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Evaluation of the Natural Circulation Capability Test Results for Ulchin Nuclear Power Plant Unit 3

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Abstract

During the Power Ascension Test (PAT) period, the transient tests related to the natural circulation capability were successfully completed for Ulchin Nuclear Power Plant Unit 3 (UCN 3). The tests were successfully completed by meeting all acceptance criteria. The post-trip PCS shows good performance as designed and the measured natural circulation capacity was demonstrated to be adequate for the core decay heat removal for UCN 3.

1. Introduction

The natural circulation phenomena in the nuclear power plant is governed by decay heat, component elevations, primary to secondary heat transfer, loop flow resistance, and void formation in the Reactor Coolant System (RCS). Component elevations in the UCN 3&4 are considered such that a satisfactory natural circulation flow for core decay heat removal is obtained by fluid density differences between the core and the steam generator tube region.

The U. S. NRC Branch Technical Position, Reactor Systems Branch (BTP RSB) 5-1[1] requires that the nuclear power plant demonstrate that it can be brought from normal operation to cold shutdown under the Natural Circulation Cooldown (NCC) condition using only safety-grade systems with either onsite or off-site power available (not both) and assuming a single failure. In response to these requirements, an NCC analysis from normal operation to shutdown cooling system entry conditions was performed[2].

A series of tests such as Hot Functional Tests (HFT) and PAT were performed as a part of initial test program[3]. In this paper, the PAT results related to the natural circulation are presented by evaluating the natural circulation capability for the post-trip decay heat removal with all RCP tripped condition for UCN 3.

2. Test Descriptions

There are two PAT cases related to the natural circulation capability for UCN 3: 1) Turbine Trip without Reactor Power Cutback System (RPCS) and Natural Circulation test[4] and, 2) Loss of Off-site Power test[5]. These tests were performed to demonstrate that the plant responds as designed following a reactor trip, and to verify that an adequate natural circulation flow can be maintained following all RCP trip.

During the Turbine Trip without RPCS and Natural Circulation (TT&NC) test, the natural circulation is initiated by manually tripping all RCPs after the post-trip plant condition has been stabilized. This test requires the initial reactor power level greater than 95%. However, loss of all RCPs occurs concurrently with the initiation of the test during the Loss Of Off-site Power (LOOP) test and requires only the initial reactor power level greater than 10%.

3. Turbine Trip without RPCS and Natural Circulation Test

3.1 Test Methods

The main purposes of this test are to demonstrate that the plant responds and is controlled as designed following a turbine trip at full power without the RPCS in service, and to verify that the adequate natural circulation flow can be maintained after all RCPs tripped. Following a turbine and reactor trip, the PCS are designed to automatically control the plant at hot standby conditions. The reactor is tripped automatically by the Diverse Protection System (DPS) since the RPCS is out of service during the test.

After the plant stabilized at hot standby conditions, all RCPs are tripped by manual as simultaneously as possible to perform the natural circulation test. The plant is maintained at stable conditions for at least 30 minutes to verify an adequate decay heat removal by the natural circulation flow. The acceptance criteria during the natural circulation test is that Power-to-Flow ratio, which is measured by the following equation, should be less than 1 under the natural circulation flow condition:

$$\text{Power-to-Flow Ratio} = \frac{Q/Q_0}{W/W_0} = \frac{\triangle h}{\triangle h_0}$$

where, Q, W and h represent the reactor power, mass flowrate and specific enthalpy, respectively, and the subscript o denotes the full power operation condition.

3.2 Test Results

The official test for "Turbine Trip without RPCS and Natural Circulation" was performed on April 22, 1998 for UCN 3. To perform this test, the plant was stabilized at approximately 100% reactor power with the initial plant conditions described in Table 1.

The manual turbine trip was initiated at 240 seconds and the reactor was automatically tripped by the DPS upon sensing the turbine trip. As shown in Figure 1, the hot leg and cold leg temperatures in the RCS was maintained at steady condition showing about 28.8 ^{o}C (52 ^{o}F) difference prior to the reactor trip. As the reactor trips with all RCPs running, the hot leg temperature decreases sharply resulting in a decrease in RCS average temperature and a reduced loop temperature difference of only 0.5 ^{o}C (0.9 ^{o}F) under the forced circulation condition.

After the plant stabilized at hot standby condition, all RCPs were tripped by manual to perform the natural circulation test at about 1,350 seconds (Figure 2). As RCPs start coastdown gradually, the reduction in RCS flowrate results in an increase in the hot leg temperature causing the RCS loop temperature difference to increase. This increased loop temperature difference developed a natural circulation flow in the RCS loop, and a fully developed natural circulation flow was reached approximately 10 minutes after the RCP trip. The RCS loop temperature difference reached a maximum value of 15 ^{o}C (27 ^{o}F) at about 6 minutes after the RCP trip and, finally, stabilized at about 13 ^{o}C (23.4 ^{o}F). As shown in Figure 3, the pressurizer pressure was maintained at the stabilized condition without any abnormal fluctuation or trends by the control action of pressurizer pressure control system during the natural circulation period. The natural circulation test was terminated at about 3,800 seconds.

As Figure 4 shows, the Power-to-Flow ratio was less than 4% during the post-trip forced circulation period and was increasing sharply when all RCPs were tripped. After reaching a peak value of 48.6% at around 6 minutes after the RCP trip, the Power-to-Flow ratio decreased and stabilized at around 45%. Based on the test and evaluation results, it is concluded that the UCN 3 has an adequate natural circulation capability for the core decay heat removal.

4. Loss of Off-site Power Test

4.1 Test Methods

The loss of off-site power test is carried out to demonstrate that the plant responds automatically as designed to achieve stabilized hot standby conditions following a simultaneous loss of the main generator and off-site power. The test is initiated by simultaneously tripping the reactor (resulting in a loss of main generator) and opening appropriate breakers (resulting in loss of offsite power). During loss of off-site power, the fast transfer of 13.8 kV alternate power breakers and 4.16 kV Non-Class 1E alternate supply breakers are disabled, resulting in automatic loss of power to the

Non-Class 1E busses when the turbine trips. A low voltage on 4.16 kV safety busses due to loss of off-site power generates an undervoltage signal. This signal starts the Class 1E Emergency Diesel Generators (EDGs) which are designed to reach rated speed, voltage and frequency within 10 seconds.

This test results in all RCPs stopping and charging including seal injection is initially lost. The RCPs can be maintained at hot idle standby without seal injection provided that component cooling water is supplied and RCP controlled bleed-off line is isolated within one minute after the loss of seal injection. The plant should be maintained in hot standby under the natural circulation flow conditions. The existence of the natural circulation flow is verified by observing the hot and cold leg temperature indications as follows:

- Hot and cold leg temperatures are constant or decreasing.
- Core temperature rise (delta-T) is less than full power delta-T of 31.7 ^{o}C (57.0 ^{o}F).

4.2 Test Results

The official test for "Loss of Off-site Power" was performed on April 25, 1998 for UCN 3. To perform this test, the plant was stabilized at approximately 15% reactor power with the initial plant conditions described in Table 1. The test was initiated by simultaneously tripping the reactor and opening appropriate breakers by manual.

The reactor trip and the loss of off-site power were initiated simultaneously at 300 seconds (Figure 5). The Steam Generator (SG) water levels (Figures 6) initially decreased due to the feedwater pump coastdown and level shrink caused by the increased SG pressure. All RCPs were automatically tripped due to the loss of offsite power. As RCPs started coastdown (Figure 5), the RCS flowrate decreased rapidly. The reduction of RCS flowrate and decrease of SG water level result in increases of hot leg temperature (Figure 7) and pressurizer pressure (Figure 8), causing the loop temperature difference to increase. The increased loop temperature difference developed the natural circulation flow in the RCS loop. The minimum pressurizer pressure was reached 154.6 kg/cm^{2}A (2198 psia) at about 385 seconds and the maximum pressurizer pressure observed was 157.5 kg/cm^{2}A (2239 psia) at about 1,400 seconds while the natural circulation was in progress. The plant achieved stable hot standby conditions within 10 minutes after the reactor trip. The LOOP test was terminated at about 2,400 seconds by closing the off-site grid breakers.

Although one of the major concerns for this test was the Auxiliary Feedwater System (AFWS) capability for restoring and maintaining the SG level, AFWS was not actuated during the test since the SG levels did not decrease to the actuation setpoint of 23.5% wide range. The ADVs were not utilized to release the primary heat to the atmosphere because the steam header pressure was not high enough to open the ADVs. The RCS temperatures show gradually decreasing trend after the full natural circulation flow developed and indicate that core temperature rise is less than 31.7 ^{o}C (57.0 ^{o}F) which is the value at full power. This result clearly demonstrates that UCN 3 has an adequate natural circulation capability for the decay heat removal.

5. Conclusions

The tests related to the natural circulation capability for UCN 3 were performed to demonstrate the availability of PCS after a turbine and reactor trip, and to verify the natural circulation capability. These tests were successfully completed by meeting all acceptance criteria.

The test results for TT&NC show that the post-trip PCS performance was as expected by the design and the natural circulation capability was demonstrated to be adequate for the core decay heat removal. In addition, following the loss of main generator and off-site power, the plant conditions were stabilized at hot standby for more than 30 minutes using only natural circulation flow. Thus, the as-built capability of equipment controls and instrumentation necessary to remove the core decay heat using only emergency power were demonstrated to be adequate. Based on the test and evaluation results, it is concluded that the UCN 3 has an adequate natural circulation capability for the core decay heat removal.

References

1. "Design Requirements of the Residual Heat Removal System," U. S. NRC Branch Technical Position (BTP) RSB 5-1, Rev.02, July 1981.
2. "UCN 3&4 FSAR, Natural Circulation Cooldown Analysis, Appendix 5D," KEPCO.
3. "UCN 3&4 FSAR, Initial Test Program, Chap. 14.2," KEPCO.
4. "Test Procedure for PAT Turbine Trip/Natural Circulation," 3S-I-000-25, 1998, KEPCO.
5. "Test Procedure for Loss of Off-site Power," 3S-I-000-30, 1998, KEPCO.

Table 1. Plant Initial Conditions

Parameters	Units	Values	
		TT&NC Test	LOOP Test
Neutron Flux Power	%	99.7	15.5
Turbine Power	Mwe	1040	99
Pressurizer Pressure	kg/cm^2 A(psia)	158.5 (2254.4)	158.5 (2254.4)
Pressurizer Level	%	51.4	35.3
RCS Avg. Temperature	°C (°F)	310.4 (590.7)	299.2 (570.6)
RRS Ref. Temperature	°C (°F)	311.3 (592.3)	297.0 (566.6)
SG Pressure	kg/cm^2 A(psia)	77.1 (1096.6)	77.1 (1162.6)
SG Level	% NR	43.7	44.8

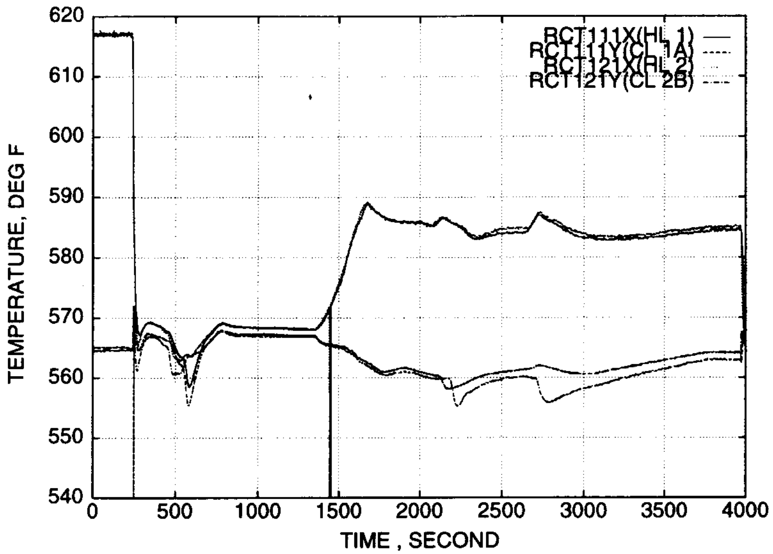

Fig 1. Hot and Cold Leg Temperature for Turbine Trip and Natural Circulation

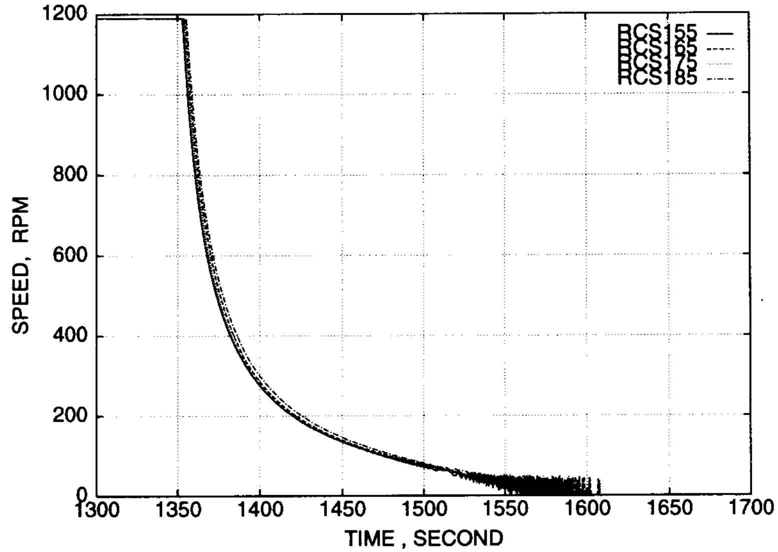

Fig 2. RCP Speed for Turbine Trip and Natural Circulation

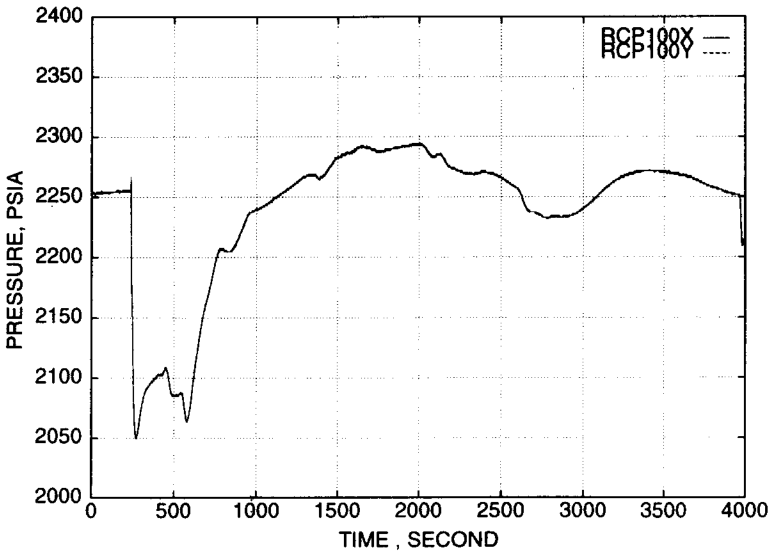

Fig 3. Pressurizer Pressure for Turbine Trip and Natural Circulation

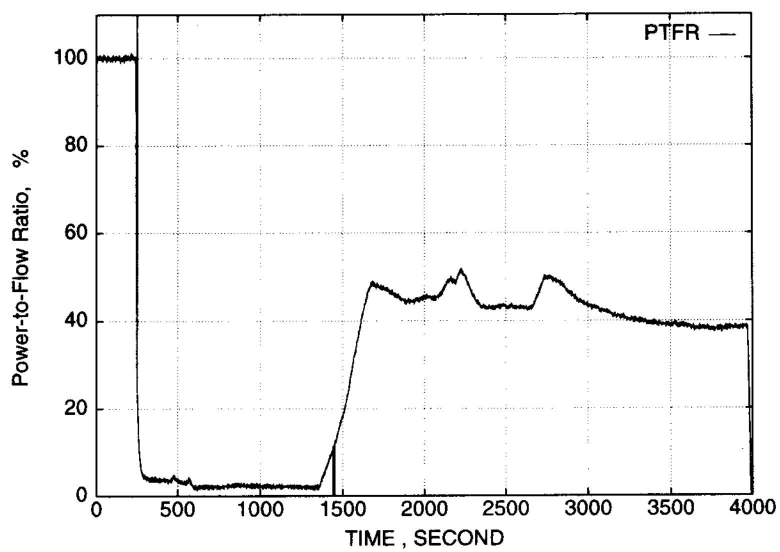

Fig 4. Power-to-Flow Ratio(PTFR) for Turbine Trip and Natural Circulation

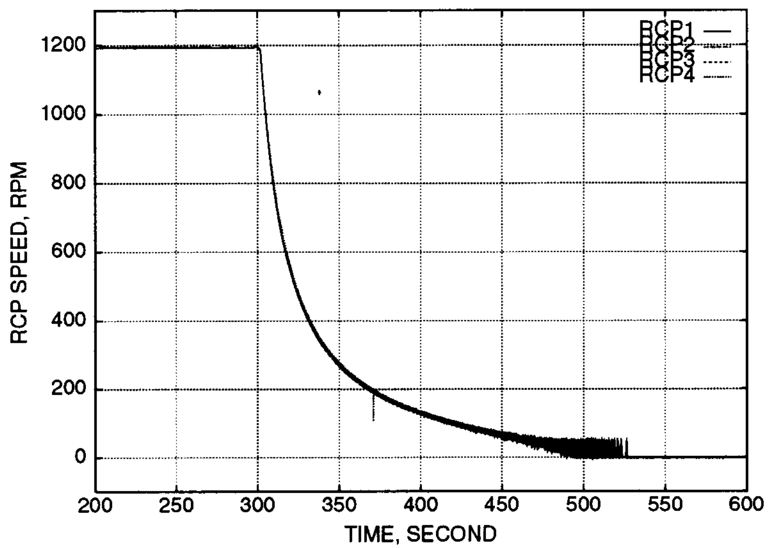

Fig 5. RCP Coastdown Speed in LOOP Test

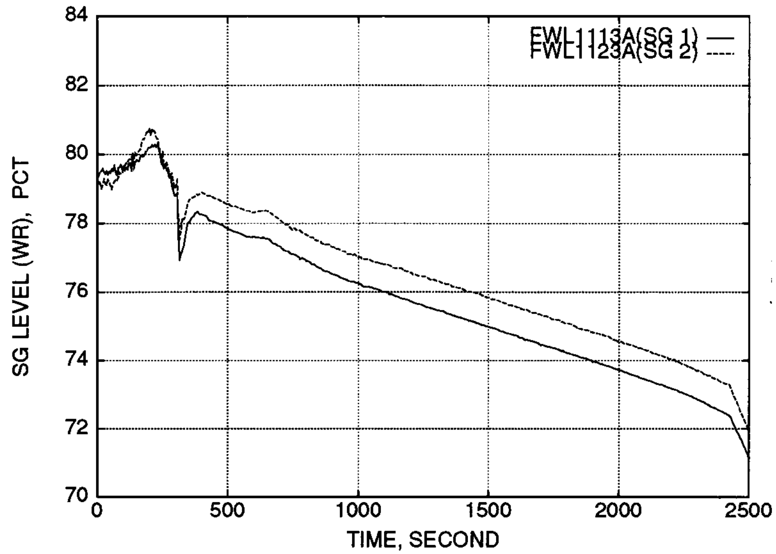

Fig 6. Steam Generator Wide Range Levels in LOOP Test

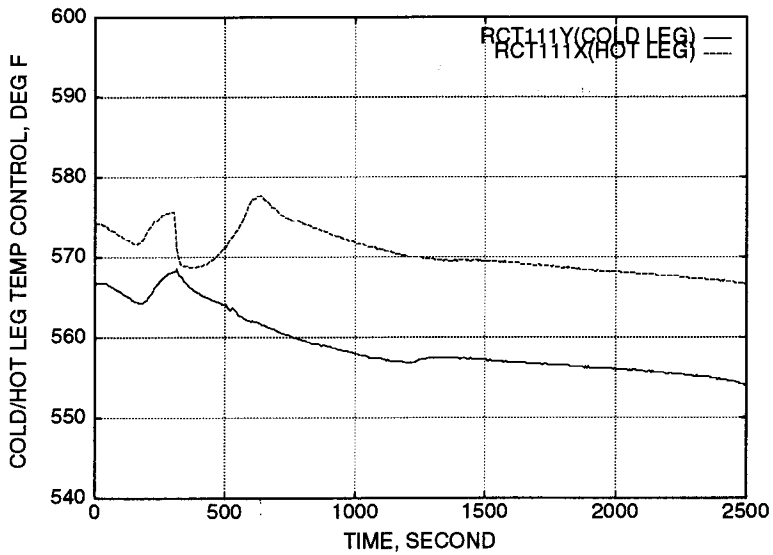

Fig 7. Reactor Coolant System Hot and Cold Leg Temperatures in LOOP Test

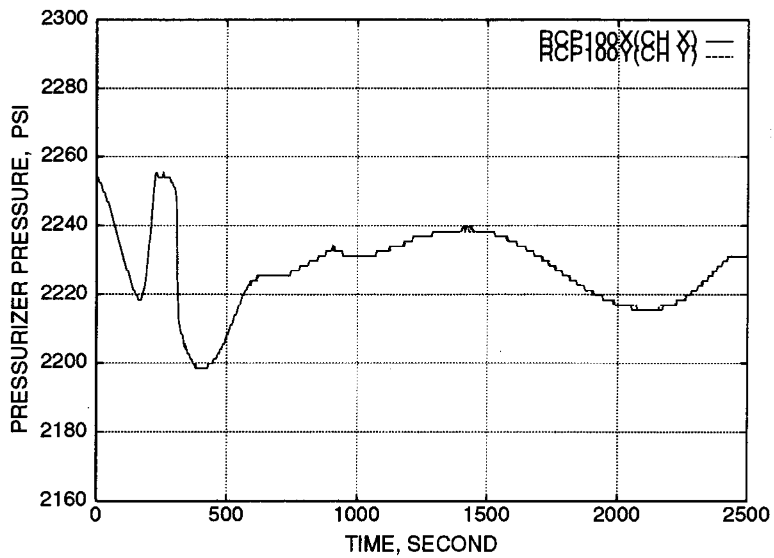

Fig 8. Pressurizer Pressures in LOOP Test