«CALCULATION OF ISOTOPE BURN-UP AND CHANGE IN EFFICIENCY OF ABSORBING ELEMENTS OF WWER-1000 CONTROL AND PROTECTION SYSTEM DURING BURN-UP».

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ABSTRACT

The report deals with fast and thermal neutron flows distribution in structural elements of WWER-1000 FA and AR, determination of absorbing isotope burn-up and worth variation in WWER reactor control and protection system rods.

Simulation of absorber rod burn-up is provided using code package SAPFIR_95&RC_WWER allowing detailed description of the core segment spatial model.

Maximum burn-up of absorbing rods and respective worth variation of control and protection system rods is determined on the basis of a number of calculations considering known characteristics of fuel cycles.

1 INTRODUCTION

Designs of fuel assembly (FA) and absorber rod (AR) for WWER type reactors of new generation require correct calculation of operating conditions parameters. This is a requirement of new methods elaboration and application of modern high-accuracy program packages.

WWER-1000 FA has some parts significantly varied in structure and functions. Thus, this is the problem of geometry assigned to consider essentially important medium components for neutron flux distribution.

WWER-1000 control and protection system members represent a bundle of absorbing rods moving within special channels inside FA. The absorbing rod is a leak-tight cladding filled with absorbing material.

The calculation of neutron flux density onto a steel end-piece retaining absorbing material within the leak-tight clad is an important element for AR safety assurance under operating conditions specified.

AR worth variation when using boron carbide is mainly caused by radial "burning" of Boron-10. The products of boron interaction with neutrons practically do not absorb neutrons. Non-uniformity of neutron absorption results in re-distribution of isotope structure of absorbing compositions over AR radius.

Correct calculation of FA and AR neutron-physics in thermal nuclear reactor cells (considering neutron microstructure distribution in non-uniform grids and delayed neutrons redistribution in case of moderator non-uniform distribution and fuel burn-up) is possible only using the codes with detailed simulation of neutron spatial-power distribution on the basis of detailed libraries of isotope cross-sections. The requirements of the problem are satisfied by code SAPFIR _95 [1].

2 CALCULATION PROCEDURE DESCRIPTION

Main input parameters - WWER-1000 FA and Control Protection System (CPS) AR geometry and structure are presented in Tables 1,2 and Figures 1, 2. Operation of CPS AR absorbing element is considered under the conditions of emergency protection (AR tip is above the fuel) and automatic control (AR is partially submerged into the core).

Table 1 – FA parameters

Parameter	Value
Specific thermal power, W/cm^3	107,5
Coolant average temperature, °C	315
Core FA pitch, m	0,236
Fuel rod number in FA, pcs.	312
Fuel rod grid pitch, m	12,75*10^{-3}
Height of fuel stack (in cold state), m	3,53

Table 2 – WWER-1000 FA absorbing element parameters

Parameter	Value
Number of absorbing elements in CPS AR, pcs.	18
Absorbing material stack height, m	3,53
Absorbing material density, kg/m^3	1,7*10^3

Only operating CPS CR group is inserted into the core during fuel burn-up cycles. The basic number of absorbing rods is withdrawn from the core during reactor operation and works under the mode of emergency protection. Thus absorbing elements withdrawn from the core are in the area of upper end-plate reflector, and the range of absorbing element position uncertainty in this area is such that neutron flux density and the value of absorbing isotope burn-up in limiting positions of this range can vary significantly.

Such significant variation of absorbing element operating conditions in WWER reactor core requires elaboration of several representative calculational models. Therefore individual geometrical model of the core segment is described for each specific problem of spatial - power neutron distribution in the initial data to code SAPFIR_95.

Assumption of two-dimensional model with the conditions of reflection in the boundaries is sufficient for calculation of CPS AR absorbing isotope burn-up in the fuel area. Three-dimensional calculated volume with various axial properties is simulated for the absorbing rods withdrawn from the core. Segment dimensions are up to 130 cm in height, including FA head structure components, the lower (fuel) part is a source of neutrons, and upper - reflector. The conditions of reflection or neutron translation are assigned on segment boundaries. Neutron leak is simulated by black absorber assigned near segment surface.

Two-dimensional geometrical model is given in Figure 3. FA three-dimensional geometrical models with the absorbing element for emergency protection conditions is given in Figure 4.

“Basic” calculation of neutron spatial - power distribution with core average parameters is provided after assignment of calculated volumes geometry. Numbers of calculations with state parameter variations are provided further. The variations of reactor state parameters are change of specific power, fuel burn-up, moderator temperature and density, content of boric acid in water, variation of CPS AR core axial position in guiding channels, etc.

Determination of isotope structure variation is provided during absorbing element burn-up within WWER-1000 fuel assemblies with assigned specific power density considering core power axial distribution. Fuel upper layer power is assigned for the absorber position above fuel. Specified power distribution over fuel layers typical for FA with a working group is assumed for the absorber submerged into the core.

3 CALCULATION RESULTS

Relative fast and thermal neutron density variations on the absorbing element end-piece with the absorbing core lower point axial position variation above the level of fuel upper boundary and FA fuel burn-up variation are shown in Figures 5, 6.

Relative neutron flux density variations on the absorbing element end-piece at absorbing part lower point position variation relatively to fuel upper boundary for the emergency protection conditions prove that CPS CR upward displacement to 8 cm from fuel lower boundary causes increase of thermal neutron flux density to absorbing element end-piece more than twice, whereas the fast neutron flux falls below 60 % of its “base” value.

Calculation results also prove that fuel burn-up in FA with control group has significant effect onto neutron flux density value. Presented data prove that the value of fast neutron flux density to absorbing element end-piece at fuel burn-up 10 MW*day/kgU is more than 15 % above its «base» value with the same power and coolant boron concentration. Similar dependence is available for CPS CR under emergency protection conditions.

Generally, the value of neutron flux to absorbing element end-piece at each specific moment of reactor operation can be determined using previously evaluated dependencies of the parameters: burn-up, boric acid concentration, CPS CR group positions, FA power etc. For evaluation of the maximum value it is necessary to take into account possible axial power field variation as a result of xenon transient and CPS CR groups control.

The increase of efficiency lowering during burn-up is typical for the absorbing element on boron carbide basis. This is caused by the decrease of absorbing element effective diameter during «burn-up» of ^{10}B. ^{10}B burn-up radial distribution with various burn-ups within fuel assemblies of average power is shown in Figure 7.

Calculation of ^{10}B burn-up along absorbing element height within 3 years with specified axial power distribution of FA with the working group (Figure 8) proves that significant concentration variation of isotope ^{10}B is not above fuel boundary. Use of combined absorbers containing dysprosium titanate absorber in the lower part of the absorbing element and boron carbide absorber in upper is expedient for improvement of absorbing properties in the lower part of absorbing element. Long-term keeping of sufficient absorbance because of slow burn-up of absorbing element dysprosium isotopes due to their reproduction and insignificant absorber swelling in high neutron fluxes allow to increase WWER-1000 CPS CR service life to three years in the working group and to 10 years in emergency protection groups.

4 CONCLUSION

Provided analysis of neutron flux distribution along FA height and burn-up of boron carbide absorbing element within WWER-1000 fuel assemblies proves:

- variation of absorbing element position respectively to fuel upper boundary with CPS groups position under emergency protection mode has a significant effect on neutron flux density and spectrum of neutrons in the end-piece area. CPS CR upward displacement to 8 cm from fuel lower boundary results in more than twice increase of thermal neutron flux density to the absorbing element end-piece;

- the value of neutron flux on absorbing element end-piece for a specified power range depends on FA power, burn-up depth, coolant boric acid concentration, CPS CR group position. Generally, the value of neutron flux at each specific moment of reactor operation can be determined using previously evaluated dependencies of the parameters specified;

- increase of worth lowering during burn-up is typical for the absorbing element with boron carbide. Calculation of ^{10}B burn-up along absorbing element height within 3 years with specified axial power distribution of FA with the working group proves that significant concentration variation of isotope ^{10}B is not above fuel boundary;

- conservative assumption of ^{10}B concentration in the lower part of absorbing element (20 cm) is ~ 40 % of the initial value with maximum insertion of working group to 30 % during three years of reactor operation at nominal power;

- combined absorbers of dysprosium titanate in the lower part and boron carbide in upper are used in WWER-1000 for absorbing element absorbance improvement.

Calculation analyses of absorbing material burn-up in WWER-1000 CPS components are planned to be continued using full-scale reactor model considering fuel load operation and core groups motion.

5 REFERENCES

1. V.G. Artemov, A,V. Elshin, A.S. Ivanov et al. “Development of neutron-physical models for various type reactors using unified algorithms of application code package SAPFIR ”. Papers of the X International seminar on reactor physics. Moscow, September 2-6, 1997.

APPENDIX

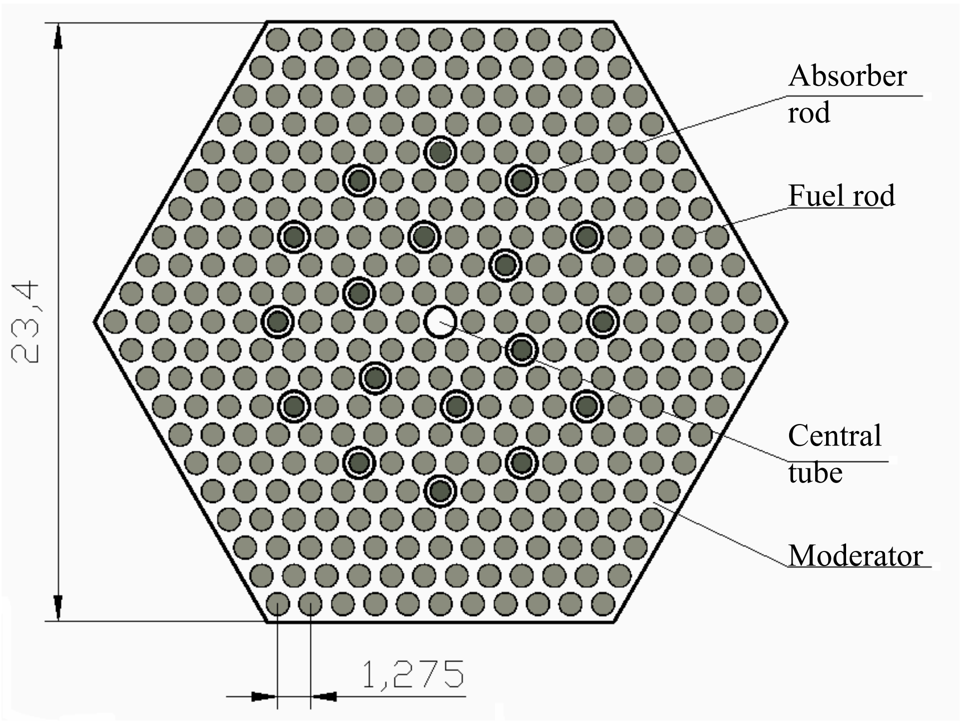

Figure 1 –WWER-1000 reactor FA

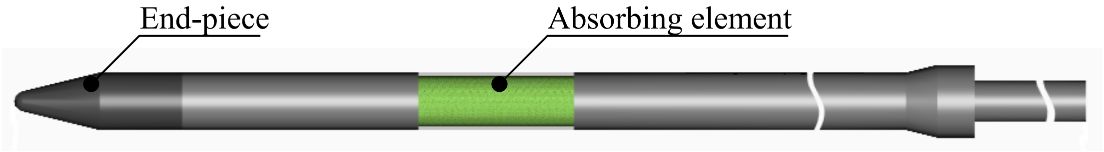

Figure 2 – WWER-1000 reactor absorbing element

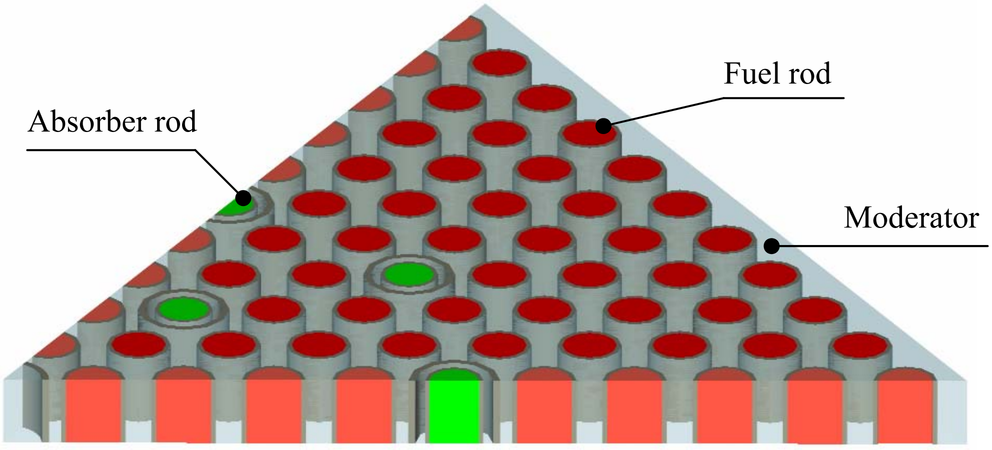

Figure 3 - Two-dimensional geometrical model of FA with CPS AR in 60˚symmetry sector

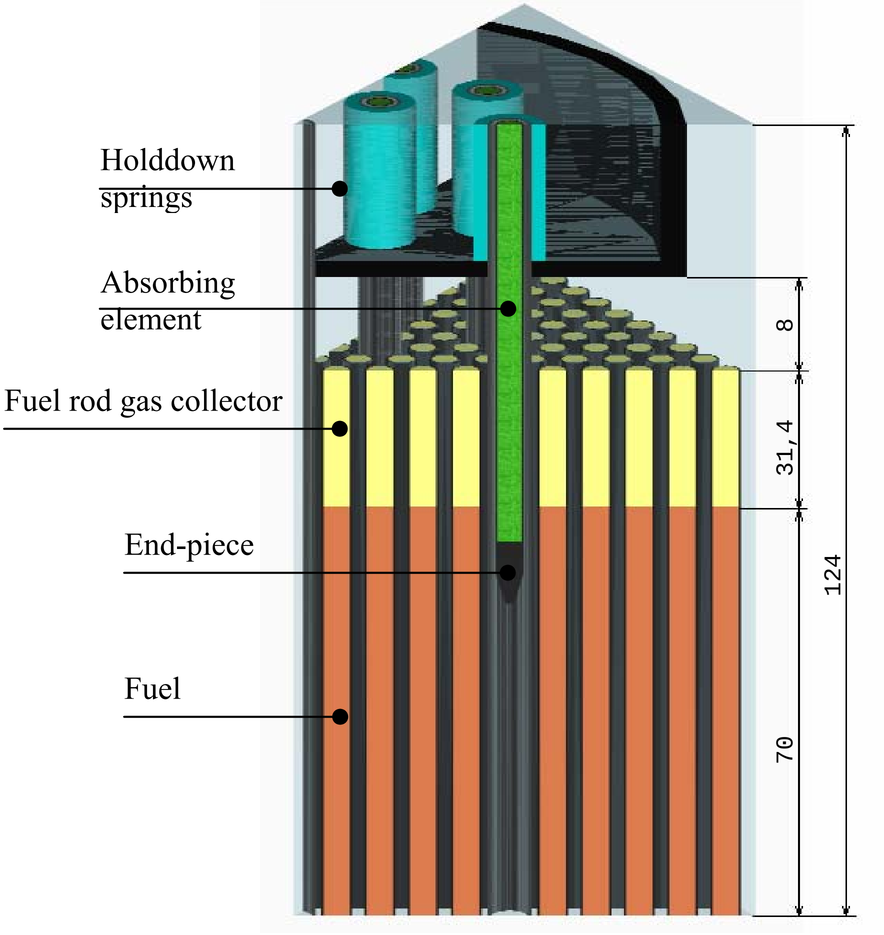

Figure 4 - Three-dimensional geometrical model of FA with absorbing element for EP conditions

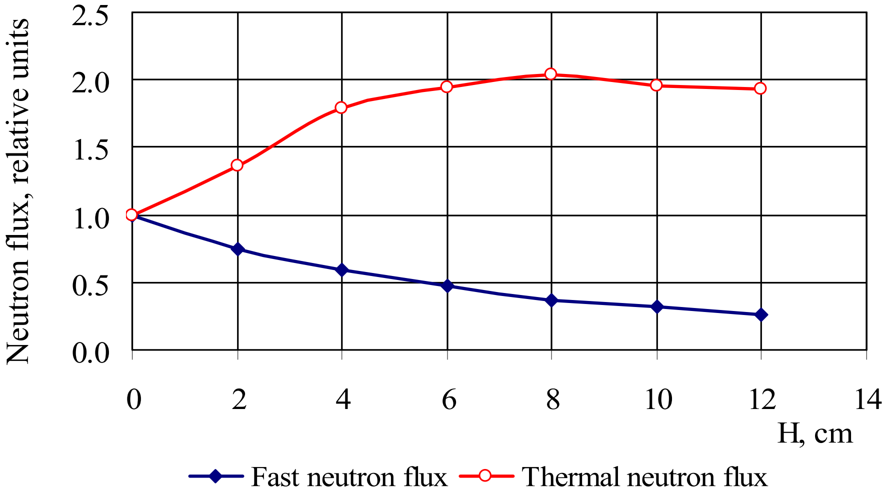

Figure 5 - Dependence of neutron flux to absorbing element end-piece from absorbing part lower point position along the height above fuel upper boundary level

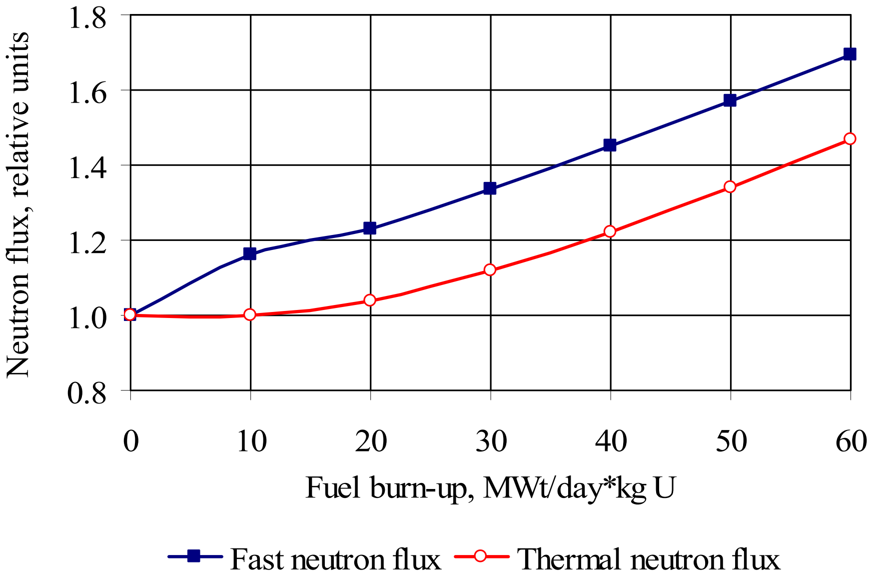

Figure 6 - Dependence of neutron flux to absorbing element end-piece from FA fuel burn-up

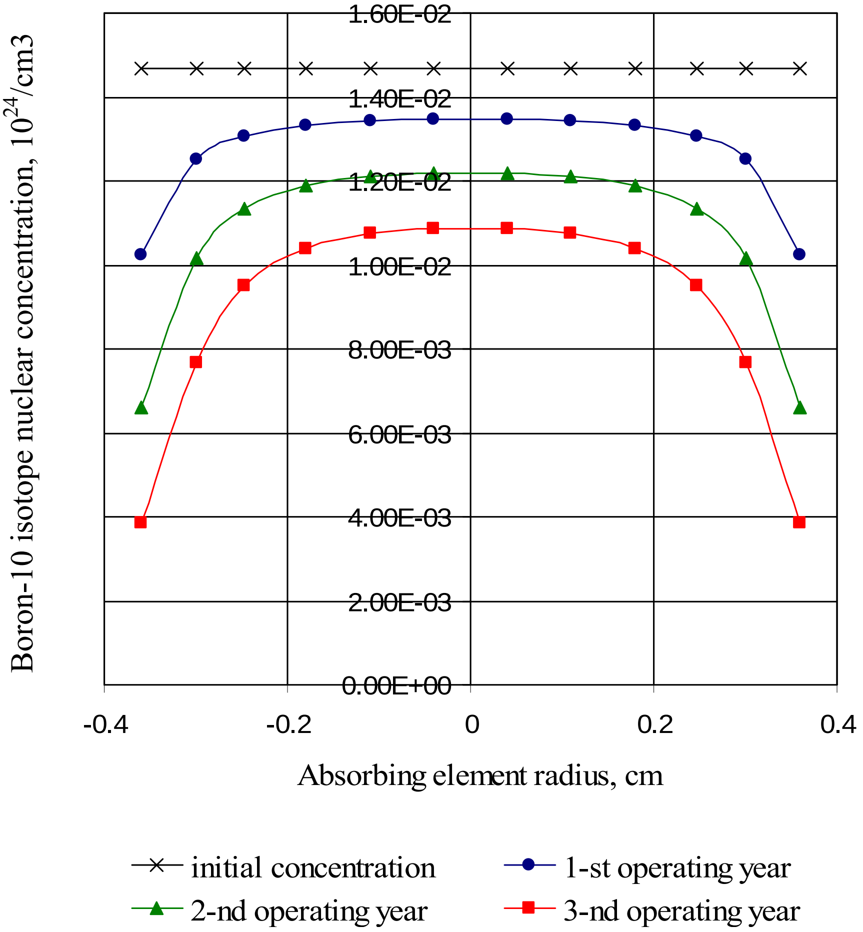

Figure 7 - Boron-10 burn-up over absorbing element radius

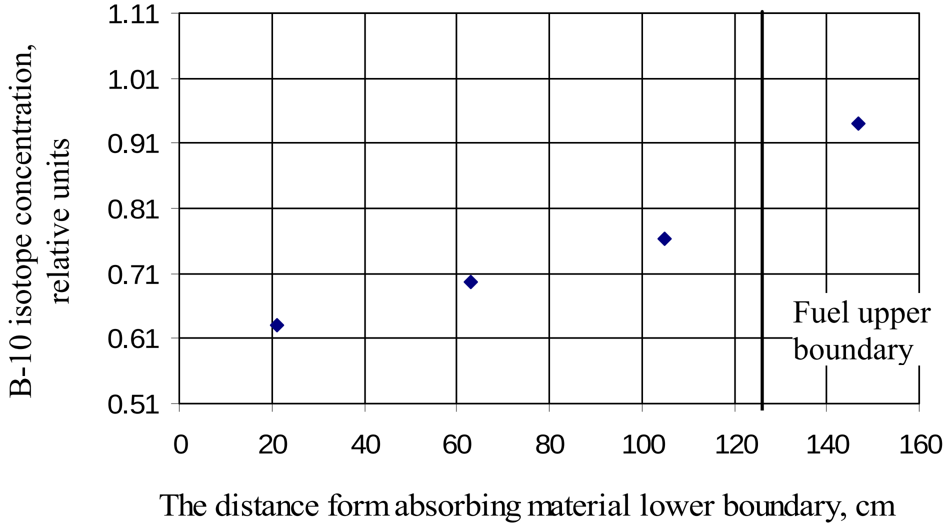

Figure 8 - Distribution of B^{10} concentration along absorbing element height respectively to absorbing rod lower boundary (with working group maximum insertion to 30 %) after three operating years