Burnup Adaptation Model in STREAM/RASTK Code System

Peng Zhang, Jiwon Choe, Sooyoung Choi, Deokjung Lee

UNIST

Jeju, 2018.05.18

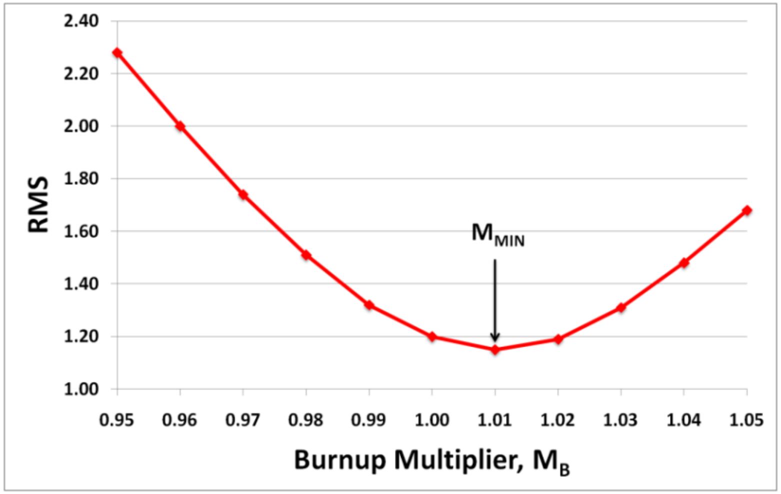
CONTACT

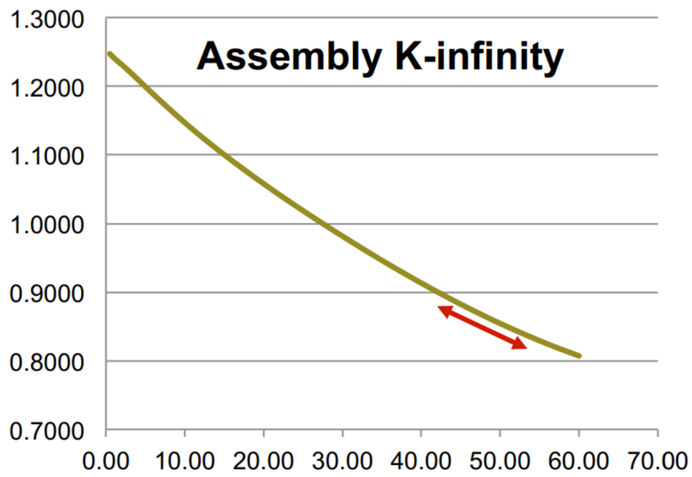
Ulsan National Institute of Science and Technology
Address 50 UNIST-gil, Ulju-gun, Ulsan, 44919, Korea
Tel. +82 52 217 0114 **Web.** www.unist.ac.kr

CORE Computational Reactor physics & Experiment lab
Tel. +82 52 217 2940 **Web.** reactorcore.unist.ac.kr

Introduction

- **Basic Concepts:**
  - **Prediction of in-core power distributions are very sensitive to the accuracy of computed assembly k-infinity (e.g., the local reactivity contribution).**
- **Example:**





- **Object of this work:**
  - **Utilizing the reference (measured) data to minimize/compensate the modeling biases by burnup adaptation.**

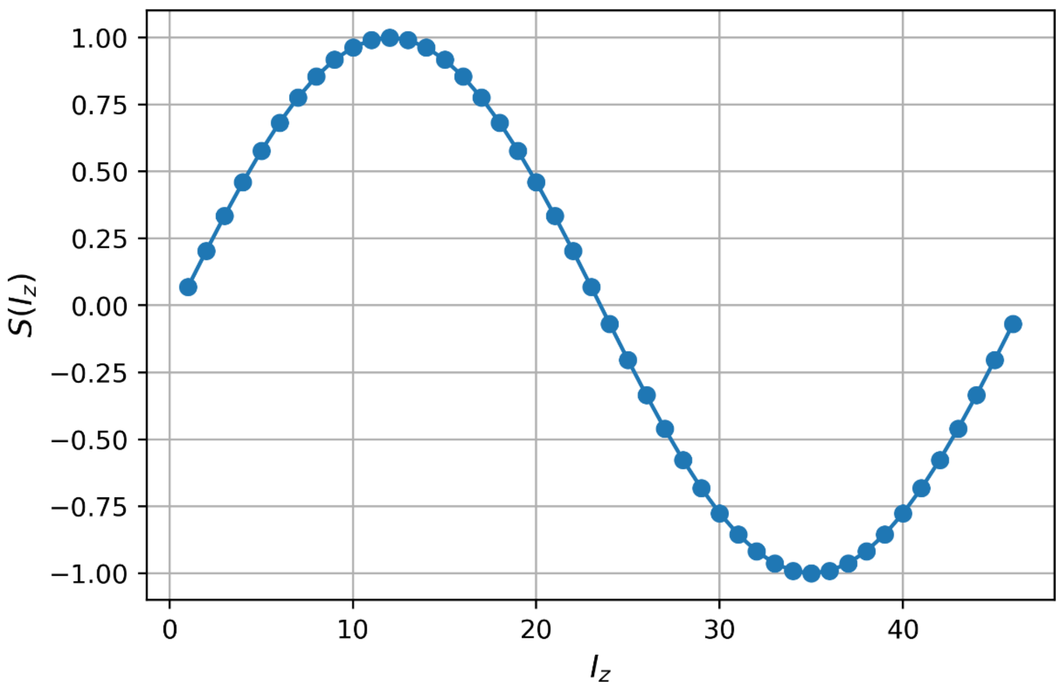
[1] K. S. Smith, et al., Benchmarks for Quantifying Fuel Reactivity Depletion Uncertainty, **EPRI**, Palo Alto, CA, 1022909, 2011.
[2] D. Lancaster, Utilization of the EPRI Depletion Benchmarks for Burnup Credit Validation, **EPRI**, Palo Alto, CA, 1025203, 2012.
[3] K. S. Smith, et al., PWR Fuel Reactivity Depletion Uncertainty Quantification – Methods Validation Using BEAVRS Flux Map Data, **EPRI**, Palo Alto, CA, 3002006432, 2015.

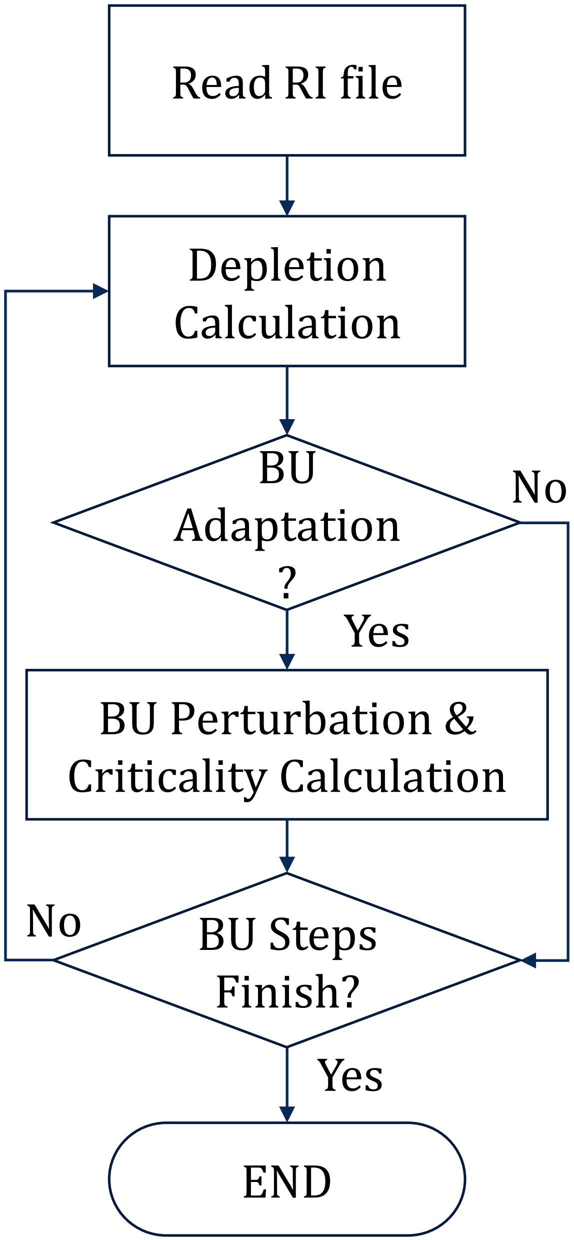
BU Adaptation (BUA) Model

- **The BU adjustment method**

$$BU_{new}(I_z) = BU_{old}(I_z) \cdot M_B \cdot \left(M_z \cdot S(I_z) + 1.0\right),$$

$$ND_{new} = ND_{old} - \left(ND_{Table,old} - ND_{Table,new}\right),$$





BU Adaptation (BUA) Model

▪ The optimization method

System function:

$$G(\mathbf{x}) = \begin{bmatrix} RMSE(\mathbf{x}) + 0.001\left|CBC_{ref} - CBC(\mathbf{x})\right| \\ \left|ASI_{ref} - ASI(\mathbf{x})\right| \end{bmatrix}, \qquad \mathbf{x} = \begin{bmatrix} M_B \\ M_z \end{bmatrix}.$$

Objective function:

$$F(\mathbf{x}) = \frac{1}{2}\mathrm{G}^T(\mathbf{x})\mathrm{G}(\mathbf{x}) = \frac{1}{2}\begin{bmatrix} \left(RMSE(\mathbf{x}) + 0.001\left|CBC_{ref} - CBC(\mathbf{x})\right|\right)^2 \\ +\left(ASI_{ref} - ASI(\mathbf{x})\right)^2 \end{bmatrix}.$$

Updating of the variables:

$$\mathbf{x}^{(1)} = \mathbf{x}^{(0)} - \gamma_0 \nabla F\left(\mathbf{x}^{(0)}\right) = \mathbf{x}^{(0)} - \gamma_0 J_G\left(\mathbf{x}^{(0)}\right)^T G\left(\mathbf{x}^{(0)}\right),$$

Solving the Jacobian matrix:

$$J_G\left(\mathbf{x}^{(0)}\right)\left(\mathbf{x}^{(1)} - \mathbf{x}^{(0)}, \quad \mathbf{x}^{(2)} - \mathbf{x}^{(0)}\right) = \left(G\left(\mathbf{x}^{(1)}\right) - G\left(\mathbf{x}^{(0)}\right), \quad G\left(\mathbf{x}^{(2)}\right) - G\left(\mathbf{x}^{(0)}\right)\right).$$

Numerical Test

- **Reactor model:**
  - **3D Quarter core of the OPR-1000.**

- **Description of the cases:**
  - **Case 1 (case w/o BUA):**
    - **100% power for C1-C3;**
  - **Case 2 (reference case):**
    - **100% power C1, 80% power C2 (to the same BU as case 1), 100% power C3;**
  - **Case 3 (case w/ BUA):**
    - **100% power for C1-C3, BUA applied at BOC of C3.**

Numerical Test

- **Sub-batch grouping**

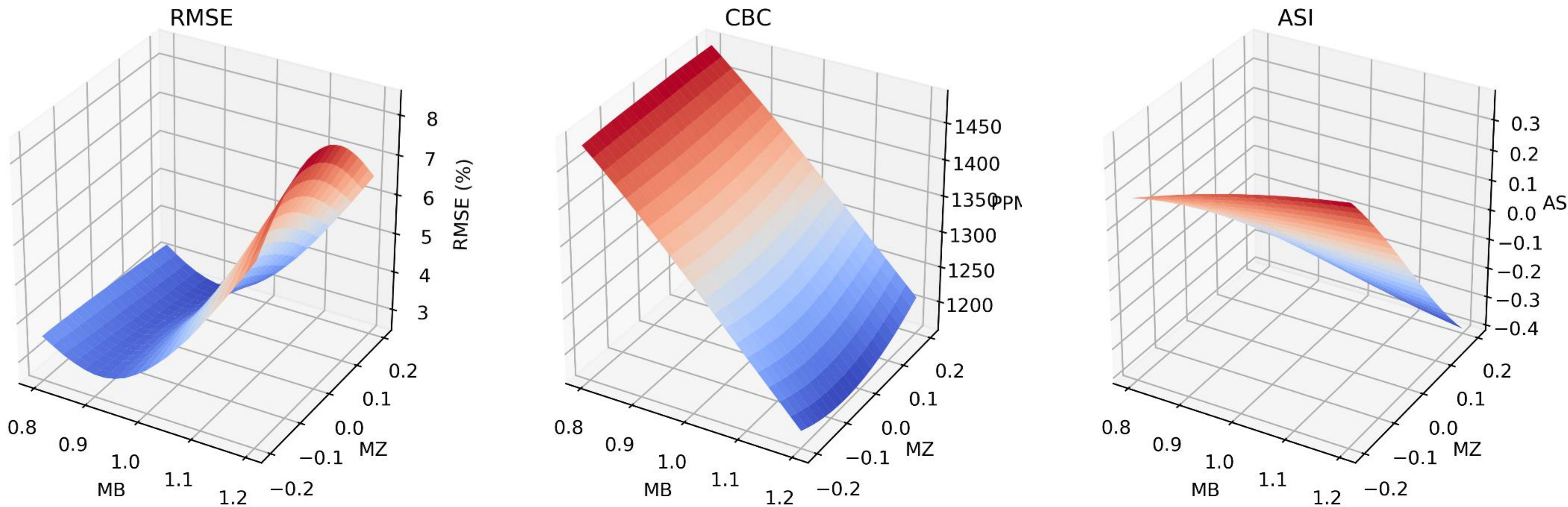
C3 loading pattern:

3	6	18	8	12	12	16	13	R
6	8	6	18	9	10	17	3	R
18	6	11	12	7	18	15	5	R
8	18	12	18	8	12	13	R	R
12	9	7	8	18	14	3	R	
12	10	18	12	14	6	R	R	
16	17	15	13	3	R	R		
13	3	5	R	R	R			
R	R	R	R					

LP	Number of FAs	Burning Cycle	Sub-batch
3	4.25	3rd	2
5	2	3rd	2
6	4	3rd	2
7	2	3rd	2
8	4	2nd	1
9	2	2nd	1
10	2	2nd	1
11	1	2nd	1
12	6	2nd	1
13	3	1st	3
14	2	1st	3
15	2	1st	3
16	1	1st	3
17	2	1st	3
18	7	1st	3
Sum	44.25	--	--

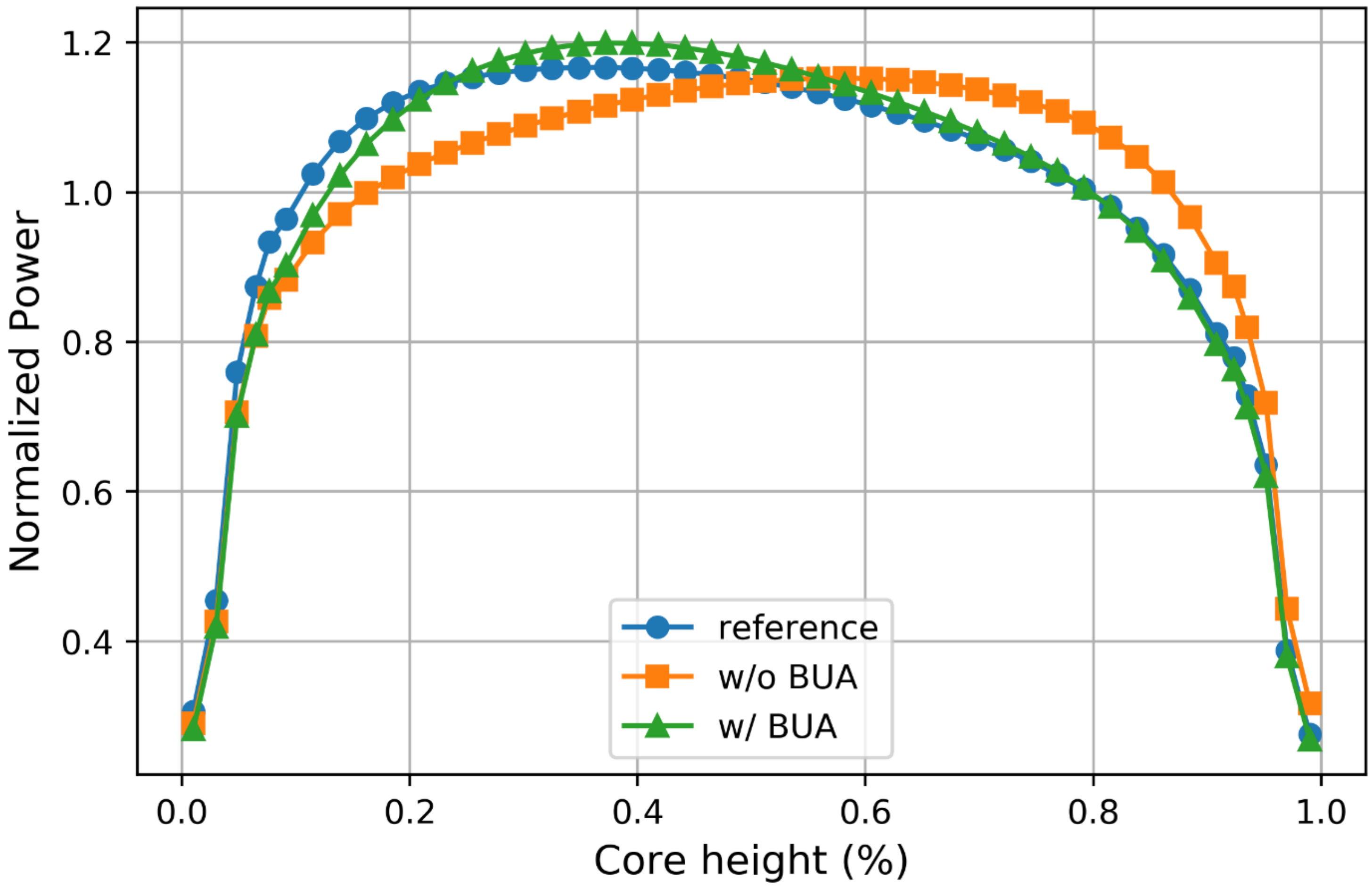
Numerical Test

- **Searching surface of the BUA factors of sub-batch 1:**



Numerical Results

Axial power profiles at C3 BOC:



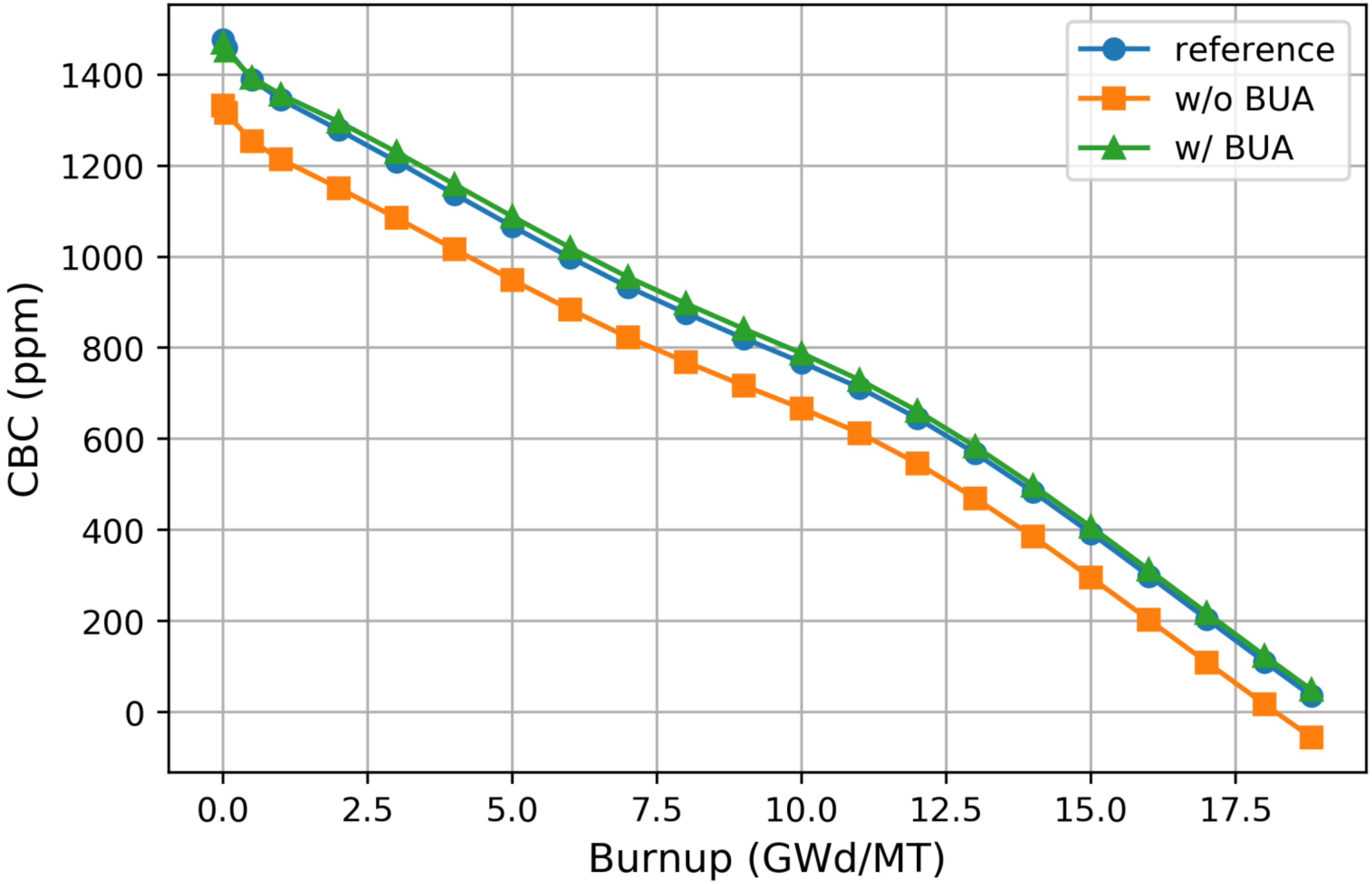
Numerical Results

Radial power differences at C3 BOC:

-5.90	-5.48	-1.53	-3.74	-5.05	-2.91	3.88	6.42
-5.31	-4.75	-1.66	-0.19	0.40	1.33	1.16	0.66
-5.48	-4.49	-3.35	-1.42	-3.73	-1.47	4.28	3.74
-4.75	-2.76	-2.75	-0.44	1.27	1.53	1.09	-1.13
-1.53	-3.35	-4.58	-3.20	-1.11	2.64	5.38	5.73
-1.66	-2.76	-2.75	-1.48	-0.06	1.03	1.00	0.41
-3.74	-1.42	-3.20	0.10	-0.85	0.33	5.44	
-0.19	-0.45	-1.48	-0.17	0.68	0.65	0.79	
-5.05	-3.73	-1.11	-0.85	3.05	4.32	3.17	
0.39	1.26	-0.06	0.68	0.81	0.51	-1.14	
-2.91	-1.47	2.64	0.33	4.31	2.81	**Min**	-5.90
1.32	1.52	1.03	0.65	0.51	-1.39		-5.31
3.87	4.28	5.38	5.43	3.17		**Max**	6.42
1.15	1.09	0.99	0.78	-1.14			1.53
6.42	3.74	5.73			w/o BUA (%)	**RMS**	3.84
0.66	-1.13	0.40			w/ BUA (%)		1.68

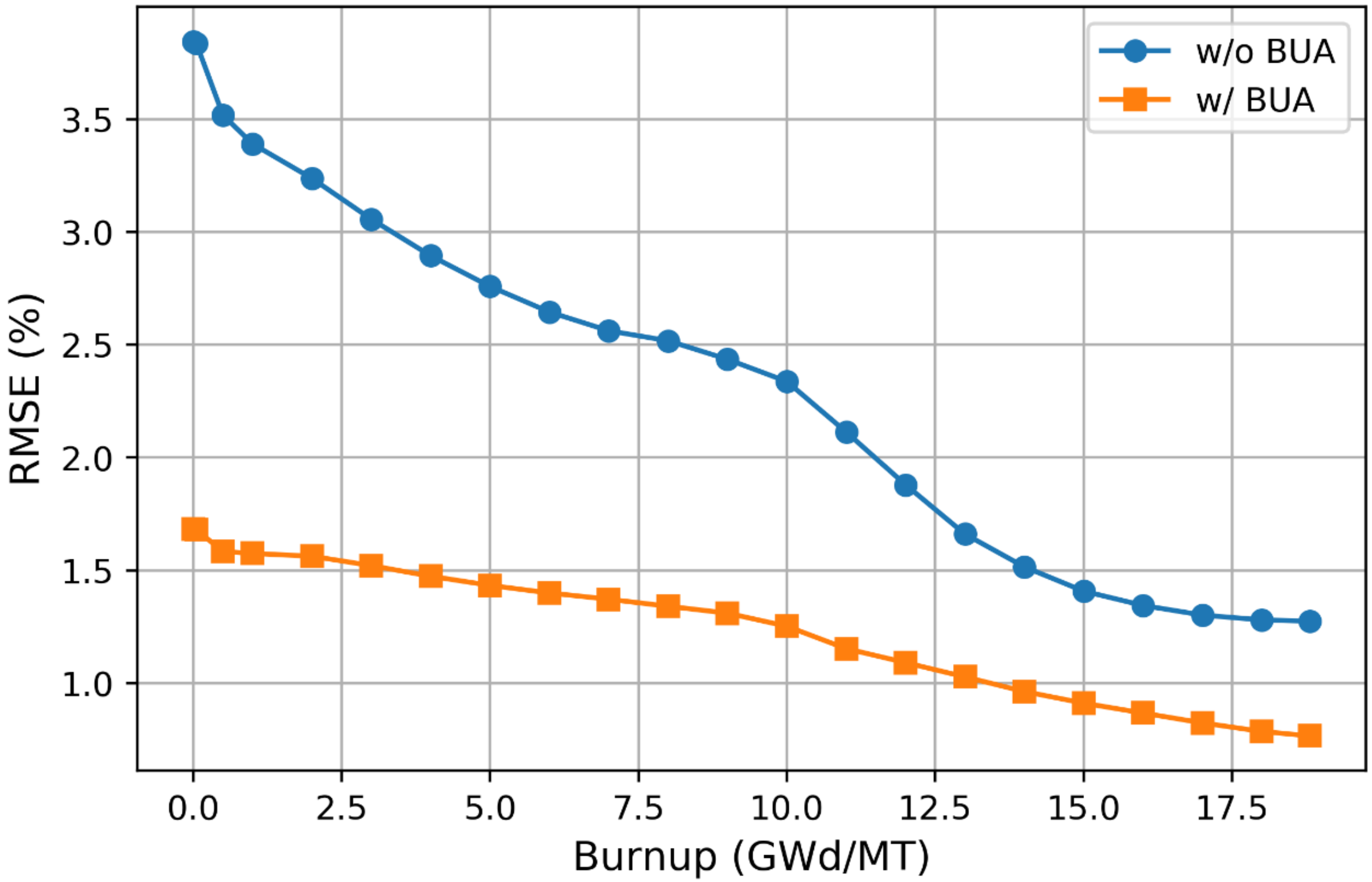
Numerical Results

CBC curve of C3:



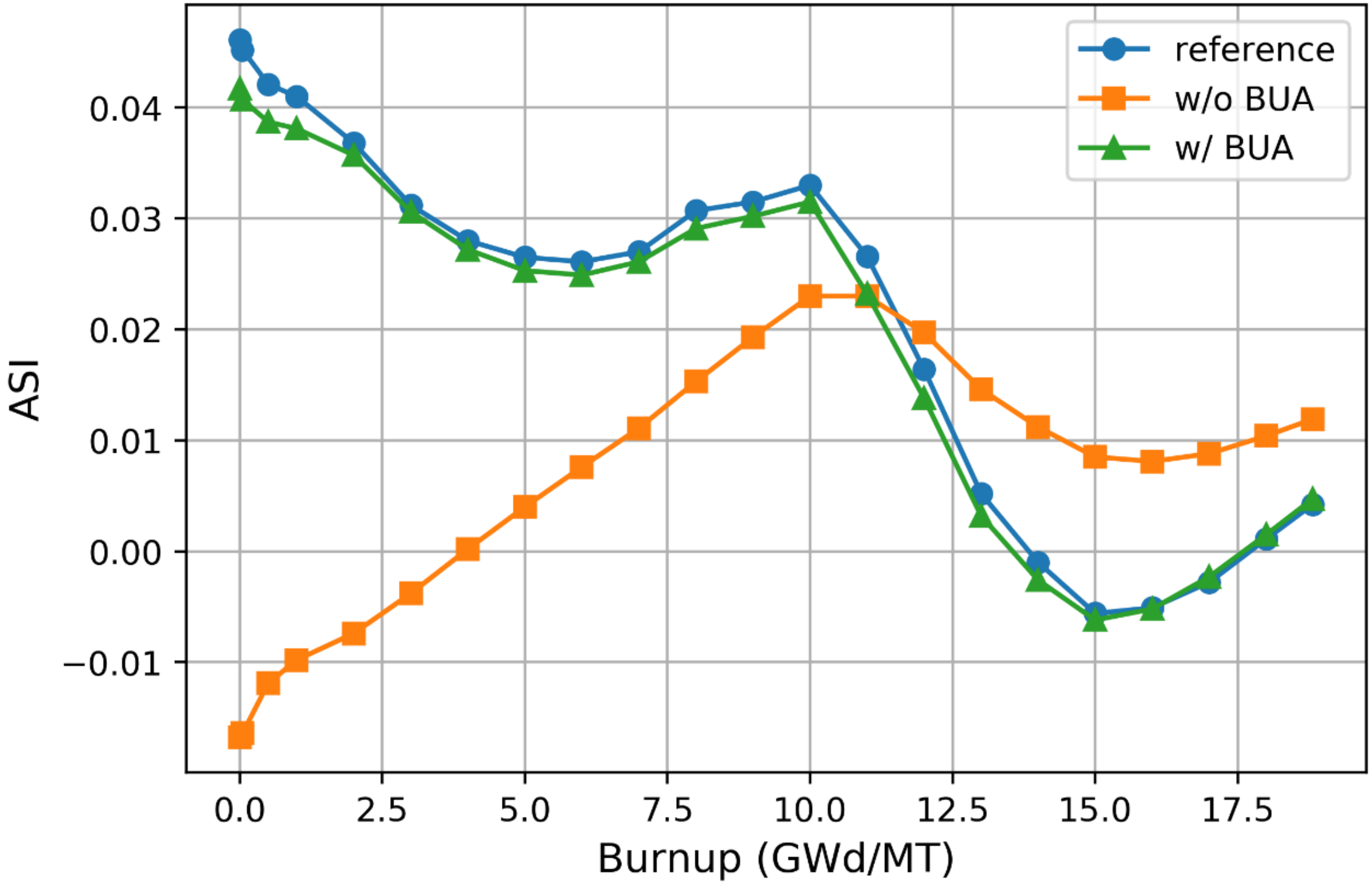
Numerical Results

Radial power RMSE of C3:



Numerical Results

ASI of C3:



Conclusions

- **A burnup adaptation model has been developed in the STREAM/RASTK 2-step code system:**
  - **Compensating the modeling biases in practical application of actual core operating analysis;**
  - **Adopting the 2D power, ASI and CBC from the reference (e.g., in-core detector system) as the target for optimization;**
  - **Utilizing the Gradient Descent method for optimization.**

- **Tests on the OPR-1000 core model is successful.**

- **Further investigation:**
  - **Auto-grouping of the FAs;**
  - **Simultaneous optimization of the factors for all groups.**

UNIST CORE