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Feasibility of Long Term Feed and Bleed Operation For Total Loss of Feedwater Event

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Abstract

The conventional Equipment Environment Qualification (EEQ) envelope is developed based on the containment responses during the design basis events. The Safety Depressurization System (SDS) design without In-containment Refueling Water Storage Tank (IRWST) adopted in the Ulchin 3&4 challenges the conventional EEQ envelope during long term Feed and Bleed (F&B) operation due to the direct discharge of high mass and energy into the containment. Therefore, it is necessary to confirm that the containment pressure and temperature history during the long term F&B operation does not violate the conventional EEQ envelope. However, this subject has never been quantitatively assessed before. To investigate the success path of long term F&B operation this paper analyzes the thermal hydraulic response of the containment and Reactor Coolant System (RCS) until the completion of depressurization and cooldown of RCS into Shutdown Cooling System (SCS) entry condition. It is found that the SCS entry condition can be reached within 6 hours without violating the EEQ curve by proper operation of SDS valves, High Pressure Safety Injection (HPSI) pumps and active Containment Heat Removal System (CHRS). The suggested strategy not only demonstrates the feasibility of long term F&B operation but also can be utilized in the preparation of Emergency Procedure Guidelines (EPGs).

1. Introduction

The Safety Depressurization System (SDS) is implemented in Ulchin 3&4 to provide a Feed and Bleed (F&B) capability by rapidly depressurizing the Reactor Coolant System (RCS) for Total Loss of Feedwater (TLOFW) event [1]. The detailed analyses for the determination of bleed capacity for Ulchin 3 &4 design are introduced in References 2, 3.

The equipments and instruments necessary for the F&B operation and safe shutdown of the plant have been qualified for the conventional existing Equipment Environment Qualification (EEQ) curve [4, 5] which is developed by enveloping the containment responses during design basis events including Main Steam Line Break (MSLB) and Loss Of Coolant Accident (LOCA). The Ulchin SDS has similar design concept as that of ABB-CE's System 80+[6], but does not include the In-containment Refueling Water Storage Tank (IRWST). In the System 80+ design the mass and energy discharges during the F&B operation are discharged into the suppression pool provided by IRWST. Therefore, it is not necessary to perform containment analysis for EEQ. However, since the Ulchin 3&4 SDS design without IRWST results in direct release of discharge flow through SDS, it is necessary to analyze the long term F&B transient in the aspect of EEQ.

The containment response during the F&B operation for TLOFW event is expected to be similar to that of small break LOCA. However, since the steam generator is not available as a heat sink, the mass and energy release to the containment will be much higher than that of small break LOCA with same break size. Therefore, the containment response for feed and bleed transient should be analyzed to ensure that EEQ envelope is not violated during the F&B operation. However, previous analyses [2, 3, 7, 8] focused only on the analysis for the determination of the required bleed capacity and/or the feasibility of existing bleed capacity. Reference 9 addressed the importance of EEQ issue but did not provide any quantitative evaluation.

If the resultant containment pressure and temperature during long term F&B operation exceeds the existing EEQ envelope, the equipment and instrument necessary for F&B need to be requalified and/or alternate design change should be considered. Therefore, it is important to investigate the success path for the long term F&B operation. The success path need to be identified not only to demonstrate the feasibility of long term F&B operation but also to be utilized for incorporation into Emergency Procedure Guidelines (EPGs). A successful long term F&B requires the completion of a controlled primary system depressurization and cooldown to achieve SCS entry conditions without violating existing EEQ pressure and temperature profiles. After reaching SCS entry condition the SDS valves can be closed, since the SCS can be used for long term decay heat removal. This mode of operation is favorable, since uncontrolled high mass and energy discharge into containment is terminated. The sooner the time to reach SCS entry condition, the better the investment protection for the facilities inside the containment.

This paper provides quantitative evaluation of the thermal hydraulic phenomena of long term feed and bleed transient for primary system and resultant containment pressure and temperature responses.

2. Ulchin 3&4 SDS Design Description

The SDS is a new design feature incorporated into Ulchin 3&4, which are two loop 2825 MWt PWR plants. The Ulchin SDS has similar design concept as that of ABB-CE's System 80+[6], but does not include the In-containment Refueling Water Storage Tank (IRWST). In the System 80+ design the mass and energy discharge during long term F&B operation is suppressed in the liquid pool provided by IRWST. However, the Ulchin 3&4 SDS design without IRWST results in direct release of discharge flow through SDS. The SDS has two separate lines connected to the top head of the pressurizer and each line discharges to the containment atmosphere through a rupture disc. The two bleed paths consist of an isolation valve and a bleed valve in series per path, and provide redundant paths for SDS operation. Both valves, motor-operated and normally closed, are opened and closed by handswitches located in the main control room. The detailed analysis of the F&B operation during TLOFW by using SDS for Ulchin 3&4 can be found in References 2 and 3.

3. Analytical Models

3.1. Computer Program Used

Since this subject is new and specific to Ulchin 3&4 design, it is necessary to evaluate the applicability of existing computer codes.

By noting the observation that the mass and energy discharge to the containment during long term F&B operation is similar to that of small break LOCA, the CONTRANS computer program [10] is selected to calculate the pressure and temperature in the containment. The CONTRANS is developed by ABB-CE and approved by USNRC to determine the pressure and temperature in the containment regions and the temperature of containment structure during LOCA and MSLB. The CONTRANS model analyzes both active and passive heat transfers within the containment. It calculates pressure and temperature transient with time stepwise integrations between the thermodynamic state points. The integrations are based on the laws of conservation of mass and energy together with thermodynamic relationships.

The mass and energy release rates from sources such as the release of reactor coolant, decay energy, and sensible heat release from the NSSS metals are calculated by using the CEFLASH-4AS/REM computer program [11]. As discussed in the References 2 and 3 the CEFLASH-4AS/REM is best estimate thermal hydraulic computer program for the analysis of Nuclear Steam Supply System (NSSS) behavior. It employs two mass, two energy, and one momentum equations. Since the CEFLASH-4AS/REM explicitly models metal sensible heat, decay heat, and mass and energy discharge through SDS, this computer code is judged to be appropriate for the analysis of mass and energy releases and RCS behavior. The two phase discharge flow rate during long term F&B operation is stored as separate file in the CEFLASH-4AS/REM, which is used as input to the CONTRANS analysis.

3.2. Analysis Procedure

Table 1 shows the initial conditions and major plant parameters for NSSS and containment systems including the containment building and active Containment Heat Removal System(CHRS).

The major assumptions and analysis procedure for the simulation of RCS response and mass and energy discharge through the SDS using CEFLASH-4AS/REM are similar to those employed in the reference analyses [2, 3]. However, since the duration of F&B simulation is much longer in this analyses, convergence problems during numerical simulation are encountered. Convergence problems are circumvented by adjusting time steps and by improving sectionalized node model for the reactor inner vessel.

The input parameters and physical models including condensation heat transfer model and containment spray model for the CONTRANS analyses are selected similarly to those used in the containment analyses for LOCA [1].

Since the operator has enough time to diagnose the event as a TLOFW event before the Pressurizer Safety Valves (PSVs) lift, the number of operable SDS bleed valves and HPSI pumps and feed and bleed initiation time can be controlled by the operator[1, 2, 3]. To evaluate whether SCS entry conditions can be reached in a reasonable time period the case with failures of both one SDS valve and one HPSI pump is considered as the base case, because this case provides minimum cooling capability. In ad-

Table 1. Initial Conditions and System Parameters for RCS and Containment

Parameter	Design Value
Initial core power (Mwt)	2815
Initial RCS pressure (bars)	155
Initial RCS flowrate (kg/hr)	55113
Initial cold leg temperature (°C)	295.8
Initial hot leg temperature (°C)	327.2
Initial SG pressure (bars)	74
Primary side volume (m^3)	329.4
Containment volume (m^3)	77222
Pressurizer volume, liquid/total (m^3)	25.5/51.4
Low SG level reactor trip setpoint (% WR)	38.5
SIAS setpoint (bars)	126
HPSI pump shutoff head (bars)	126.5
RWT temperature (°C)/volume (m^3)	49/2271
PSV setpoint (bars)/number	172/3
PSV capacity (steam at 152 bars), per valve (kg/hr)	247517
CSP setpoint (bars)/number	2.39/2
CSP flow rate, per pump (m^3/min)	18926.5
Containment fan cooler, number	4

dition analyzed are the cases where a bleed valve and a HPSI pump are operable at PSVs lift time and both of bleed valves are opened and two HSPI pumps are available after 30 minutes. These cases are expected to result in more mass and energy releases to the containment than the case with no failure described above.

Following F&B transient the mass and energy releases to the containment will pressurize the containment atmosphere, which will actuate containment active heat removal system. To consider single failure the cases with a loss of one train of CHRS and no failure of CHRS are analyzed.

4. Results and Discussions

This section discusses various long-term F&B procedures and resultant RCS and containment responses. By comparing and evaluating the results against the SCS entry conditions of (28.27 bar, 176.7°C) and conventional EEQ pressure and temperature profiles, the success paths of feed and bleed operation are investigated.

4.1. RCS Response and Mass and Energy Release Rates

The case of the minimum cooling capability is chosen first to estimate the longest time to reach SCS entry condition. The case NR1F1B, where failures of one bleed path and one feed train are assumed occur and the operator initiates F&B operation at the time of PSVs lift, would result in the longest F&B operation until reaching SCS entry condition. As shown in Figures 1 and 2 the primary system reaches SCS entry condition within 20000 seconds (6 hours). The primary pressure and temperature at 20000 seconds are 15.86 bar and 171.1°C, respectively. Since this case provides the minimum cooling capability, it is likely that the uncontrolled energy discharge through SDS during the F&B operation can be terminated within 6 hours.

If the water inventory of Refueling Water Tank (RWT) is not depleted during long term F&B transient, the enthalpy of HPSI inflow will be at cold water enthalpy of 49.45 kcal/kg [1]. The case NR1F1B is based on this enthalpy. However, the use of containment spray and HPSI pumps eventually depletes the cold water inventory of the RWT. Then the suctions of HPSI pumps and Containment Spray Pump (CSP) are switched from RWT to containment sump, which will result in the increase in the enthalpy of HPSI inflow. The recirculation time of 6000 seconds is estimated based on the conservative assumption of two CSPs actuation. The sump water enthalpy after recirculation is also calculated to be 132.8 kcal/kg by using containment design pressure and temperature for Ulchin 3 and 4 PSAR [1]. R1F1B case, where case NR1F1B is modified to account for recirculation is considered. The primary pressure and temperature at 20000 seconds for cases R1F1B are 46.33 bar and 259.4°C respectively. The SCS entry condition can be reached around 33000 seconds (9 hours) for the case R1F1B.

The bleed flow rate through SDS and HPSI inflow are shown in Figure 3. The bleed flow through SDS is directly discharged into the containment, since Ulchin 3 & 4 design does not have IRWST. As shown in the figure the discharge flow through SDS becomes two phase after 7000 seconds. This two phase discharge flow will boil and flash into steam at containment pressure which is much lower than RCS pressure. The steam portion is assumed to be added to containment atmosphere and the liquid portion is drained to the sump.

To consider the case of maximum mass and energy release into containment, the case R2F2B where one bleed valve and one HPSI pump are operated at the time of PSVs lift and two bleed valves and two HPSI pumps are operated after 30 minutes is considered. The increased enthalpy due to recirculation is used, which would maximize mass and energy discharge into containment. As shown in the Figures 1 and 2 the R2F2B case does not reach SCS condition before 20000 seconds. Therefore, a little correction on the enthalpy of the sump water is considered. As the recirculation enthalpy of 132.8 kcal/kg is too conservative compared to the calculated containment condition, the recirculation enthalpy of 121.1 kcal/kg is recalculated based on the calculated maximum pressure and temperature of sump water resulted from the CONTRANS analysis discussed below. For R2F2BM case, where the recirculation enthalpy of 121.1 kcal/kg is considered, the resultant pressure and temperature is calculated to be 16.48 bar and 176.9°C. The SCS entry condition can be reached within 20000 seconds (6 hours). The primary pressure and temperature for the cases R1F1B, R2F2B and R2F2BM during the transient are shown in Figures 1 and 2. The bleed flow rates and HPSI inflows are shown in Figure 4. The discharge mass flowrate for this case is much higher than that of case R1F1B.

4.2. Containment Pressure and Temperature Analysis

To conclude the feasibility of long term F&B procedures, the containment response should be anal-

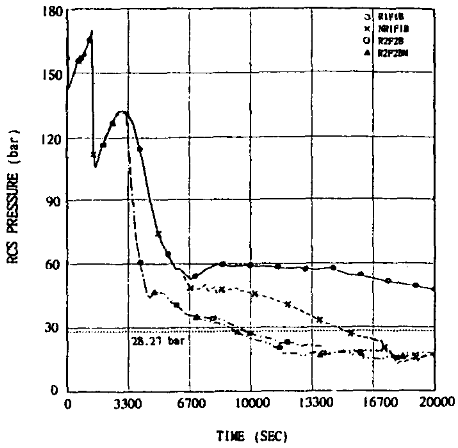

Fig. 1. Primary Pressure

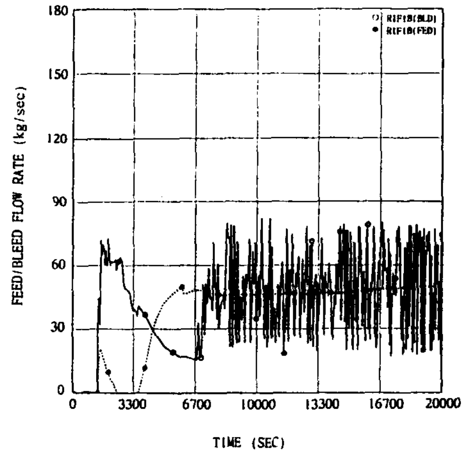

Fig. 3. Feed and Bleed Flow Rates (Case R1F1B)

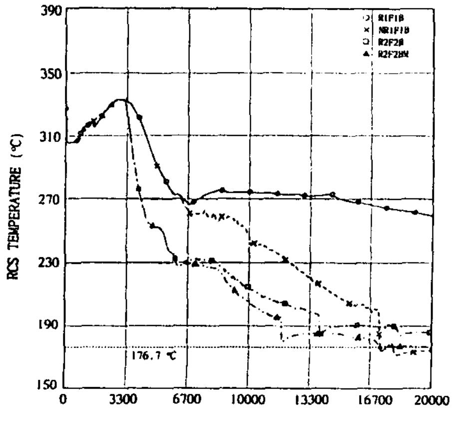

Fig. 2. Primary Temperature

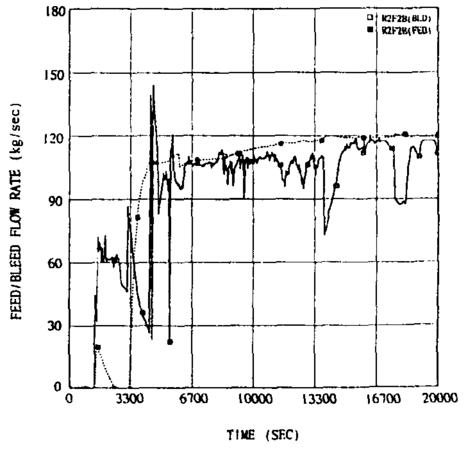

Fig. 4. Feed and Bleed Flow Rates (Case R2F2B)

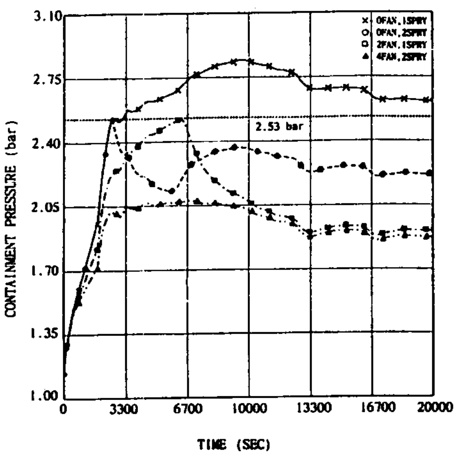

Fig. 5. Containment Pressure (Case R2F2B)

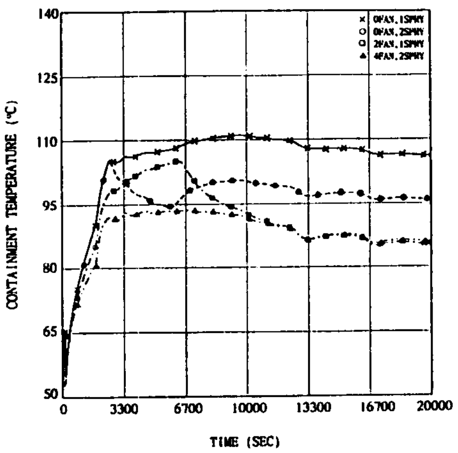

Fig. 6. Containment Temperature (Case R2F2B)

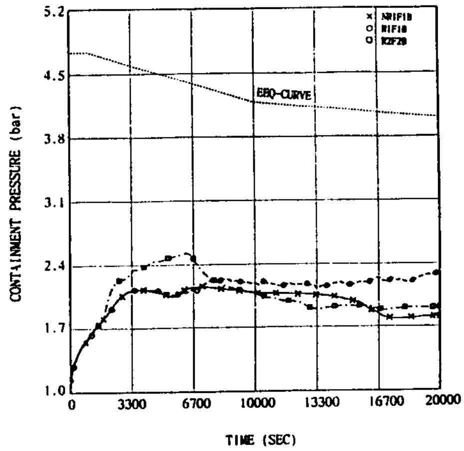

Fig. 7. Containment Pressure with Loss of one CHRS

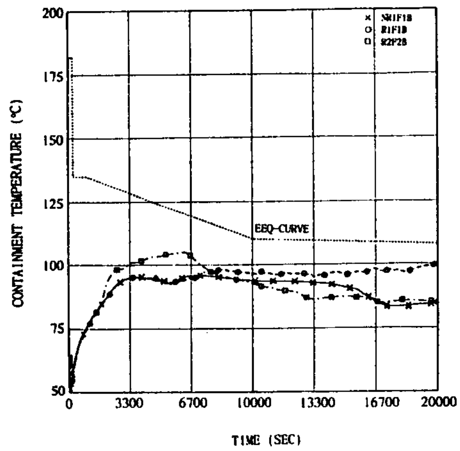

Fig. 8. Containment Temperature with Loss of one CHRS

yzed.

Since the case R2F2B results in largest mass and energy release into the containment among the cases considered above, R2F2B case is selected to analyze containment pressure and temperature responses for various modes of CHRS operation. The active CHRS consists of four fan coolers and two containment spray pumps [1]. Passive heat removal is accomplished by containment internals and wall structures. Figures 5 and 6 show the containment pressure and temperature responses depending on various modes of containment heat removal systems. It is shown that if all the four fan coolers are operating the containment pressure does not reach containment spray nominal setpoint of 2.39 bar (Maximum analysis setpoint of 2.53 bar is used for the containment analysis). Since the containment spray is not actuated for this case, the recirculation does not occur. The results for the cases with no fan confirm the conservatively assumed time of recirculation for cases R1F1B and R2F2B.

It may not be necessary to consider single failure in the analysis of containment response, since TLOF-W is a beyond design basis event. However, the single failure scenario is considered here to demonstrate the safety margin of Ulchin 3&4 design. To evaluate whether the resultant containment pressure and temperature for the cases R1F1B and R2F2B meet the EEQ envelope, the containment pressures and temperatures are calculated with a single failure assumption on the operation of active CHRS. The worst single failure of active CHRS is a failure of one train of active CHRS where two fan coolers and one CSP are not operable.

The results are shown in Figures 7 and 8 where the comparisons with existing EEQ profiles are demonstrated. The results show that even with a worst single failure the EEQ envelope is not violated during the long term F&B operation.

It is also to be noted that the containment is not pressurized enough to reach CSP actuation setpoint for the R1F1B case. Since the mass and energy releases from the case R1F1B are greater than those of case NR1F1B, the containment spray will not be actuated for the F&B transient where F&B is initiated at the time of PSVs lift by one bleed valve and one HPSI pump. Therefore this transient can be represented by the case NR1F1B. In previous section it was shown that the SCS entry condition can be reached within 20000 seconds (6 hours) for case NR1F1 B. Since this case provides the minimum cooling capability, it is confirmed that the uncontrolled energy discharge through SDS during the F&B operation can be terminated within 6 hours without violating the EEQ envelope.

Above information will be very helpful in developing EPGs to facilitate the investment protection and demonstrating the feasibility of long term F&B operation.

5. Conclusions

Since Ulchin 3&4 SDS design does not include IRWST, the direct discharges of mass and energy into the containment during long term F&B operation challenges conventional EEQ envelope during F&B operation. In this paper analyzed are the thermal hydraulic behavior of RCS during long term F&B operation and resultant containment pressure and temperature responses.

By comparing the results against the SCS entry condition (28.27 bar, 176.7°C) and existing EEQ pressure and temperature profiles, the following success paths of long term F&B operation have been identified.

For the F&B case where one bleed valve and one HPSI pump is initiated at the time of PSVs lift the SCS entry condition can be reached within 6 hours without actuating the CSP. For the case where F&B is initiated by one bleed valve and one HPSI pump at PSVs lift time and both of bleed valves are opened and two HSPI pumps are available after 30 minutes the SCS entry condition can also be reached within 6 hours. It is found that containment pressure and temperature resulting from the F&B transient by both cases do not violate the EEQ envelope.

It can be concluded that the suggested success paths not only demonstrate the feasibility of long term F&B operation but also can be utilized for the development of Emergency Procedure Guidelines (EPGs).

References

1. *Ulchin Units 3&4 Preliminary Safety Analysis Report*, Korea Electric Power Corporation (1992)
2. Young M. Kwon, Jin H. Song, and Tae S. Ro, *Analysis of Total Loss of Feedwater Event for the Determination of Safety Depressurization System Bleed Capacity, Journal of Korean Nuclear Society*, Vol. 27, No. 4 (1995)
3. Young M. Kwon, Jin H. Song, and Tae S. Ro, *A Comparative Simulation of Feed and Bleed Operation during the Total Loss of Feedwater Event by RELAP5/MOD3 and CEFLASH-4AS/REM*

Computer Codes, Journal of Nuclear Technology, Vol. 112, November (1995)

4. *Appendix 3, Technical Specifications, Ulchin 3 & 4 NSSS Supply Contract*, PUB-P-91ED02, Hanjung (1992)
5. *Class 1E Classification*, CENPD-255-A, Combustion Engineering (1985)
6. *CESSAR-DC*, Chapter 6, ABB-Combustion Engineering (1993)
7. G.G. Loomis and J.J. Cozzuol, *Decay Heat Removal Using Feed-and-Bleed for U.S. Pressurized Water Reactor*, NUREG/CR-5072, Idaho National Engineering Laboratory (1988)
8. B.E. Boyack et. al., *Los Alamos PWR Decay-Heat Removal Studies Summary Results and Conclusions*, NUREG/CR-4471 (1985)
9. W.R. Cramond et. al., *Shutdown Decay Heat Removal Analysis of a Combustion Engineering 2-Loop Pressurized Water Reactor*, NUREG/CR-4710 (1987)
10. *Containment Thermodynamic Analysis*, CENPD-140-A, C-E Power Systems (1986)
11. *Realistic Small Break LOCA Evaluation Model*, CEN-373-P, Combustion Engineering (1987)