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

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1. ABSTRACT

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 the some of problem with fuel utilisation (leakage FA, problem with Cb calculation and other). And the last issue of report is presentation of future new fuel implementation (WWER-440/1000).

2. KEYWORDS

WWER, TWSA, TWS-W, FA Second Generation, FA-II, Westinghouse, NPP, DYN3D, DERAB.

3. INTRODUCTION

For years of activity SSTC NRS actively participates in process of fuel reloading licensing and in the course of implantation of new nuclear fuel types at the nuclear power plants of Ukraine [1]. 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, №2 HmNPP and №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 units №2 and №3 YUNPP contains fuel TVSM + TVSA + TVS-W.

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

RIVNE NPP, Unit #1, WWER-440	Zr RK + TVS
RIVNE NPP, Unit #2, WWER-440	Zr RK+TVS,RK_II+TVS_II
RIVNE NPP, Unit #3, WWER-1000	TVSM+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	TVSM+TVSA
YUZHNO-UKRAINSKAYA NPP, Unit #2, WWER-1000	TVSM+TVSA+TVS-W
YUZHNO-UKRAINSKAYA NPP, Unit #3, WWER-1000	TVSM+TVSA+TVS-W
HMELNICKAYA NPP, Unit #1, WWER-1000	TVSM+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, 2011 on the basis of the calculations fulfilment in SSTC NRS (DYN3D/DERAB, [1-5]) 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 implantation are presented in Table 3.

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

NPP	2008	2009	2010	2011
RNPP-1	1.02	-	-	1.03
RNPP-2	1.07	-	1.06	1.06
RNPP-3	0.87	0.89	-	0.98
RNPP-4	0.80	-	0.98	1.05
ZNPP-1	0.93	0.96	1.06	1.06
ZNPP-2	0.93	0.97	1.05	1.07
ZNPP-3	1.03	-	1.09	**1.10**
ZNPP-4	0.95	0.99	1.06	1.06
ZNPP-5	0.98	1.07	1.08	-
ZNPP-6	0.90	0.92	0.98	1.08
YUNPP-1	0.85	0.89	-	**0.92**
YUNPP-2	0.87	0.97	1.03	1.07
YUNPP-3	0.90	-	0.91	**0.92**
HmNPP-1	0.80	0.85	1.05	-
HmNPP-2	0.80	0.99	1.06	1.08

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

5. LICENSING TVS-W ("WESTINGHOUSE" FUEL, 42 FAS, UNIT №3 YUNPP, 2010). THE BASIC RESULTS (SSTC N&RS AND TUV SUD INDUSTIRIE SERVICE)

The decision on an possibility of loading in a reactor core of alternative vendor fuel was accepted in 90e years. Within the framework of realization of this decision in 2005 in a reactor core of the unit №3 YUNPP 6 assemblies of a TVS-W fuel manufacture by campaign "Westinghouse" for pilot operation were loaded. New system in-core measurements BEACON was installed also. Up to this moment the large work as in NAEK «ENERGOATOM», and Committee of nuclear regulation of Ukraine was done. The Centre of core designing (CPAZ) is created which carries out scientific and technical support of introduction of new fuel. The normative base determining the basic requirements and criterion is developed. This stage was finished in 2005 by loading 6 TVS-W in an reactor core. After end of operation of 6 pilot TVS-W and examination of their technical condition the decision on continuation of their operation at Unit №3 YUNPP is accepted. The 42 FAs was loaded in core in 2010. Technical review of Safety Reports was carried out by two organisations: SSTC NRS and TUV SUD Industry Service, Munich, Germany. The basic remarks and problems, which were marked during review of the technical decisions on implementation of fuel TVS-W (SSTC NRS and TUV SUD):

- Quality of reports and documents, the necessity of representation the more detailed verifying reports on codes;
- Using “old” methods and approaches (point kinetic for RIA);
- Achieving criteria for fuel pin maximal power k_r. Necessary to calculate this value at the different CR of WR position;
- Assessments of fast neutron fluence on the in-vessel devices;
- Assessments of neutron fluence on the control rod (possibility to use CR with new fuel);
- In view of more high levels of burnup of fuel the necessity of reassessment of radiologic consequences of accidents is marked.

6. LICENSING TVS-W ("WESTINGHOUSE" FUEL, 42 FAS, UNIT №2 YUNPP, 2011). THE BASIC RESULTS

During realisation of the program of the alternative supplier fuel use in 2011 on Unit №2 YUNPP 42 TVS-W is loaded. The basic remarks and problems, which were marked during review of the technical decisions on implementation of fuel TVS-W:

- Increase of checks and tests quantity for the in-core measurement system;
- Taking into account of the reactor projects differences (320/338) at a substantiation of TVS-W mechanical reliability;
- Necessary to develop LCS specification for TVS-W type of fuel;
- FA compression in the mixed core (TVSM+TVSA+TVS-W). Distance between pad and vessel internals (shaft).

7. LICENSING FA_II (SECOND GENERATION, HF- SHIELDING) (RIVNE NPP/2, 2010). THE BASIC RESULTS

Implantation of fuel type “Second Generation” on reactors WWER-440 of the RNPP has begun in 2010 with implantation as reload fuel on Unit №2. 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;
- Model of pellet-cladding gap thermal conductivity;
- In view of more high levels of burnup of fuel the necessity of reassessment of radiologic consequences of accidents is marked.

8. 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. The basic introductions of new types of fuel are:

- Implementation WWER-440 FAs of the second generation on blocks №1 RNPP (2011-2012);
- Loading 42 TVWS FAs on the unit №5 ZNPP (2012).

9. 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.

9.1 WORK OF WWER-1000 REACTOR ON 3 MCP

The given mode has been realised on Unit №1 YUNPP during cycle №25. In the end of cycle (240 fpd) one of 4 MCP has failed. Considering small term of work till the end of cycle and duration of tender procedures on purchase of the new equipment the decision to finish campaign №25 (240-273 fpd) at the lowered level of reactor power to 67 % and at work 3 MCP was accepted. Necessary reports have been developed for a substantiation of core safety. Thus, considering long idle time Unit #1, burnup distribution at moment 240 fpd it is defined taking into account decay Pm to Sm. At a substantiation following cycle №26 the analysis of non-symmetry cooling flow influence on neutronic characteristic of core has been carried out. Changing of neutronic characteristics of core was within an error of codes. Any features in behaviour of fuel has not been noted.

9.2 WORK OF REACTORS AT PARTIAL LEVEL OF POWER

Last years, after the "economic crisis" beginning, in Ukraine the electricity power consumption has decreased. It was reflected in a power schedule of units. 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. Some examples of power schedules units WWER-1000 are below presented. 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.

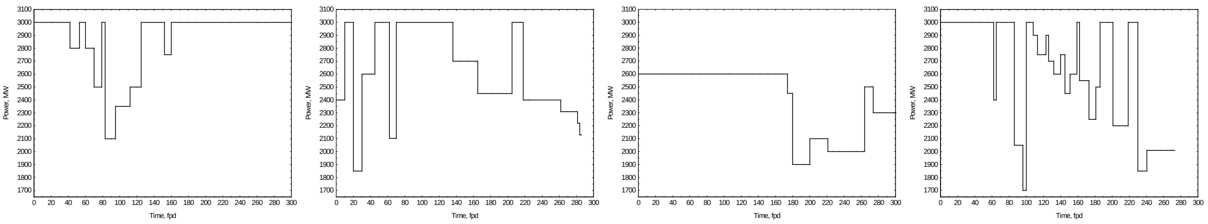


Fig. 1 –Examples of WWER-1000 power schedules

9.3 FAILURE OF FUEL (LEAKEDGE, MECHANICAL DAMAGES)

In the Table 4 data about failure FA for 2008-2011 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 this 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. 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.

Table 4 - The types of FA loaded in reactor core of Ukrainian NPPs

NPP	2008	2009	2010	2011
RNPP-1	0	-	-	0
RNPP-2	1	-	0	0
RNPP-3	3	0	-	0
RNPP-4	0	0	0	0
ZNPP-1	0	0	0	0
ZNPP-2	0	0	0	-
ZNPP-3	0	-	0	-
ZNPP-4	0	0	0	0
ZNPP-5	0	1	0	-
ZNPP-6	0	0	0	0
YUNPP-1	1	0	-	**9**
YUNPP-2	1	1	1	0
YUNPP-3	0	-	2	1
HmNPP-1	0	1	0	-
HmNPP-2	1	0	3	**3**
Σ	7	3	6	13

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

For today for the Ukrainian’s NPPs the problem of the increased error of calculation of boric acid concentration and of cycle duration is actual. According to BIPR-7A code specification an error of calculation C_B and duration of cycle arrange:

Critical concentration of boric acid on the cycle beginning .... ±0.3 g/kg
Duration of fuel loading ....±3 %

For many Units of Ukrainian’s NPPs these declared errors are not carried out. As an example on Fig. 2 comparison calculation and experimental data is presented.

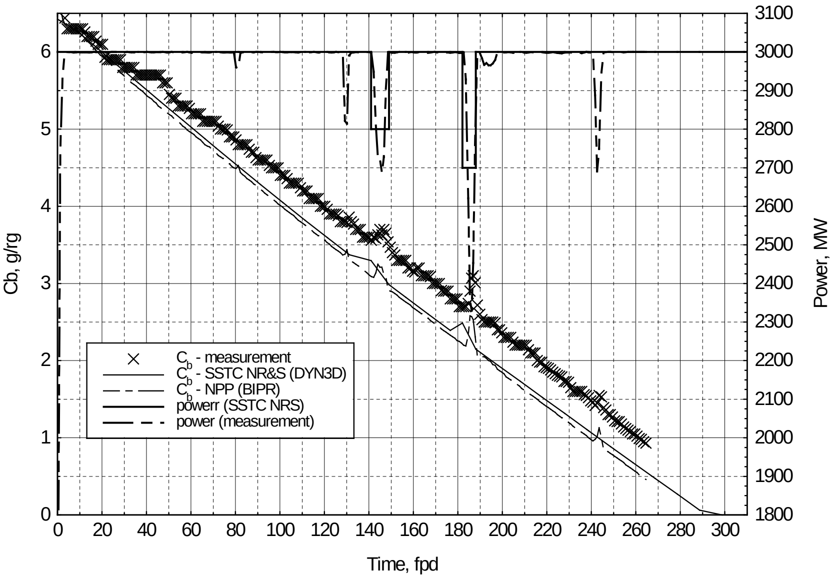


Fig. 2 –Example of a deviation of C_b calculation and of cycle duration from operational data

The first factor - errors of calculation C_b. One of the major factors defining experimental value of boric acid concentration in cooling - the isotope ^{10}B maintenance in a boron. At preparation of neutronic constants the tabular maintenance of an isotope ^{10}B in a boron of 19.8% is used. However in practice it is far not so. Using passport characteristics of boric acid which is delivered on the NPP, the isotope maintenance ^{10}B is in limits from 18.5% to 21.5%. Such differences can lead to a deviation of results of measurement of boric acid concentration more than 0.35 g/kg that is beyond an error of BIPR code. Other factor which influences the isotope maintenance ^{10}B is its burning out during an neutrons irradiation. However, considering total of boric acid on Unit, this factor considerably below a deviation of the maintenance of an isotope ^{10}B in delivered acid from factory. For the decision of a problem of the raised error of calculation CB three basic directions for today are defined:

- modernisation of monitoring system for possibility of ^{10}B concentration measurement in cooling;
- transition to calculation of core neutron characteristics depending on concentration ^{10}B in cooling;
- updating of codes, libraries of neutronic constants.

For an example of necessity of ^{10}B concentration measurement system implantation in the cooling on Fig. 3 comparison of data of measurement Cв, ^{10}B with calculated data is presented.

The following factor - duration of fuel loading. With this factor 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 ≈40 fpd (Table 5) At the same time for separate units this 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.

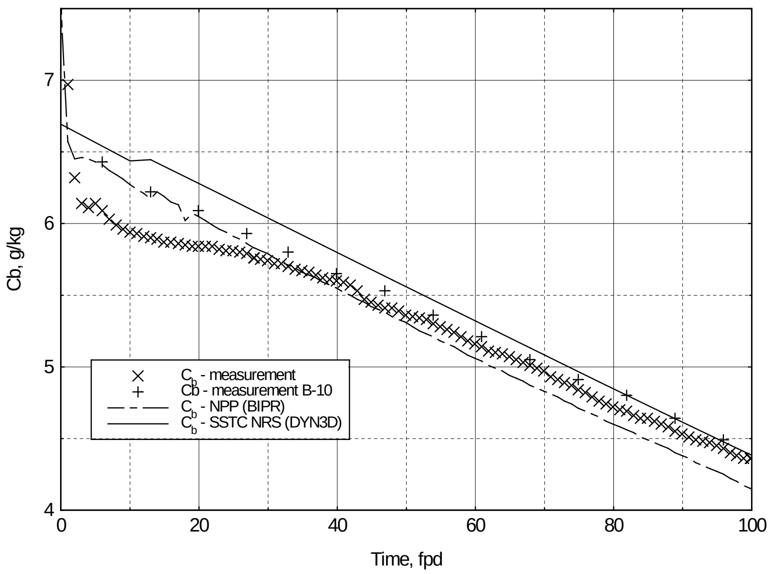


Fig. 3 –Example of use of ^{10}B concentration measurement results in cooling and comparison with calculation data

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 №22, 43 TVSA	≈315	≈303	-12
ZNPP-2, cycle №23, 43 TVSA	≈310	≈298	-12
ZNPP-3, cycle №22, 42 TVSA	≈325	≈300	-25
ZNPP-4, cycle №22, 42 TVSA	≈310	≈300	-10
ZNPP-5, cycle №21, 42 TVSA	≈307	≈283	-24
ZNPP-6, cycle №14, 42 TVSA	≈325	≈285	-40
YUNPP-1, cycle №25, 36 TVSA + 1 TVSM	≈270	≈260	-10
YUNPP-2, cycle №22, 42 TVSA + 1 TVSM	≈315	≈295	-20
YUNPP-3, cycle №20, 42 TVSA	-*	-	-
HMNPP-1, cycle №22, 48 TVSA	≈308	≈308	0
HMNPP-2, cycle №5, 42 TVSA	≈324	≈314	-10
RNPP-1, cycle №27, 84 RK+TVS	≈290	≈280	-10
RNPP-2, cycle №27, 78 RK+TVS	≈293	≈280	-13
RNPP-3, cycle №22, 42 TVSA	≈265	≈270	+5
RNPP-4, cycle №4, 42 TVSA	-*	-	-

*- Last cycles of units were maintained at partial level of power that complicates and brings an additional error in definition of cycle up to depletion of reactivity on boron

9.5 RADIATION GROWTH OF TVSA. INCREASE STRAIN COMPRESSION

As is known, the FA of type TVSA is developed for elimination of lacks of the previous type of FA-TVSM, and in particular low cross stiffness of TVSM. As a result of it was applied rigid skeleton which has put a number of opposite problems. As a result of it fuel transport operations efforts have increased (up to the fact of FA jamming in pool); position of protection tubes pads rather shaft has changed, that has led to change of FA strain compression at reactor assembling after reloading. On the Ukrainian’s NPPs the protection tubes revision for backlash 15-21 mm maintenance have been realized.

Other problem which costs now before the NPPs of Ukraine is an operation of the mixed core with TVS-W. At implementation of TVSA it was supposed, that quantity TVSA in a core will increase and gradually load will pass to FAs of this type. At implementation TVS-W in a core with TVSA the situation will be opposite. Quantity of TVSA will be decrease with increase of mechanical load at the individual FA of this type. Thus radiation growth of TVSA with high level of burnup will be the additional factor, especially for last cycle with TVSA. It is obvious, that of FA strain compression in the mixed core should be realized on the bottom limit, with preservation of all design characteristics.

9.6 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

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. 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.

9.7 RECONSTRUCTION OF A POWER DISTRIBUTION IN REACTORS WWER-440

After implantation of new nuclear fuel “Second generation” on Unit №2 RNPP the quantity axial layers in the power distribution reconstruction systems based on SPS has been increased up to 42. It has led to incorrect work of this system to what presence not-physical "humps" with amplitude to 8 % ((Fig. 4).

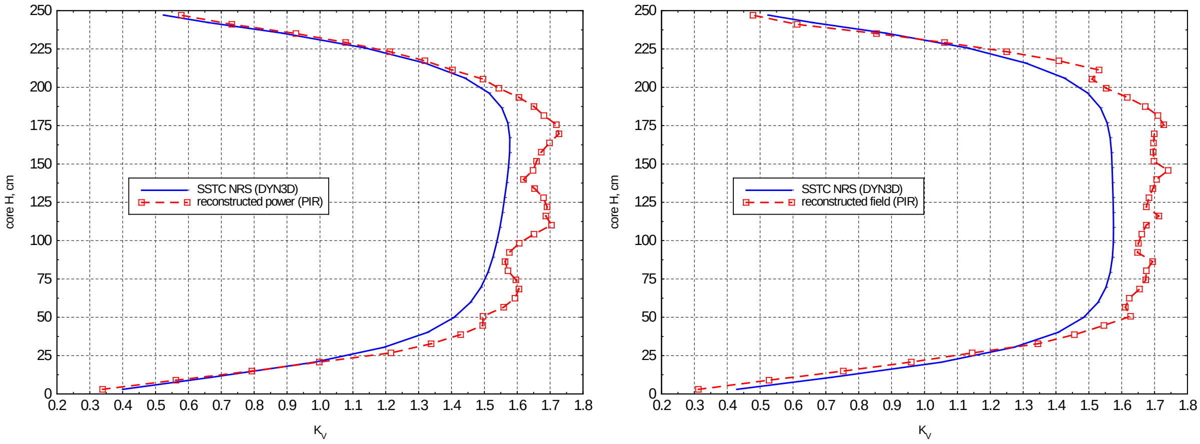


Fig. 4 –Example to incorrect work of the power distribution reconstruction systems

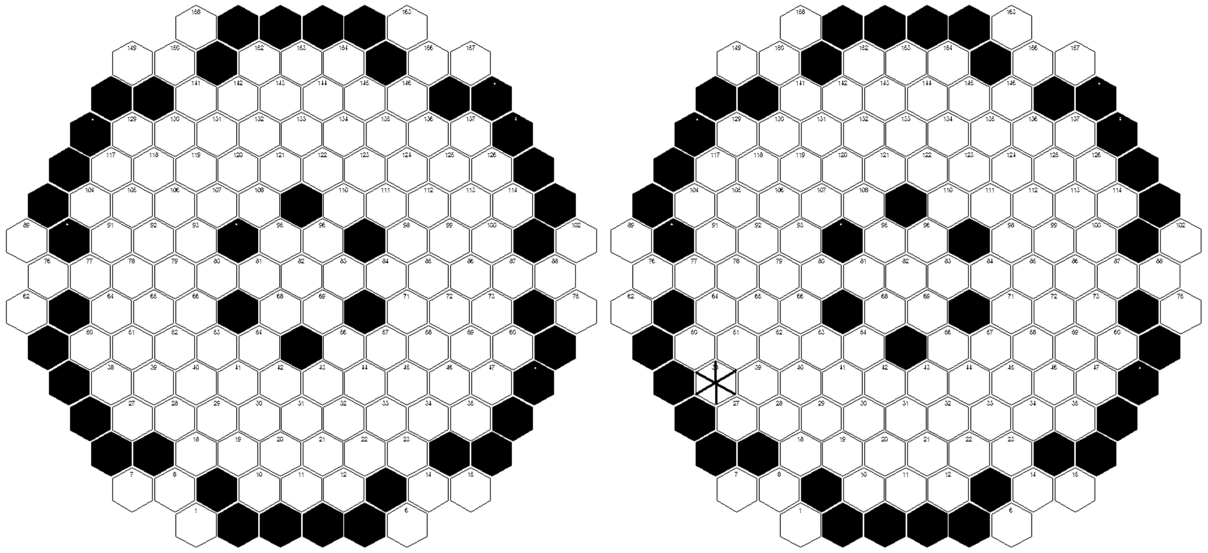
As a provisional measure, before problem elimination, it is offered to decrease limit values on power distribution on size of discrepancy of power distribution reconstruction systems based on SPS.

9.8 EXCESS FUEL ROD POWER LIMIT K_R IN CALCULATIONS SSTC NRS AFTER REPLACEMENT OF THE REJECTED FA

Everyday occurrence at WWER reactors operation is rejection of FAs during reloading. FA are rejected for the reason of leakage or in the presence of mechanical damages. As a result of it there is a change of the reactor loading scheme developed before. Usually for replacement use burnt out FA which were planned to an unloading in pool. But fresh FA of low initial enrichment are sometimes loaded (1.6 % TVSM, 2.2 % TVSA, see Fig. 5). In this case changes of power distributions are maximum and come nearer to limiting values on fuel rod power limit k_r (limiting value k_r=1.50). Thus are frequently marked distinction in results of calculations by NPPs (BIPR/PERMAK) and SSTC NRS (DYN3D/DERAB). Calculations SSTC NRS show a little larger splash of pod power k_r in the FA next to fresh FA of low initial enrichment (1.6 % or 2.2 %). SSTC NRS carries out calculation k_r by two methods: With use of code DERAB (diffusion model) and DYN3D (a method of power distribution reconstruction in the FA). Results of calculations on both codes are close and often show excess of a limit value k_r> 1.50.

Situation with distinction results of calculation k_r the NPPs and SSTC NRS arose repeatedly and for today the following plan of the problem decision is offered:

- The analysis of validation reports of codes BIPR/PERMAK relatively pin-power calculations;
- Working out the test problems, benchmarks (for example by codes MCNP, HELIOS) and their joint solution by experts of the Ukrainian’s NPPs and SSTC NRS.



Regular loading of fresh fuel

Core with in addition loaded fresh FA of low initial enrichment (1.6 % or 2.2 %)

⬢ - Fresh fuel

✳ - The fresh FA of low initial enrichment (1.6 % or 2.2 %)

Fig. 5 –Position of fresh fuel in WWER-1000 core

10. 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.

- Implantation of alternative vendor fuel ("Westinghouse" fuel) successfully proceeds.

- 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.

11. 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
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

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