Transactions of the Korean Nuclear Society Autumn Meeting
Gyeongju, Korea, October 24-25, 2013

Development of the Diverse Means for Reactor Shutdown Function of EU-APR1400

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1. Introduction

Diversity is the fundamental principle in safety system design of a new nuclear power plant, which uses different mitigation measures to provide diverse ways of responding to a significant event. Regarding the diversity principle, EU-APR1400 (European APR1400) safety system should be in accordance with European design requirements [1,2,3].

EBS (Emergency Boration System) is designed to provide the diverse means to shut down the reactor against ATWS (Anticipated Transient Without Scram) and to mitigate the event consequences in the EU-APR1400.

This paper provides general descriptions of the EBS focusing on basic design characteristics such as system function, configuration and operation, and presents results from the preliminary verification of system performance.

2. System Function

The function of the EBS is to provide the diverse means of injecting highly concentrated borated water into RCS (Reactor Coolant System) through DVI (Direct Vessel Injection) nozzles upon EBAS (Emergency Boration Actuation Signal) following the ATWS to shut down the reactor to a subcritical state. The EBS injects borated water at the rate sufficient to bring the reactor core into sub-criticality from any operational or anticipated transient, and is required to maintain the sub-criticality over a long period of time. The EBS could also be actuated manually by operator action.

3. System Configuration

By adopting “N+1” design concept the EBS consists of two mechanically and electrically separated trains as shown in Fig. 1. Each train of EBS has full capacity to maintain the core in a sub-critical condition.

Diversity is one of the principles in safety system design by using different mitigation measures to provide diverse ways of responding to a significant accident. In the event of ATWS, in conjunction with a single failure in mechanical or electrical equipment, the flow from at least one EB pump is available for reactor shutdown function.

Two independent electrical buses supply power to each EB pump and associated valves. When normal electrical power sources are unavailable, emergency power sources are automatically activated and connected to the buses.

Each EB pump discharge piping is connected to the two DVI nozzles. The EBS train 1 injects the borated water into RCS through the DVI nozzles 1A and 1B, and the EBS train 2 injects to the DVI nozzles 2A and 2B. This is schematically presented in Fig. 1. The EBS trains contain the emergency boration isolation valves, which are normally closed during normal plant power operation.

The EBS is designed as a Safety Class 3 system, except for piping of retaining RCS pressure and mechanical equipment that form part of the reactor coolant pressure boundary inside of the containment; these are Safety Class 1.

The system is designed to prevent boron precipitation during all operating modes. Heat tracing provision to prevent boron precipitation is provided in the EBT and piping.

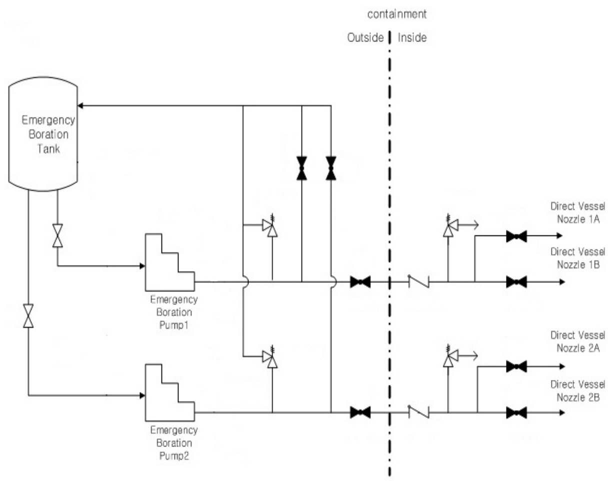

Fig. 1. Schematic diagram for the EBS

4. System Operation

4.1 Operation during Normal Plant Conditions

During normal plant operation the EBS is aligned for injection mode with all EB isolation valves closed.

4.2 Operation during Plant Accident Conditions

The EBS automatically actuates upon the EBAS, which is generated in case the failure of the CEA (Control Element Assembly) dropping into the core have occurred in spite of the reactor trip signal from

DPS (Diverse Protection System) as shown in Fig. 2. Upon the EBAS, the two EB pumps start to run and EBS isolation valves open simultaneously to inject highly borated water into the RCS.

4.3 Manual Actuation

Provision for manual actuation of the EBS is provided. Manual operation of the EBS could be performed in case automatic actuation fails.

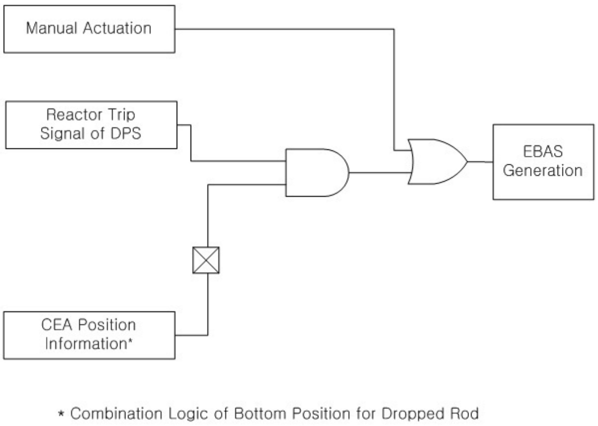

Fig. 2. Conceptual actuation logic for the EBAS

5. Preliminary Verification of System Performance

5.1 ATWS events

The major concerns of the ATWS are an expected high primary system pressure and a challenge to fuel integrity. Even if there are several ATWS events, one typical event (i.e. Excess Increase of Steam Flow) is chosen to evaluate the performance.

5.2 Description of the Excess Increase of Steam Flow

An increase in steam flow causes an increase of heat transfer from the primary to the secondary, a decrease in reactor coolant temperature, an increase in core power and heat flux, and a decrease in reactor coolant pressure.

An Inadvertent Opening of Main Steam Atmospheric Dump Valve is used here to illustrate the event of the Excess Increase of Steam Flow.

5.3 Analysis Results

The maximum RCS pressure at the reactor coolant pump discharge is 18.31 MPa which is below acceptance criteria of 20.68 MPa (120% of design pressure), ensuring primary system integrity.

The minimum DNBR (Departure from Nucleate Boiling Ratio) remains above SAFDL (Specified Acceptable Fuel Design Limit) value of 1.29 during the transient. Therefore, there is no fuel cladding failure.

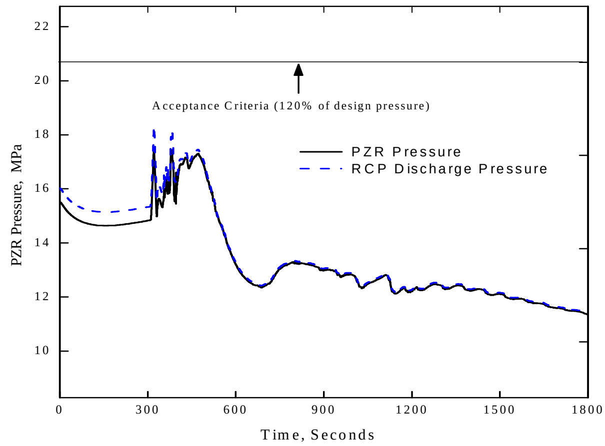

Fig. 3. RCS pressure vs. time

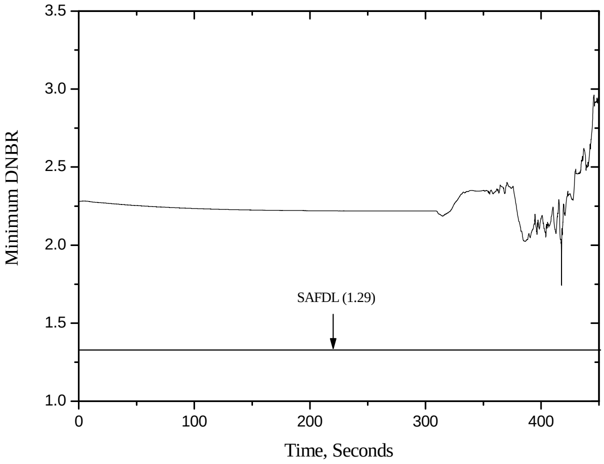

Fig. 4. Minimum DNBR vs. time

6. Conclusions

The diverse means for the reactor shutdown function of EU-APR1400 have been developed to comply with the diversity principle of the European design requirements of a new nuclear power plant.

The preliminary verification of the EBS performance was done by the ATWS analysis. The analysis results show that the EBS was designed properly.

REFERENCES

[1] IAEA (International Atomic Energy Agency), Safety of Nuclear Power Plants: Design, IAEA Safety Standards Series No. SSR-2/1, 2012

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[3] EUR Organization, European Utility Requirements for LWR Nuclear Power Plants, Revision D, Chapter 2.1, 2012