Analyses of Decrease in Reactor Coolant Flow Rate in SMART

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1. Introduction

SMART is a small integral reactor, which is under development at KAERI[1] to get the standard design approval by the end of 2011. SMART works like a pressurized light-water reactor in principle though it is more compact than large commercial reactors. SMART houses major components such as steam generators, a pressurizer, and reactor coolant pumps inside the reactor pressure vessel. Due to its compact design, SMART adopts a canned-motor type reactor coolant pump which has much smaller rotational inertia than the ones used in commercial reactors. As a consequence, the reactor coolant pump has very short coastdown time and reactor coolant flow rate decreases more severely compared to commercial reactors. The transients initiated by reduction of reactor coolant flow rate have been analyzed to ensure that SMART can be safely shutdown on such transients. The design basis events in this category are complete loss of flow, single pump locked rotor with loss of offsite power, and single pump shaft break with loss of offsite power.

2. Events description and Acceptance Criteria

Complete loss of flow event is initiated by complete loss of AC power to all RCPs. Offsite power is lost at the beginning of the event. Locked rotor or shaft break accident occurs when a single RCP malfunctions due to mechanical defects. Offsite power is lost at the moment of reactor trip. A RCP stops immediately when a RCP rotor is locked. When a RCP shaft has broken, the impeller of a broken shaft may rotate in any direction according to the direction of coolant flow.

Among the three events in the category, complete loss of flow is an AOO(anticipated operational occurrence). The others are postulated accident. Fuel cladding failure is not allowed in AOOs. Fuel cladding failure is allowed in postulated accidents but the resulting radiological effect should not exceed a few fraction of 10 CFR 100. Minimum DNBR during transients decides whether failure in fuel cladding occurs or not. DNBR SAFDL in SMART is 1.5. Minimum DNBR lower than the DNBR SAFDL means some failure in fuel cladding.

3. Analysis Method

2.1 Mathematical Model and Code

Primary and secondary coolant systems are modeled as nodes and paths to simulate their thermal-hydraulic behavior. The coastdown behavior is simulated by solving an angular momentum equation. The hydraulic behavior of the pump is represented as a set of homologous curves. The curves are obtained from a series of experiments using a scaled-down pump.

The transients are analyzed by using TASS/SMR-S code[2] which simulates thermal-hydraulic behavior by solving basic conservation equations on mass, momentum, and energy. In addition, TASS/SMR-S has built-in kinetics model, steam generator model, and pump model required to simulate the transients. TASS/SMR-S also evaluates DNBR online by using a built-in fast calculation module.

2.3 Analysis conditions

Each event is analyzed in various initial conditions and a limiting condition is selected in terms of minimum DNBR during transients. Initial conditions are adjusted so that all the events are initiated on the power operating limit with a same power margin.

Major assumptions for conservative analysis are[3]:

- The scram reactivity insertion curve is for the limiting bottom-skewed axial power shape.
- Fuel temperature coefficient and moderator temperature coefficient are bounding values expected for whole fuel cycles.
- The pumps begin coastdown at the time of AC-power loss. There is no time delay between power loss and onset of coastdown.

Reactor trips on detecting low RCP speed in complete loss of flow and locked rotor event. In shaft break event, reactor trips on detecting low RCP flow rate since RCP speed is not measured properly.

3. Analysis Results

Table 1 describes the sequence of the events.

Minimum DNBR does not hit DNBR SAFDL in any of the events which means no fuel failure occurs(Fig. 1). The maximum RCS pressure is far below the upper limit (110% of the design pressure) and not a significant concern. Thus, the acceptance criteria are satisfied[4].

Fig. 2 shows power decrease at the beginning of coastdown prior to the scram. The core power decreases due to moderator temperature feedback. As the forced coolant flow is lost, the core coolant flow reduces significantly and the core coolant temperature rises. MTC is negative above the power level of 20% and raised coolant temperature mitigates the consequences of RCP failures. Scram begins at about two seconds by the trip signals on low RCP speed or low RCP flow rate. Minimum DNBR occurs at 3 seconds or so. At the moment, the core power has decreased sufficiently. However, the core heat flux is still high due to the thermal inertia(Fig. 3) despite the core flow rate is already reduced to a half of the initial value(Fig. 4). DNBR rises as scram completed and decrease in heat flux catches up the decreased core flow rate.

Noticeable is the result that the consequence of the shaft break event limits that of the locked rotor event in SMART. This is due to the pump design. The pumps in commercial reactors have an anti-reverse rotating device while the canned-motor pump in SMART has no such device and an impeller may rotate in reverse direction when its shaft is broken.

4. Conclusions

Analyzed cases are the design bases events under the category of decrease in reactor coolant flow rate. The conservative analyses show that no fuel failure occurs and the reactor can be safely shutdown and cooled down on the events.

REFERENCES

[1] SMART System Description, 000-NA403-001, KAERI, 2010.
[2] TASS/SMR-S Code Topical Report, KAERI, 2010.
[3] SMART Loss of Flow Events Analysis Method, 911-TH474-003, KAERI, 2010.
[4] SMART Standard Safety Analysis Report, KAERI, 2010.

Table 1 Sequence of the RCS flow reduction events

Sequence of events (Sequence start at 0s)	Time of event, s		
	CLOF	Locked Rotor	Shaft Break
Trip condition reached	0.37	0.0	0.1
Trip signal raised	1.47	1.1	1.3
Scram begins	1.97	1.6	1.8
Minimum DNBR occurs	3.0	2.7	2.9
Peak RCS pressure reached	12.0	11.6	12.0

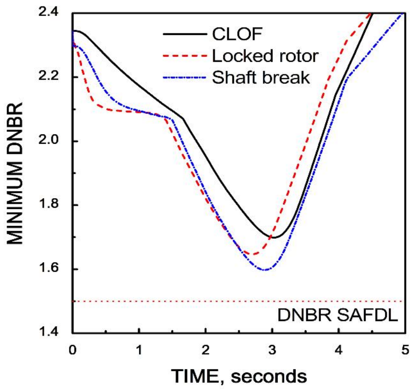

Fig. 1 Minimum DNBR

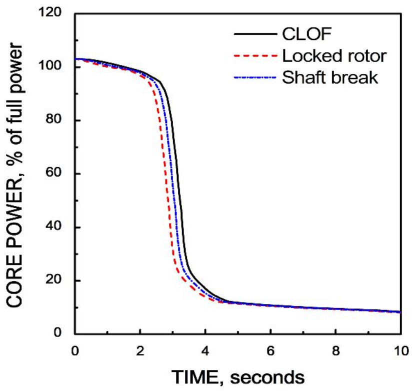

Fig. 2 Core power

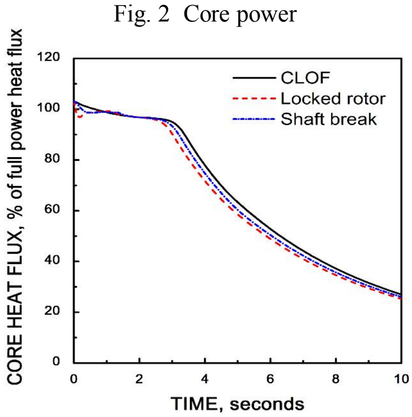

Fig. 3 Core heat flux

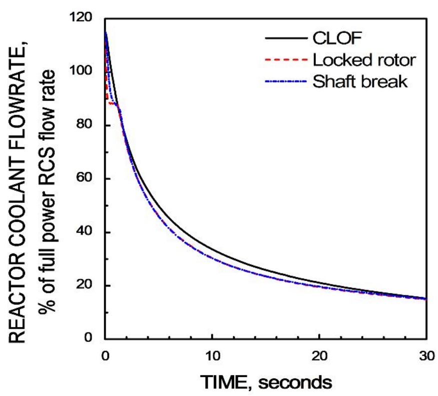

Fig. 4 RCS coolant flow rate