1.1 INFORMATION ABOUT AER WG A ON IMPROVEMENT, EXTENSION AND VALIDATION OF PARAMETRIZED FEW-GROUP LIBRARIES FOR VVER 440 AND VVER 1000

Pavel Mikoláš
ŠKODA JS a.s., Orlík 266, 316 06 Plzeň, Czech Republic
Tel: +420 378042828, Fax: +420 378042305, E-mail: pavel.mikolas@skoda-js.cz

ABSTRACT

Joint AER Working Group A on „Improvement, extension and validation of parameterized few-group libraries for VVER-440 and VVER-1000“ and AER Working Group B on „Core design“ nineteenth meeting was hosted by VÚJE a.s. in Modra - Harmónia (Slovakia) during the period of 20th to 22nd April 2010.

There were present altogether 12 participants from 8 member organizations and 9 papers were presented (8 of them in written form).

Objectives of the meeting of WG A are: Issues connected with spectral calculations and few-groups libraries preparation, their accuracy and validation.

Presentations were devoted to some aspects of transport and diffusion calculations and to the benchmark dealing with VVER-1000 core periphery power tilt.

Tamás Parkó (co-authors István Pós and Sándor Patai Szabó) described in his presentation “***Application of Discontinuity factors in C-PORCA 7 code”***, Radoslav Zajac (co-authors Petr Dařílek and Vladimír Nečas) spoke about “***Fast Reactor Nodalisation in HELIOS Code“***, Gabriel Farkas presented “***Calculation of Spatial Weighting Functions of Ex-Core Neutron Detectors for VVER-440 Using Monte Carlo Approach”*** and Daniel Sprinzl (co-authors Václav Krýsl, Pavel Mikoláš and Jiří Švarný) provided a definition of a benchmark in ***“’MIDICORE’ VVER-1000 core periphery power tilt benchmark proposal”***.

Future activities are also shortly described in the end of the paper.

INTRODUCTION

Joint AER Working Group A on „Improvement, extension and validation of parameterized few-group libraries for VVER-440 and VVER-1000“ and AER Working Group B on „Core design“ nineteenth meeting took place in Modra - Harmónia (Slovakia) during the period of 20th to 22nd April 2010.

There were present altogether 12 participants from 8 member organizations (List of participants is attached in the end of this paper) and 9 presentations were read (List of presentations is also attached).

Objectives of the meeting of WG A: Issues connected with spectral calculations and few-groups libraries preparation, their accuracy and validation.

PRESENTATIONS

Four papers were presented in frame of WG A:

Mr. Parkó (co-authors: I. Pós and S. Patai Szabó) described in his paper “**Application of Discontinuity factors in C-PORCA 7 code”**

First, he explained Status of HELIOS/C-PORCA codes at the Paks NPP and their application for:

Off-line analysis (with functions):

- Node & Pin-wise 2GR XS data calculations for fuel and non fuel regions
- Core loading optimization as a part of CERBER model
- Calculation of core characteristics for safety analysis of cycles
- Core follow calculation and preparation of fuel isotope inventory

and

On-line analysis in VERONA core monitoring system (with functions):

- 3D diffusion calculations within minutes (2 NG, full core, max. 50 axial layers)
- Burn-up calculation and following of some specific isotopes (Sm, Pm, U-238, Pu-239, 240, 241, Np-239)
- Xe process calculation.

Then he expressed an idea flux discontinuity factors and showed calculation of them.

The goal of utilization of discontinuity factors is:
To ensure the real neutron current between adjacent nodes with the neutron flux correction, so that the transport flux will be continuous instead of diffusion flux. Of course the neutron current remains continuous. If the transport solutions were known in two adjacent nodes the above described method would give the right current through the border.

Although in the practice of reactor physical calculations the exact transport flux is not known, the utilization of DC factors seems to be a good correction of the neutron current at the node borders.

The methods for determination of discontinuity factors:

For fuel nodes:

during the XS homogenization process the real Helios border flux is divided by flat flux calculated from the homogenized XS data.

Discontinuity factors are identical at all six borders.

$DC=\varphi_{He}/\Phi_{flat}$

For non multiplying nodes:

Additional diffusion calculation is made in a homogenized node using boundary neutron currents calculated by Helios transport code.

absorbers: DC factors are identical at all six borders.

others: DC factors are different at each borders of the hexagon

$DC=\varphi_{He}/\Phi_{diffusion\ model}$

The magnitude of calculated discontinuity factors for different nodes is the following:

The extent of DC factors for fuel nodes:
For fast group: 0.98-1.0
For thermal group: 1.1-1.3.

The extent of DC factors for absorber and reflector nodes:
For fast group: 1.2
For thermal group: 0.4-0.6.

Investigation of the radial power distribution K_q concerning discontinuity factors was also performed. During the test of discontinuity factors a lot of real reactor core states were calculated and the results of NoDCFactor and DCFactor models were compared. Generally, the biggest deviation between two methods was found next to the radial reflector and the vicinity of control rods GR6.

Some examples were shown from this investigation. The presented (but not repeated here) Kq distributions came from the Paks NPP unit 4 cycle 1, because in first cycles the core contained assemblies with enrichment 1.6 w% of ^{235}U, 2.4 w% of ^{235}U and 3.6 w% of ^{235}U. Bigger difference in enrichment gives bigger difference in DCFactors.

Next, an investigation of the control group H6 worth concerning discontinuity factors was performed: Problems were observed with H6 worth - during power change process simulations by VERONA, the calculated integral worth of group H6 was less than expected. The discrepancy was 100-120 pcm. The measured integral and differential control group worth was greater than calculated ones.

Also, the control rod follower induced local power peak benchmark was evaluated: Some results of this benchmark were presented in the A&B group meeting in 2009. Result of C-PORCA 7 was presented. (As the reference data they used MCNP results prepared by Jošek R.: WWER-440 control rod follower induced local power peaking computational benchmark, Report ÚJV Z 2115, Revision 2, July 2008.) Calculation of the benchmark by HELIOS/C-PORCA codes using DC factors was performed. Xs data calculations for fuel,

non-fuel nodes and pins were made by HELIOS as it is done during standard Xs data preparation. Node-wise finite element flux distribution for the whole investigated region was calculated by C-PORCA. The fast flux inside 'super-assemblies' was interpolated from the nodewise results. Pin-wise thermal flux and power distribution in 'super-assemblies' was calculated by a pin-wise model integrated into C-PORCA.

Conclusions

- The discontinuity factor calculation and its usage is a standard method in the HELIOS/C-PORCA code system was presented.
- The fulfilled tests showed its applicability and correctness from all important aspects.
- The method installation into off-line and on-line functions has been finished.

R. Zajac (co-authors – P. Darilek and V. Necas) spoke about **„Fast Reactor Nodalisation in HELIOS Code"**.

On a base of FA of SUPERPHENIX 2 – fast reactor, a SUPERPHENIX assembly was modeled by HELIOS 1.10; where real fuel assembly (*with 271 pins*) was simplified *with* pseudo fuel assembly (*also with 271 pins).*

The main part of his paper was devoted to strategy for optimal discretization of a basic cell. Basis cell in discretization strategy consists in modeling of 4 regions cell:
(***Coolant*** – Natrium, ***Cladding***, ***Fuel*** – MOX, 23.2 % Pu, 0.25 % U-235 with ***central hole***).

A system consisting from the regions can be divided into the smaller regions by the spatial discretization:

Spatial discretization in fuel:

8 regions model of the cell, 5 regions in the fuel
14 regions model of the cell, 11 regions in the fuel
24 regions model of the cell, 21 regions in fuel
34 regions model of the cell, 31 regions in fuel

Spatial Discretization in coolant:

14 regions model of the cell, 11 regions in the coolant
19 regions model of the cell, 16 regions in the coolant
29 regions model of the cell, 26 regions in the coolant
39 regions model of the cell, 36 regions in the coolant

Optimized strategy:

16 regions: coolant (11), fuel (5)
27 regions: coolant (16), fuel (11)
47 regions: coolant (26), fuel (21)
67 regions: coolant (36), fuel (31) - reference model, high requirements on operation memory allocation

Final results - for burn up: 136 GWd/tU using computer Intel(R) Core(TM)2 CPU, 2.67 GHz, 3.00 GB RAM are in the following table:

Fuel regions					
	Basic model	5	11	21	*31*
k_{inf}	1.16282	1.16296	1.16320	1.16362	*1.16406*
Deviation	-0.11	-0.098	-0.077	-0.041	*-0.0034*
CPU(min) time	9.04	43.19	92.87	185.23	*306.35*
CPU time factor	1.0	4.77	10.27	20.49	*33.89*
Coolant regions					
	Basic model	11	16	26	*36*
k_{inf}	1.16282	1.16283	1.16281	1.16288	*1.16286*
Deviation	-0.11	-0.109	-0.111	-0.105	*-0.107*
CPU(min) time	9.04	10.54	12.46	14.93	*19.71*
CPU time factor	1.0	1.17	1.38	1.65	*2.18*
Optimized strategy					
	Basic model	18	27	47	*67*
k_{inf}	1.16282	1.16297	1.16319	1.16368	*1.16410*
Deviation	-0.11	-0.097	-0.078	-0.036	*Ref.*
CPU(min) time	9.04	52.50	101.02	197.75	*306.66*
CPU time factor	*1.0*	*5.81*	*11.17*	*21.88*	*33.92*

Conclusions

- The limit of memory allocation reduces the possibilities to divide cells with rings into the regions, no more than 67.
- The elimination of memory allocation troubles can lead to k_{inf} true value.
- The spatial discretization in the coolant influences only insignificantly.
- The future analysis will be concentrated only on the spatial discretization in the fuel.
- The future plan will repeat the spatial discretization test also for the VVER-440 fuel.

G. Farkas presented paper "**Calculation of Spatial Weighting Functions of Ex-Core Neutron Detectors for VVER-440 Using Monte Carlo Approach**".

In the beginning, he explained motivation for his work.

As it is well known, the contribution of fuel assemblies to the ex-core detector response depends not only on the power, but also on the position of the given assembly in the core.

Precise knowledge of the spatial weighting functions can be very beneficial for the solution of various reactor physical, operational, and safety problems. It can be useful for the proper interpretation of the startup test measurements, calculation of ex-core detector response in deep subcritical reactor states, evaluation of influence of the core loading pattern on the detector response, etc.

A very important application area is the reactor safety analysis. In this case the elaborate weighting functions can be helpful in investigating how effectively certain transients which cause a sudden change in the power density distribution can be detected by the ex-core detectors.

Problem of weighting functions:

The spatial weighting function gives a relationship between the spatial power distribution in the core and the ex-core detector response. Schematically it can be expressed as follows:

Ex-core detector response:

$$D = C \cdot P \cdot \int_V p_0(r) w(r) dV$$

Numerical solution

$$D \cong C \cdot P \cdot \sum_i P_i W_i$$

SCORPIO, BIPR,... | MCNP

where:
Wi – weighting factor of *i*-th volume element
Pi - corresponding relative power
Volume element is the twentieth of fuel pin height.

Method of calculation:

Source region boundaries cover all of the fuel pin elements with Wi > 0,5 % Wi,max. Calculation of Wi is performed only in the source fuel pins → quasi-regular grid. Required is uncertainty of the MC calculation < 3,5 % (for peripheral pins < 1,0 %). Calculation is performed by the so named “Fix Source method”.

Approximation of weighting functions:

w(r) → approximation of analytical function in two steps:

- Vertical (1D) approximation → wa(z)
- Horizontal (2D) approximation → wh(x,y) or Volume (3D) approximation

Vertical approximation:

- Finding an analytical function which properly describes Wi distribution in vertical direction (that is along the source fuel pins).
- Smoothing the calculated (MCNP) Wi values for a horizontal approximation.

Horizontal approximation:

- Approximation of two-dimensional function for layers of the twentieth of fuel pin height.
- Calculation of Wi values in non-source fuel pins.

Approximation methods:

Vertical approximation - weighted least square method

Horizontal approximation - the polyhedral approximation of closed Jordan surfaces.

Results - universal model of VVER-440/V213 in MCNP5

Precise 3D whole-core model of the VVER-440 was developed in MCNP5.

The model enables:

- to define any core loading pattern and different operational parameters,
- to define axial and radial burnup profile as well as coolant (moderator) temperature/density profile in the core,
- to specify temperature profile of the in-vessel and ex-vessel reactor components,
- to fill the ionization chamber channels with given detectors.

The following models were also described:

- Model of the VVER-440 in MCNP5
- Model of FA in MCNP5
- Absorber part of the CA in MCNP5
- Fuel part of the CA in MCNP5

Results – axial weighting functions

Total number of source fuel pins $\Rightarrow$ 193 (that is 3860 volume elements).
Axial weighting factor (Wi) distribution was presented (but not shown here) for selected 16 source pins (320 elements).

The proposed polynomial function: $w_a(z)=a_0+a_1z+\ldots+a_Mz^M$; M=8.

The shapes of approximation curves correspond to the theoretically expected weighting factor distribution in vertical direction. Extension of the curves (that is increase in the FWHM) with increasing distance of a given fuel pin from the ex-core detector is mainly caused by geometrical reasons. Shapes of distribution curves in dependence on source pin positions show transient character between a typical “bell” curve (close pins) and “arc” curve (distant pins).

Results – horizontal weighting factor distribution

At average, 3 - 4 source pins were calculated for each FA, except core periphery where 5 – 7 pins per FA were computed. Weighting contribution of the closest 20 peripheral fuel assemblies to the ex-core detector signal represents 92 % from the sum of the core weighting factor values, in the closest fuel assembly region to the ex-core detector, in the direction from the maximum weight position to the core centre, approximately eight-fold decrease of weighting factor values is observed, it can be expected that horizontal weighting function will “warp” in the upper and lower part of the source region, i.e. their values will not be mainly determined by the distance from the ex-core detector.

It can be expected that the horizontal weighting function will have a character of exponential polynomial function of the 3rd - 8th order of magnitude, generally expressed by:

$$w_h(x,y) = \exp\left(\sum_{i=0}^{K}\sum_{j=0}^{L} a_{ij} x^i y^j\right)$$

The following specific form can be designed:

$w_h(x,y)=\exp(a_0+a_1x+a_2y+a_3x^2+a_4x+a_5y^2+a_6x^3+a_7y^4+a_9y^4+a_{10}x^5+a_{11}y^5+a_{12}x^6+a_{13}y^6$

Results – sensitivity and parametric analysis

Influences of changes of different reference parameters were also checked (not presented here).

Conclusion

- Precise and complex whole-core model of the VVER-440 was developed in MCNP5 and applied for solution of various reactor-physical problems (Bohunice NPP & Mochovce NPP).
- Determination of weighting factors and weighting functions was performed for the source range ex-core detector CPNB44 (Bohunice NPP)
- At present, database of spatial weighting factors is generated.

D. Sprinzl (co-authors V. Krýsl, P. Mikoláš and J. Švarný) provided a definition of a benchmark in "**'MIDICORE' VVER-1000 core periphery power tilt benchmark proposal**"

In the "Background" he explained the purpose of such a benchmark:

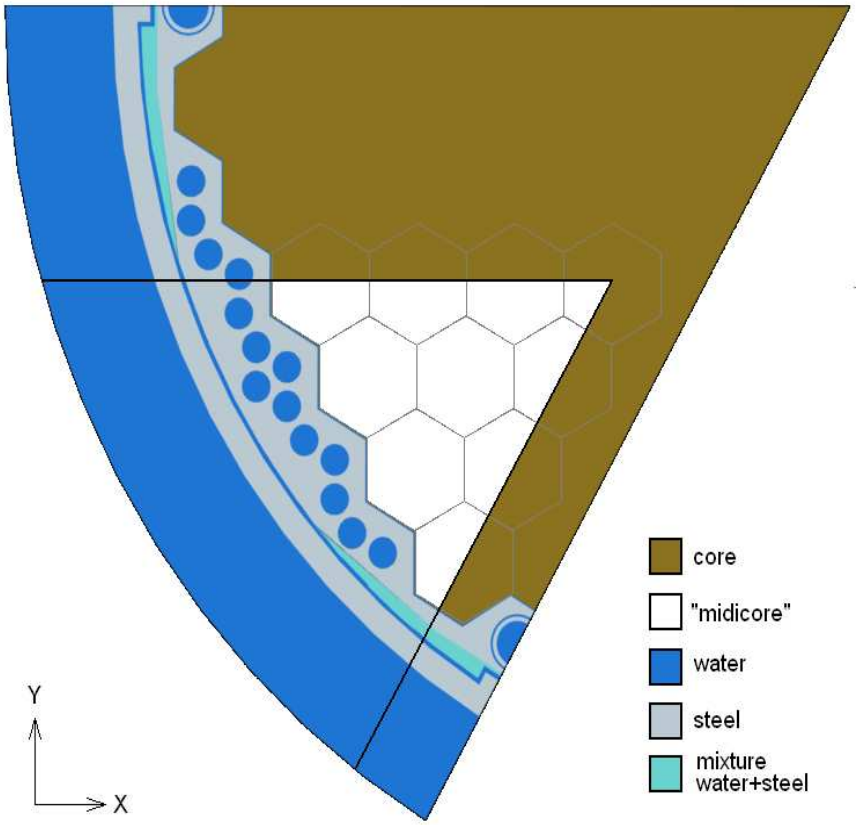
The 9th loading of Temelin NPP, Unit 1 (VVER-1000) (the 1st loading *only* with TVSA-T fuel assemblies made by TVEL) was computed by different codes (BIPR & PERMAK, MOBY-DICK, ANC, ANDREA) and different pin-power distribution was observed for:

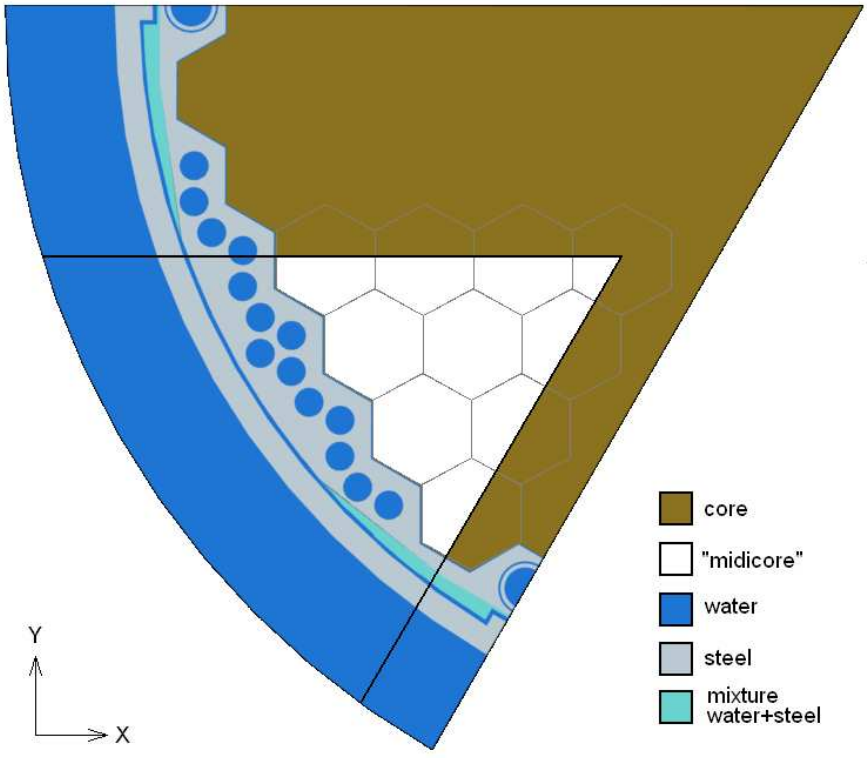
- *nodal solution with reconstruction,*
- *pin-wise calculation using diffusion and finite difference approximation.*

So, a proposal for solving of a small testing core („MIDICORE") to clear up the origin of the differences was propounded.

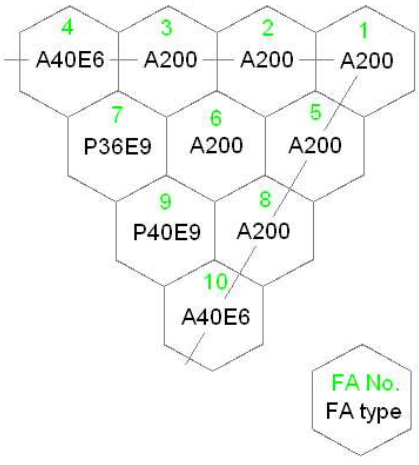
"MIDICORE" general:

"MIDICORE" is a segment of the VVER-1000 core near the periphery.





Cartogram of "midicore"



Reference calculation was performed by MCNP code:

- 2D calculation;
- Cold state geometry and densities of materials (except for coolant);
- Coolant density given for 600 K and 15.7 MPa;
- Temperature of all materials is 600 K;
- No RCCA inserted (=coolant in guide tubes).

Benchmark objective is to calculate:

- k_{eff}
- integral fission power of all 10 FA's
- pin by pin fission power distribution in FA's No. 6, 7 and 9

Types of FA's used are A200 (40B), A40E6, P36E9, P40E9 and their description are provided:

Fuel assemblies' specification

- RCCA guide tubes
- Central channel
- Stiffening angles
- Number of grids

Fuel pins' specification

- Fuel pins cladding
- Fuel pellet

Materials' specification

Alloys E-110; E-635; Core basket and core barrel materials; Coolant material.

Core basket geometry:

Suggestions I:

- Use at least one row of "reflector" FA's in macro-code calculation.

Suggestions II:

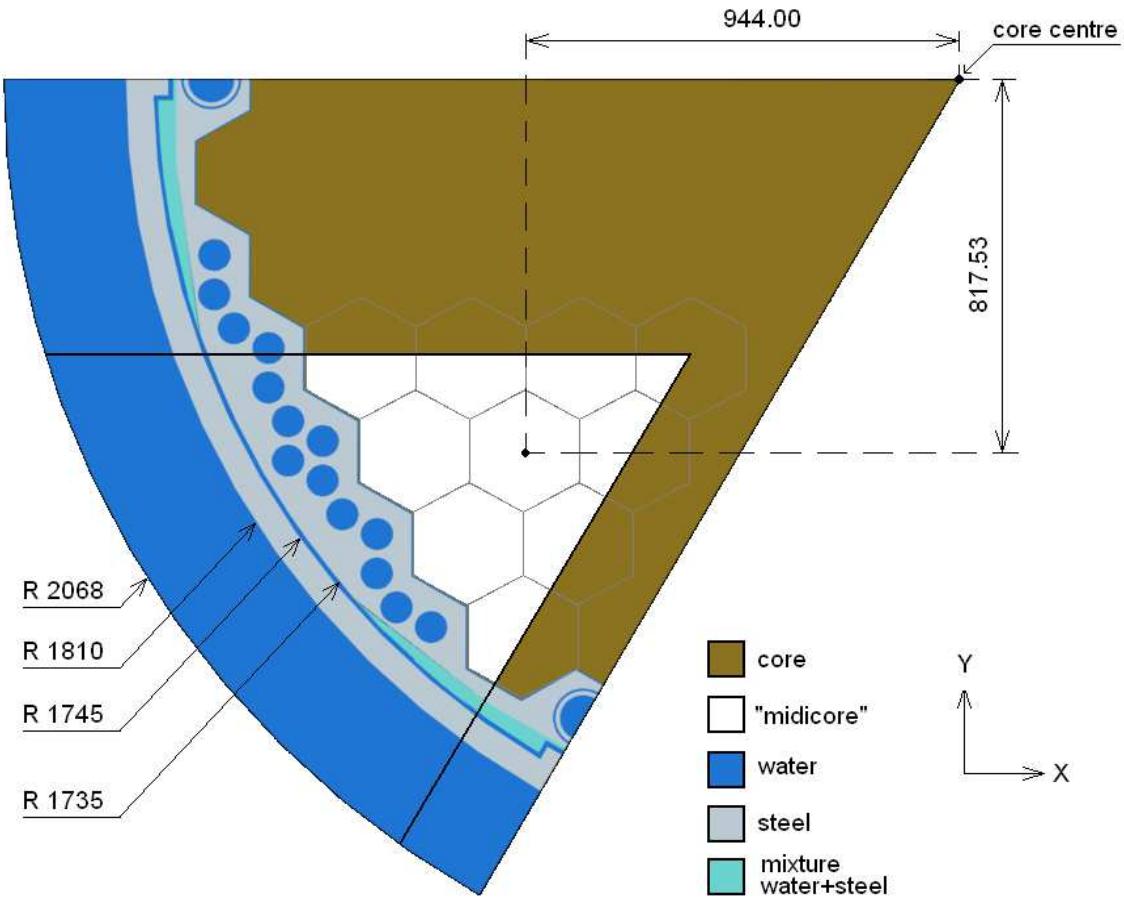
- The norm for the integral fission power of FA's:
  - The norm of integral fission powers of FA's should be set for the whole "MIDICORE" (37 FA's). The mean value of all integral fission powers for all 37 FA's equals 1.
- The norm for the fuel pins:
  - The norm of pin powers in each FA should be set separately for each FA. The mean power of fuel pin should be equal 1 in each FA.

Suggestions III:

Data format – ASCII, preferred numbering of fuel pins provided.

Preliminary results of reference calculations were shown.

“MIDICORE” geometry:



Conclusions

- VVER-1000 calculation benchmark “MIDICORE” has been proposed
- Analysis of needed MCNP precision has been presented together with preliminary reference results

CONCLUSION

Four papers were presented on WG A, which are devoted to different topics.

Effort was concentrated on special effects like discontinuity factors or weighting functions.

Proper determination of boundary conditions is still an important issue. A benchmark was focused to this point. Conclusions from the solution of this benchmark will result to improvement, if necessary, in industrial codes.

APPENDIX

List of presentations

WG A

- **Welcome Address, *Petr Dařílek, Nuclear Design and Fuel Management, VUJE, Inc.***
- ***T. Parkó*: Application of Discontinuity Factors in C-PORCA**
- ***R. Zajac*: Fast Reactor Nodalisation in HELIOS Code**
- ***G. Farkaš*: Calculation of Spatial Weighting Functions of Ex-Core Detectors for WWER-440 Using Monte Carlo Approach**
- ***D. Sprinzl et al*: „MIDICORE“ - VVER-1000 Core Periphery Power Tilt Benchmark Proposal**
- **Discussion about benchmark proposal**

WG-B

- ***P. Dařílek*: Proposal of Core PEriphery POwer Tilt Benchmark for VVER-440 (PEPO-440)**
- ***P. Mikoláš*: VVER-440 Fuel Cycle Possibilities Using Modified FA Design**
- ***J. Bajgl*: Possibility of the CFA 5-Year Fuel Cycle**
- ***P. Páleník*: Arrangements for new fuel Gd-II-487 in Mochovce NPP**
- **Discussion about situation in NPP Bohunice, PEPO-440, future benchmarks and other activities**

List of participants

Nr.	Name	Institute / NPP
1.	**BAJGL** Jozef	Dukovany NPP
2.	**DAŘÍLEK** Petr	VUJE, Inc.
3.	**FARKAŠ** Gabriel	FEI STU
4.	**CHRAPČIAK** Vladimír	VUJE, Inc.
5.	**KAČMÁR** Milan	Bohunice NPP
6.	**MIKOLÁŠ** Pavel	ŠKODA JS, a.s.
7.	**PÁLENÍK** Peter	Mochovce NPP
8.	**PARKÓ** Tamás	Paks NPP
9.	**PATAI-SZABÓ** Sándor	TS-Enercon Ltd
10.	**PUKLICKÝ** Kamil	Dukovany NPP
11.	**SPRINZL** Daniel	ŠKODA JS, a.s.
12.	**ZAJAC** Radoslav	VUJE, Inc.