ULOF and UTOP Analyses of a Conceptual Small Liquid Metal-cooled Fast Reactor

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Introduction

▪ Motivation

- One of the new concept reactors : Small liquid-metal cooled fast reactor (SLFR) is studied.
- SLFR have some advantages :

Atmospheric pressure operation	Low activity with water and steam
High boiling point	High retention of fission products

- Localization of LFR technology is necessary → UNIST studied and designed the LFR.
- To confirm the specific effects of the LFR → Detailed analysis of the designed reactor is required.

▪ Objective

- Current LFR safety analysis was performed → To evaluate the safety of the current LFR designed by UNIST

▪ Current LFR

Table. 1. Current LFR design components

Primary side			
Power	300MWth	**Reactor type**	Pool-type
Fuel material	UO_2	**Clad material**	15-15Ti
Working fluid	Lead-Bismuth Eutectic (LBE) coolant		
Natural circulation	4m height difference (between SG, Core)		
Secondary side			
SG power	50MWth	**Number of SGs**	6
DHR train power	12MWth	**Number of DHR trains**	2

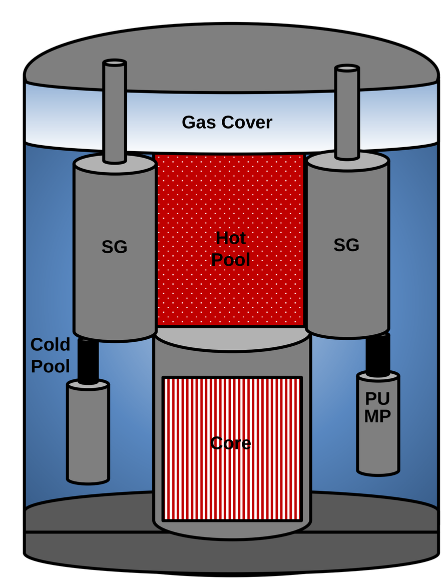


Fig. 1. Designed LFR primary loop schematic diagram

Table. 2. Design parameters comparisons of few LFRs and SMR

	Studied LFR	ALFRED	SSTAR	PGSFR
Designer	The present study	Ansaldo Nucleare	Argonne National Laboratory	Korea Atomic Energy Research Institute
Type	Pool	Pool	Pool	Pool
Power	300MWth	300MWth	45MWth	400MWth
Coolant	LBE	Pb	Pb	Sodium
Core inlet temperature	300ºC	400ºC	420ºC	390ºC
Core outlet temperature	450ºC	480ºC	564ºC	545ºC
System pressure	1 bar	1~1.5 bar	1 bar	~1 bar
Secondary working fluid	Water / Steam	Superheated steam	Supercritical CO_2	Water / Steam

Analysis Methods

▪ Safety Criterion

Table. 3. Safety criteria along with the reactor components

Material	Safety criterion	Reason
UO_2 fuel	Below 2740°C	Fuel melting temperature
15-15Ti clad	Below 1500°C	Clad melting temperature
	Below 650°C	Clad failure criterion
LBE coolant	125°C to 1670°C	Over LBE melting temperature, under boiling temperature

- Reactor structure corrosion : 500°C ~ 550°C temperature or 2m/s over coolant velocity → Not included in the accident safety criterion.

▪ Analysis Condition

- Low melting point, low chemical reactivity of LBE → Reactor inherent safety increased.

Table. 4. The importance of overcooling accidents according to the coolant type

Lead coolant		LBE coolant
High melting temperature (327°C)	vs	Low melting temperature (125°C)
Overcooling accidents are important		Overcooling accidents are not important

- ULOF, ULOHS, ULOOP, UTOP were analyzed. The SCRAM signal failed in all unprotected case.

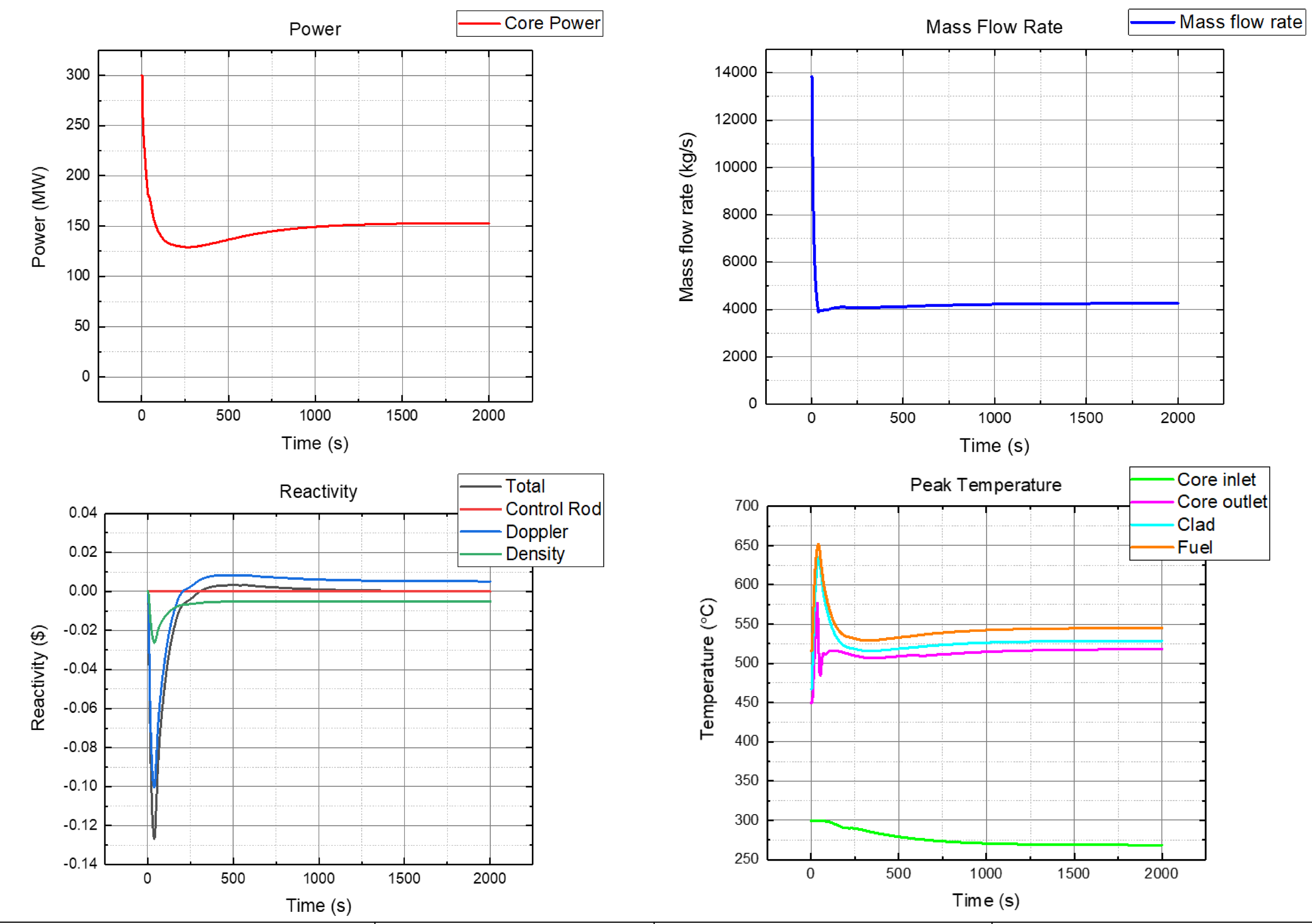
Results and Discussions

Table. 5. Analysis base introduction

Code used for analysis	MARS-LBE
Introduced accident	ULOF, UTOP
SCRAM signal	Pump speed < 5 rad/s
	Core outlet temperature > 470°C.

▪ Unprotected Loss of Coolant (ULOF)

- Reactor temperature rises → Negative reactivity feedback occurs : Doppler effect, negative coolant temperature coefficient.
- New power state is established - Overall higher temperature, lower thermal margin.
- Peak temperatures of coolant, clad, and fuel are below the safety criterion.

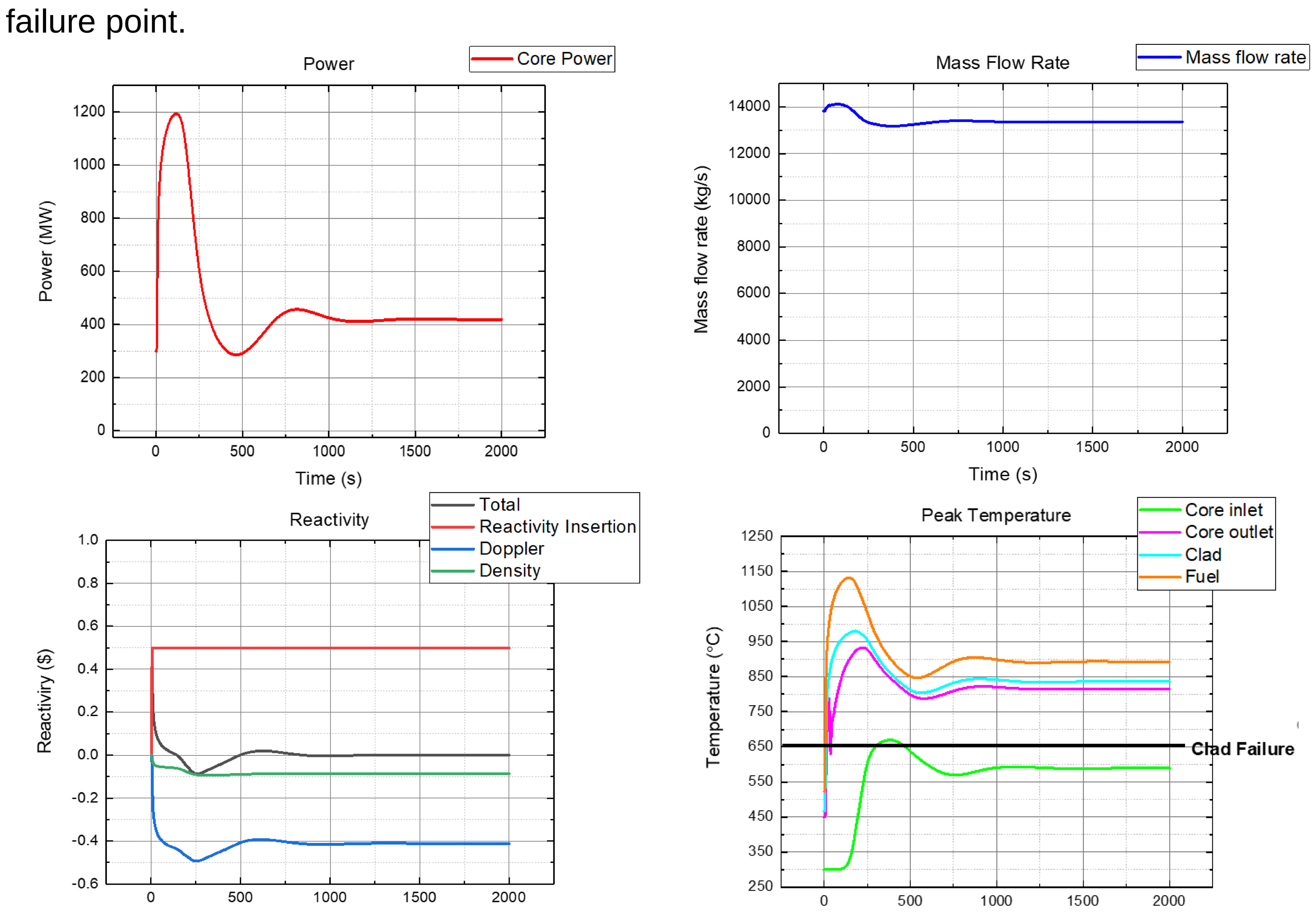


Material	LBE coolant	15-15Ti clad	Fuel
Peak / Maximum temperature	576.68°C	634.69°C	659.51°C

Fig. 2. Analysis results under ULOF case

▪ Unprotected Transients Overpower (UTOP)

- Negative reactivity feedback is inserted : Doppler effect, negative coolant temperature coefficient.
- The new state is established - Has a higher power level
- The peak cladding temperature → Did not exceed the melting point but exceeded the clad failure point.



Material	LBE coolant	15-15Ti clad	Fuel
Peak / Maximum temperature	933.25°C	980.65°C	1131.65°C
Peak positive reactivity	0.45$		

Fig. 3. Analysis results under UTOP case

▪ Comparison with ALFRED

Table. 6. Peak temperatures comparison with ALFRED at ULOF

	The current LFR	ALFRED
Peak coolant temperature	577°C	710°C
Peak clad temperature	635°C	764°C

- ALFRED had a higher temperature and lower thermal margin in ULOF case.
- Lead coolant in ALFRED → Higher core inlet temperature, higher mass flow rate.

Table. 7. Peak temperatures and power comparison with ALFRED at UTOP

	The present LFR	ALFRED
Reactivity insertion	400pcm	250pcm
Maximum power	1194MWth	610MWth
Peak coolant temperature	933°C	Below 600°C
Peak clad temperature	981°C	Below 600°C

- The LFR had higher peak temperature in this case: reactivity insertion by removing one control rod assembly → Control rod reactivity insertion has a difference

Summary

✓ Two accidents with higher peak temperatures were introduced : ULOF, UTOP
✓ New states were established, and peak cladding temperature was below the melting point.
✓ Peak coolant temperature, Maximum fuel temperature : Below the safety criterion.
✓ New states had a lower thermal margin, so operating the reactor at a new state is not recommended.