RIMANUS Meeting 20240322

March 22, 2024

1 Scenario: Unprotected Loss of Flow (ULOF) in SFR (Almost impossible)

- Complete failure of redundant shutdown systems (Suzuki, Tohru and Tobita, Yoshiharu and Kawada, Kenichi and Tagami, Hirotaka and Sogabe, Joji and Matsuba, Kenichi and Ito, Kei and Ohshima, Hiroyuki, 2015)
- Failure forced circulation (e.g. Station Blackout) (Zhao, Haiqi and Lu, Daogang and Zhang, Yuhao and Zhang, Xueyuan, 2023)
- Thermal mixing happens primarily due to natural convection (Guenadou, David, 2022)

[1]

References

[1] "Zusatzversorgung des öffentlichen Dienstes,"

[2] J. Zuo, W. Tian, R. Chen, S. Qiu, and G. Su, "Two-dimensional numerical simulation of single bubble rising behavior in liquid metal using moving particle semi-implicit method," *Progress in Nuclear Energy*, vol. 64, pp. 31–40, Apr. 2013.

[3] A. Afflard, R. Zamansky, K. Paumel, W. Bergez, and P. Tordjeman, "Bubble detection in liquid metal by perturbation of eddy currents: Model and experiments," *Journal of Applied Physics*, vol. 134, p. 134502, Oct. 2023.

[2]

2 What is the natural circulation/convection?

- Sodium: high thermal conductivity (Ishida, Shinya and Kawada, Ken-ichi and Fukano, Yoshitaka, 2020)
- Thermal stratification in sodium pool (Zhao, Haiqi and Lu, Daogang and Zhang, Yuhao and Zhang, Xueyuan, 2023)
- Induced by temperature difference of coolant at the inlet and outlet of the core (, 2015)
- Temperature difference –> Density difference –> Convection (Guenadou, David, 2022)
- Decay heat removed without electricity (, 2015)
- One of the most important mechanisms of passive safety (, 2015)

3 How fast is the natural convection? (Guenadou, David, 2022)(Zhao, Haiqi and Lu, Daogang and Zhang, Yuhao and Zhang, Xueyuan, 2023)

- Locally different
- No more than 0.6m/s
- Lack of study until 2022 (Guenadou, David, 2022)

4 From natural circulation to Core Disruptive Accident (CDA)

- 15 hours from failure of forced circulation to total sodium boiling without natural circulation (Bachrata, Andrea and Bertrand, Fréderic and Marie, Nathalie and Serre, Fréderic, 2021)

5 What is the process of CDA? (Ishida, Shinya and Kawada, Ken-ichi and Fukano, Yoshitaka, 2020)

- Initial Phase (IP)
- Transition Phase (TP)

- Post-Accident Material Relocation/Post-Accident Heat Removal (PAMR/PAHR) phase

- Sketch of CDA

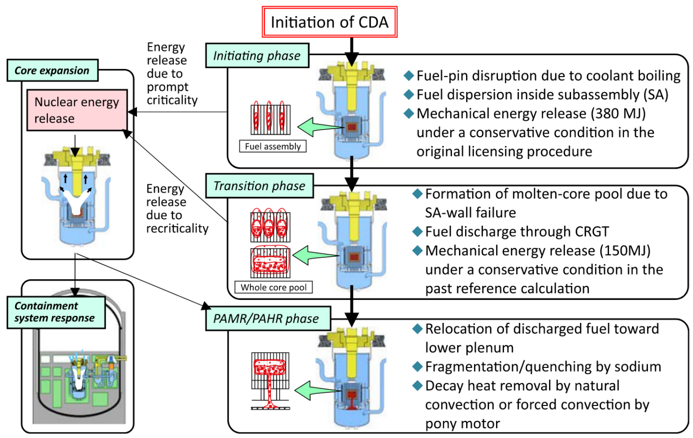

Fig. 1 – **Categorization of unprotected loss-of-flow (ULOF) sequence and outline of event progression.**

- Components of the meltdown

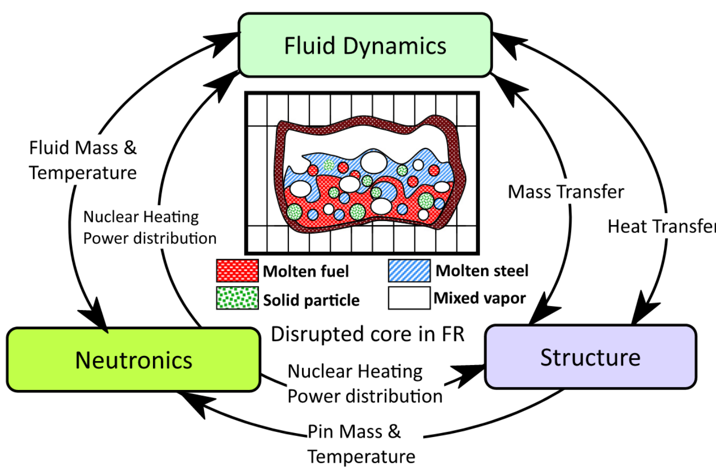

Fig. 6 – **Framework of SIMMER-III/IV code.**

- Transient of reactivity and power in initiating phase

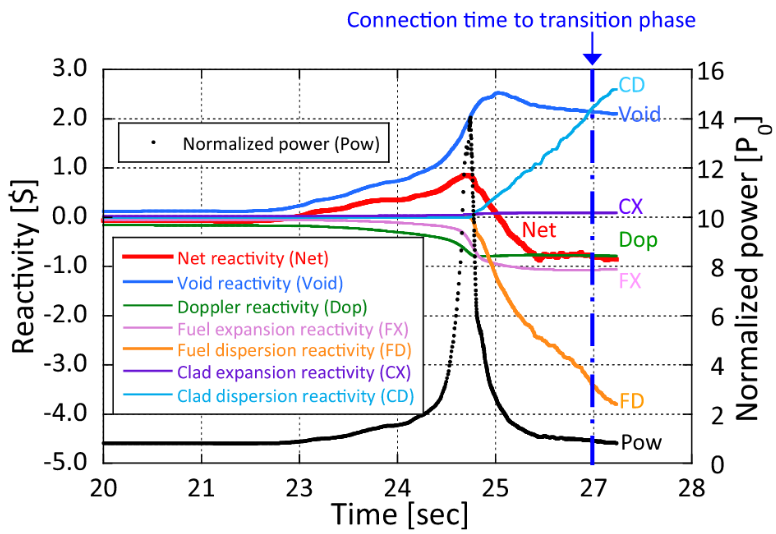

Fig. 3 – Transient of reactivity and power in initiating phase under reference condition.

- Components of the mixture

Table 1 List of ingredients of hierarchical architecture

System	Sub systems	Modules	Constituents	Phases	Geometrical configurations	Field
SFR	Reactor vessel	Core	Fuel in fuel pin	Solid / Liquid / Vapor	Pellet / Stub	Energy (heat / mechanical) / Mass / Momentum
			Cladding (Steel)	Solid	-	Energy (heat / mechanical) / Mass / Momentum
			Fission product in fuel pin	Solid / Vapor	-	Energy (heat / mechanical) / Mass
			As-fabricated gas (He)	Vapor	-	Energy (heat / mechanical)
			Fuel	Solid / Liquid / Vapor	Chunk / Crust / Multi phase flow	Energy (heat / mechanical) / Mass / Momentum
			Steel	Solid / Liquid / Vapor	Chunk / Crust / Multi phase flow	Energy (heat / mechanical) / Mass / Momentum
			Fission product	Vapor	Multi phase flow	Energy (heat / mechanical) / Mass / Momentum
			Coolant (Sodium)	Liquid / Vapor	Multi phase flow	Energy (heat / mechanical) / Mass / Momentum
			Structure (Steel)	Solid	Multi phase flow	Energy (heat) / Mass / Momentum
			Plenum gas	Vapor	-	Energy (heat / mechanical) / Momentum

6 About viscosity

- Viscosity ↑ Coalescence ↓ (Important)

7 Quotes

> The reduction of the coolant flow causes (1) the fuel temperature rise and (2) the fuel thermal expansion, and the thermal expansion changes the fuel-cladding gap width. This change affects (3) the gap conductance and the thermal condition changes accordingly. The events progress while the thermal behavior and the mechanical behavior interact with each other. The coolant gradually boils and it causes the cladding temperature rise. In an assembly where the strength of the cladding is sufficiently degraded due to the temperature rise, (4) the fuel pellets temperature rises, the molten cavities develop, and (5) the fuel is disrupted when the fuel pellets cannot maintain their shape due to the strength degradation. Hence, the fuel disruption largely depends on the fuel pin thermal behavior and the fuel pin mechanical behavior. Furthermore, when the power excursion occurs due to the positive reactivity insertion which is caused by the coolant boiling, (6) the pressure applied by the fuel to the cladding, which is called the contact pressure, causes (7) the fuel pin failure in an assembly where the cladding keeps the strength due to sufficient cooling. (Ishida, Shinya and Kawada, Ken-ichi and Fukano, Yoshitaka, 2020)

> Experiments show that the viscosity has a greater impact on the bubble coalescence. The greater the viscosity, the harder the bubbles are to coalesce. (Dai, Caili and Zhao, Guang and You, Qing and Zhao, Mingwei and Liu, Yifei and Zhao, Fulin, 2022)

[3]

8 Bibliography

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Dai, Caili and Zhao, Guang and You, Qing and Zhao, Mingwei and Liu, Yifei and Zhao, Fulin (2022). *Theory and Technology of Multiscale Dispersed Particle Gel for In-Depth Profile Control*, Elsevier.

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Ishida, Shinya and Kawada, Ken-ichi and Fukano, Yoshitaka (2020). *Validation Study of SAS4A Code for the Unprotected Loss-of-Flow Accident in an SFR*, Mechanical Engineering Journal.

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Suzuki, Tohru and Tobita, Yoshiharu and Kawada, Kenichi and Tagami, Hirotaka and Sogabe, Joji and Matsuba, Kenichi and Ito, Kei and Ohshima, Hiroyuki (2015). *A Preliminary Evaluation of Unprotected Loss-of-Flow Accident for a Prototype Fast-Breeder Reactor*, Nuclear Engineering and Technology.

Zhao, Haiqi and Lu, Daogang and Zhang, Yuhao and Zhang, Xueyuan (2023). *Numerical Simulation of Natural Circulation Characteristics under Different DHX Layout Schemes in Pool-Type SFR during Station Blackout Accident*, Progress in Nuclear Energy.

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[2] J. Zuo, W. Tian, R. Chen, S. Qiu, and G. Su, "Two-dimensional numerical simulation of single bubble rising behavior in liquid metal using moving particle semi-implicit method," *Progress in Nuclear Energy*, vol. 64, pp. 31–40, Apr. 2013.

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