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Application of Emergency Boration System for ATWS Mitigation of Innovative Small Modular Reactor

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1. Introduction

Anticipated transients without scram (ATWS) is accident that a failure of the reactor protection system (RPS) to initiate the reactor trip in response to the anticipated operational occurrence (AOO). The main concern of ATWS is over pressurization in the reactor coolant system (RCS) and, therefore, to maintain the integrity of reactor coolant pressure boundary.

The emergency boration system (EBS) is a safety feature of injecting highly concentrated borated water into the RCS to reduce the core power and to maintain core subcritical in the event of an ATWS.

This paper evaluates the possibility of the EBS to mitigate a postulated ATWS accident for an innovative small modular reactor (i-SMR).

2. Method of Analysis

The SPACE code [1] is used to evaluate major thermal and hydraulic system behavior. Normal operating conditions and nominal plant design values are assumed for the purpose of applying best estimate analysis method. The nodalization of SPACE code for the analysis is shown in Fig. 1. A loss of condenser vacuum (LOCV) is assumed for the initiating AOO in this postulated ATWS. The loss of secondary heat removal is expected to greatly increase RCS pressure during the transient. The major parameters assumed for EBS operation are summarized in Table I.

3. Results

3.1 Without Emergency Boration System

Table II shows the sequence of the event and the major thermal/hydraulic behavior are presented in Fig. 2 to Fig. 4. LOCV decreases the heat transfer rate from the RCS to the secondary system which results in the increase of RCS temperature. The RCS pressure increases due to the volumetric expansion of the RCS coolant. After a while, the pressurizer pressure reaches the high pressure reactor trip set-point but fails to scram the reactor due to a postulated ATWS. The reactor power decreases according to the inherent negative reactivity feedback effect. The auxiliary secondary coolant loop begins in response to the RPS reactor trip signal but is insufficient to remove the heat generation in the core. This mismatch in heat balance increases the pressure of RCS that repeatedly lifting the pressurizer safety valves (PSVs) to protect over pressurization on the RCS. The loss of reactor coolant inventory occurs due to the opening of PSVs that eventually produce loss of coolant accident (LOCA) related signal to initiate the emergency core cooling system (ECCS). The ECCS transports low temperature coolant to the core that inserts positive reactivity resulting in failure to maintain the core in a subcritical condition.

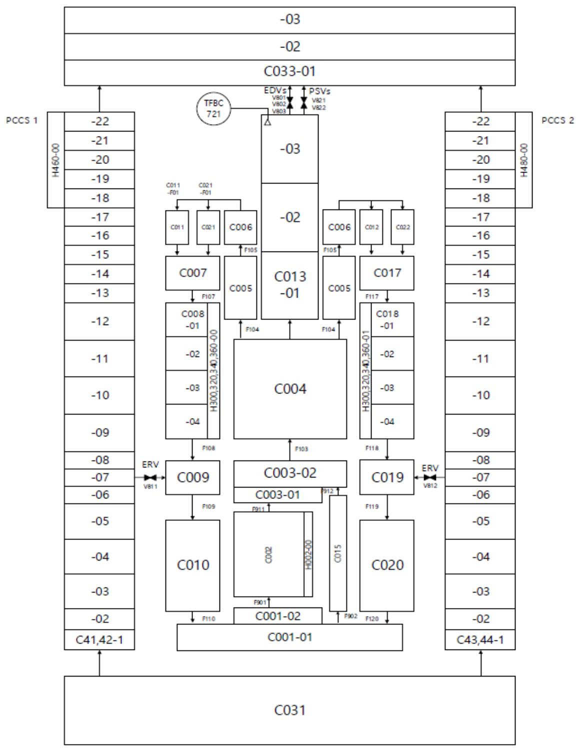

Fig. 1 SPACE Nodalization for ATWS analysis of i-SMR

Table I: Major Parameters for EBS

Parameter	Value
Set-point	RPS Fail + 60 s.
Total Flow Rate	0.00315 m^3/s (50 gpm)
Boron Concentration	7,000 ppm

3.2 Application of Emergency Boration System

Based on the results from previous section, the following concerns are identified in a postulated ATWS condition.

1) Imbalance between heat generation and removal
2) Positive reactivity feedback due to the initiation of ECCS
3) Fails to control the reactivity which is one of the fundamental safety functions

The major thermal and hydraulic behavior with EBS in a postulated ATWS are found in Fig. 5 to Fig.7.

The sequence of event in Table II is similar to without EBS case except the EBS injection on reactor trip signal.

With the advantage of high concentrated borated water of injected EBS coolant, it is known that the core maintains subcritical throughout the transient. The low coolant temperature of EBS injection gradually decreases the RCS temperature, hence lowering RCS pressure, prevents lifting the PSVs. The ECCS actuation signal is not generated following the inventory makeup by EBS injection.

Based on the analysis results, it is found that the plant remains in a safe and stable condition with the application of EBS in a postulated ATWS.

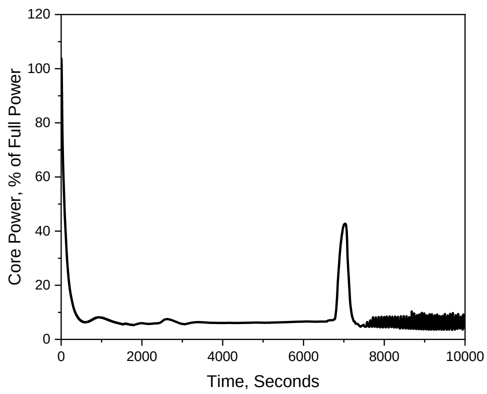

Fig. 2 Core Power (without EBS)

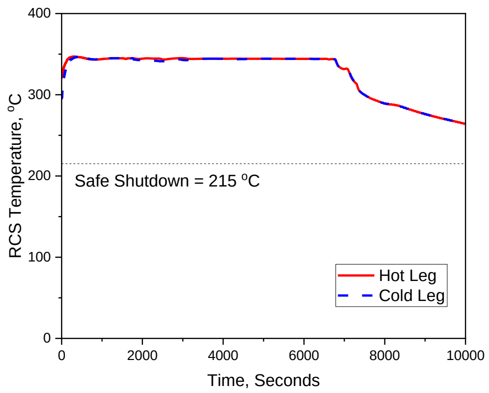

Fig. 3 RCS Temperature (without EBS)

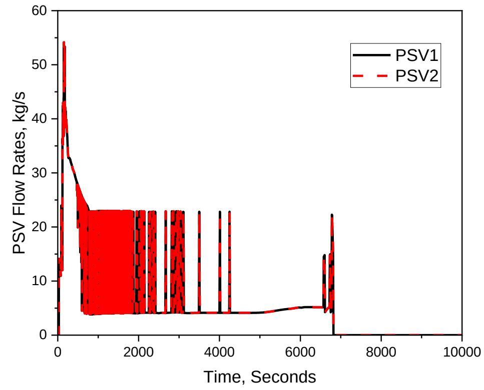

Fig. 4 PSV Flow Rates (without EBS)

Table II: Sequence of Events for ATWS with and without EBS

Time (s)	without EBS	with EBS
0	- Loss of Condenser Vacuum	- Loss of Condenser Vacuum
12	- RPS Trip Setpoint Reached	- RPS Trip Setpoint Reached
13	- RPS Trip Failed - Auxiliary Secondary Cooling Loop Initiated	- RPS Trip Failed - Auxiliary Secondary Cooling Loop Initiated
28	- PSVs Open Started	- PSVs Open Started
73	-	- EBS Initiated
6,780	- ECCS Initiated - Core Power Increase	-
10,000	-	- Safe and Stable Condition Reached

4. Conclusions

The effects of EBS are evaluated for a postulated ATWS of the i-SMR. From the results, insufficient heat removal rate in auxiliary secondary cooling loop lifts PSVs. This causes loss in the RCS inventory which initiates the ECCS to transport low temperature coolant to the core. The positive reactivity insertion increases the core power. The application of EBS is evaluated to provide negative reactivity by means of injecting highly concentrated borated water to the RCS resulting the core in a subcritical. Also, both the RCS inventory makeup and temperature decreasing capability derive the plant into safe and stable condition.

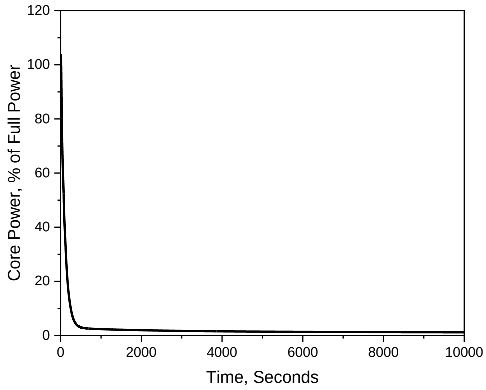

Fig. 5 Core Power (with EBS)

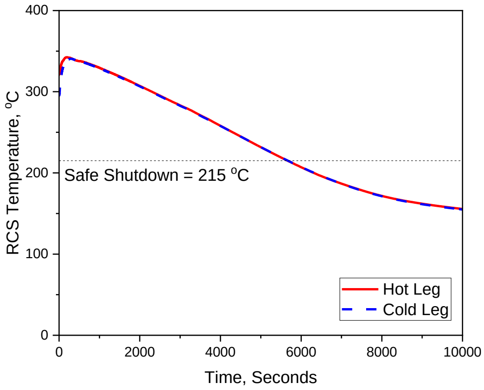

Fig. 6 RCS Temperature (with EBS)

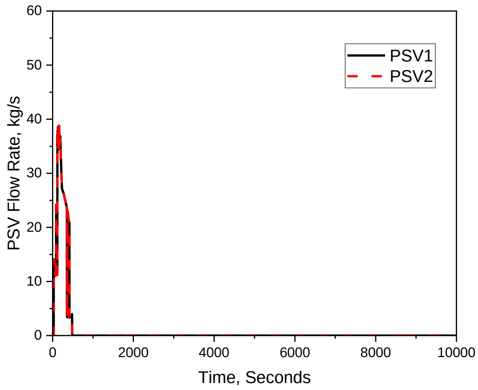

Fig. 7 PSV Flow Rates (with EBS)

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REFERENCES

[1] SPACE 3.3 User Manual, SQA Document, 2022.