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Advancing Nuclear Design: Optimizing Burnable Poison Configurations for Extended Cycle Small Modular Reactors

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1. INTRODUCTION

- **Objective:** Explore the Double Tube Burnable Poison (DTBP) design to extend the operational cycle of Small Modular Reactors (SMRs) while maintaining low soluble boron concentrations.
- **Context:** Addressing limitations of conventional Burnable Poisons (BPs) like IFBA, Erbia, and WABA in extended 24-month cycles.

2. REFERENCE DESIGN AND COMPUTATIONAL CODES

- **Reactor:** SMART (100 MWe, 17×17 Westinghouse fuel assembly)
- **Challenge:** Incorporation of HALEU fuel, leading to high excess reactivity and neutron leakage.
- **Codes Used:** DeCART2D and MASTER for assembly and core calculations.

TABLE 1. Design goals for developed smart reactor

Design Parameters	Limitation
Max. fuel enrichment (w/o)	9.90
Min. cycle operating length (EFPY)	3.5 (> the reference design by ~ 1 year)
Max. CBC (ppm)	< 350
Max. 2D power peaking factor (Fq-XY)	1.59
Max. 3D power peaking factor (Fq-XYZ)	2.6
Moderator temperature coefficient (MTC) (pcm/°C)	0 ~ -80

3. DTBP DESIGN CONCEPTS

- **DTBP Configurations:**
  - **DTBP-Wet:** Features a water hole.
  - **DTBP-Dry:** ZIRLO rod replaces the water hole.
- **Design Adaptations:** Increase in Gd_2O_3 concentration for better control of reactivity.

TABLE 2. Design parameters of a DTBP design

Design Parameters	DTBP
Inner Cladding I.D. (cm)	0.44196
Inner Cladding O.D. (cm)	0.54864
Inner Tube O.D. (cm)	0.67818
Inner Tube Absorber Material	Al_2O_3-B_4C
Outer Tube O.D. (cm)	0.80772
Outer Tube Absorber Material	ZIRLO-Gd_2O_3
Outer Cladding O.D. (cm)	0.96774
Cladding Material	ZIRLO
Gap Thickness (cm)	0.01397
Gap Material	Air

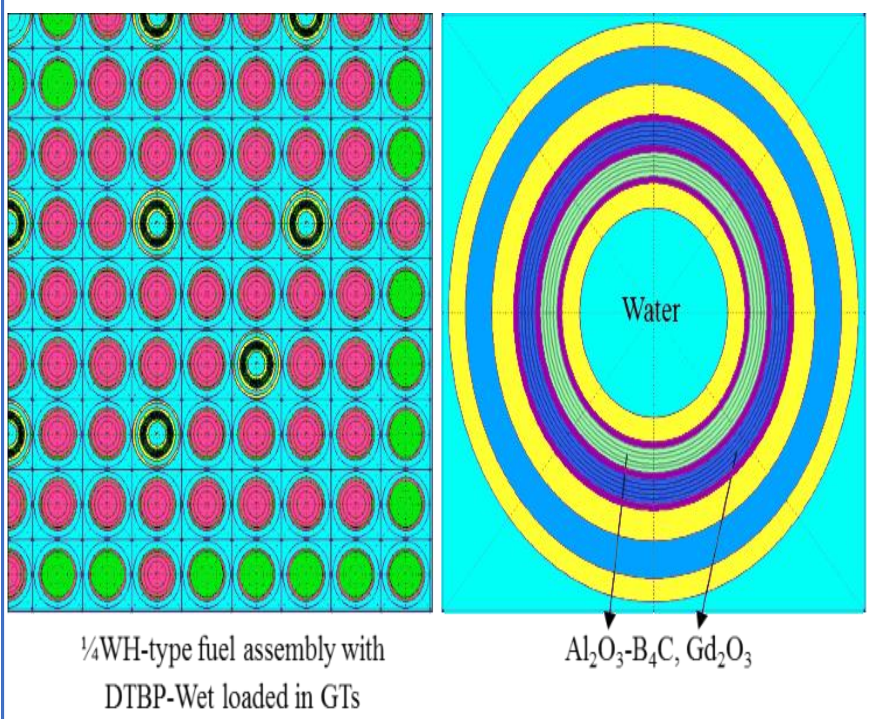

FIG. 1. DTBP-Wet design

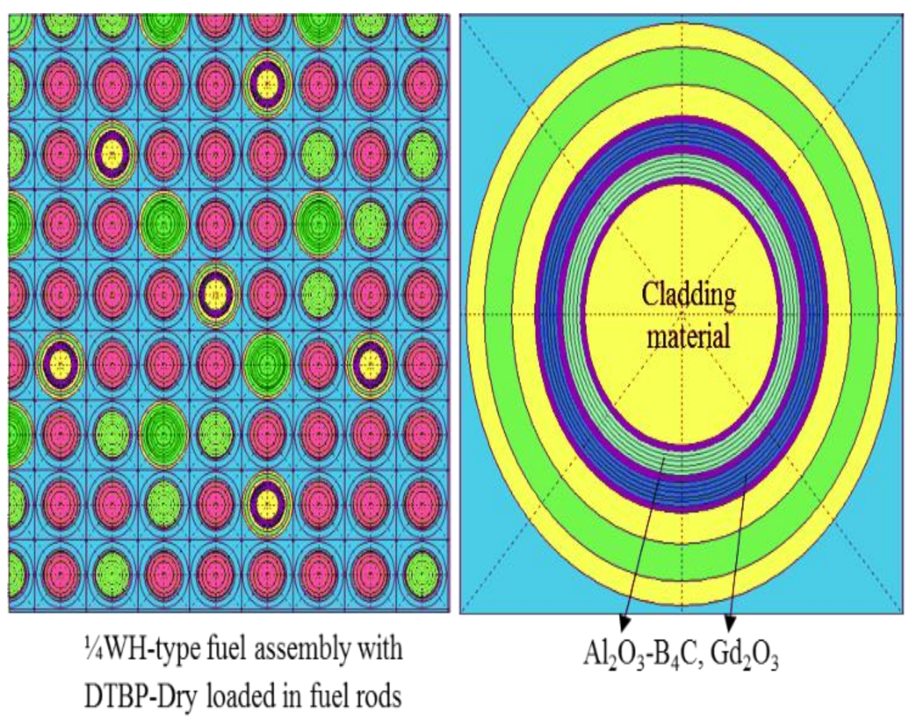

FIG. 2. DTBP-Dry design

4. OPTIMIZING K-INFINITE LETDOWN CURVE

- **Step 1:** Increase Gd_2O_3 concentration to flatten the k-infinite curve at EOC.
- **Step 2:** Combine DTBP with Erbia to flatten the k-infinite curve at BOC and MOC.

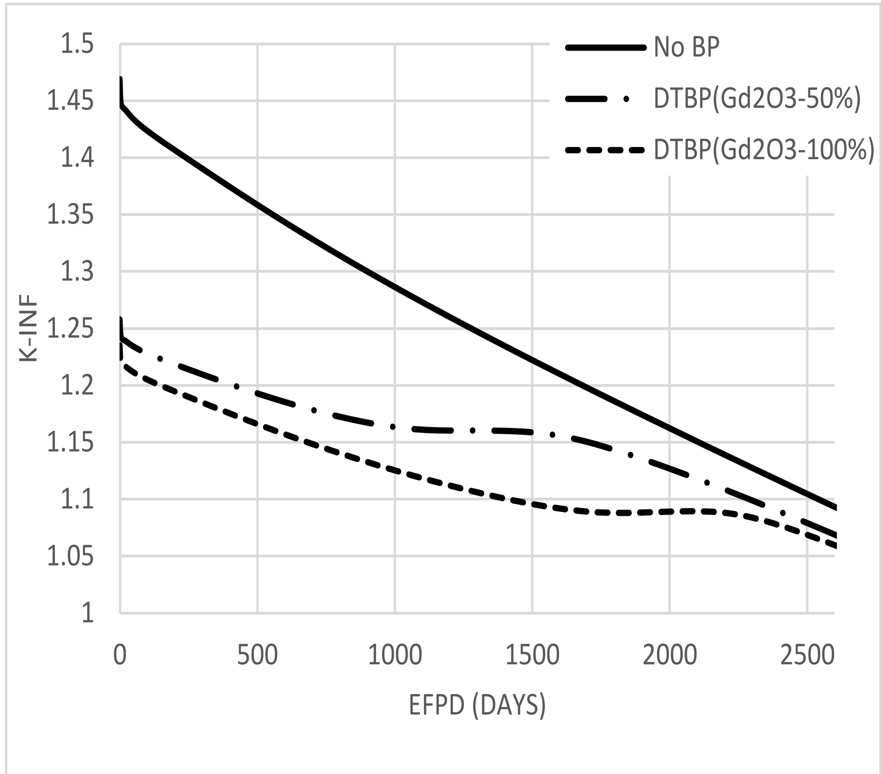

FIG. 3. Comparison of k-infinite letdown curve for different DTBP cases

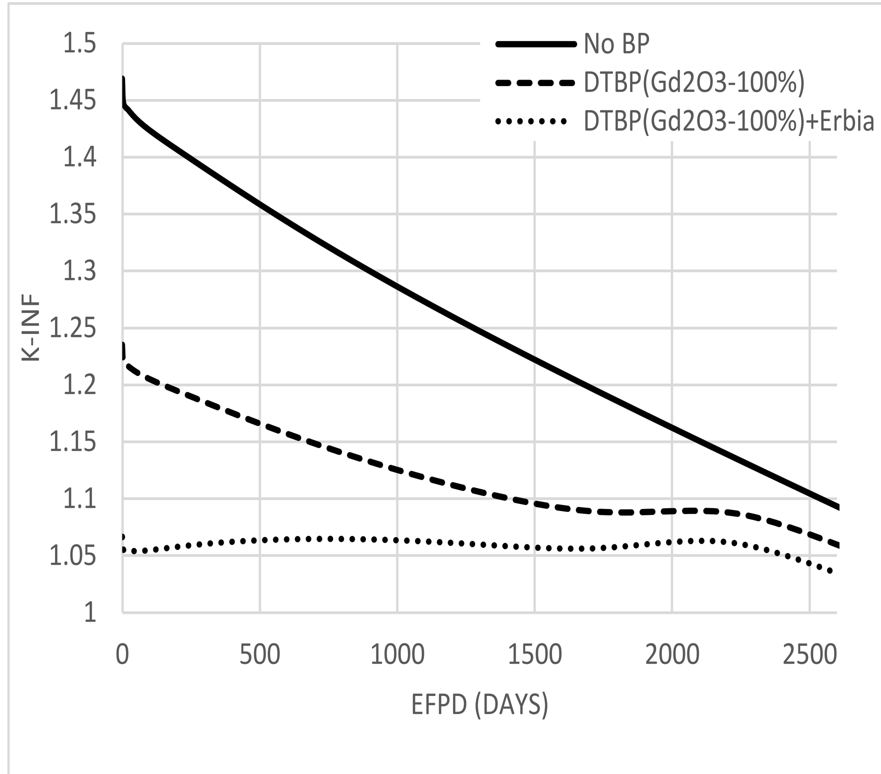

FIG. 4. Comparison of k-infinite letdown curve for DTBP & DTBP+Erbia cases

5. RESULTS AND DISCUSSION

- **Cycle Length:** DTBP-Wet&Dry + Erbia core achieves 1295 Effective Full Power Days (EFPD).
- **CBC:** Lower than reference core, within design goals.
- **MTC:** Within acceptable limits, lower than reference core.
- **Power Peaking Factors:** Slightly higher but within design limitations.

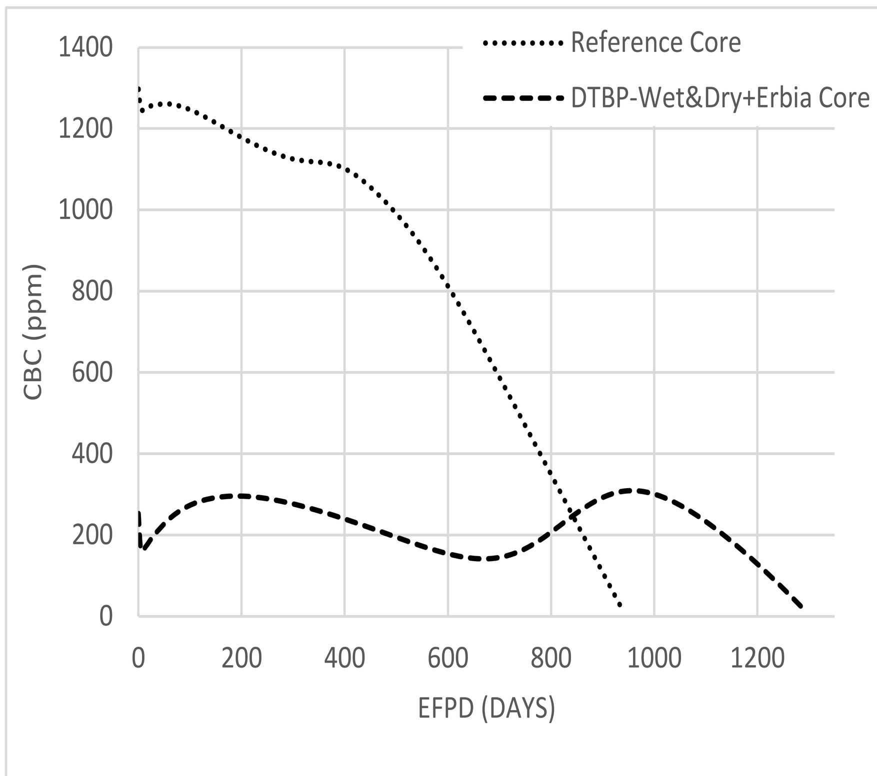

FIG. 5. Comparison of CBC for Reference & DTBP-Wet&Dry + Erbia cores

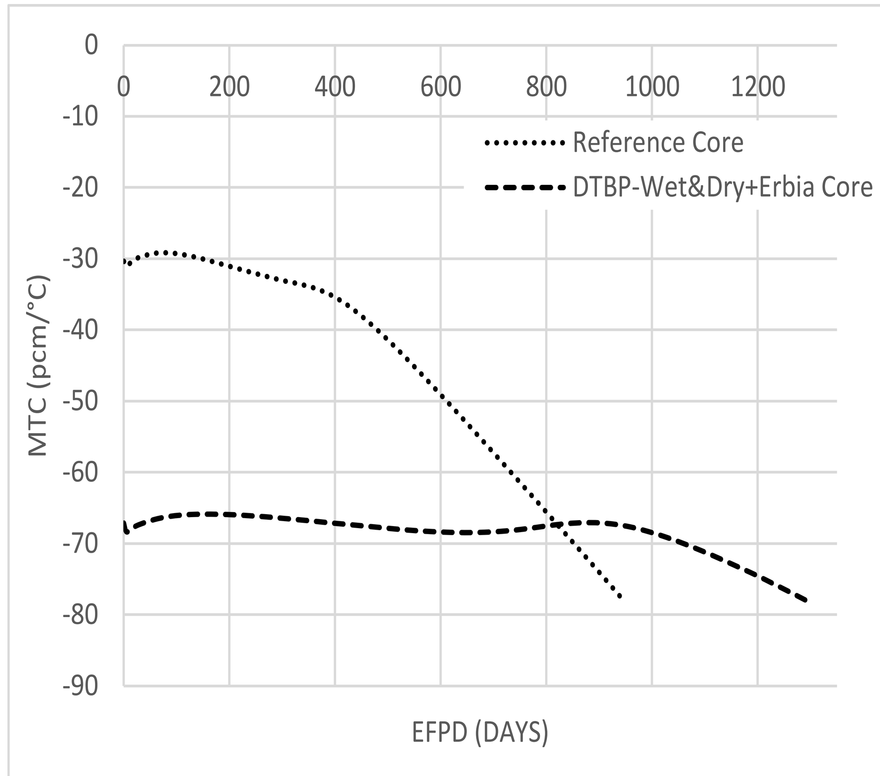

FIG. 6. Comparison of MTC for Reference & DTBP-Wet&Dry + Erbia cores

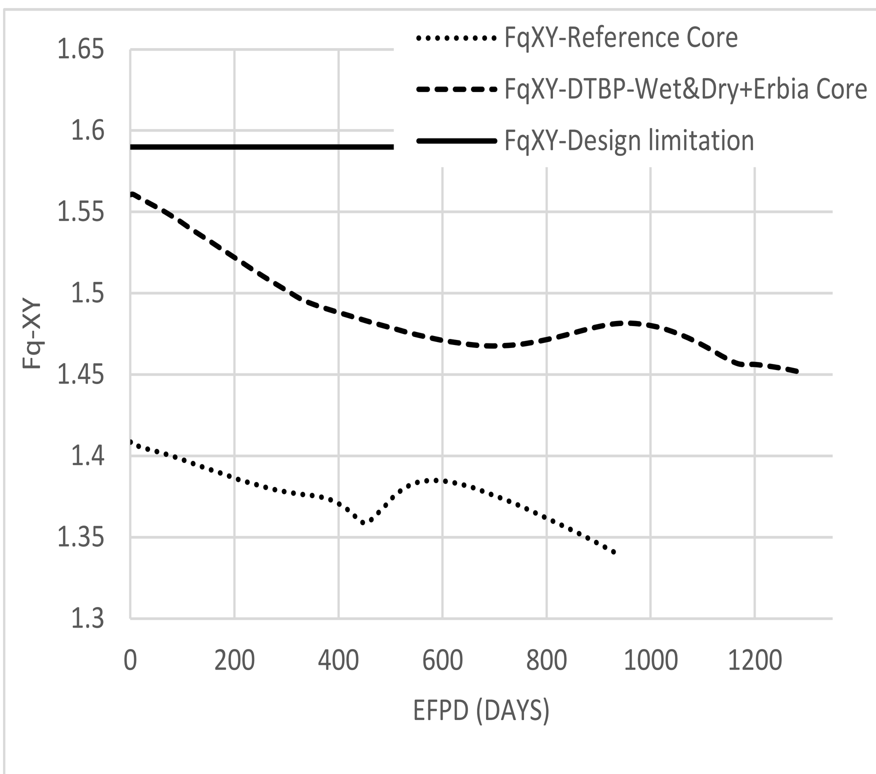

FIG. 7. Comparison of Fq-XY for Reference & DTBP-Wet&Dry + Erbia cores

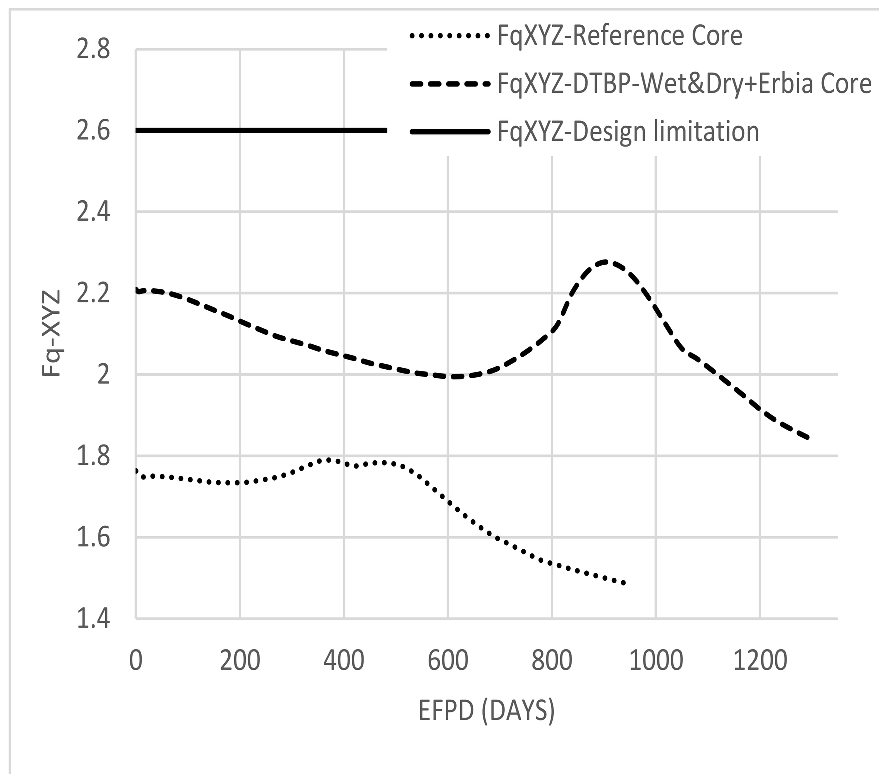

FIG. 8. Comparison of Fq-XYZ for Reference & DTBP-Wet&Dry + Erbia cores

6. CONCLUSION

- **Findings:** DTBP-Wet&Dry + Erbia core design effectively extends SMR operational cycles while maintaining safety and reactivity control.
- **Future Work:** Further optimization of DTBP designs for broader reactor applications.

7. CONTACT

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