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# Parametric study on the cumulative damage fraction for SALUS

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## 1. Introduction

The SALUS(Small, Advanced, Long-cycled and Ultimate Safe sodium-cooled fast reactor)[1] is a 100MWe long fuel cycle sodium-cooled fast reactor system under development in KAERI. The overall system design characteristics of SALUS are similar to those of the 150MWe PGSFR (Prototype Gen-IV Sodium-cooled Fast Reactor) except for the core.

Due to the long fuel cycles, the safety assessment for each cycle is very important. The safety acceptance criteria for SALUS are assumed to be the same as those for PGSFR. CDF(Cumulative Damage Fraction)[2] is an important safety acceptance criteria for AOO and DBA-1 and coolant temperature is that for DBA-2 and DEC conditions[3].

The CDF has been widely used as an effective parameter to confirm the integrity of cladding in various sodium cooled fast reactors such as PGSFR, EBR-II, CRBR, PFBR, etc.

In this study, parametric study on the CDF for SALUS has been done using MARS-LMR code[4,5] and some implication on CDF for SALUS are described.

## 2. Method

Nodalization of MARS-LMR model for the analysis of SALUS was presented in the previous study[4]. The safety analysis has been done under the transient overpower accident due to single control rod withdrawal. The design value which has not been decided was assumed to be the same as those of PGSFR.

### *2.1 Safety Design Criteria*

In Table. 1 summarized the safety acceptance criteria of SALUS for transient condition. These criteria was decided based on the metallic fuel experimental databases and experiences which have been conducted by research groups in Argonne National Laboratory(ANL).

### *2.2 Hot Channel Factor*

The cladding middle wall temperature considering hot channel factor is calculated by the following equation. The first term and the second term represent the Direct HCF and Statistical HCF, respectively.

**Table. 1 Safety acceptance criteria**

| Plant Condition (F:Frequency/Reactor Year) | Offsite Radiological Consequence | Fuel, Cladding, Structure, Containment Damage Limit | CDF |
|---|---|---|---|
| **AOO** (F>10^-2) | 10 CFR 50 Appendix I | - No fuel melting,<br>- Maintain clad integrity,<br>- Core coolability<br>- ASME Service Level B<br>- Maintain design leakage rate | $CDF_{\Sigma AOO} < 0.05$ |
| **DBA-1** (10^-2>F>10^-4) | 10 % of 10 CFR 100 Limit | - No fuel melting<br>- A small fraction of fuel pin failure<br>- Core coolability<br>- ASME Service Level C<br>- Maintain design leakage rate | $CDF_{EACH} < 0.05$ |
| **DBA-2** (10^-4>F>10^-6) | 100 % of 10 CFR 100 Limit | - Fuel pin coolable geometry<br>- Fuel Temp. < 1,237 ℃<br>- Clad Temp. < 1,075 ℃<br>- No bulk sodium boiling<br>- ASME Service Level D<br>- Maintain design leakage rate | N/A |
| **DEC** (10^-6>F>10^-8) | 100 % of 10 CFR 100 Limit | - Core coolable geometry<br>- No bulk sodium boiling<br>- ASME Service Level D<br>- Maintain design leakage rate | N/A |

$$T_{cladMW} = T_{inlet} + \Delta T_{coolant} + \Delta T_{film} + \Delta T_{cladMW}$$

$$\Delta T_u = \sum_{i=1}^{m} \Delta T_{ud,i} + \alpha \left[ \sum_{j=1}^{n} \left\{ \sum_{i=1}^{m} \Delta T_{ud,i} \cdot (F_{ij} - 1) \right\}^2 \right]^{1/2}$$

$$where\ \alpha = \frac{2}{3}\ \text{for}\ 2\sigma\ \text{and}\ \alpha = 1\ \text{for}\ 3\sigma$$

*2.3 Cumulative Damage Fraction*

CDF is defined as follows. It is widely used to predict the failure of component induced by creep damage at elevated temperatures[2]. It has been accepted as a means of predicting a fuel pin failure in LMR systems.

$$CDF = \int_0^{t_f} \frac{1}{t_r} dt$$

$$t_r = \theta \times exp\left(\frac{Q}{RT}\right)$$

The Dorn parameter(θ) can be calculated from Hoop stress, which can be evaluated based on the cladding thickness and pressure in gas plenum. The more detailed procedures and equations needed for evaluating CDF are introduced in ref [2].

## 3. Results

Fig. 1 shows the single pin power and temperature of fuel and cladding under the accident condition. The accident was assumed to begin at 10 seconds. The single pin power begins to decrease steeply right after shows the small peak near 10 seconds. As the decrease of power, the temperature of fuel and cladding also decrease. The peak temperature with HCF and without HCF reaches at 923 K and 843 K, respectively.

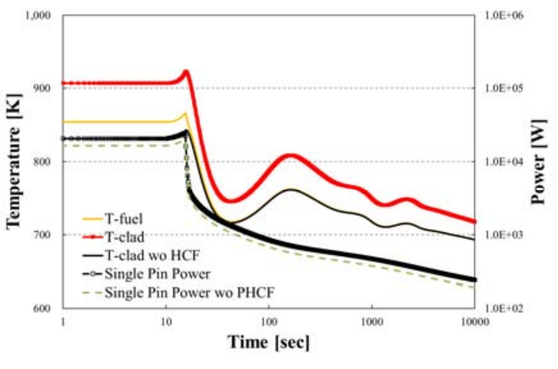


**Fig. 1 Cladding temperature with & without HCF**

Temperature differences induced by HCF at the peak amounts to 80 K. However, it isn't high enough to affect the cladding thickness since the eutectic penetration is effective at the temperature greater than 988K.

Fig. 2 shows the fission rate in gas plenum of single fuel pin and hoop stress of cladding with and without HCF. Compared to those without HCF, the fission rate and hoop stress are increased by 25% and 9% respectively, based on the peak value. However, the effect of HCF on the hoop stress decreases with the decrease of fuel temperature. Due to the steeply reduced fission power, fission rate differences due to HCF become negligible after an accident.

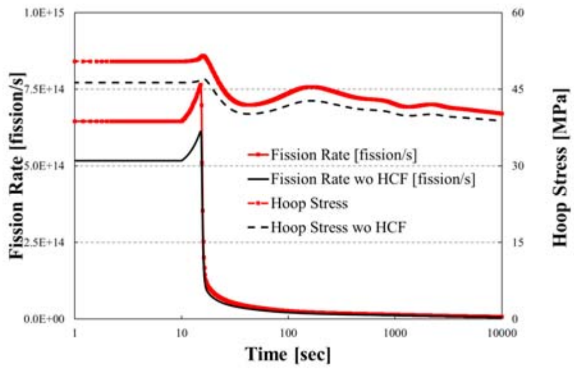


**Fig. 2 Fission rate and hoop stress with & without HCF**

Fig. 3 shows the CDF and time-to-rupture variation with and without HCF. As shown in the figure, HCF contribute to increase CDF by decreasing time-to-rupture. The CDF increases with time until 20 seconds, however, it does not show great change anymore due to the steeply increased time-to-rupture. The converged CDF value has enough margin comparing to safety acceptance criteria of AOO.

It is important to note that CDF accumulates during the initial 10 seconds, which corresponds to the normal operating period, before the accident begins. The fuel pin of SALUS will be exposed to the normal operating temperature condition during very long period (targeting almost 20 years) in compared to PGSFR. It represents that CDF variation during normal operation condition should be observed more than those during accident condition.

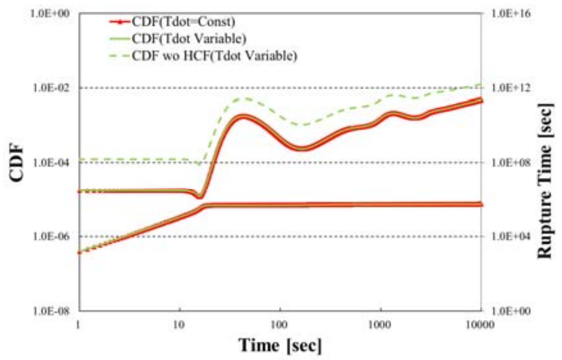


**Fig. 3 Time to rupture with & without HCF**

## 3. Conclusions

The CDF variation at transient overpower accident is investigated in 100MWe long fuel cycle sodium-cooled fast reactor. Safety design criteria are introduced and the effects of the hot channel factor are examined. The CDF at accident condition is found to have enough margin in comparison to safety acceptance criteria. It should be noted that CDF accumulation during normal operating period may be more important due to long plant operating time in SALUS.

## 4. Acknowledgement

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