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Development of Digital Boron Dilution Alarm System (DBDAS)

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1. Introduction

It is imperative that a reactor which has been shutdown remain subcritical and not inadvertently return to power. Such an event could occur for instance through failure of a component in the complex control system or inadvertent action taken by the operator. In any case, during such an event the reactor approaches criticality exponentially with respect to time thus making it more difficult for the operator to detect the event and take appropriate action before the reactor goes to criticality [Ref. 1].

This paper is prepared for the development of the Digital Boron Dilution Alarm System (DBDAS) to improve the sub-criticality monitoring of Advanced Power Reactor 1400 Standard Nuclear Power Plant (APR1400). This system is designed to provide operators with useful information about an inadvertent boron dilution event occurring with the plant in Modes 3, 4, 5, and 6 before the reactor coolant system is diluted sufficiently to result in a total loss of shutdown margin. The acceptance criteria of APR1400 for an unplanned boron (moderator) dilution specify at least 30 minutes in all operational modes. The main features of DBAS are the use of digital information from the startup neutron monitoring channels and a boronometer

2. Digital Boron Dilution Alarm System (DBDAS)

2.1 Difficulties in BDAS

An inadvertent approach to criticality in most PWRs is detected and an alarm is generated through on-line monitoring of the neutron flux, such as BDAS. The difficulties in BDAS are occurred at the low levels of neutron flux in a subcritical reactor or by neutron detectors with low sensitivity. Figure is a plot of the neutron flux versus time for a typical approach to criticality assuming constant positive reactivity insertion, which would occur for instance during an inadvertent boron dilution event. As can be seen from the figure, the function is basically exponential with a slow rise in flux early in the event followed by rapidly increasing flux leading to criticality. While selection of a large change in flux for use in triggering an alarm will obviously distinguish an inadvertent approach to criticality, such a change in flux does not occur until late in the event and therefore would not allow sufficient time to initiate alarm. On the other hand, if the selected change in flux used to trigger the alarm is too small, spurious alarms could be generated in view of the low signal to noise ratio and the random nature at low count rates of the neutron flux signal used to measure reactor shutdown margin. Although the increment of the sampling (or filtering) time is useful to avoid spurious alarms caused by noise and static perturbation, the response time of BDAS will be lapsed in proportion to the sampling (or filtering) time.

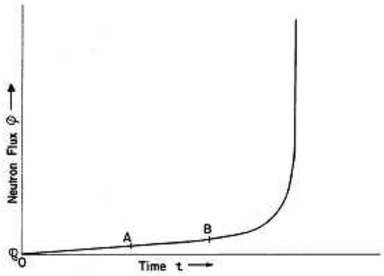

Fig.1 Neutron flux as a function of time during a typical approach to criticality

2.2 FEATURES IN DBDAS

The core is initially subcritical with the shutdown margin at the minimum value consistent with the Technical Specification limit for cold shutdown. An inadvertent deboration event causes unborated water to be pumped into the RCS. The resulting decrease in RCS boron concentration adds positive reactivity to the core.

The operator is alerted to a decrease in the RCS boron concentration by a high neutron flux alarm on the startup flux channel, through sampling, or by observation of boronometer indications or the boric acid flow rate. He turns off the charging pump(s) and closes the letdown control valves in order to halt further dilution. Next, he increases the RCS boron concentration by implementing the emergency boration procedure for achieving cold shutdown boron concentration.

The boronometer provides nuclear power plant operators with a permanent record of the boron concentration contained in a water cooling circuit by way of continuous sampling. The equipment performs real-time measurements and processes them to compile assorted information that can be displayed or transmitted to other digital or analogue systems within the power plant unit. All of this information is generally used in the process to drive the reactor power.

The standard equipment includes; a sampling tank, neutron source, neutron detector, temperature probe, a rack that supports the conditioning and process electronics, and process display. The operator knows in real time the concentration of boron due to permanent recorded/displayed measurements;

Although the boronometer brings safety to the operators by the continuous monitoring of the boron concentration during all the reactor operating conditions, the accuracy in highly borated water (from 1,000 ppm to full scale) is decreased to ± 5% of the measured value.

Due to the low accuracy and reliability of the boronometer in highly borated water, the BDAS uses only the count rates from startup neutron monitoring channel to detect an inadvertent dilution event. The BDAS is apt to caused spurious alarms at low neutron level by highly borated water. The DBDAS utilizes the digital boron concentration from PMAS (Plant Monitoring and Alarm System) measured by the boronometer to remove unnecessary alarms caused by noise and static perturbation(Figure 2).

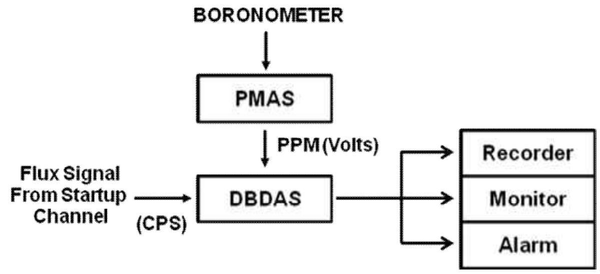

Fig. 2 Schematic diagram of DBDAS

Firstly, the preset time interval between the average flux count rate signals and the preselected multiplication factor are selected on the basis of a number of interacting criteria. The multiplication factor should be large enough that spurious alarms are not generated. Yet if it is too large, an alarm will not be generated until too late in the event to prevent the reactor from going critical since the neutron flux count rate in such an event increases exponentially with respect to time. When a smaller multiplication factor is selected, the time interval must be lengthened, but too long an interval will cause an alarm to be generated under some circumstances of normal operation. In addition, if too long an interval is selected, conditions under which the two average flux count rate signals are generated, such as the temperature in a PWR plant, can change, making the calculations more difficult. It has been determined that a multiplication factor of between 1.5 and 3.0 and preferably 2.0, with an interval of 1 to 30 minutes and preferably 1 minutes provides rapid response without unduly limiting normal operation or generating spurious alarms.

Secondly, when the average flux count rate signals are over the preselected multiplication factor, DBDAS determines whether the boron concentration is over the preselected one or not. The DBDAS shall provide the reactor operator with two different alarms that are depend on the situation of a boron dilution event. If the flux signal is greater than the Alarm Setpoint and the the boron concentration from the boronometer is less than the preselected ppm, the DBDAS generates the alarm of Level I. If the flux signal is greater than the Alarm Setpoint and the boron concentration from the boronometer is higher than the preselected ppm, the DBDAS generates the alarm of Level II.

Finally, DBDAS provides operators with a variety of graphs to identify the shot-term status and long-term trends of core. Also, these graphs of DBDAS included CPS vs. time, PPM vs. time, ICRR vs. time and ICRR vs. PPM help operator take the proper actions to mitigate or terminate the inadvertent approach to criticality (Figure 3). If there is the alarm of Level I due to an actual core alternation, the operator acknowledges the alarm and resets the DBDAS alarm logic to the new. If there is the alarm of Level II, the reactor operator has to grasp the status of core and take the actions more prudently and immediately than the alarm of Level I.

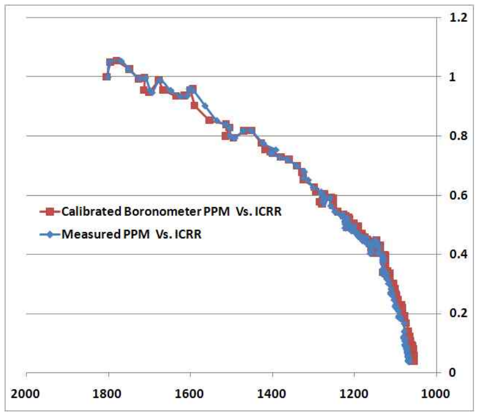

Figure 3 ICRR vs. Boron Concentration of DBDAS

3. Conclusion

The main features of DBAS are the use of digital information from the startup neutron monitoring channels and a boronometer. The DBDAS utilizes CPS (counts per second) of the startup channel for neutron flux signal without converting count rates into volts DC signals. The DBDAS provides operators with a variety of graphs to identify the short-term status and long-term trends of core. Also, the graphs of DBDAS included CPS vs. time, PPM vs. time, ICRR vs. time and ICRR vs. PPM help operator take the proper actions to mitigate or terminate the inadvertent approach to criticality. The DBDAS can meet the acceptance criteria of APR1400 that detect a boron dilution event and alarm the reactor operator of this event at least 30 minutes for Modes 3, 4, 5, and 6 before inadvertent criticality resulting from boron dilution is achieved

Reference

[1] NEA/CSNI/R(94)-13-B "Generic Study on Reactivity Relative Events Reported through the Incident Reporting System (IRS)", OECD/NEA.