Safety Analysis of ATWS Events for PGSFR

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1. Introduction

KAERI has developed a specific design of the PGSFR (Prototype Gen-Ⅳ Sodium-cooled Fast Reactor) with the thermal power of 392.2 MWt, which is the pool type SFR (Sodium-cooled Fast Reactor) with metallic fuel of U–10%Zr for a core having inherent reactivity feedback mechanisms and high thermal conductivity. The PGSFR consists of the PHTS (Primary Heat Transport System), the IHTS (Intermediate Heat Transport System), and the DHRS (Decay Heat Removal System) [1].

Four events of Unprotected Transient Over-Power (UTOP), Unprotected Loss OF Flow (ULOF), Unprotected Loss Of Heat Sink (ULOHS), and Unprotected Station Black-Out (USBO) are selected as representative events for the Anticipated Transient Without Scram (ATWS). Safety analysis of four representative ATWS events are carried out with MARS-LMR code [2].

2. Safety Analysis Methodology

DECs (Design Extension Conditions) events such as ATWS events are analyzed with a best-estimate deterministic evaluation method (a best-estimate code and best-estimate input and BCs) considering sensitivity analysis of uncertainty effects of the reactor kinetic parameters. Safety acceptance criterion related with DECs events is that sodium bulk temperature shall be under sodium boiling temperature [1, 3].

Fig. 1 shows the safety analysis nodalization for the specific design of the PGSFR. The core is modeled by fifteen parallel flow channels such as nine hottest subassemblies, the rest of driver fuel assemblies, control rod assemblies, IVS (In Vessel Storage) assemblies, reflector assemblies, shield assemblies, and leakage flow. The PHTS is placed in a large pool, which is divided into hot pool and cold pool zones. The four sodium-to-sodium DHXs (Decay Heat eXchangers) and two pumps are located in the cold pool, whereas four IHXs (Intermediate Heat eXchagers) are located in the hot pool to transfer the reactor generated heat from the PHTS to the SG (Steam Generators). The IHTS consists of the two IHXs tube side, piping, one EM pump, and one SG shell side. The SG inlet feed-water boundary region is adopted with a constant mass flow-rate condition. In addition, the SG outlet boundary region nearby high-pressure turbine is adopted with a constant pressure condition. Each DHRS is modeled by PDHRS and ADHRS, respectively. DHX is located and submerged in the cold pool region and the sodium-to-air heat exchanger is located in the upper region of the reactor building. The air boundary regions are adopted with a pressure condition for simulating natural circulation phenomena.

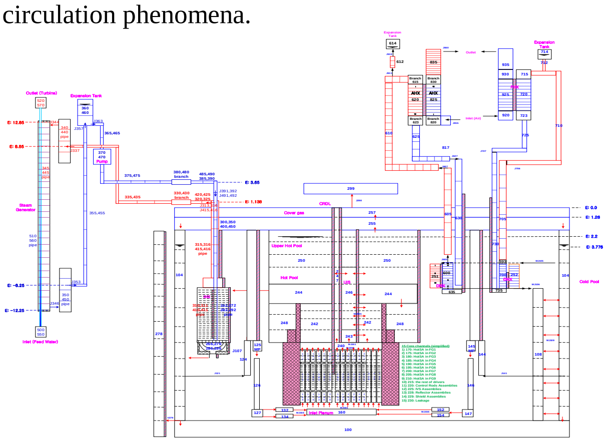


Fig. 1. Safety analysis nodalization for specific design of PGSFR.

3. Safety Analysis Results

The inherent safety characteristics of ATWS events in the PGSFR are achieved by five reactivity feedbacks such as fuel Doppler, sodium density, fuel pin axial expansion, core radial expansion, and control rod driveline and reactor vessel (CRDL/RV) expansion. The reactivity feedbacks in this study are considered based on the point kinetic theory.

3.1 Unprotected Transient Over-Power (UTOP)

The event is initiated by the insertion of positive reactivity in an unprotected condition as a result of a control rod assembly withdrawal, which is caused by the failures of the control rod assembly driving device and the reactor control system, or an operator mistake. The event leads to increases in the core power and the core outlet temperature. The dampers are fully opened and the blower of the DHRS is operated by the ESF (Engineering Safety Features) actuation signal.

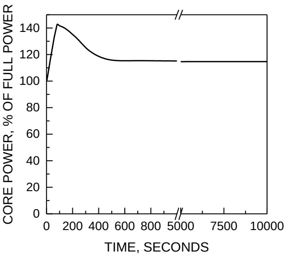
Fig. 2 shows the safety analysis results. At 0.0 second, the core power increases since a positive reactivity is inserted due to a control rod assembly withdrawal. The high center fuel assembly outlet temperature reaches the setpoint at 51.56 seconds, and then the DHRS actuation signal is activated after 6.0 seconds later. At 77.66

seconds, the DHRS dampers are fully opened and the blower begins to operate. As a result, the peak assembly outlet temperature is 656.7 ℃.

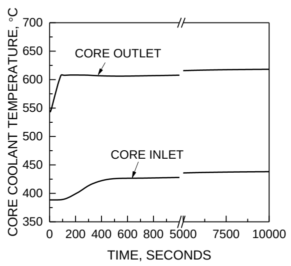
3.2 Unprotected Loss Of Flow (ULOF)

The event is initiated when both PHTS pumps stop under unprotected conditions. The event leads to decreases in the core coolant flow rates, and an increase the core coolant temperature. The dampers are fully opened and the blower of the DHRS is operated by the ESF actuation signal.

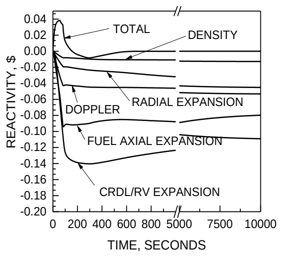
Fig. 3 shows the safety analysis results. At 0.0 second, both PHTS pumps are tripped. The high center core fuel



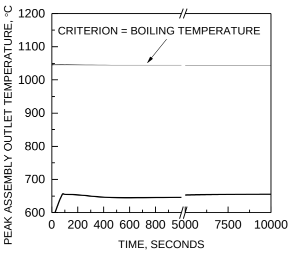
(a) Core power



(b) Core average temperature

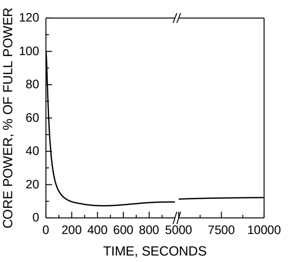


(c) Reactivity feedbacks

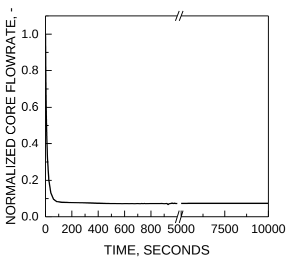


(d) Peak assembly temperature

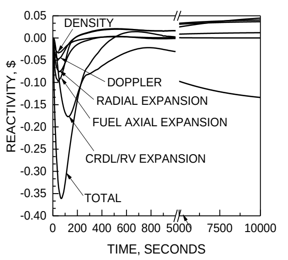
Fig. 2. Safety analysis results of UTOP.



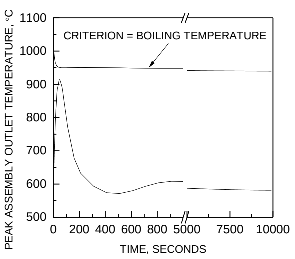
(a) Core power



(b) Core coolant flowrate



(c) Reactivity feedbacks



(d) Peak assembly temperature

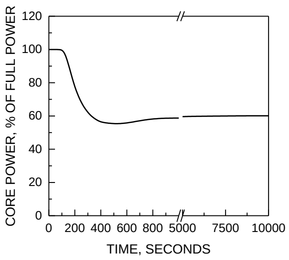
Fig. 3. Safety analysis results of ULOF.

assembly outlet temperature reaches the setpoint at 6.06 seconds, and then the DHRS actuation signal is activated 6.0 seconds later. At 32.17 seconds, the DHRS dampers are fully opened and the blower begins to operate. As a result, the peak assembly outlet temperature is 914.1 ℃.

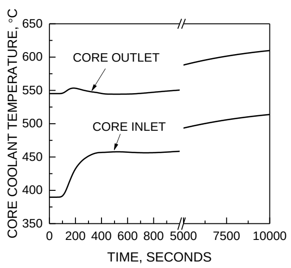
3.3 Unprotected Loss Of Heat Sink (ULOHS)

The event is initiated by a single feedwater pump trip, associated with the assumption that the RPS has failed. Since coastdown occurs in the affected feedwater pump, the feedwater flow rate is gradually decreased. Because the heat of the IHTS sodium cannot be transferred to the affected steam generator, the PHTS coolant temperature increases continuously. DHRS is operated by the ESF actuation signal which is a high core inlet coolant temperature.

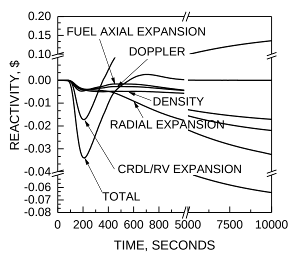
Fig. 4 shows the safety analysis results. At 0.0 second, a single feedwater pump is tripped. The high core inlet temperature reaches the setpoint at 133.55 seconds, and then the DHRS actuation signal is activated 6.0 seconds later. At 159.65 seconds, the DHRS dampers are fully opened and the blower begins to operate. As a result, the peak assembly outlet temperature is 624.0 ℃ at 10,000 seconds



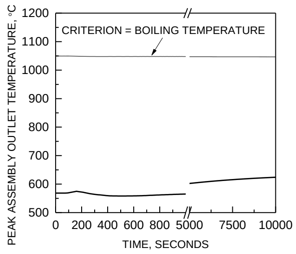
(a) Core power



(b) Core average temperature



(c) Reactivity feedbacks



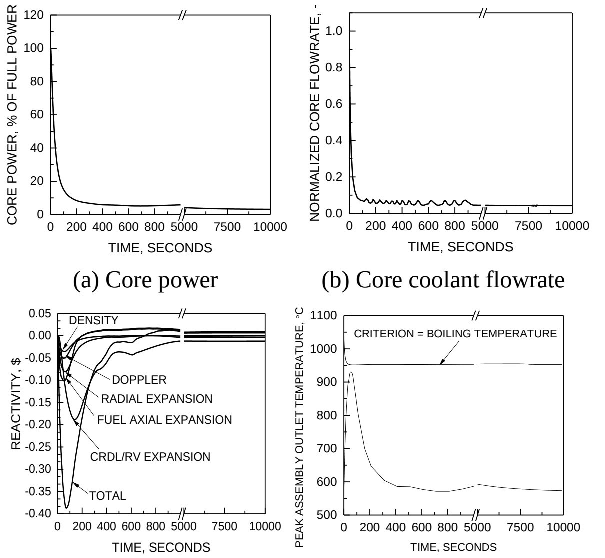
(d) Peak assembly temperature

Fig. 4. Safety analysis results of ULOHS.

3.4 Unprotected Station Black-Out (USBO)

SBO is initiated by a simultaneous loss of both offsite power sources and on-site power sources including emergency diesel generator. Even though blower of FHX is not operated, ADHRS has at least 50% of heat removal capacity against a complete loss of power. The event leads to decreases in the core coolant flow rates, and an increase the core coolant temperature. The dampers are fully opened by the ESF actuation signal.

Fig. 5 shows the safety analysis results. At 0.0 second, station black-out occurs. The high center core fuel assembly outlet temperature reaches the setpoint at 6.41 seconds, and then the DHRS actuation signal is activated 6.0 seconds later. At 32.51 seconds, the DHRS dampers are fully opened and the blower begins to operate. As a result, the peak assembly outlet temperature is 930.5 ℃.



(a) Core power (b) Core coolant flowrate

(c) Reactivity feedbacks (d) Peak assembly temperature

Fig. 5. Safety analysis results of USBO.

4. Conclusions

Safety analysis of four representative ATWS events has been implemented using MARS-LMR code. As a results, the peak assembly outlet temperatures fulfill the safety acceptance criteria. Furthermore, peak assembly outlet temperature of USBO event is higher than that of other events such as UTOP, ULOF, and ULOHS.

ACKNOWLEDGEMENTS

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