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Neutronics Analysis of SMR with Natural Circulation using STREAM/RAST-K 2.0

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Introduction

□ Small Modular Reactors (SMRs) with their small size, reducing dependence on active control system and providing siting flexibility for locations unlike traditional larger reactors are receiving research interest from many countries.

□ The natural circulation in the reactor coolant system (RCS) primary loop is one of research topics in the SMR. It removes the reactor coolant pump (RCP) and provides passive safety systems into new nuclear power plant designs.

1. To mitigate the effect of human errors and equipment failures
2. To provide increased time to enable the operators to prevent or mitigate severe accidents

□ This paper investigates the neutronics aspects of the SMR design using the natural circulation (NC) compared to that using the forced circulation (FC) by the STREAM/RAST-K 2.0 (ST/R2) code system.

Description

□ Single-phase loop momentum equation for steady flow

$$-g\oint \rho dz = \frac{1}{2}K_1\frac{\dot{m}^2}{A^2\rho_l}$$

- **$\dot{m}$: mass flow rate**
- **A : flow area**
- **g : the acceleration by gravity**
- **K_1 : sum of the single-phase frictional and form losses around the loop**
- **ρ_1 : liquid density**

$$\dot{m} = \left(\frac{2A^2\beta g\rho_l^2\Delta L\dot{Q}}{C_pK_1}\right)^{\frac{1}{3}},$$

- **$\dot{Q}$: thermal power of the reactor**
- **ΔL : height differences between core and steam generator**
- **ρ_1 : liquid specific heat**
- **β : liquid volumetric expansion coefficient**

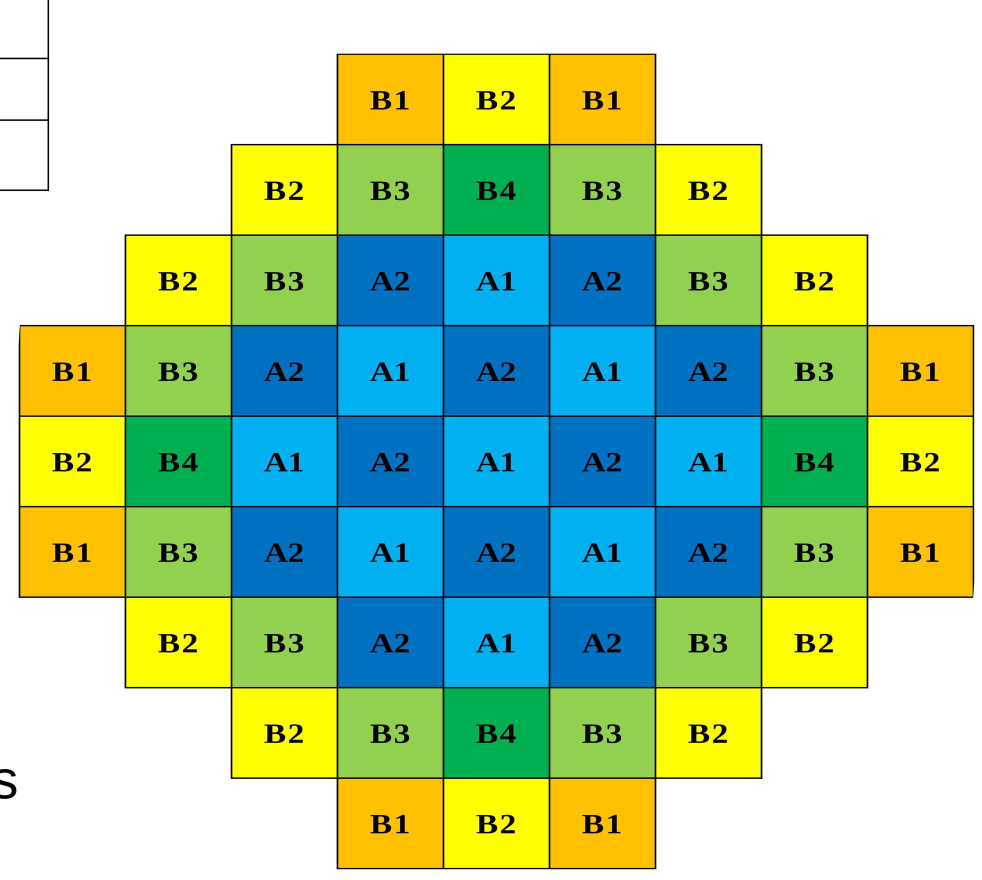
□ Scaling method of mass flow rate of arbitrary SMR

$$\dot{m} = \left(\frac{2A^2\beta g\rho_l^2\Delta L\dot{Q}}{C_pK_1}\right)^{\frac{1}{3}}, \quad \Rightarrow \quad \frac{\dot{m}_{arbitrary}}{\dot{m}_{reference}} \approx \left(\frac{A^2_{arbitrary}\dot{Q}_{arbitrary}}{A^2_{reference}\dot{Q}_{reference}}\right)^{\frac{1}{3}},$$

□ Core design parameters of reference SMR

Parameter	Value
$\dot{Q}$ (MWt)	160
No. of FA	37
$\dot{m}$ (kg/s)	587.7
T_{in} (℃)	258
T_{out} (℃)	314
ΔT (℃)	56
T_{avg} (℃)	283.89

□ Test SMR consists of 57 FA including two enrichment region
- Low enrichment region A (2.82 w/o U^{235})
- High enrichment region B (4.95 w/o U^{235})
- Gd enrichment (8.0 w/o)



□ Test SMR core design parameters for FC and NC condition

Parameter	FC	NC
$\dot{Q}$ (MWt)	330	330
No. of FA	57	57
$\dot{m}$ (kg/s)	2090	997.8
T_{in}(℃)	296	263
T_{out} (℃)	323	323
ΔT (℃)	27	60
T_{avg} (℃)	309.86	295.06

□ Results

RCS Circulation	NC	FC
Mass flow rate	Lower	Higher
T_{avg}	Lower	Higher
CBC	Higher	Lower
MTC	Less negative	More negative
ASI (at BOC)	Bottom-Skewed	Unskewed
PPFs	Similar	
MDNBR	Lower	Higher

□ The moderator temperature rise is larger and the average moderator temperature becomes lower in the NC case due to the smaller mass flow rate.

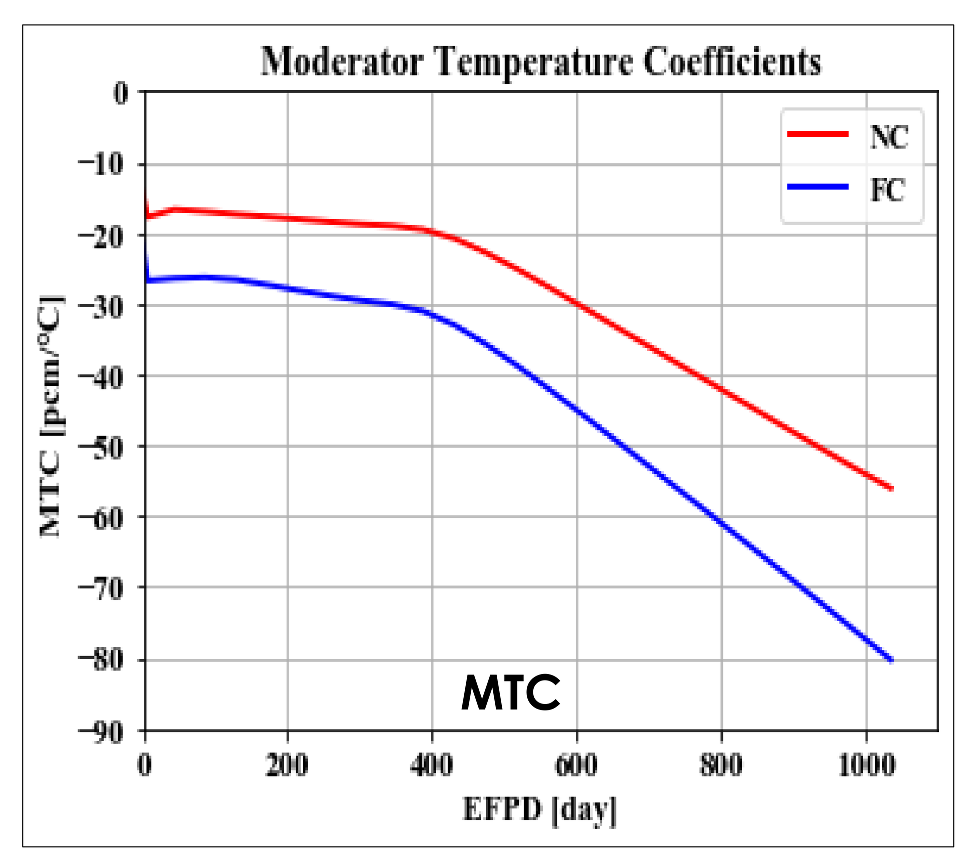
□ The CBC in the NC case becomes higher to compensate the positive reactivity caused by the lower moderator temperature.

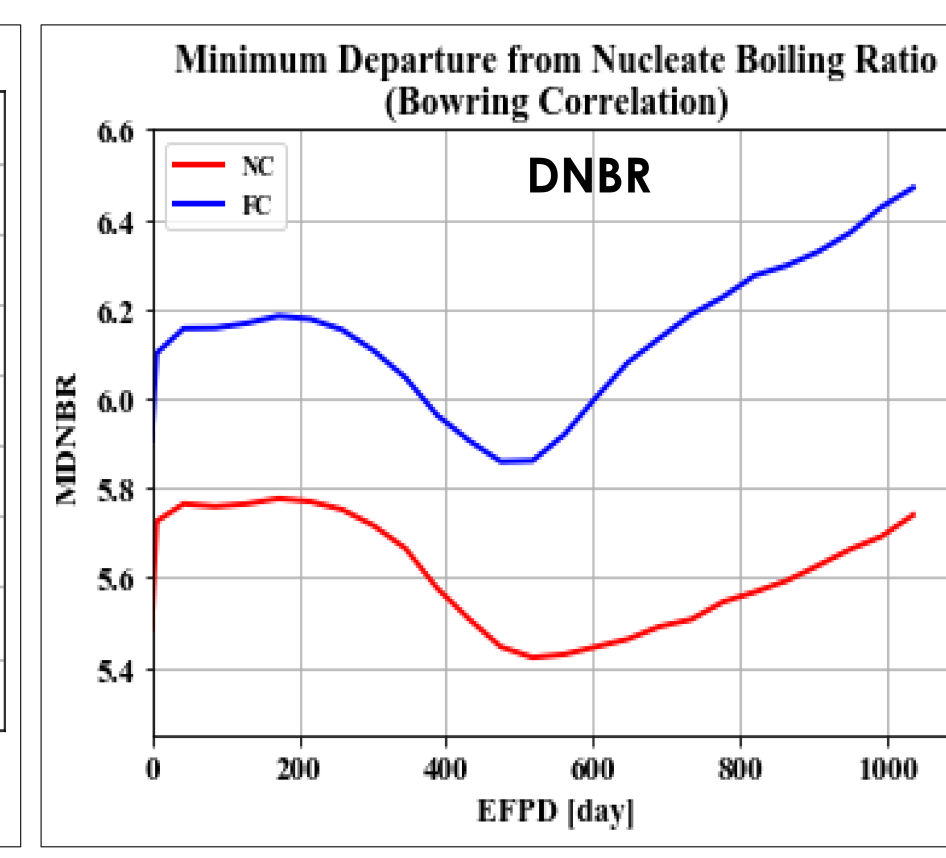
□ The MTC for the NC case becomes less negative due to the lower moderator temperature and the higher CBC.

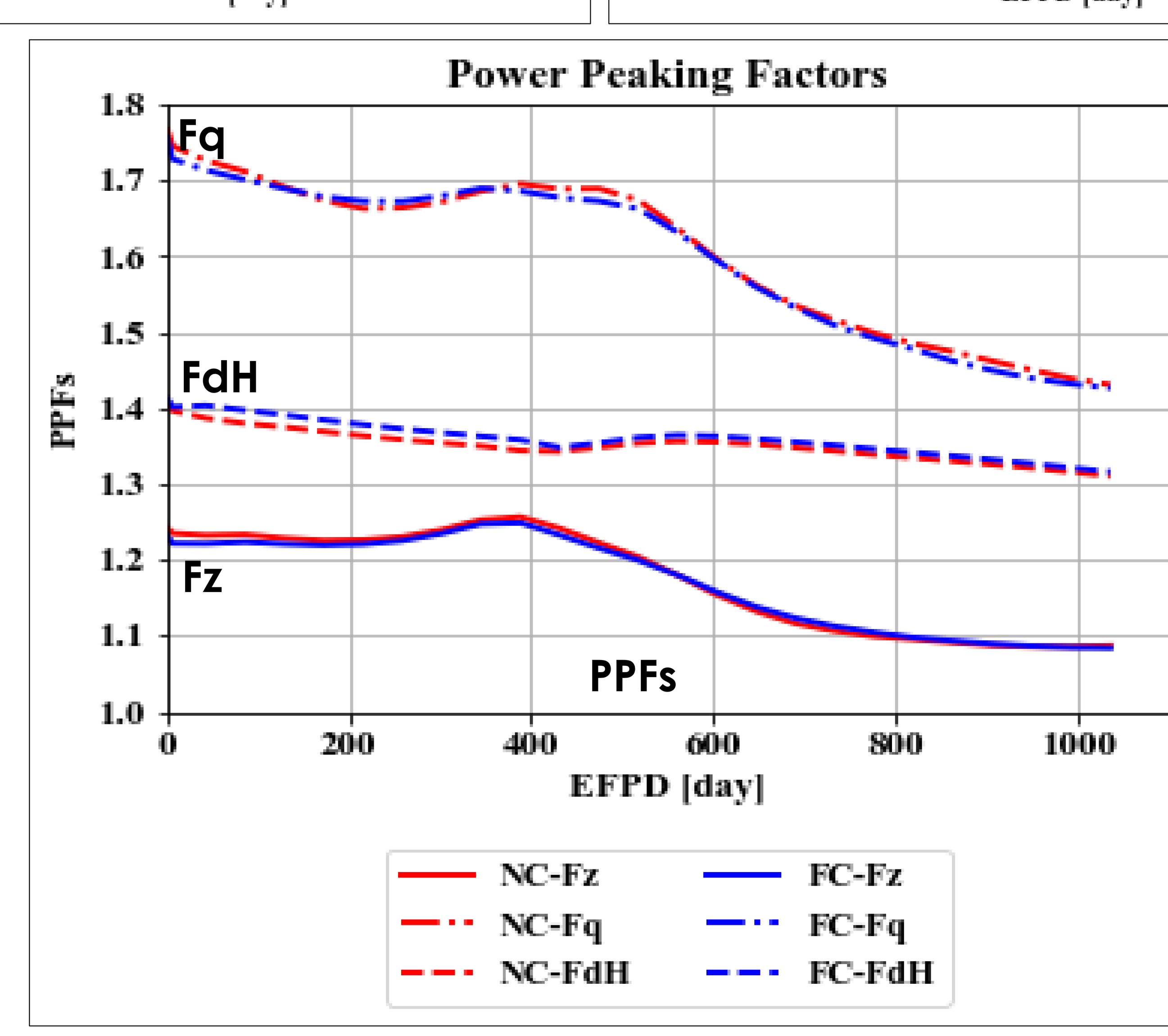
□ The ASI of the NC case is higher than that of the FC case at the BOC, while it becomes similar as the burnup proceeds.

□ The PPFs (Fz, FdH, and Fq) of the NC and the FC cases are most similar

□ The DNBR is slightly reduced in the NC case, where the critical heat flux is calculated by the Bowring critical heat flux model







Conclusion

□ The cycle length of the NC case becomes slightly enhanced due to the lower moderator temperature.

□ the PPFs of the NC and the FC cases are almost similar.

□ the MDNBR becomes smaller in the NC case. However, compared to the DNBR safety limit (1.3), the DNBR margin of the NC case is still sufficient for the normal operation condition.

□ The concept of the NC can be applied to the SMR core design without big change in the core design parameter.