# Validation of UNIST MCS Monte Carlo Code System for OPR-1000

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## Introduction

- This poster presents the validation of Monte Carlo (MC) code development at Ulsan National Institute of Science and Technology (UNIST) for the OPR-1000 reactor.
- The 3D whole-core depletion calculation for OPR-1000 reactor in MCS model is coupled with various feedback options such as one dimensional thermal hydraulics (TH1D), depletion, Critical Boron Concentration (CBC), Equilibrium Xenon (Eq-Xe), quadratic and OpenW.
- MCS calculated results of CBC is compared with the measured data and Nuclear Design Report (NDR) data. MCS calculated results of axial and radial power distribution at Middle Of Cycle (MOC) and End Of Cycle (EOC) are compared with measured data.





# **OPR – 1000 Core Design**

- Pressurized Water Reactor (PWR) to operate at 2,815 MWth
- Number of Fuel Assemblies (FAs): 177
- **FA type** : PLUS7 (16 x 16 array of 236 fuel rods and 5 guide tubes)  $\circ$  Fuel pellet: UO<sub>2</sub> with low enriched <sup>235</sup>U (1.2 ~ 3.42 w/o)  $\circ$  Burnable Poison: Gadolinia fuel with Gd<sub>2</sub>O<sub>3</sub> contents of 6 ~ 8 w/o
- Loading Pattern of Reference Core OPR 1000 Cycle 01





### > Normalized Radial and Axial Power Distributions at MOC (6.0GWD/MTU)



Simulations and Results         Table I. Problem Description.         Core Parameter       Value         Core Power (MW)       2,815         Inlet Coolant Temperature (K)       569.26         Average Moderator Temperature (K)       584         Pressure (psia)       2,250         Core Flow Rate (kg/s)       16,315         Control Rod Position       ARO         Simulation Conditions       Mession of UO2 pin       Note (Ing / 10 axial nodes - Division of Gd <sub>2</sub> O <sub>3</sub> pin       ON         Division of Gd <sub>2</sub> O <sub>3</sub> pin       -1 ring / 10 axial nodes       -10 rings / 10 axial nodes       -10 rings / 10 axial nodes         Depletion       34 steps (13.978 GWD/MTU)       -5000       -7000 cycle 01         Whende Core Calculation       3,925       -7000 cycle 01       -7000 cycle 01         Memory usages (MB)       6,500       -5000       -7000 cycle 01       -7000 cycle 01         Core trainer and density) and burn up distribution with measure data       -70000 cycle 01       -70000 cycle 01         Core colsection       -70000 cycle 01       -70000 cycle 01       -700000 cycle 01         Core colsection       -700000 cycle 01       -700000 cycle 01       -7000000000000000000000000000000000000	A A C A C A   A A A B A A B C   Fresh Normal Fuel Fuel with Gd Fig. 1. MCS Quarter Comparence	bre Model for OPR-1000.	13       0.936       0.957       1.210       0.900       1.030       0.718       RMS       1.10         14       1.170       1.186       1.064       0.900       0.577       Max       3.32         15       0.892       0.785       0.598       Mcs       1.2         -5       5       Mcs       Normalized Power         Normalized Radial and Axial Power Distributions at EOC (13.8 GWD/MTU
Core Parameter Core Power (MW)Value 2,815Inlet Coolant Temperature (K)569.26Average Moderator Temperature (K)584Pressure (psia)2,250Core Flow Rate (kg/s)16,315Control Rod PositionAROSimulation ConditionsQuarter CoreModelingQuarter CoreLibraryENDF/B-VII.1Active/inactive/history/sub-cycle20 / 5 / 10,000 / 100Quadratic, EqXeONTH1D- 1 ring / 10 axial nodes- Division of UO2 pin- 1 ring / 10 axial nodes- Division of Gd2O3 pin- 10 rings / 10 axial nodes- Division of Gd2O3 pin- 10 rings / 10 axial nodes- Division of Core Calculation3,925Memory usages (MB)6,500CBC uncertainty (ppm)1.506	Simulations and Results Table I. Problem Description.		H         J         K         L         M         P         R           0.864         0.900         0.959         1.188         0.955         0.946         1.149         0.885           0         0.000         0.959         1.188         0.955         0.946         1.149         0.885           0         0.000         0.959         1.188         0.955         0.946         1.149         0.885
Core Power (MW)2,815Inlet Coolant Temperature (K)569.26Average Moderator Temperature (K)584Pressure (psia)2,250Core Flow Rate (kg/s)16,315Control Rod PositionAROSimulation ConditionsModelingLibraryENDF/B-VII.1Active/history/sub-cycle20 / 5 / 10,000 / 100Quadratic, Eq-XeONTH1D- 1 ring / 10 axial nodes- Division of Gd2O3 pin- 10 rings / 10 axial nodes- Division of Gd2O3 pin- 10 rings / 10 axial nodes- Division of Core Calculation3,925Memory usages (MB)6,500CBC uncertainty (ppm)1.506	Core Parameter	Value	$9 \begin{bmatrix} 0.898 & 0.926 & 1.238 & 0.976 & 1.227 & 0.961 & 1.184 & 0.797 \\ \hline 0.960 & 1.976 & 1.182 & 0.961 & 1.184 & 0.797 \\ \hline 0.960 & 1.971 & 0.980 & 1.182 & 0.968 & 1.162 & 1.112 & 0.640 \\ \hline 0.960 & 0.976 & 0.980 & 1.182 & 0.968 & 1.162 & 1.112 & 0.640 \\ \hline 0.960 & 0.976 & 0.980 & 0.980 & 0.968 & 0.968 & 0.968 & 0.9640 \\ \hline 0.960 & 0.976 & 0.980 & 0.968 & 0.968 & 0.968 & 0.9640 \\ \hline 0.960 & 0.968 & 0.968 & 0.968 & 0.968 & 0.968 & 0.9640 \\ \hline 0.960 & 0.968 & 0.968 & 0.968 & 0.968 & 0.9640 \\ \hline 0.960 & 0.968 & 0.968 & 0.968 & 0.968 & 0.9640 \\ \hline 0.960 & 0.968 & 0.968 & 0.968 & 0.968 & 0.9640 \\ \hline 0.960 & 0.968 & 0.968 & 0.968 & 0.968 & 0.968 & 0.9640 \\ \hline 0.960 & 0.968 & 0.968 & 0.968 & 0.968 & 0.968 & 0.9640 \\ \hline 0.960 & 0.968 & 0.968 & 0.968 & 0.968 & 0.9640 \\ \hline 0.960 & 0.968 & 0.968 & 0.968 & 0.968 & 0.968 & 0.9640 \\ \hline 0.960 & 0.968 & 0.968 & 0.968 & 0.968 & 0.9640 \\ \hline 0.960 & 0.968 & 0.968 & 0.968 & 0.968 & 0.968 & 0.9640 \\ \hline 0.960 & 0.968 & 0.968 & 0.968 & 0.968 & 0.968 & 0.9640 \\ \hline 0.960 & 0.968 & 0.968 & 0.968 & 0.968 & 0.968 & 0.9640 \\ \hline 0.960 & 0.968 & 0.968 & 0.968 & 0.968 & 0.968 & 0.9640 \\ \hline 0.960 & 0.968 & 0.968 & 0.968 & 0.968 & 0.968 & 0.9640 \\ \hline 0.960 & 0.968 & 0.968 & 0.968 & 0.968 & 0.968 & 0.968 & 0.968 & 0.9640 \\ \hline 0.960 & 0.968 & 0.968 & 0.968 & 0.968 & 0.968 & 0.968 & 0.9640 \\ \hline 0.960 & 0.968 & 0.968 & 0.968 & 0.968 & 0.968 & 0.968 & 0.9640 \\ \hline 0.960 & 0.968 & 0.968 & 0.968 & 0.968 & 0.968 & 0.968 & 0.968 & 0.9640 \\ \hline 0.960 & 0.968 & 0.968 & 0.968 & 0.968 & 0.968 & 0.968 & 0.968 & 0.9640 \\ \hline 0.960 & 0.968 & 0$
Inlet Coolant Temperature (K)569.26Average Moderator Temperature (K)584Pressure (psia)2,250Core Flow Rate (kg/s)16,315Control Rod PositionAROSimulation ConditionsModelingModelingQuarter CoreLibraryENDF/B-VII.1Active/inactive/history/sub-cycle20 / 5 / 10,000 / 100Quadratic, Eq-XeONTH1D- 1 ring / 10 axial nodes- Division of Gd_2O_3 pin- 1 ring / 10 axial nodes- Division of Gd_2O_3 pin- 10 rings / 10 axial nodes- Division of Gd_2O_3 pin- 10 rings / 10 axial nodes- Division of Image (MB)6,500CBC uncertainty (ppm)1.506	Core Power (MW)	2,815	$10 \begin{array}{ c c c c c c c c c c c c c c c c c c c$
Average Moderator Temperature (K)584Pressure (psia)2,250Core Flow Rate (kg/s)16,315Control Rod PositionAROSimulation ConditionsImage: Core Core Core Core Core Core Core Core	Inlet Coolant Temperature (K)	569.26	$11 \begin{bmatrix} 1.205 & 0.984 & 1.195 & 0.983 & 1.177 & 0.918 & 0.923 \\ 0.968 & 1.248 & 0.974 & 1.176 & 1.192 & 1.985 & 0.622 \\ 0.968 & 1.248 & 0.974 & 1.176 & 1.192 & 1.985 & 0.622 \\ 0.968 & 0.968 & 0.974 & 0.974 & 0.974 & 0.974 & 0.974 & 0.975 & 0.622 \\ 0.968 & 0.968 & 0.974 & 0.974 & 0.974 & 0.974 & 0.975 & 0.622 \\ 0.968 & 0.968 & 0.974 & 0.974 & 0.974 & 0.974 & 0.975 & 0.622 \\ 0.968 & 0.968 & 0.974 & 0.974 & 0.974 & 0.974 & 0.975 & 0.622 \\ 0.968 & 0.968 & 0.974 & 0.974 & 0.974 & 0.974 & 0.975 & 0.622 \\ 0.968 & 0.968 & 0.974 & 0.974 & 0.974 & 0.974 & 0.975 & 0.622 \\ 0.968 & 0.968 & 0.974 & 0.974 & 0.974 & 0.974 & 0.975 & 0.622 \\ 0.968 & 0.968 & 0.974 & 0.974 & 0.974 & 0.974 & 0.975 & 0.622 \\ 0.968 & 0.968 & 0.974 & 0.974 & 0.974 & 0.974 & 0.975 & 0.622 \\ 0.968 & 0.968 & 0.974 & 0.974 & 0.974 & 0.974 & 0.975 & 0.622 \\ 0.968 & 0.968 & 0.974 & 0.974 & 0.974 & 0.974 & 0.975 & 0.622 \\ 0.968 & 0.968 & 0.974 & 0.974 & 0.974 & 0.974 & 0.975 & 0.622 \\ 0.968 & 0.968 & 0.974 & 0.974 & 0.974 & 0.974 & 0.974 & 0.975 & 0.622 \\ 0.968 & 0.968 & 0.974 &$
Pressure (psia)2,250Core Flow Rate (kg/s)16,315Control Rod PositionAROSimulation ConditionsModelingModelingQuarter CoreLibraryENDF/B-VII.1Active/inactive/history/sub-cycle20 / 5 / 10,000 / 100Quadratic, Eq-XeONTH1D- 1 ring / 10 axial nodes- Division of Gd2O3 pin- 1 ring / 10 axial nodes- Division of Gd2O3 pin- 1 ring / 10 axial nodes- Division of Gd2O3 pin- 34 steps (13.978 GWD/MTU)Whole Core Calculation- 1 ring / 10 axial nodesExecution Time (core hour)3,925Memory usages (MB)6,500CBC uncertainty (ppm)1.506	Average Moderator Temperature (K)	584	$12 \begin{bmatrix} 0.968 & 1.248 & 0.974 & 1.176 & 1.195 & 1.085 & 0.052 \\ 0.940 & 0.962 & 1.157 & 0.918 & 1.072 & 0.776 & PMS = 1.67 & 30 \end{bmatrix} \begin{bmatrix} 40 \\ -30 \\ -30 \end{bmatrix}$
Core Flow Rate (kg/s)16,315Control Rod PositionAROSimulation ConditionsImage: Core Control Rod PositionModelingQuarter CoreLibraryENDF/B-VII.1Active/inactive/history/sub-cycle20 / 5 / 10,000 / 100Quadratic, Eq-XeONTH1D- 1 ring / 10 axial nodes- Division of Gd2O3 pin- 1 ring / 10 axial nodesDepletion34 steps (13.978 GWD/MTU)Whole Core Calculation- 10 rings / 10 axial nodesExecution Time (core hour)3,925Memory usages (MB)6,500CBC uncertainty (ppm)1.506	Pressure (psia)	2,250	$\begin{array}{ c c c c c c c c c c c c c c c c c c c$
Control Rod PositionAROSimulation ConditionsModelingQuarter CoreLibraryENDF/B-VII.1Active/inactive/history/sub-cycle20 / 5 / 10,000 / 100Quadratic, Eq-XeONTH1D- 1 ring / 10 axial nodes- Division of UO2 pin- 1 ring / 10 axial nodes- Division of Gd2O3 pin- 10 rings / 10 axial nodesDepletion34 steps ( 13.978 GWD/MTU)Whole Core Calculation3,925Memory usages (MB)6,500CBC uncertainty (ppm)1.506	Core Flow Rate (kg/s)	16,315	$14 \begin{bmatrix} 1.120 & 1.109 & 1.092 & 0.914 & 0.028 \\ 0.964 & 0.779 & 0.622 \end{bmatrix} = 10000000000000000000000000000000000$
Simulation Conditions       Intervention         Modeling       Quarter Core         Library       ENDF/B-VII.1         Active/inactive/history/sub-cycle       20 / 5 / 10,000 / 100         Quadratic, Eq-Xe       ON         TH1D       - 1 ring / 10 axial nodes         - Division of UO2 pin       - 1 ring / 10 axial nodes         - Division of Gd2O3 pin       - 10 rings / 10 axial nodes         Depletion       34 steps ( 13.978 GWD/MTU)         Whole Core Calculation       - Compare TH parameters (fuel temperature, moder temperature and density) and burn up distribution with measure data         Memory usages (MB)       6,500         CBC uncertainty (ppm)       1.506	Control Rod Position	ARO	15     0.864     0.779     0.853       -5     5       Rel. Error (%)     0     0.2     0.4     0.6     0.8     1     1
ModelingQuarter CoreLibraryENDF/B-VII.1Active/inactive/history/sub-cycle20 / 5 / 10,000 / 100Quadratic, Eq-XeONTH1D Division of UO2 pin- 1 ring / 10 axial nodes- Division of Gd2O3 pin- 10 rings / 10 axial nodesDepletion34 steps (13.978 GWD/MTU)Whole Core Calculation-Execution Time (core hour)3,925Memory usages (MB)6,500CBC uncertainty (ppm)1.506	Simulation Conditions		
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Active/inactive/history/sub-cycle20 / 5 / 10,000 / 100Quadratic, Eq-XeONTH1D Division of UO2 pin- 1 ring / 10 axial nodes- Division of Gd2O3 pin- 10 rings / 10 axial nodesDepletion34 steps ( 13.978 GWD/MTU)Whole Core Calculation-Execution Time (core hour)3,925Memory usages (MB)6,500CBC uncertainty (ppm)1.506	Library	ENDF/B-VII.1	
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TH1D       - 1 ring / 10 axial nodes         - Division of UO2 pin       - 1 ring / 10 axial nodes         - Division of Gd203 pin       - 10 rings / 10 axial nodes         Depletion       34 steps (13.978 GWD/MTU)         Whole Core Calculation       - 10 rings / 20 axial nodes         Execution Time (core hour)       3,925         Memory usages (MB)       6,500         CBC uncertainty (ppm)       1.506	Quadratic, Eq-Xe	ON	FOC agreement with the measured data with a maximum relativ
<ul> <li>Division of UO<sub>2</sub> pin</li> <li>1 ring / 10 axial nodes</li> <li>Division of Gd<sub>2</sub>O<sub>3</sub> pin</li> <li>10 rings / 10 axial nodes</li> <li>34 steps (13.978 GWD/MTU)</li> <li>Whole Core Calculation</li> <li>Execution Time (core hour)</li> <li>Memory usages (MB)</li> <li>CBC uncertainty (ppm)</li> <li>1.506</li> </ul>	TH1D		difference less than 5%.
- Division of Gd2O3 pin- 10 rings / 10 axial nodesDepletion34 steps (13.978 GWD/MTU)Whole Core Calculation	- Division of UO <sub>2</sub> pin	- 1 ring / 10 axial nodes	The critical boron concentration results are closer to the measure
Depletion34 steps (13.978 GWD/MTU)Whole Core Calculation- Compare TH parameters (fuel temperature, moder temperature and density) and burn up distribution with measu dataExecution Time (core hour)3,925Memory usages (MB)6,500CBC uncertainty (ppm)1.506	- Division of Gd <sub>2</sub> O <sub>3</sub> pin	- 10 rings / 10 axial nodes	data than the NDR.
Whole Core CalculationCompare TH parameters (fuel temperature, moder temperature and density) and burn up distribution with measu dataExecution Time (core hour)3,925Memory usages (MB)6,500CBC uncertainty (ppm)1.506	Depletion	34 steps (13.978 GWD/MTU)	Future work
Execution Time (core hour)3,925temperature and density) and burn up distribution with measure dataMemory usages (MB)6,500dataCBC uncertainty (ppm)1.506Perform Refueling and compute the successive operation cy	Whole Core Calculation		<ul> <li>Compare TH parameters (fuel temperature, moderato</li> </ul>
Memory usages (MB)6,500dataCBC uncertainty (ppm)1.506Perform Refueling and compute the successive operation cy	Execution Time (core hour)	3,925	temperature and density) and burn up distribution with measure
CBC uncertainty (ppm) 1.506 Interval In	Memory usages (MB)	6,500	data
	CBC uncertainty (ppm)	1.506	Perform Refueling and compute the successive operation cycle

- - (Cycle 02, 05, 04)