# APR1000 Boron Dilution Prevention System (BDPS) Concept Design

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## 1. Introduction

In case of the boron dilution, the minimum time requirements of 15 minutes and 30 minutes without operator action for the OPR1000 Nuclear Power Plant (NPP) and APR1400 NPP are respectively satisfied by the Boron Dilution Alarm System (BDAS). In APR1000, the capacity of the Reactor Coolant System (RCS) is downsized to 1000MW to meet the needs from European countries, but the time required for no operator action by EUR Rev. E is still 30 minutes which is identical to the time for the APR1400 with the BDAS. With the downsized RCS, the existing BDAS is not sufficient to meet the EUR Rev. E in APR1000. Therefore, there needs to be a new system that performs preventing boron dilution automatically in the APR1000 design, which is called Boron Dilution Prevention System (BDPS). In this paper, the BDPS design background, the basic design concept of APR1000 adapting the system classification methodology and the time requirement for no operator action from EUR Rev. E, and European technical standards are introduced.

## 2. Methods and Considerations

Designing the BDPS in APR1000 requires detailed review of several design considerations and backgrounds, as indicated in each sub-clause of this section.

### 2.1 Boron Dilution Event Trend and APR1000

In the OPR1000 or APR1400 units, the operator can take manual action from alarm information provided by the non-safety grade BDAS upon an inadvertent boron dilution event only after the secured time. In OPR1000, the secured time is at least 15 minutes from the point of time the alarm is initiated by the occurrence of an event to the point of time the criticality is reached. In APR1400, the time is secured for at least 30 minutes due to larger RCS than the OPR1000.

As addressed in Section 1 above, the APR1000 design is aimed at 1000MW scale output with reduced capacity of RCS compared to APR1400, and the APR1000 standard design is currently undergoing to be certified by EUR Rev. E. To do that, the time requirement of at least 30 minutes inside the Main Control Room (MCR) and 60 minutes outside the MCR for no operator action upon an inadvertent boron dilution event must be met.

The analysis result in response to the boron dilution event in APR1000 has shown that the 30-minute requirement for no operator action is not guaranteed or satisfied due to the reduced RCS capacity compared to APR1400. Since the core will reach the criticality point if no action is taken within 30 minutes after the boron dilution event occurs, there needs to be an automation design so that no constraint is bounded by the 30-minute requirement. Therefore, this result makes it legitimate to apply a new type of system that can automatically prevent boron dilution when demanded.

### 2.2 Requirements

There are several documents to consider for incorporating the BDPS design into APR1000 to suit the needs of European countries.

The operator action time requirements are provided in Section 6.7.1 of [1] as follows:
> *... autonomy objectives: the release targets of AOOs and Accident Conditions shall be met without Operator action in the MCR during the first 30 minutes from the first significant signal, ...*

In the first 30 minutes from the signal of an accident, the action should be automated without operator action in the MCR.

Requirements related to a safety class are given in section 4.2.2 of [1], which requires designing the BDPS as a safety class.

In the APR1400 of BNPP (Barakah Nuclear Power Plant), the BDAS has recently been upgraded from a non-safety to a safety class according to local regulatory guide FANR-REG-03.

### 2.3 Boron Dilution Prevention System (BDPS)

The BDPS is the system that responds to the situation in which an inadvertent boron dilution event occurs. The BDPS is designed to reduce the reactivity of the core by closing the Reactor Makeup Water (RMW) isolation valves when required. Once activated, the BDPS will automatically stop boron dilution before the plant loses its shutdown margin.

#### 2.3.1 Categorization and Classification

The function of the BDPS is to bring the plant to a safe state after Anticipated Operational Occurrence (AOO). If this function is not actuated, the consequences may challenge the fuel cladding integrity and primary system overpressure protection. Therefore, the BDPS is

classified as a safety class, and the classification of related Structures, Systems, and Components (SSCs) performing its function is also determined as a safety class.

Section 5.1.5 'C' of [1] describes the general design requirements and their classifications. The Single Failure Criterion (SFC) is required to be applied to the BDPS design.

### 2.3.2 Fluid System Considerations

Accidents are related to boron dilution failure in the domain of Chemical Volume Control System (CVCS). In order for APR1000 to satisfy the 30-minute requirement of EUR Rev. E through the BDAS, the Startup Range Monitoring Ratio (SRM Ratio) alarm setpoint must be significantly lowered. It is concluded to be inappropriate that this particular alarm setpoint is lowered significantly because the relevant Instrumentation and Control (I&C) system exceeds the acceptable level of uncertainty when the setpoint goes significantly low. In order to satisfy the EUR Rev. E requirement without lowering the setpoint, the BDPS must be adopted to automatically generate a signal to close the charging flow valves.

### 2.3.3 I&C System Considerations

The I&C portion of the BDPS is also classified as a safety class and must satisfy SFC.

As the input signals, startup neutron flux increasing rates of the Ex-core Neutron Flux Monitoring System (ENFMS) are used. The BDPS initiation signal is generated when the startup neutron flux increasing rate exceeds the variable setpoint. Considering the SFC, a BDPS initiation signal is generated if two channels simultaneously satisfy the initiation condition from the inputs of the four ENFMS channels. Figure 1 shows a simple schematic diagram of input/output operation of the BDPS.
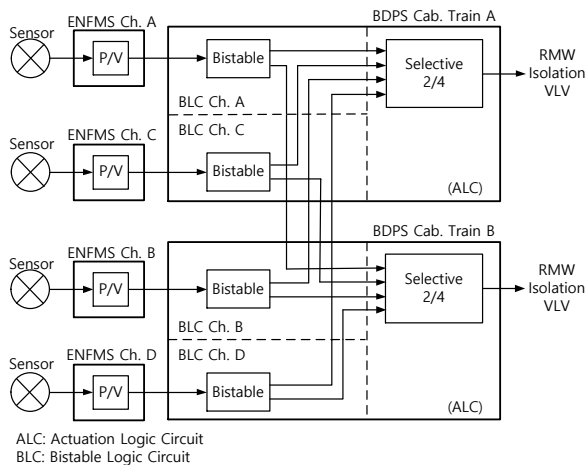
The BDPS initiation signal is also generated when the reactor is shutdown. Additionally, it can be generated manually in the MCR. The bistable function of high startup neutron flux increasing rate shall have the operating bypass capability to permit startup and shutdown of the plant without unnecessary trips and channel bypass capability for the purpose of maintenance and operation as design features.

The BDPS is designed based on hardware without software. Accordingly, the possibility of Common Cause Failure (CCF) of the safety classified I&C system software is excluded. The alarm function of the BDAS has been incorporated as part of the BDPS, which makes it unnecessary to implement a separate BDAS in the APR1000 design.

### 3. Conclusions

EUR Rev. E requires the safety to be secured without operator action in the MCR for 30 minutes after the accident. The analysis result of the boron dilution event classified as an AOO in APR1000 shows that the 30-minute operator requirement of EUR Rev. E is not satisfied only by the BDAS. The BDPS, being designed in APR1000, takes necessary automatic action within 30 minutes after the boron dilution event occurs, thereby satisfying the time requirement for no operator action from EUR Rev. E. In addition, it will relieve the operator from the burdensome action that may have to be taken after the boron dilution event occurs. In conclusion, the automated BDPS will contribute to enhancing the safety of NPPs by reducing the burden on operators and the possibility of criticality caused by the boron dilution event.

### REFERENCES

[1] EUR Rev. E Ch2.1 – 2016, "Volume 2 Generic and Nuclear Island Requirements Chapter 1 Safety Requirements", December 2016.



Fig. 1. BDPS Block Diagram