor thermal power (MW)

## The state of the fuel as of September 21, 2017

For time interval from April 1 to July 31, 2017, data on fuel cycle No.4 at BNPP-1 were analyzed in Technical Report [1]. Additional analysis was performed for data from July 31 to September 21, 2017.

The following conclusions were drawn.

As of September 21, 2017, there was at least one leaking fuel rod in the core. The upper estimate for the number of leaking fuel rods in the core was 2. No indications of fuel washout into coolant were detected.

## Current state of the fuel in the core

Data on fuel cycle No.4 at BNPP-1 from September 21 to October 15, 2017, are analyzed below.

Reactor power was dropped twice within the time interval under consideration: in September 25-26 by ~ 70%, and in October 5-6 by ~ 20%. The other time reactor operated under the nominal power. Power drops were accompanied by spiking in activity of 131I and radioactive noble gases. During the power drops, ratios of activities 131I/134I and 88mKr/135Xe increased. When the reactor returned to the nominal power level, activity of all the reference radionuclides tended to return to previous values. This gives evidence of no new fuel failures in September and October.

Throughout the campaign activities of long-lived 134Cs and 137Cs were low, no more than ~ 2⋅10–8 Ci/kg, just as before the fuel failure (background level of activity). Activities of 134Cs and 137Cs didn’t increase significantly during fuel failure in May 2017 and during power drops in September-October 2017. This may indicate low fuel burnup in the leaking fuel rod (rods). At low fuel burnup only a small amount of cesium accumulates in the fuel. Hence, while spiking, its activity doesn't exceed even the background level. On this basis it may be supposed that the leaking fuel is under its 1st or 2nd year of operation.

Contamination of the core by tramp uranium was monitoring by method [2,3]. It was shown that no fuel washout into the primary circuit took place throughout the campaign.

## Conclusions and recommendations

As of October 15, 2017, most probably there is one leaking fuel rod in the core. The upper estimate for the number of leaking fuel rods in the core is 2. According to preliminary estimations, leaking fuel may be under its 1st or 2nd year of operation. It should be noted that one FA can contain more than one leaking fuel rod.

No indications of fuel washout into coolant are detected.

Bushehr-1 NPP has no equipment for sipping leakage tests in the mast of the refueling machine. So, currently the following approach for detection of the leaking fuel may be proposed for the upcoming reactor outage.

First, leakage tests in the FFDS casks should be performed for fuel assemblies after their 1st cycle. If a leaking FA is found, leakage tests in the FFDS casks may be stopped. However, it is recommended to test all the FAs after 1 and 2 years of operation. It is helpful to assure that no leaking fuel will be loaded in the core before the 5th campaign. FAs of greater burnup should be tested only if leaking FA was not found among FAs after 1 and 2 years of operation[[1]](#footnote-1).

The above recommendations may be corrected in the course of further monitoring of activity and after processing the data on cesium spiking during reactor shutdown.

References

1. Likhanskii V.V., Evdokimov I.A., *et al.*, “Fuel integrity analysis for fuel cycles at WWER-1000 power units during quarters I-II, 2017. Post-test analysis of fuel cycles finished in quarter I, 2017,” Tech. report SRC RF TRINITI #10/NIR-7302, 09.10.2017 (*in Russian*)
2. Evdokimov I.A., Likhanskii V.V., *et al.*, “Advanced techniques of fuel integrity analysis during reactor operation for up-to-date fuel cycles and fuel types”, Intern. Tech. Meet. on WWER fuel performance, Bulgaria, Nessebar, September 26-30, 2016 (*in Russian*)
3. Likhanskii V.V., Evdokimov I.A., *et al.*, “Elaboration of advanced techniques of fuel integrity analysis during reactor operation. Criteria for detection of severe secondary degradation of leaking fuel rods and fuel washout into coolant to meet the objectives of “Zero Failure Level” Project”, Tech. report SRC RF TRINITI #10/NIR-7127, 28.07.2016 (*in Russian*)
4. RG NO[[2]](#footnote-2) 1.1.2.10.0521-2009 «Fuel assemblies for WWER-1000 nuclear reactors. Standards for detection of leaking fuel”, Revision #2, Rosenergoatom, 2016 (*in Russian*)

1. There were some cases in WWERs when standard technique of leakage testing in the FFDS casks didn’t reveal leaking fuel rods even with large-scale visible damage. This is because during reactor operation radionuclides wash out from the region of the fuel rod which is close to the defect in cladding. In this case the release of fission products from the leaking fuel rod during the standard leakage test may be insignificant compared to background activity. There is more sensitive technique of leakage testing which involves pressure cycling in the FFDS casks [4]. “Express-variant” of this test technique has little effect on duration of the leakage test and on dose rates for the staff. [↑](#footnote-ref-1)
2. RG NO = regulation guidelines for nuclear operator. [↑](#footnote-ref-2)