Improvement of Axial Shape Index Prediction of STREAM/RAST-K by Considering the Moderator Temperature History

KNS 2023 Spring

May 19th, 2023

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Introduction

Introduction

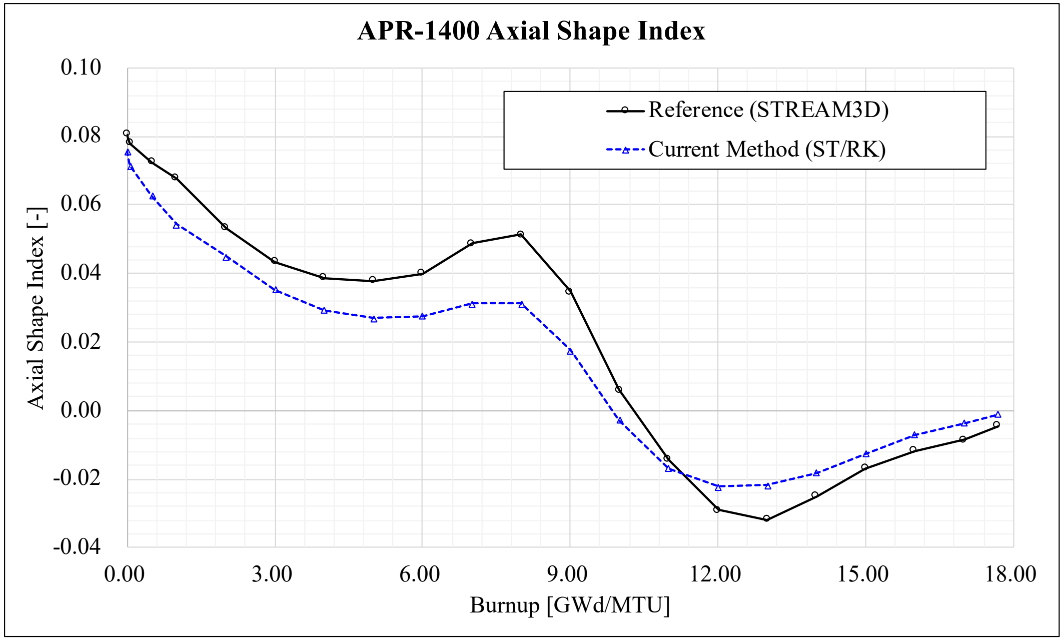
- **STREAM2D**
  - **2D lattice code**
  - **Group constants generation**
  - **PSM for resonance treatment**

- **STREAM3D**
  - **3D transport code**
  - **High-fidelity**
  - **PSM for resonance treatment**

- **ASI predicted by STREAM2D/RAST-K and STREAM3D**
  - **Axial Shape Index**

$$ASI = \frac{P_{BOT} - P_{TOP}}{P_{BOT} + P_{TOP}}$$

  - **Inconsistency appeared**
  - **Slope of ASI**



STREAM2D/RAST-K cross section feedback

Cross section model of RAST-K

▪ Functionalized cross section

$$\sigma = f\left(BU, ppm, \sqrt{T_{fuel}}, T_{mod}, CR\right)$$

– Burnup [GWd/MTU]

– Boron concentration [ppm]

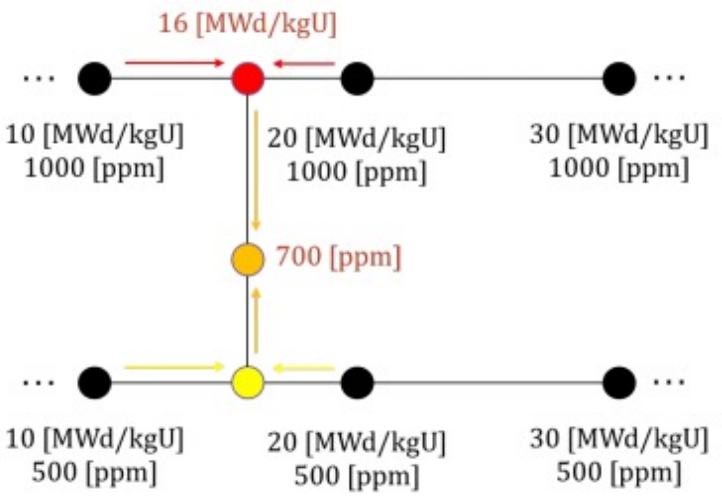
– Fuel Temperature [K]

– Moderator Temperature [K]

– Control rod

▪ Cross section feedback

- Interpolation between state points



Cross section feedback in RAST-K

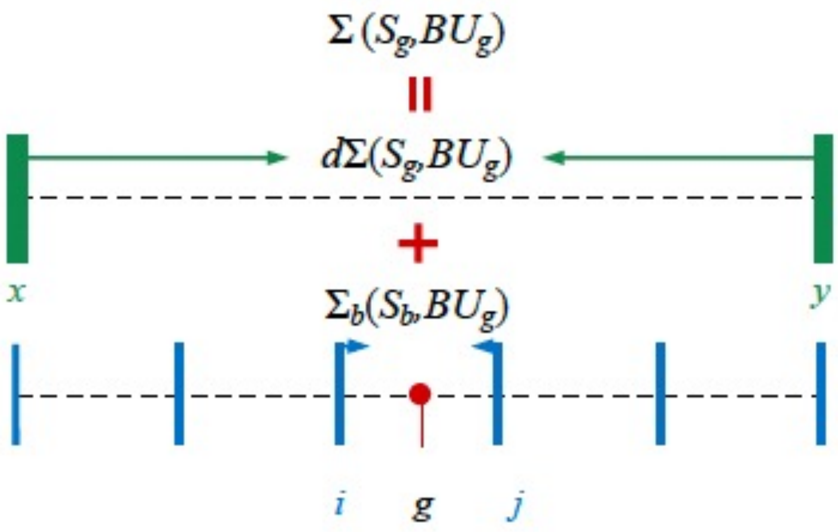
▪ Cross section feedback method

$$\boldsymbol{\Sigma}(\boldsymbol{S_g}, \boldsymbol{BU_g}) = \boldsymbol{\Sigma_b}(\boldsymbol{S_b}, \boldsymbol{BU_g}) + \mathbf{d}\boldsymbol{\Sigma}(\boldsymbol{S_g}, \boldsymbol{BU_g})$$

Σ	Any kind of cross-section
Σ_b	The base cross-section
S_b	The base state point (Reference state)
$d\Sigma$	The deviation of cross-section from the base state
S_g	The given state

Burnup grid (Branch)

Burnup grid (Base)



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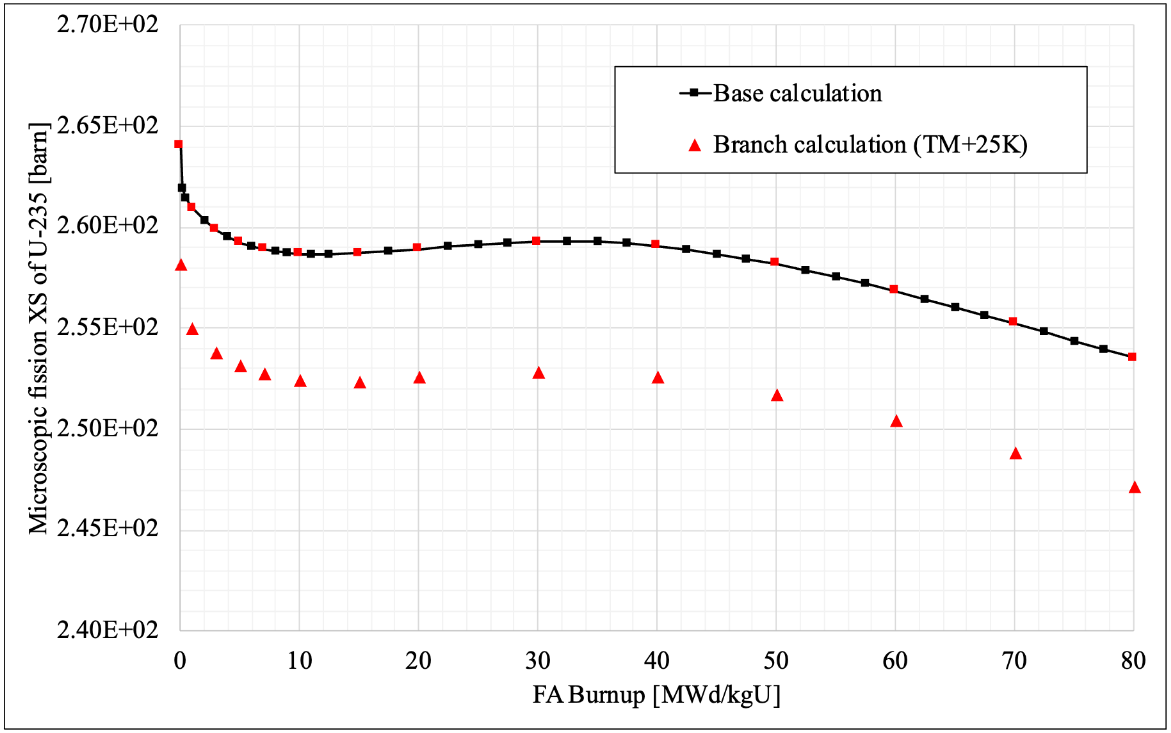
Base & Branch calculation

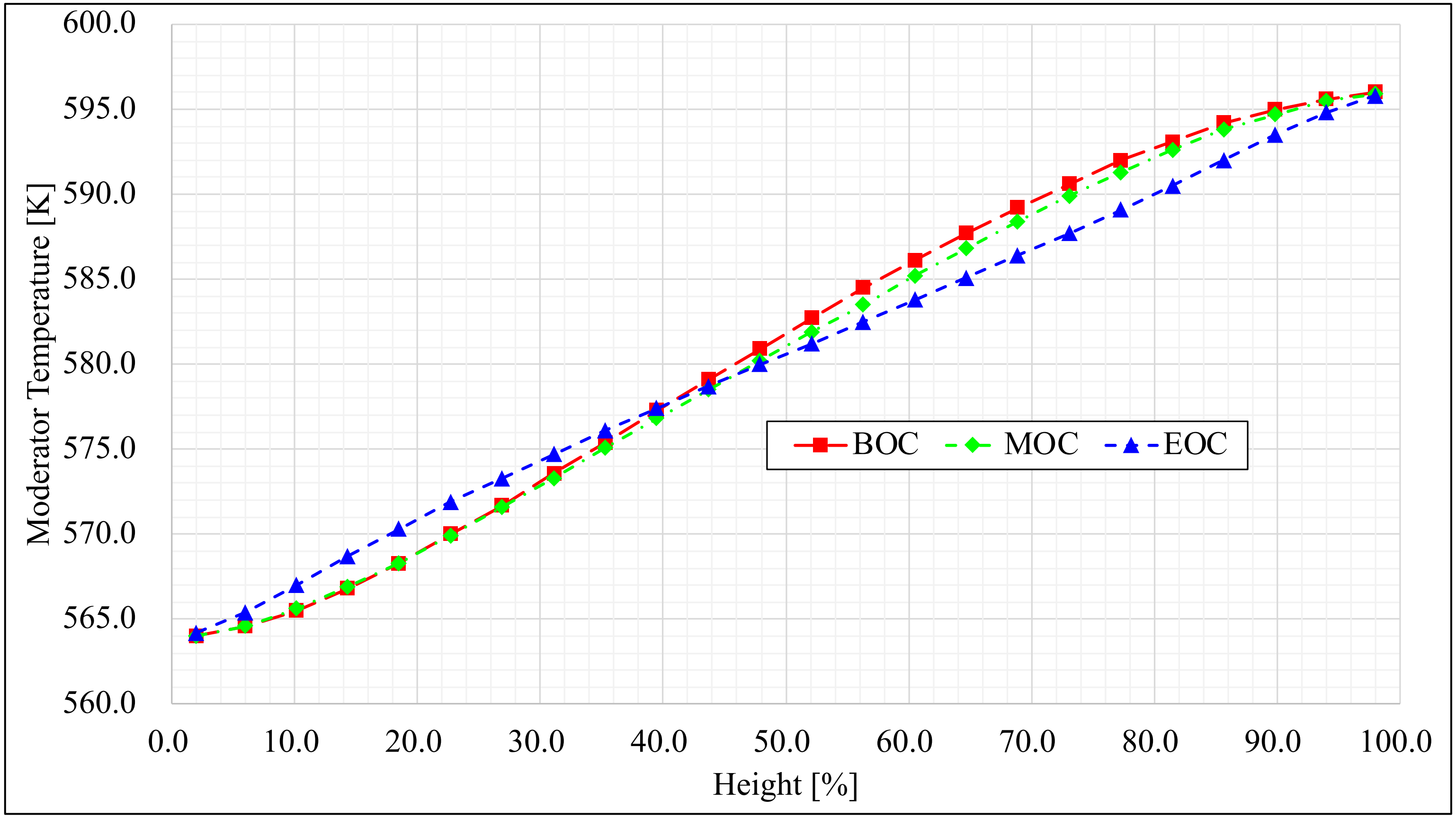
- **Base calculation**
  - **Calculation of Σ_b**
  - **Reference state point**
  - **Depletion calculation**
  - **Fine burnup grid**
  - **Write restart files**

- **Branch calculation**
  - **Calculation of $d\Sigma$**
  - **Read depletion data from restart file**
    - **generated by the base calculation**
  - **Coarse burnup grid**
  - **Various state points**



Limitation of current single-history XS

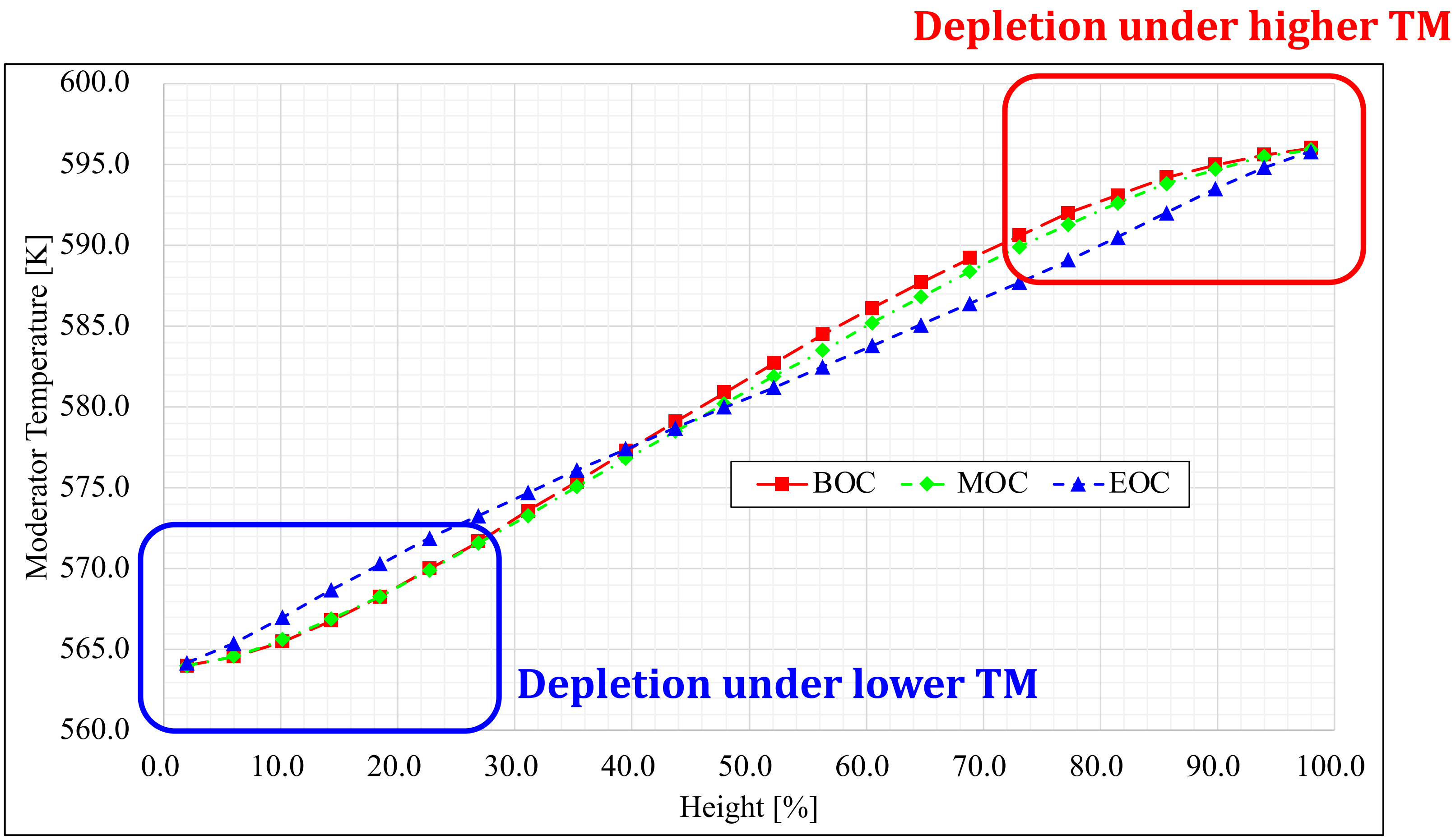
- **Commercial PWR's Axial TM distribution**



Axial moderator temperature distribution of APR-1400

Limitation of current single-history XS

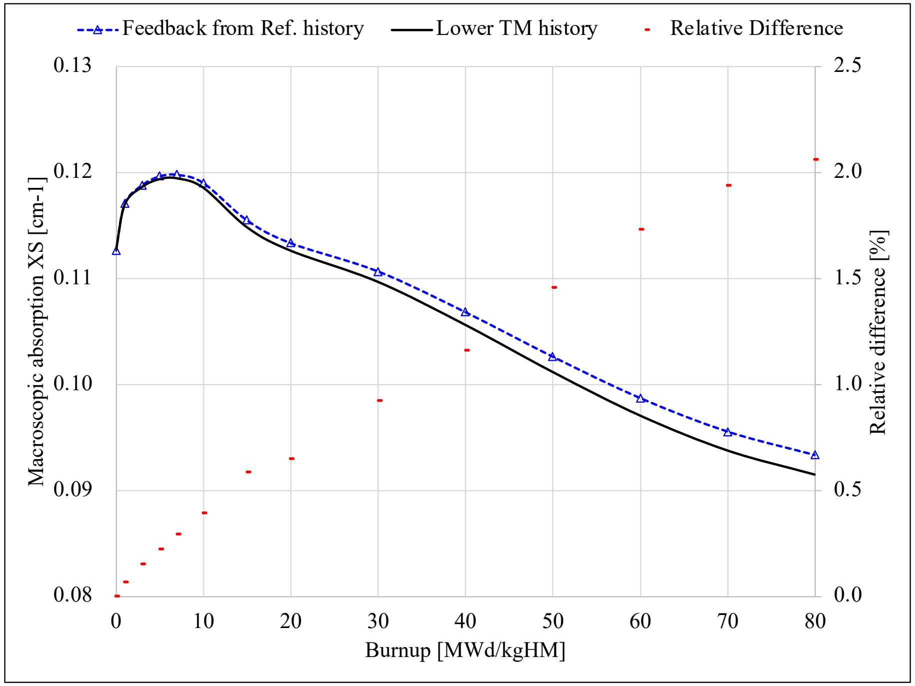
- **Commercial PWR's Axial TM distribution**



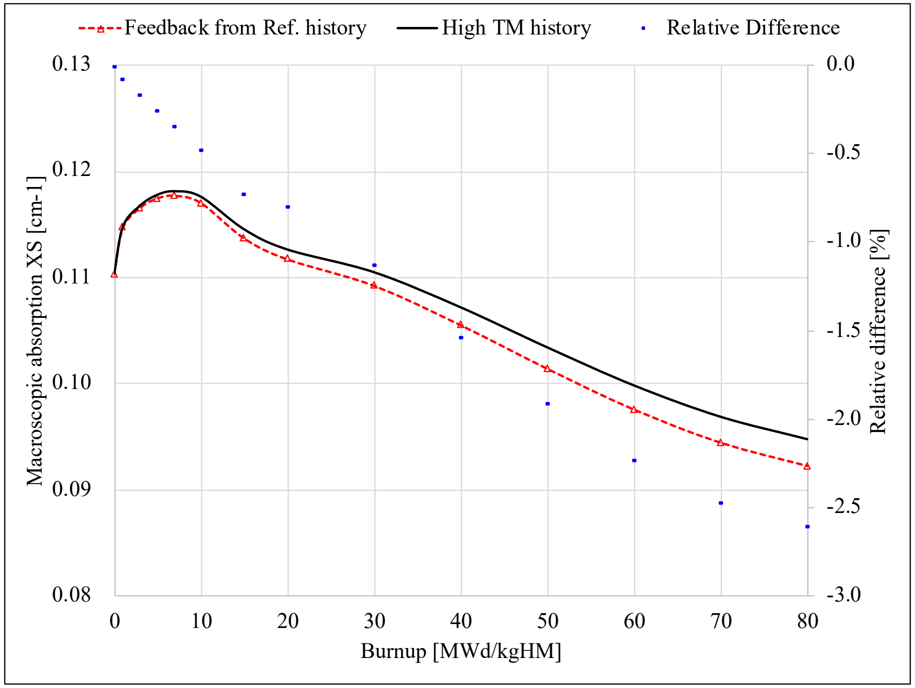
Axial moderator temperature distribution of APR-1400

Limitation of current single-history XS

- **Inconsistency of cross section**
  - **Different depletion history**
    - Cross section by compensation
    - Cross section feedbacked at exact history



Σ_a at lower TM condition

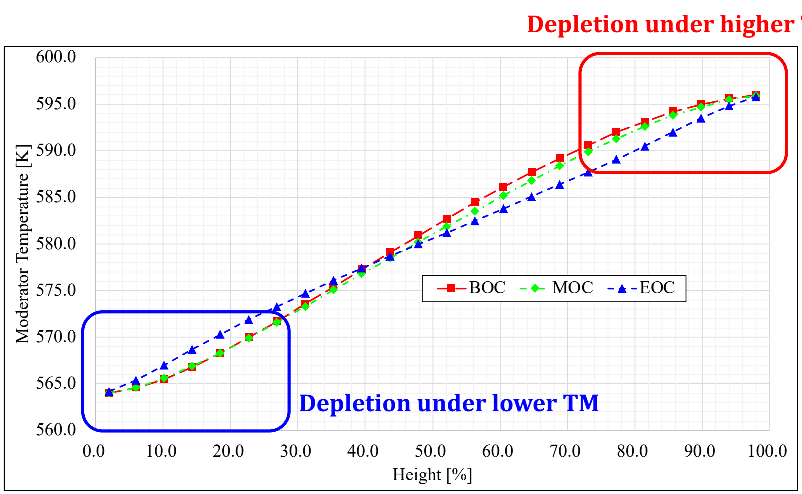


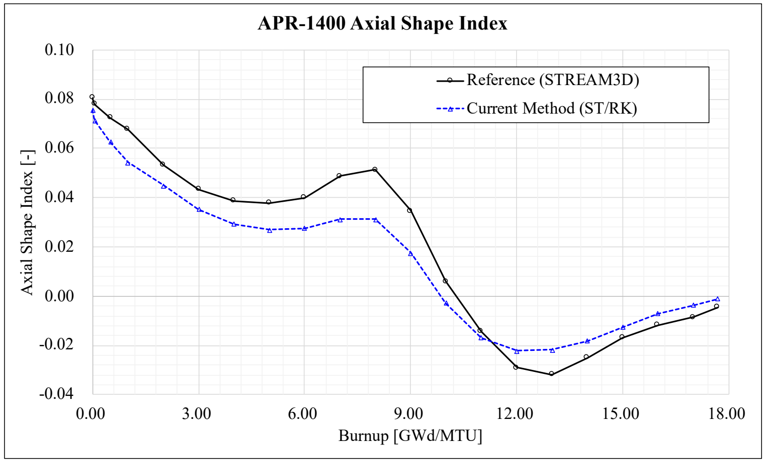
Σ_a at higher TM condition

Limitation of current single-history XS

- **Current XS contains only single-history of depletion**
  - **For the reference state**

- **Axial Shape Index (ASI)**
  - **History following cross section feedback**
  - **Additional history for the upper/lower region**



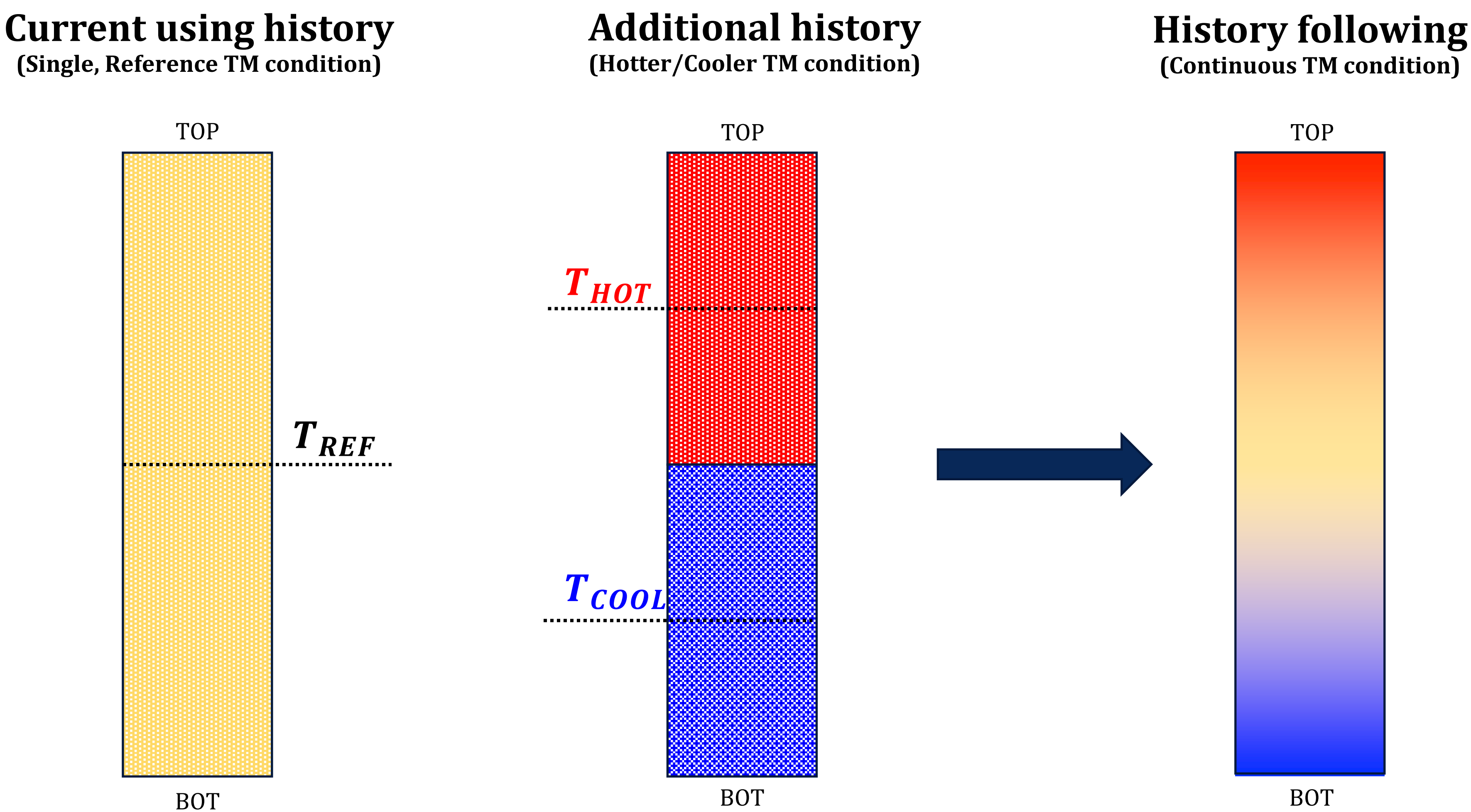


Modification of cross section feedback

Utilizing multi-history XS

Multiple depletion history

- **Utilizing the additional history**
  - **Additional 2 depletion history for the upper/lower region**

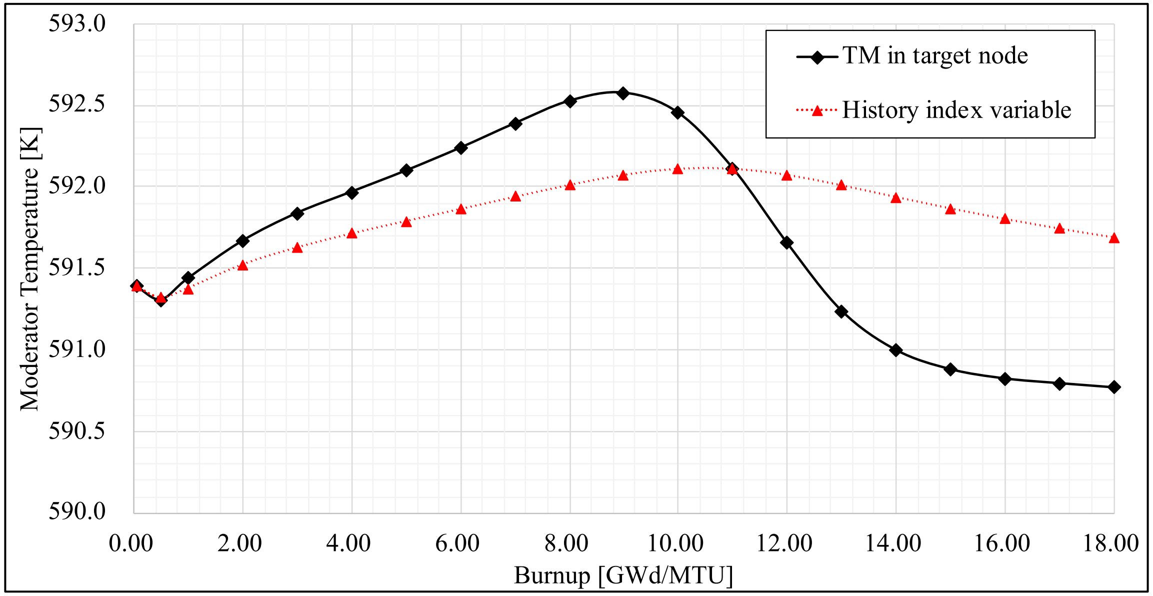


Node-wise cross section feedback utilizing multi-history XS

▪ TM History index variable

$$T_{Mod}^{Hist}(k) = \frac{\sum_{i=1}^{k} T_{Mod}^{i} \cdot \Delta BU_i}{\sum_{i=1}^{k} \Delta BU_i}, \qquad (k = \text{current burnup step})$$

- **Node-wise variable saving depletion history**
- **Burnup weighted average of moderator temperature**



Moderator temperature history index

Cross section feedback using TM History index variable

- **Lower moderator temperature history (lower region)**
  - Weighting factor, w_L

$$w_L = \frac{T_{REF} - T_{mod}^{Hist}}{T_{REF} - T_{COOL}}$$

  - Cross section feedback

$$\sigma = (1 - w_L) \cdot \sigma_{REF} + w_L \cdot \sigma_{COOL}$$

- **Higher moderator temperature history (upper region)**
  - Weighting factor, w_U

$$w_U = \frac{T_{mod}^{Hist} - T_{REF}}{T_{HOT} - T_{REF}}$$

  - Cross section feedback

$$\sigma = (1 - w_U) \cdot \sigma_{REF} + w_U \cdot \sigma_{HOT}$$

RAST-K depletion calculation results

Critical boron concentration/Axial Shape Index results

RAST-K depletion calculation

Model Information

- APR-1400
- Steady state (Critical boron search)
- Eq.Xe, ARO
- Core power : 3983 MWth (100 % power)
- Moderator inlet temperature: 563.75 K
- Comparable parameter: Critical Boron Concentration, Axial Shape Index

Reference case

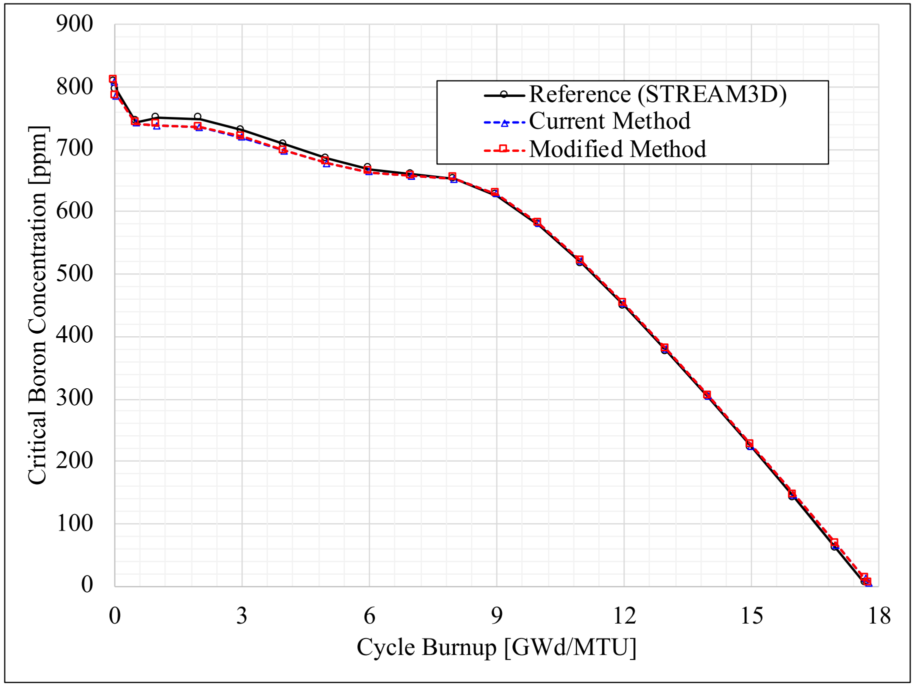
- STREAM3D output

Test cases

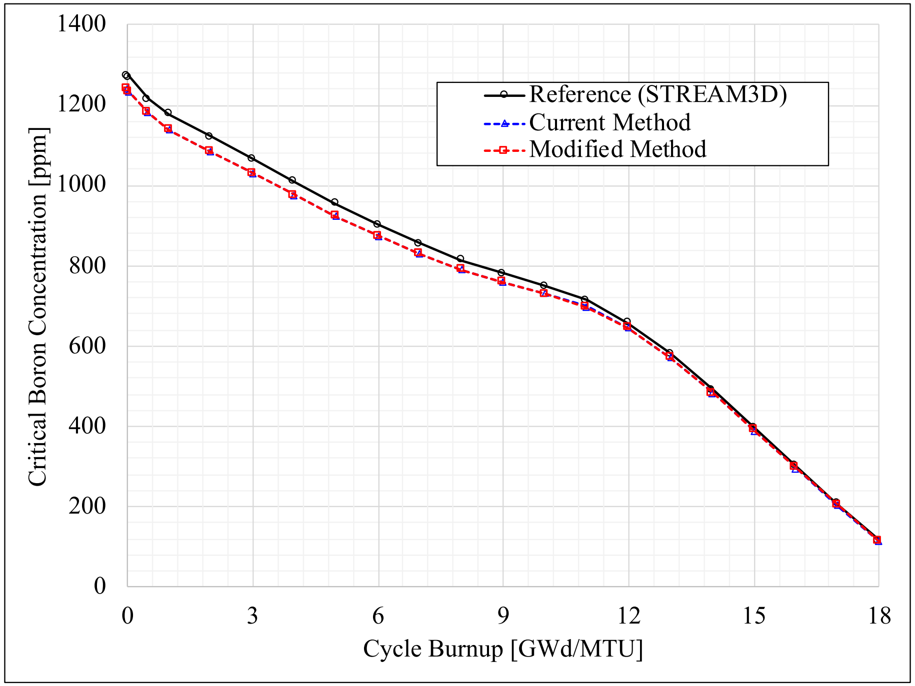
- RAST-K output utilizing single-history XS (Ref. TM : 584 K)
- RAST-K output utilizing multi-history XS (Ref. TM : 559 / 584 / 609 K)

Critical Boron Concentration

- **Global variable**
  - **CBC difference between current and modified method < 5 ppm**
  - **Reactivity change of upper/lower region were balanced**



Predicted CBC of initial core



Predicted CBC of 3rd cycle

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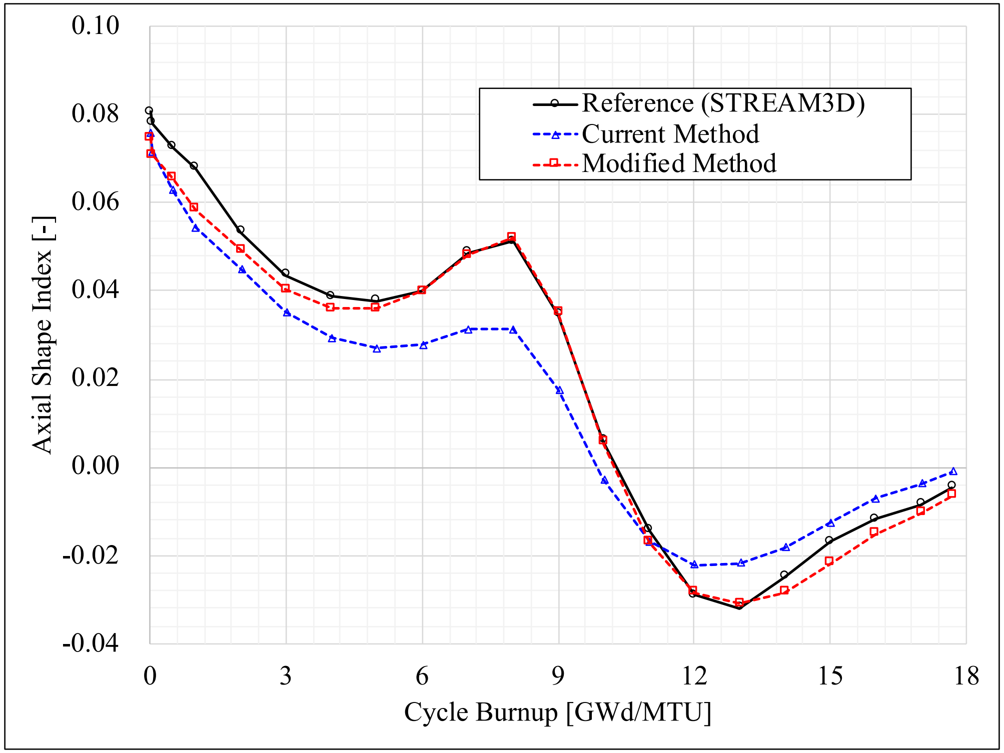
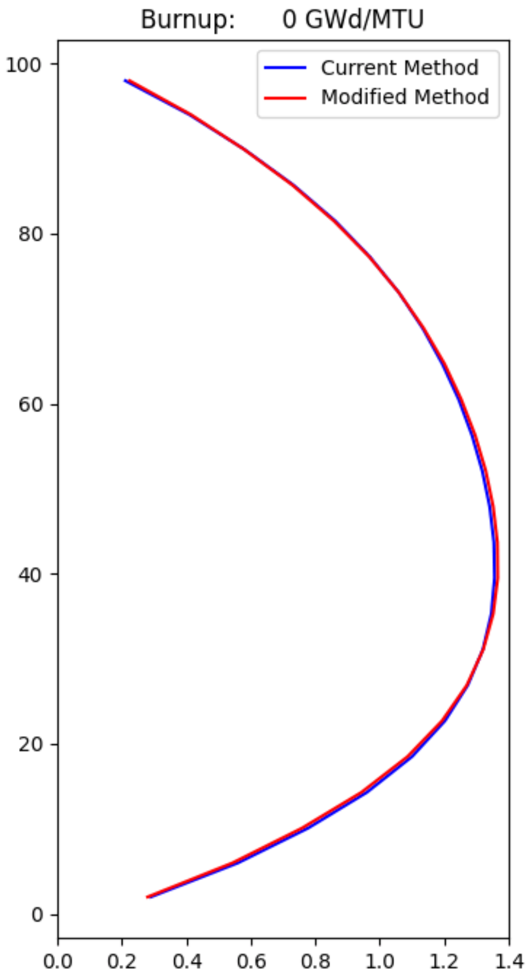
Axial Power Prediction

- **Initial core**
  - **At BOC**
    - Higher power at lower region
    - More moderation due to dense moderator



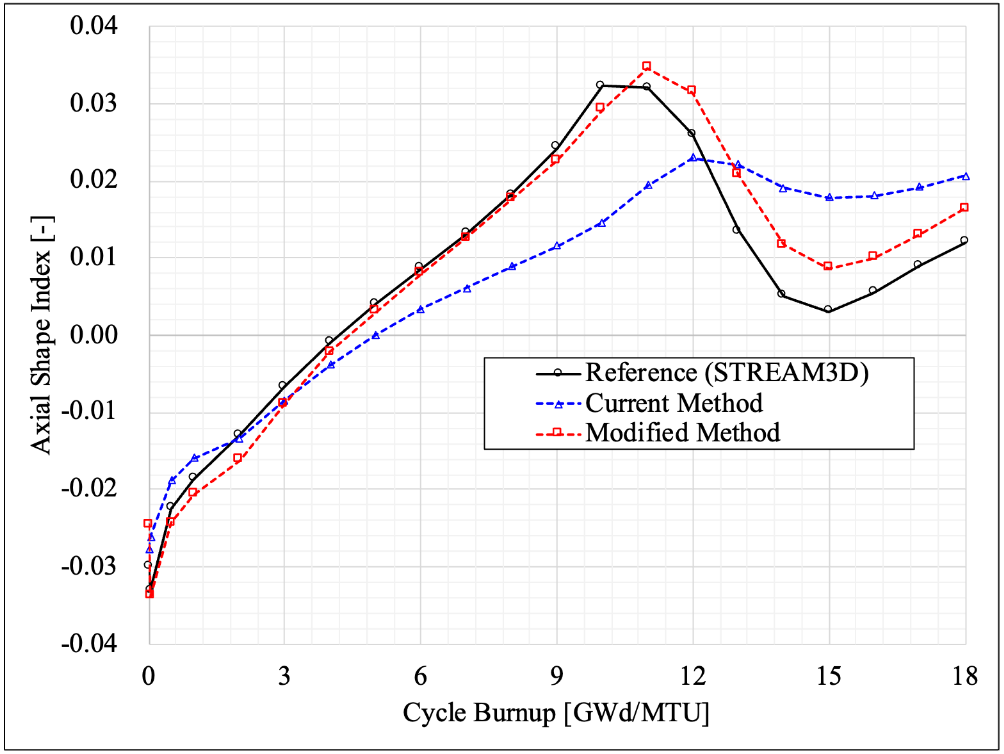
Predicted ASI of initial core



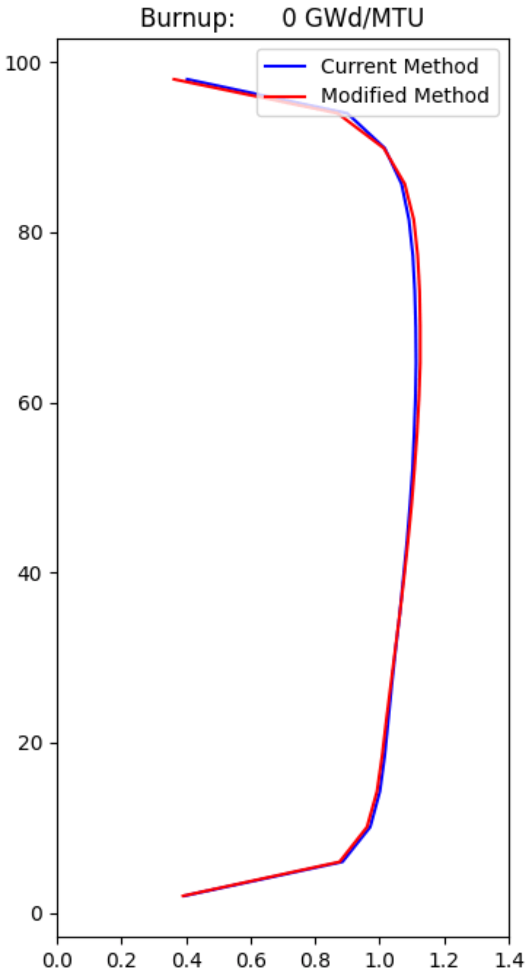
Axial power distribution

Axial Power Prediction

- **Cycle 3**
  - **At BOC**
    - Higher power at upper region
    - Higher burnup of lower region (burnt fuel)



Predicted ASI of 3rd cycle



Axial power distribution

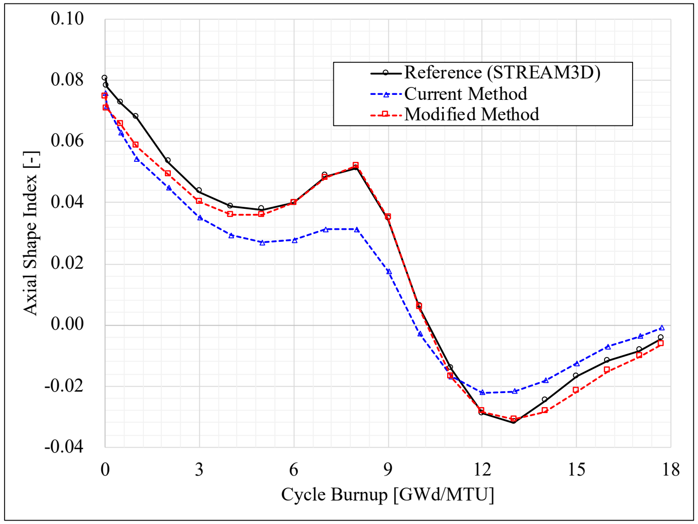
Conclusion

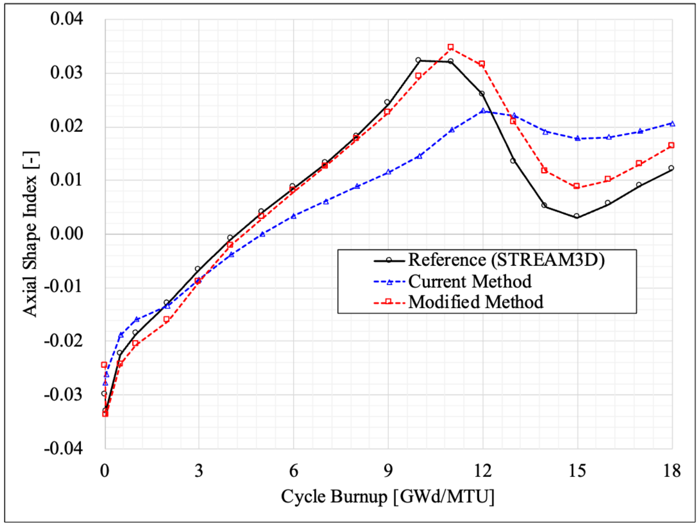
Conclusion

- **Limitation of single-history based cross section feedback**
  - **Cross section feedback under different depletion environments**

- **Additional histories for the accurate cross section feedback**
  - **To follow axially heterogeneous history**

- **Improved Axial Shape Index prediction accuracy**
  - **Improved prediction of axial power distribution due to depletion**





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