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# Evaluation of the Control Rods Withdrawal in a Small Modular Sodium Fast Reactor and Analysis of the Impact on the Core Design

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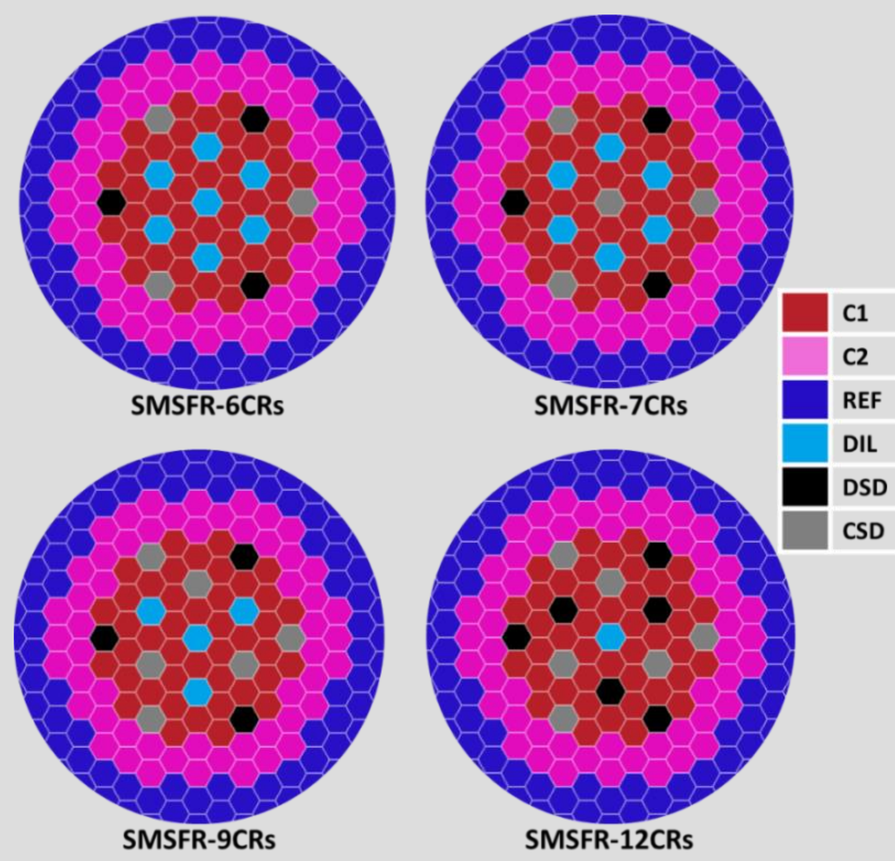
## Introduction

**Small Modular Sodium Fast Reactor (SMSFR):**

- ✓ Enlarge the application range of nuclear energy
- ✓ Reduce the impact on capital costs

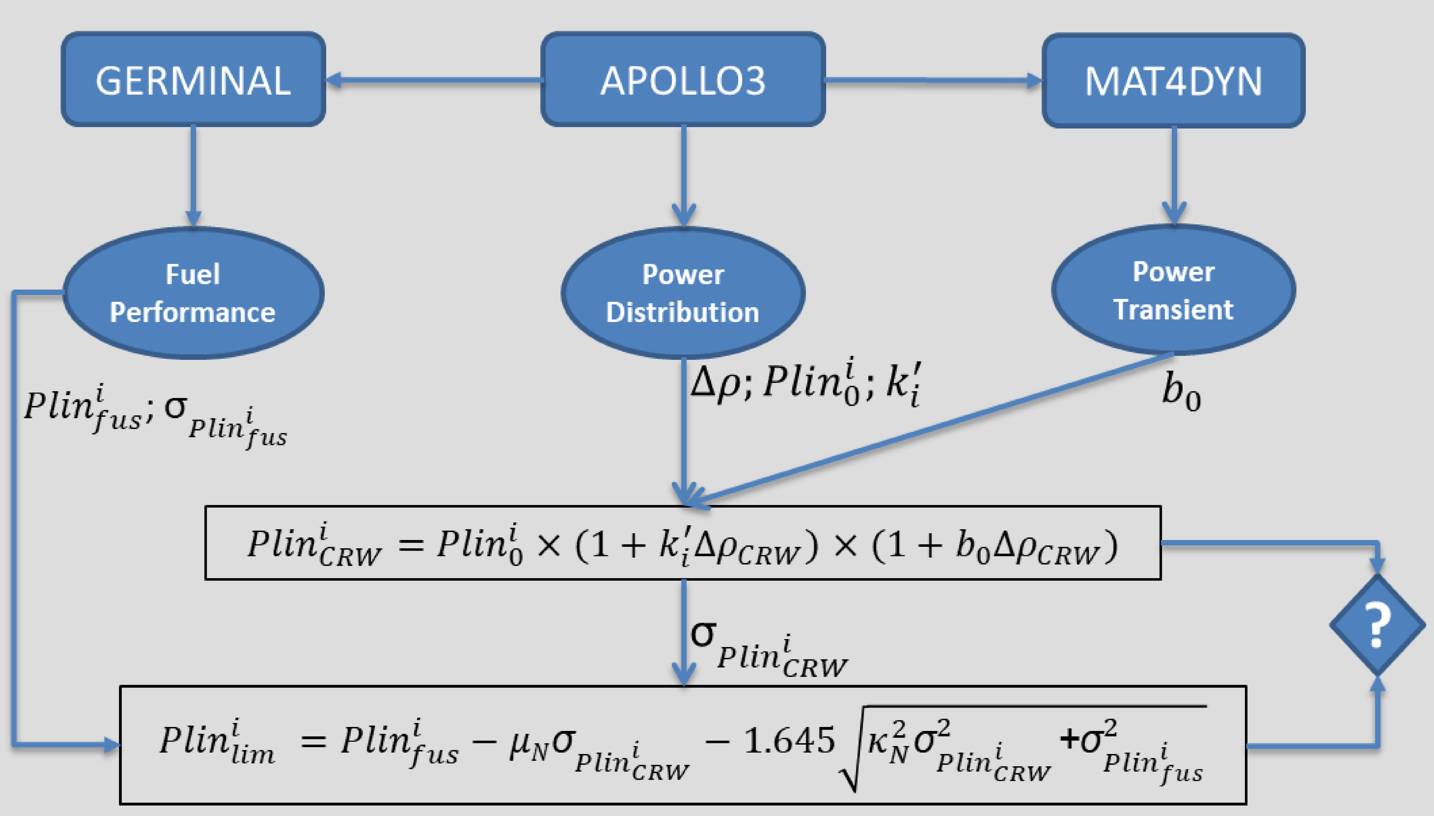
| Main characteristics of SMSFR | |
|---|---|
| Core Power | 320 MWth |
| Fuel Cycle | 375×5 EFPD |
| No. Fuel Assembly | 42 \| 54 |
| Plutonium content | 22.3 % \| 27.2 % |
| Fuel Volume | 1.27 $m^3$ |
| Blanket Volume | 0.45 $m^3$ |
| Average $P_{vol}$ | 250 $MWth/m^3$ |
| Peak $P_{lin}$ | 420 W/cm |
| Peak Burn-up | 150 GWd/t |
| Peak Flux | $3.3\times10^{15}$ $n/cm^2/s$ |
| Void Effect | -1.47 $ |
| Doppler Constant | -1.99 $ |
| Reactivity Loss | -8.5 pcm/EFPD |




**SMSFRs usually exhibit an important burn-up reactivity loss and thus a high excess reactivity at start-up.**

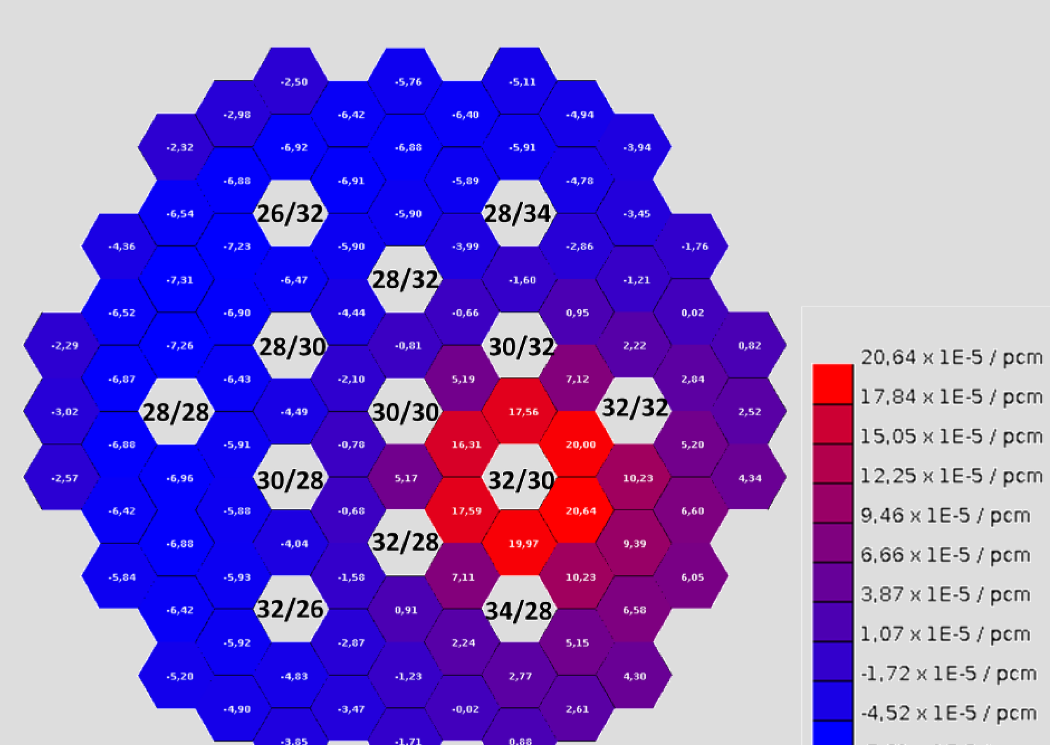
## Control Rod Withdrawal (CRW) Accident

**Any malfunction of a control rod drive would lead to a CRW accident, which is an Unprotected Transient Over-Power (UTOP) that would lead to local or even global fuel melting of fuel.**




| | |
|---|---|
| SMSFR-6CRs | $2.41\times10^{-3}$ |
| SMSFR-7CRs | $2.35\times10^{-3}$ |
| SMSFR-9CRs | $2.17\times10^{-3}$ |
| SMSFR-12CRs | $2.03\times10^{-3}$ |

$b_0$: Relative variation of the global power per unit of inserted reactivity



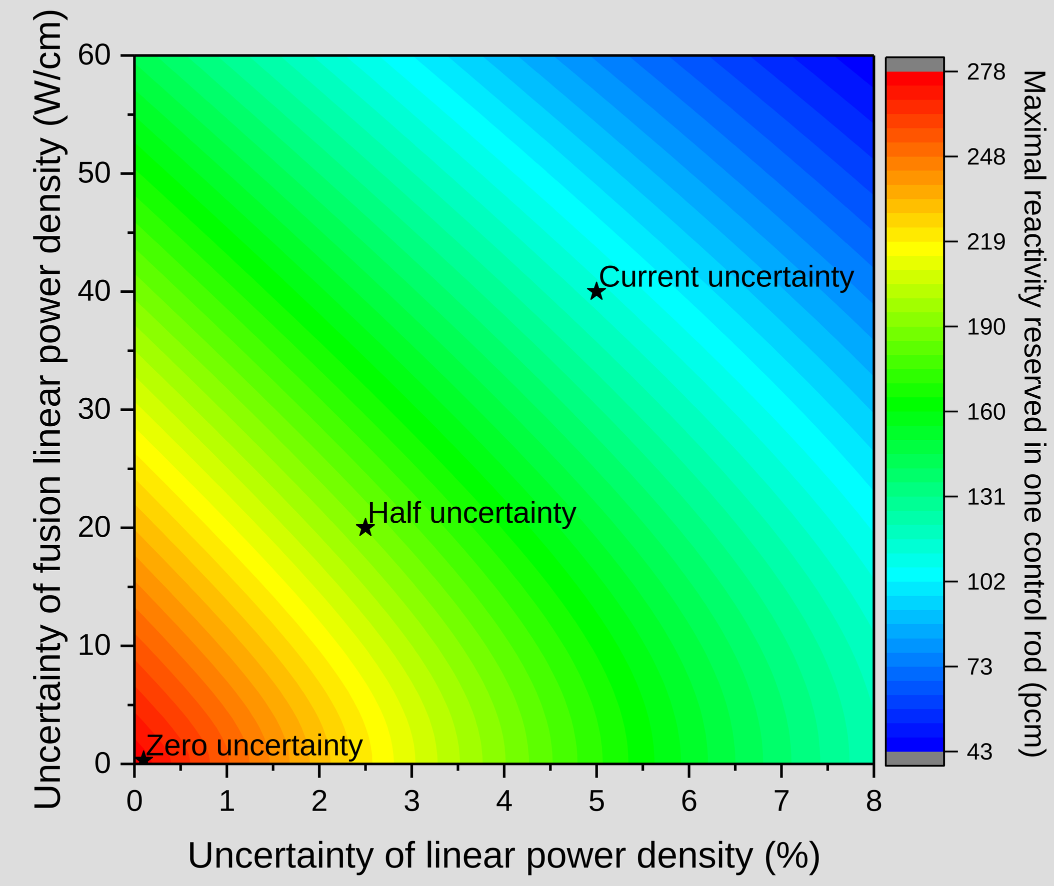

$k'_i$: Relative variation of the local power per unit of inserted reactivity

| Core | Case | Withdrawn CR position | Maximal excess reactivity (pcm) | Mean worth (pcm/CR) | Allowed cycle length (EFPD) |
|---|---|---|---|---|---|
| SMSFR-6CRs | Case1 | 34/28 | 642 | 107 | -- |
| SMSFR-7CRs | Case2 | 30/30 | 630 | 90 | 9 |
| | Case3 | 34/28 | 794 | 113 | |
| SMSFR-9CRs | Case4 | 34/28 | 1073 | 119 | 35 |
| | Case5 | 32/30 | 927 | 103 | |
| SMSFR-12CRs | Case6 | 34/28 | 1446 | 120 | 76 |
| | Case7 | 32/30 | 1347 | 112 | |
| | Case8 | 32/28 | 1368 | 114 | |

**Even with an important number of control rods, the allowed cycle length is very limited in SMSFR because of CRW accidents, which means a high refuel frequency and reduced economic efficiency.**

## Potential Solutions

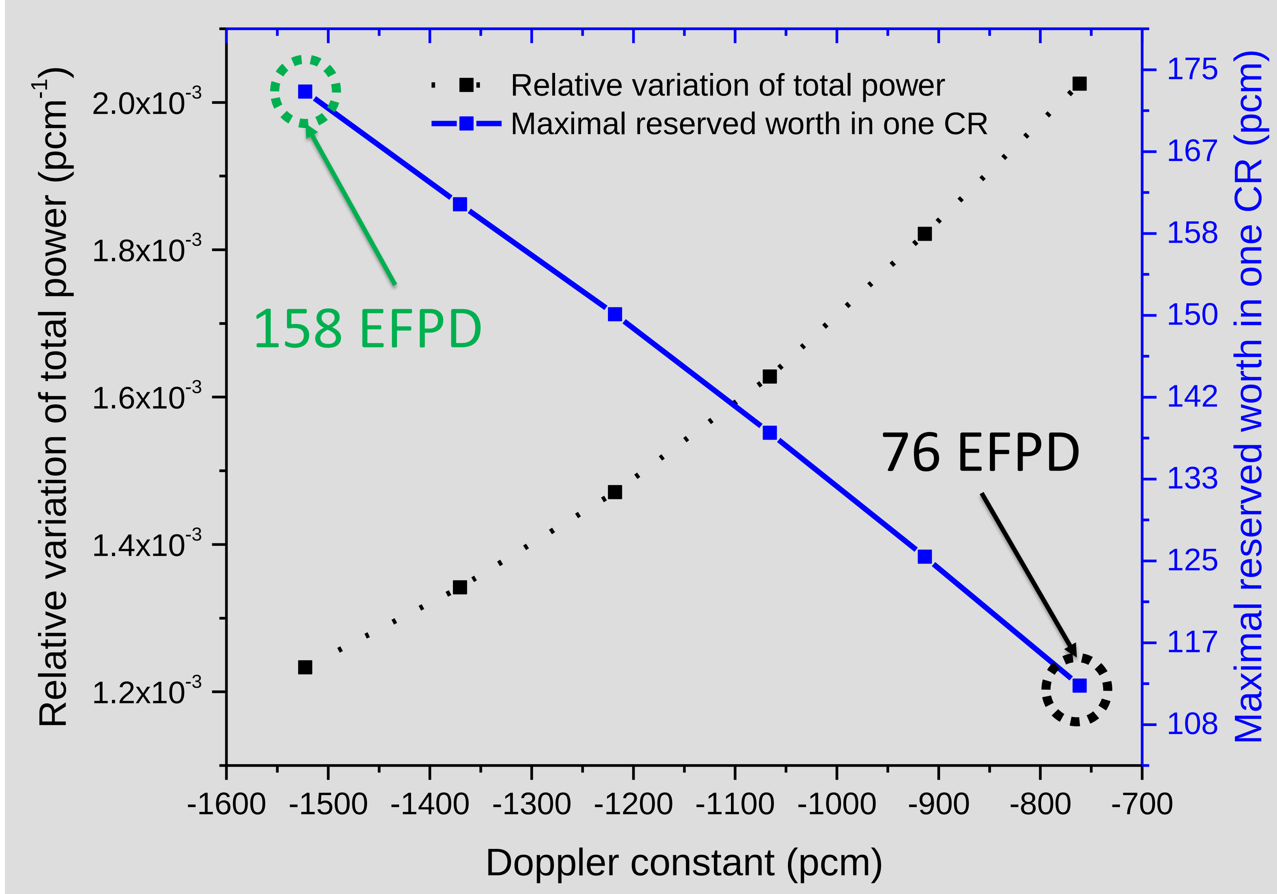
### 1. Reduce modeling uncertainty




| Uncertainty | Cycle length |
|---|---|
| Current | 76 EFPC |
| Half | 186 EFPD |
| Zero | 310 EFPD |

Fig. Sensitivity of maximal reactivity reserved in one control rod to calculation uncertainty

### 2. Reinforce Doppler effects



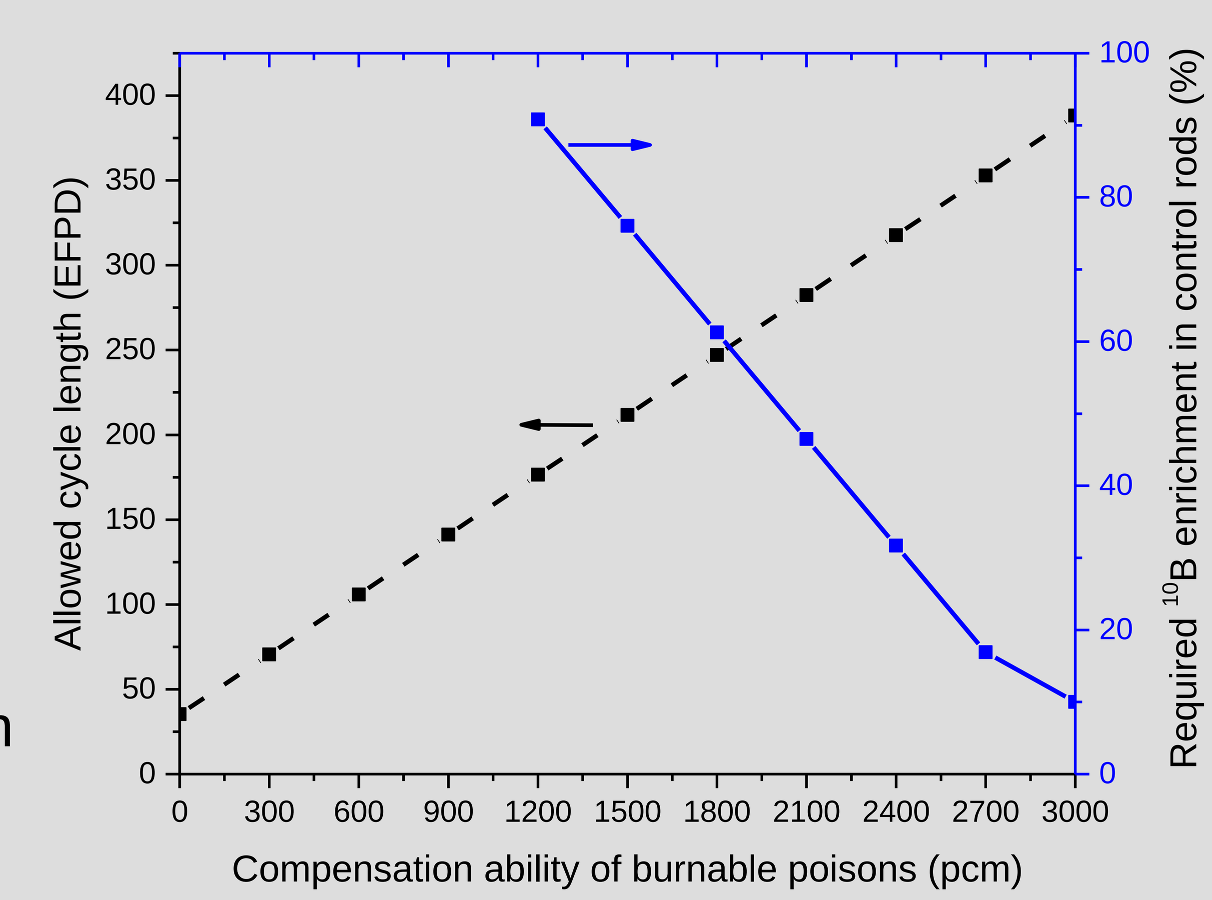

**CADOR**

**C**ore with **A**dding **DO**ppe**R** effect

Fig. Sensitivity of maximal reactivity reserved in one control rod to $K_D$

### 3. Burnable poisons (BP) in SFRs

Fig. Variation of cycle length and required $^{10}B$ enrichment in $B_4C$ with the compensation ability of BP




To achieve 375 EFPD operations without fuel melting risk in CRW, the BPs should compensate for 2888 pcm reactivity loss.

## Conclusions and Perspectives

**The high burnup reactivity loss in small reactor leads to the fuel melting in CRW accidents, which limits their allowed cycle length and thus the economic efficiency.**

**The potential solutions are investigated:**

- ✓ **Improvement of the calculation accuracy**
- ✓ **Adding of the Doppler Effect**
- ✓ **Application of burnable poisons**

**Perspectives:**

- ❑ **Coupling APOLLO3 and CATHARE3**
- ❑ **Design of burnable poisons in fast reactors**