Verification of STREAM/RAST-K for a Soluble Boron-Free Small Modular Reactor Core Using MCS

Ian Nam[a], Kyeongwon Kim[a], Hyungwoo Sohn[a], Sungju Kwon[b], Hyunsik Hong[b], Deokjung Lee[a]*

[a]Department of Nuclear Engineering, Ulsan National Institute of Science and Technology, 50 UNIST-gil, Ulsan 44919, Republic of Korea
[b]KEPCO NF, 242 Daedeok-daero 989 beon-gil, Yuseong-gu, Daejeon 34057, Republic of Korea

*Corresponding author: deokjung@unist.ac.kr

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ABSTRACT

This study evaluates STREAM/RAST-K (ST/RK) for first-cycle whole-core depletion calculations of a soluble-boron-free small modular reactor (SBF-SMR) with high-absorption burnable absorbers (HABAs). Calculations were performed under all-rods-out (ARO) and control-rod-inserted (CR) conditions over 42 burnup steps to 20 MWd/kgU. The critical control rod bank positions were searched by RAST-K and evaluated using MCS. The effective multiplication factor, axial shape index, peaking factor, and distributions of power, burnup, and coolant temperature were compared with reference solutions generated using MCS. Maximum k_{eff} differences are 453 pcm for ARO and 322 pcm for CR. Radial power RMS errors remain at or below 1.54%, and the maximum axial coolant temperature difference is 1.92 K. Future work will focus on identifying the underlying physical causes of the increased discrepancies in the SBF-SMR core.

INTRODUCTION

- Reactivity control using burnable absorbers and control rods
- Local spectrum distortions from HABAs and control rod movement
- RAST-K critical control rod bank search and MCS evaluation
- First-cycle whole-core depletion, ST/RK verification against MCS under ARO and CR conditions

DESCRIPTION

- Modeling and parameters

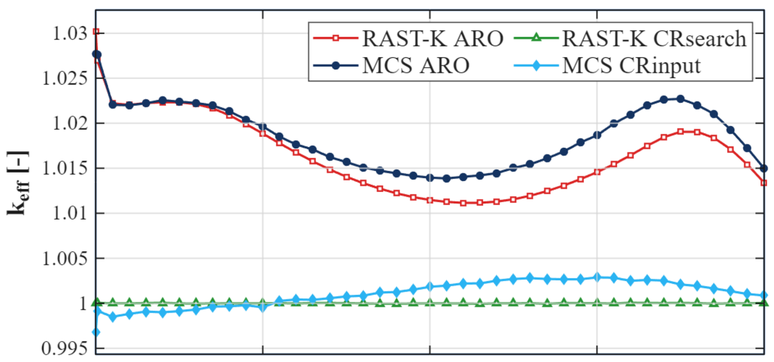
- 69-assembly core, Westinghouse-type 17 × 17 fuel-assembly lattices
- 240 cm active height, HABAs and heavy metal reflectors
- ST/RK verification for SBF-SMR using MCS reference solutions
- STREAM, pin-based pointwise energy slowing-down, U-238 resonance up-scattering with Doppler broadening rejection correction, semi-predictor/corrector depletion
- RAST-K, multigroup nodal diffusion solver
- ST/RK and MCS, quadratic depletion method for HABAs, equilibrium xenon, TH1D multi-physics solver, gap conductance 10,000 W/m²K

Parameter	Calculation setting
Burnup steps	42 steps to 20 MWd/kgU
Number of axial meshes	24
MOC ray spacing / angles	0.01 cm / 96 azimuthal / 6 polar
Fuel / HABA ring meshes	UO_2: 3 / HABA: 15
MCS cycles	15 inactive + 30 active
MCS histories	2×10^6 per cycle, 9×10^7 total

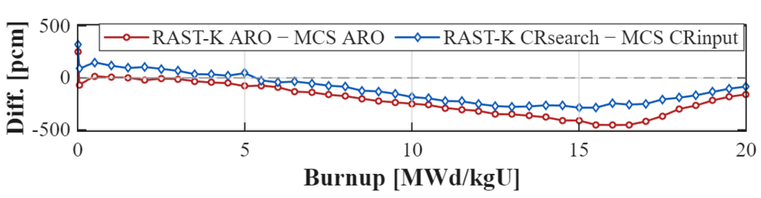
- Critical rod search

- RAST-K CR-search, critical positions of regulating banks R1–R4
- Same control rod bank positions in RAST-K CR-search and MCS CR-input

- Effective multiplication factor



- **453 pcm** maximum k_{eff} difference (ARO, 16.0 MWd/kgU)

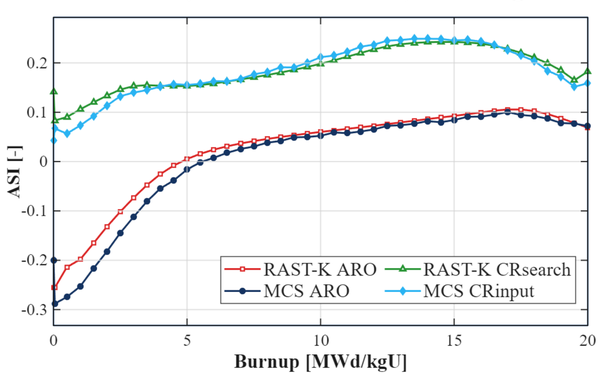


- **322 pcm** at BOC, RAST-K CR-search vs. MCS CR-input
- **6–9 pcm** MCS standard deviations
- MCS depletion trend followed by ST/RK

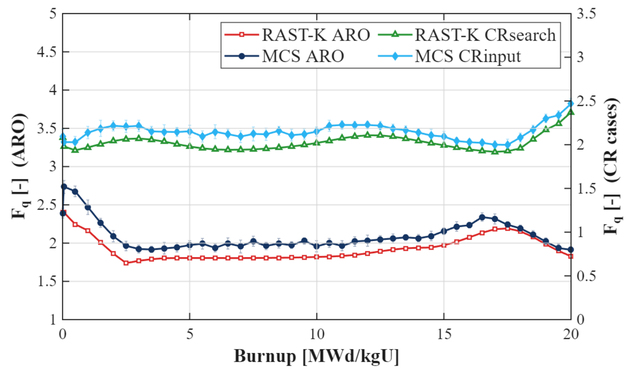
- Critical bank positions and corresponding MCS results

Burnup (MWd/kgU)	R4 / R3 / R2 / R1 position (cm)	MCS k_{eff}	Δk_{eff} (pcm)	MCS σ (pcm)
0.0	12 / 111 / 231 / 252	0.99677	**322**	9
5.0	52 / 172 / 252 / 252	0.99954	46	8
10.0	89 / 209 / 252 / 252	1.00183	−184	9
15.0	71 / 191 / 252 / 252	1.00287	−286	6
20.0	140 / 213 / 252 / 252	1.00086	−84	7

- Axial shape index and peaking factor



(a) ASI, ARO and CR cases



(b) F_q, ARO and CR cases

- Maximum ASI differences, ARO **0.060** (0.5 MWd/kgU) and CR **0.099** (BOC)
- Maximum F_q differences, ARO **0.431** (0.5 MWd/kgU) and CR **0.202** (6.0 MWd/kgU)
- Upper-half power suppression from regulating-bank insertion

- Radial power and burnup distributions

ARO MOC 10.00 MWd/kgU

1.209	1.177	1.209	1.143	0.776
1.234	1.198	1.218	1.141	0.758
0.12	0.11	0.14	0.10	0.10
-1.97	-1.75	-0.70	0.15	2.28
1.177	1.174	1.188	1.069	0.740
1.199	1.193	1.198	1.063	0.723
0.08	0.06	0.06	0.05	0.08
-1.80	-1.59	-0.83	0.58	2.47
1.209	1.188	1.130	0.986	0.605
1.222	1.200	1.132	0.975	0.588
0.10	0.06	0.08	0.08	0.12
-1.00	-0.97	-0.19	1.14	2.88
1.143	1.069	0.986	0.700	RAST-K
1.146	1.066	0.976	0.689	MCS
0.12	0.06	0.07	0.10	MCS Rel. SD [%]
-0.31	0.27	0.99	1.53	Rel. Error [%]
0.776	0.740	0.605	Rel. Diff. [%]	
0.766	0.725	0.591	RMS	1.54
0.15	0.10	0.10	Min	-1.97
1.33	2.08	2.40	Max	2.88

(a) ARO case at MOC

CR cases EOC 20.00 MWd/kgU

1.233	1.190	1.175	1.108	0.811
1.245	1.192	1.164	1.103	0.819
0.12	0.11	0.09	0.10	0.12
-0.96	-0.17	0.95	0.48	-1.04
1.190	1.093	1.172	1.074	0.778
1.191	1.059	1.166	1.073	0.788
0.12	0.07	0.08	0.06	0.10
-0.05	3.24	0.51	0.10	-1.35
1.175	1.172	1.125	0.985	0.627
1.161	1.163	1.122	0.990	0.640
0.11	0.08	0.07	0.09	0.10
1.22	0.71	0.26	-0.55	-2.05
1.108	1.074	0.985	0.711	RAST-K
1.099	1.069	0.989	0.728	MCS
0.09	0.09	0.08	0.10	MCS Rel. SD [%]
0.82	0.53	-0.45	-2.37	Rel. Error [%]
0.811	0.778	0.627	Rel. Diff. [%]	
0.815	0.785	0.640	RMS	1.24
0.17	0.10	0.07	Min	-2.37
-0.47	-0.93	-1.96	Max	3.24

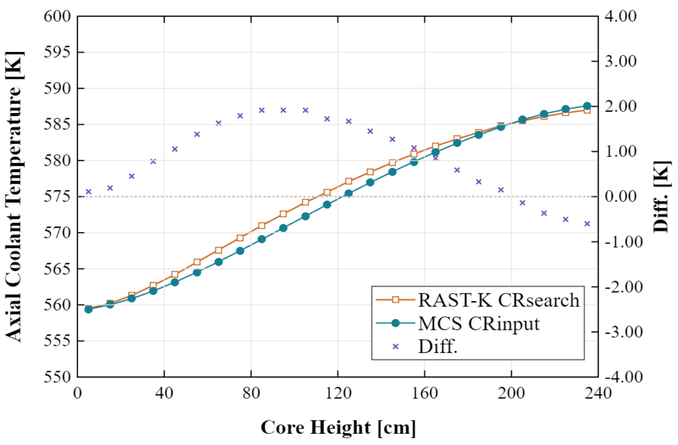
(b) CR case at EOC

- Radial power RMS errors **≤ 1.54%** across all cases
- Maximum relative differences, **2.88%** for ARO at MOC and **3.24%** for CR at EOC

RMS error (%)	Case	BOC	MOC	EOC
Radial power	ARO	0.66	**1.54**	1.28
	CR	1.07	0.68	**1.24**
Radial burnup	ARO	—	1.51	1.22
	CR	—	0.85	0.51

- Radial burnup, maximum relative differences **2.60%** (ARO) and **1.66%** (CR)
- Lower RMS errors from MOC to EOC
- CR at EOC, lower central and higher outer-assembly burnup than ARO

- Axial coolant temperature distribution



CR case at MOC

Max. |ΔT| (K)	ARO	CR
BOC	1.18	1.07
MOC	0.71	**1.92**
EOC	0.78	0.62

- **1.92 K** maximum axial temperature difference, CR at MOC
- Identical constant inlet temperature in ST/RK and MCS

CONCLUSION

ST/RK whole-core depletion results for the ARO and CR cases were compared with the corresponding MCS results for a representative first-cycle SBF-SMR problem. Maximum k_{eff} differences are 453 pcm for ARO and 322 pcm for CR. Radial power RMS errors remain at or below 1.54%, and the maximum axial coolant temperature difference is 1.92 K. Maximum k_{eff} differences exceed the 200 pcm range for conventional PWR benchmarks. Future work will analyze local spectrum distortion, neutron leakage, and heavy metal reflectors.