SOME ASPECTS OF NUCLEAR FUEL UTILISATION AT UKRAINIAN'S NPPS DURING LAST TWO YEARS

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1. ABSTRACT

For years of activity SSTC NRS actively participates in process of fuel reloading licensing and in the course of implementation of new nuclear fuel types at the nuclear power plants of Ukraine. In paper results of the nuclear fuel use for last years are presented. The results are received on the basis of the NPP's documentation represented for licensing in regulating body of Ukraine, and on the basis of fulfilment of own estimations and independent calculations. In the first part of the report the brief characteristic of the realized fuel cycles on Ukraine's NPPs, types of loaded fuel is described. Experience of new fuel type implementation are present (FA Second Generation for WWER-440. Westinghouse FA for WWER-1000). Next issue of report is presentation of future new fuel implementation (WWER-1000). And the last issue of report is the some of problem with fuel utilisation (leakage FAs, problem with Westinghouse FA and other).

2. KEYWORDS

WWER, TVSA, TVSA-12, TVS-W, FA Second Generation, FA-II, Westinghouse, NPP, DYN3D, HELIOS, DERAB.

3. INTRODUCTION

For years of activity SSTC NRS actively participates in process of fuel reloading licensing and in the course of implementation of new nuclear fuel types at the nuclear power plants of Ukraine [1, 2]. In given article results of the nuclear fuel use for last years are presented. The results are received on the basis of the NPP's documentation represented for licensing in regulating body of Ukraine, and on the basis of fulfilment of own estimations and independent calculations.

4. USES OF FUEL ASSEMBLIES ON UKRAINE NPPS

Below, in Table 1, the types of FA loaded in reactor core of Ukrainian NPPs are submitted. At the current moment a reactor core completely consists from TVSA on units №№ 1-6 ZNPP, №№ 1-2 HmNPP and №№3-4 RNPP. There is also a several reactors, where the core contains 1-2 TVSM, loaded instead of the rejected FAs. The core of the unit №3 YUNPP contains fuel TVSM + TVSA + TVS-W. Both WWER-440 reactors (RNPP -1,2) are loaded by "Zirconium" FAs and "Second Generation" FAs.

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

RIVNE NPP, Unit #1, WWER-440	Zr RK+TVS,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
ZAPORIZHE NPP, Unit #1, WWER-1000	TVSA
ZAPORIZHE NPP, Unit #2, WWER-1000	TVSA
ZAPORIZHE NPP, Unit #3, WWER-1000	TVSA
ZAPORIZHE NPP, Unit #4, WWER-1000	TVSA
ZAPORIZHE NPP, Unit #5, WWER-1000	TVSA
ZAPORIZHE NPP, Unit #6 ,WWER-1000	TVSA
YUZHNO-UKRAINSKAYA NPP, Unit #1, WWER-1000	TVSA[1]
YUZHNO-UKRAINSKAYA NPP, Unit #2, WWER-1000	TVSM+TVSA[1]
YUZHNO-UKRAINSKAYA NPP, Unit #3, WWER-1000	TVSM+TVSA+TVS-W
HMELNICKAYA NPP, Unit #1, WWER-1000	TVSA
HMELNICKAYA NPP, Unit #2, WWER-1000	TVSA

Below, in Table 2, power generation of FA on the different Ukrainian's NPPs are presented. The data have been received on the end of July, 2013 on the basis of the calculations fulfilment in SSTC NRS (DYN3D/DERAB, [1, 3-6]) with taking into account real power schedules of units. Power generation of the one FA was proposed as the basic criterion, i.e. the characteristic of one core cell use efficiency. For the information the power generation of FA declared by the vendor at the new nuclear fuel types implementation are presented in Table 3.

[1] Unloaded in 2013 year

Table 2 - Power generation of FA at the Ukrainian's NPPs (relative)

NPP	2010	2011	2012	2013
RNPP-1	-	1.03	1.04	1.09
RNPP-2	1.06	1.06	**1.20**	-
RNPP-3	-	0.98	1.05	1.08
RNPP-4	0.98	1.05	1.12	**1.14**
ZNPP-1	1.06	1.06	1.09	1.10
ZNPP-2	1.05	1.07	1.10	-
ZNPP-3	1.09	1.10	1.11	1.10
ZNPP-4	1.06	1.06	1.07	1.06
ZNPP-5	1.08	-	1.11	1.10
ZNPP-6	0.98	1.08	1.08	1.09
YUNPP-1	-	**0.92**	0.95	0.94
YUNPP-2	1.03	1.07	0.94	0.95
YUNPP-3	0.91	**0.92**	**0.92**	0.99
HmNPP-1	1.05	-	1.06	1.04
HmNPP-2	1.06	1.08	1.04	1.06

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

NPP	Power generation of FA, revalive
RNPP-2, TVS_II	1.07
RNPP-1, TVS_II	1.01
ZNPP-3, TVSA	0.99
HmNPP-2, TVSA	1.08
YUNPP-1, TVS-A	0.94
YUNPP-3, TVS-W	1.06
YUNPP-2, TVS-W	1.07
ZNPP-5, TVS-W	1.07
RNPP-4, TVSA-12	**1.38**

5. LICENSING TVS-W ("WESTINGHOUSE" FUEL, 42 FAS, UNIT №5 ZNPP, 2012). THE BASIC RESULTS

During realisation of the program of the alternative supplier fuel loading in 2012 on unit №5 ZNPP 42 TVS-W was planned. The basic remarks and problems, which were marked during review of the technical decisions on implementation of fuel TVS-W:

- Necessary to develop LCS specification for TVS-W type of fuel;
- Compatibility of CR and TVS-W core (mechanical aspects, neutron flux, etc.);

- Validation and verification of the cross-section libraries for core design code and for in-core measurement system;
- Definition of limits for maximal pin power k_r of TVS-W;
- Definition of operational limits for coolant activity.

Taking into account the problem with core reloading under repair shutdown on YUNPP-2, 3 in 2012 the planes to use TVS-W on unit №5 ZNPP not been realized.

6. LICENSING FA_II (SECOND GENERATION, HF- SHIELDING) (RIVNE NPP/1, 2011). THE BASIC RESULTS

Implementation of fuel type "Second Generation" on reactors WWER-440 of the RNPP has begun in 2010 with implementation as reload fuel on unit №2. Next step of implementation this fuel type was loading in core of unit №1 RNPP. FAs contain the raised quantity of uranium at the expense of fuel column increase and reduction of internal diameter of an uranium pellets. Also the top part of the FA contains hafnium absorber for splash linear power decrease in fuel pins next TVS at moving CR. The basic remarks and problems, which were marked during review of the technical decisions on implementation of fuel "Second Generation":

- Maintenance of critical criteria at a storage of fresh fuel, spend fuel in water pool and transport cask TK-6;
- In view of more high levels of burnup of fuel the necessity of reassessment of radiologic consequences of accidents is marked.
- Exceeding of FP power jump limits after reloading;
- Change of operational limits from FA power (k_q, k_v) to FP power (k_r, k_o);
- Expand SAR by event "Incorrect placing of FA under core reloading";
- Analysis of maneuvering regimes (following by power) and increased power 108% was excluded from SAR.

7. 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 № 436-p from 27.07.2006y), the decree of Ukrainian President 156/2008 and planes of NAEK Energoatom. The basic introductions of new types of fuel are:

- Implementation TVSA-12 WWER-1000 FAs on unit №4 RNPP (2014);
- Implementation TVS-W with new design on the unit №3 YUNPP (2014).

8. 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.

8.1 WORK OF REACTORS AT PARTIAL LEVEL OF POWER

Last years Ukrainian's NPPs has not worked in 100% power level. Many of units worked at power levels, limited by the dispatcher of a power grid system. Cases the stopping of units in a "cold" reserve were frequent. For example in june of 2013 5 unit were under repair and 2.5 GW capasity were in reserve. Some examples of power schedules units WWER-1000 are presented below. 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 behaviour 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.

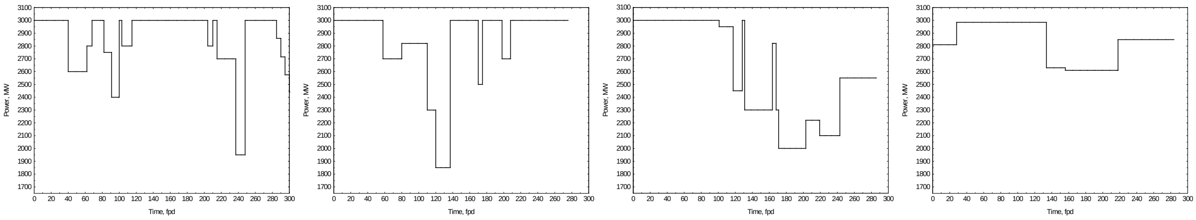

Fig. 1 –Examples of WWER-1000 power schedules

8.2 FAILURE OF FUEL (LEAKEDGE, MECHANICAL DAMAGES)

In the Table 4 data about failure FA for 2010-2013 are presented. As failure FA take into account only the FA previously unloaded from the reactor core. FA which were planned for an unloading in pool, in the resulted table are not considered.

The most problem situation is noted in 2011 year. These are 9 rejected FAs on YUNPP-1, 3 FAs on HmNPP-2. Thus one FA on HmNPP-2 has reached of failure criterion. Operational limit of coolant activity on HmNPP-2 was reached.

One of probable causes of a failure is influence of debris-damages. For elimination of this factor there is begun use of TVSA fuel with anti-debris filters.

During a core reload in 2012 on the unit №2 and №3 YUNPP the mechanical damages of TVS-W FAs have been found. For more details see next chapter.

Table 4 – Number of failure FAs for 2010-2013 on Ukrainian NPPs

NPP	2010	2011	2012	2013
RNPP-1	-	0	**4**	-
RNPP-2	0	0	0	-
RNPP-3	-	0	1	1
RNPP-4	0	0	1	0
ZNPP-1	0	0	0	0
ZNPP-2	0	0	0	-
ZNPP-3	0	0	0	0
ZNPP-4	0	0	0	0
ZNPP-5	0	0	0	-
ZNPP-6	0	0	0	0
YUNPP-1	-	**9**	0	-
YUNPP-2	1	0	0 (15[2])	0 (27[2])

[2] TVS-W, mechanical problem

NPP	2010	2011	2012	2013
YUNPP-3	2	1	0 (17^2)	0 (+12^3)
HmNPP-1	0	1	0	-
HmNPP-2	<u>*3*</u>	<u>**3**</u>	2	-
Σ	6	13	8 (32^2)	1 (27^2-12^3)

8.3 MECHANICAL PROBLEM OF THE "WESTINGHOUSE" FUEL (TVS-W)

During a core reload in 2012 on the unit №2 and №3 YUNPP the mechanical damages of TVS-W FAs have been found. Damages have been found at visual inspection of FAs. The some of spacer grids has been damaged. Breakages of SG fragments, squeeze, deformation of petals and an attrition have been detected. Two FAs are recognised as an unsuitable to the further operation, some FAs can be use in a core only after repair, a part of FAs it is ready to operation one cycle and then obligatory inspection at the stand of repair and inspection. The reasons of problems at a core reload and of defects of FAs:

- Lacks of a design of the top nozzle of the FA. The FAs are placing «one on another».
- Insufficient mechanical strength of SGs to radial and axial efforts.
- Lacks of a design of the bottom nozzle of the FAs. Corners, sharp edges increase probability of FAs damage at a core reload.
- Bending of FAs.
- Loading in transitive cycles of FAs of type TVSA for which the bending above design values and at the same time high rigidity of a skeleton also is typical. (Maximum design value of a FA bend is 7 mm. Maximum measurements value of blend is 29 mm [ZNPP, 7]).

After detection of mechanical problems of FAs TVS-W expansion of operation of FAs of this type on ZNPP-5 was forbidden. This year the FAs TVS-W from YUNPP-2 core was completely unload. Since 2014 the beginning of operation of modernised FAs TVS-W for which are offered constructive changes for elimination of the above-noted lacks is planned. Also it is necessary to notice, that this year on YUNPP-3 the installation of the stand of repair and inspection is planned.

8.4 INCREASED ERROR OF BORIC ACID CONCENTRATION CALCULATION, DURATION OF CYCLE CALCULATION

The problem of the increased error of calculation of boric acid concentration and of cycle duration in [2] was described. At present 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. However one of the main questions remains while without attention.

This questions is duration of fuel loading. With this questions the situation is little bit more difficult. The basic question which it is possible to formulate on the basis of the analysis of comparison of real duration of fuel loading with calculation data, is difference errors for different units at identical fuel and practically identical strategy of a core loading. Maximal underestimation of cycle duration ≈19 fpd (Table 5). At the same time for separate units this

[3] TVS-W, returned from water pool (planned in 2013)

error =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.

Also it is necessary to define a position of experts SSTC NRS on a following question. For today as one of possible ways of the decision a problem with increased error of boric acid concentration and of cycle duration is definition of a regular error separately for different units. In our opinion, definition of a separate regular error should be based on real physical differences in characteristics of same type units core. In other case it not physical and is not possible.

Table 5 - Definition of cycle duration up to depletion of boron reactivity on the different NPPs of Ukraine

NPP, cycle, number of fresh FA in loading	Cycle duration up to depletion of boron reactivity, fpd		
	experiment	NPP calculation	different calculation-experiment
ZNPP-1, cycle №25	≈303	≈294	-9
ZNPP-2, cycle №25	≈283	≈279	-4
ZNPP-3, cycle №25	≈308	≈290	-18
ZNPP-4, cycle №25	≈318	≈299	-19
ZNPP-5, cycle №23	≈293	≈278	-15
ZNPP-6, cycle №17	≈306	≈294	-12
YUNPP-1, cycle №27	≈281	≈282	+1
YUNPP-2, cycle №24	≈282	≈282	0
YUNPP-3, cycle №22	≈287	≈278	-9
HMNPP-1, cycle №24	≈290	≈290	0
HMNPP-2, cycle №8	≈306	≈293	-13
RNPP-1, cycle №30	≈280	≈285	+5
RNPP-2, cycle №29	≈302	≈297	-5
RNPP-3, cycle №23	≈299	≈301	+2
RNPP-4, cycle №7	≈285	≈285	0

8.5 MEASUREMENT OF SCRAM (CR) EFFICIENCY ON REACTORS WWER-440

The problem of difference of the measured scram (CR) efficiency against calculated value is marked already repeatedly and is typical for reactors WWER-440, especially for unit №1 RNPP. In Table 6 calculated values and results of experiments of scram efficiency without taking into account and with taking into account jamming of the most effective CR on unit №1 RNPP are presented.

Table 6 – Scram efficiency without taking into account and with taking into account jamming of the most effective CR on unit №1 RNPP

Measurement		Calculation (BIPR)	
Efficiency 37 CR,%	Efficiency 36 CR,%	Efficiency 37 CR,%	Efficiency 36 CR,%
16.5	12.3	10.3	7.5
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	11.5	8.3

It is necessary to note as well as high value of scram efficiency at 37 CRs regarding 36 CRs, and the big error of calculation by code BIPR (it is similar and for calculations SSTC NRS by code DYN3D). For unit №2 RNPP the problem is not so actual. Probably, it is connected with core difference (on unit №1 install dummy-cassettes) and/or with difference of reactivity measurement systems.

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 NAEK Energoatom has a plan to buy special computer code/method for solving this problem.

8.6 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 is actual. It is typical for start of cycle in 0-20 fpd. Further asymmetry decreases owing to a poisoning of a core and growth of FA burnup. The possible reasons of this phenomenon:

- 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 at their burning , degradation of cables and connectors etc).

For today in NAEK 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 are planned.

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

9. CONCLUSION

- Used on the Ukrainian’s NPPs fuel types allow to maintain units with improvement of indicators of reliability, profitability and to meet modern requirements of a power supply system of Ukraine.

— Implementation of alternative vendor fuel ("Westinghouse" fuel) has not been successful. The mechanical problem during a core reload in 2012 have been detected. The testing operation of TVS-W fuel will be to continue only on one unit YUNPP-3. Since 2014 the beginning of operation of modernised FAs TVS-W is planned.

— 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.

10. LIST OF NOMENCLATURE

CR .... Control Rod
FA .... Fuel Assembly
FP .... Fuel Pin
Fpd .... Full Power Days
HmNPP .... Hmelnickaya NPP
LCS .... Leakage Control System
MCP .... Main Circulating Pump
NPP .... Nuclear Power Plant
RK_II+TVS_II... WWER-440 Fuel "Second Generation"
RNPP .... Rivne NPP
SAR.................... Safety analysis report
SG .... spacer grid
SPS..................... Self Powered Sensor
SSTC NRS .... State Scientific and Technical Centre for Nuclear and Radiation Safety
TVS .... Fuel Assembly
TVSA .... Type of "TVEL" Fuel Assembly
TVSM .... Type of "TVEL" Fuel Assembly
TVS-W .... "Westinghouse" Fuel Assembly
UTVS .... Type of "TVEL" Fuel Assembly
WG..................... Working Group
WR..................... Working Rod
WWER.............. Soviet Design of Pressurized Water Reactor.
YUNPP .... Yuzhno-Ukrainskaya NPP
ZNPP................. Zaporizhe NPP
Zr RK+TVS .... "Zirconium" WWER-440 Fuel

11. REFERENCE

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