PROBABILISTIC ANALYSIS OF THE INADVERTENT BORON DILUTION ACCIDENT FOR WH NUCLEAR POWER PLANT

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Introduction

⟐Definition of a inadvertent boron dilution accident

◆ It may caused by improper operator action or by a failure in the boric acid makeup flow path, which reduces the flow of borated water to the charging pump suction

◆Either cause can produce a boron concentration of the charging flow, which is below the concentration of the reactor coolant.

◆This event is classified as an Anticipated Operational Occurrences

⟐Analysis method

◆ The boron dilution accident is performed through deterministic safety analysis method

- So the result is very limited
- Most limited boron dilution flow rate is assumed

◆The boron dilution accident was performed using probabilistic analysis method

- It can eliminating unnecessary conservatism
- A more realistic analysis of boron dilution accident was performed

Methods and Assumption

⟐Basic assumptions for probabilistic analysis of boron dilution accident

◆ Plant : WH type domestic 2-loop nuclear power plant

◆ Operating mode : shutdown mode 5 (cold shutdown)

◆ Using Failure Modes Effects Analysis (FMEA)

- FMEA is performed to determine equipment failures and operator errors that could lead to an inadvertent boron dilution of the RCS
- Passive components (heat exchangers, tanks, pipes, and manual valves) were not included in this analysis
- operator errors to open or close manual valves that could lead to an inadvertent boron dilution initiating event are considered in this analysis

◆ An event tree is constructed to assess mitigation of the boron dilution initiating events

- The dilution flows to the RCS for each inadvertent boron dilution initiating events
- Corresponding available time that the operator has after the neutron flux multiplication alarm activates

Analysis Results

⟐ FMEA results

◆ The potential initiators identified in the FMEA is 9 cases.

- CVCS Mixed-Bed Demineralizer Flushing Operation
- CVCS Cation-Bed Demineralizer Flushing Operation
- BTRS(Boron Thermal Regeneration System) Boron Flushing Operation
- BTRS(Boron Thermal Regeneration System) Regin Flushing Operation
- Radiation Monitor Flushing Operation
- BCMS(Boron Concentration Measurement System) Flushing Operation
- Chemical Mixing Tank Flushing Operation
- RMS(Reactor Makeup System)
- Emergency Boration Line Flushing Operation

◆ Final case of initiating an inadvertent boron dilution event are three cases (Chemical addition, CVCS mixed bed demineralizer flush, Reactor makeup system).

⟐ Chemical addition

◆ A boron dilution event could be initiated either during or after chemical addition, if both the inlet and outlet valves to the chemical mixing tank are not closed.

◆ The initiating event frequency of a dilution event occurring during chemical addition is 4.0E-04 per reactor years and these values were calculated by quoting the values in NUREG/CR-1278

⟐ CVCS mixed bed demineralizer flush

◆ CVCS mixed bed demineralizer flush is divided to 2 cases

- Boron dilution event during the CVCS mixed bed demineralizer flushing operation
- Boron dilution event after the CVCS mixed bed demineralizer flushing operation

◆ Boron dilution initiating event frequency

- During the CVCS mixed bed demineralizer flushing operation : 6.4E-04
- After the CVCS mixed bed demineralizer flushing operation : 8.0E-04
- One demineralizer is assumed to be flushed once per reactor year. The initiating frequencies for Mode 5 is 1.4E-03 per reactor year

⟐ Reactor makeup system

◆ Event tree is constructed to determine the total initiating event frequency contribution from the reactor makeup system(Figure 1, Table 1 & Table 2)

◆ According to Table 2, the dilution flowrate is divided into three category. Table 3 lists the initiating event probabilities and frequencies (per reactor year) for an inadvertent boron dilution event during reactor makeup operation

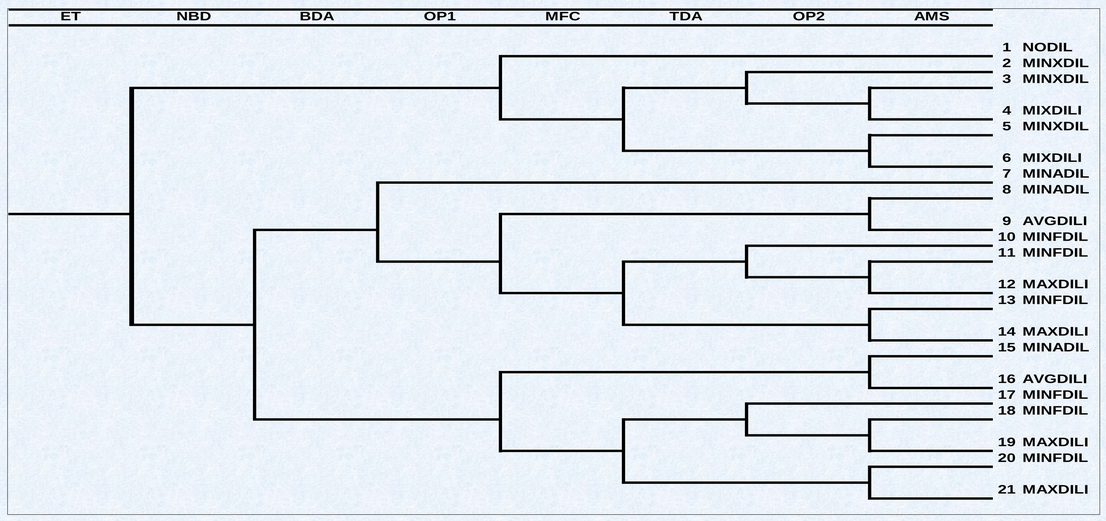

Figure 1. Configurations for Multiple Misloading Feed Assemblies

Failure	Description
NBD	Boric acid is not delivered to the makeup operation
BDA	Boric acid deviation alarm fails to activate
OP 1	Operator fails to diagnose the cause of the boric acid deviation alarm and fails to stop the reactor makeup water pump
MFC	The reactor makeup water flow control valve fails to wide open position
TDA	Total makeup deviation alarm fails to activate
OP 2	Operator fails to diagnose the cause of the total makeup deviation alarm
AMS	Reactor makeup is not automatically stopped by the VCT level controller

Table 1. Description of the failure mode

Parameter	Description
NODIL	No boron dilution event is initiated
MINXDIL	The incorrect boron concentration has been delivered to the RCS. RCS boron concentration is being diluted to maximum value
MIXDILI	The incorrect boron concentration has been delivered to the RCS and a boron dilution event is initiated. Reactor makeup water is being blended with boric acid.
MINADIL	Boric acid is not being delivered to the reactor makeup system. RCS boron concentration is being reduced by reactor makeup water at the setpoint flowrate average value
AVGDILI	Boric acid is not being delivered to the reactor makeup system. Reactor makeup water is delivered at the setpoint flowrate average value
MINFDIL	Boric acid is not being delivered to the reactor makeup system. RCS boron concentration is reduced by reactor makeup water at the maximum flow rate
MAXDILI	Boric acid is not being delivered to the reactor makeup system. Reactor make up water is delivered at the maximum flowrate

Table 2. The result of the reactor make up system operation

Initiator	Designator	Dilution Flowrate to RCS(gpm)	Probability	Frequency (per reactor year)
RMW Case 1	MIXDILI	Minimum	9.10E-05	1.82E-04
RMW Case 2	AVGDILI	Average	2.74E-04	5.49E-04
RMW Case 3	MAXDILI	Maximum	8.85E-08	1.77E-07

Table 3. Reactor Makeup Initiating Events

⟐ Boron dilution mitigation event tree results

◆ The dilution event has initiated, it is assumed that the flux multiplication alarm will activate

- If the alarm succeeds, the operator take the appropriate operator action to restore the required shutdown margin
- The operator will isolate the boron dilution source
- The operator will close the VCT outlet isolation valves and open the valve from the RWST

◆ Figure 2 depicts the boron dilution mitigation event tree, and the description of the failure mode is given in Table 4. The loss of shutdown margin frequencies (per reactor year) calculated by reflecting the results in Table 1 and 4 are depicted in Table 5.

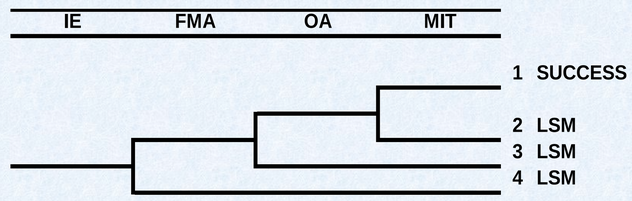

Figure 2. Boron Dilution Mitigation Event Tree

Failure	Description
IE	The initiating event frequency of the boron dilution
FMA	Flux multiplication alarm activates
OA	Operator takes action on the flux multiplication alarm
MIT	The VCT valves are closed and RWST valve is opened
LSM	Total loss of shutdown margin occurs

Table 4. Description of the failure mode

Event	Frequency, Per reactor year
Chemical Addition	4.91E-07
CVCS Demineralizer Flush	1.13E-04
Reactor Makeup (Case 1, minimum dilution flowrate)	4.32E-07
Reactor Makeup (Case 2, average dilution flowrate)	4.43E-05
Reactor Makeup (Case 3, maximum dilution flowrate)	4.52E-08
Total	1.58E-04

Table 5. Loss of Shutdown Margin Frequency

Conclusions

◆Probabilistic boron dilution accident analysis was performed and through this analysis potential flow paths between the unborated water supply and RCS were identified.

◆ Loss of shutdown margin frequency for total potential initiators (Chemical Addition, CVCS Mixed Bed Demineralizer Flush, Reactor Makeup System) fequency is more conservative than the occurrence frequency of AOO.

◆ It is too conservative to assume maximum dilution flowrate in deterministic safety analysis

◆ It is reasonable to assume average dilution flowrate in deterministic safety analysis boron dilution accident analysis