Estimation of Plutonium Production in a Graphite-moderated Reactor using Graphite Isotope Ratio Method and MCS

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ABSTRACT

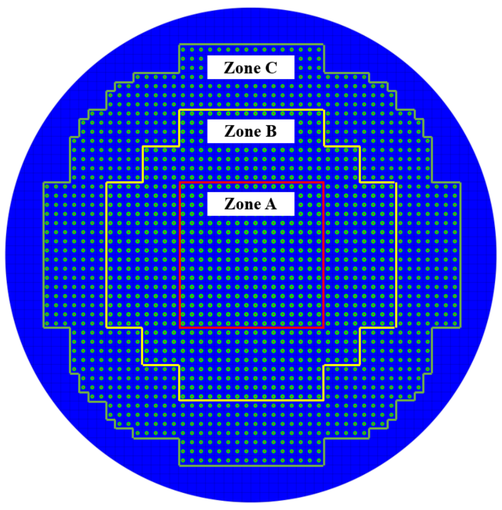
The international community, and especially the South Korean government, is making efforts to denuclearize the North Korea. If North Korea accepts a complete denuclearization, it would be essential to estimate the amount of plutonium produced by them. This estimation would help to determine the number of produced plutonium nuclear weapons, by that verifying the status of denuclearization. It is known that the North Korea is producing weapon-grade plutonium using a Magnox-type reactor. The amount of plutonium produced in a Magnox reactor can be estimated using a correlation between the ratio of impurity indicator isotopes and the generated plutonium. This paper presents an estimation of ^{239}Pu production in a graphite-moderated nuclear reactor using a Graphite Isotope Ratio Method (GIRM) paired with our code MCS. In this study, the ratio of ^{10}B/^{11}B isotopes was used as the impurity indicator. The total cumulative ^{239}Pu production calculated by MCS and GIRM show a difference of 1.157% RMS on average, with the maximum and the minimum RMS of 3.306% and -1.250%, respectively.

INTRODUCTION

- It is assumed that North Korea is producing weapon-grade plutonium using a Magnox-type reactor.
- The amount of plutonium can be estimated using a correlation between the ratio of impurity indicator isotopes (^{10}B/^{11}B) and the generated plutonium.
- An estimation of ^{239}Pu production in a graphite-moderated nuclear reactor using a GIRM using our code MCS.
- MCS is a continuous-energy Monte Carlo code developed at the CORE Lab. of UNIST.

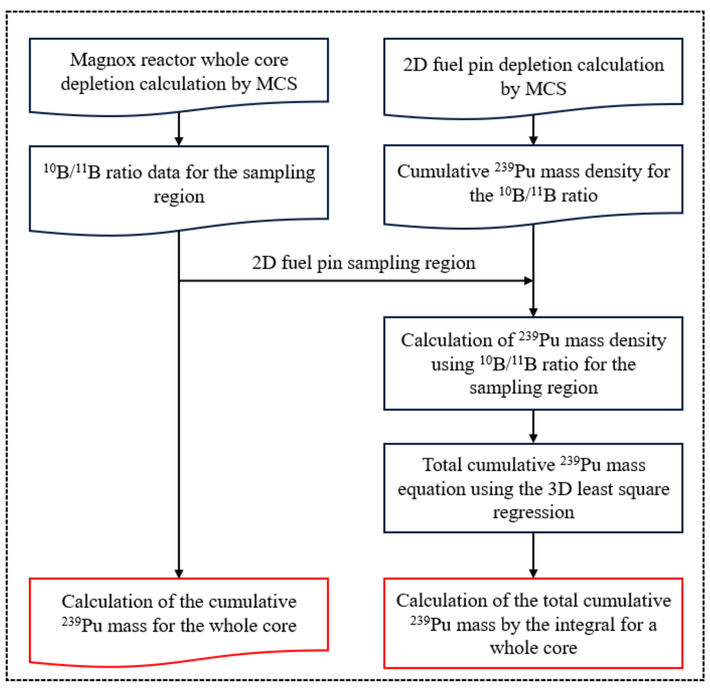
DESCRIPTION

- Magnox Reactor
  - Magnox reactor uses natural uranium as fuel, graphite as moderator and carbon dioxide (CO_2) gas as the heat exchange coolant.



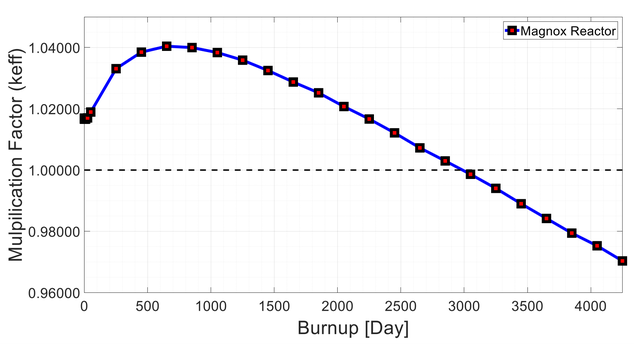
Parameter		Value	Unit
Power		182	MW_{th}
Active height		640	cm
Active diameter		945	cm
Fuel pin radius		1.4610	cm
Cladding radius		2.0400	cm
Coolant radius	Zone A	5.2080	cm
	Zone B	5.0165	
	Zone C	4.5847	

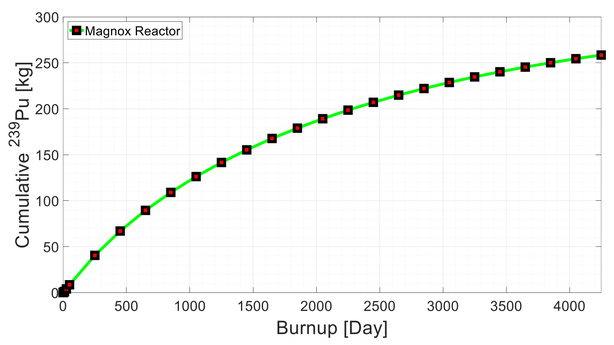
- Flowchart of GIRM process



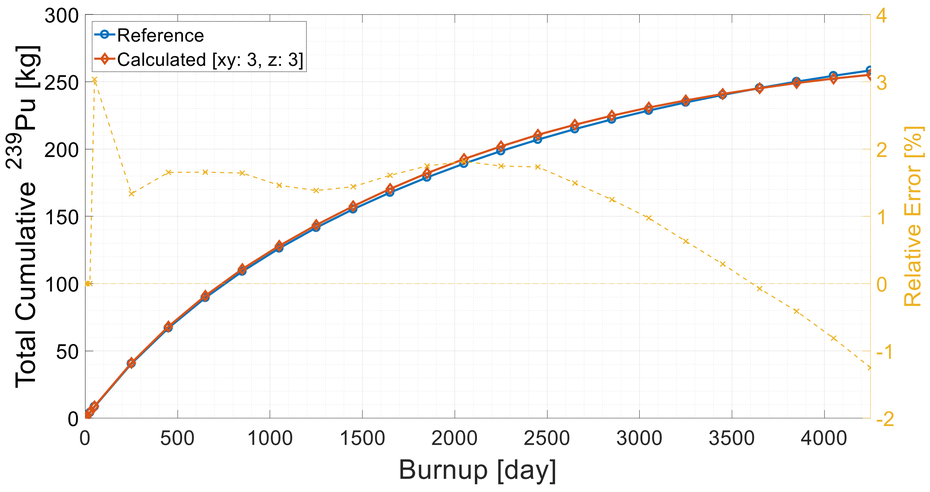
- ^{239}Pu mass density for the ^{10}B/^{11}B ratio is calculated for each depletion step using MCS 2D fuel pin simulation.
- ^{239}Pu mass density is estimated using a corresponding 2D fuel pin ^{10}B/^{11}B ratio for each sampling region of a 3D whole core simulation.
- A 3D space-dependent equation of ^{239}Pu mass density for the whole core is derived through a least-squares regression using a ^{239}Pu mass density for each sampling region.
- The total estimated ^{239}Pu production is calculated by integrating the equation over the whole core 3D space.

- MCS depletion simulation





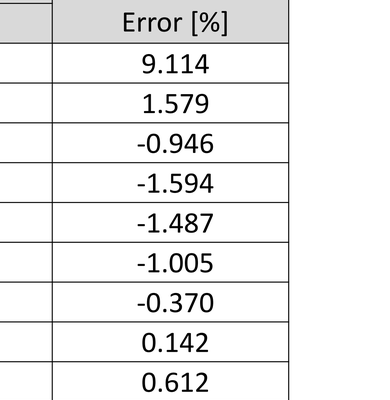
- Total cumulative ^{239}Pu production calculated by MCS and GIRM



- Axial and pin-wise cumulative ^{239}Pu production calculated by MCS and GIRM on depletion step of 3250 day

Height [cm]		MCS	Estimated	Relative Error [%]
Bottom	Top	Total Cumulative ^{239}Pu [kg]		
100	132	9.208	10.047	9.114
132	164	10.421	10.586	1.579
164	196	11.174	11.069	-0.946
196	228	11.682	11.496	-1.594
228	260	12.045	11.865	-1.487
260	292	12.301	12.178	-1.005
292	324	12.477	12.431	-0.370
324	356	12.607	12.625	0.142
356	388	12.681	12.759	0.612
388	420	12.719	12.832	0.884
420	452	12.725	12.843	0.921
452	484	12.689	12.791	0.808
484	516	12.606	12.676	0.560
516	548	12.485	12.497	0.097
548	580	12.309	12.253	-0.459
580	612	12.056	11.943	-0.944
612	644	11.691	11.566	-1.072
644	676	11.176	11.122	-0.484
676	708	10.423	10.609	1.784
708	740	9.209	10.028	8.891

Fuel Pin Index	MCS	Estimated	Relative Error [%]
	Total Cumulative ^{239}Pu [kg]		
1	0.121	0.124	2.704
2	0.145	0.148	2.205
3	0.135	0.137	1.570
4	0.155	0.154	-0.468
5	0.157	0.155	-1.093
6	0.158	0.153	-3.385
7	0.144	0.146	1.350
8	0.158	0.154	-2.112
9	0.161	0.156	-2.940



CONCLUSIONS

- The total cumulative ^{239}Pu production calculated by MCS and GIRM show a difference of 1.157%, with the maximum and the minimum of 3.306% and -1.250%.
- The space dependence of the ^{239}Pu estimation was evaluated by comparing the cumulative ^{239}Pu production for various axial regions and individual fuel pins.
- The future work will be applying other impurity indicator isotope ratios such as ^{6}Li/^{7}Li, ^{48}Ti/^{49}Ti and ^{235}U/^{238}U. In addition, more sensitivity tests for the number and position of sampling regions will be performed because practical location of sampling region in the actual reactor is unclear.