Calculations for BDAS Setpoint with Non-conservative Boron Dilution Analysis

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1. Introduction

In order to prevent to boron dilution accidents, BDAS (Boron Dilution Alarm System) is equipped at CE type pressurized water reactors. BDAS utilizes the ex-core detector instrumentation signals to detect a possible inadvertent boron dilution event during operation mode 3, 4, 5, 6.

For boron dilution analysis, discrepancies in the active coolant volume and the assumed linearity of the ex-core instrumentation response were identified for CE type PWR and they were reported by NASL-04-02[1]. These discrepancies have potential to impact to determine BDAS setpoint in a non-conservative manner.

Therefore, in this study, the calculation of BDAS setpoint with those discrepancies condition about OPR1000 was performed and analyzed for checking the safety of BDAS.

2. Methods and Results

2.1 Boron Dilution Alarm System

BDAS functionally alarm to operator when the Boron Dilution Alarm Logic(BDAL) in BDAS detect a possible boron dilution accident by monitoring the neutron flux indications, as shown in Figure 1 and 2. When neutron flux signal increase to equal or greater than the calculated alarm setpoint(Delta setpoint), alarm signals are generated. There is a reset capability to allow the operator to acknowledge the alarm and reinitialize the system.

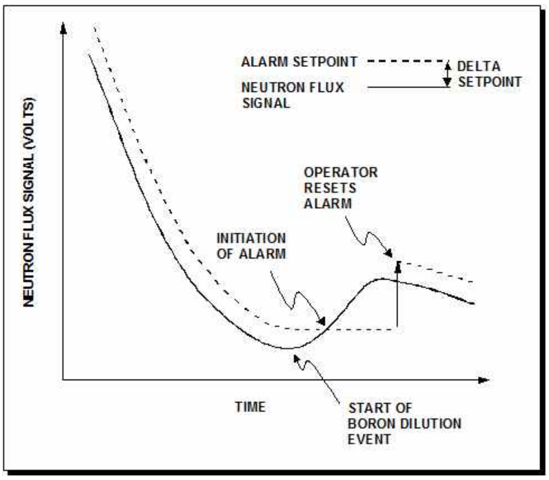

Fig. 1 BDAS Operation Principle

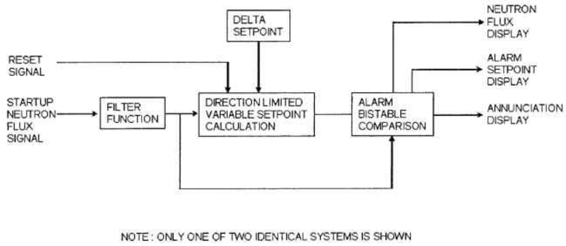

Fig. 2 BDAS Functional Flow Chart

2.2 Conservative Conditions

There are two identified discrepancies; the one is reactor coolant system (RCS) active mixing volume that plays a part in a boron dilution process. RCS volume was calculated too large for CE type PWR analysis. However, this discrepancy is not related to OPR1000, then that is not considered in this study.

The second discrepancy is the modeling of the ex-core detection/dilution alarm response for sub-critical modes. For boron dilution analysis, the Inverse Count Rate Ratio (ICRR) method is used for calculations of time that approach criticality at the most worst boron dilution accident case. Westinghouse type PWRs use generic ICRR curve which generated a conservative ICRR curve using measured ICRR data.

However, CE type PWRs use non-conservative ICRR curve during boron dilution that is proportional to the sub-critical. This curve resulted in a longer time to reach the BDAS from the start of event and thus a shorter time to criticality after the BDAS is reached.

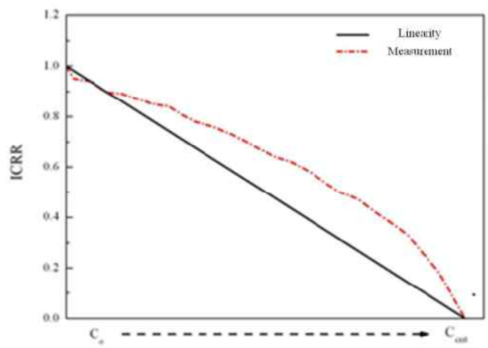

Fig. 3 Boron Dilution Curves (Linearity vs. Nonlinearity)

Therefore, we selected the conservative ICRR curve which measured at OPR1000 and both ICRR curves show in Figure 3.

2.3 Calculations of SRM ratio

SRM(Source Range Monitoring) ratio is used for BDAS setpoint and it was calculated through the most severe inadvertence boron dilution accident. When operating mode 3, 4, 5 and the most severe inadvertence boron dilution accident is occurred, operator should have over 15 minutes to taking pertinent actions as written in Technical Specification.

The SRM ratio is calculated as followings

$$SRM\ ratio = \frac{Source\ range\ signal\ at\ alarm}{Source\ range\ signal\ at\ start\ of\ dilution}$$

We calculated SRM ratio in condition with non-conservative ICRR curve at most severe boron dilution accident, which are Shutdown Cooling System Operation at mode 4, 5 and Drained Down Operation at mode 5, and so on. And we finally find out the SRM ratio which accepts Technical Specification limit at all cases, that is 2.50[2].

2.4 Calculations of BDAS Setpoint

Delta setpoint of BDAS is representative for BDAS setpoint. Delta, Maximum, and Minimum setpoint are calculated as following equations.

Delta Setpoint = Alarm setpoint – Flux Signal
Maximum Delta Setpoint
= Alarm Setpoint – 2log(Flux Signal)
= 2log(SRM Alarm Ratio) – Uncertainty
Minimum Delta Setpoint
=Overall BDAS Uncertantiy

BDAS uncertainty is calculated by root sum square about uncertainty of ex-core detector and that of control card. They are consisted of neutron flux startup channel uncertainty, voltage converter and BDAS control card. It is resulted of 0.362 V[3].

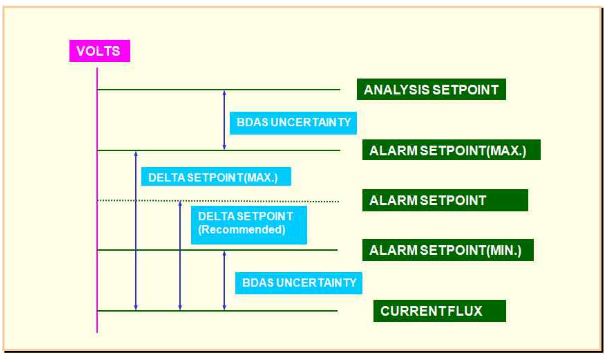

Fig. 4 BDAS Alarm Setpoints

Delta Setpoint is determined by the average value of maximum and minimum delta setpoint as shown in Figure 4.

3. Results

In order to apply the Westinghouse Advisory about non-conservative condition at inadvertence boron dilution accident, we calculated about BDAS setpoint by using conservative boron dilution analysis in satisfied with Technical Specification at OPR1000.

Table 1 shows the difference BDAS delta setpoint between using linear ICRR curve and using non-linear ICRR curve. There is about 5% difference between both results. The BDAS setpoint using by non-linear ICRR curve is lower than linear one. That means that conservative condition makes the time for operator action reduce.

Table 1. BDAS setpoints with Linear and Non-Linear ICRR curve

ICRR Curve	Linear	Non-linear
SRM Ratio	2.62	2.5
BDAS Uncertainty	±3.62%	±3.62%
Max. Delta Setpoint,	0.475	0.434
Min. Delta Setpoint	0.362	0.362
Delta Setpoint,	0.42	0.4

4. Conclusions

The new BDAS setpoint is calculated with conservative condition which recommended from Westinghouse Electric Company. The setpoint of BDAS using non-linear ICRR curve decrease to about 5% compared to the setpoint of that using linear ICRR curve. And this effect of the non-linearity is to slightly delay the boron dilution alarm during the inadvertence boron dilution at mode 3, 4, and 5.

However, a boron dilution event progresses slowly and the impact on a reduction in alarm response time is small, plant operators would have sufficient time to identify the dilution and take corrective action, even if the identified discrepancy was uncorrected.

However, it is needed to revise the BDAS setpoint using the non-linearity ICRR method for the nuclear power plant safety.

REFERENCES

[1] "Non-Conservative Boron Dilution Analysis", NSAL-04-2, Westinghouse Electric Company, 2004.02.18
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[3] "Boron Dilution Alarm System Uncertainties for Yonggwang Nuclear Power Plant Unit 5 and 6", 9-640-Z-301-009, 1999.3.30