Some Aspects of Nuclear Fuel Use at Ukrainian NPPs during Last Two Years

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Abstract

For many years SSTC NRS actively participates in licensing of fuel reloading and in the implementation of new nuclear fuel types at the nuclear power plants in Ukraine. Results of the nuclear fuel use for last years are presented in the paper. The results are based on NPP documentation submitted for licensing to the regulating body of Ukraine and based on our estimations and independent calculations. The first part of the paper contains a brief characteristic of the fuel cycles at Ukrainian NPPs. Types of loaded fuel are described also. Experience of new fuel type implementation is presented (Westinghouse FA and TVSA-12 for WWER-1000 reactors). The next part of the paper presents a new regulatory document under development and further new fuel implementation (WWER-1000 reactors). The last part of the paper describes some issues with fuel use.

Keywords: WWER, TVSA, TVSA-12, TVS-W, TVS-WR, Westinghouse, NPP

1. Introduction

For many years SSTC NRS actively participates in the licensing of fuel reloading and in the implementation of new nuclear fuel types at the nuclear power plants of Ukraine [1, 2, and 3]. This paper presents results on the nuclear fuel use for last two years. The results are received on the basis of the NPP documentation represented for licensing to regulatory authority of Ukraine (SNRIU), and on the basis of own estimations and independent calculations.

2. Use of Fuel Assemblies on Ukrainian NPPs

Table 1 below lists the types of FA loaded in reactor core of Ukrainian NPPs. At the current moment, the reactor core completely consists of TVSA at ZNPP units 1-6, KhNPP units 1-2 and RNPP units 3-4. Usually both WWER-440 reactors

Table 1. The types of FA loaded in reactor core of Ukrainian NPPs

RIVNE NPP, Unit 1, WWER-440	RK_II+TVS_II
RIVNE NPP, Unit 2, WWER-440	Zr RK+TVS,RK_II+TVS_II
RIVNE NPP, Unit 3, WWER-1000	TVSA
RIVNE NPP, Unit 4, WWER-1000	TVSA
ZAPORIZHZHYA NPP, Unit 1, WWER-1000	TVSA
ZAPORIZHZHYA NPP, Unit 2, WWER-1000	TVSA
ZAPORIZHZHYA NPP, Unit 3, WWER-1000	TVSA
ZAPORIZHZHYA NPP, Unit 4, WWER-1000	TVSA
ZAPORIZHZHYA NPP, Unit 5, WWER-1000	TVSA
ZAPORIZHZHYA NPP, Unit 6, WWER-1000	TVSA
SOUTH UKRAINE NPP, Unit 1, WWER-1000	TVSA
SOUTH UKRAINE NPP, Unit 2, WWER-1000	TVSA
SOUTH UKRAINE NPP, Unit 3, WWER-1000	TVSA+TVS-W+TVS-WR
KHMELNITSKY NPP, Unit 1, WWER-1000	TVSA
KHMELNITSKY NPP, Unit 2, WWER-1000	TVSA

Table 2. Power generation of FA at Ukrainian NPPs (relative)

NPP	2012	2013	2014	2015
RNPP-1	-	1.03	1.04	1.09
RNPP-2	1.06	**1.06**	**1.20**	-
RNPP-3	1.09	**1.10**	1.20	-
RNPP-4	1.10	-	1.10	-
ZNPP-1	**1.11**	**1.10**	1.19	1.21
ZNPP-2	1.07	1.06	1.21	**1.24**
ZNPP-3	**1.11**	**1.10**	1.22	**1.24**
ZNPP-4	1.08	1.09	1.21	1.23
ZNPP-5	0.95	0.94	1.05	1.01
ZNPP-6	0.94	0.95	1.10	-
SUNPP-1	0.92	0.99	0.99	0.97
SUNPP-2	1.06	1.04	1.19	-
SUNPP-3	1.04	1.06	1.18	-
KhNPP-1	1.09	**1.10**	1.20	-
KhNPP-2	1.10	-	1.10	-

Table 3 . Power generation of FA declared by the vendor at the new nuclear fuel type implementation (relative)

NPP, fuel type	Power generation of FA, relative
RNPP-2, TVS_II	1.07
RNPP-1, TVS_II	1.01
ZNPP-3, TVS-A	0.99
KhNPP-2, TVS-A	1.08
SUNPP-1, TVS-A	0.94
SUNPP-3, TVS-WR	1.01
SUNPP-3, TVS-W	1.06
SUNPP-2, TVS-W	1.07
ZNPP-5, TVS-W	1.07
RNPP-4, TVSA-12	**1.38**

(RNPP–1 and 2) are loaded with second-generation FAs, but in case of non-leak-tight assemblies, they are replaced by zirconium FAs from time to time (RNPP unit 2).

Table 2 presented FA power generation for different Ukrainian NPPs. The data were received at the end of July 2015 on the basis of the calculations performed at SSTC NRS (DYN3D/DERAB, [1, 4-7]) taking into account the actual power schedules for the units. Power generation of one FA was calculated as the basic criterion, i.e. the value of one core cell use efficiency. In addition, the power generation of one FA declared by the vendor for the new nuclear fuel type implementation is shown in Table 3.

3. Licensing of TVS-WR (Westinghouse FUEL, 42 FAs, SUNPP Unit 3, 2015)

Contract for the introduction of fuel from Westinghouse for Ukraine NPP was provided for production and supply of nuclear fuel during 2011-2015 for the annual batch reload of three WWER-1000 units. In 2011-2012 four reload batches of TWS-W fuel assemblies were supplied to SUNPP units 2 and 3.

During the refueling outage in 2012 were found mechanical damages of TVS-W spacer grids, which operated in the SUNPP core units 2 and 3. Root cause of damage of spacer grids was found as design flaws of TVS-W. Thus all TVS-W, operated in the cores of SUNPP units 2 and 3, considered tight. In order to achieve greater stiffness of fuel assembly design Westinghouse Company performed works on completion of construction of the fuel assembly. Specialists of Westinghouse to demonstrate improvement in performance tested the new modification of FA named “TVS-WR”.

In July 2013 the National Nuclear Energy Generating Company Energoatom developed the conceptual technical decision “On introduction of TVS-WR improved design in SUNPP unit 3” and submitted it to the SNRIU of the application licensing for TVS-WR (improved design) and technical design conditions in the TVS-WR.

In November 2014 a reload batch of 42 TVS-WR for unit 3 was delivered and accepted at the site of SUNPP.

In December 2014 the SNRIU agreed a loading of 42 TVS-WR made by Westinghouse company in the core of SUNPP unit 3 during the 2014 outage, which is ended in April 2015. And it operates now without any issues

During the outage in 2014 from 16 to 28 February 2015 conducted inspection and examination of the TVS-W, which operated as part of the fuel loading SUNPP unit 3, using SIRP equipment.

30/12/2014 Westinghouse and Energoatom signed additions to the contract for the supply of nuclear fuel from Westinghouse Company (TVS-WR) till 2020.

Now SNRIU reviews a technical solution to expand the trial operation of TVS-WR improved design to other WWER-1000 units. There expressed an intention to use the remaining TVS-W in subsequent batches.

4. Status of TVSA-12 (TVEL FUEL)

TVSA-12 is designed for use in VVER-1000 reactor core in 5x1 (five-year fuel cycle) and 3x1.5 (18-month fuel cycle) fuel cycles. TVSA-12 has an enhanced design with a reduced number of spacing grids, redesigned fuel rods, and increased uranium consumption.

Experimental batch of TVSA-12 at Ukraine NPP was previously planned in 2014 at RNPP unit 4 according to „Conceptual solution for implementation of TVSA-12 on the power unit RNPP 4“ agreed by SNRIU.

Substantiating materials for TVSA-12 under the „Program on justification and introduction of TVSA-12 fuel at Rivne nuclear power plant unit 4“ were sent for review and approval to SNRIU, but were returned for review requests to JSC „TVEL“ relating extended dry storage of TVSA-12 spent fuel and reference experience report for these FA from Kalinin NPP unit 1.

By decision of Energoatom implementation of TVSA-12 is postponed up to obtaining the required information [8].

5. The Plans on Implementation of New Fuel on Ukrainian NPPs

The plans for implementation of new types of fuel are defined by necessity of increase of economic parameters NPPs, strategy of development of atomic engineering of Ukraine till 2030 (order Cabinet Minister of Ukraine N 436-p from 27.07.2006), the decree of Ukrainian President 156/2008 and dispositions of Energoatom. The basic introductions of new types of fuel are:

- Implementation of TVSA-12;
- Implementation of TVS-WR.

6. Load-following Operation Mode

Functioning of the United Energy System of Ukraine in a changing economic environment, as well as a new model of the electricity market of Ukraine, which will take effect in 2017, led to the feasibility of nuclear power plants to operate in the daily power control.

From April 20 to May 12 this year on the 2nd unit of Khmelnitsky nuclear power plant was carried out a next step of a trial operation mode of daily power control. For the purpose of the trial operation, the necessary documentation has been developed and agreed with the SNRIU (conceptual engineering solution, technical decision to hold the trial operation and the program of work).

Implementation of the operating mode of daily power control provides for the first 200 days of the NPP fuel cycle change in the electrical power in the range from 750 to 1000 MW.

During the trial operation of the operation mode an analysis of the parameters of transients associated with a decrease and an increase in power output was implemented; and recommendations for process adjusting were preparing. This trial operation was completed successfully (primary circuit activity, offset).

It was another step of the trial operation of the load-following operation mode. Previous tests of the operation mode have been conducted in 2006 at the 2nd unit of Khmelnitsky nuclear power plant and were successful. A decision to implement this mode of operation will occur after the completion of all test steps.

7. Improvements in Regulations

As part of the implementation of new fuel at Ukrainian nuclear power plants currently two documents SNRIU are in effect:

Order No. 65 of 16.05.2002 „Approaches to the regulation of nuclear and radiation safety during implementation of the new modifications of nuclear fuel in Ukraine „;

NP 306.2.106-2005 «Requirements for the modifications of nuclear installations and their safety evaluation procedure»

In order to standardize the regulatory framework and to bring regulations into line with the later introduced national documents and foreign documents SNRIU was decided to develop a new version of the document NP 306.2.106-2005 and complementary low-level regulatory document (Regulatory Guide).

Right now a document developed is being approved in the ministries and organizations involved.

Other document that is under development, is a new version of the document USSR containing the requirements for assessing the safety of handling fresh and spent fuel at nuclear power plants - PNAEG 14-029-91.

Previously, we developed a new version of the document, which contains modern approaches to safety analysis. Currently it is finalized section on handling damaged nuclear fuel. Despite the presence of damaged fuel at the Chernobyl nuclear power plant and South Ukraine NPP in Ukraine, there is currently no regulatory document that would contain requirements for dealing with it. Approval and implementation of the document is expected next year.

8. Lifetime Extension of WWER-1000 Reactors

Most of Ukraine‘s operating units were commissioned in the 1980s and now came or come to the end of life (except for Zaporizhzhya-6, which is in operation since 1995, and Hm-2 / Pivne-4, in operation since 2004). It was decided by regulatory authority to extend the period of operation after a proper justification and the implementation of necessary organizational and technical measures.

Design life cycle duration of existing nuclear power plants in Ukraine is 30 years. In 2010, the State Nuclear Regulatory Inspectorate of Ukraine issued a license to extend the life of the first two units of the Rivne NPP for another 20 years.

December 31, 2012 expired operation SUNPP-1 and in November 2013 the College of the State Nuclear Regulatory Inspectorate of Ukraine by considering the results of the safety assessment deemed reasonable operation of the first nuclear unit SUNPP for another 10 years - until the next safety revaluation.

In May 2015 came to the end a 30-year period of operation of the SUNPP second unit. The unit is in outage until May 2016, after which he will be appointed a new life cycle.

Due to the long outages, which precede a decision to extend the operation lifetime, the need to increase the capacity of the remaining units to compensate for the shortage of electricity.

9. Power Uprate of WWER-1000 Reactors

Consideration is being given for two concepts to increase nuclear unit generating capacity: raising the heat output to 1.5% or 4%. Energoatom decided to proceed gradually, and the first to raise up to the 101.5% Nnom to estimate the amount of the changes in support and equipment of and then get permission from the regulatory authority to increase capacity to 104%.

Increased thermal power of operating units with VVER-1000 reactors to 3045 MW provided by performing a range of works to improve the measurement accuracy of feedwater flow by 1.0% and increase the accuracy of the power control of the reactor at 0.5%.

When considering accident states the original thermal power at 3120 MW (104% Nnom) is assumed. The value of the design deviations from the nominal thermal power equal to 120 MW consists of limiting design errors of determining +60 MW and maintaining (+60 MW).

Improving the accuracy of measurement and the power control is achieved through the replacement of existing measuring devices for equipment of a higher accuracy class, as well as by substantiation the accuracy of the reactor power justification.

As a result of these changes will be conditions to increase reactor thermal power generation of SUNPP units 1, 2 up to 1.5% Nnom, i.e. up to 3045 MW. Further step is implementation of power uprate to 4%. Management of Energoatom intends to increase share of nuclear power plants on the electricity market to December from the current 55% to 60% including through throw the power uprate.

10. The Problems Noted for Last Two Years

In section some features of FAs operation, the characteristic not-design regimes which were taking place lately, and also the arisen problems are noted. The data presented in section are based on results of technical reviews of Safety Reports and do not cover all spectrum of the questions connected with nuclear fuel use at Ukrainian's NPPs.

10.1. Work of Reactors at Partial Level of Power

Last years Ukrainian's NPPs have not operated at 100% Nnom power level. Many of units operated at power levels, limited by the dispatcher of a power grid system. The holding units in a „cold" reserve were frequent. For example in June of 2013 5 unit were under repair and 2.5 GW capacity were in reserve. Now such practice is almost avoided. In 2014-2015 more than half of the NPPs operated at nominal power resulting share of NPPs in electricity market about 55-60%. Some examples of power schedules units WWER-1000 are presented below, Fig. 1.These schedules are based on real experimental data and used at calculation by DYN3D code. It is necessary to notice that the time scale is resulted in effective days and does not show idle times of units. Any features in behavior of fuel has not been noted. Work of units in a not-base regime reduced the general economic characteristics, complicated operation and influence on a mode of unit start-up after a fuel reload.

10.2. Increased Error of Boric Acid Concentration Calculation, Duration of Cycle Calculation

The problem of the increased error of calculation of boric acid concentration and cycle duration was described in previous reports [2, 3]. Now the problem is being solved at industry level during fulfillment of the special program. The new equipment for measurement of the isotope ^{10}B concentration in the coolant is being installed, neutron libraries of constants and computer codes are updated.

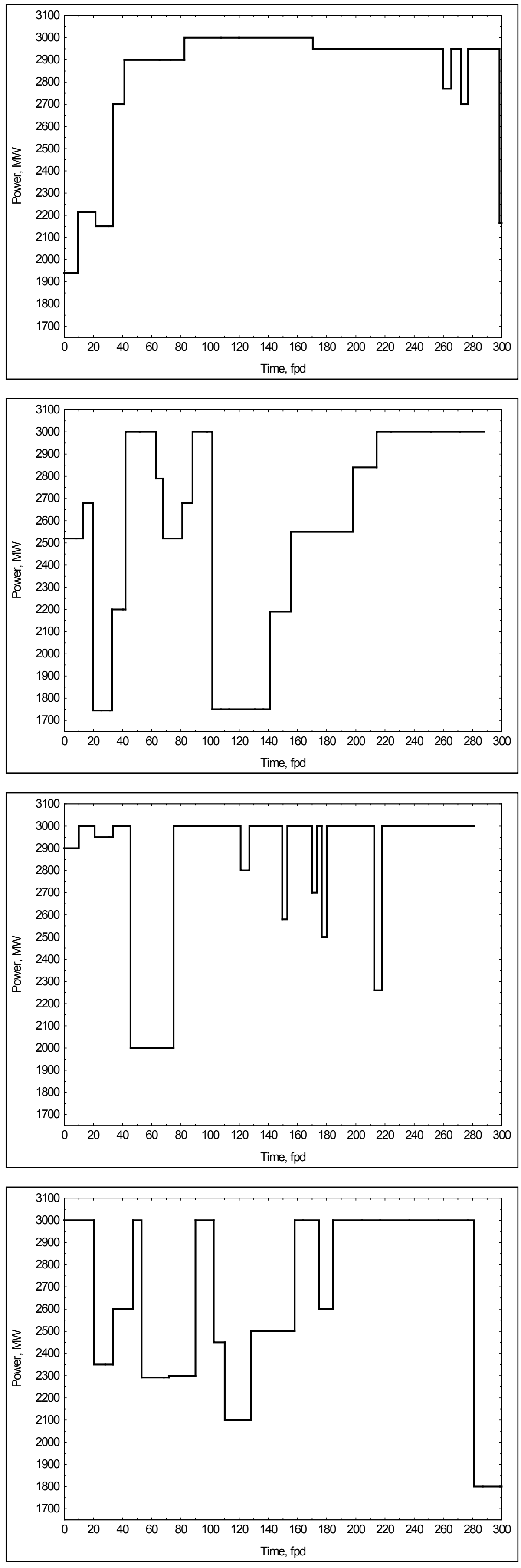

Figure 1. Examples of WWER-1000 power schedules

This led to the fact that difference of real duration of fuel cycle with calculation data for different units and identical fuel and practically identical strategy of a core loading has decreased in comparison with the previous years. Maximal underestimation of cycle duration reaches ≈9 fpd (Table 5). At the same time for some units this error is equal to 0. On this basis the problem of an error of definition of fuel loading duration is necessary for dividing on two, independent from each other:

- an error of a code, libraries of neutronic constants;
- definition of the real reasons of various errors of fuel loading duration definition for different units the Ukrainian's NPPs.

Decreasing of a difference between real and estimated duration of fuel cycle (Table 5) is due to modification of neutronic constants and software at NPPs.

10.3. Measurement of Scram (CR) Efficiency on Reactors WWER-440

The problem of difference of the measured scram (CR) efficiency against calculated value is already noticed and is typical for reactors WWER-440, especially for RNPP unit 1. In Table 6 calculated values and results of experiments of scram efficiency without taking into account and taking into account a jamming of the most effective CR on RNPP unit 1 are presented.

It is necessary to note as well as high value of scram efficiency at 37 CRs regarding 36 CRs, and the big discrepancy of calculation by code BIPR (it is similar and for calculations SSTC NRS by code DYN3D). For RNPP unit 2 the problem is not so crucial. Probably, it is connected with core difference (unit 1 has dummy assemblies installed) and/or with difference of reactivity measurement systems.

Table 5. Definition of cycle duration up to depletion of boron reactivity on the different NPPs of Ukrain

NPP, cycle	Previous difference (2013)	Cycle duration up to depletion of boron reactivity, fpd		
		experiment	NPP calculation	difference calculation-experiment
ZNPP-1, cycle 26	-9	≈309	≈304	-5
ZNPP-2, cycle 27	-4	≈297	≈297	0
ZNPP-3, cycle 27	-18	≈306	≈309	+3
ZNPP-4, cycle 27	-19	≈306	≈300	-6
ZNPP-5, cycle 25	-15	≈298	≈298	0
ZNPP-6, cycle 18	-12	≈317	≈308	-9
SUNPP-1, cycle 29	+1	≈267	≈276	-9
SUNPP-2, cycle 26	0	≈288	≈281	-7
SUNPP-3, cycle 24	-9	≈291	≈287	-4
KhNPP-1, cycle 26	0	≈312	≈318	6
KhNPP-2, cycle 9	-13	≈304	≈297	-7
RNPP-1, cycle 31	+5	≈314	≈314	0
RNPP-2, cycle 31	-5	≈306	≈309	+3
RNPP-3, cycle 26	+2	≈296	≈303	+7
RNPP-4, cycle 9	0	≈306	≈307	+1

Table 6. Scram efficiency without taking into account and with taking into account jamming of the most effective CR on RNPP unit 1

Measurement		Calculation (BIPR)	
Efficiency 37 CR,%	Efficiency 36 CR,%	Efficiency 37 CR,%	Efficiency 36 CR,%
16.4	8.6	10.2	7.4
16.8	9.1	10.5	7.6
16.8	8.4	10.6	7.4
16.8	8.8	11.50	8.30
15.4	8.8	11.15	8.34

Now this problem is noted and for reactor WWER-1000. The difference between of the measured scram (CR) efficiency and calculated value exceed code specification limit in 20%.

The problem decision is offered on a way of the account of spatial effects and use of a special dynamic code for calculation of correction factors at processing of experimental data. For today Energoatom has a plan to buy special computer code/method for solving this problem.

10.4. Asymmetry of a Power Distribution in Reactors WWER-1000

Last years asymmetrical distribution of a measured power of FAs in a reactor core and asymmetrical distribution of a difference between the measured and calculated value was actual. It is typical for start of cycle in 0-20 fpd. Further asymmetry decreases due to a poisoning of a core and FA burnup increase. The possible reasons of this phenomenon are the followings:

- Non-uniformity of reflector properties on a reactor azimuth (a bending of FAs and reactor core, various gaps between in-vessel units, difference of properties of the coolant on loops etc.).
- Features of power measurement system (non-uniformity of the detectors properties due to their burning, degradation of cables and connectors etc.).

For today in Energoatom activity by definition of the possible reasons of this phenomenon and developing of a method of their account at definition of design engineering factors, calculations FAs power and fluence on vessel is planned.

Additional materials for this question are presented at conference in PowerPoint version of this report.

11. Conclusions

- Use of fuel types at Ukrainian NPPs allows improvement of indicators of reliability, profitability and compliance meet modern requirements for power supply system in Ukraine.
- Experimental batch loading of new fuel type, TVS-WR, for SUNPP unit 3 was completed March 16, 2015. Now SNRIU reviews a technical solution to expand the trial operation of TVS-WR improved design to other WWER-1000 units. There expressed an intention to use the remaining TVS-W in subsequent batches.
- Due to the long outages, which precede a decision to extend the operation lifetime, the need to increase the capacity of the remaining units to compensate for the shortage of electricity. As a result of these changes will be conditions to increase reactor thermal power generation of WWER-1000 units up to 101.5% Nnom, i.e. up to 3045 MW. Further step is implementation of power uprate to 104%. Management of Energoatom intends to increase share of nuclear power plants on the electricity market to December from the current 55% to 60% including through throw the power uprate.
- Problems which are taking place on the NPPs of Ukraine from the point of view of use of fuel, successfully solving by NPPs operators and are included in plans of scientific and technical support.

12. List of Abbreviations

FA	Fuel Assembly
fpd	Full Power Days
KhNPP	Khmelnitsky NPP
Nnom	Nominal power level
NPP	Nuclear Power Plant
RK_II+TVS_II	Second-generation WWER-440 Fuel
RNPP	Rivne NPP
SIRP	Stand for fuel inspection and repair
SNRIU	State Nuclear Regulatory Inspectorate of Ukraine
SSTC NRS	State Scientific and Technical Centre for Nuclear and Radiation Safety
SUNPP	South Ukraine NPP
TVSA	Type of Fuel Assembly designed and produced by JSC TVEL
TVS-W	Fuel Assembly designed and produced by Westinghouse Company (WFA)
TVS-WR	Fuel Assembly designed and produced by Westinghouse Company (Robust Westinghouse Fuel Assembly, RWFA)
WWER	Soviet Design of Pressurized Water-Water Reactor.
ZNPP	Zaporizhzhya NPP
Zr RK+TVS	“Zirconium” WWER-440 Fuel

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