다물리 해석을 위한 DeCART-MATRA 연계 현황

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Contents

DeCART Development Status

◆DeCART Code

- INERI 1: 2002 ~ 2004, 고신뢰도 원자로 통합모의, DeCART 원형 코드 개발
- INERI 2: 2004 ~ 2006, VHTR 응용을 위한 DeCART 확장
- INERI 3 : 2008 ~ 2011, DeCART 코드 실용성 향상, CORONA 연계
- INERI 4 : 2011 ~ 2014, DeCART 기능 보완, VHTR 수치검증/실험검증 문제 해석
- DeCART/CHORUS/MASTER 핵설계체계 개발중
- CASL Project의 MPACK 코드 개발의 기반이 됨

◆DeCART2D Code

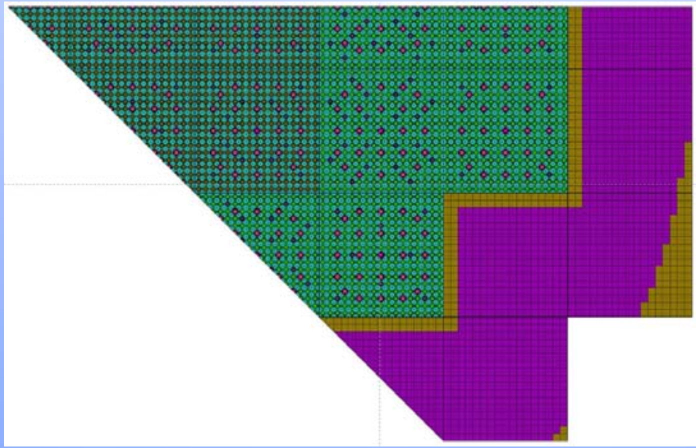
- 2-Step 핵설계 체계용 DeCART 2-D version
- Release: 불가리아 Sofia 대학, KAIST, 경희대, UNIST, 한양대, 세종대, 부산대, 교육 및 연구용으로 무상제공
- 경수로 해석용 DeCART2D/MASTER 핵설계체계 – 인허가 목표로 V&V 진행중
- VHTR 해석용 DeCART2D/CAPP 핵설계 코드체계

DeCART Code

- ◆ Adaptation of DeCART Specific Library Format
- ◆ Sub-Pin Level Planar MOC Transport Calculation
  - Cell or Assembly based Modular Ray Tracing
  - Resonance Treatment based on Subgroup or RIT Method for Whole Core
  - Depletion Calculation based on Krylov Subspace Method
  - Up to P3 Anisotropic Calculation
  - Double Heterogeneity Treatment by Sanchez Method
- ◆ Pin Based Axial SP3 Transport Calculation with Subplane Scheme
- ◆ CMFD Acceleration for Irregular Mesh
- ◆ Gamma Diffusion Calculation
- ◆ MPI and OpenMP based Parallel Computation
- ◆ Transient Calculation (need more verification)
- ◆ Thermal Feedback (Simplified T-H or Coupling with CORONA or KARMA)
- ◆ Reload Core Calculation
- ◆ Lattice Code Capability: B1 Criticality Calculation, HGC File Generation
- ◆ Equivalent Group Constant: SENM for Rectangular and TPEN for Hexagonal

Nuclear Design Parameter Evaluation for SMART

- **DeCART Model**
  - **1/8 Core Model**
  - **Explicit Baffle Treatment**
  - **Coolant Temperature: Assembly-wise Lumped Channel Model**
  - **Fuel Temperature: Pin-wise Tf-Table Model**
  - **Axial 22 Planes including Top and Bottom Reflector**



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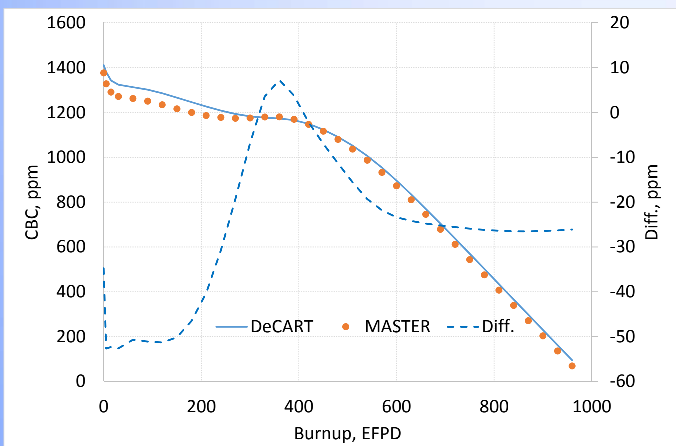
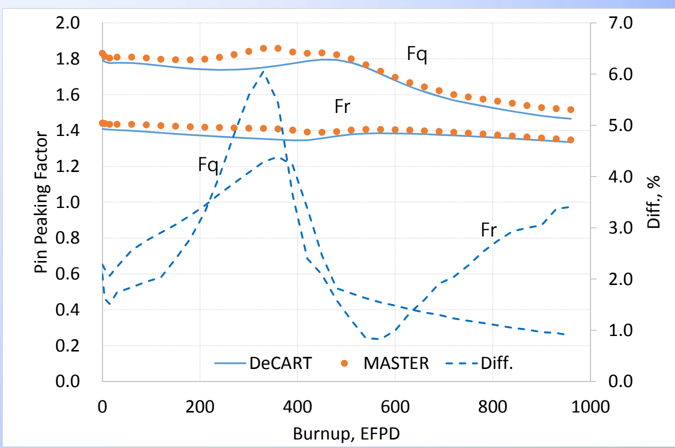
Nuclear Design Parameter Evaluation for SMART





- **CBC**
  - **Maximum difference ~ 30 ppm < Uncertainty of CASMO-3/MASTER**
- **Peaking Factor**
  - **Fq Maximum difference ~ 3% < Uncertainty of CASMO-3/MASTER**
  - **Fr Maximum difference ~ 4.3% < Uncertainty of CASMO-3/MASTER**
  - **CASMO-3/MASTER generates more conservative results**
- **CASMO-3/MASTER generates Fxy, AO, Power distribution etc within Uncertainty**

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DeCART Development Status

◆Procedure of Nuclear Design System

- Highly Depend on the Capability of Lattice Code
- The Conventional System uses 2-D Lattice Code with Ideal Boundary Condition
- Recently Sugimura Proposed Hybrid core calculation system using CASMO-4 2-D whole core transport capability, which reflects realistic radial interface effects.

  N. SUGIMURA et al., "Development of Hybrid Core Calculation System using Two-Dimensional Full-Core Heterogeneous Transport Calculation and Three-Dimensional Advanced Nodal Calculation," *J. of Nuc. Sci. and Tech.*, 43, No. 7, p731-742 (2006).

- KAERI Proposed DeCART/CHORUS/MASTER Code System using DeCART 3-D Whole Core Calculation

  Jin Young Cho, Jae Seung Song, and Kyung Hoon Lee, "Three Dimensional Nuclear Analysis System DeCART/CHORUS/MASTER," ANS 2013 Annual Meeting, June 16-20, 2013

  Jin Young Cho, "3-D Whole-Core Transport based Nuclear Analysis System, DeCART/CHORUS/MASTER," 2013 KNS 추계 원자로물리 및 계산과학 연구현홍 워크숍, 10.23, 2013

DeCART/CHORUS MASTER

◆DeCART/CHORUS/MASTER

- Uses the 3-D whole core transport calculation capability of the DeCART code.
- Though 3-D whole core transport calculation is possible, all the design calculation of more than ten thousand for safety related data generation can not be performed by the DeCART code.
- DeCART has a role to produce the nodewise equivalent constants for MASTER nodal code by 3-D transport calculation.
- CHORUS: Editing Program to generate MASTER Library
- MASTER: 3-D Nodal Code (use SENM for Rectangular Core and TPEN for Hexagonal Core)
- Reduce the design uncertainties to the DeCART Uncertainty Level
- Applied to YGN3 Cycle 1 BOC and EOC, and Hexagonal Benchmark problems

Procedure of New Nuclear Design System

Depletion
DeCART

BOC — MOC — EOC

Variation
DeCART

PPM, Temperature Variation Calculations

XS Edit

Few Group MASTER XS for each Burnup

Core Analysis
MASTER

3-Dimenstional Nodal Diffusion Analyses

Equivalent Constants for MASTER Code

- **Equivalent Group Constant: Homogenized Group Constants and Surface Flux Discontinuity Factor(SDF)**
- **Homogenized Group Constant can be Calculated by the DeCART Solution**

$$\Sigma_{xg}^{m} = \frac{\sum_{i\in m}\sum_{j\in g}\Sigma_{x,j}^{i}\phi_j^i V^i}{\sum_{i\in m}\sum_{j\in g}\phi_j^i V^i}$$

- **SDF requires Homogeneous Surface Flux which is not a DeCART Solution**

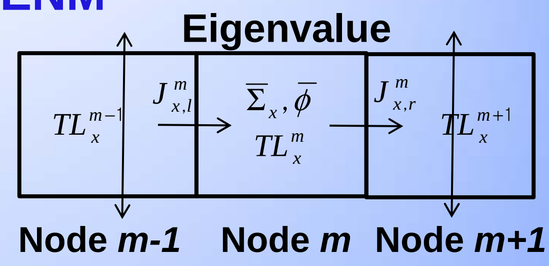
$$f_{xg,r}^{m} = \frac{\phi_{xg,r}^{m,het}}{\phi_{xg,r}^{m,ho}}$$

- **Implementation of One-Node SENM and TPEN Kernel to DeCART**

Equivalent Constants for MASTER Code

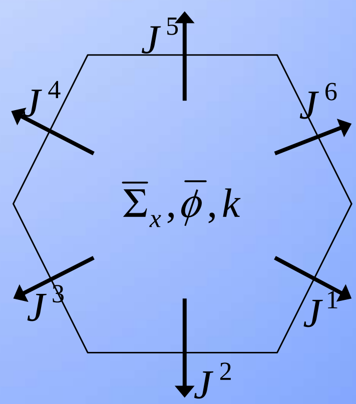
◆Given Condition for One-Node SENM

- ➢Node Average Flux and Eigenvalue
- ➢Homogeneous Group Constants
- ➢Surface Flux and Net Currents
- ➢Transverse Leakage



◆Given Conditions for TPEN

- ➢Node Average Flux and Eigenvalue
- ➢Homogeneous Group Constants
- ➢Surface Flux and Net Currents
- ➢Transverse Leakage for Axial NEM



Examination for Rectangular Core

◆YGN3 (Yong Gwang Unit 3) Cycle 1 BOC and EOC

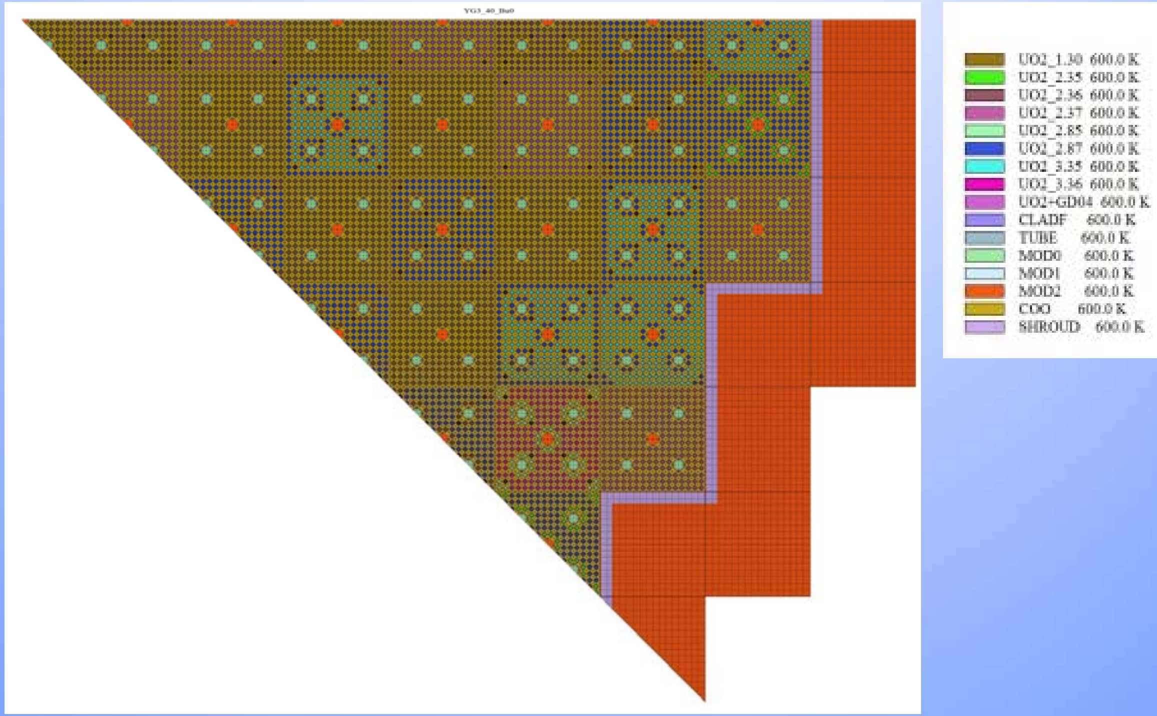
- ➢2-D Fixed Temperature Problem
- ➢3-D HFP Problem at BOC
- ➢3-D HFP Problem at EOC

◆DeCART Calculation Model

- ➢1/8 Symmetric Core
- ➢Explicit Shroud Modeling
- ➢Barrel is Replaced by Coolant
- ➢Explicit Axial Position Model for Spacer Grid
- ➢Assemblywise Enthalpy Calculation and Pin-wise Fuel Temperature Calculation using C-E Correlation

Examination

◆DeCART 2D Radial Model



2-D Fixed Temperature Problem

0.8962 0.8960 -0.02	1.1051 1.1048 -0.03	1.2791 1.2788 -0.02	0.9002 0.9000 -0.02	1.2311 1.2310 -0.01	1.0566 1.0567 0.01	1.1785 1.1788 0.03	0.9549 0.9554 0.05
	1.3384 1.3380 -0.03	0.9160 0.9158 -0.02	1.3341 1.3339 -0.01	0.8741 0.8741 0.00	1.2112 1.2113 0.01	1.1369 1.1372 0.03	0.8111 0.8115 0.05
		1.2363 1.2360 -0.02	0.8467 0.8466 -0.01	1.1887 1.1886 -0.01	0.8449 0.8449 0.00	1.0857 1.0859 0.02	0.5427 0.5429 0.04
			1.1652 1.1651 -0.01	0.8272 0.8272 0.00	1.2137 1.2137 0.00	0.9737 0.9738 0.01	
				1.1278 1.1277 -0.01	1.0461 1.0461 0.00	0.5484 0.5484 0.00	
					0.6501 0.6501 0.00		

	k
DeCART	0.982039
MASTER	0.982044
Diff.(%)	0.0005

Assembly Power Error at 3-D HFP BOC

0.8568 0.8582 0.16	1.0493 1.0506 0.12	1.2152 1.2165 0.11	0.8755 0.8761 0.07	1.1983 1.1986 0.03	1.0497 1.0491 -0.06	1.1873 1.1861 -0.10	0.991 0.991 0.00
	1.2628 1.2642 0.11	0.8837 0.8845 0.09	1.2802 1.2812 0.08	0.8646 0.8647 0.01	1.2007 1.2001 -0.05	1.1513 1.15 -0.11	0.8501 0.8501 0.00
		1.1875 1.1886 0.09	0.8338 0.8342 0.05	1.1717 1.1719 0.02	0.857 0.8565 -0.06	1.1112 1.1104 -0.07	0.5765 0.5768 0.05
			1.1475 1.1479 0.03	0.8364 0.8361 -0.04	1.2276 1.2266 -0.08	1.0093 1.009 -0.03	
				1.1429 1.1421 -0.07	1.0811 1.0803 -0.07	0.5847 0.5848 0.02	
					0.6895 0.6898 0.04		

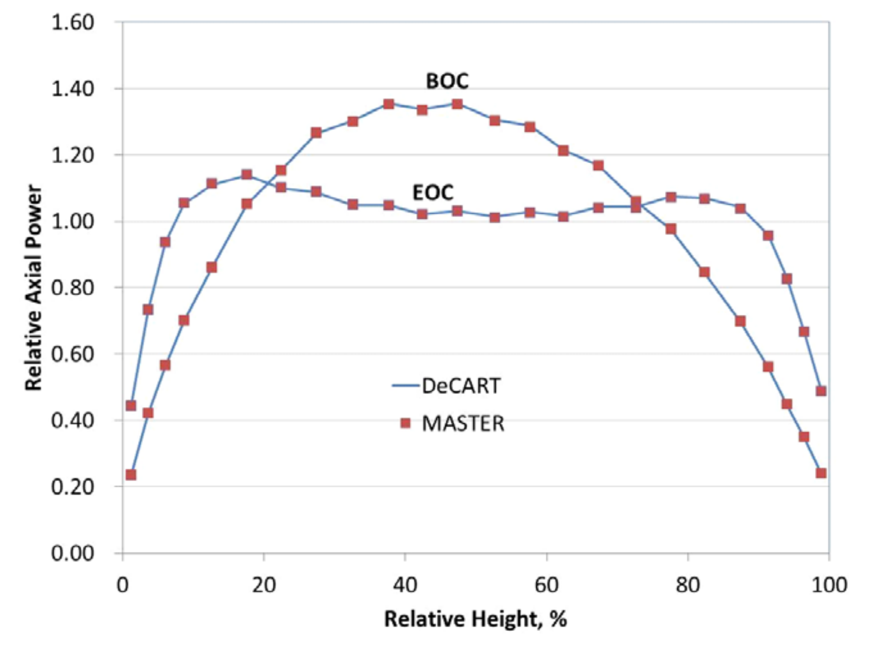
	k
DeCART	0.999996
MASTER	0.999890
% Diff.	-0.010

Assembly Power Error at 3-D HFP EOC

0.9438 0.9404 -0.36	1.0849 1.0815 -0.31	1.1325 1.1298 -0.24	0.9556 0.9532 -0.25	1.1341 1.1327 -0.12	1.0958 1.0953 -0.05	1.1323 1.1336 0.11	0.8525 0.8562 0.43
	1.1335 1.1305 -0.26	0.9547 0.9519 -0.29	1.2517 1.2499 -0.14	0.9536 0.9520 -0.17	1.1275 1.1272 -0.03	1.1077 1.1085 0.07	0.7658 0.7687 0.38
		1.1962 1.1941 -0.18	0.9615 0.9594 -0.22	1.1894 1.1886 -0.07	0.9309 0.9303 -0.06	1.0693 1.0705 0.11	0.5705 0.5733 0.49
			1.1964 1.1953 -0.09	0.9549 0.9540 -0.09	1.1884 1.1892 0.07	0.9163 0.9191 0.31	
				1.1684 1.1688 0.03	1.0845 1.0860 0.14	0.5894 0.5921 0.46	
					0.6997 0.7028 0.44		

	k
DeCART	1.000003
MASTER	1.000444
% Diff.	0.044

Axial Power Distribution at 3-D HFP



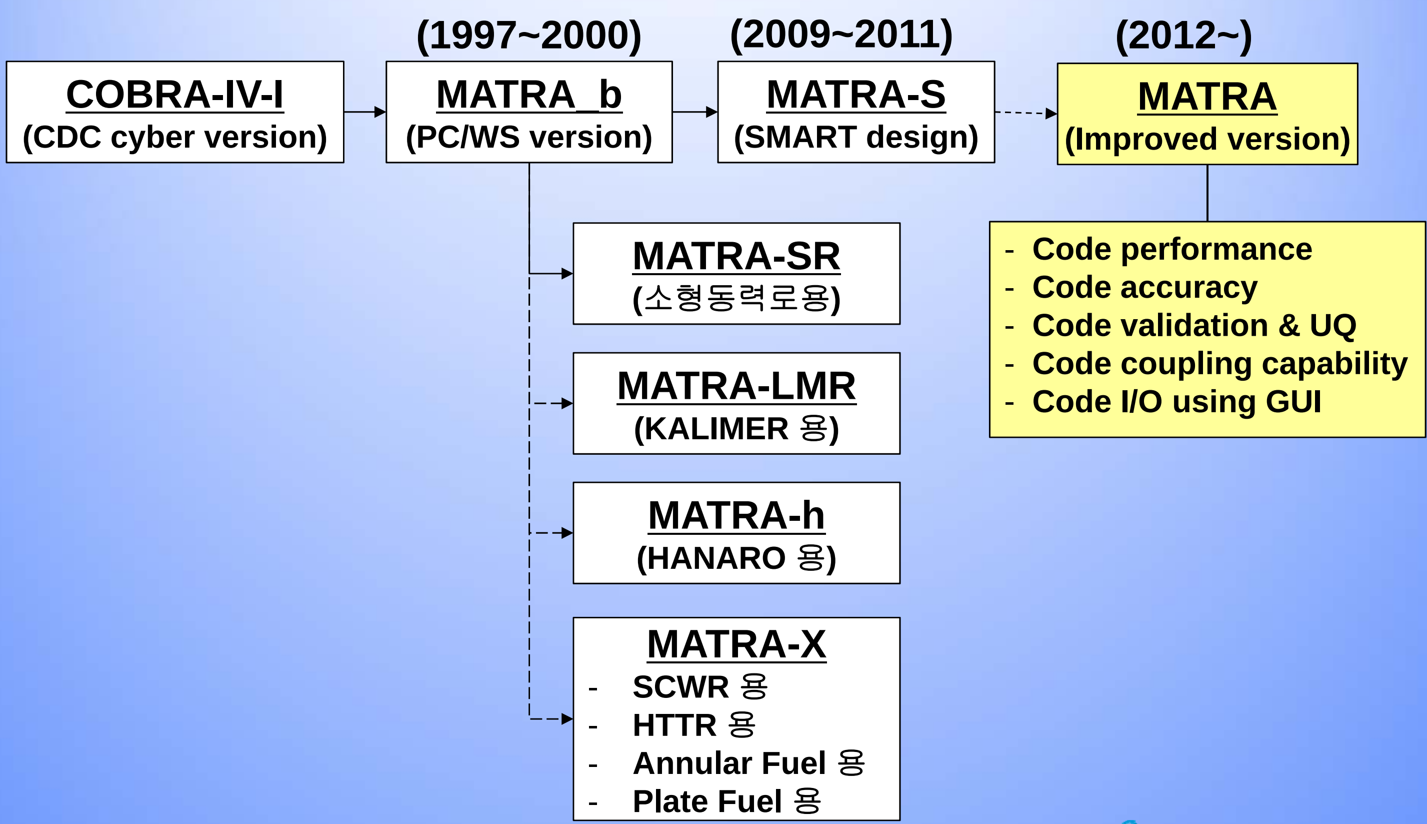
Bank Worth Comparison w/ Pseudo XS

	DeCART	ΔΣ by Procedure		Worth (pcm)		Diff(%)	DeCART2D /MASTER	Diff(%)
		MASTER	Δρ (PCM)	DeCART	MASTER			
ARO	1.038195	1.038198	0.3					
R5	1.033572	1.033584	1.1	431	430	-0.20	461	7.00
R54	1.028144	1.028166	2.1	942	940	-0.19	1007	6.94
R543	1.022237	1.022289	5.0	1504	1499	-0.31	1579	5.01
R5432	1.016881	1.016979	9.5	2019	2010	-0.46	2090	3.52
R54321	0.999581	0.999591	1.0	3721	3720	-0.02	3886	4.44
ARI	0.878286	0.878332	6.0	17537	17531	-0.03		

MATRA Development Status

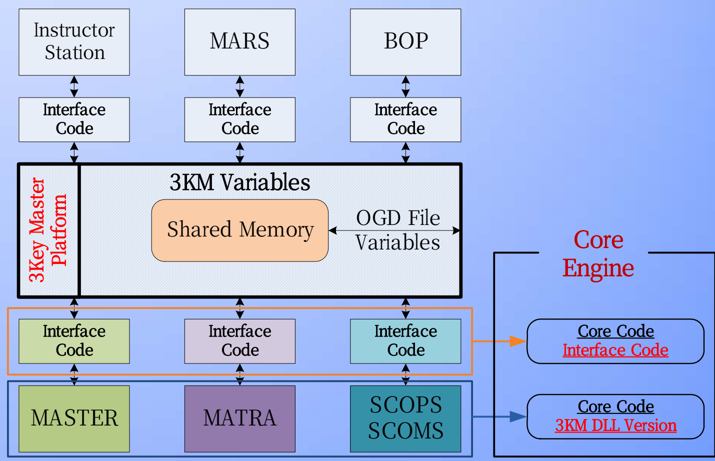
- MATRA(Multichannel Analyzer for steady state and Transient in Rod Array)
- Sub-channel Analysis Code developed at KAERI
  - Based on COBRA-IV-I, but fully re-constructed
  - Improvement for Single-phase and Two-phase Flow Models
  - Improvement for Fuel Heat Transfer Models
  - Improvement for Solution Methods
  - Solves T-H in Steady-state or Transient Condition in the Core
  - Approved for SMART core TH design analysis
- Coupled with
  - MASTER Nodal Diffusion Code
  - DeCART 3-D Transport Code
  - FRAPCON-3 Fuel Performance Code

MATRA Pedigree



MASTER-MATRA Coupling

- Conducted as a part of the SMART simulator
- The engines consisting of the SMART simulator were coupled on the 3-KEYMASTER(3KM[5]) platform
- 3KM provides pipes to connect each code. Registering as common variables, it can be accessed in any code on the 3KM platform
- MATRA needs the heat flux distribution, and operating conditions such as T-inlet, mass flux, and exit pressure.
- MASTER needs Tf, Tm, Dm
- Data is transferred through 3KM shared memory

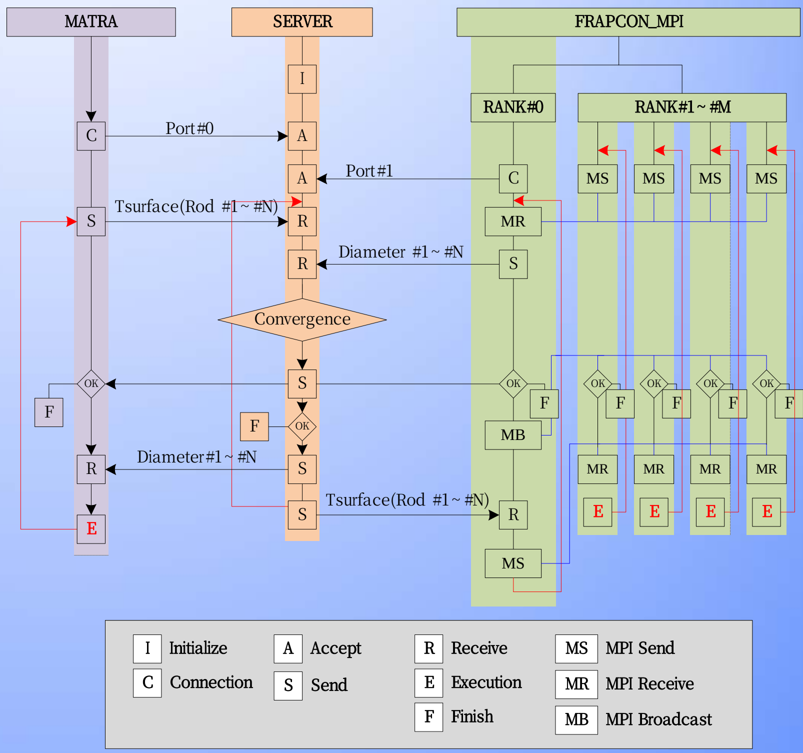


FRAPCON-MATRA Coupling

- FRAPCON-3 Code
  - Code to calculate the steady-state response of fuel rods during a long-term burnup in a light-water reactor
  - Temperature, pressure, and deformation of a fuel rod can be estimated by this code according to the variation of the coolant and rod power.
    1) Heat conduction through the fuel and cladding to the coolant
    2) Cladding elastic and plastic deformation
    3) Fuel-cladding mechanical interaction
    4) Fission gas release from the fuel and rod internal pressure
    5) Cladding oxidation
- FRAPCON-MATRA coupling
  - Socket based coupling & MPI technique for FRAPCON
  - MATRA receives the geometrical information and sends the heat transfer coefficient
  - MATRA modifies subchannel information such as the flow area, wetted and heated perimeter

FRAPCON-MATRA Coupling

- **Problem: SMART Whole Core Pin by Pin Coupling**
- **Socket based Data Transfer**
  - **Between MATRA & Server, FRAPCON & Server**
  - **Geometric Info.**
  - **Each Rod Info.**
- **MPI based Data Transfer**
  - **Interior data transfer of FRAPCON between each rods**



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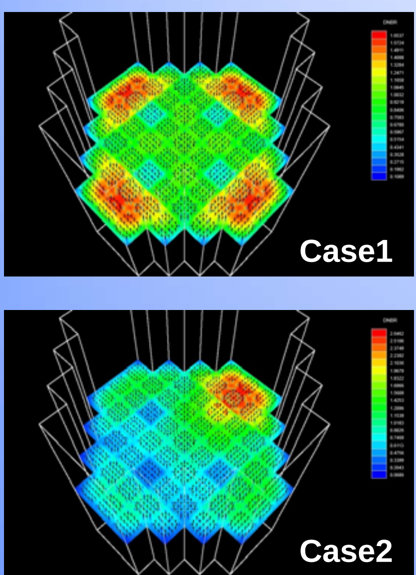
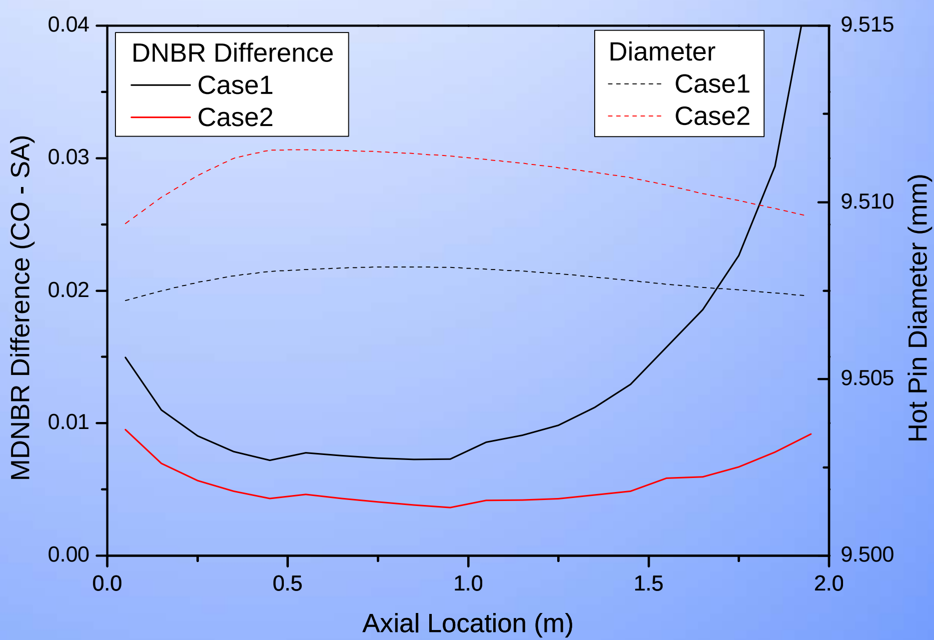
FRAPCON-MATRA Coupling

- **FRAPCON-MATRA coupled Calculation**
  - **Hot Rod**



Radial Power Distribution



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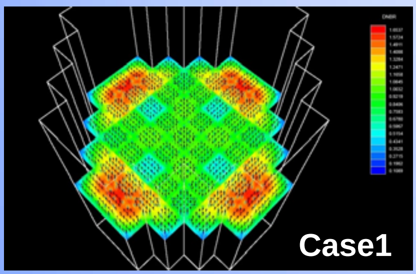
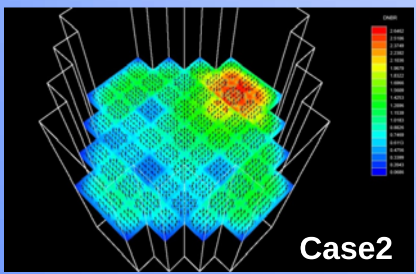
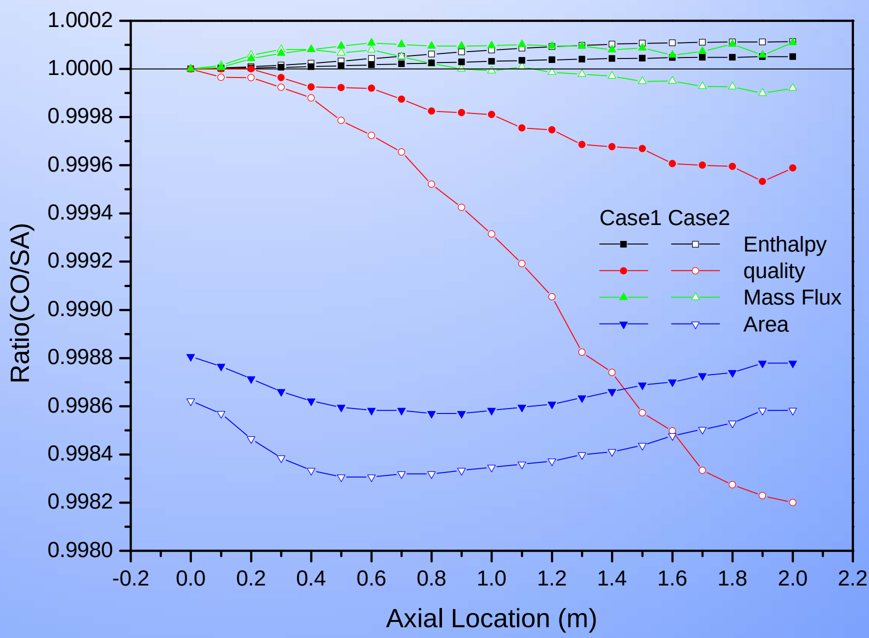
FRAPCON-MATRA Coupling

- **FRAPCON-MATRA coupled Calculation**
  - **Hot Channel**



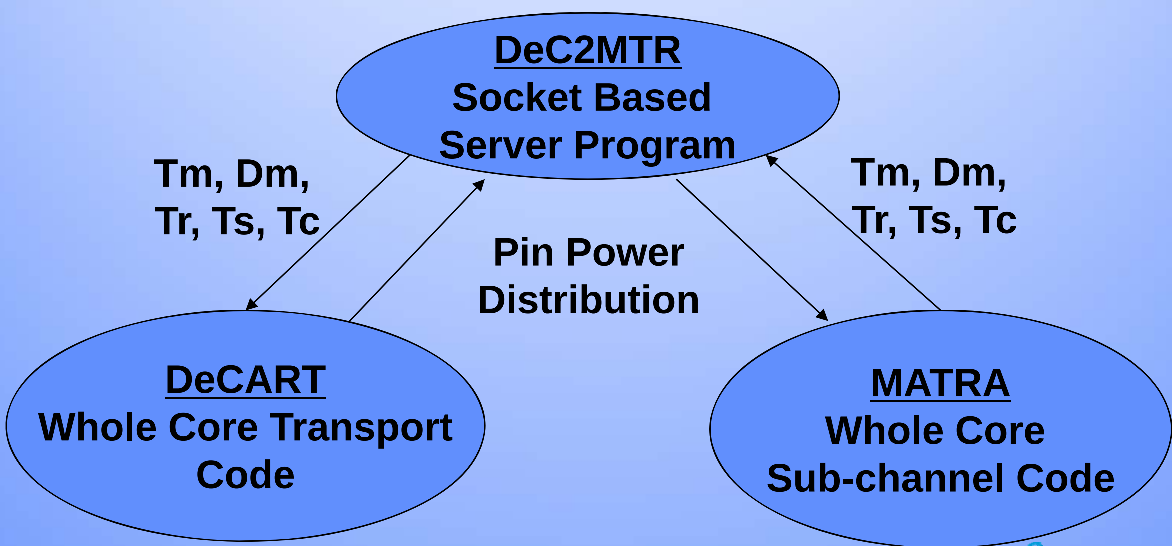


Radial Power Distribution



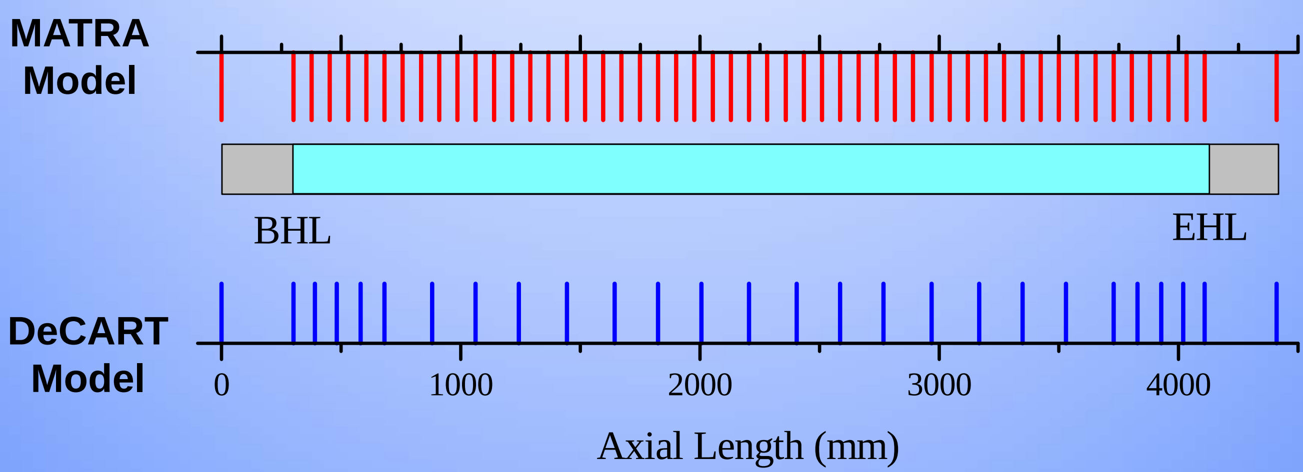
DeCART-MATRA Coupling

- **Socket based Data Transfer**
  - **Pin-wise Data Transfer**
  - **Coolant Density and Temperature, Rod Surface Temp. and Fuel Surface and Center Temperature from MATRA to DeCART**
  - **Pin-wise Power Distribution from DeCART to MATRA**

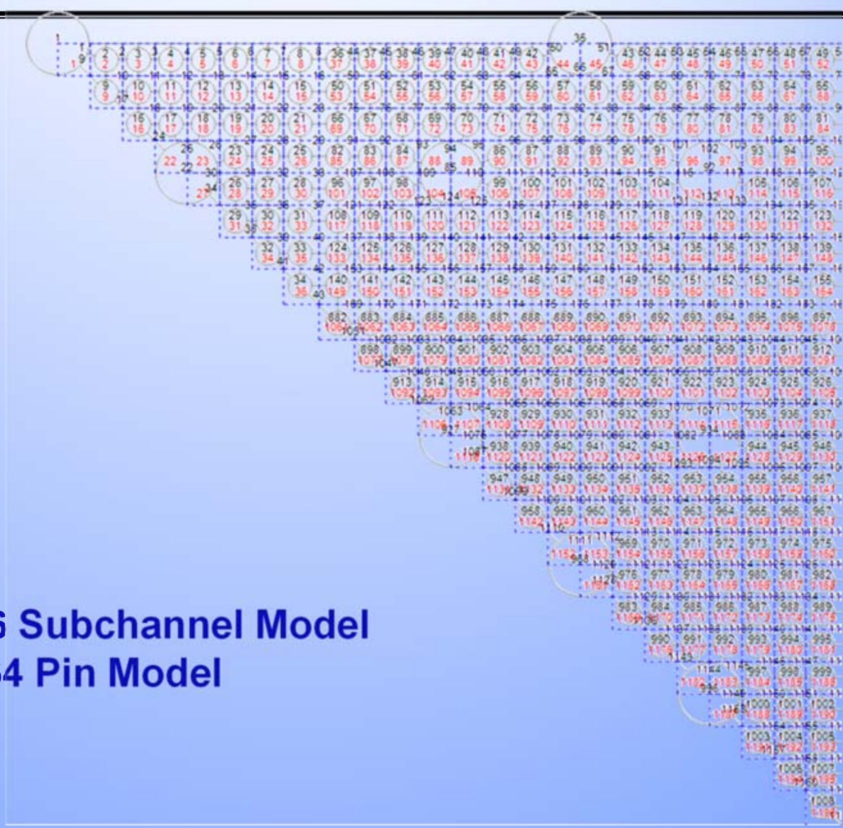


DeCART-MATRA Coupled Calculation(YGN3)

- **Axial Mapping for DeCART-MATRA Coupling**
  - **MATRA: 52 Nodes Model**
  - **DeCART: 26 Plane Model**

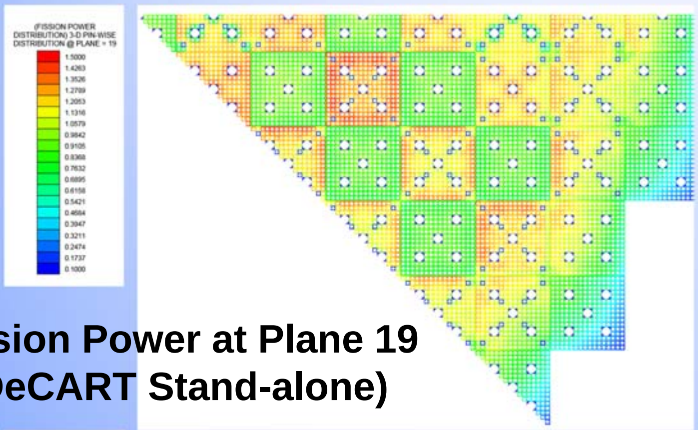


DeCART-MATRA Coupled Calculation(YGN3)

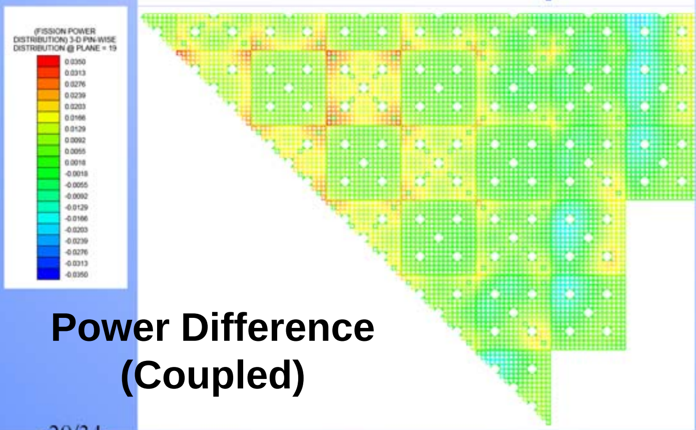


- **Radial Mapping**
  - **MATRA: 5706 Subchannel Model**
  - **DeCART: 7764 Pin Model**

DeCART-MATRA Coupled Calculation(YGN3)



Fission Power at Plane 19
(DeCART Stand-alone)



Power Difference
(Coupled)

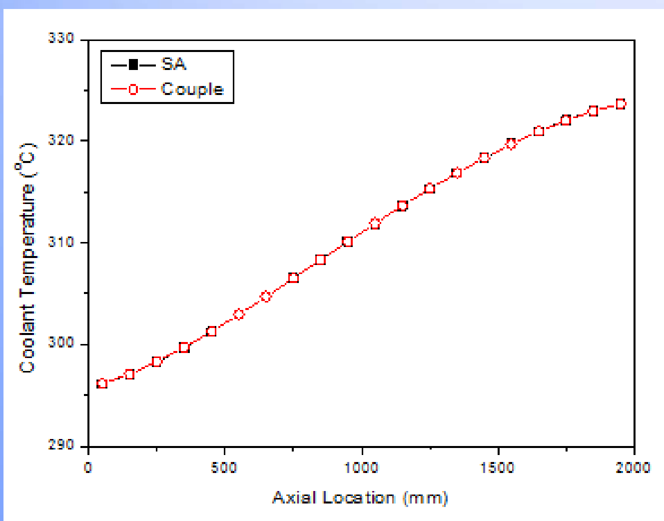
◆ **Difference in Power Distribution**

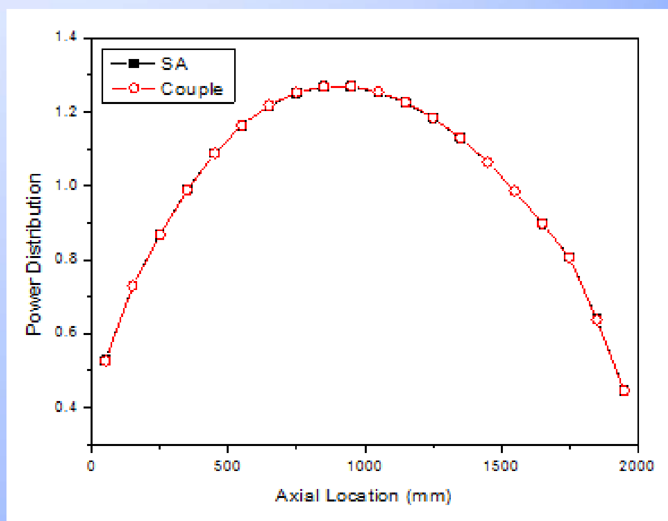
Parameter	Min.	Max.
Fq	-0.0509	0.0416
Fr	-0.0121	0.0115
Fq(Node)	-0.0328	0.0363
Fr(Node)	-0.0039	0.0028

DeCART-MATRA Coupled Calculation(SMART)

◆ **Axial Distribution**

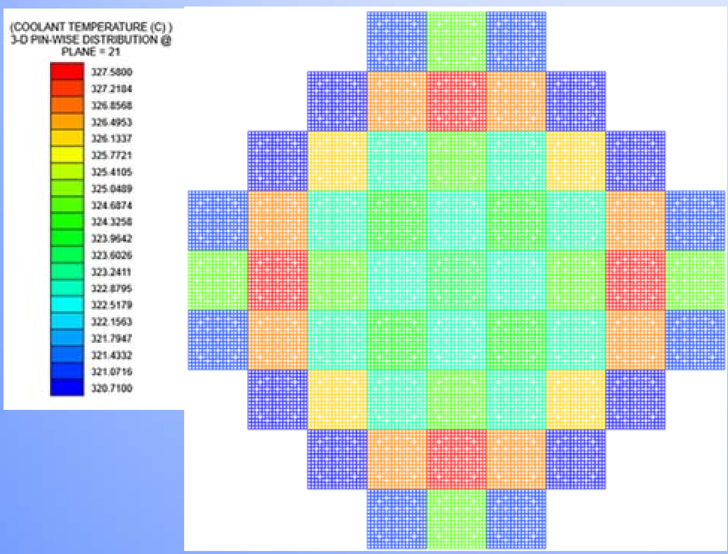
➢ **Very Similar Distribution**

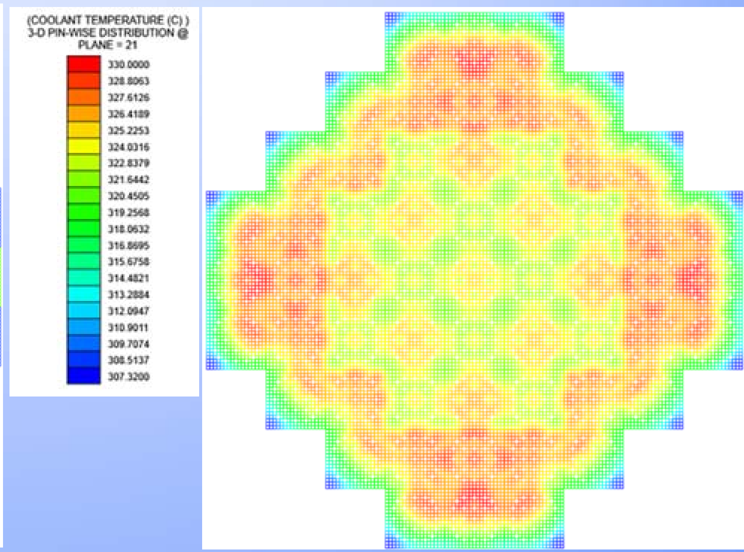




DeCART-MATRA Coupled Calculation(SMART)

- **Exit Coolant Temperature Distribution**
  - **Maximum Difference shown at Peripheral Assemblies**
  - **Temperature Difference from -7.43 ~ 13.48**

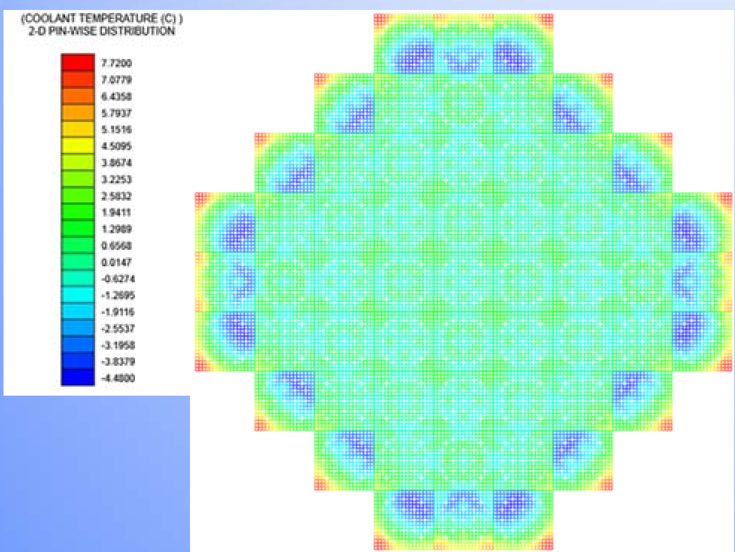


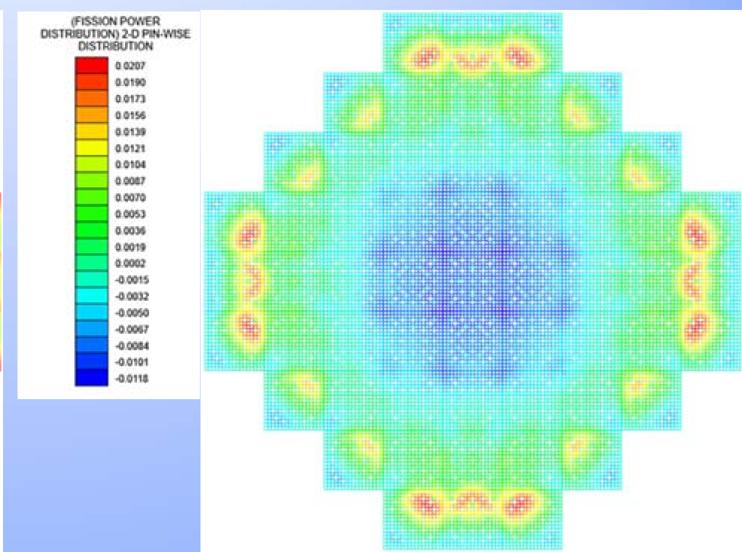


DeCART Stand-alone **DeCART-MATRA Coupling**

DeCART-MATRA Coupled Calculation(SMART)

- **2-D Tm and Power Distribution**
  - **Temperature Difference from -4.48 ~ 7.72 ℃**
  - **Power Difference from -0.0118 ~ 0.0207**





Coolant Temperature **Power Distribution**

DeCART-MATRA Coupled Calculation(SMART)

◆ Peaking Factor Comparison

Factor	Stand-alone	Coupled	Difference
AO	-0.0382	-0.0367	-0.0015
Fq(Node)	1.4845	1.4802	0.0043
Fxy(Node)	1.2626	1.2657	-0.0031
Fr(Node)	1.1538	1.1533	0.0005
Fq	1.7809	1.7787	0.0022
Fxy	1.4972	1.5039	-0.0067
Fr	1.4006	1.4015	-0.0009
Fz	1.2716	1.2693	0.0023

Conclusion

◆Preliminary Multi-Physics Calculation

- DeCART-MATRA Coupled Calculation for YGN3 and SMART
- MATRA-FRAPCON Coupled Calculation for SMART

◆Future Work

- DeCART-MATRA-FRAPCON Coupled Calculation
- Depletion Calculation with Coupled System
- Development of DeCART/CHORUS/MASTER System
- Transient Simulation