

# Joint work

## Monte-Carlo Parallel computing of full-scale model VVER-1000

Mikhail I. Gurevich, Dmitry S. Oleynik, Denis A. Shkarosky  
RRC "Kurchatov institute"

Reported at Workshop on Reactor Physics

July 6 -10, 2009

GRS, Garching, Germany

## Full-scale VVER-1000 model for Monte-Carlo calculation of neutron characteristics of core. MCU-PD and BIPR-7A results comparison.

Sergei S. Gorodkov, Vyacheslav G. Dementiev, Dmitry S. Oleynik  
RRC "Kurchatov institute"

Reported at 19<sup>th</sup> AER SYMPOSIUM on VVER Reactor Physics and Reactor Safety

September 21-25, 2009

St. St. Constantine and Elena, Bulgaria



## ***Introduction.***

---

Application of a Monte Carlo method for simulating of neutron transport in nuclear reactors has more than fifty years of history and widens permanently.

Monte Carlo approach allows to simulate radiation transport in systems with complex geometry on the basis of the most exact information on particles interaction with core matter without additional approximations and simplifications.

It is well known, that in many cases the Monte Carlo method used with evaluated nuclear data, may replace experiment. At present days such codes are used at the analysis of radiation and nuclear safety of existing and at designing new objects of atomic energy and for other purposes.



## ***Introduction.***

---

More and more challenging problems have been solved last years. One of present-day problems is three-dimensional calculations of full-scale reactor cores.

But these calculations require to simulate a huge number of neutron histories to obtain acceptable statistical uncertainty. It is possible due to modern multiprocessor computers.



## *MCU-PD code.*

---

MCU-PD is new version of Russian code on the basis of Monte-Carlo method which refers to MCU Project. MCU Project has being developing in RRC "Kurchatov institute" since 1982.

MCU-PD is a project on development and practical use of a universal computer code for simulation of particle transport (neutrons, photons, electrons, positrons) in three-dimensional systems by means of the Monte Carlo method. Also MCU-PD code has a unit for depletion calculations.

Some of characteristics of MCU-PD code

- is written in standard Fortran-90/95/2003 language;
- has modular construction;
- allows to calculate independently of operating system.



## *Purposes.*

---

### **Purposes of the work:**

- Adaptation MCU-PD code to parallel computing on modern multiprocessor computers;
- Verification of MCU-PD to calculation of full-scale core of VVER-1000.

### **In the frame of the work:**

- 3D full-scale model of VVER-1000 first unit of Volgodonsk NPP was developed;
- MCU-PD code is adapted to parallel calculations on modern multiprocessor computers;
- New algorithms on the basis of MPI (Message Passing Interface) were developed for parallel computing;
- 8 critical and subcritical states of fresh VVER-1000 core were calculated by MCU-PD and BIPR-7A.



## *MCU-PD code.*

---

MCU-PD is new version of Russian code on the basis of Monte-Carlo method which refers to MCU Project. MCU Project has being developing in RRC "Kurchatov institute" since 1982.

MCU-PD is a project on development and practical use of a universal computer code for simulation of particle transport (neutrons, photons, electrons, positrons) in three-dimensional systems by means of the Monte Carlo method.

Some of characteristics of MCU-PD code

- is written in standard Fortran-90/95/2003 language;
- has modular construction;
- allows to calculate independently of operating system.



## *Parallelization.*

---

Also well-known that calculation by Monte-Carlo code is required a lot of time. Monte-Carlo code mainly executes scalar operations.

Computation time of Monte-Carlo calculation is inversely to number of processors in the best possible way. Parallelization using several threads in the frame of a processor isn't efficient in comparison with that.

Thus, the most efficient parallelization of Monte-Carlo code calculation consists in independent work of each processor.

Calculation by MCU-PD code was paralleled using MPI (Message Passing Interface) library specification for message-passing. MPI was chosen because of this is the most acceptable for fast upcoming clusters, which are constructed by architecture of distributed memory.



## ***Scheme of parallel computing by MCU-PD code.***

The scheme of parallel computing by MCU-PD code has simple form.

1. Head processor reads initial data and broadcasts their to other processors.
2. Each processor simulates radiation transport independently of others. It is possible due to unique initial neutron distribution and unique random-number sequence.
3. At the end of calculation head processor collects and unites all statistical data to obtain tallies.

The main idea of this approach is minimal number of synchronizations between head processor and others. The points of synchronization are end of calculation and interim saving of data to the disk. The second one is set by user and is necessary to continue calculation from last saving in cases of interruption of computing .



## ***Data broadcasting.***

---

Transput between processors is relatively slow operation. So the main trouble of parallelization was optimization of data broadcasting.

Data in MCU-PD code subdivide into 2 types: constant and transient data. The first one is the information about initial data of task and are equal for all processors. They are broadcasted on each processor before calculation part.



## ***Data broadcasting.***

---

Transient data is unique for each processor. Therefore their broadcasting might take large memory. For example, depletion tasks might take 25 Mb for one processor.

Transient data subdivide into 3 types.

- 1.Data about state of simulating process.
- 2.Amass information about functional.
- 3.Data to accelerate calculation.

Amount of transient data were optimized. This work consists in changing some algorithms to minimize used memory.



## ***Parallelization of burnup unit.***

---

Calculation of depletion was paralleled also. The scheme of parallelization is similar to simulation of radiation transport.

1. Head processor reads initial data of one material from transfer files after radiation transport simulation and broadcasts their to another processor.
2. Each processor receives data and starts calculation.
3. At the end of calculation head processor collects and unites all results and saves their to a disk.

Such scheme allows to save on main storage since at any moment data of only one material is required.



## *Tests.*

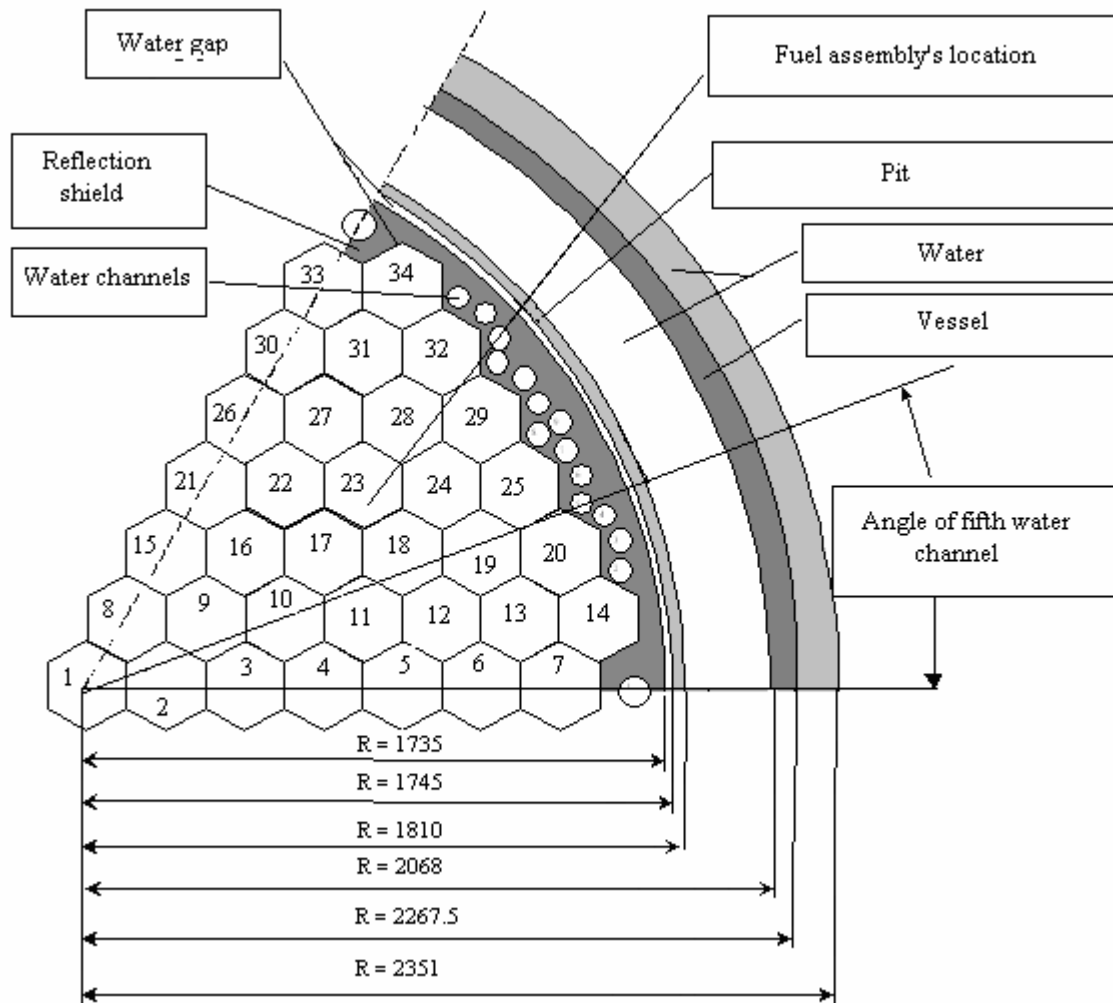
---

Parallel version of MCU-PD code was tested on full-scale three-dimensional model of first unit of Volgodonsk nuclear power plant.

Model technical characteristics (geometrical sizes of the reactor fragments, material structure, etc.) are based on the design data and on this unit starting experiments data. Such details, as a cavity in a fuel tablet, or channels in core buffer, or height structure of a control and protection system absorbing rod were explicitly described.



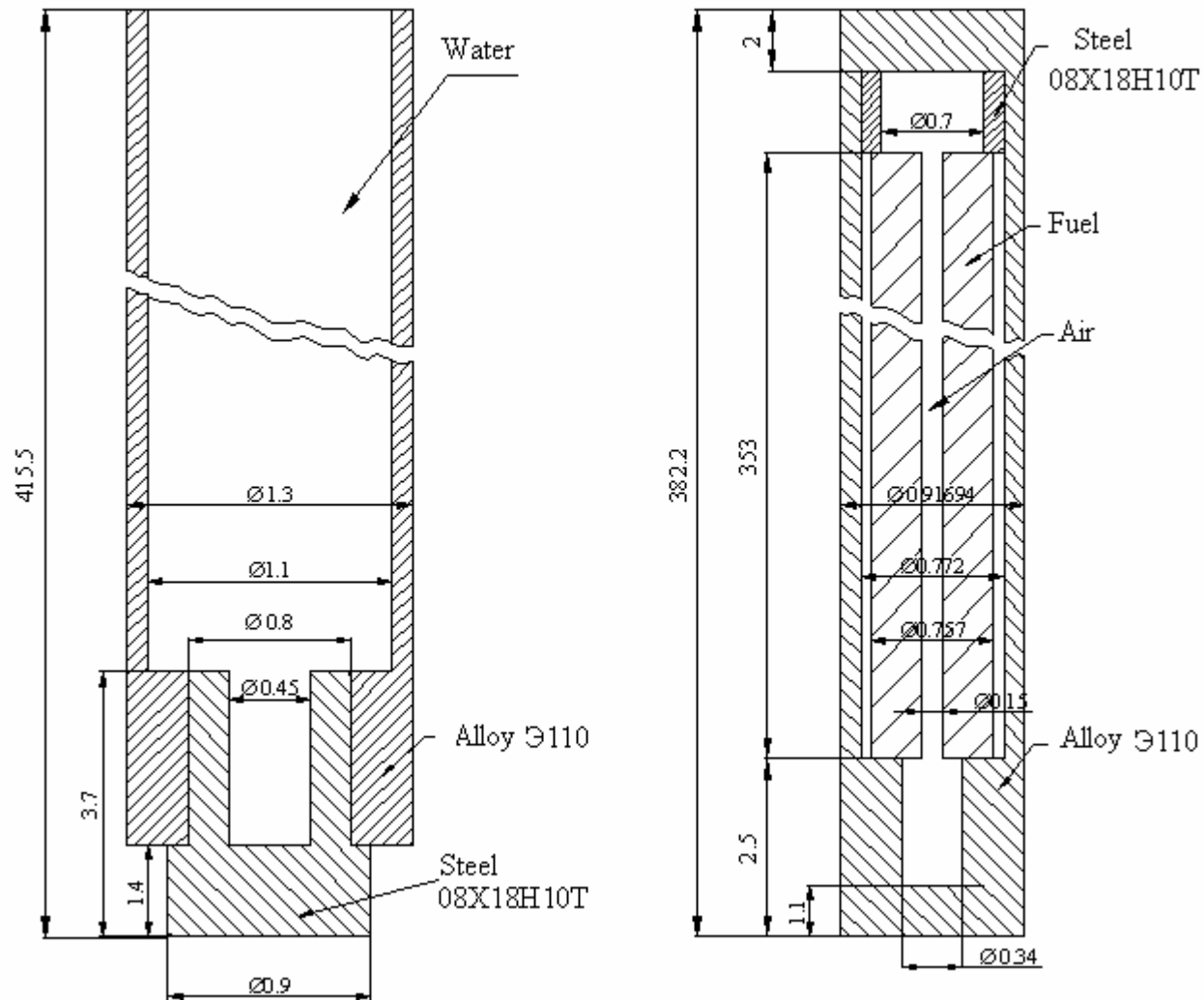
## Horizontal section of power plant.



- 3D geometry
- 163 fuel assemblies
- 7 different types of fuel assemblies
- height of core  $\approx 353$  cm
- height of the model  $\approx 473$  cm
- 360 degree

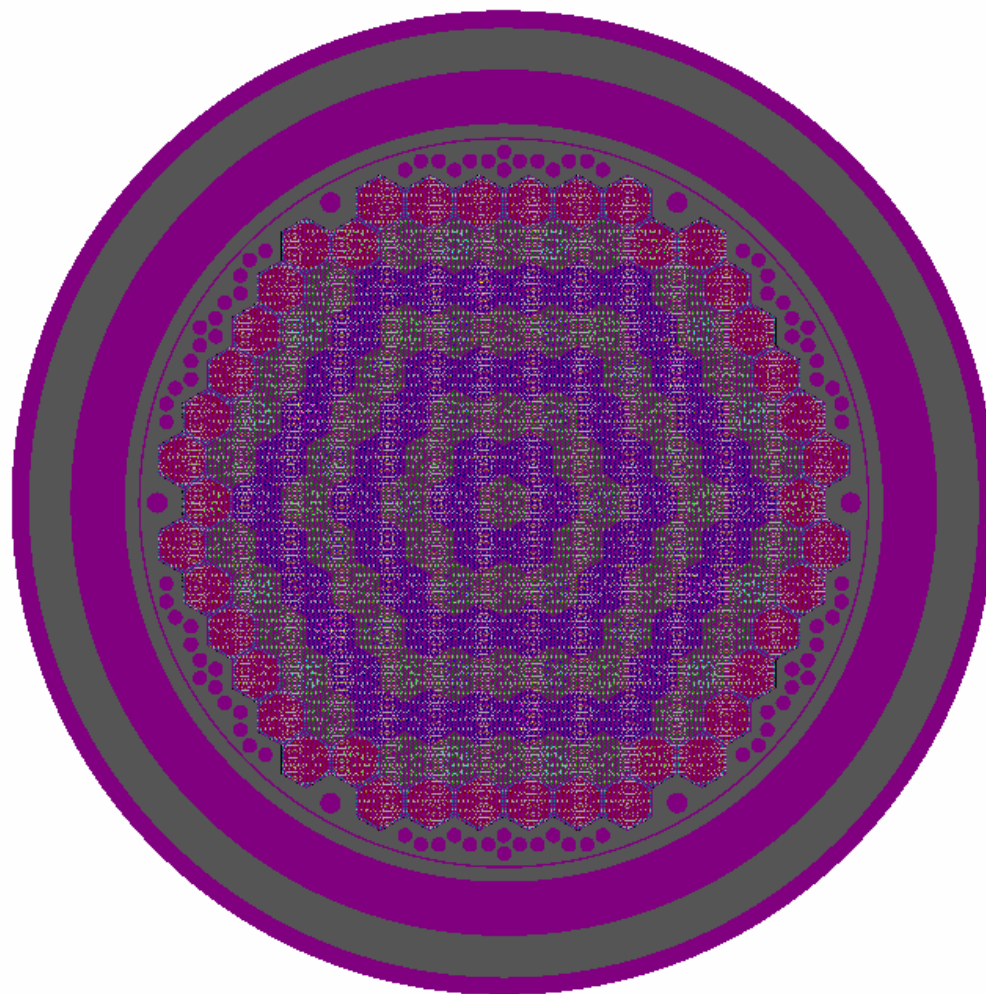


### 3D model of fuel element and guide channel.



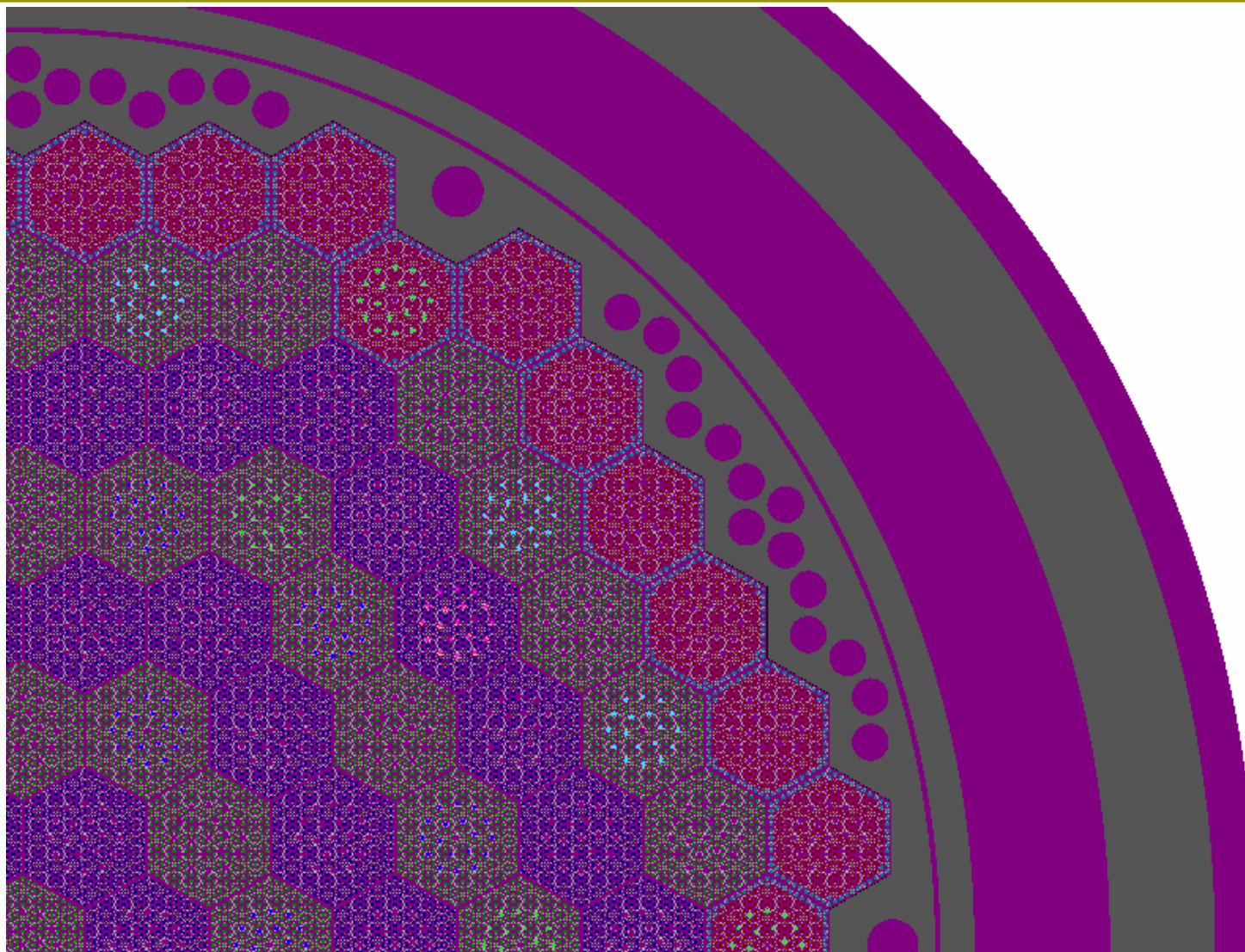


## *Horizontal section of initial data.*





## *Horizontal section of initial data.*





## *3D model.*

---

Video of 3D model is available at

<http://www.youtube.com/watch?v=W0ZtMWTdEgI>

or

[http://mcu.vver.kiae.ru/docs/sa3l1fa013\\_d1\\_c2.avi](http://mcu.vver.kiae.ru/docs/sa3l1fa013_d1_c2.avi)



## *Test variants.*

---

8 critical and subcritical states of the first unit Volgodonsk nuclear power plant on minimal controlled level were calculated.



## *Simulating parameters.*

For calculation of the model following parameters of simulating were chosen:

- Random initial neutron distribution in core;
- Number of neutrons in the generation –  $M = 3000$ ;
- Number of generations which are united in series for proper estimation of statistical error –  $NBAT = 400$ ;
- Number of generation in calculation is equal to 34000;
- Number of skipped generations is equal to 400;
- So number of neutron histories is approximately equal to 1 billion;
- One standard equation  $\approx 1 - 1,5 \%$  for fission rate in fuel assembly against location;
- Calculation time on 16 processors  $\approx 20$  hours;
- Calculations were made on multiprocessor computer of RRC Kurchatov Institute;



## *Calculations.*

---

For MCU code full core was specified without explicit indication of core symmetry in input data. One of advantages of such description is in possibility to evaluate the reliability of functional statistical error calculations. This evaluations results from analysis of deviations of power distribution in symmetrically placed FA's from theirs average one. Those deviations must be consistent with statistical errors calculated.

<  $1\sigma$  – About 65,8 % of results

<  $2\sigma$  – About 99,9 % of results

<  $3\sigma$  – 100 % of results

This analysis results confirm accuracy of MCU statistical error evaluation.



## *Calculations.*

The results of calculation were compared with well-known BIPR-7A code and with experimental data.

As results of calculations for each variant were received

- effective multiplication coefficients,
- power distribution by different FA's,
- power height distribution for each FA.

One standard deviation of MCU results here  $\sim 0,003$  %.

State #	MCU	BIPR-7A	MCU – BIPR-7A, %
A1	1,0025	1,0040	-0,14
A2	0,9391	0,9398	-0,07
A3	0,9551	0,9545	0,06
A4	1,0026	1,0039	-0,13
A5	0,9389	0,9394	-0,06
A6	0,9517	0,9515	0,02
A7	1,0020	1,0032	-0,12
A8	0,9387	0,9395	-0,08



## Calculations.

In the first column of table with experimental estimations reactimeter readings are shown.

In the second column – results of out-of-core ionization cameras data processing, based on special method, designed for spatial effects elimination.

State №	MCU	BIPR-7A	experiment	
			Reactimeter	Method*)
A2	6,74	6,80	6,38±0,38	7,5±0,7
A3	4,96	5,16	5,76±0,35	5,8±0,5
A5	6,77	6,84	6,32±0,38	7,5±0,7
A6	5,34	5,49	5,85±0,35	6,2±0,6
A8	6,72	6,76	6,39	6,7±0,5

Both codes results agree between themselves (in  $\sim 3\%$  limits), but their difference with experimental data, corrected on spatial effects, achieve 15 % because of influence of experimental values errors.



## *Calculations.*

---

MCU and BIPR-7A differences in FAs power distribution are less than  $\sim 11\%$  for critical and those subcritical states with all control rods dropped. This difference is not in contradiction with MCU and BIPR-7A authors declared codes uncertainties.

For subcritical states A3, A6 with control rods in one FA get stuck this difference is bigger. If in most power loaded FA both codes results are fairly close, then in other FAs, whose power is much less than core average this difference may achieve  $\sim 40\%$ .



## *Calculations.*

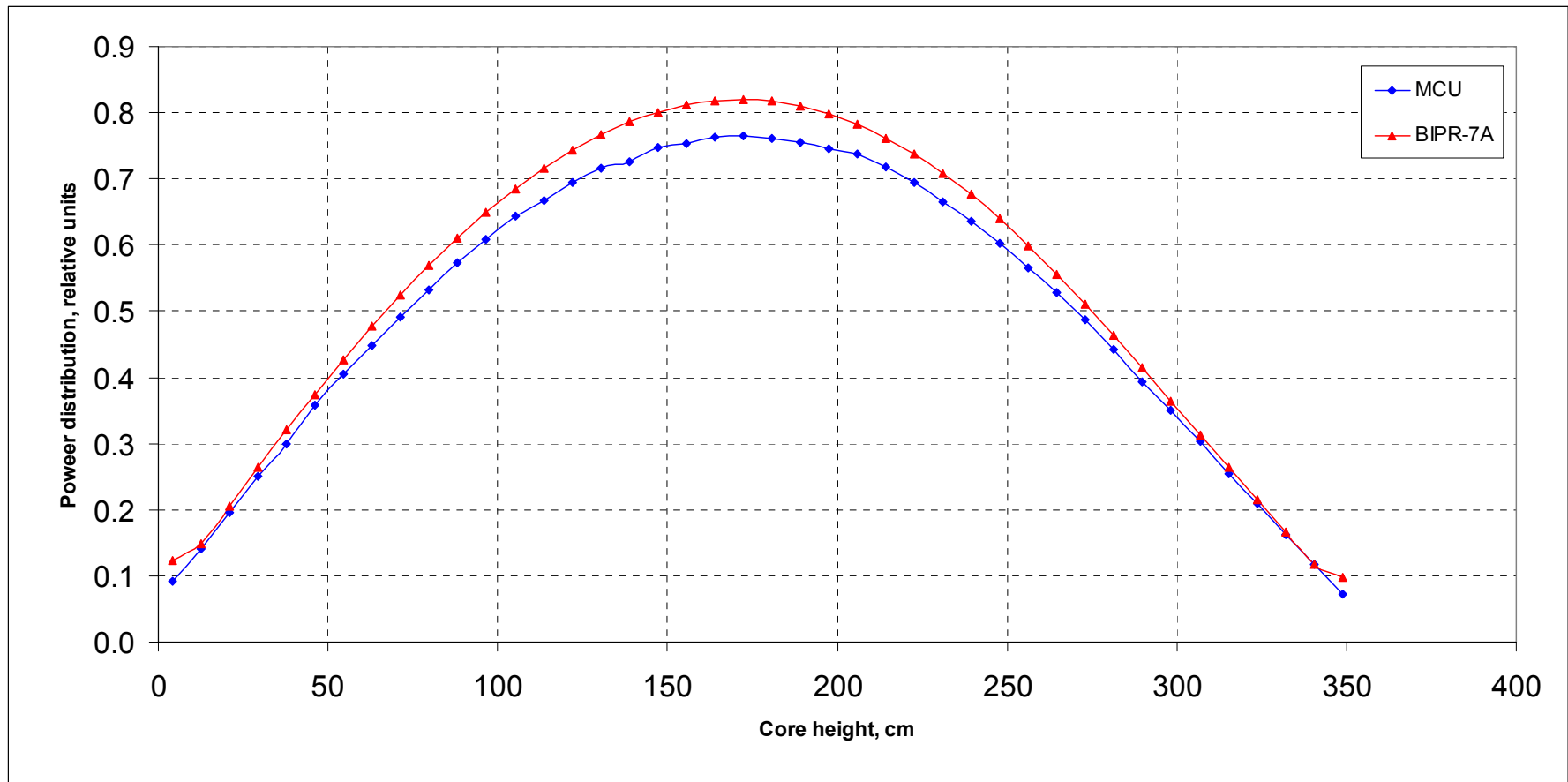
More than 90 % of height power distribution results differ less than 10 %. But in some places near core borders this difference amounts to more than 20 %. It can be attributed to BIPR-7A using border conditions, which are calculated preliminary by fine-mesh codes and BIPR-7A cell characteristics.

Interval	Values part, %
Less than 1 %	17,2
1 - 3 %	25,3
3 - 5 %	21,4
5 - 10 %	26,7
10 - 20 %	7,1
More than 20 %	2,3



## Calculations.

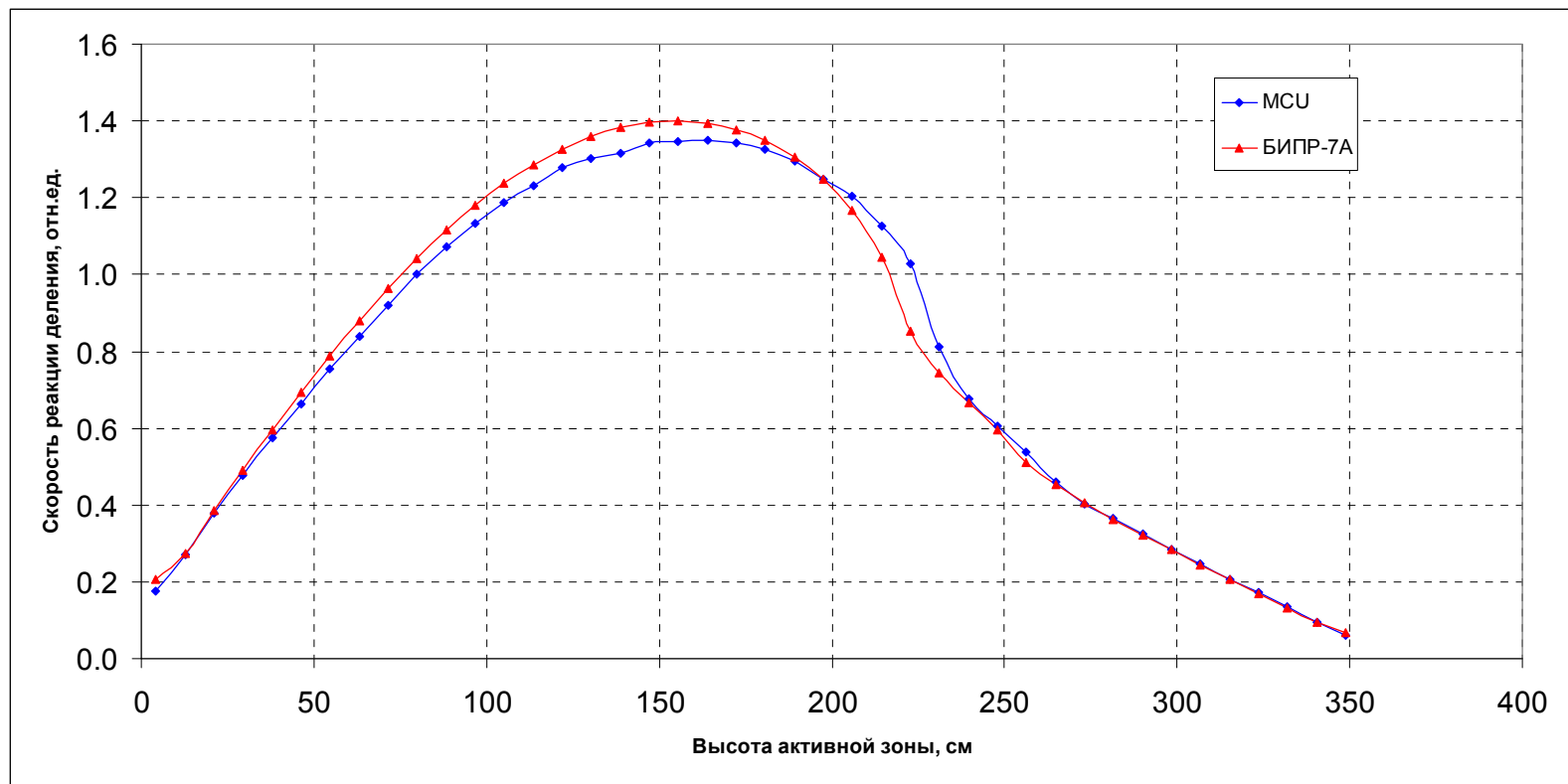
Figure demonstrates attributed height distribution in FA distant from control rods. It is easy to see that results of both codes differ at core top and bottom.





## Calculations.

The most pronounced irregularity of height distribution occurs in FAs with partially inserted CPS CR groups. Figure presents such distribution for one of state A7 FAs with 38% inserted CPS CR group 10.





## ***Conclusion.***

---

MCU-PD code was successfully adapted to parallel computing. It allows carrying out very complex calculation for a short time. Coefficient of parallelization is almost equal to 1 if interim synchronization is off. It means that computation time of calculation is inversely to number of processors.

3D full-scale model of VVER-1000 first unit of Vokgodonsk NPP was developed. Based on this model 8 critical and subcritical states were calculated. Analysis and comparison of the results were fulfilled.

3D full-scale VVER model and received results can be used as benchmarks in verification process of modern operative and high-precision codes, designed for VVER safety validation.

This work will be continued. It is planned as the next point to calculate pin by pin height distribution in core.