Gap Material and Radial Geometry Modeling Dependency on a T/H Analysis in a Channel of CANDU6 Reactor

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Contents

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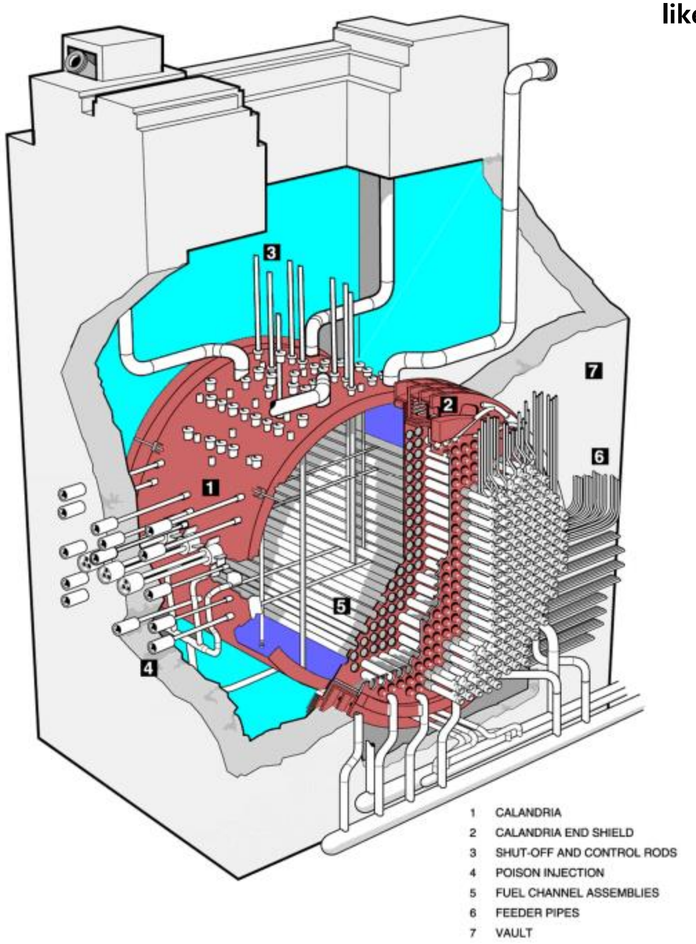
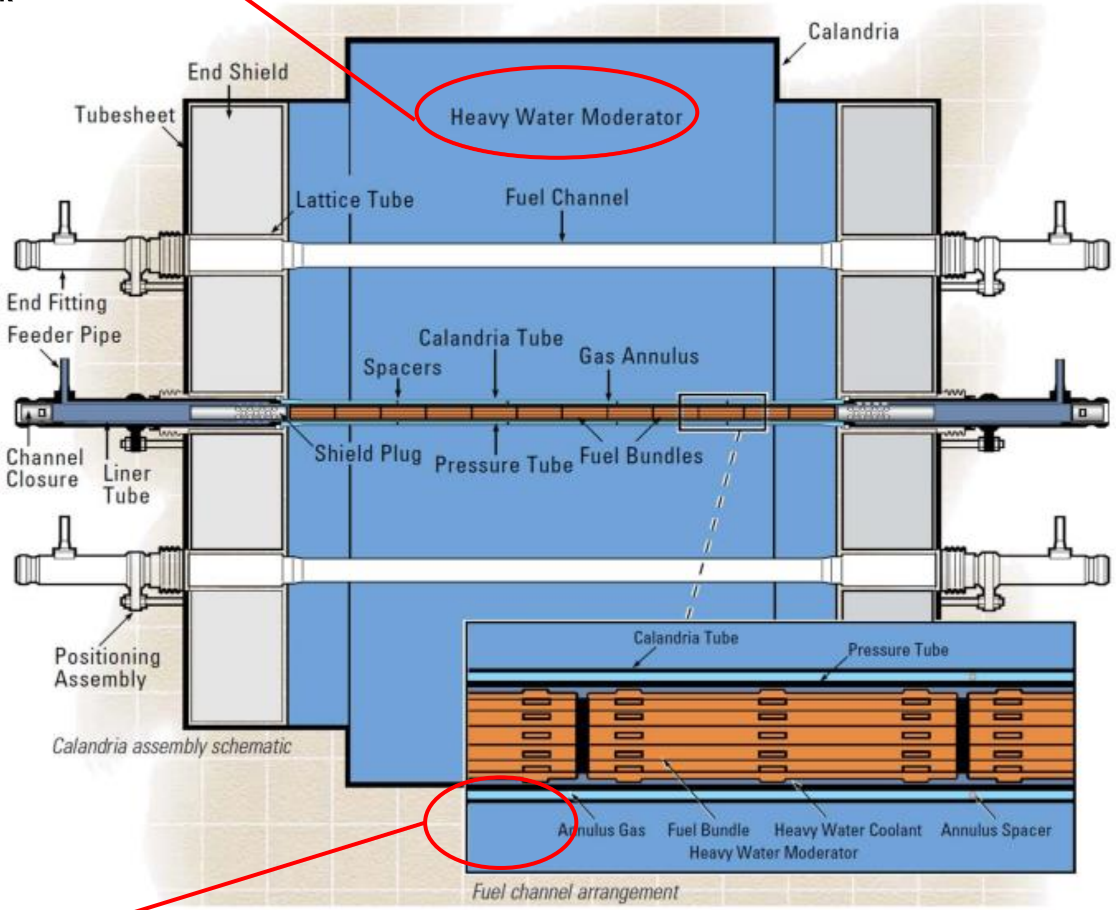
CANDU6 Reactor Core and Channel Structure

Independent system of constant temperature of 69℃, something like ultimate heat sink





CO_2

Motivation of the Analysis

☐ Quantitative Gap Material Dependency

- **CUPID Material List**
  - Helium, Hydrogen, Nitrogen, Krypton, Xenon, Air, Argon and SF6
- **Real Annulus Gas System (AGS)**
  - CO_2
  - Separate system
- **Energy Transport without Main Fluid**
  - Radial direction to moderator, Axial direction with AGS material

☐ Quantitative Modeling Dependency

- **Computational Effort**
  - Omitting Pressure Tube, AGS and Calandria Tube is better
  - Using symmetry is better
- **Reflecting Reality**
  - Describing every details will be better
  - It is known that heat dissipation to moderator is about 4% on channel average
  - Experimental results indicates that there is no symmetry although it seems that results should have symmetry

Motivation of Single Channel Analysis

Conventional CCP Calculation

- **CCP for All Channels**
  - Conventional CCP calculations were done for every single channel of 380 channels
  - There is 3 mode which require Trip Set Point (TSP)
  - Each mode has several hundreds of calculation cases which have 380 CCP results individually
- **CCP Tendency**
  - In general, large value for channel with large power so that large flow rate is required
  - In parallel, large power causes large pressure tube deformation, thus decrement from aging effect is large in magnitude in large power channel

Practical Limitation

- **Modeling Difficulty**
  - Modeling of all 380 channels is really large and cumbersome work (every channel has its own deformation value and status)
- **Computational Difficulty**
  - Even though we assume we can modeling all 380 channels despite of huge amount of works for modeling, calculation will not end in reasonable time

Connection with Future Work

☐ Geometry Modeling Set up

- **Full**
- **Half with out PT, gap**
- **CT, Half with PT, gap, CT**

CCP Calculation cases which are under consideration

☐ Validity of Usage of Other Non Condensible Gas (NCG)

- **Necessity of gap modeling**
  - Rather, gap modeling doesn't require after study

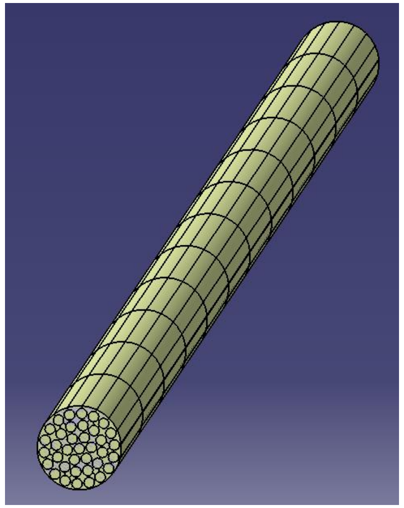


그림. Case 1 (변형전) 카티야 모델

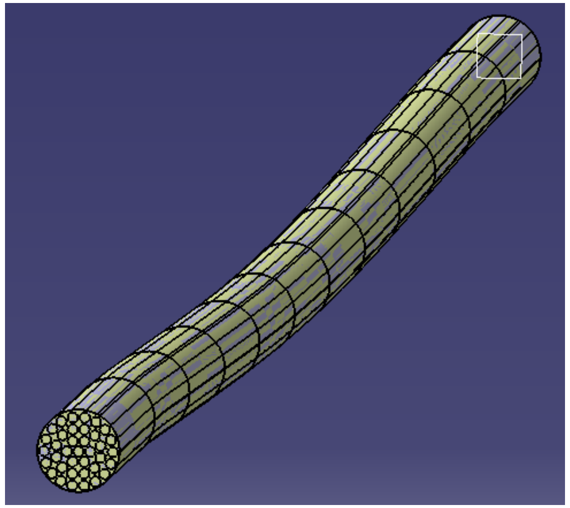


그림. Case 2-1-a (처짐) 카티야 모델

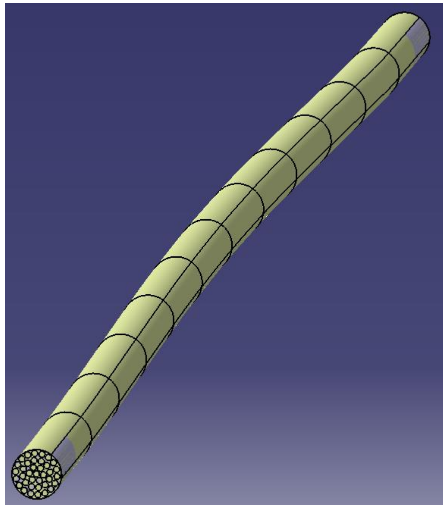


그림. Case 2-3-a (복합) 카티야 모델

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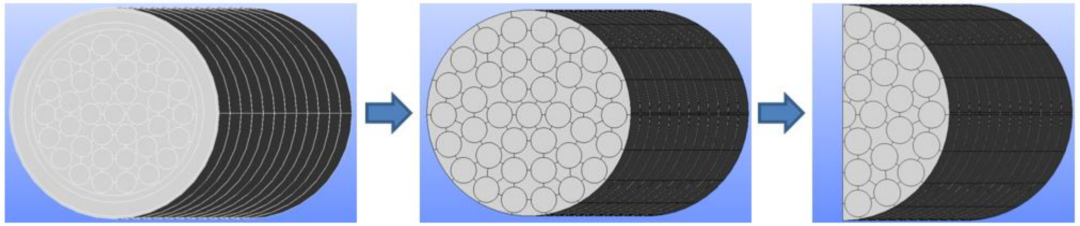
Geometry Changes and Some Specifications

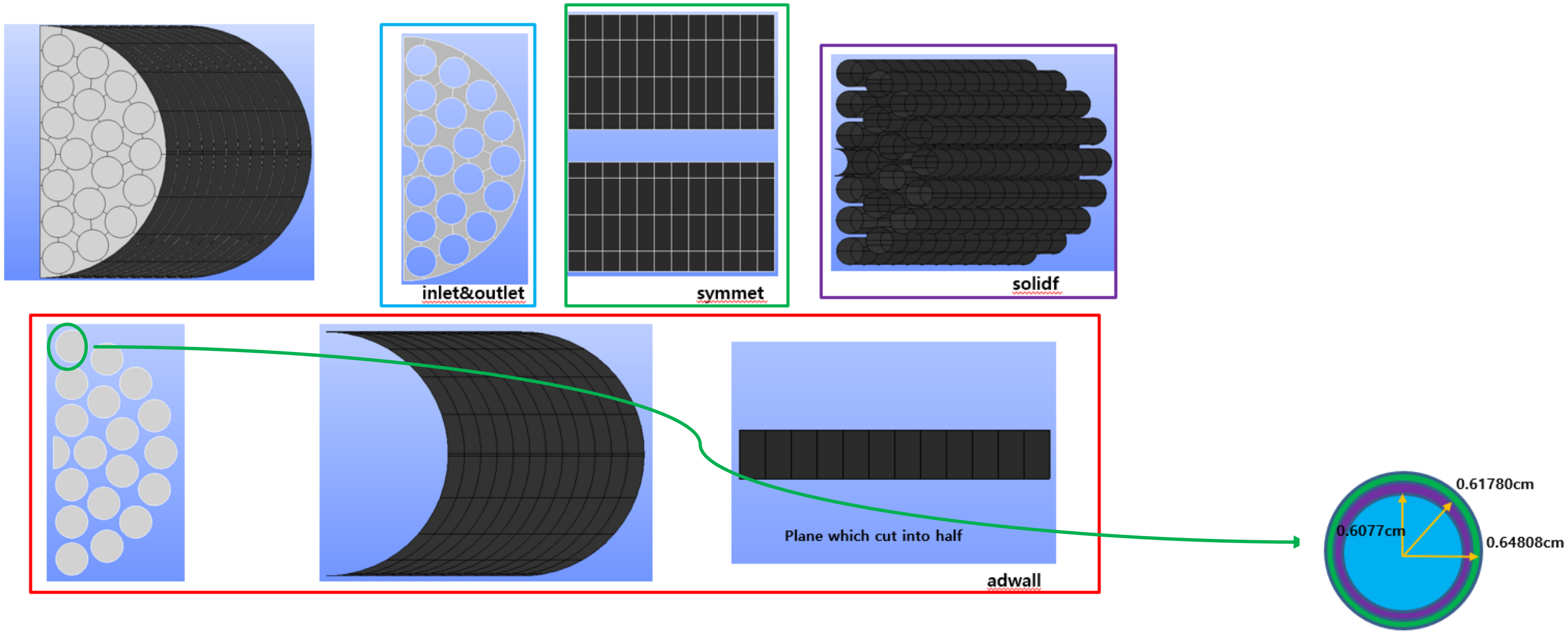
Geometries of Interest



Material and Temperature in the Simulation and Real Channel

Region Boundary	Specification (cm)	Reference/CUPID Material	Reference/CUPID Initial Temp. (K)
Fuel Radius	0.64808	UO_2, He, Zr4/ UO_2+He+Zr4 Volume Weighted	960.15/535.61
Pressure Tube Inside Radius	5.1689	D_2O(99% purity)/D_2O only	561.15/535.61
Pressure Tube Outside Radius	5.6032	Zr-Nb/Stainless Steel	561.15/342.15
Calandria Tube Inside Radius	6.4478	CO_2/Air	451.65/451.65
Calandria Tube Outside Radius	6.5875	Zr-2/Stainless Steel	342.15/342.15
Bundle Length	49.53	N/A	N/A
Number of Bundles	12	N/A	N/A

Boundary Conditions and Initial Conditions



	Initial Value	Inlet Condition	Outlet Condition
Pressure (Pa)	11.4E6		10.0E6
Liquid Temperature (K)	535.61		N/A
Void Fraction	0.0		N/A
NCG Quality	0.0		0.0
Velocity (m/s)	8.3229		N/A

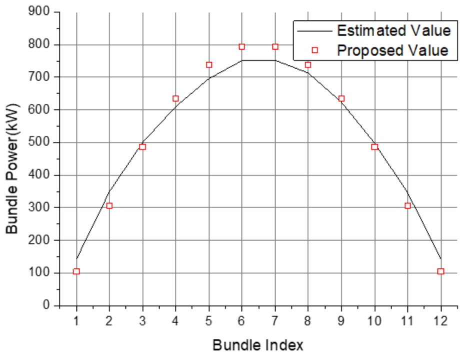
Integrated Fuel Region and Axial Power Shape

Thermal Conductivity after Volume Weighted Average

Region Name		Pellet	Gap	Cladding	Merged Material
Volume Fraction		0.88	0.03	0.09	1.00
Material		UO_2	He	Zr	UO_2+He+Zr
Temperature (K)		Thermal Conductivity (w/mK)			
1	273.15	7.3		13.6	7.7
2	373.15	7.3		14.1	7.7
3	473.15	6.7		14.8	7.2
4	573.15	5.8		15.8	6.6
5	673.14	5.1		16.9	6.1
6	773.15	4.6		18.1	5.7
7	873.15	4.2		19.5	5.5
8	973.15	3.8	0.151	21.1	5.3
9	1073.15	3.5		22.8	5.2
10	1173.15	3.3		24.6	5.1
11	1273.15	3.1		26.8	5.2
12	1373.15	2.9		29.2	5.2
13	1473.15	2.8		31.7	5.3
14	1573.15	2.6		34.4	5.5
15	1673.15	2.5		37.3	5.6
16	1773.15	2.5		40.4	5.9

Heat Capacity after Volume Weighted Average

Region Name		Pellet	Gap	Cladding	Merged Material
Volume Fraction		0.88	0.03	0.09	1.00
Material		UO_2	He	Zr	UO_2+He+Zr
Temperature (K)		Heat Capacity (J/m^3K)			
1	273.15	2.43E+06		1.88E+06	2.306E+06
2	373.15	3.01E+06		2.08E+06	2.838E+06
3	473.15	3.17E+06		2.21E+06	2.987E+06
4	573.15	3.24E+06		2.29E+06	3.055E+06
5	673.14	3.24E+06		2.38E+06	3.070E+06
6	773.15	3.31E+06		2.38E+06	3.124E+06
7	873.15	3.31E+06		3.63E+06	3.245E+06
8	973.15	3.32E+06	927.3	4.46E+06	3.327E+06
9	1073.15	3.33E+06		4.95E+06	3.379E+06
10	1173.15	3.34E+06		5.12E+06	3.401E+06
11	1273.15	3.34E+06		4.95E+06	3.393E+06
12	1373.15	3.35E+06		4.46E+06	3.354E+06
13	1473.15	3.35E+06		3.36E+06	3.256E+06
14	1573.15	3.36E+06		2.38E+06	3.174E+06
15	1673.15	4.12E+06		2.38E+06	3.841E+06



Bundle-wise power difference between proposed and estimated value

Ring-wise Power Distribution inside of a Bundle at Average Exit Burnup

Element Ring	Number of Elements	Element Power		Percent Power	
		Nor. To Bundle Avg.	Nor. To Outer Element	Per Element	Per Ring
Outer	18	1.120	1.000	3.026	54.46
Intermediate	12	0.9254	0.8266	2.501	30.01
Inner	6	0.8247	0.7367	2.229	13.37
Center	1	0.7843	0.7006	2.120	2.120

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Gap Material Dependency

❑ Tried Materials

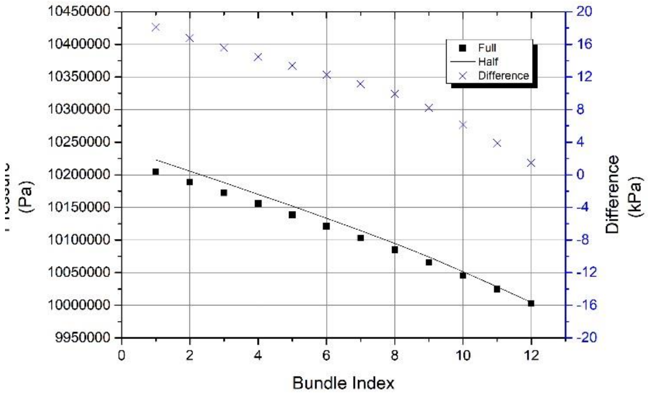
Symbol (Atomic Number)	M. P. (℃)	B. P (℃)	Density (g/L)	k (w/mK)	C (j/molK)
He(2)	-272	-269	0.1786	0.1513	20.78
H(1)	-259	-253	0.0899	0.1805	28.84
N(7)	-210	-196	1.251	25.83	29.12
Kr(36)	-157	-153	3.749	0.0094	20.79
Xe(54)	-112	-108	5.984	0.0057	20.79
Air(N/A)	192	-194	1.225	0.025	29.07
Ar(18)	-189	-186	1.784	0.0177	20.79
SF6(N/A)	-78	-78	1.87	0.0166	51.07

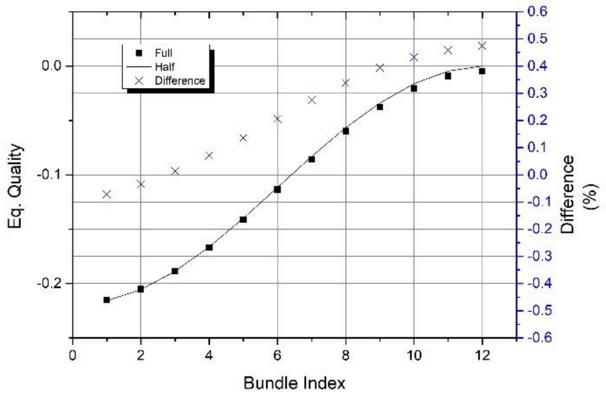
❑ Heat Transport Fraction for Materials

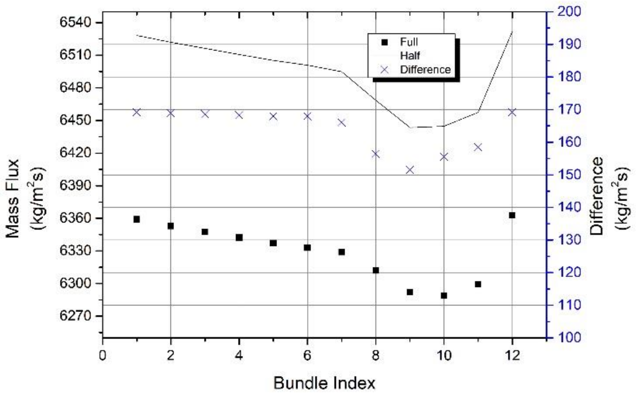
	Gap Mater ial	PHTS (%)	AGS (%)	MODER -ATOR (%)
1	Helium	93.4	0.2	6.4
2	Hydrogen	93.5	0.1	6.4
3	Nitrogen	93.1	1.4	5.5
4	Krypton	92.5	4.2	3.3
5	Xenon	92.1	6.6	1.3
6	Air	93.1	1.5	5.5
7	Argon	93.0	1.5	5.0
8	SF6	92.0	2.0	0.8

Modeling Dependency on CHF

☐ Parameters related with CHF







- **CHF Determination**
  - Referring 3-dimensional CHF table of mass flux, pressure and equilibrium quality

- **Magnitude of Effect from Difference**
  - Mass Flux > Pressure > Equilibrium Qualtiy

- **Crucial for CHF Determination**
  - The amount of difference can cause meaningful difference
  - It is better to depict all geometry as it is as possible

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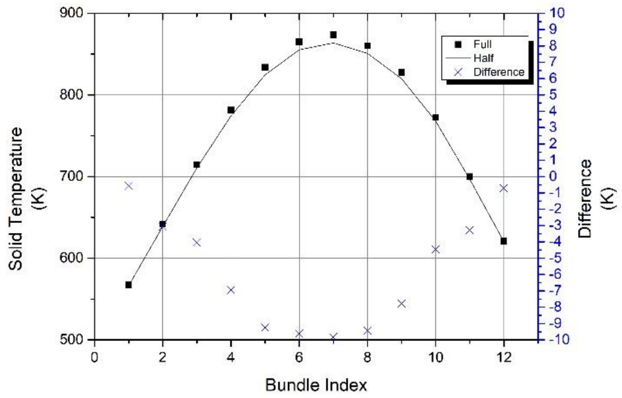
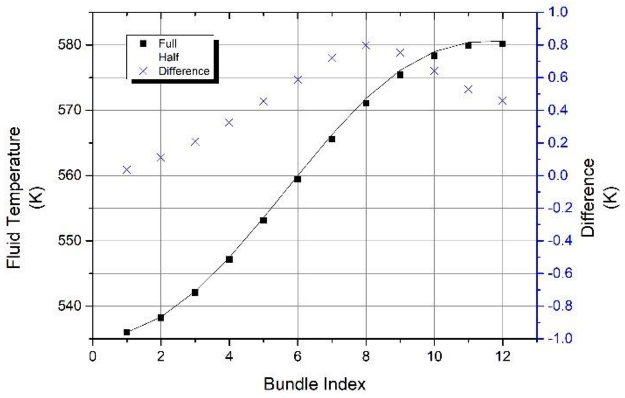
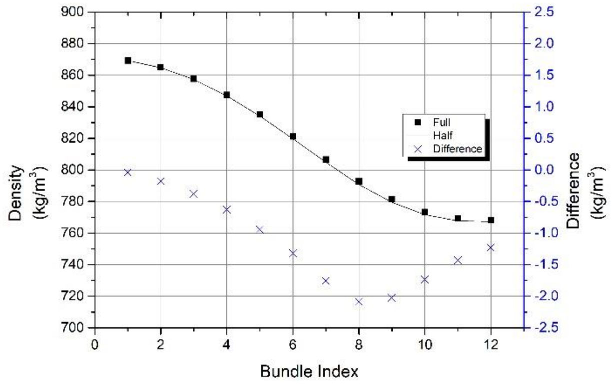
Modeling Dependency on General Parameters







❑ Solid Temperature

- **Less solid temperature is observed when half geometry is used**

❑ Fluid Temperature

- **Because of reduced heat transport without main fluid, fluid temperature will rise**

❑ Density

- **Natural result onsidering fluid temperature**

Conclusions

☐ Summary

- **Heat Transport Ratios depend on material ranges,**
  - Primary fluid, **92%~93.4%**
  - Gas axial transport, 0.1%~6.6%
  - Radial transport, 0.8~6.4%
  - Summation of Heat Transport except for primary flux, 6.6%~8.0%

- **Effects of Modeling Dependency**
  - Meaningful changes for CHF parameters
  - Negligible changes for the other prameters

☐ Future Works

- **Modeling Reflection**
  - Because of effects on CHF, it is recommended to include every geometrical details when channel analysis, specially for CCP calculation

- **Gap Material Consideration**
  - The amount of heat transport by main fluid is not change much depending on gap material species
  - Any gas can be used currently

References

- J. J. Jeong, H. Y. Yoon, I. K. Park and H. K. Cho, The CUPID Code Development and Assessment Strategy, NET, Vol.42, Issue 6, pp. 635-655, 2010.
- H. Y. Yoon et al., CUPID CODE MANUAL VOLUME II: User's Manual, KAERI/TR-4404, 2011.

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