Analyses of the B&W-1810 and KRITZ-2 Critical Experiments with nTRACER

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  - Overview of the Experiments
  - Modeling of the Cores
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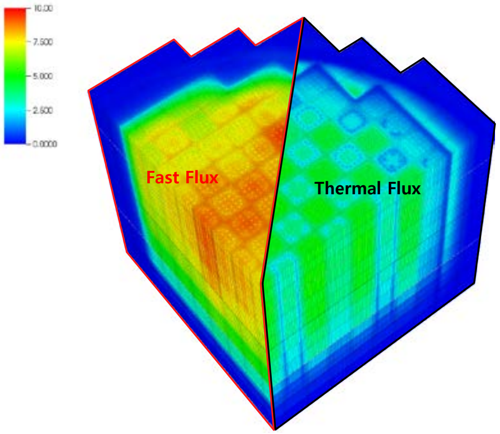
Introduction

☐ nTRACER Direct Whole Core Calculation Code



- Calculation features
  - Planar MOC based 2D/1D calculation
  - Sub-pin level transport calculation
  - On the fly resonance self-shielding
- Validation through actual core calculation
  - OPR1000, AP1000 and APR1400 PWR cores
  - BEAVRS and VERA benchmark problems

☐ Need for Experimental Core Benchmarks Problems

- Simulation capability of nTRACER for the commercial reactors has been validated consistently
- Validations on various core configurations are still required

☐ Purpose of the Work

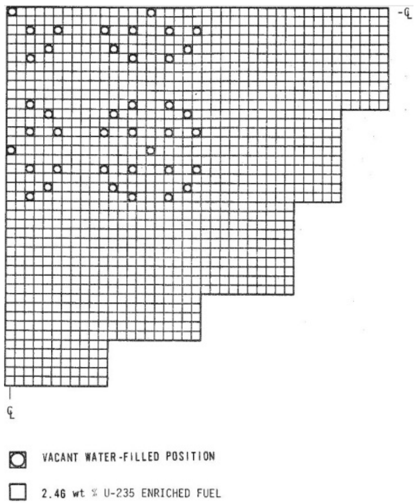
- Verifying the simulation capability and extending the applicability of nTRACER by performing calculations on the critical experiment benchmarks
  - B&W-1810 and KRITZ-2 critical experiments were analyzed

Analysis of the B&W-1810 Critical Experiments

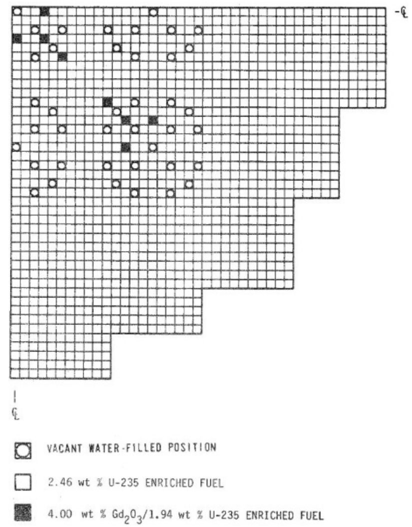
Overview of B&W-1810 Experiments

Core Configurations

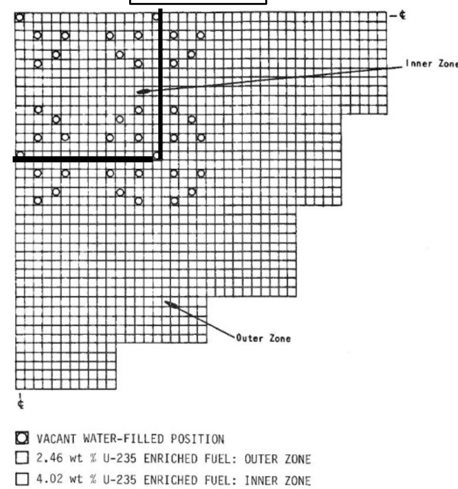
Core 1



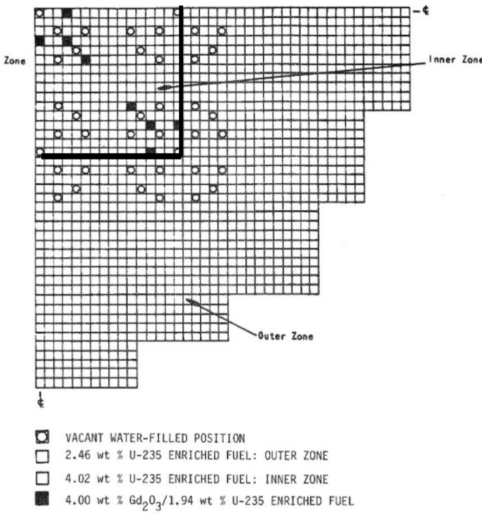
Core 5



Core 12



Core 14



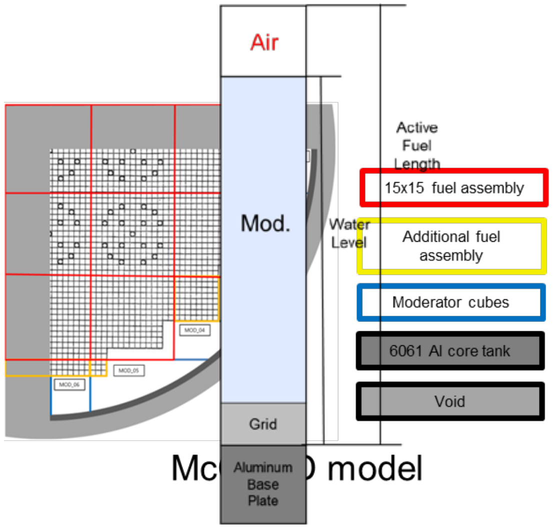
Number of	Core 1	Core 5	Core 12	Core 14
2.46w/o U-235 fuel pins	4808	4780	3920	3920
4.02w/o U-235 fuel pins	0	0	888	860
Gd fuel pins	0	28	0	28
Water holes	153	153	153	153
Boron (ppm)	1337.9	1208.0	1899.3	1653.8

Modeling of B&W-1810 Cores

☐ McCARD Core Modeling

- Radial geometry
  - Modeled up to the core tank
  - 8 fuel assemblies with 15x15 lattice, 5 additional fuel assemblies, and 6 moderator blocks
- Axial geometry
  - Modeled from the aluminum base plate to the top of fuel rods
  - Parts of fuel rods above the water level modeled

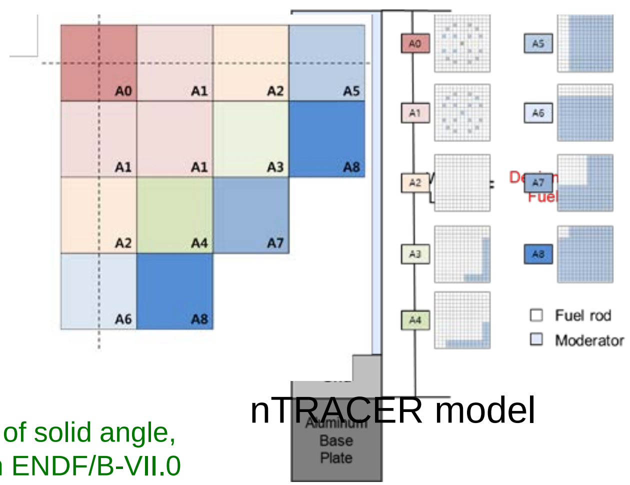
* McCARD parameters : 2,000,000 particles, 400/800 inactive/active cycles
continuous energy library based on ENDF/B-VII.0



☐ nTRACER Core Modeling

- Radial geometry
  - Modeled up to the assemblies which have fuel rods
  - Core tank was not modeled due to modeling complexity and its negligible effect on solution (~6 pcm)
- Axial geometry
  - Modeled from the aluminum base plate to the water level
  - Only parts of fuel rods below the water level modeled

- nTRACER parameters : 0.05cm ray spacing, 16/4 azimuthal/polar angles in the octant of solid angle, P2/P0 scattering, 47 group RPL cross section library based on ENDF/B-VII.0



nTRACER model

Comparison with Measurements

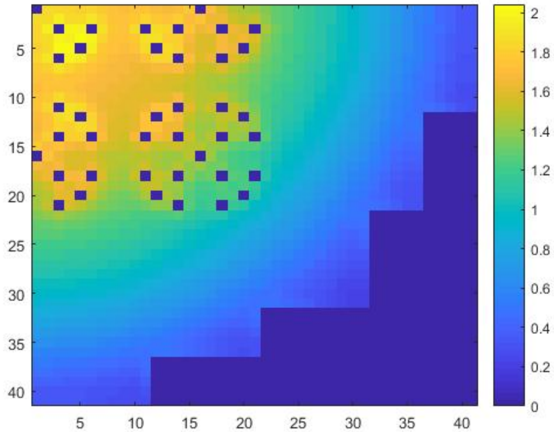
☐ Good Agreement with Measurements

- With P0 scattering
  - Difference of k-eff from criticality ≤ 266 pcm
  - Abs. ΔP : RMS ≤ 0.35 %, Max ≤ 1.13 % (for the central assembly)
- With P2 scattering
  - Difference of k-eff from criticality ≤ 64 pcm
  - Abs. ΔP : RMS ≤ 0.27 %, Max ≤ 0.60 % (for the central assembly)

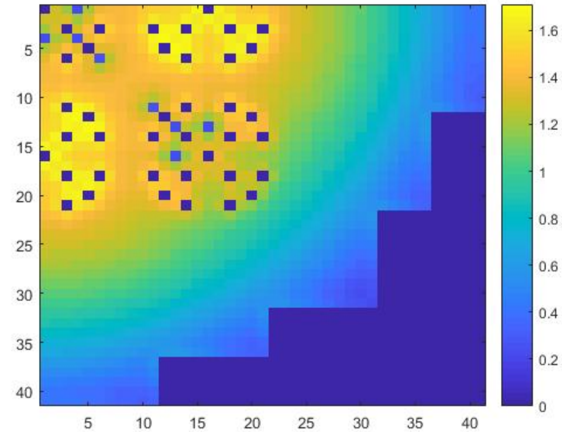
Core	Cal.	k-eff	Δρ (pcm)	Abs. RMS (%)	Abs. Max (%)
Core 1	**P2**	**1.00004**	**4**	**0.19**	**0.60**
	P0	0.99801	-199	0.28	1.10
Core 5	**P2**	**0.99936**	**-64**	**0.22**	**0.60**
	P0	0.99764	-236	0.29	1.05
Core 12	**P2**	**0.99992**	**-8**	**0.21**	**0.50**
	P0	0.99734	-266	0.29	1.13
Core 14	**P2**	**0.99961**	**-39**	**0.27**	**0.60**
	P0	0.99742	-258	0.35	0.90

Comparison with McCARD

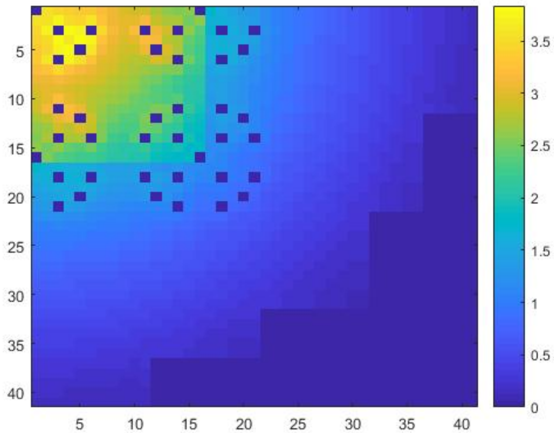
□ Power Distributions in McCARD



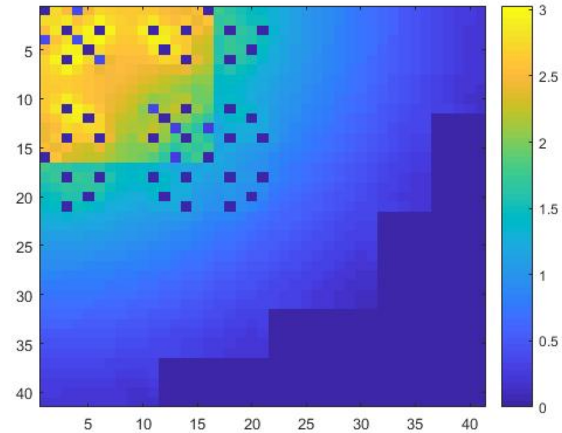
Core 1



Core 5



Core 12



Core 14

McCARD parameters :
2,000,000 particles,
400/800 inactive/active cycles
Std. : 2pcm

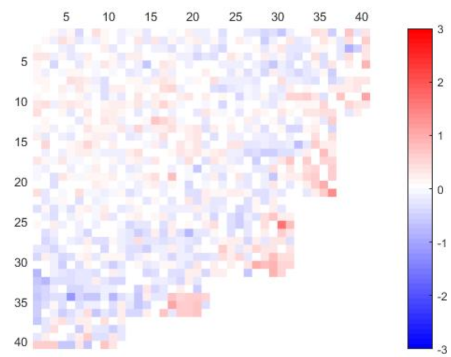
Comparison with McCARD

☐ Power Differences for the Full Core (%)

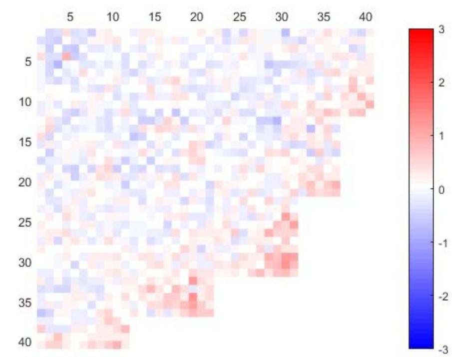
- Measured data were given for pins in the central assembly
- McCARD solutions were utilized to assess the power distribution of the full core

Core	Cal.	Abs. RMS	Abs. Max	Rel. RMS	Rel. Max
Core 1	**P2**	**0.25**	**1.10**	**0.29**	**1.63**
	P0	0.31	1.80	0.42	1.90
Core 5	**P2**	**0.26**	**1.10**	**0.29**	**1.26**
	P0	0.31	1.20	0.39	1.74
Core 12	**P2**	**0.48**	**2.70**	**0.47**	**1.62**
	P0	1.04	4.90	0.60	1.65
Core 14	**P2**	**0.45**	**2.10**	**0.39**	**1.18**
	P0	0.93	4.90	0.57	1.74

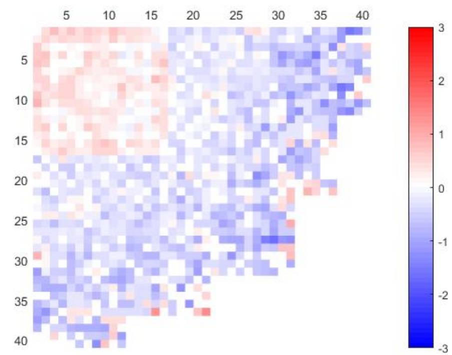
Core 1



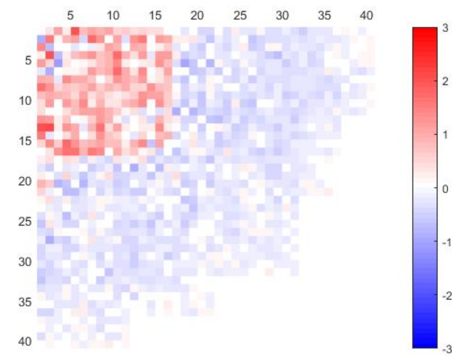
Core 5



Core 12



Core 14

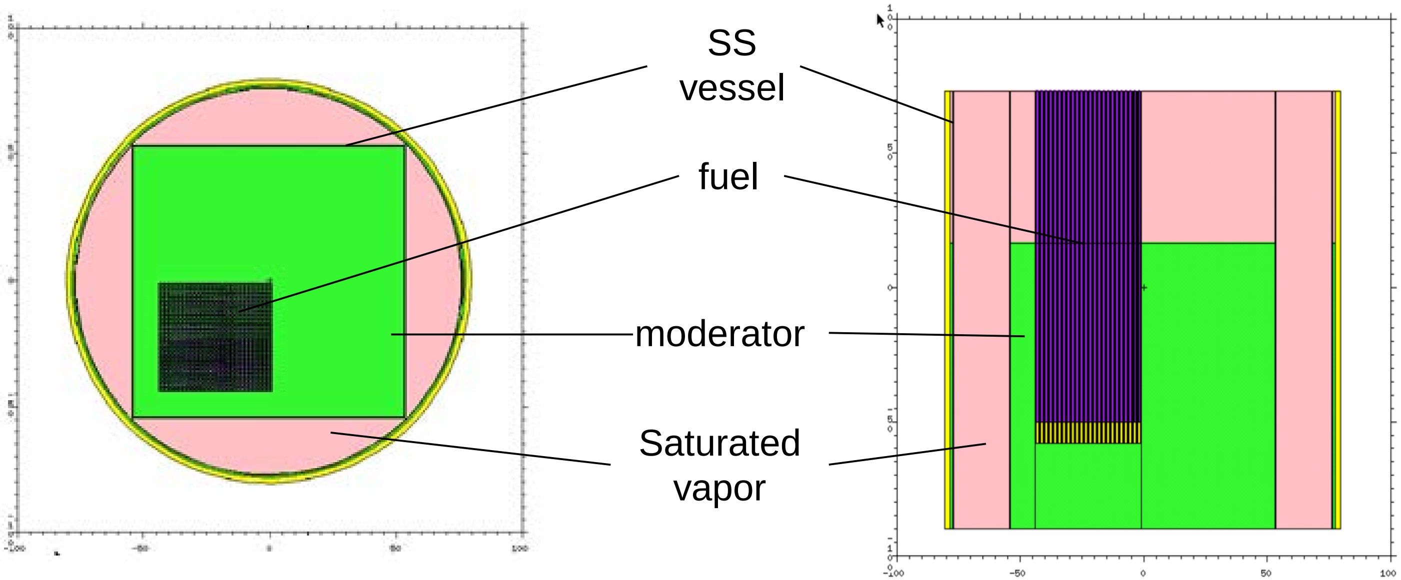


Analysis of the KRITZ-2 Critical Experiments

Overview of the KRITZ-2 Critical Experiment

☐ Core Configuration

- Radial Cross Section
- Axial Cross Section



- Cylindrical outer vessel and square inner vessel
- Space between outer vessel and inner vessel filled with saturated vapor (~ 245℃)
- Top portions of the fuel rods extended in steam region
- Same thickness of water reflector on west side and south side
- Fuel rods supported by cylindrical stainless steel

* McCARD model was made same with the benchmark model

Overview of the KRITZ-2 Critical Experiment

☐ Description of the Experiment

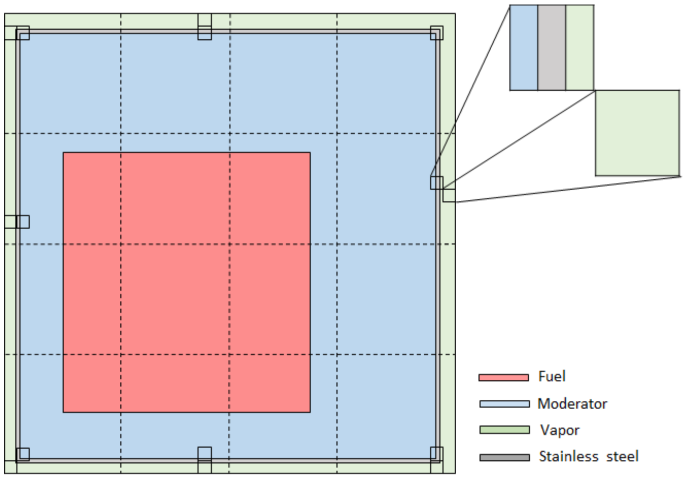
- Core cases analyzed
  - Core 1 : 44x44 UO_2 fuel at room temperature and elevated temperature
  - Core 13 : 40x40 UO_2 fuel at room temperature and elevated temperature
  - Core 19 : 25x24 MOX fuel at room temperature and elevated temperature
- Boron concentrations and water level adjusted to meet critical condition at room temperature and elevated temperature (~245℃)
- Critical level was measured at low power (~ 10W)
- k-eff and power distributions for some specific locations are given
  - For critical experiments, the difference of k-eff is difference from criticality
  - Only several pins were measured which were located in specific position; therefore, the comparison with experimental data were done for only these specific pins
  - McCARD results were used as reference for comparing the power distributions for all pins

Modeling of the KRITZ-2 Cores

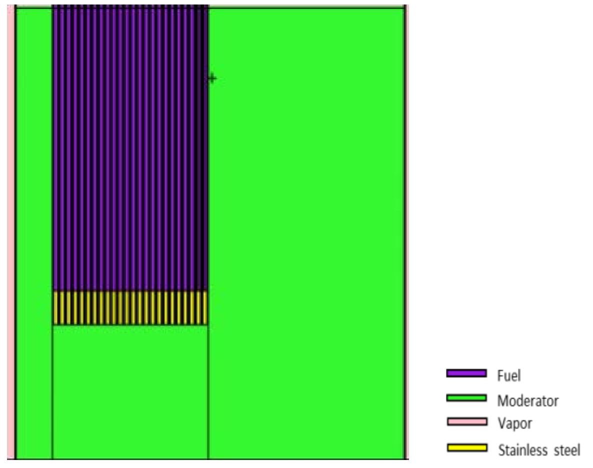
☐ Details of the nTRACER Modeling

- Geometry in nTRACER is composed of square pins where it is hard to model the cylindrical outer vessel and tank
  - Cylindrical outer vessel and pressure tank are neglected.
- Vapor region above the water level or between inner vessel and outer vessel makes trouble in nodal and CMFD solver
  - Axially, only the parts of the fuel rods below water level are modeled
  - Radially, only a little part of vapor region are modeled to complete the proper number of pins

* nTRACER parameters : 0.05cm ray spacing, 16/4 azimuthal/polar angles, P2/P0 scattering, 47 group RPL cross section library based on ENDF/B-VII.0



Radial Cross Section



Axial Cross Section

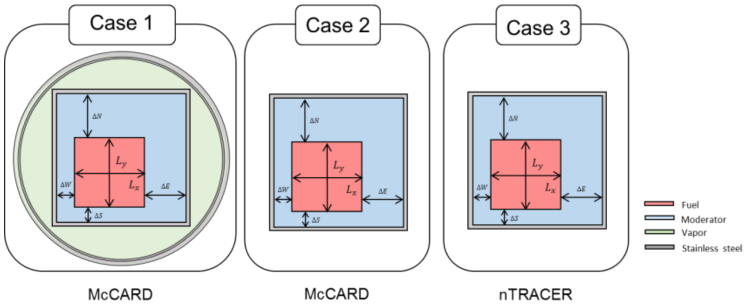
Modeling of KRITZ-2 Cores

☐ Assessment of the Modeling Bias

- Performed calculations on three cases
  - Case 1 : fully explicit (McCARD) model, with McCARD code
  - Case 2 : simplified (nTRACER) model, with McCARD code
  - Case 3 : simplified (nTRACER) model, with nTRACER

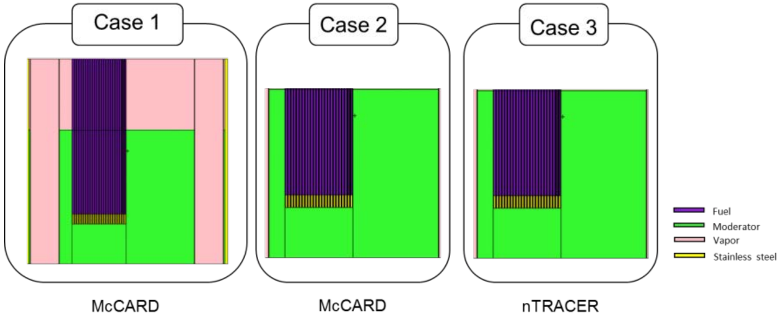
- By comparing Case 1 and 2, errors from the modeling difference can be evaluated

Radial cross section



- By comparing Case 2 and 3, errors from the **code** can be evaluated

Axial cross section



McCARD parameters :
2,000,000 particles,
400/800 inactive/active cycles
Std. : 2pcm

Comparison with Measurements

☐ Difference of k-eff from Criticality (pcm)

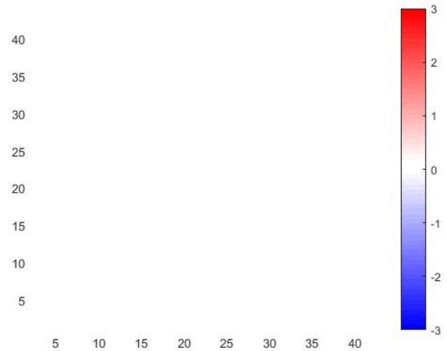
- Case2 and 3 which use simplified model **(nTRACER model)** show extremely large underestimations especially in core1 and core13

		Case 1 (explicit model, with McCARD)	Case 2 (simplified model, with McCARD)	Case 3 (simplified model, with nTRACER)
Core 1	cold	-137	-1286	-1438
	hot	-338	-919	-1031
Core 13	cold	93	-262	-274
	hot	-72	-458	-577
Core 19	cold	446	-76	-16
	hot	84	-211	20

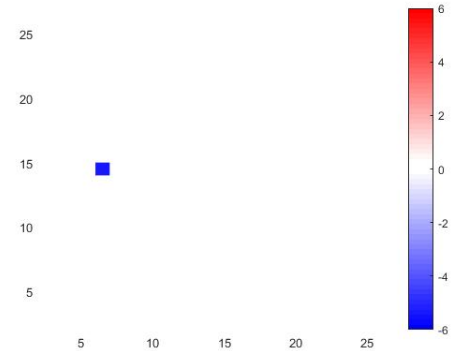
☐ Comparison of Pin Powers (Cold)

- Most pins show errors within 3.0% except two kinds of pins
  - 1) peripheral pins which have **low reference power**
  - 2) pins measured with **high uncertainty** due to bent rod or inhomogeneity in material

Pins with error > 3.0%



Core 13



Core 19

Comparison with Measurements

McCARD parameters :
2,000,000 particles,
400/800 inactive/active cycles
Std. : 2pcm

☐ Difference of k-eff from Criticality (pcm)

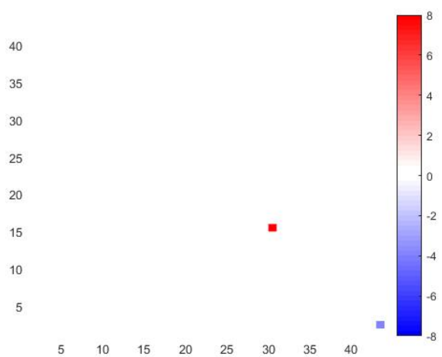
- Case2 and 3 which use simplified model **(nTRACER model)** show extremely large underestimations especially in core1 and core13 .

		Case 1 (explicit model, with McCARD)	Case 2 (simplified model, with McCARD)	Case 3 (simplified model, with nTRACER)
Core 1	cold	-137	-1286	-1438
	hot	-338	-919	-1031
Core 13	cold	93	-262	-274
	hot	-72	-458	-577
Core 19	cold	446	-76	-16
	hot	84	-211	20

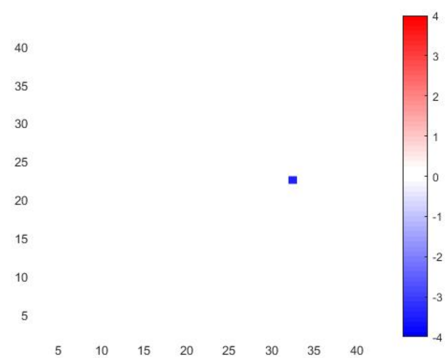
☐ Comparison of Pin Powers (Hot)

- Most pins show errors within 3.0% except two kinds of pins
  - 1) peripheral pins which have **low reference power**
  - 2) pins measured with **high uncertainty** due to bent rod or inhomogeneity in material

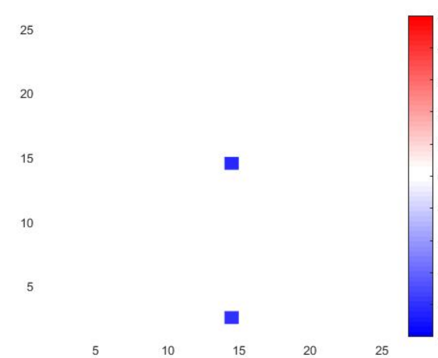
Pins with error > 3.0%



Core 1



Core 13



Core 19

Error due to Modeling

McCARD parameters :
2,000,000 particles,
400/800 inactive/active cycles
Std. : 2pcm

☐ Comparison of k-eff

- Differences between case 1 and 2 are much larger than those between case 2 and 3
  - Simplifications of the model in nTRACER have a big impact on the results
  - This tendency is more evident when there is more part of fuel rods that is not designed axially (e.g. Core 1 at cold condition in which the ratio of fuel rods that was not designed is 82.12% has difference of k-eff over 1000pcm)

Case	Δk-eff (ref. vs), pcm							
	Error due to **radial simplification**		Error due to **axial simplification**		Case 1 vs Case 2 **(Error due to Modeling)**		Case 2 vs Case 3 **(McCARD vs nTRACER)**	
	Cold	Hot	Cold	Hot	Cold	Hot	Cold	Hot
Core 1	-17	-120	-1131	-421	-1149	-581	-152	-112
Core 13	-1	-25	-353	-362	-355	-386	-12	-119
Core 19	-16	-77	-504	-191	-522	-295	60	231

Height of fuel rods designed(cm) and un-designed length ratio(%)

Case	McCARD model (Case 1), cm		nTRACER model (Case 2, 3), cm		Neglected length ratio, %	
	Cold	Hot	Cold	Hot	Cold	Hot
Core 1	365.00	365.92	65.28	105.52	82.12	71.16
Core 13	365.00	365.89	96.17	110.96	73.65	69.67
Core 19	123.20	123.20	66.56	100.01	45.97	18.82

Case1 : Explicit model, with McCARD code
Case2 : Simplified model, with McCARD code
Case3 : Simplified model, with nTRACER code

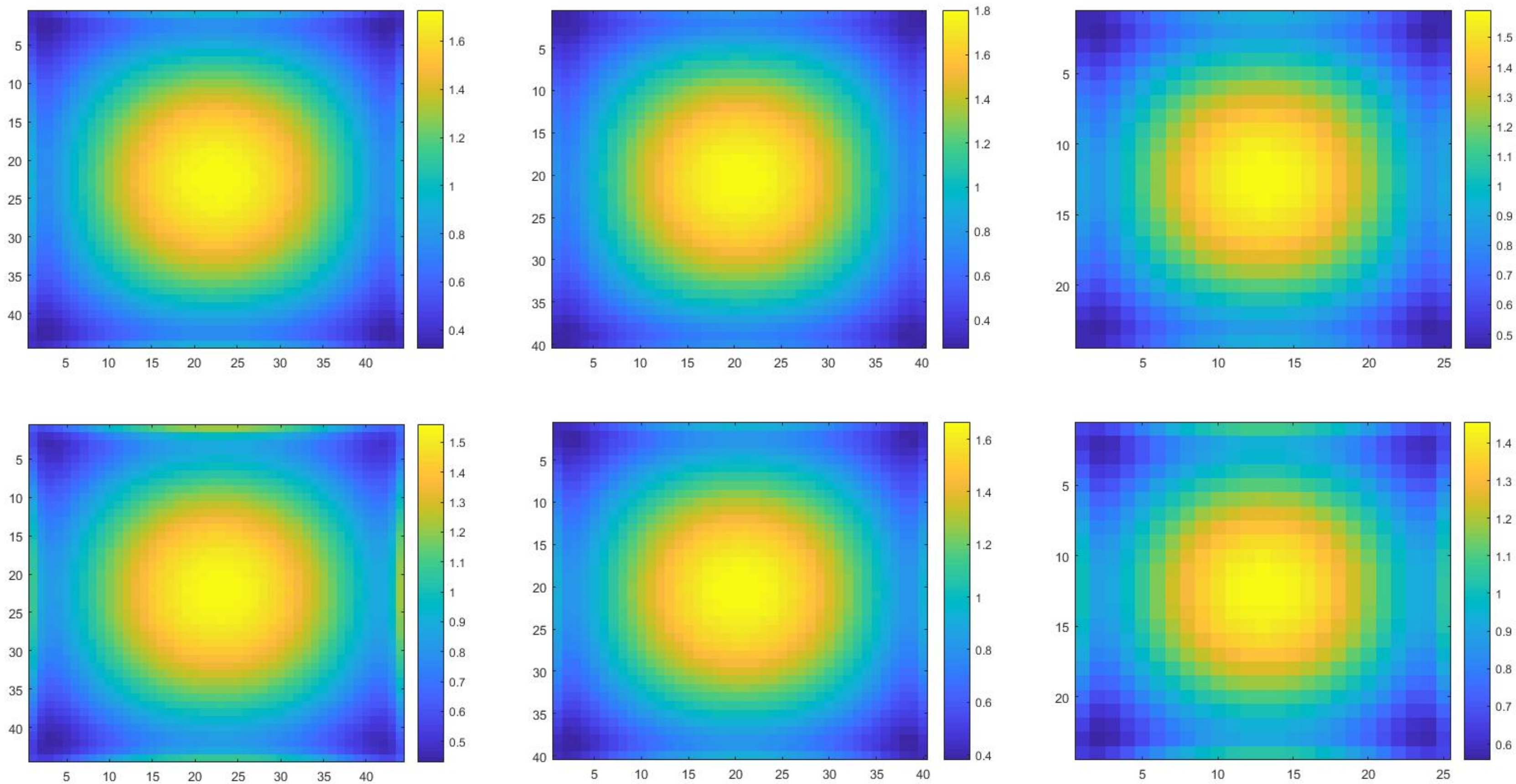
Comparison with McCARD

☐ Power Distributions in McCARD

Core 1 | Core 13 | Core 19

Cold

Hot



Comparison with McCARD

- **Larger Errors in Core 19 with MOX Fuel**
- **Good Agreement with McCARD in P2**
  - Difference of k-eff from criticality ≤ 231 pcm
  - Abs. ΔP : RMS ≤ 0.46 %, Max ≤ 1.01 %

At cold condition

Core	Cal.	k-eff	Del. Rho (pcm)	Abs. RMS (%)	Abs. Max (%)
Core 1 44x44 UO_2	**McCARD**	**0.98714**			
	P2	0.98562	-156	0.12	0.41
	P0	0.98491	-229	0.19	0.64
Core 13 40x40 UO_2	**McCARD**	**0.99738**			
	P2	0.99726	-12	0.18	0.54
	P0	0.99616	-123	0.25	0.60
Core 19 25x24 MOX	**McCARD**	**0.99924**			
	P2	0.99984	60	0.40	0.78
	P0	0.99955	31	0.41	0.80

At hot condition

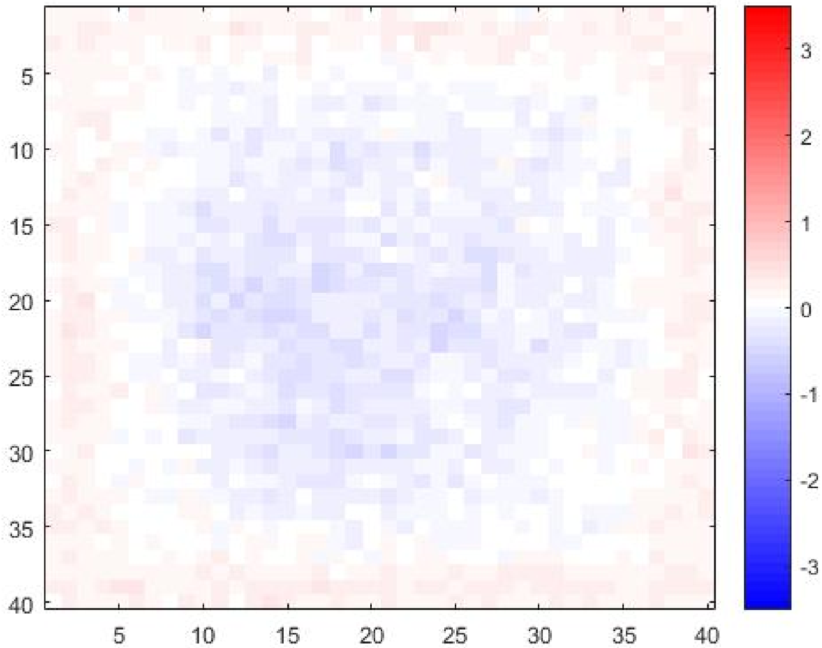
Core	Cal.	k-eff	Del. Rho (pcm)	Abs. RMS (%)	Abs. Max (%)
Core 1 44x44 UO_2	**McCARD**	**0.99081**			
	P2	0.98969	-114	0.32	0.75
	P0	0.98860	-226	0.44	1.50
Core 13 40x40 UO_2	**McCARD**	**0.99542**			
	P2	0.99423	-120	0.32	0.77
	P0	0.99337	-207	0.40	0.90
Core 19 25x24 MOX	**McCARD**	**0.99789**			
	P2	1.00020	231	0.46	1.01
	P0	1.00034	245	0.66	1.50

Comparison with McCARD

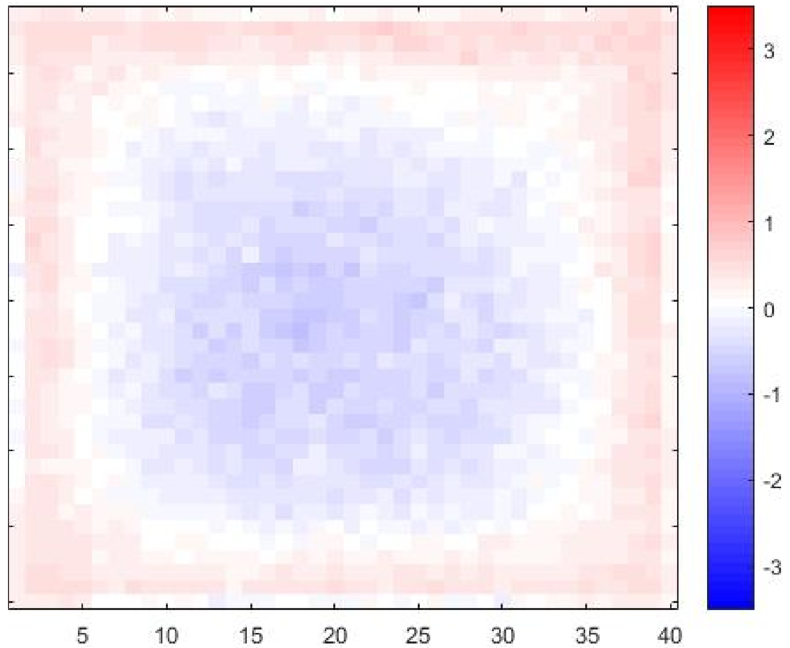
☐ Comparison of Power Distributions

* Absolute Error Distributions of Pin Power in Core 13 (%)

Err. in Core 1 & 13 < Err. in Core 19



Cold



Hot

Conclusions

☐ Verification of Solution Capability of nTRACER for Experimental Reactors

- Calculations for the B&W-1810 and KRITZ-2 critical experiments were performed with nTRACER and compared with measurements and McCARD
- nTRACER yielded good agreement with the reference
  - In the B&W-1810 critical experiment
    - Δk_{eff} ≤ 64 pcm (from criticality)
    - nTRACER vs. **measurements** for the **center assembly,** RMS ≤ 0.3%, Max ≤ 0.6%
    - nTRACER vs. **McCARD** results for the **full core**, RMS ≤ 0.5%, Max ≤ 1.6%
  - In the KRITZ-2 critical experiment
    - Δk_{eff} ≤ 231 pcm (from McCARD result)
    - nTRACER vs. **measurements,** relative errors in most pins < 3.0%
    - nTRACER vs. **McCARD** results with the **same model**, RMS ≤ 0.5%, Max ≤ 1.0%

☐ Required Improvement

- Substantial discrepancy due to negligence of void region in KRITZ-2 experiments
  - Especially in Core 1 with the negligence ratio of axially undersigned fuel rods larger than 70%, the differences of k-eff were over 1000 pcm
- Necessity of void region treatment for more rigorous verification

Thank you for your attention.