사단법인 한국원자력학회 KOREAN NUCLEAR SOCIETY

Autumn Annual Conference of KNS, 2021

Evaluation of Depletion Uncertainty for Spent Fuel Storage Pool using Monte Carlo Random Sampling by Considering Boron Concentration in Depletion Calculation

Kyu Jung Choi[1], Dong Jin Kim[1], Chang Ho Shin[1], Kiyoung Kim[2], and Ser Gi Hong[1]*

***Corresponding Author: hongsergi@hanyang.ac.kr**

2021. 10. 21

This work was supported by KOREA HYDRO & NUCLEAR POWER CO., LTD. (No. 2019-TECH-14)

[1] **Department of Nuclear Engineering, Hanyang University**
Computational Transport & Reactor Physics Laboratory

[2] **Central Research Institute, Korea Hydro & Nuclear Power Company Limited**

CT&RPL Computational Transport & Reactor Physics Laboratory

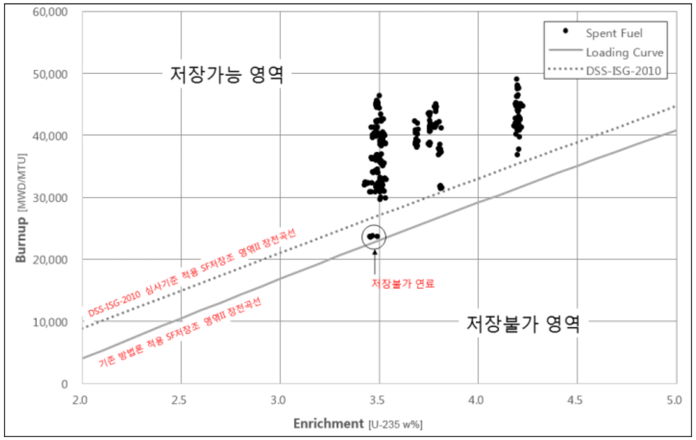
Table of Contents

Introduction

❑ Revised standard review plan by U.S. NRC (DSS-ISG-2010-01)

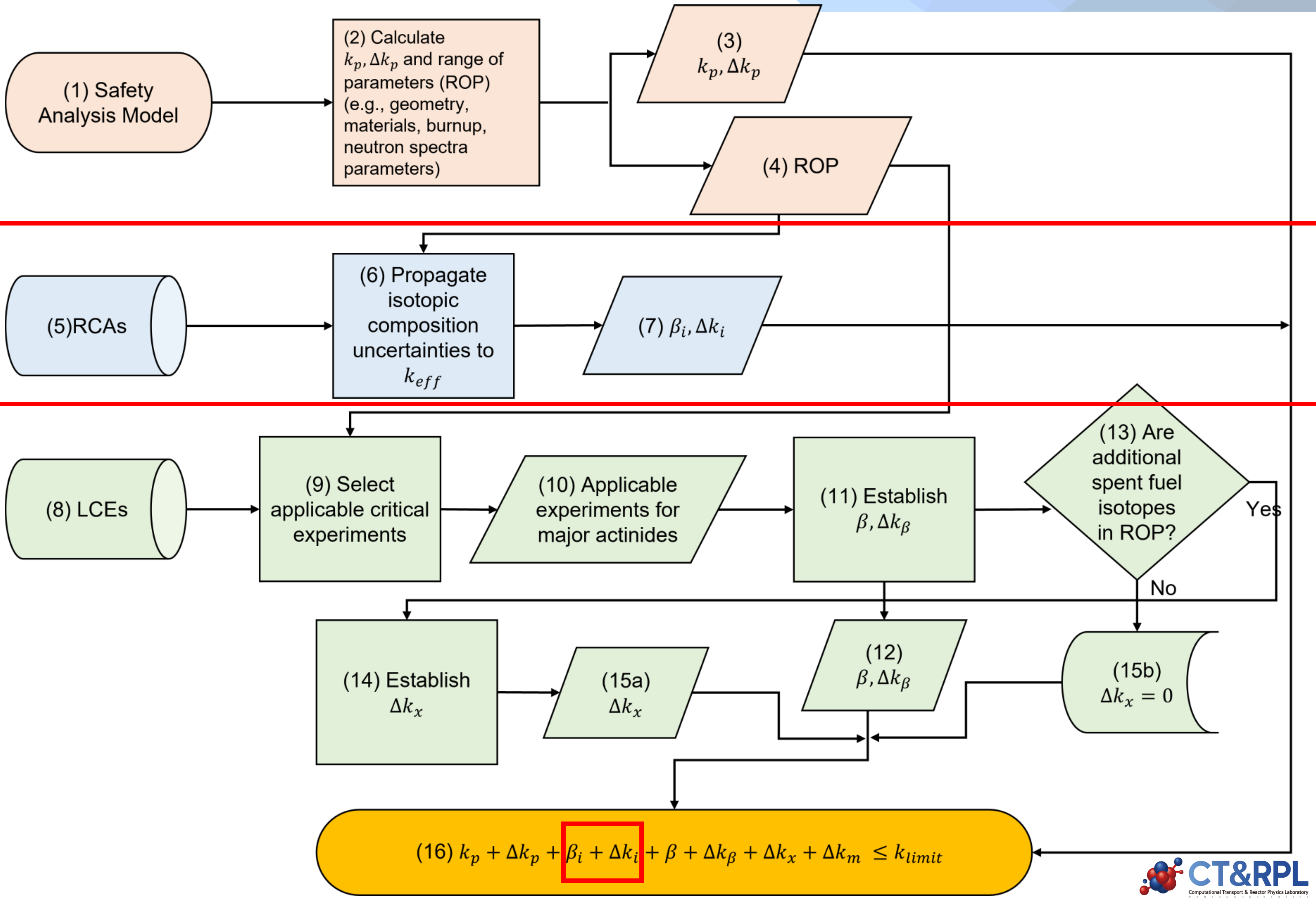
- The U.S. NRC requires the application of revised guidance for spent fuel pool nuclear criticality analyses and operations from 2011.
- Domestic regulatory body requires application of the revised guidance of the U.S. NRC from 2015.
- The k_{eff}, including all biases and uncertainties at a 95% confidence level, should not exceed 0.95 under all credible normal, off-normal, and accident conditions for all storage operations.

	DSS-ISG-2010-01	Current state in our country	Safety Margin
Boron credit	Yes	No	Up
Axial burnup profile	NUREG/CR-6801	Uniform profile	Down
Code validation – k_{eff}	NUREG/CR-6698	Yes	Down
Code validation – Isotopic depletion	NUREG/CR-7108	No or excessive conservatism	Down



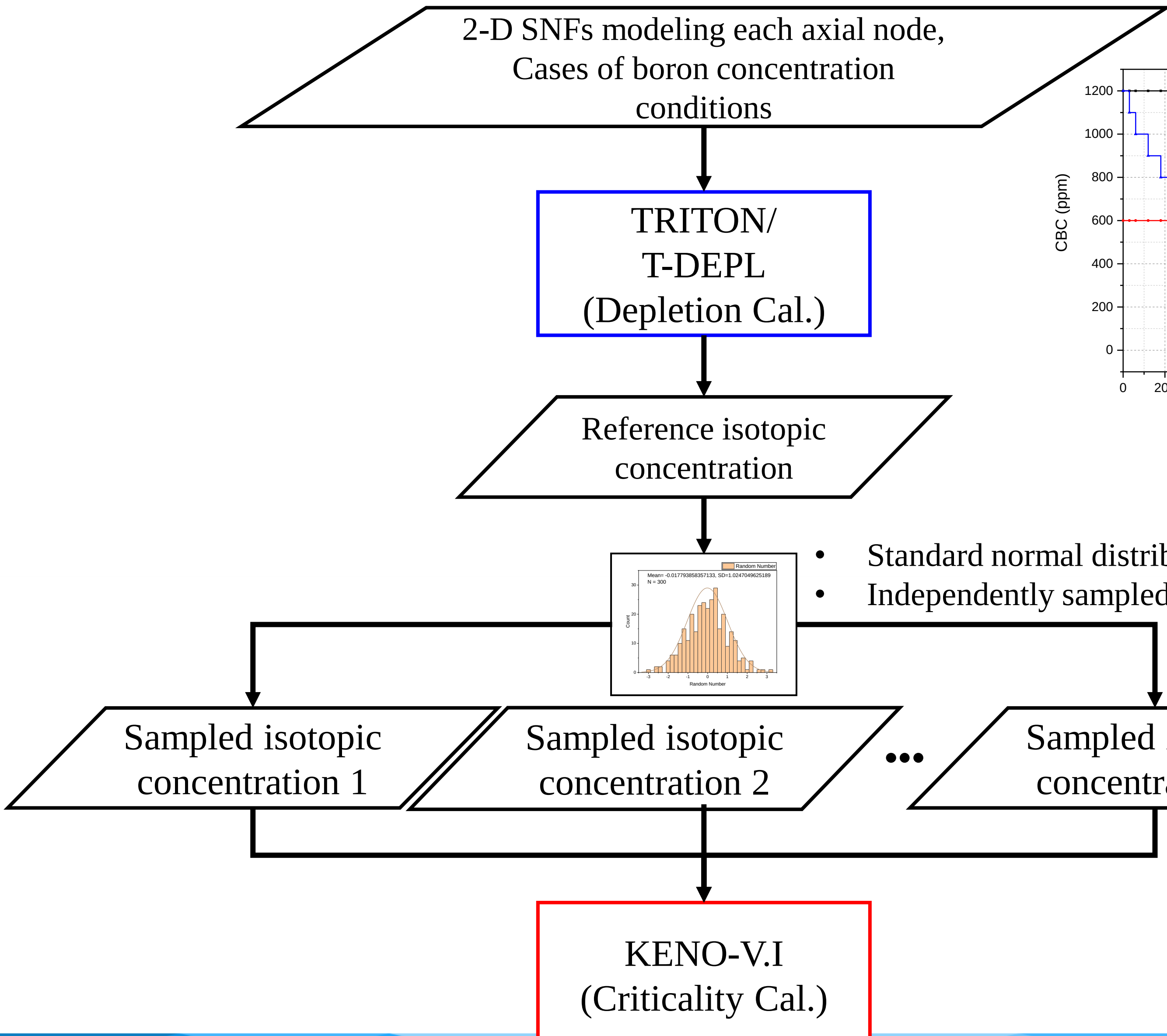
Introduction

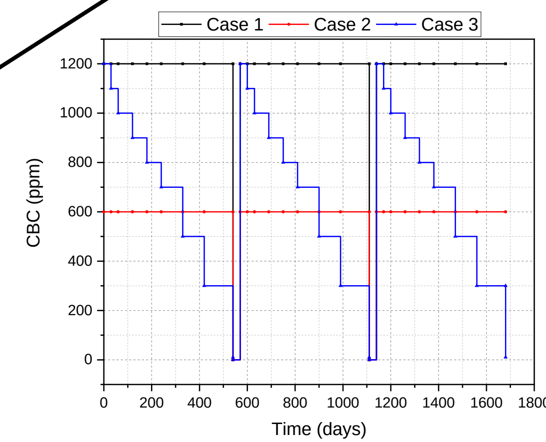
- Overview of the burnup credit validation process



Methods and Results

❑ Workflow of the evaluation of depletion uncertainty by considering boron concentration





- Standard normal distribution
- Independently sampled concentration each nuclide

Methods and Results

❑ Computer code system

SCALE6.2.4/TRITON

- Neutron transport, depletion calculation, estimation of inventory
- ENDF/B-VII.1 based 252-group neutron cross section library
- 17×17 (17V5H) fuel assembly 2D modeling
- Axial burnup profile for each 18 nodes

SCALE6.2.4/KENO-VI

- Monte Carlo criticality transport calculation
- The region II spent fuel pool 3D modeling
- Criticality calculations with the sampled nuclide concentration sets

Major Actinides (9)

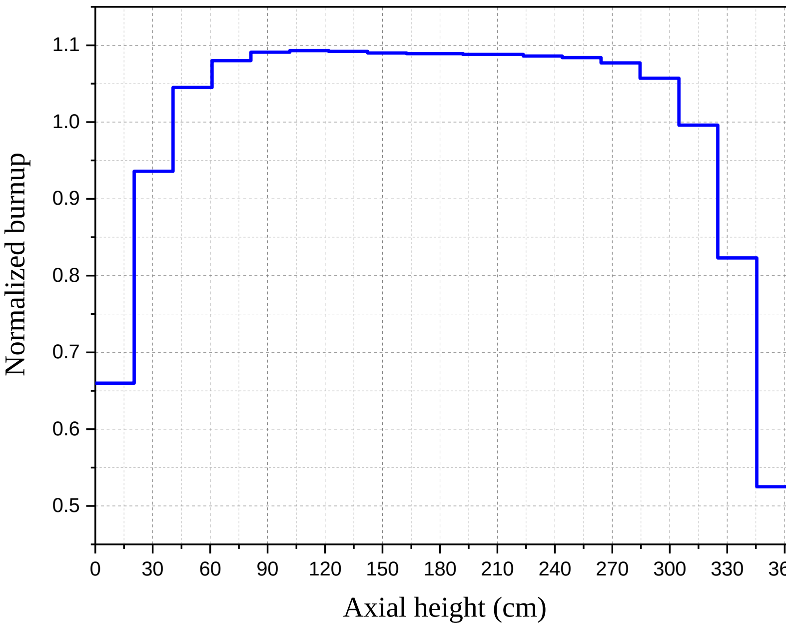
^{234}U ^{235}U ^{238}U ^{238}Pu ^{239}Pu ^{240}Pu ^{241}Pu ^{242}Pu ^{241}Am

Fission Products (19)

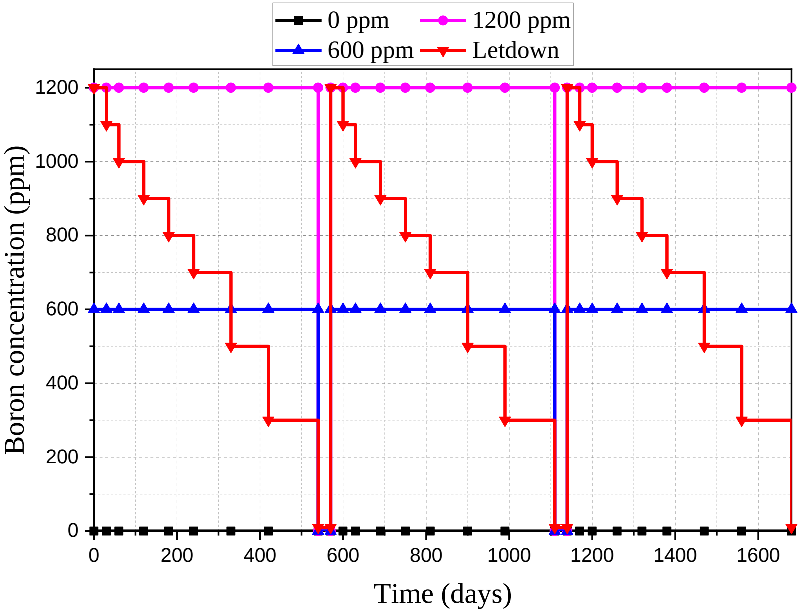
^{95}Mo ^{99}Tc ^{101}Ru ^{103}Rh ^{109}Ag ^{133}Cs ^{147}Sm ^{149}Sm ^{150}Sm ^{151}Sm
^{152}Sm ^{143}Nd ^{145}Nd ^{151}Eu ^{153}Eu ^{155}Gd ^{236}U ^{243}Am ^{237}Np

Methods and Results

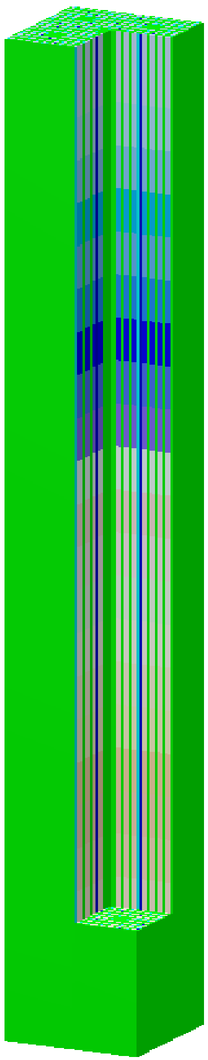
❑ Fuel assembly depletion modeling



[Fig. Bounding axial burnup profile*]



[Fig. Boron concentration conditions]



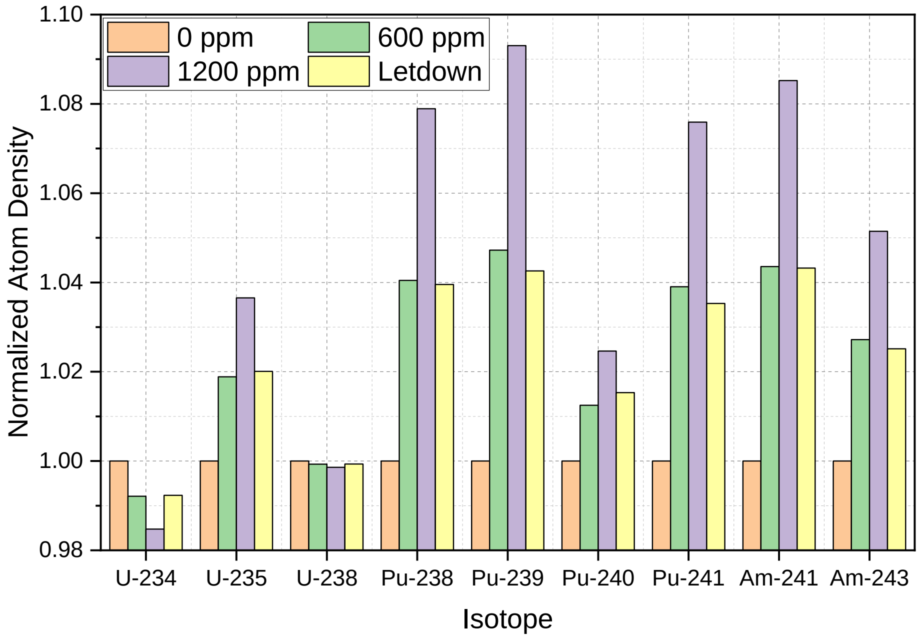
[Table. Modeling parameters]

Parameters	Values
^{235}U enrichment (wt%)	5.0
Burnup (MWd/kg)	40.0
Number of cycles	3
Cycle period (days)	540
Total cycle period (days)	1680
O/H period (days)	30

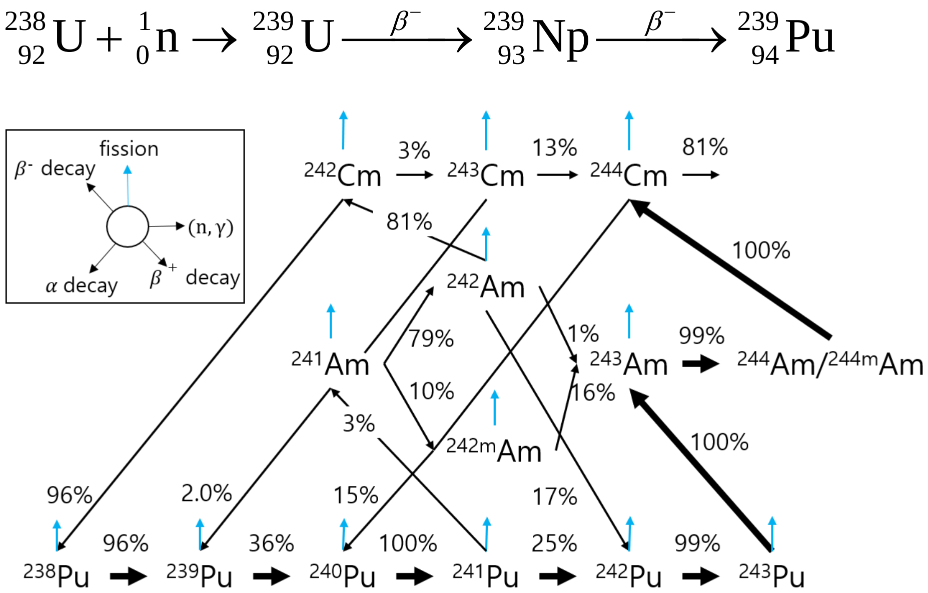
* J. C. Wagner, M. D. DeHart, and C. V. Parks, Recommendations for Addressing Axial Burnup in PWR Burnup Credit Analyses, In: NUREG/CR-6801, U.S. NRC, Washington, DC., ORNL/TM-2001/273, Oak Ridge National Laboratory, Oak Ridge, Tennessee 2001.

Methods and Results

❑ Isotopic inventory estimation of SNFs



[Fig. Actinides inventory for different boron conditions]



[Fig. Predominant path up to 244Cm and transmutation ratio*]

[Table. Comparison of keff for boron condition]

Boron condition (ppm)	Values	Δρ (pcm)
0	0.83620	-
600	0.84063	630
1200	0.84721	1554
Letdown	0.84054	671

- The SNFs depleted under high boron concentration conditions have a high fissile content.
- The result obtained wit the *letdown* concentration is similar to that with 600 ppm.

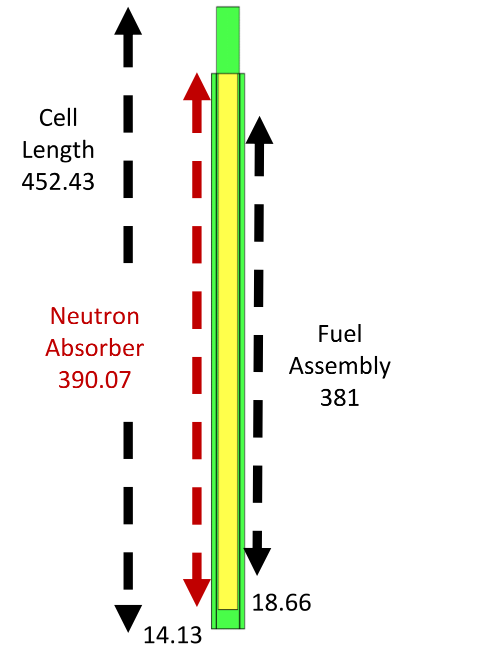
* Akihiro SASAHARA, Tetsuo MATSUMURA, Giorgos NICOLAOU & Dimitri PAPAIOANNOU Neutron and Gamma Ray Source Evaluation of LWR High Burn-up UO2 and MOX Spent Fuels, Journal of Nuclear Science and Technology, Vol 41, No. 4, pp. 448-456, 2004.

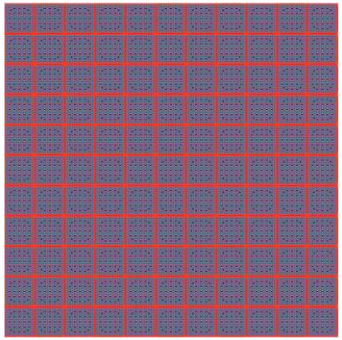
Methods and Results

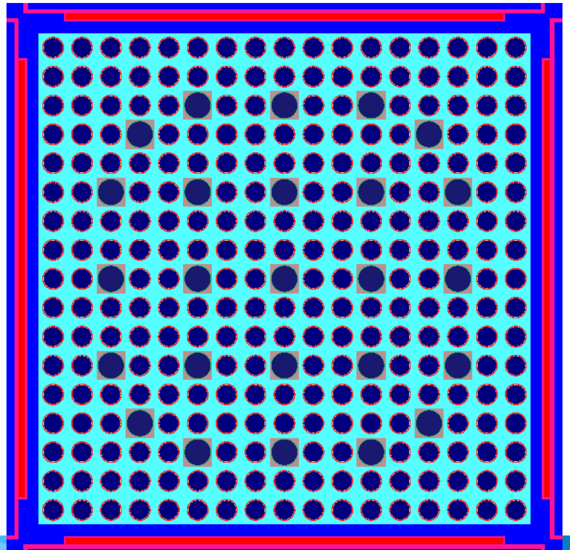
❑ Spent fuel storage rack (SFSR) model

[Table. Design parameters of the spent fuel storage rack region II]

Parameter	Value
Storage cell wall material	SS304
Storage cell inner dimension(cm)	21.511
Storage cell wall thickness(cm)	0.1905
Storage cell length(cm)	425.43
Neutron absorber material	Metamic
Neutron absorber width(cm)	18.36
Neutron absorber thickness(cm)	0.27
Neutron absorber length(cm)	390.07
Distance between neutron absorbers(cm)	14.13
Fuel assembly pitch(cm)	18.66







[Fig. Configuration of the spent fuel storage rack region II]

Methods and Results

❑ Calculation of Bias and Bias Uncertainty in Calculated Nuclide Concentrations

- The measured-to-calculated nuclide concentration ratio, X_n^j (M/C ratio)

$$X_n{}^j = M_n{}^j / C_n{}^j$$

- Sample mean $\overline{X_n}$, and sample standard deviation s_n

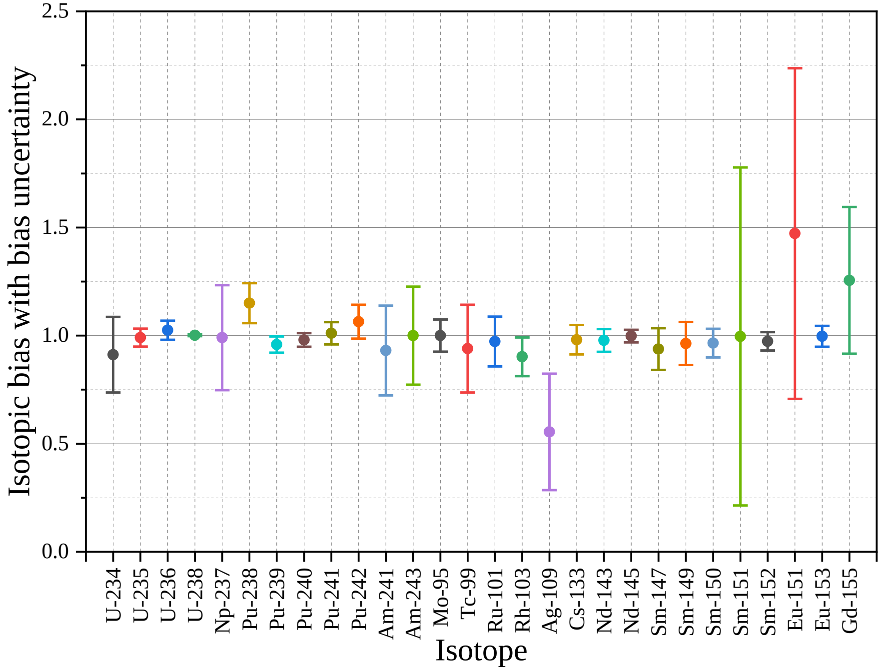
$$\overline{X}_n = \sum_{j=1}^{N_n} X_n{}^j / N_n$$ **Bias**

$$s_n = \sqrt{\sum_{j=1}^{N_n} \left(X_n^j - \overline{X}_n \right)^2 / (N_n - 1)}$$

- The isotopic bias uncertainty σ_n

$$\sigma_n = \begin{cases} s_n \cdot tf_2^{\,n},\ N_n \geq 10 \\ s_n \cdot tf_1^{\,n},\ N_n < 10 \end{cases}$$ **Uncertainty**

$tf_2^{\,n}$ The two-sided tolerance limit factor



[Fig. Isotopic bias and bias uncertainty values for PWR SNF compositions*]

*Georgeta Radulescu, Ian C. Gauld, Germina Ilas & John C. Wagner (2014) Approach for Validating Actinide and Fission Product Compositions for Burnup Credit Criticality Safety Analyses, Nuclear Technology, 188:2, 154-171, DOI: 10.13182/NT13-154

Methods and Results

❑ Nuclide Concentration for k_{eff} Calculations

- Nuclide concentration random sampling

$$C_{n,b}^{k} = \begin{cases} C_{n,b}(\overline{X_n^b} + \sigma_n^b \bullet R_n^k \big|_{normal\ dis.}), & N_n \geq 10 \\ C_{n,b}(\overline{X_n^b} + \sigma_n^b \bullet R_n^k \big|_{uniform\ dis.}), & N_n < 10 \end{cases}$$

- k_{eff} mean $\bar{k}_{eff}$, and k_{eff} standard deviation $\sigma_{k_{eff}}$

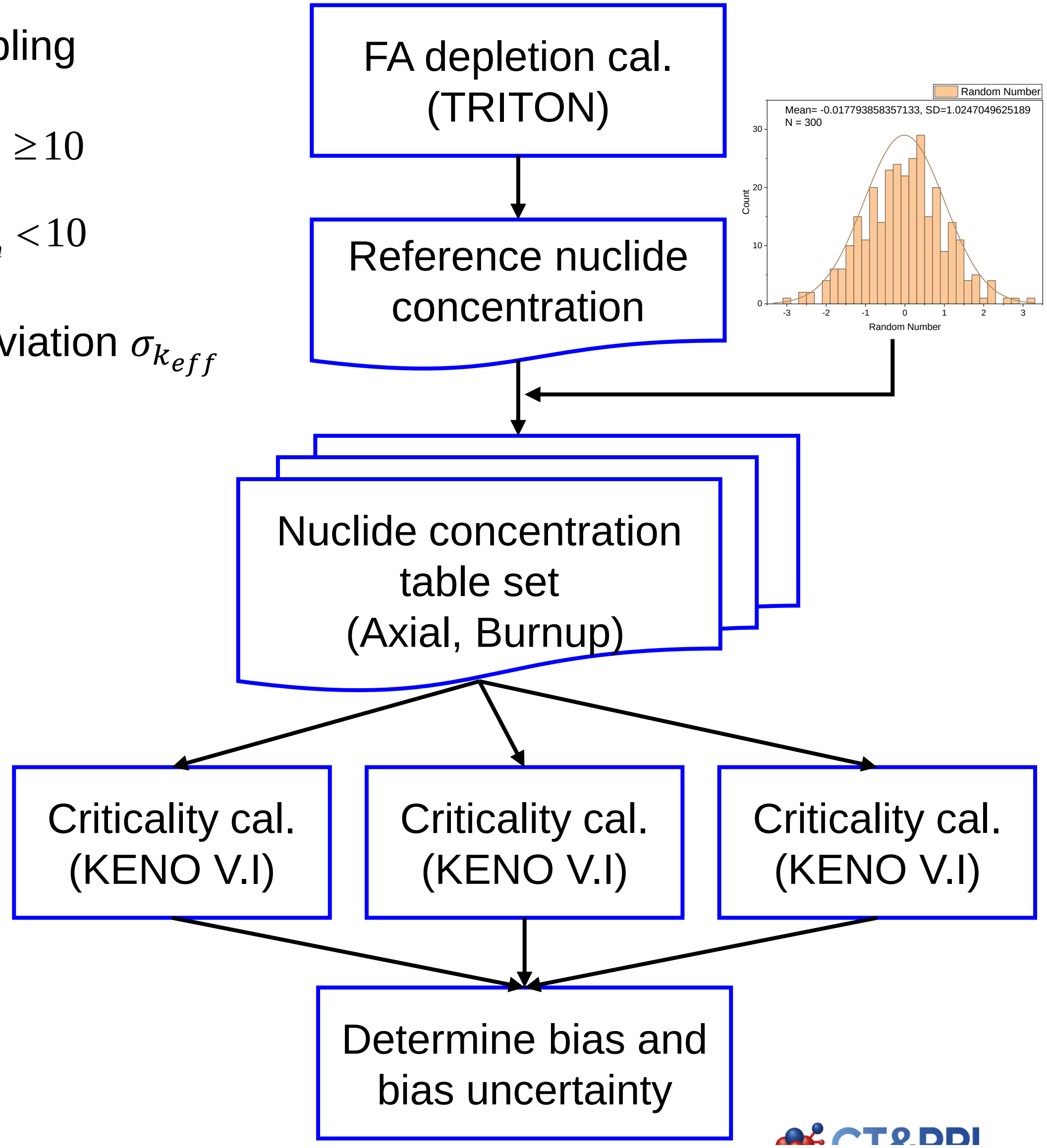
$$\bar{k}_{eff} = \sum_{i=1}^{N_c} k_{eff}^i \,/\, N_c$$

$$\sigma_{k_{eff}} = \sqrt{\sum_{i=1}^{N_c} \frac{(k_{eff}^i - \bar{k}_{eff})^2}{N_c - 1}}$$

- Bias and bias uncertainty of k_{eff}

$$\beta_{depl} = \bar{k}_{eff} - k_{eff}^{REF}$$ Bias

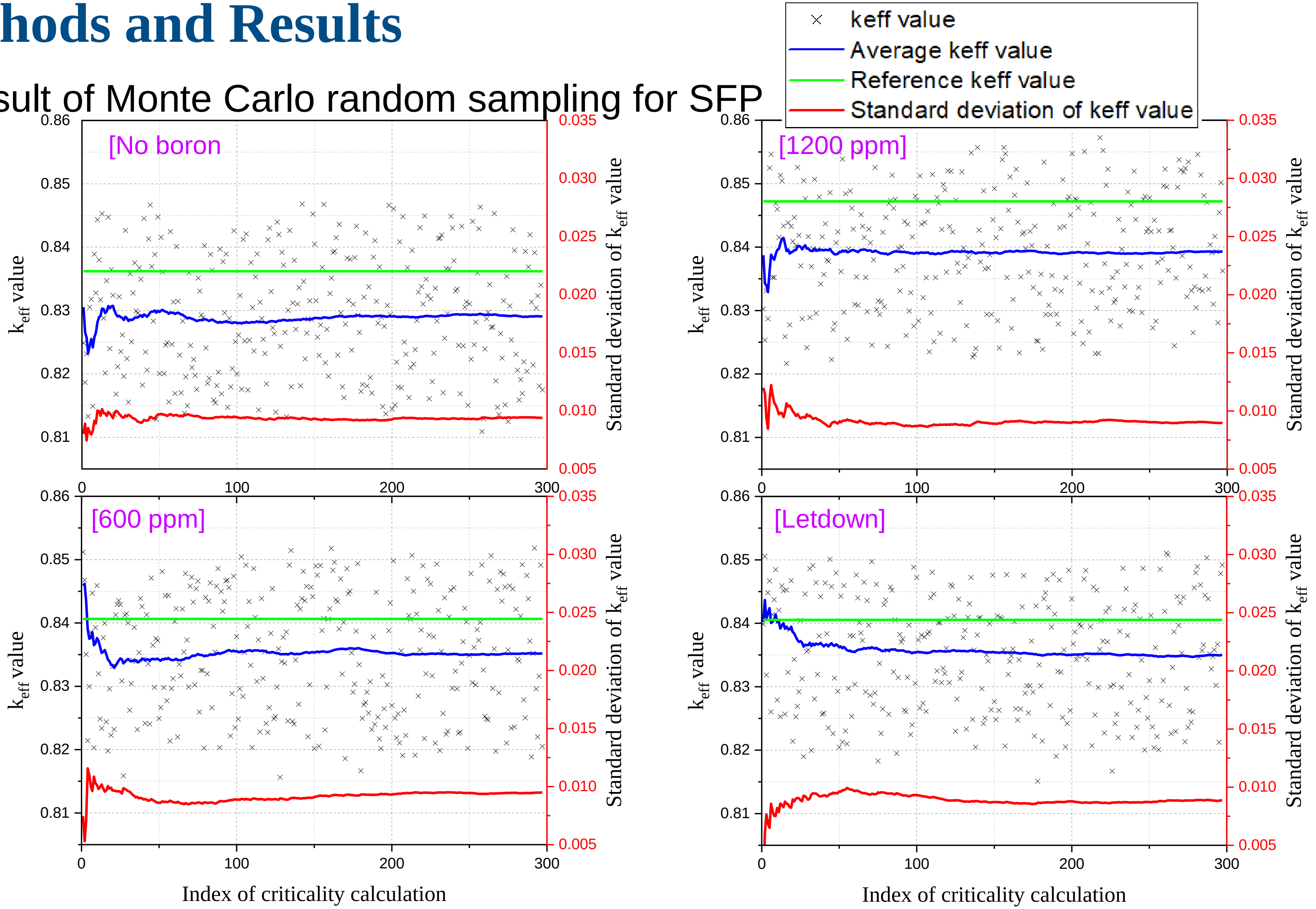
$$\Delta k_i = \sigma_{k_{eff}} \bullet tf^{N_c}$$ Uncertainty



[Fig. Workflow of calculation of bias and bias uncertainty in k_{eff}]

Methods and Results

❑ Result of Monte Carlo random sampling for SFP



	Reference k_{eff}	Average k_{eff}	S/D of k_{eff}	Bias of k_{eff}	Bias uncertainty of k_{eff}	Total depletion uncertainty
0 ppm	0.83620	0.82905	0.00940	-0.00715	0.01941	0.01941
600 ppm	0.84063	0.83515	0.00951	-0.00548	0.01964	0.01964
1200 ppm	0.84721	0.83929	0.00896	-0.00792	0.01850	0.01850
Letdown	0.84054	0.83502	0.00888	-0.00552	0.01834	0.01834

Conclusion

- This study evaluated depletion uncertainty for SNF pool using Monte Carlo random sampling by considering boron concentration in depletion calculation.
- If the inventory of fissile material in the SNFs is large, the reactivity of the SFSR increases.
- Because high boron concentration leads to spectrum hardening.
- Depletion uncertainty for SFSR was estimated using Monte Carlo random sampling.
- Bias of k_{eff} were estimated negative values for each boron conditions and total depletion uncertainty (include bias and bias uncertainty) values were estimated from 0.0183 to 0.0196 Δk.
- If the inventory of fissile material in the SNFs is large, the reactivity of the SFSR increases.

Thank you for your attention