Evaluation of Anticipated Transient without Scram for SM-SFR using SAS4A/SASSYS-1

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Abstract. Small Modular Sodium-cooled Fast Reactor (SM-SFR) was developed in UNIST as a breeder reactor with the target of ultra-long cycle operation. The depletion analysis and quasi-static reactivity balance analysis were performed to see its inherent safety in the neutronics point of view. In this study, the inherent safety evaluation is performed in the thermal-hydraulic point of view by using transient analysis for LMR code SAS4A/SASSYS-1 which was developed in Argonne National Laboratory. Three major events of Anticipated Transient without Scram (ATWS) were tested for this research; Unprotected Loss of Flow (ULOF), Unprotected Loss of Heat Sink (ULOHS), Unprotected Transient Over Power (UTOP). Every perturbation for each transient event occurs at 10 second and each simulation time is 100 minute. The power to flow change, the reactivity profiles, and the temperature changes were investigated to trace each transient trend. It has been confirmed that SM-SFR has inherent safety from the fact that any of the events doesn't have a clad failure or a coolant boiling.

Key Words: SM-SFR, ATWS, Inherent Safety.

1. Introduction

Small Modular Sodium-cooled Fast Reactor (SM-SFR) was developed in UNIST as a breeder reactor with the target of ultra-long cycle operation. The depletion analysis and quasi-static reactivity balance analysis were performed to see its inherent safety in the neutronics point of view [1]. In this paper, the inherent safety evaluation is performed in the thermal-hydraulic point of view by using transient analysis code. Three major events of Anticipated Transient without Scram (ATWS) were tested for this research; Unprotected Loss of Flow (ULOF), Unprotected Loss of Heat Sink (ULOHS), Unprotected Transient Over Power (UTOP).

2. Condition and Method

SM-SFR is a sodium-cooled fast reactor utilizing breed-and-burn strategy to achieve an ultra-long cycle operation. There are some design characteristics to realize the operation strategy. At the same time, this core has several constraints to be designed as a small and modular reactor core.

2.1.Reactor Condition

The target operation time of SM-SFR is 30 years without refueling. During such long cycle time, the reactivity swing is set as less than 1,000 pcm to reduce the number of control rods as possible in this small core. The transportable size of the core barrel is one of the most important design constraints that it has been set as less than 300 cm. Metallic fuel form is necessary to have inherent safety in any condition of the reactor operation. In the primary system, electromagnetic pump is deployable as a primary pump for the small size fast reactor with liquid metal coolant.

TABLE I: DESIGN PARAMETERS FOR SM-SFR.

Parameters	**Value**
Thermal power (MWth)	240
Electric power (MWe)	100
Barrel diameter (cm)	292
Core inlet/outlet temperature (ºC)	355/510
Pin bundle pressure drop (psi)	4.6
Fuel form	U-Zr
Fuel cycle (year)	30
Average burnup (%)	13
Average power density (kw/l)	66.1

Figure 1 shows the core configuration of SM-SFR in radial and axial cross section for each. It is expectable with the figure that this core ignites at the LEU region and breeds to the blanket region along the radial direction. For this ATWS study, the core state after 25 years operation where the center power peak is the most apparent is assessed so the power distribution of the core is Bessel function shape with the center power peak.

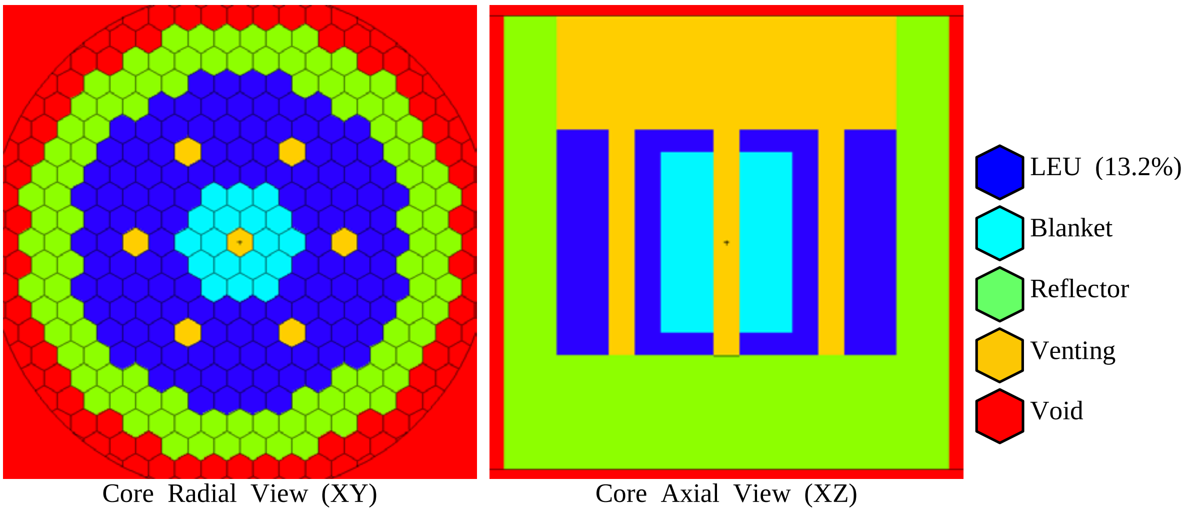


FIG. 1. Radial and axial core configuration of SM-SFR.

2.2. Analysis Method

The SAS4A/SASSYS-1 code were developed in Argonne National Laboratory for thermal-hydraulic and neutronic analysis of power and flow transient for liquid metal cooled fast reactor (LMR). SAS4A was developed to analyze severe accidents transient or core disruption with coolant boiling and fuel melting. It contains mechanic models of transient thermal, hydraulic, neutronic, and mechanical phenomena to describe the response of the reactor core with its coolant, fuel, and structure to given transient conditions. SASSYS-1 was developed to address loss of decay heat removal accidents and it has evolved to assess design basis accident (DBA) analysis and beyond design basis accident (BDBA) analysis. It contains not only the same core models as SAS4A for fuel heat transfer and single- and two-phase coolant thermal-hydraulics, but also the sodium and steam circuit models to provide a detailed thermal-hydraulic simulation of the primary and secondary sodium coolant and the balance of plant (BOP) steam/water circuit. It has also capability of a plant protection and control system modeling [2].

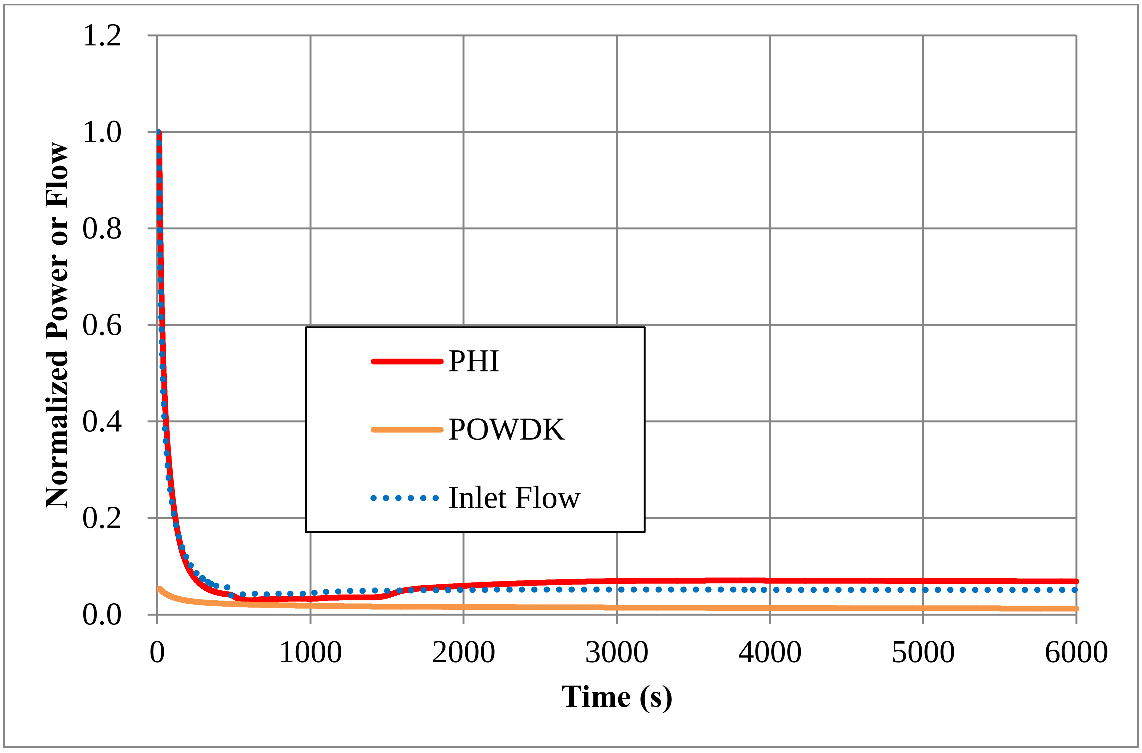
3. Results and Analyses

3.1. Simulation Condition

SAS4A/SASSYS-1 can easily set various transient scenarios by modifying a few values in its input. For each ATWS transient case, a variable to be changed and its time variable set a table for a perturbation transient. The table is pump head vs. time for ULOF, normalized temperature vs. time for ULOHS, and reactivity insertion vs. time for UTOP. Every perturbation for each transient event occurs at 10 second and each simulation time is 100 minute. For the convenience, the x axis for each graph is expressed as logarithmic scale. The reactivity coefficients adopted in the calculation is from the core calculation performed by neutronics analysis code.

3.2. ULOF Transient Event

There are several possible causes for the ULOF scenario that it is assumed that the coolant pumps for the primary and intermediate loops are out of order due to the power supply failure and etc. while the scram system is also fails. As shown in Fig. 2, the flow decreases first at 10 seconds and is followed by the power reduction. The natural circulation flow rate is 5.1 % at 10 minute. In Fig. 3, net reactivity becomes negative right after loss of flow mainly by the radial and axial expansion because the power to flow ratio is more than unity until 142 seconds and it causes temperature increase of the core. The strong net negative reactivity leads the power to flow ratio back to unity and even less than unity, which is followed by core temperatures decrease. The fluctuations of reactivity in the Fig. 2 are according to the power/flow ratio and they influence each other. During this 100 minute of ULOF, the peak clad temperature doesn’t reach the clad temperature limit of 923 K and coolant boiling doesn’t occur although the sodium saturation temperature decreases as shown in Fig. 4.



PHI: power, POWDK: decay power

FIG. 2. Normalized power and inlet flow during ULOF.

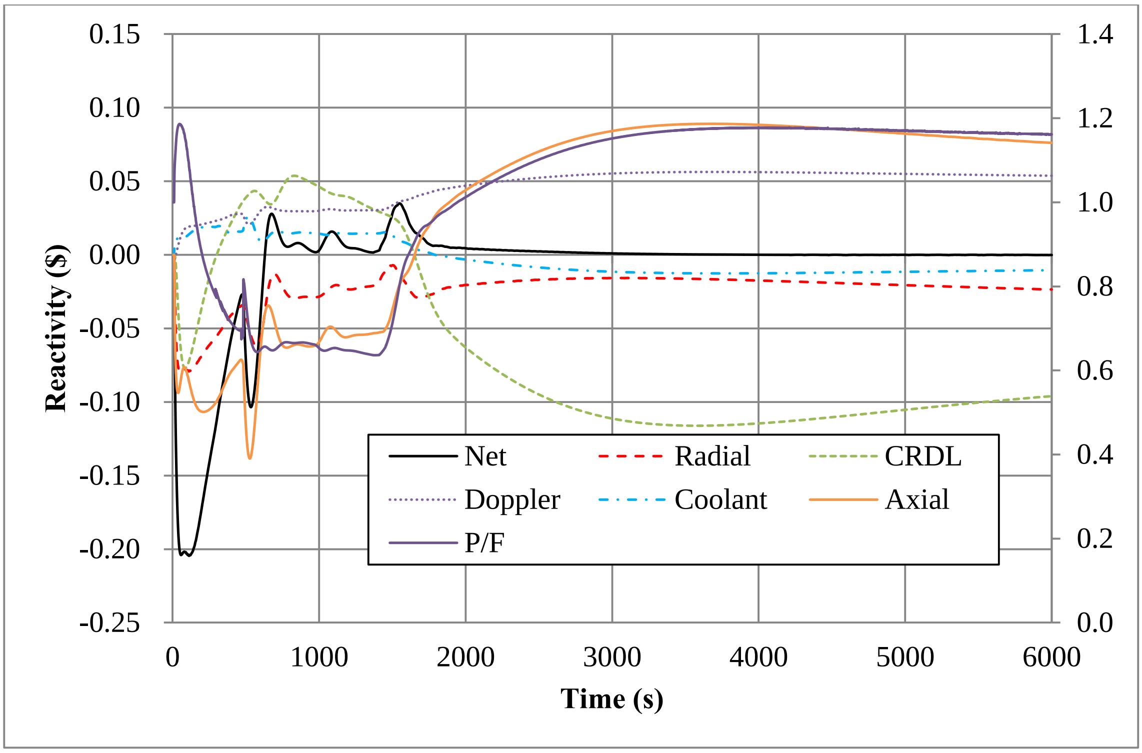


FIG. 3. Reactivity profile and normalized power/flow during ULOF.

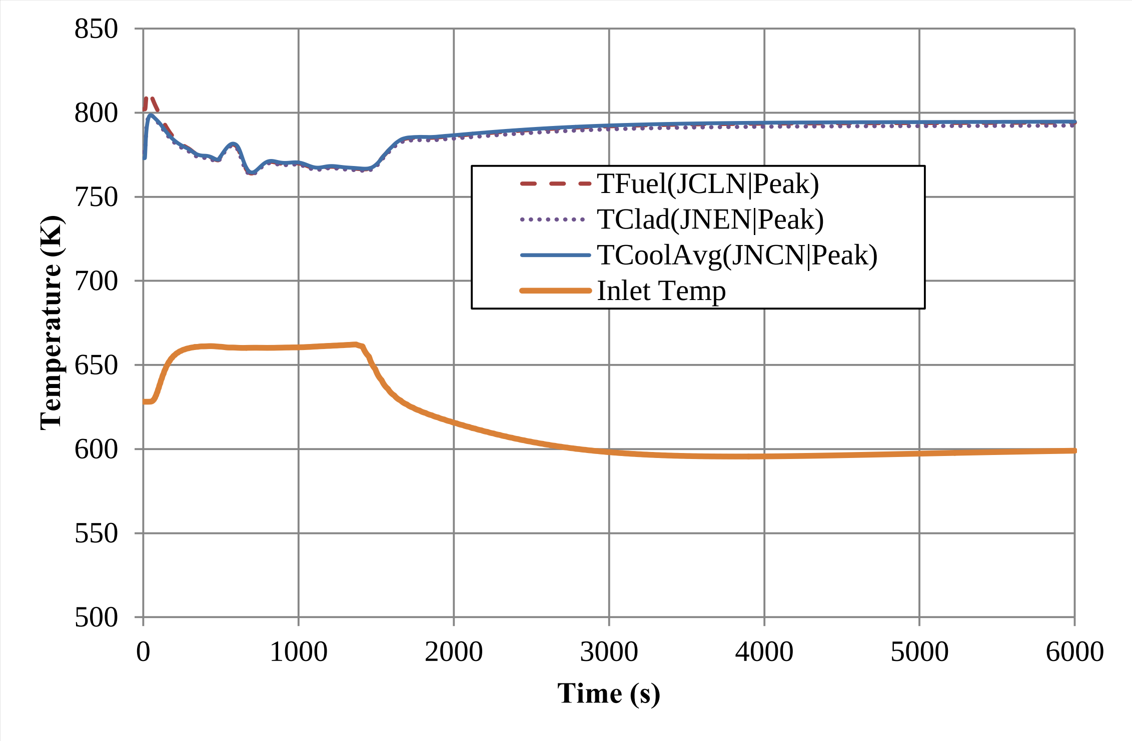
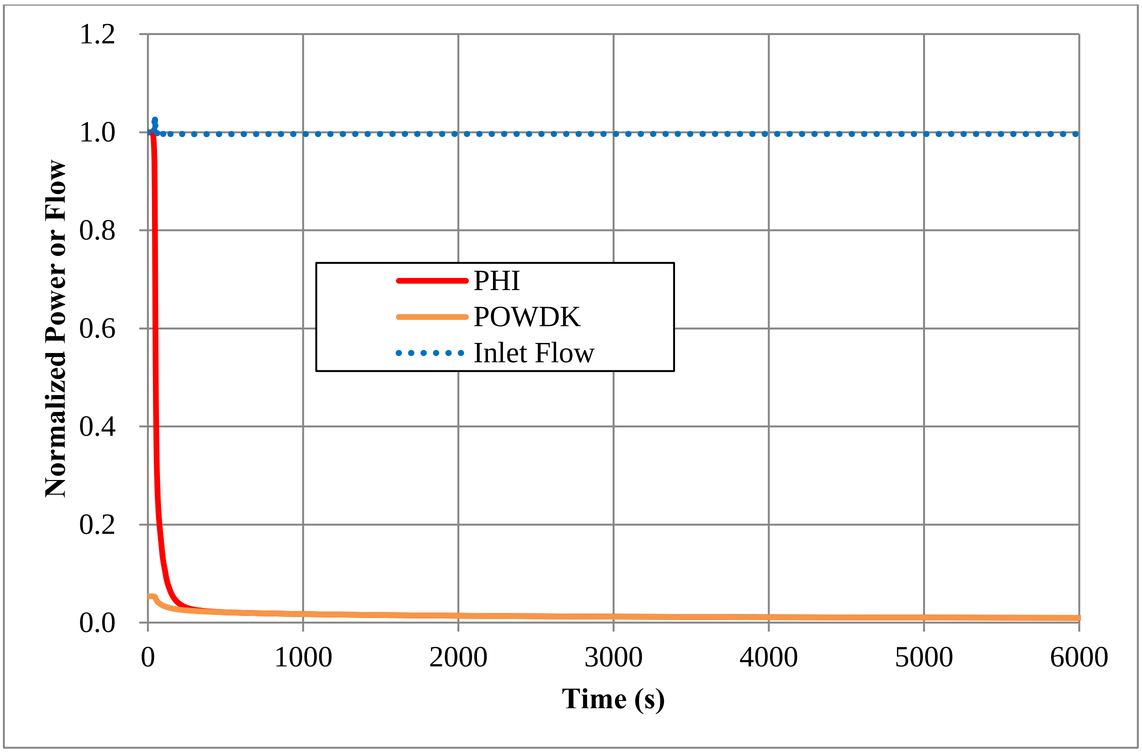


FIG. 4. Temperature change during ULOF.

3.3.ULOHS Transient Event

The response of ULOHS transient takes time to be visible because it is relatively indirect perturbation from the reactivity feedback while ULOF and UTOP has prompt or direct reactivity insertion to the core. In ULOHS, the heat rejection process is stopped caused by the feed water pump failure, and consequently the inlet temperature increases as shown in Fig. 7. This leads the net negative reactivity in the core and consequently core power decreases as shown in Fig. 5 and Fig. 6. The peak temperatures don’t violate their limit for this ULOHS event.



PHI: power, POWDK: decay power

FIG. 5. Normalized power and inlet flow during ULOHS.

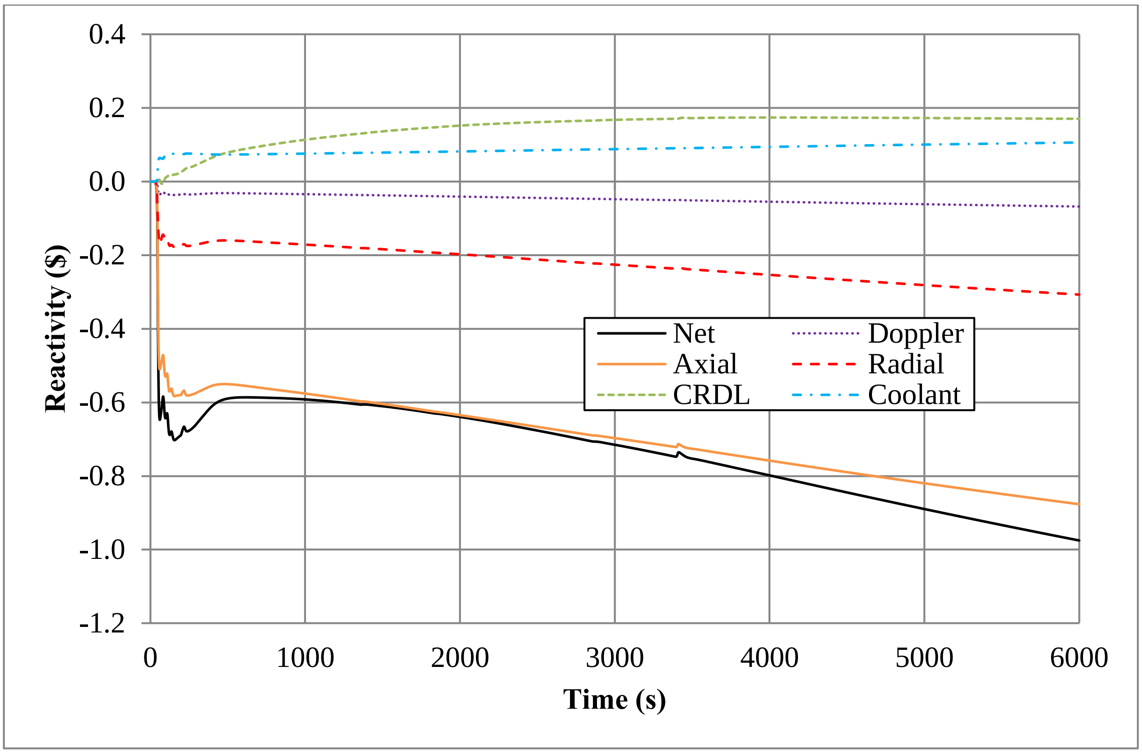


FIG. 6. Reactivity profile during ULOHS.

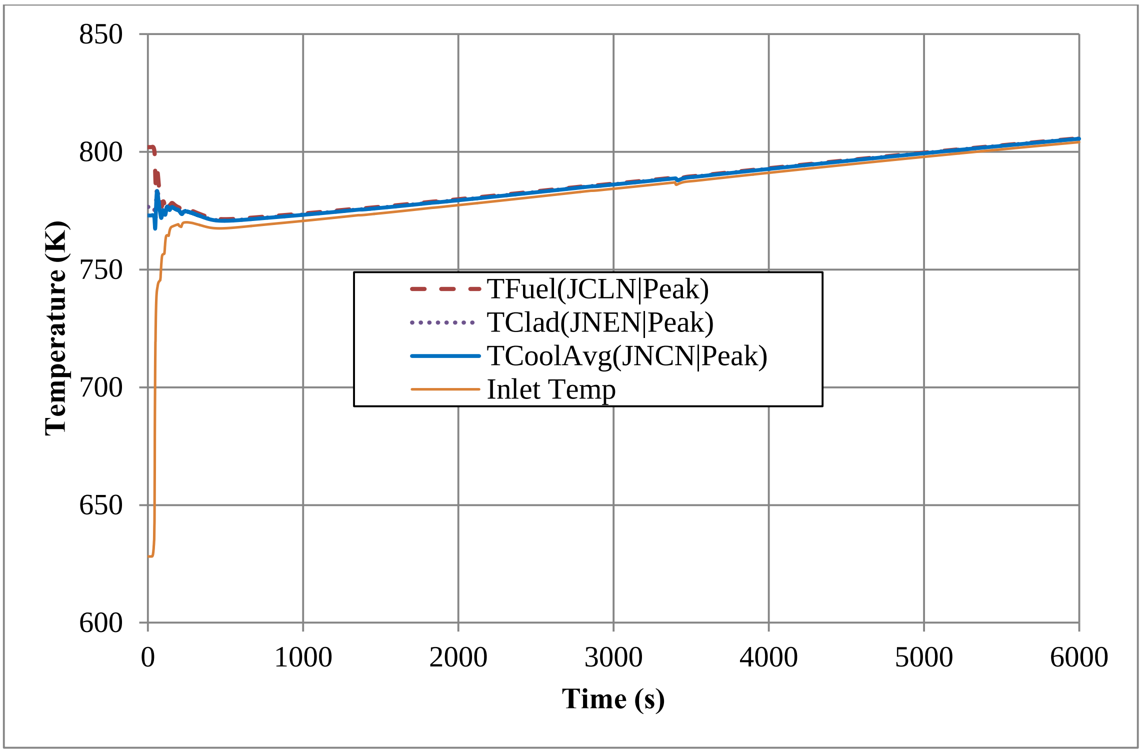
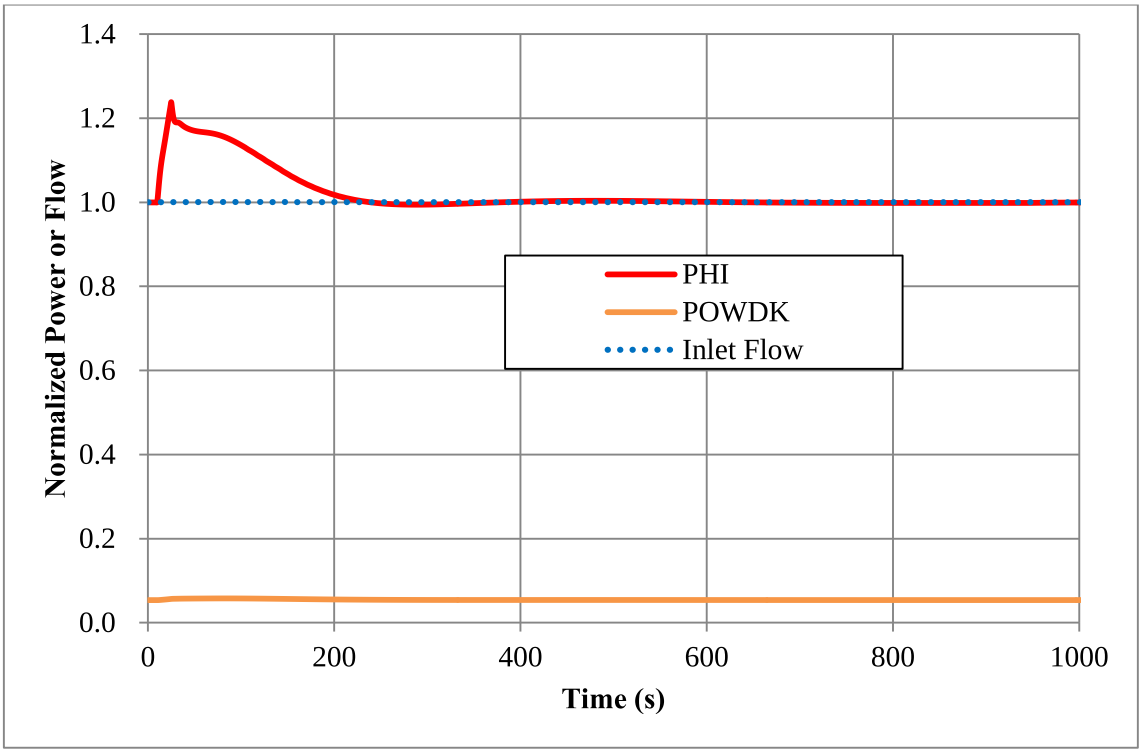


FIG. 7. Temperature change during ULOHS.

3.4.UTOP Transient Event

For UTOP event, a programmed reactivity of 30 ¢ is inserted linearly through 15 seconds and it remains to the end of the transient as shown in Fig. 9, which simulates a control rod extraction by an accident. The reactivity insertion leads the power increase which causes negative reactivity. Finally the net reactivity becomes negative and the power is back to unity after around 200 seconds as shown in Fig. 8. During this event, the fuel and the clad temperature increase first and the temperature level becomes constant. But it doesn’t reach the sodium saturation temperature limit of 1,200 K as shown in Fig. 10.



PHI: power, POWDK: decay power

FIG. 8. Normalized power and inlet flow during UTOP.

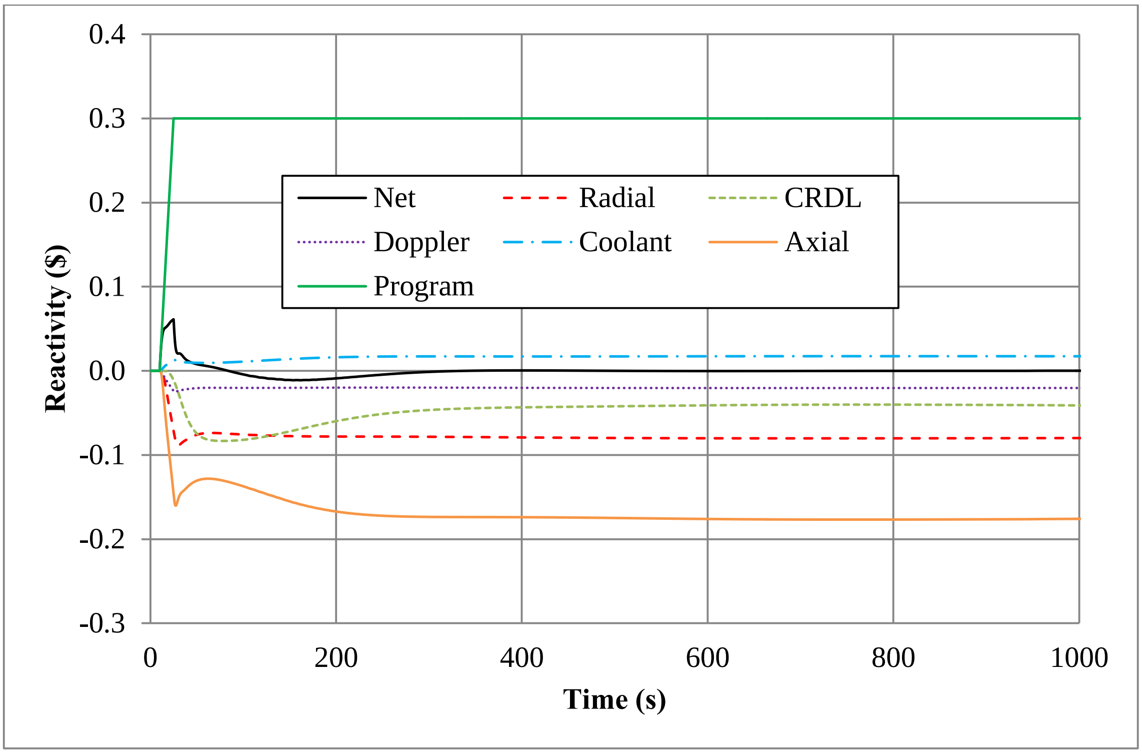


FIG. 9. Reactivity profile during UTOP.

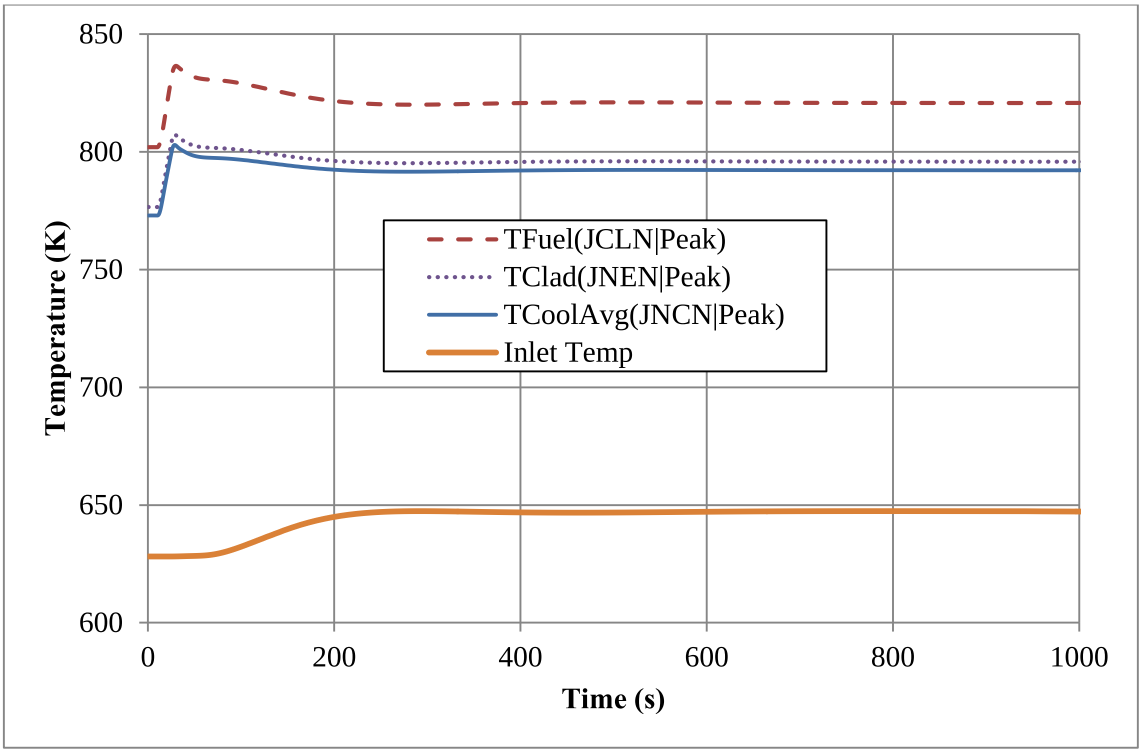


FIG. 10. Temperature change during UTOP.

4. Conclusions

Safety assessment for SM-SFR was conducted by evaluating the transient of ATWS events using SAS4A/SASSYS-1. The simulations for three ATWS events, ULOF, ULOHS, UTOP, were performed, and the power to flow change, the reactivity profiles, and the temperature changes were investigated to trace each transient trend. It has been confirmed that SM-SFR has inherent safety from the fact that any of the events doesn't have a clad failure or a coolant boiling.

Acknowledgement

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Reference

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