

Core Follow Calculation for Palo Verde Unit 1 in Cycles 1 through 4 using DeCART2D/MASTER4.0 Code System

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1. Introduction

Korea Atomic Energy Research Institute (KAERI) has developed DeCART2D [1]/MASTER4.0 [2] design system as nuclear core design. The DeCART2D code is a neutron transport code to generate assembly-wise homogenized and group condensed effective group constant data used in nodal diffusion core analysis code for 2-step procedure. The MASTER4.0 code is based on the multi-group diffusion theory to calculate the steady state and transient pressurized water reactor core and is designed as the static core design, transient core analysis and operational support.

To verify and validate the DeCART2D/MASTER4.0 design system, core follow calculations of Palo Verde Unit 1(PV-1) in cycles 1 through 4 are performed. The calculation results are compared with the measured data [3] and will be used in the generation of bias and uncertainty factors in the DeCART2D/MASTER4.0 design system.

2. Generation of Cross Section Library

Cross section library (XSL) and heterogeneous form-function library (HFF) should be generated for the core follow calculation using MASTER code. Homogenized group constants (HGCs) generated from DeCART2D are converted into XSL and HFF by using PROLOG [4]. XSL is composed of three parts such as fuel assembly cross sections, radial reflector cross sections and axial reflector cross sections. These cross sections are generated by DeCART2D, respectively.

2.1. Cross Sections for Fuel Assembly

In PV-1, 22 types of fuel assemblies are loaded and additional fuel assemblies which include incore detector are considered. So, there are total 44 types of fuel assemblies in PV-1.

DeCART2D calculations are performed for each fuel assembly and produce HGC files. These data are transformed to MASTER library form for core calculation via PROLOG. Figure 1 shows the configuration of fuel assembly in the DeCART2D code

2.2. Cross Sections for Radial Reflector

The procedure to generate radial reflector cross sections is to make 2-dimensional whole core model including the radial reflector region which contains up to the core support barrel. DeCART2D performs the whole

core transport calculation without simplification or homogenization of core elements and produces two equivalent constants of the homogenized group constant (HGC) and the assembly discontinuity factor (ADF). Then, PROMARX converts HGCs into radial reflector library format for MASTER. Figure 2 shows the radial reflector model in the DeCART2D code.

2.3. Cross Sections for Axial Reflector

The procedure to generate axial reflector cross sections is to make simplified 1-dimensional core model and HGCs for top and bottom reflector from this model. Then, PROMARX converts HGCs into radial reflector library format for MASTER. Figure 3 shows the axial reflector model in the DeCART2D code.

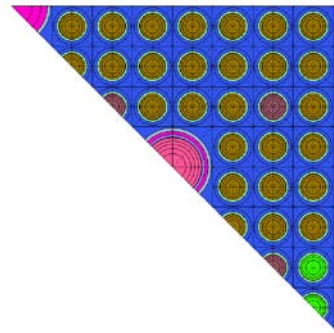


Figure 1. Radial Fuel Assembly Configuration

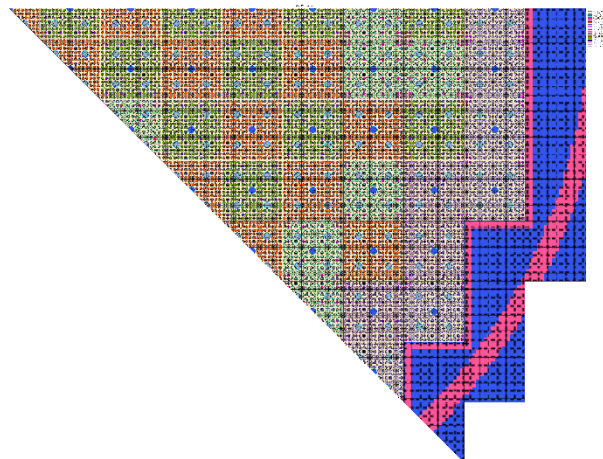


Figure 2. Radial Reflector Model

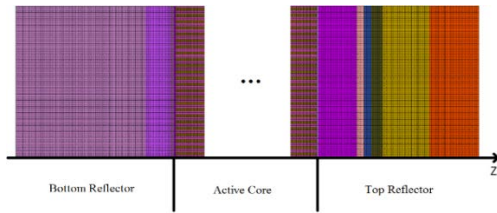


Figure 3. Axial Reflector Model

3. Core Follow Calculation

Core follow calculations were made for PV-1 in cycles 1 through 4. The 2-group cross section sets and heterogeneous formfunctions are prepared by DeCART2D and processed by PROLOG for the format required by MASTER. Using these libraries, MASTER calculations are done to generate following parameters: reactivity at hot full power(HFP), end point boron concentrations at cold zero power(CZP) and hot zero power(HZP), isothermal temperature coefficient, inverse boron worth, control rod worth at CZP and HZP and assembly power distributions. And the calculated values are compared with the measured data.

3.1. Comparison Results - Reactivity

Critical boron concentrations (CBC) were calculated at hot full power (HFP) and ARO conditions. And boron worths(BW) and power coefficients (PC) were also calculated. Differences between the measured and calculated CBC's were transformed into reactivities at the same burnups, powers and rod positions. Fig. 1 shows the CBC differences between measured data and calculation results for cycle 1 through cycle 4. Fig. 2 shows the reactivity differences between measured data and calculation results for cycle 1 through cycle 4.

3.2. Comparison Results - Assembly Power

In PV-1, 61 incore detectors are loaded for all cycles. Assembly powers which incore detector are located are calculated from the detector reaction rate of MASTER.

The maximum differences and standard deviation of assembly power at various burnup steps are shown in Table I. The maximum standard deviations for each cycle are 2.12%, 2.37%, 1.91% and 1.70%.

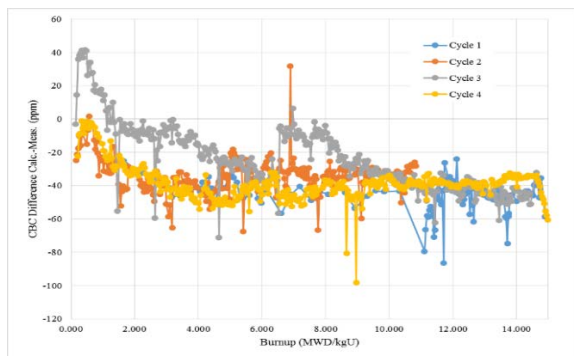


Figure 1. Critical Boron Concentration Differences (ppm)

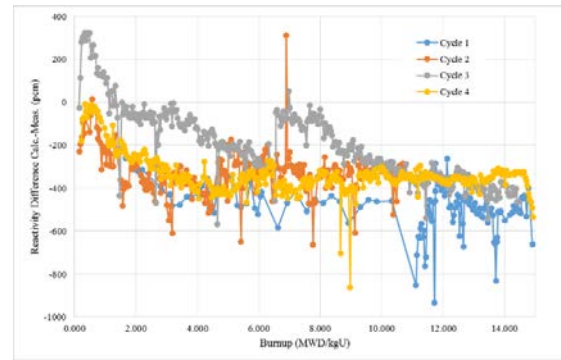


Figure 2. Reactivity Differences (pcm)

Table I: Assembly Power Comparisons for PV-1

Cycle	Burnup (MWD/kgU)	Max. %	SD %
1	3.343	-4.10	2.00
	4.492	-4.33	2.12
	5.642	-4.20	2.07
	6.791	-3.23	1.74
	7.941	-3.01	1.69
	9.091	-2.79	1.54
	10.240	-2.63	1.46
	12.540	-2.69	1.35
	13.689	-2.91	1.46
2	14.838	-2.89	1.38
	1.150	5.34	2.37
	2.301	5.19	2.29
	3.451	4.54	2.11
	4.601	4.10	2.04
	5.751	4.43	2.33
	6.902	4.34	2.25
	8.052	-4.23	2.29
3	9.202	-3.55	1.93
	10.849	-3.79	2.13
	3.423	-5.17	1.91
	4.564	-4.34	1.65
	5.704	-2.19	1.17
	6.845	2.22	1.05
	9.127	2.53	1.05
4	10.268	2.75	1.09
	11.409	3.19	1.31
	12.550	3.16	1.33
	10.315	-4.09	1.70
	11.461	-3.45	1.55
	12.607	-3.33	1.54
	13.753	-3.55	1.60

3.1. Comparison Results - Startup Parameters

The calculated end point boron concentrations (EPC), control rod worths (RW), isothermal temperature coefficients (ITC) and inverse boron worths (IBW) were compared with the measured data. For cycle 1, all parameters were calculated in conditions of CZP and HZP. For cycles 2 and 3, all parameters were calculated

in HZP condition only. In this chapter, results of CASMO-3/MASTER1.0 design system [3] are compared with the measured data as well.

Table II shows the differences of end point boron concentrations for cycle 1 at CZP, cycle 1 at HZP, cycle 2 at HZP, cycle 3 at HZP and cycle 4 at HZP. The differences between DeCART2D/MASTER4.0 results (D) and measured data(M) at cycle 1 are less than 20 ppm. The maximum differences at cycle 2 are 50 ppm and it is quite large rather than other cycles. The differences at cycle 3 are within 10 ppm.

Table III shows the differences of control rod worths for each cycle condition. The maximum differences at cycle 1 at CZP, cycle 1 at HZP, cycle 2 at HZP, cycle 3 at HZP and cycle 4 at HZP are 55, 48, 55 and 54 pcm.

Table IV shows the differences of isothermal temperature coefficients for each cycle condition. The maximum differences at cycle 1 at CZP, cycle 1 at HZP, cycle 2 at HZP and cycle 3 at HZP are +0.78, +0.72, -0.65 and +0.75 pcm/°C.

The differences for inverse boron worths are shown in Table V. The maximum differences at cycle 1 at CZP, cycle 1 at HZP, cycle 2 at HZP, cycle 3 at HZP and cycle 4 at HZP are 2.59, 1.59, 0.90 and 4.03 ppm/%Δρ.

Table II: Differences for End Point Boron Concentration for PV-1

Cycle	Bank	D-M (ppm)	C-M (ppm)
1 CZP	ARO	-11	-19
	5	-9	-17
	5+4	-12	-19
	5+4+3	-14	-19
	5+4+3+2	-19	-20
	5+4+3+2+1	-17	-13
1 HZP	5+4+3+2+1+B	3	15
	ARO	-19	-37
	5	-16	-35
	5+4	-14	-32
	5+4+3	-13	-10
	5+4+3+2	-8	-26
2 HZP	5+4+3+2+1	-20	-39
	ARO	-46	-15
	1	-39	-11
3 HZP	B	-49	-24
	ARO	7	17
3 HZP	1	-5	5
	B	6	12

D : DeCART2D/MASTER4.0
C : CASMO-3/MASTER1.0
M : Measured Data

Table III: Differences for Control Rod Worths for PV-1

Cycle	Bank /Ref. Position	D-M (pcm)	C-M (pcm)
1 CZP	5	-19	-22
	4(5)	-5	-29
	3(5+4)	-2	-16
	2(5+4+3)	-7	-74
	1(5+4+3+2)	55	-7
1 HZP	5	-30	-27
	4(5)	-22	-37
	3(5+4)	-47	-34
	2(5+4+3)	-48	-74
	1(5+4+3+2)	-20	-20
2 HZP	5/56%(1)*	6	-8
	4/43%(1)	10	-4
	3/11%(1)	-50	-37
	2/42%(1)	55	39
	1	13	23
	A/43%(B)	25	-17
3 HZP	B	51	49
	5	16	17
	4	41	38
	3	33	24
	2	35	31
	1	-41	-54
3 HZP	A	-54	-74
	B	-11	-18

* 56%(1) means that Bank 1 is inserted 56%.

Table IV: Differences for Isothermal Temperature Coefficient for PV-1

Cycle	Bank	D-M (pcm/°C)	C-M (pcm/°C)
1 CZP	5 (27%)	+0.40	-1.39
	5+4+3+2+1	+0.78	-2.38
1 HZP	5 (33%)	+0.41	+1.26
	5+4+3	+0.72	+1.15
2 HZP	ARO	-0.65	+0.46
	B	-0.29	+0.42
3 HZP	ARO	-0.04	+0.26
	B	+0.75	+0.64
	3 (84%)	+0.18	+0.33

Table V: Differences for Inverse Boron Worth for PV-1

Cycle	Bank	D-M (ppm/%Δρ)	C-M (ppm/%Δρ)
1 CZP	ARO	2.59	2.65
1 HZP	5	-0.80	0.00
	5+4	-0.34	0.55
	5+4+3	1.59	2.47
2 HZP	B	0.90	3.07
3 HZP	ARO	4.03	6.01

4. Conclusions

Core follow calculations of Pale Verde Unit 1 in Cycles 1 through 4 have been performed. Reactivities, assembly powers and startup parameters such as EPC, RW, ITC and IBW are compared with the measured data. This work will be used in the generation of bias and uncertainty factors in DeCART2D/MASTER4.0 design system.

REFERENCES

- [1] J. Y. Cho, et al., "DeCART2D v1.1 User's Manual," KAERI/UM-40/2016, 2016.
- [2] J. Y. Cho, et al., "MASTER v4.0 User's Manual," KAERI/UM-41/2016, 2016.
- [3] J. S. Song, et al., "Verification and Uncertainty Evaluation of CASMO-3/MASTER Nuclear Analysis System," KAERI/TR-806/97, 1997.
- [4] J. S. Song, et al., "PROLOG1.1 User's Manual," KAERI/UM-4/99, 1999.