Verification of Microscopic Depletion Module of Diffusion Code RAST-K 2.0

Minyong Park [a*], Deokjung Lee [a*], Eunki Lee [b]
[a]*Interdisciplinary School of Mechanical and Nuclear Engineering, UNIST, UNIST-gil 50, Ulsan 689-798, Republic of Korea*
[b]*KHNP-Central Research Institute, 1312-gil 70, Yuseong-daero Yuseong-gu, Daejeon 305-343, Republic of Korea*
[*]*Corresponding author: saioitjs@unist.ac.kr*

1. Introduction

In the nuclear design procedure, especially two step method many diffusion code such as RAST-K 1.0, SIMULATE [1], PARCS [2] adopt macroscopic depletion. Also MASTER [3] use few heavy nuclide chain and it leads to huge number density error in the initial burnup step points. Basically, macroscopic depletion of diffusion code use macroscopic cross section from the result of depletion calculation of transport code. But transport code assume that a single fuel assembly is infinitely arranged, so it leads to inconsistent macroscopic cross section generation using different neutron spectrum due to different situation with diffusion code where different fuel assemblies which has different burnup and enrichment are arranged. In addition, there are inconsistent macroscopic cross section by interpolating burnup due to difference between burnup point of transport code and burnup point of diffusion code. Therefore accurate number density calculation during depletion is very important in the diffusion code. RAST-K 2.0 adopt microscopic depletion using CRAM (Chebyshev Rational Approximation Method) [4] and compare its accuracy with MASTER. For generation of cross section, KARMA [5] developed by KAERI is used as a transport code and its depletion results are used as a reference.

2. Methods and Results

2.1 Depletion Chain

In the RAST-K 2.0, number densities of 24 heavy nuclides, 4 fission products and B-0 are calculated. Fig. 1 shows these depletion chain. Compared with MASTER, (n, 2n) reaction of Pu-239 is added and merged nuclides which has very small half-life such as U-237, U-239, Np-238, Np-240, Pu-243 and Am-244 are added to reduce huge number density error in the initial burnup step points. Furthermore for better accuracy in the entire burnup points, more detail chain is adopted. For example, Am-242, Am-242m and Cm-243 nuclides are added and alpha decay of Pu-238, Cm-243 and Cm-244 are added. Also Pm-147, Pm-148 and Pm-148m are added in the fission product depletion chain. However, since KARMA has no capability of generation of fission yield Pm-147, only Pm-149 and Sm-149 are used in this paper.

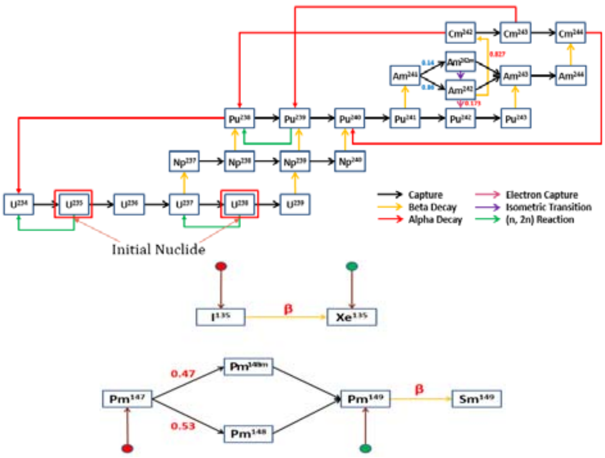


Fig. 1. Depletion chain of RAST-K 2.0

2.2 Depletion Calculation Method

For depletion calculation, Bateman equation is solved. In case of heavy nuclide, matrix form of Bateman equation is modeled and its solution form is matrix exponential.

$$\mathbf{A}=[a_{ij}],\ a_{ii}=-(\lambda_i+\sum_{g=1}^{G}\sigma_{ig}\phi_g),\ a_{ij}=\ell_{ij}\lambda_j+\gamma_{ij}\sum_{g=1}^{G}\sigma_{jg}\phi_g \quad (1)$$

where

ℓ_{ij} = decay fraction (nuclide i to j)
λ_j = decay constant
ϕ_g = multi-group flux
γ_{ij} = production yield of nuclide j
by neutron reaction of nuclide i
σ_{jg} = multi-group microscopic cross section of nuclide j

$$\frac{dX(t)}{dt}=\mathbf{A}\cdot X(t),\ X(t)=e^{\mathbf{A}t}\cdot X(0) \quad (2)$$

By using CRAM, approximate this matrix exponential.

$$X(t)=e^{\mathbf{A}t}\cdot X(0)\approx\alpha_0 X(0)+2\,\mathrm{Re}\left\{\sum_{m=1}^{k/2}\alpha_m-\left(\mathbf{A}t-\theta_m\mathbf{I}\right)^{-1}X(0)\right\} \quad (3)$$

k is approximation order and α_m, θ_m are partial fraction decomposition coefficients. In case of fission product, analytic solution of Bateman equation are used.

2.3 Results

Plus7 F0 type fuel assembly model which has no burnable absorber is used. KARMA depletion results are used as a reference and critical spectrum calculation is not performed. k-inf and number density are compared with MASTER. RAST-K 2.0 shows better result than MASTER.

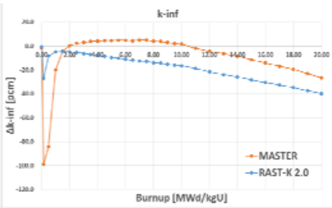
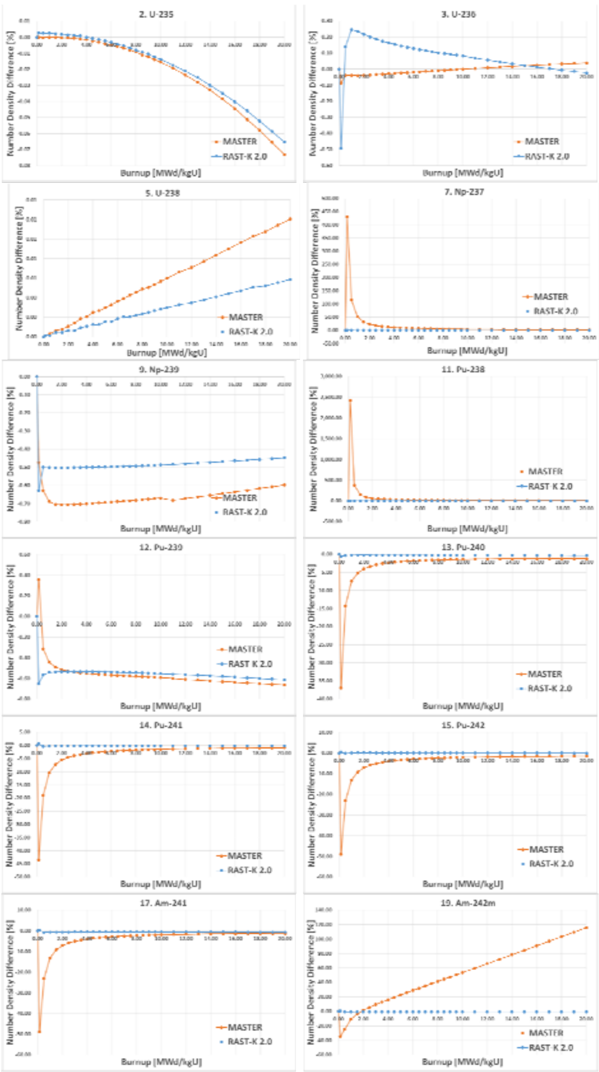


Fig. 2. k-inf comparison between RAST-K 2.0 vs MASTER



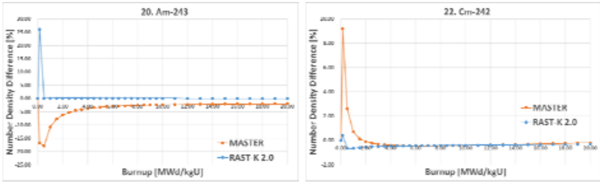


Fig. 3. Number density of heavy nuclides comparison between RAST-K 2.0 vs MASTER

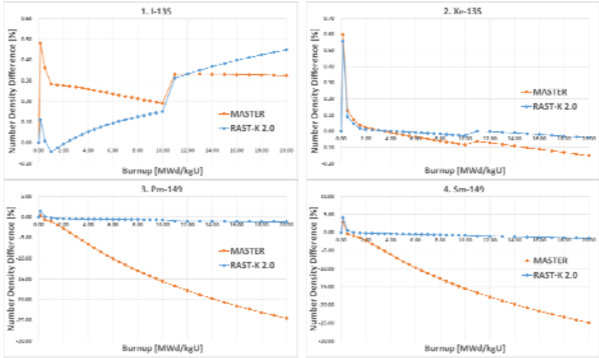


Fig. 4. Number density of fission products comparison between RAST-K 2.0 vs MASTER

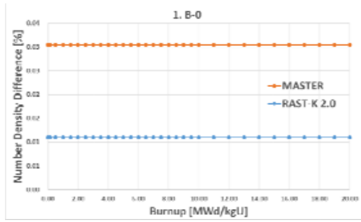


Fig. 5. Number density of B-0 comparison between RAST-K 2.0 vs MASTER

3. Conclusions

Microscopic depletion module has been implemented in diffusion code RAST-K 2.0 and its accuracy has been compared with MASTER.

4. ACKNOWLEDGMENT

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