The use of RELAP5-3D© code in the OECD/NEA VVER-1000 CT-1 and CT-2 Benchmark

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RELAP5-3D© Users Seminar
Holiday Inn SunSpree Resort – West Yellowstone – USA
16 – 18 August 2006

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OBJECTIVES

- To assess the TH-3D NK system codes nodalizations for analyzing VVER1000 transients
- To assess the RELAP5-3D© for coupled TH/3D NK calculations in hexagonal geometry
- To assess the RELAP5-3D© for 3D vessel simulations

V1000-CT1 Benchmark

- **V1000-CT1 Benchmark: originally simulated at UNIPI by RELAP5/PARCS coupled codes**
- **New modelling for RELAP5-3D**
- **Transient test scenario repeated → activities still in progress**

The transient test scenario is as follows:

- At reactor power 29.45% Nom MCP#3 is switched on
- After switching on MCP#3 the reactor power increases to 29.8%Nnom
- Pressurizer water level decreases from 744 cm to 728 cm
- Water level in the Steam Generator #3 decreases with 9 cm
- The flow rate in loop #3 reverses back to normal at the 13th sec. of the switching on MCP#3. The timing is consistent with reactivity increase, as observed through the reactor power set points

THERMAL-HYDRAULIC MODELING

- T-H core model developed from the one already completed (and used for 0-D NK calculations) for allowing the coupling with 3-D NK → 29 independent core TH channels

- 4 Loops with 4 Steam Generator

- ECCS Modeling

- Number of Heat Structures = 2898

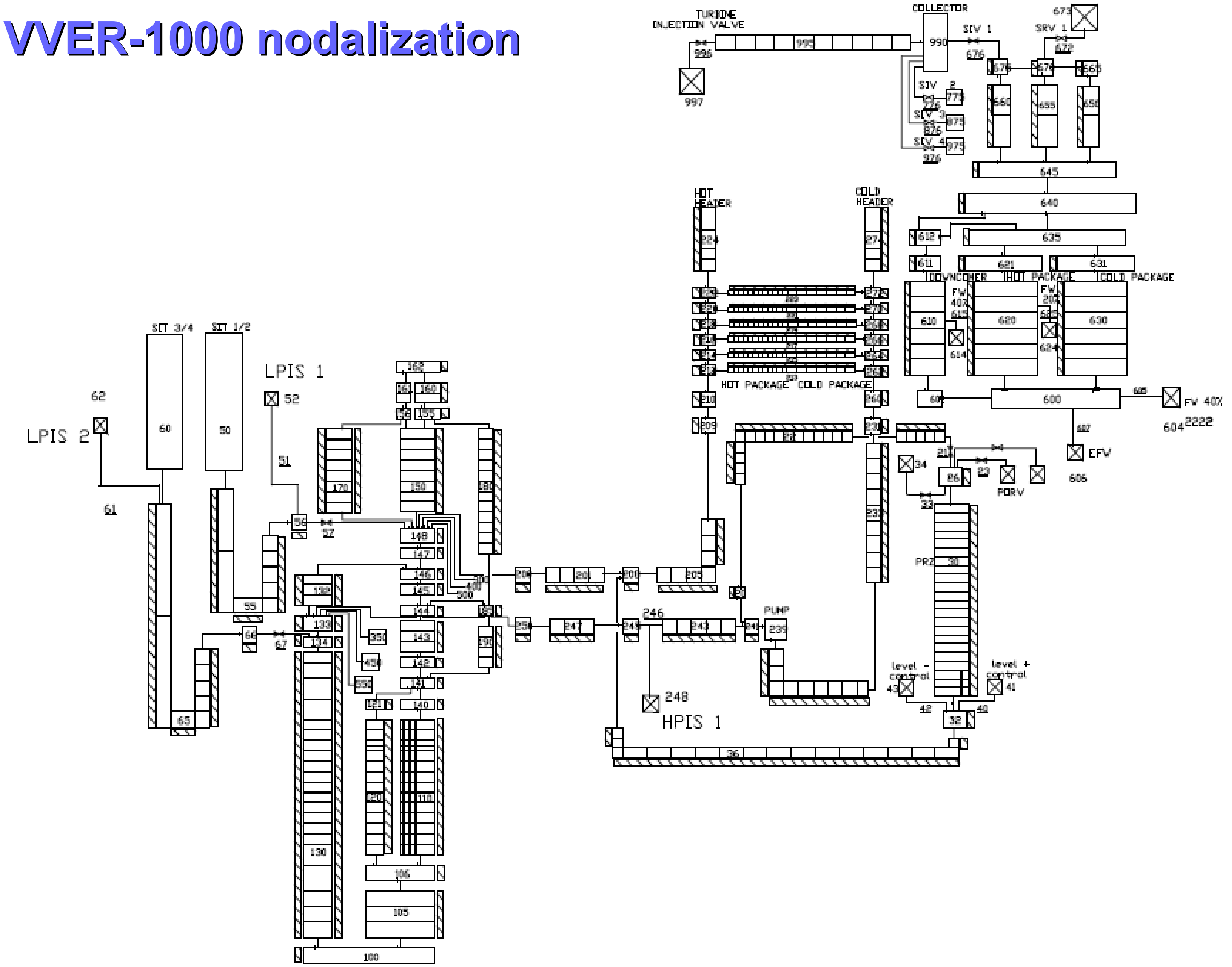
- Number of Mesh Points = 19700

- Number of Volumes = 2263

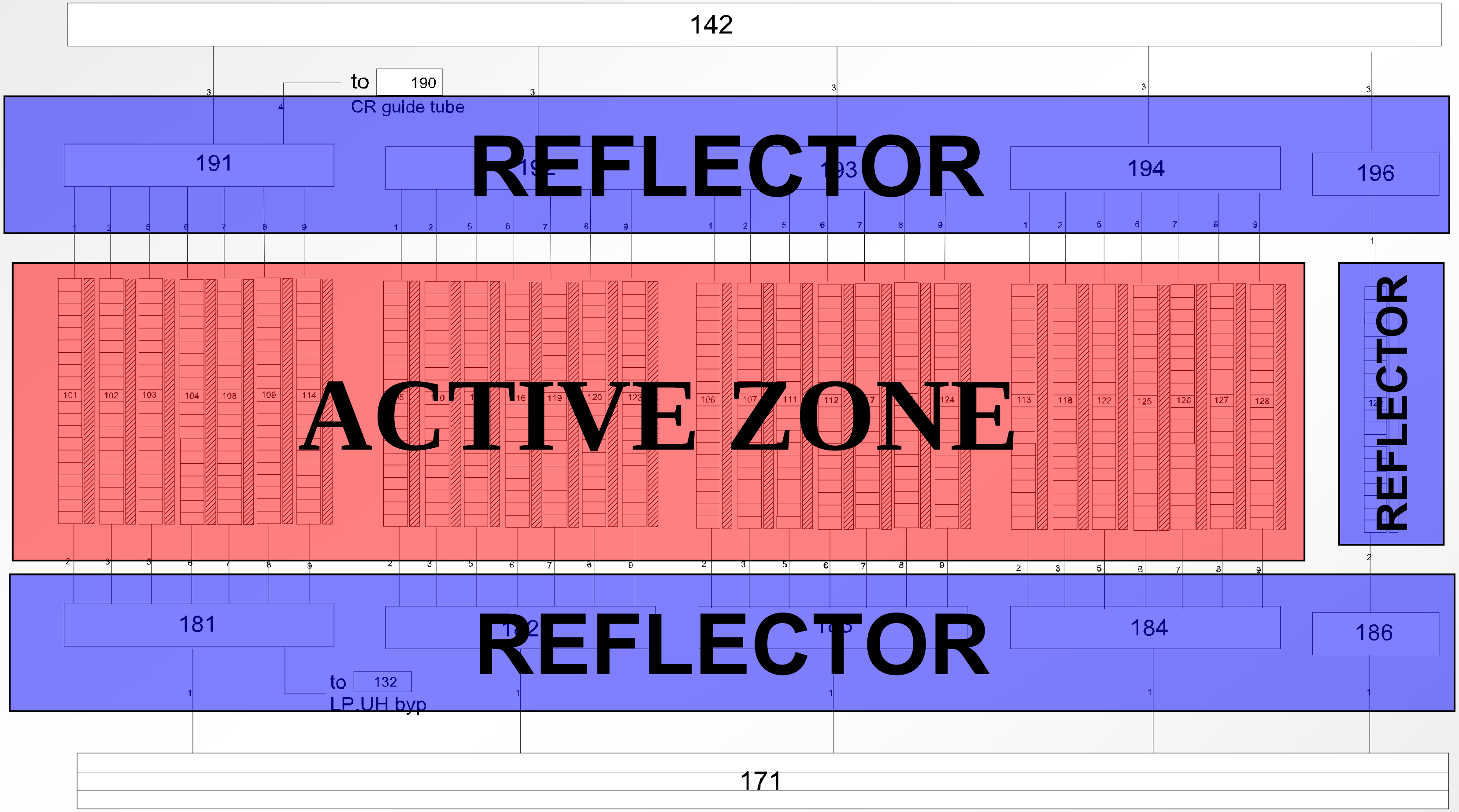
- Number of Junctions = 2349

T-H Model: RELAP5-3D©

VVER-1000 nodalization

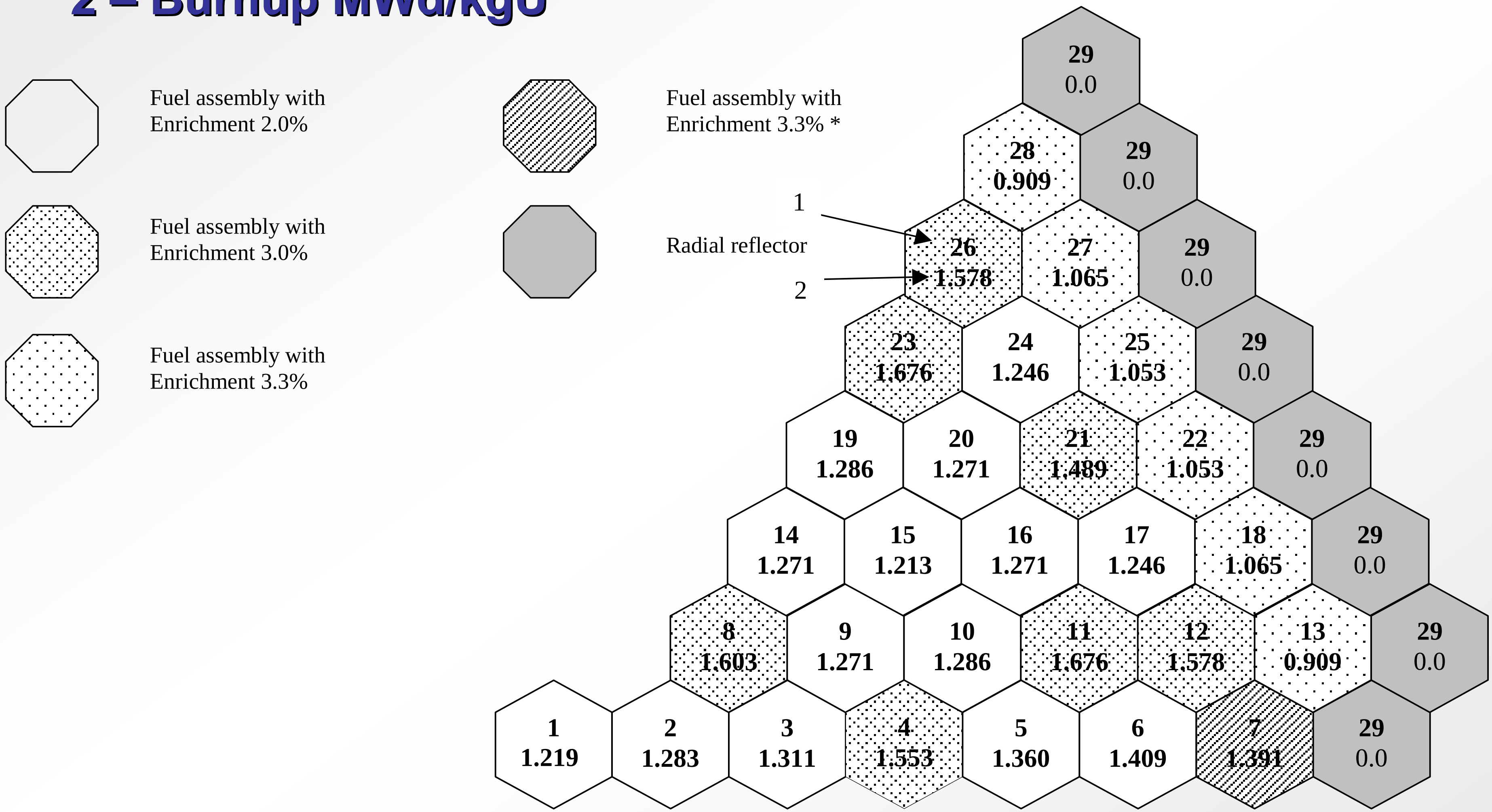


T-H Model: Core Nodalization



Cross Section Modelling – FA Types

1 – Type of fuel assembly
2 – Burnup MWd/kgU



Cross Section Format

- Calculation performed with HELIOS Lattice Physics Code
- Generated XSec Libraries for BOL
- Each of 28 composition divided by 10 layer → 28 x 10 = 280 Fuel Compositions
- 3 Compositions (# 281, 282, 283) used for Bottom, Radial and Top Reflector
- ADF directly included in the Cross Section values

	Assembly type																												
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29
1	281	281	281	281	281	281	281	281	281	281	281	281	281	281	281	281	281	281	281	281	281	281	281	281	281	281	281	281	281
2	1	11	21	31	41	51	61	71	81	91	101	111	121	131	141	151	161	171	181	191	201	211	221	231	241	251	261	271	282
3	2	12	22	32	42	52	62	72	82	92	102	112	122	132	142	152	162	172	182	192	202	212	222	232	242	252	262	272	282
4	3	13	23	33	43	53	63	73	83	93	103	113	123	133	143	153	163	173	183	193	203	213	223	233	243	253	263	273	282
5	4	14	24	34	44	54	64	74	84	94	104	114	124	134	144	154	164	174	184	194	204	214	224	234	244	254	264	274	282
6	5	15	25	35	45	55	65	75	85	95	105	115	125	135	145	155	165	175	185	195	205	215	225	235	245	255	265	275	282
7	6	16	26	36	46	56	66	76	86	96	106	116	126	136	146	156	166	176	186	196	206	216	226	236	246	256	266	276	282
8	7	17	27	37	47	57	67	77	87	97	107	117	127	137	147	157	167	177	187	197	207	217	227	237	247	257	267	277	282
9	8	18	28	38	48	58	68	78	88	98	108	118	128	138	148	158	168	178	188	198	208	218	228	238	248	258	268	278	282
10	9	19	29	39	49	59	69	79	89	99	109	119	129	139	149	159	169	179	189	199	209	219	229	239	249	259	269	279	282
11	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180	190	200	210	220	230	240	250	260	270	280	282
12	283	283	283	283	283	283	283	283	283	283	283	283	283	283	283	283	283	283	283	283	283	283	283	283	283	283	283	283	283

Automatic Cross Section Processing

NEMTAB & NEMTABR text files for

Rodded & *UnRodded*

Fuel Compositions

→

- Cross Section reference values and variation coefficients automatically calculated by FORTRAN program NESTLECONV
  - 4D Linear Interpolation for reference value
  - Minimum Least Square method for variation coefficients
    - User can select : Libraries Dimension & Reference conditions for the interpolation

←

OBTAINING XSEC IN NESTLE & PARCS FORMAT

3-D Neutronic Model – NESTLE vs. PARCS codes

PARCS

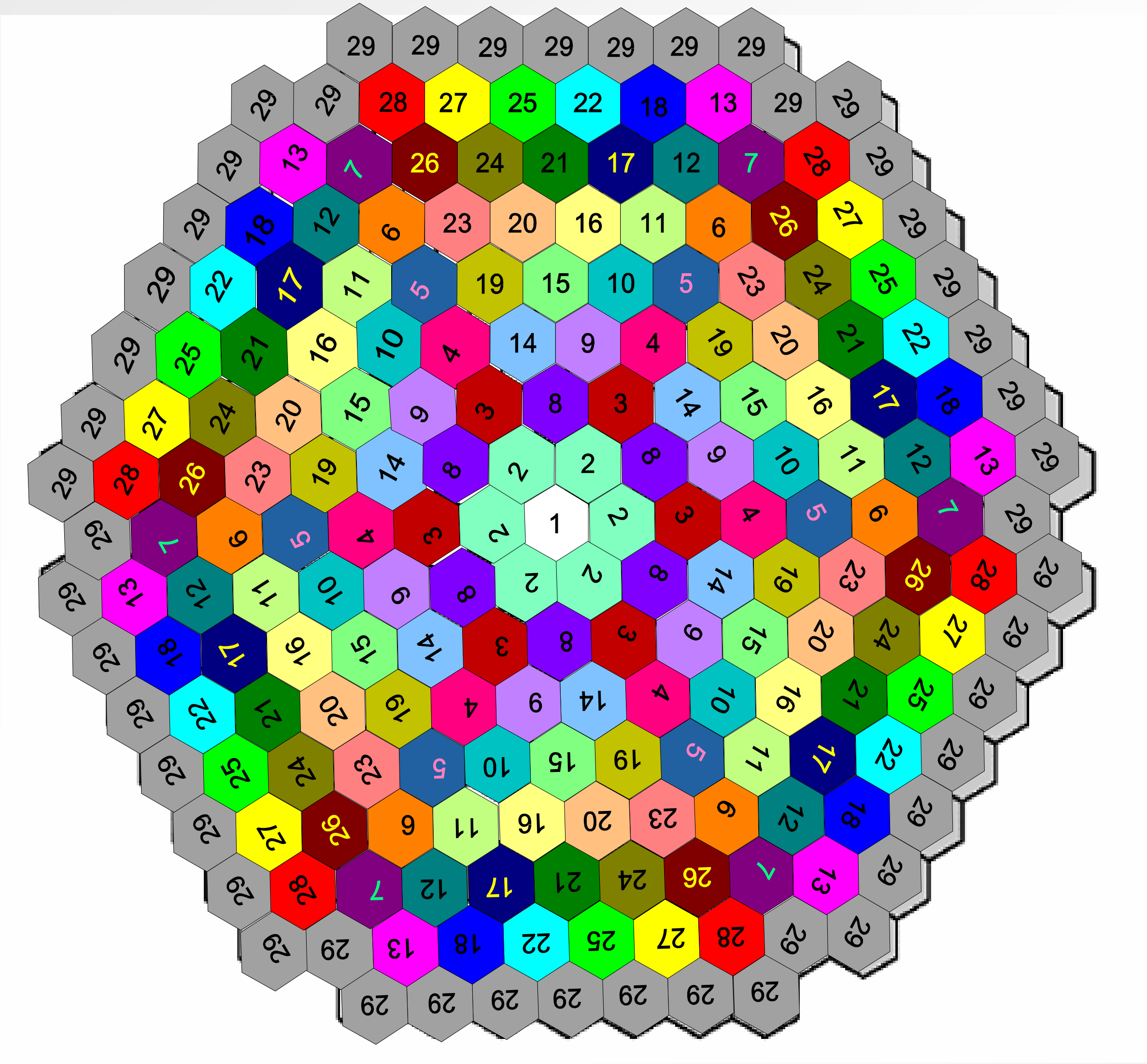
- US-NRC reference 3D Neutron Kinetic Code – v 2.6
- Solution of the two-group diffusion equations system with the Triangular Polynomial Expansion Nodal method (TPEN) for Hexagonal Geometry
- Coupled with RELAP5 via Parallel Virtual Machine (PVM) protocol

NESTLE

- Fully integrated in RELAP5-3D©
- Based on Nodal Expansion Method (NEM)
- Internally coupled with the TH module (RELAP5-3D)

➢ **Comparison executed in order to increase confidence in NK codes results**

3D NK Model

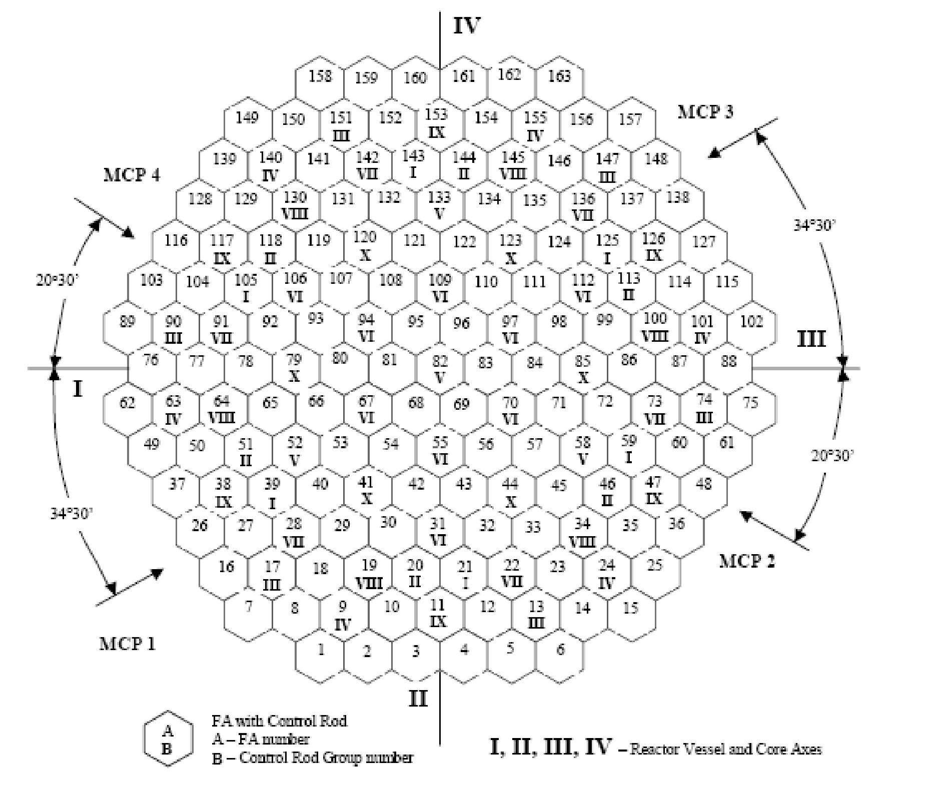


- **4642 NK nodes**
- **Radial, Upper and Bottom Reflector modeled**
- **22 axial layer (2 for top/bottom reflector, 20 for the core)**
- **280 unrodded + 110 rodded compositions**
- **Delay neutron constants & fractions specified for each composition**

HZP/HFP Conditions

Steady State calculations executed for HZP and HFP SS conditions:

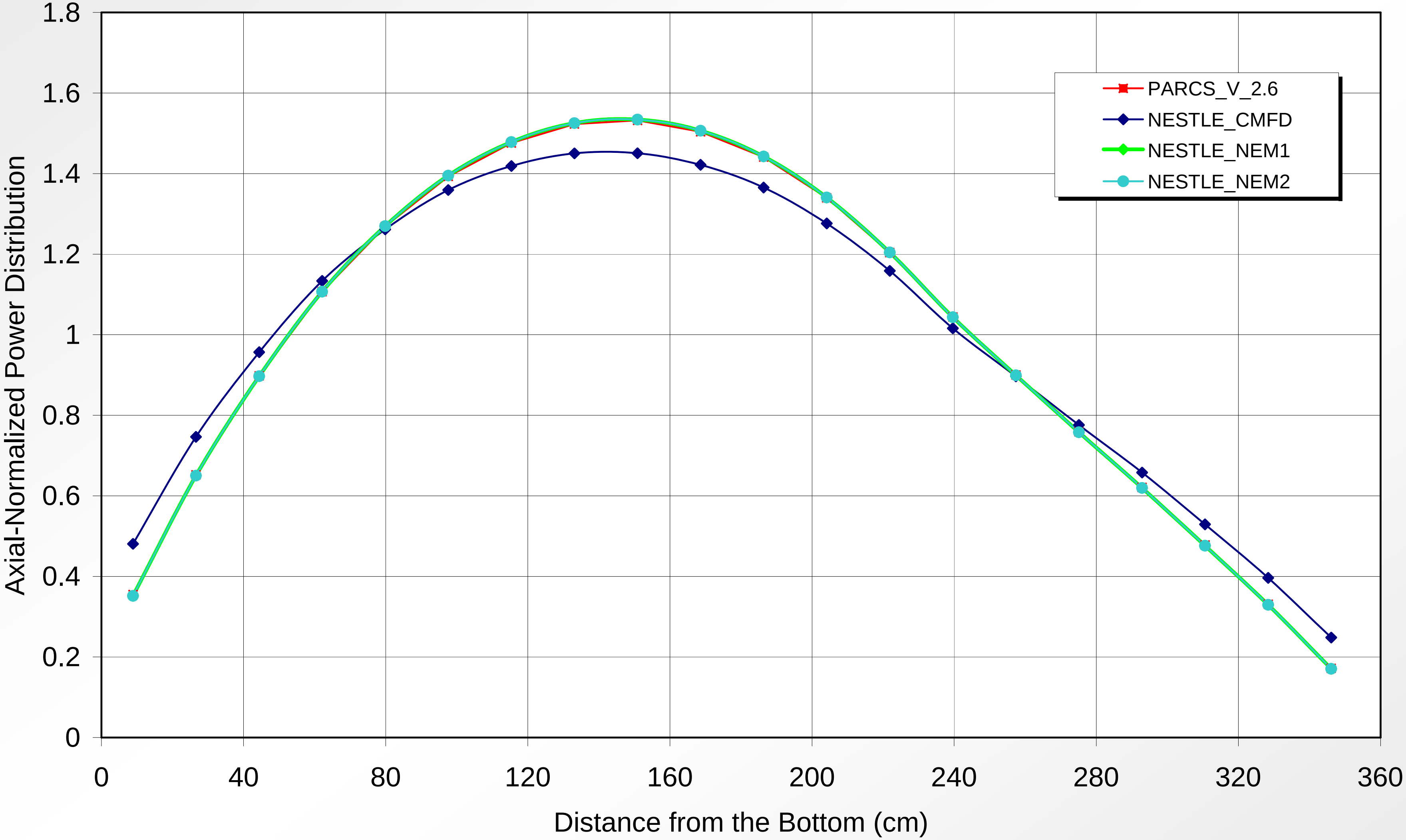
Number	T-H conditions	Control rod positions
0	HZP	Groups 1 - 8 ARO[†] Group 9 – 36 % in (250.8 cm) Groups 10 ARI[‡]
1	HP	Groups 1-9 ARO Group 10 is 36% in (250.8 cm)



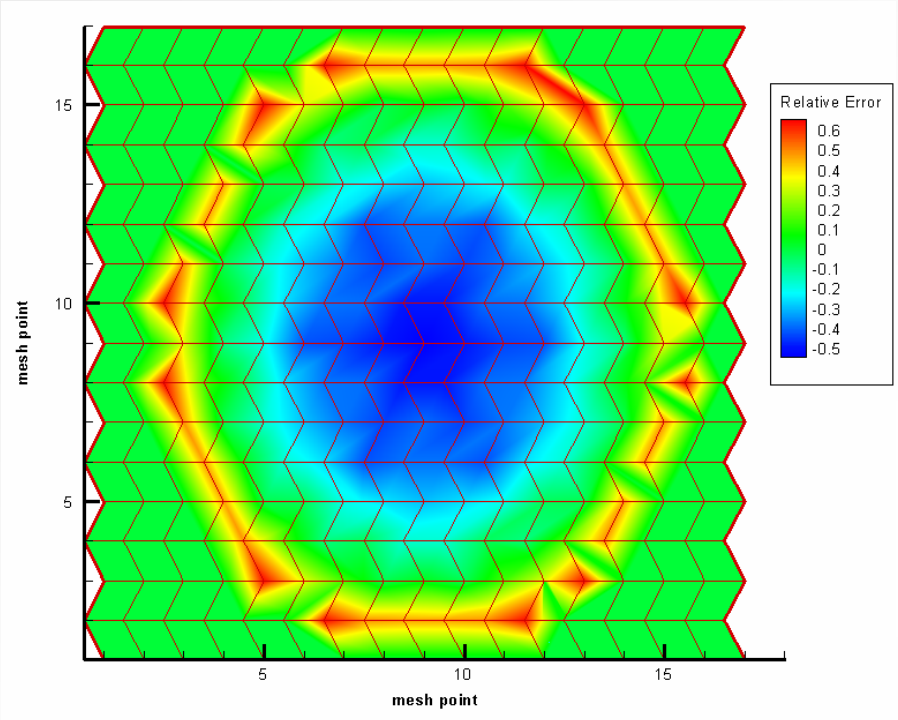
HZP → 3 MW; XSec reference values for Tf = Tm = 552 K

HFP → 3000 MW; XSec reference values for Tf = 900 K, Tm = 567 K

HZP Axial Power distributions

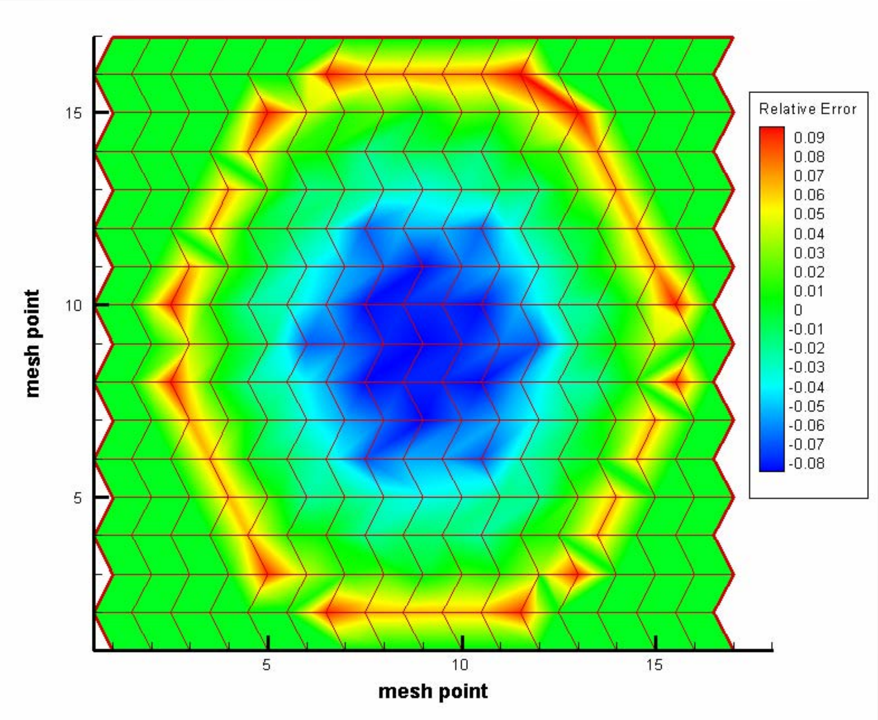


Radial Power at HZP conditions



HZP

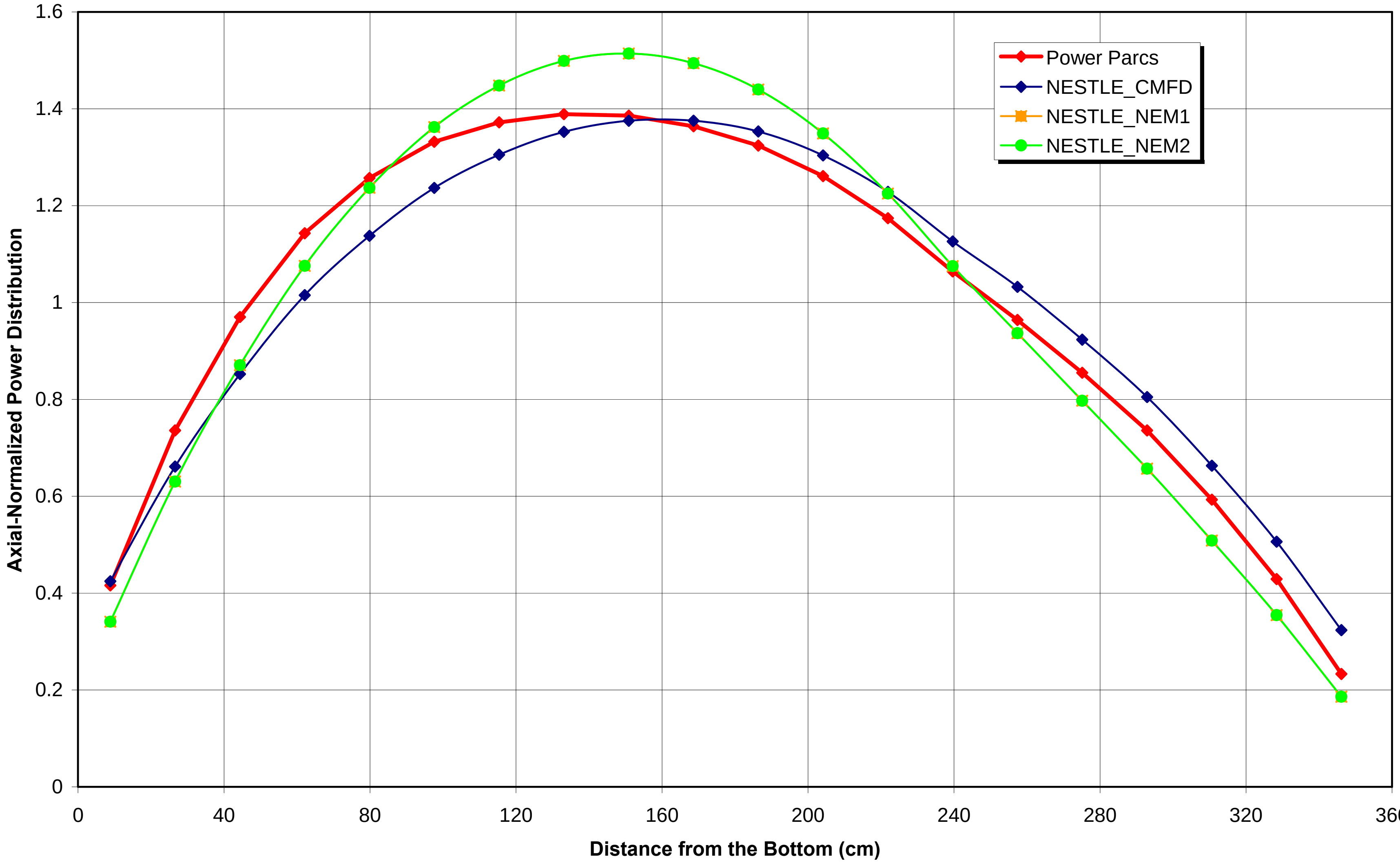
PARCS (TPEN) – NESTLE (CMFD)



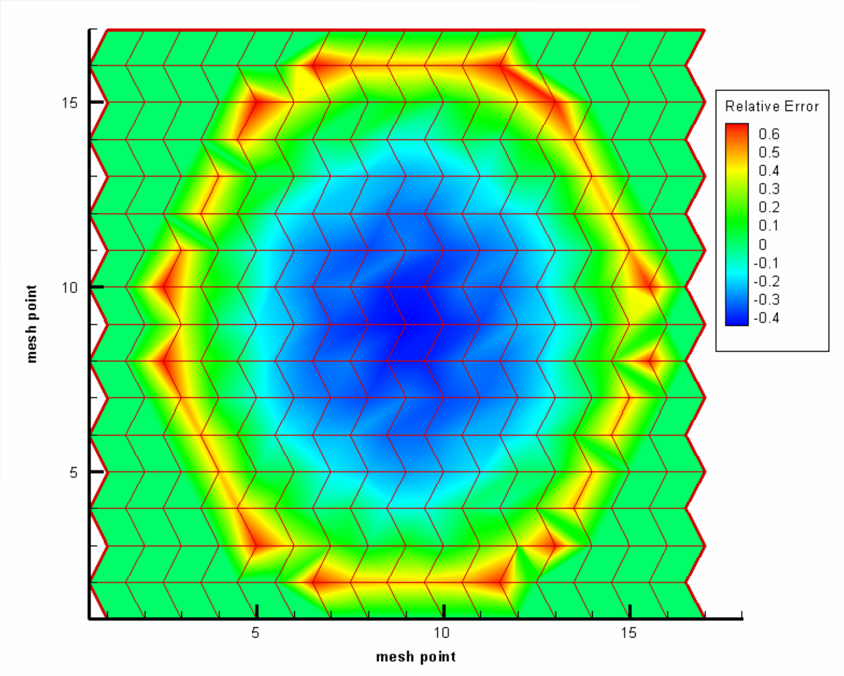
HZP

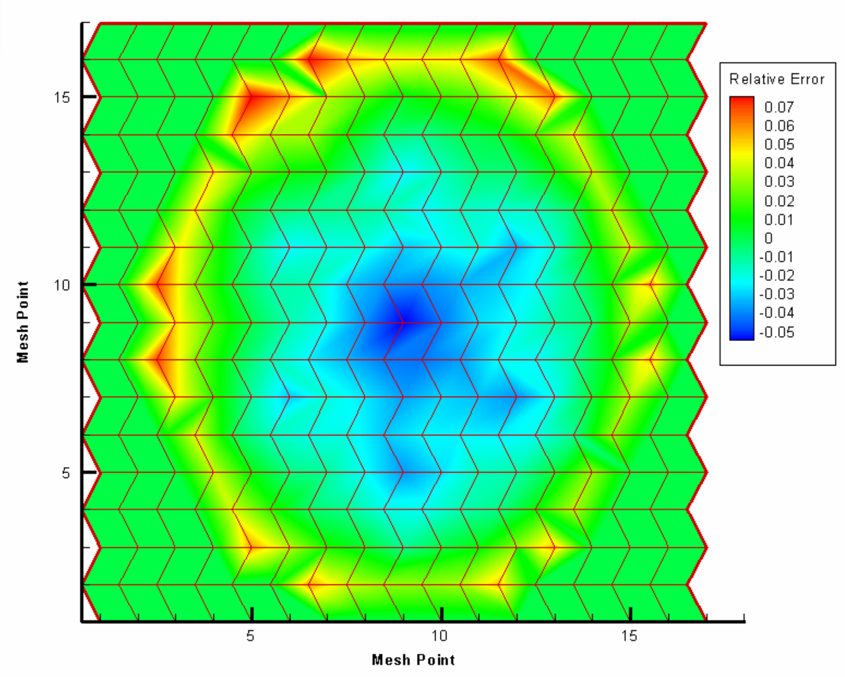
PARCS (TPEN) – NESTLE (NEM)

HFP SS Axial Power



Radial Power at HFP conditions





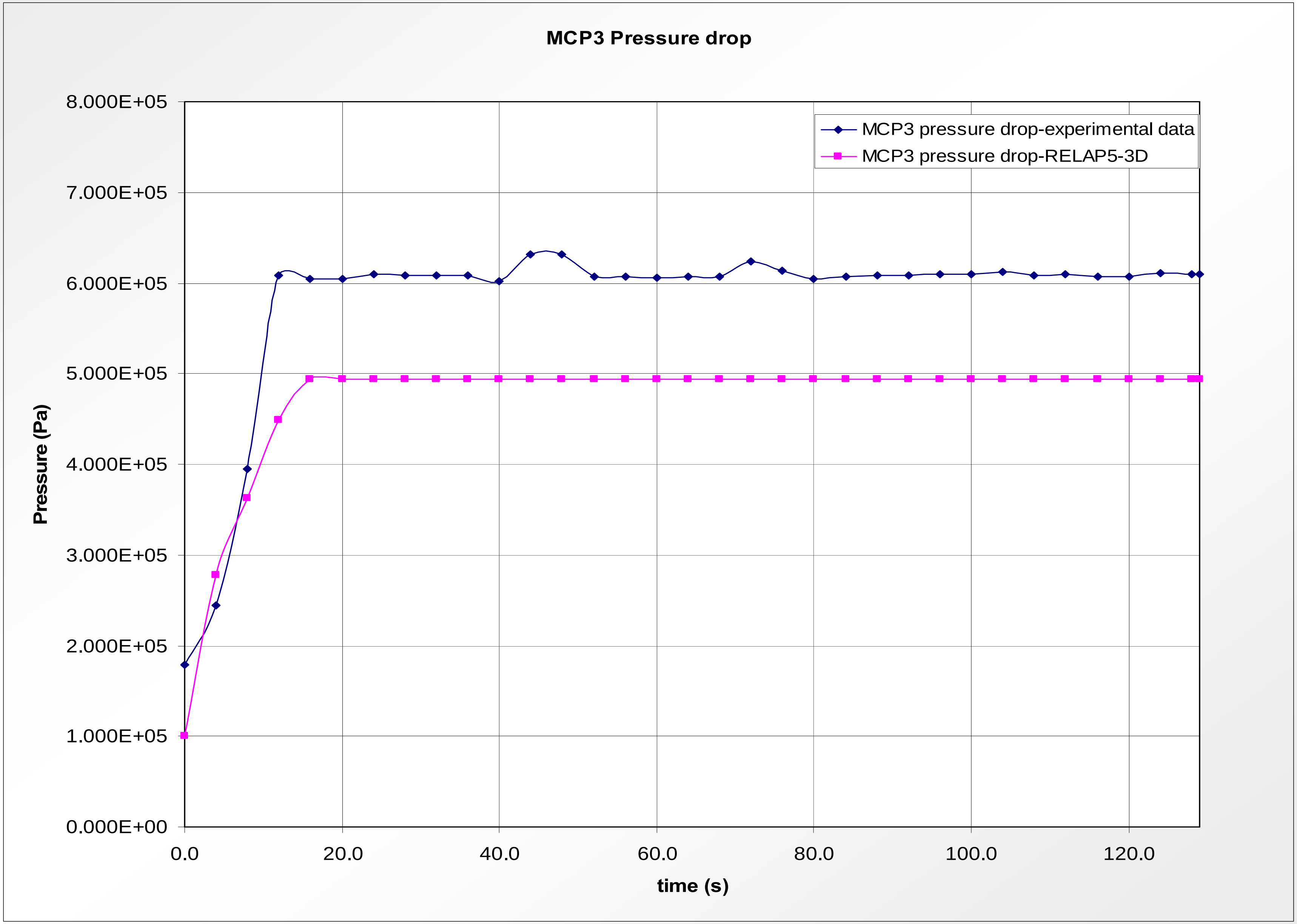
HFP

PARCS (TPEN) – NESTLE (CMFD)

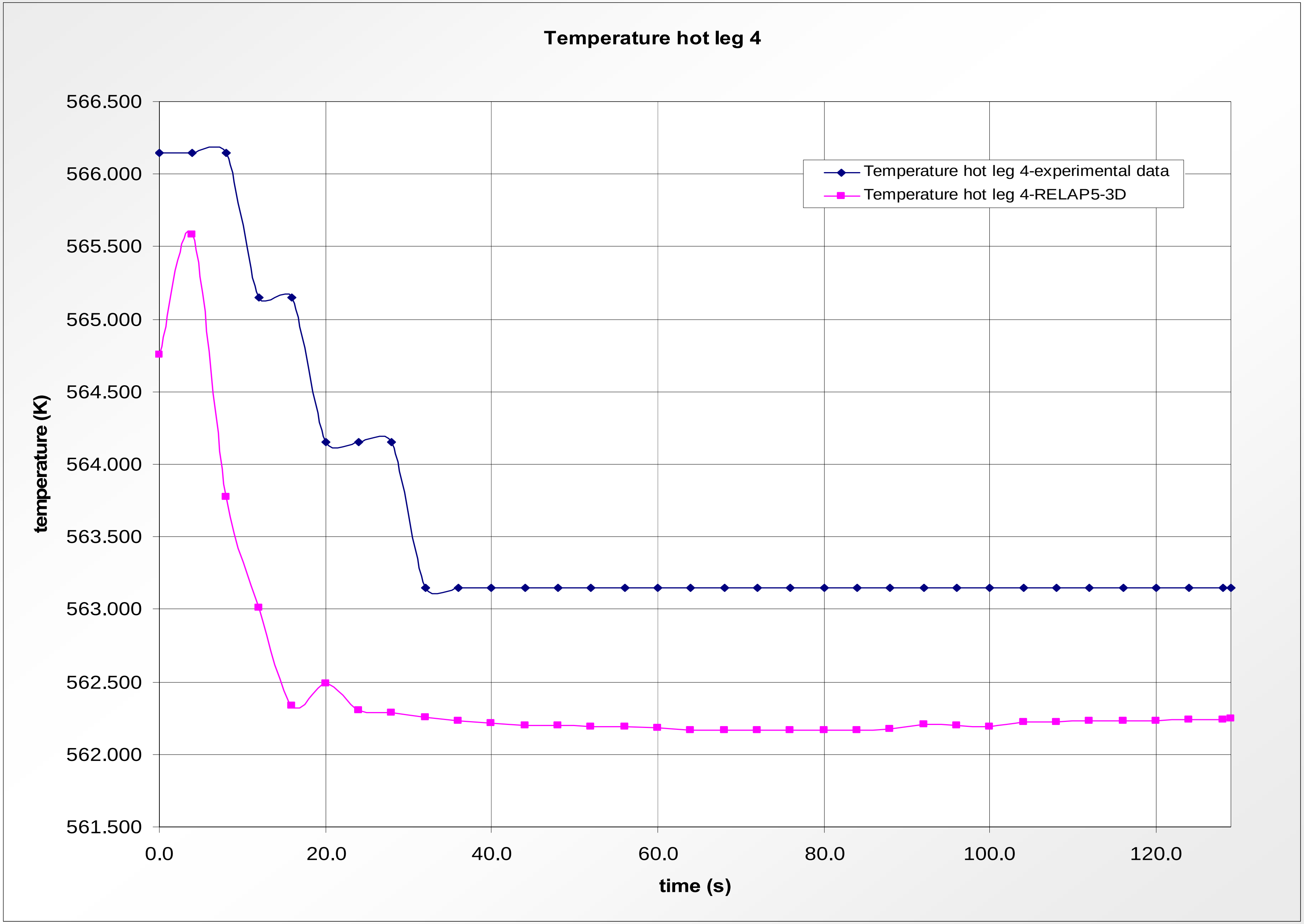
HFP

PARCS (TPEN) – NESTLE (NEM)

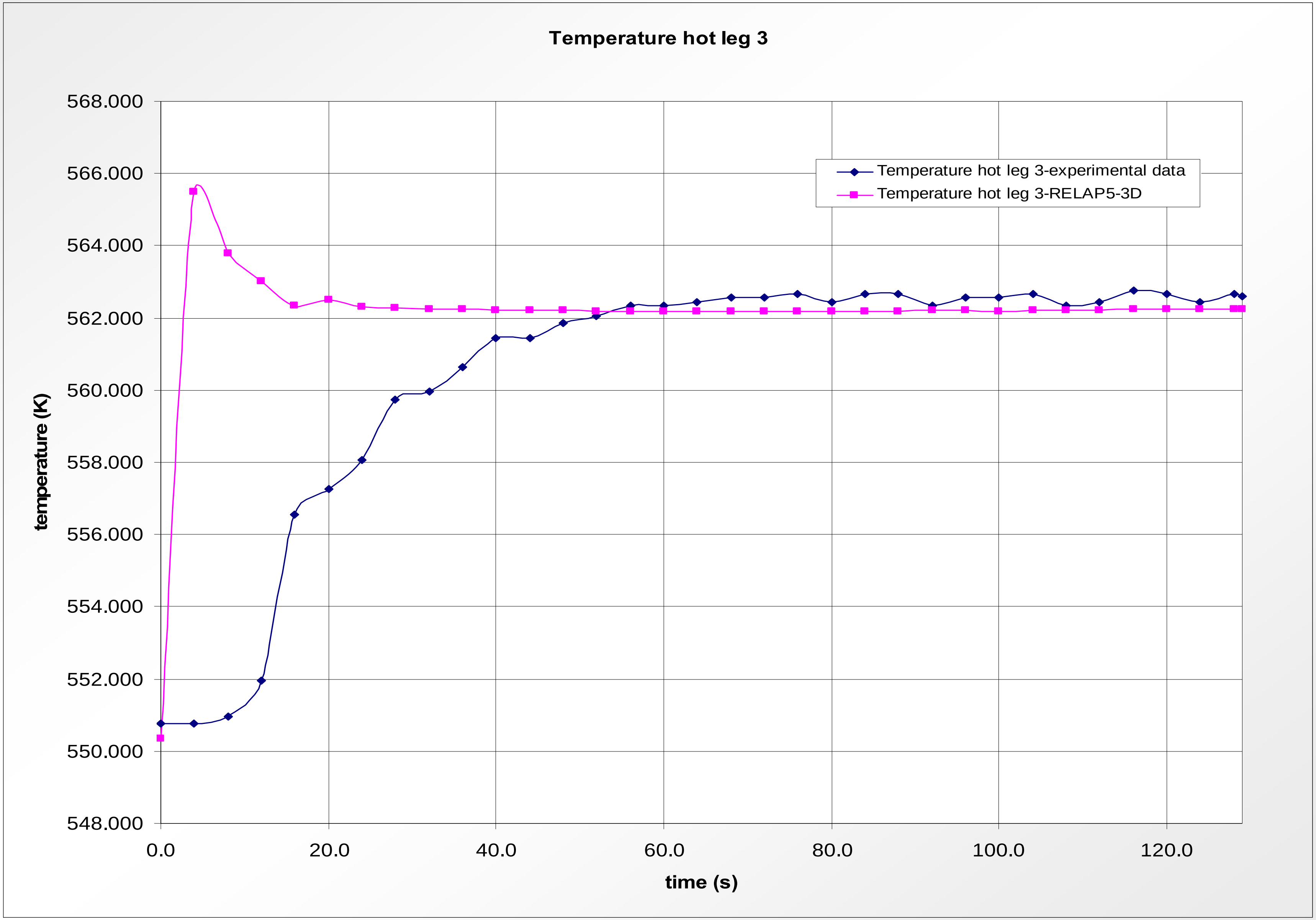
V1000-CT1 – Sample Transient Results



V1000-CT1 – Sample Transient Results



V1000-CT1 – Sample Transient Results



V1000-CT1 – Final Considerations

- RELAP5-3D© model was able to simulate plant transient
- Further works needed on the SG model for eliminate some discrepancies
- 3D NK model confirmed PARCS results → NEM method increased accuracy of one order of magnitude

V1000-CT2 Benchmark

The purpose of the V1000CT-2 benchmark is three-fold:

- **To test flow mixing models (CFD, coarse-mesh and mixing matrix), against measured data and in code-to-code comparison.**
- **To fully test the 3-D neutronics/vessel thermal-hydraulic coupling.**
- **To evaluate discrepancies between predictions of coupled codes in best-estimate transient simulations.**

V1000-CT2 Benchmark

Phase 2 of Benchmark composed by 3 exercises:

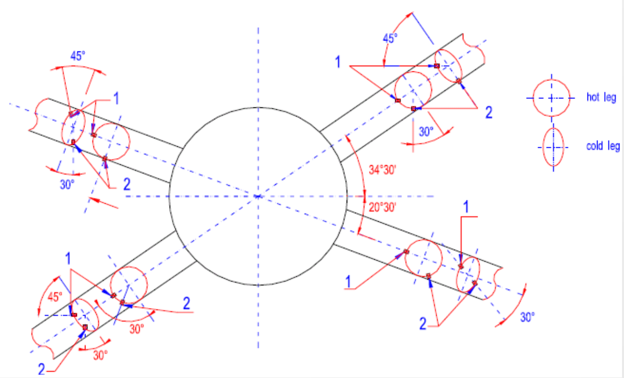
- Exercise 1 – Calculation of RPV coolant mixing experiments ← Work in progress
- Exercise 2 – MSLB with specified vessel boundary conditions
- Exercise 3 – MSLB full plant computation

Exercise 1

- Test performed during Kozlokuy-6 NPP commissioning
- reactor power at 281 MW (9.36% of P_{nom})
- all 4 MCP and SG in operation
- isolation of SG-1 (closure of SIV-1 and FW valve)

Objective of the experiment (experimental data available)

- Mixing coefficient between each pair of loops, for two in-vessel flow paths
  - From cold legs to the inlet of fuel assemblies
  - From cold legs to hot legs
- Azimuthal shift (rotation) of loop flows relative to cold leg axes



VVER1000 RELAP5-3D Model

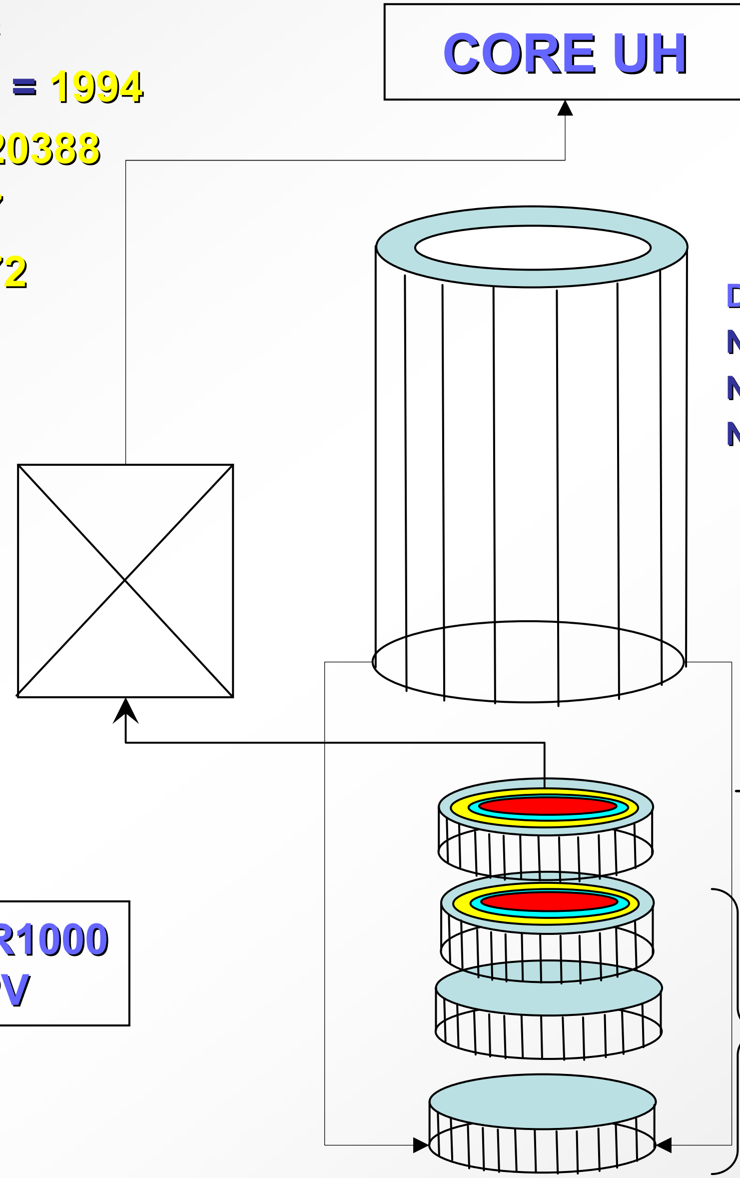
Nodalization characteristic

Number of Heat Structures = 1994

Number of Mesh Points = 20388

Number of Volumes = 3057

Number of Junctions = 5472

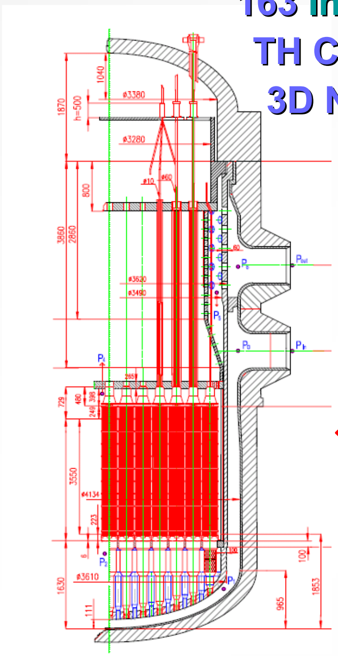


Downcomer: one 3D TH volume
Number of radial nodes = 1
Number of azimuthal nodes = 20
Number of axial nodes = 20

CORE
163 Independent TH Channels + 3D NK model

Lower core plate: 3D TH vol
Number of radial nodes = 9
Number of azimuthal nodes = 60
Number of axial nodes = 1

Lower Plenum 1, 2, 3: 3D TH vols
Number of radial nodes = 4, 4, 8
Number of azimuthal nodes = 20, 20, 20
Number of axial nodes = 1, 1, 1



VVVER1000 RPV

VVER1000 3D Model – Sensitivity analyses

Geometry

- Downcomer with 20 azimuthal nodes
- Downcomer with 40 azimuthal nodes
- Downcomer with 60 azimuthal nodes

Downcomer azimuthal loss coefficients

- Reynolds forward/reverse loss coefficient= 0.1
- Reynolds forward/reverse loss coefficient= 1

3D NK

- FDM solution technique
- NEM solution technique

Experimental Mixing Coefficient

Experimental flow mixing coefficients from cold leg #1 to fuel assembly outlets:

$C_{ik} = Mflow_i / Mflow_{tot}$ (i=1 to 4)

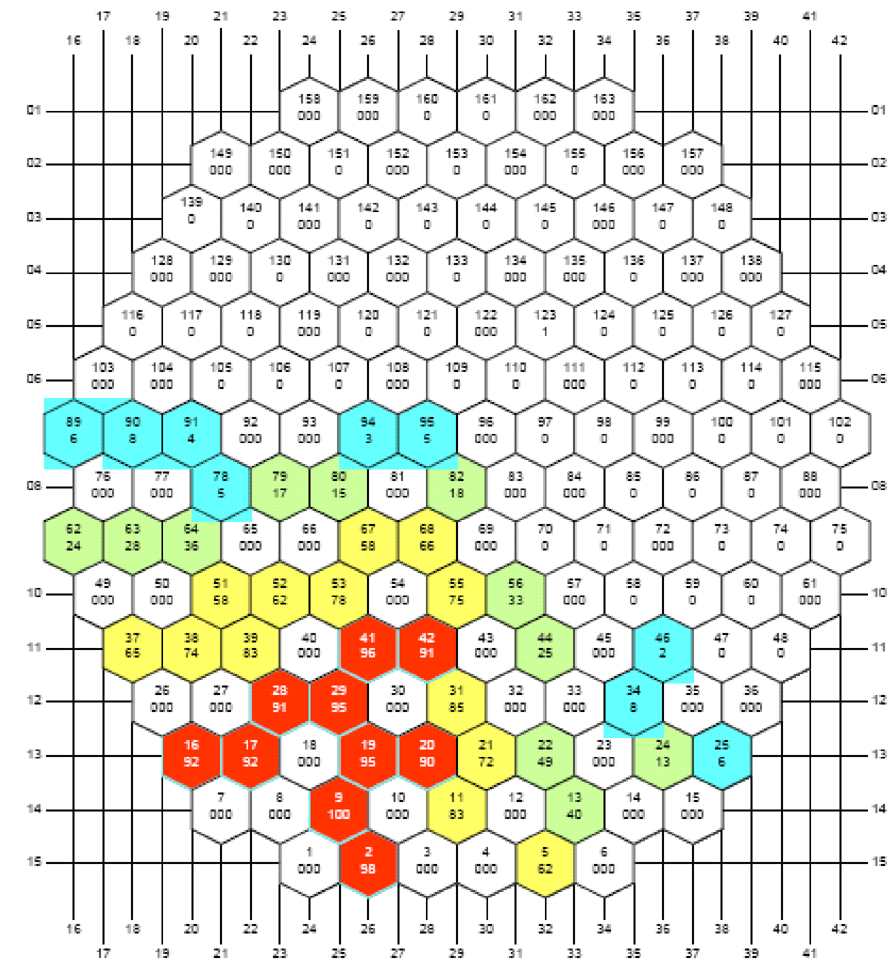
RELAP5-3D calculations executed with the following procedure:

- constant mass flow rate per FA

$\Theta = (T_{hot} - T_{assembly}) / (T_{hot} - T_{cold})$

$\Theta = 1 \rightarrow$ complete mixing

$\Theta = 0 \rightarrow$ no mixing



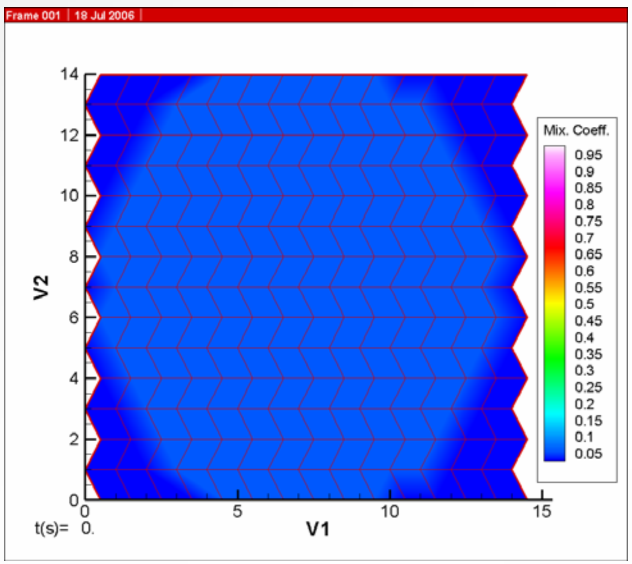
2 – assembly number
98 – mixing coefficient $C_{1,2}$ %

Experimental Flow Mixing Coefficients

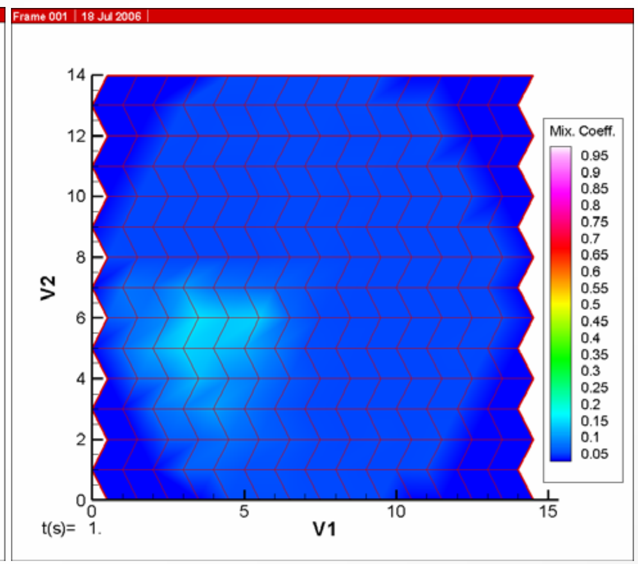
Cold leg 1 to FA inlet

VVER1000 3D Model – prelimary calculations

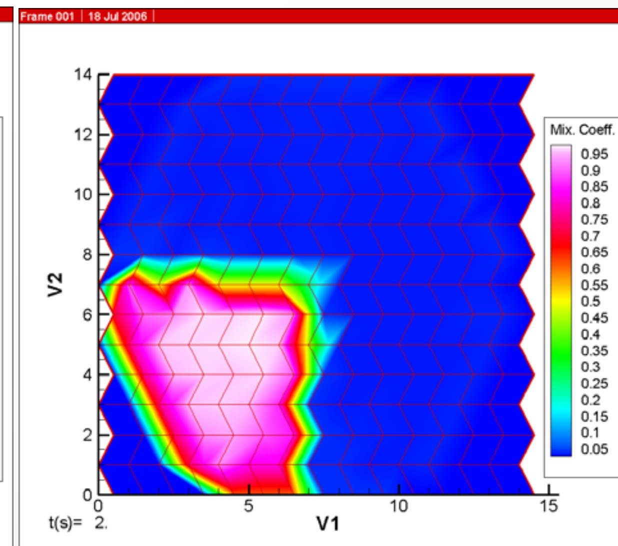
- Preliminary calculations executed to assess code capabilities
- User's defined transient: injection of cold water (10 deg. below average temperature) → complete mixing after 10 secs
- Flow mixing coefficients from cold leg 1 to fuel assemblies



Time t= 0 seconds



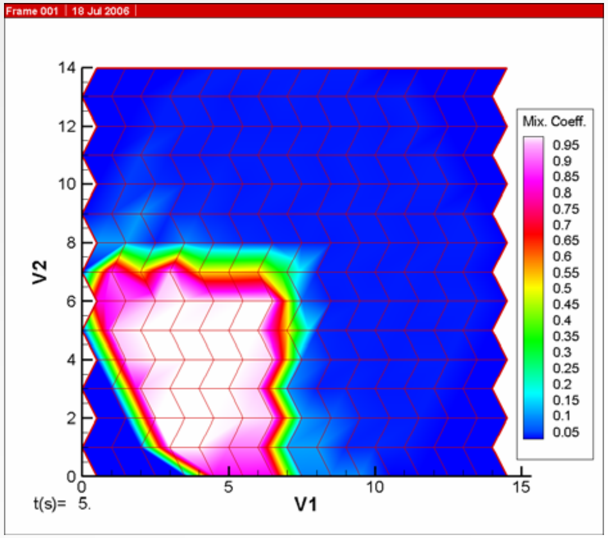
Time t= 1 seconds



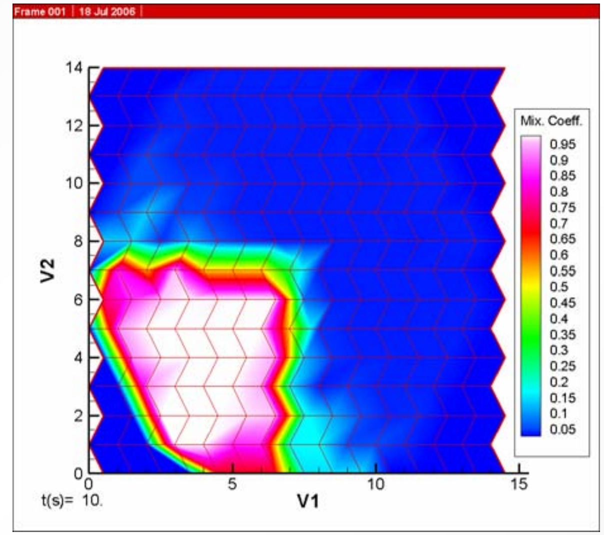
Time t= 2 seconds

VVER1000 3D Model – prelimary calculations

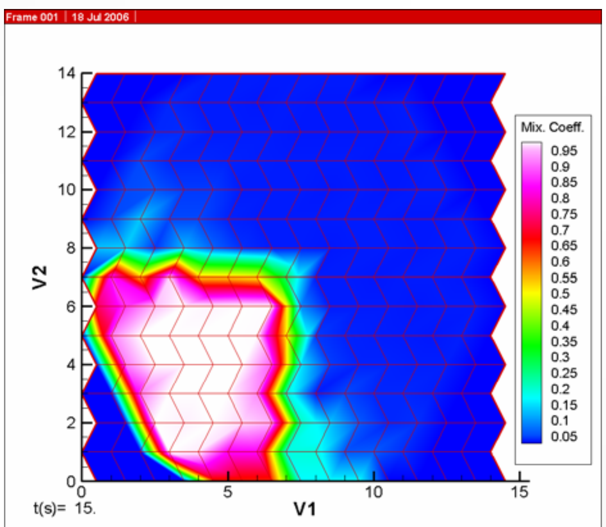
- Flow mixing coefficients from cold leg 1 to fuel assemblies



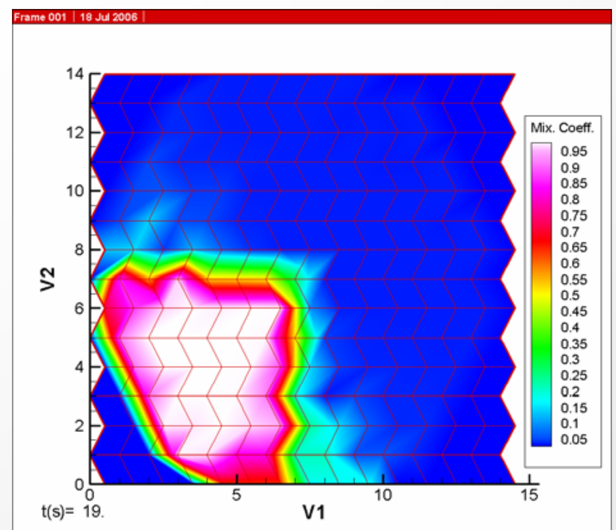
Time t= 5 seconds



Time t= 10 seconds



Time t= 15 seconds



Time t= 19 seconds

CONCLUSIONS and FUTURE WORK

- **For VVER1000 CT1 benchmark:**
  - **Considering the absolute errors against experimental data, we can conclude transient results trends are well predicted by RELAP5-3D© and the model developed is capable to properly simulate transient scenario for a VVER1000**
  - **Works in progress to improve TH model**
  - **The error in radial power distributions between RELAP5/PARCS and RELAP5-3D© shows the same trend both for HZP and HP conditions. The symmetric error distribution shows that the error has to be related to solver methods**

- **For VVER1000 CT2 benchmark:**
  - **A Reactor Vessel 3D TH & NK model was developed**
  - **RELAP5-3D is capable to simulate the vessel mixing phenomena**
  - **Work in progress for <u>qualify</u> model and execute exercises 1 & 2**
  - **Code capabilities increase needed for handling large model (3D TH + NK + Plant) for execution of 3rd exercise (MSLB + Vessel 3D)**