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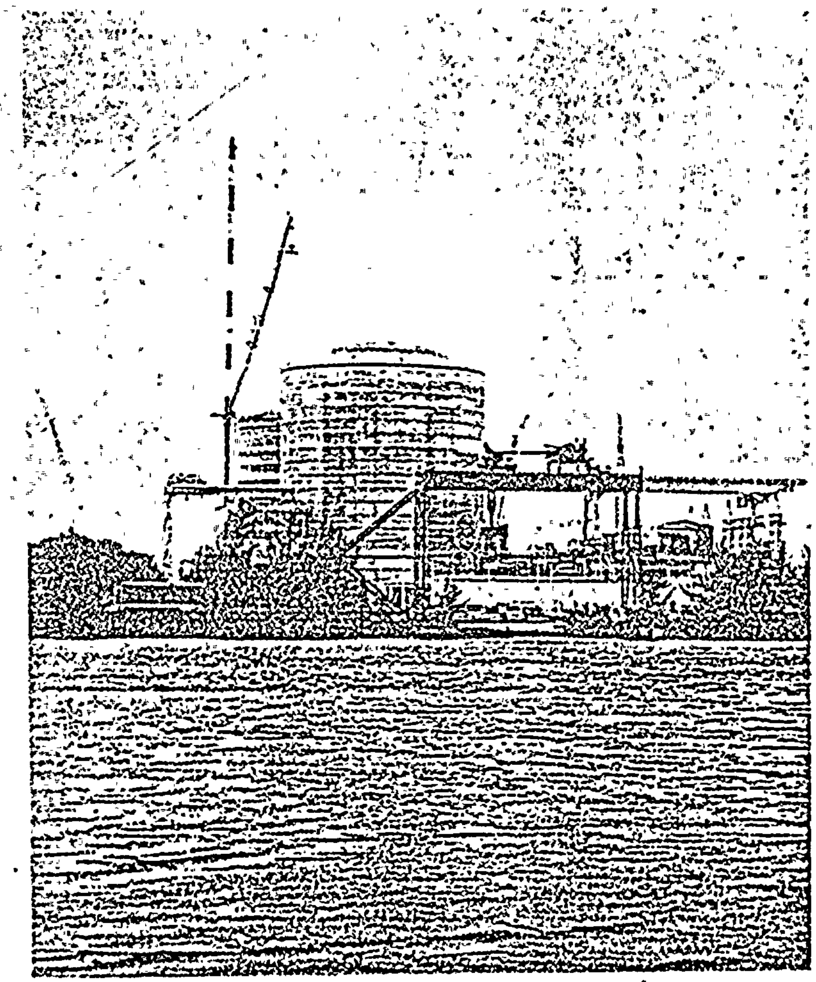
Analysis and Evaluation of St. Lucie Unit 1 Natural Circulation Cooldown



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Nuclear Safety Analysis Center
Institute of Nuclear Power Operations

Analysis and Evaluation of St. Lucie Unit 1 Natural Circulation Cooldown

NSAC-16/INPO-2

December 1980

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ABSTRACT

A cooldown by natural circulation of the Pressurized Water Reactor, St. Lucie Unit 1, has been analyzed by NSAC and INPO. This event occurred on June 11, 1980. Key items of interest discussed in the report include:

1. unexpected formation of a steam bubble under the reactor vessel head,
2. initially undetected small loss of reactor coolant inventory, and
3. additional instrumentation required for natural circulation cooldown.

Additional items for the operators to consider when employing natural circulation in a PWR are presented. These items should be included in procedures for conducting natural circulation cooling and plant cooldown under natural circulation.

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ST. LUCIE UNIT 1*

NATURAL CIRCULATION COOLDOWN ON 6/11/80

NARRATIVE

On June 11, 1980 an electrical failure caused a component cooling water isolation valve to shut off cooling water flow to the seals on all four reactor coolant pumps. The St. Lucie plant of the Florida Power and Light Co. was operating at nearly full power. The loss of cooling water to the reactor coolant pump seals required the operators to shut down the reactor in order to allow them to stop the reactor coolant pumps. This action protected the pump seals from being damaged due to operation without seal cooling water flow. The reactor coolant system was then cooled down with natural circulation providing coolant flow to the core and depressurized to the point where a low pressure shutdown cooling system could be used for the final stages of cooldown. Unexpected behavior of pressurizer level was observed approximately four hours after natural circulation was initiated.

Evaluations by Florida Power and Light Company, Combustion Engineering Corp., Institute of Nuclear Power Operations, and the Nuclear Safety Analysis Center have agreed that the unexpected pressurizer level behavior was caused by steam formation in the reactor vessel head. As the pressurizer cooled down, steam formed in the reactor vessel head, which had become the hottest part of the system, displacing water from the reactor coolant system into the pressurizer. The operators had no temperature reading in the reactor vessel head area. The anomalous behavior continued for about six hours until the reactor vessel head had been cooled.

Evaluation of the natural circulation cooldown shows that despite the anomalous pressurizer level behavior and the steam formation in the reactor vessel head, natural circulation continued without any evidence of perturbation until forced circulation and cooling were established by the shutdown cooling system. To date, two of the four reactor coolant pump seals have been disassembled and inspected. No damage has been found. The remaining two seals are scheduled for inspection.

*An 810 MWE Combustion Engineering Pressurized Water Reactor, first commercial operation, December 1976.

Florida Power and Light personnel have determined that the initiating electrical failure was caused by an accumulation of moisture in an electrical junction box containing a terminal board for the component cooling water valve solenoid. The moisture came from a steam leak at a nearby piping flange. The steam leak was repaired and the junction box was made less susceptible to moisture intrusion.

Three areas of importance highlighted by this event are:

1. Unexpected formation of a steam bubble in the reactor vessel
2. Initially undetected loss of reactor coolant inventory during natural circulation cooldown
3. Additional instrumentation required for natural circulation cooldown.

FINDINGS AND CONCLUSIONS

1. Natural circulation decay heat removal and subsequent cooldown of the reactor coolant system were adequate.

2. Anomalous pressurizer level behavior occurred after several hours into the cooldown when a steam bubble was formed in the reactor vessel head. This resulted from cooling the pressurizer below the temperature of the head area.

3. There is no temperature instrumentation in the reactor vessel head area. Such instrumentation could alert the operator of approaching saturation conditions in the reactor vessel head area.

4. Normal instrumentation for reading RCS hot leg temperature was not usable once the system was cooled below 515°F.

5. The subcooling monitor instrument is also not usable below 515°F since it receives its hot leg temperature input from a narrow range instrument.

6. Although wide range pressure indication was available to the operators, no automatically recorded pressure trending was available once system pressure was below 1500 psi. The operators manually recorded reactor coolant pressures at 30 minute intervals during the cooldown.

7. After the shutdown cooling system was valved into the RCS approximately 10,000 gallons of reactor coolant was drained inadvertently to the Refueling Water Tank at a rate of about 50 gpm.

8. Letdown system operations continued for a period of about three hours after the pressurizer level anomalies started.

9. At the time the steam bubble first started to form under the reactor vessel head, there existed in the reactor vessel a temperature difference of about 200°F between the top of the vessel flange and the coolant nozzles. This condition is not normally analyzed as part of the ASME Section III analysis.

10. A single malfunction in the common reactor coolant pump seal water cooling system led to the shutdown of all four reactor coolant pumps.

11. The initially unaccounted-for loss of reactor coolant inventory, which was concurrent with and masked by abnormal pressurizer level behavior, must be given serious consideration as it may apply to a future event where a greater loss of inventory may also initially go undetected.

12. Formation of a steam bubble under the reactor vessel head should be avoided through procedural control and operator training. However, operations during certain emergency conditions, e.g., steam generator tube rupture or reactor coolant pump seal failure, may lead to the formation of a steam bubble under the head. Maintenance of subcooling in the hot legs is a good indication of adequate coolant inventory and natural circulation. Should loss of subcooling in the hot legs occur as a result of condensation of the steam bubble or through simultaneous loss of coolant inventory, the post-TMI training and procedures should ensure that the operators will take corrective action by initiating the emergency core cooling systems, restoring subcooling and coolant inventory. Natural circulation should not be impaired as restoration of subcooling will prevent voids from accumulating in the coolant loops.

APPENDIX SOE

SEQUENCE OF EVENTS

Sequence of Events
St. Lucie
June 11, 1980

Plant Status Prior to the Event:

St. Lucie was operating at 99.6% reactor power with all the control element assemblies (CEA's) fully withdrawn. Four reactor coolant pumps (RCPs) were operating. The letdown and charging systems were in service. Reactor Coolant System pressure was approximately 2250 psi and average temperature was 563.4°F. A steam leak in the penetration room just outside of the containment building caused a fault in a solenoid on a pilot actuated pneumatically operated valve. At 2:26 am, the plant experienced the failure (failed closed) of a single Component Cooling Water (CCW) return header isolation valve. The failure caused a loss of cooling capability to all RCPs, so a reactor power level reduction was initiated and the following sequence of events ensued. (Ref. 50,16,6,9,49)

Time	Event	Remarks and References
2:33 am	Reactor trip Turbine/Generator trip Auxilary Feedwater pumps A and B on Steam Generator 1A and 1B low level alarms Feedwater pump 1B off	The operator tripped the reactor. System responses were normal. (Ref. 6,8,7,16).
2:34 am	Feedwater pump 1A off Feedwater pump 1B on Reactor coolant pump 1B1 off	Actions were taken to control steam generator water levels. The stopping of the RCPs indicated that actions were underway to place the reactor coolant system (RCS) in natural circulation. Natural circulation is used to remove decay heat from the core when RCPs are unavailable (Ref. 6, 16).
2:35 am	RCPs 1A1, 1B2 and 1A2 off	These actions along with bleeding steam from the steam generators removed decay heat from the RCS using natural circulation (Ref. 6, 16).
2:38 am	RCP 1B1 on	The continued rate of increase in the RCS hot-leg temperature prompted action by the operator to force

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Time	Event	Remarks and References
		coolant water through the reactor core to remove decay heat (Ref. 6, 13, 14, 15).
2:39 am	RCP 1B1 off	Returned to cooling of the RCS using natural circulation (Ref. 6, 13, 14, 15).
2:45 am	Feedwater pump 1B off	Steam generator water levels were controlled from this time on by using Auxiliary Feedwater pumps 1A and 1B (Ref. 6, 64, 16).
2:50 am (approx.)	Indicated pressurizer level returned to the control setpoint level	Changes in loop temperatures, RCS pressure, and pressurizer level following the initial transient had steadied (Ref. 63, 55, 57).
3:00 am (approx.)	Natural circulation cooldown commenced	A decreasing trend in loop temperatures with approximately 20 to 25°F ΔT indicates that a cooldown of the RCS using natural circulation was taking place (Ref. Appendix TH, 55, 57, 16).
3:12 am	Auxiliary feed pump 1C on	Ref. 6
3:50 am	The CCW flowpath was restored to all RCPs.	Ref. 49, 50
3:54 am	Auxiliary feed pump 1C off	Ref. 6
4:00 am	Commenced boration of RCS	Ref. 49, 52
4:35 am	Pressurizer low pressure safety injection actuation pre trip signal received.	RCS pressure had decreased to approximately 1700 psi. The cold leg temperature was indicating approximately 400°F. Cooldown of the RCS using natural circulation appeared to be normal (Ref. 6, 57, 1, 55).
4:45 am	Completed boration of RCS	Shutdown boron concentrations were established in the RCS (Ref. 49, 52).
4:45 am	Commenced lowering steam generator 1B level from 63% to 20%	This action was taken by the operators to make room in the steam generators for the addition of a cold slug of

Time	Event	Remarks and References
		water during the later stages of the cooldown process. The addition of cold water at that point is used to speed the cooldown process when the amount of steam produced by the heat transfer from the RCS to the steam generators has been reduced to low values. These low values slow the cooldown process when the temperatures and pressures in the RCS are slightly above the operating temperature and pressure required for shifting cooling from the steam generators to shutdown cooling using the LPSI system (Ref. 64).

Plant Status at Approximately 4:55 am

The reactor was shutdown. Reactor coolant pumps in the loops were stopped. The indicated cold leg temperature (≈380°F) and in core temperatures (412-415°F) were indicating a cooling trend. RCS pressure was approximately 1450 psi. Both steam generator water levels were being maintained at levels to support a natural circulation cooldown. Pressure in both steam generators indicated approximately 200 psi. CCW had been restored to the reactor coolant pumps.

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5:00 am (approx.)	Commenced lowering steam generator 1A Level from ≈65 to 20%	Reference 4:45 am Entry.
5:40 am (approx.)	Steam Generator 1B Level reached 20% Main steam isolation valves (MSIVs) closed Main condenser vacuum breaker open	With the MSIVs closed and vacuum broken (pressure at atmospheric values in the condenser), heat transfer from the steam generators to the main condenser was stopped. Pressure in both generators indicated approximately 100 psi. Steam discharge from the steam generators was directed to the atmosphere through the atmospheric dump valves. (Ref. 6, 16, 48, 64).
6:00 am	RCS pressure indicates 1140 psi Incore temperatures indicate in the range of 349-352°F Loop T_H indicated approximately 349°F Loop T_C indicated approximately 325°F	Indications at this time show that cooldown using natural circulation was proceeding as anticipated (Ref. 1, 16, 57, 55).
6:13 - 6:15 am (approx.)	Pressurizer level increasing Loop T_H indicates ≈346°F Loop T_C indicates ≈320°F	Auxiliary spray into the pressurizer was used to decrease the RCS pressure (1140 to 690 psi) from 06:00 through 06:30. This action caused the formation of a steam bubble

Time	Event	Remarks and References
	Incore temperatures indicate in the range of 342°F to 344°F	under the reactor vessel head, and resulted in an unexpected pressurizer level increase (Ref. 63, 1, 16, 55, 57). Appendix TH
6:20 am (approx.)	Steam Generator 1A level reached 20%	Refer to the 05:00 and 05:40 entries (Ref. 64).
6:35 am	LPSI pumps 1A and 1B on	LPSI pumps were placed in recirculation to warm up the Shutdown Cooling System piping in preparation for shutdown cooling using the LPSI system (Ref. 54, 6).
6:40 am	Pressurizer level increased significantly	The level change (46% to 96%) and the rate of level increase changed significantly from approximately 06:40 through 7:05 am (Ref. 63).
7:00 am	Loop T_H indicates ≈325°F Loop T_C indicates ≈305°F Pressurizer pressure indicates 500 psi Incore temperatures indicate in the range of 325°F to 327°F	Plant parameters indicate that cooldown using natural circulation was continuing, uninterrupted by the steam bubble in the reactor vessel head (Ref. 6, 55, 57, 16, 1).
8:45 am (approx.)	Steam Generator 1A and 1B levels increasing	Indicated levels in the 1A and 1B steam generators were approximately 27% of the operating range. Indicated pressure in steam generator 1A and 1B was <75 psi. Filling the generators with cold feedwater aids in cooling down the primary system to a temperature compatible with initiating shutdown cooling using the Low Pressure Safety Injection System. (Refer to the 5:00 am and 5:40 am entries. Ref. 64, 48).
9:40 am (approx.)	Steam Generator 1A and 1B levels reach ≈65%	Ref. 64
10:00 am (approx.)	Letdown isolated	Anomalies in pressurizer level response were continuing. It was reported that level rose rapidly when auxiliary spray from the charging pumps was directed to the pressurizer followed by a rapid decrease in level when charging was directed to the loops. The letdown system was isolated by the operators to prevent draining of reactor

SOE-4

Time	Event	Remarks and References
		coolant from the reactor coolant system. Although this was the first logged isolation, the operators reported that letdown was shutoff between 8:15 am and 8:55 am. (Ref. 69, 16, 63, 9).
10:06 am	LPSI pumps 1A and 1B off	Warm up of the LPSI system was complete. Valve alignment was started to align the LPSI system for shutdown cooling (Ref. 6, 59).
10:10 am	Auxiliary Feedwater pump 1A off	One of the two running auxiliary feedwater pumps (1A & 1B) was stopped. Capacity to meet steam generator level requirements was maintained with one pump (Ref. 6).
10:28 am (approx.)	LPSI system lined-up to the RCS	LPSI system pressure indicated ≈235 psi while RCS pressure indicated 235 psi. Loop T_H indicated ≈290°F while Loop T_C indicated ≈275°F. (Ref. 59, 55, 57, 1).
10:33 am	LPSI pump 1B on	LPSI pump discharge pressure spiked to a value in excess of 400 psi. It was reported that the discharge relief valve lifted resulting in the subsequent stopping of the LPSI pump 1B (Ref. 59, 6, 16, 54, 69).
10:34 am	LPSI pump 1B off	Reference 10:33 entry (Ref. 6).
10:37 am	Pressurizer pressure - 230 psi Hot Leg Temperature - 289°F Cold Leg Temperature - 273°F	The parameters listed were manually recorded in the control room log. (Ref. 49).
10:51 am	LPSI pump 1B on	To establish shutdown cooling of the reactor coolant system using the LPSI system (Ref. 54, 59, 6).
11:00 am (approx.)	Flow indicated in the LPSI system	Ref. 59, 54.
11:07 am (approx.)	Shutdown cooling established using the LPSI system	Ref. 49

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Time	Event	Remarks and References
11:27 am	Auxiliary Feedwater pump 1B stopped	As heat removal of the RCS had been established using the LPSI system, heat removal through the steam generators was no longer required (Ref. 6, 8).
11:35 am-12:23 pm (approx.)	Indicated LPSI system pressure decreasing	LPSI system pressure was steadily decreasing from the pressure indicated at start-up (≈255 psi) to an indicated low value of ≈150 psi at 12:26 pm. Anomalous pressurizer level response was continuing in response to shifting the charging water entry point into the RCS. (Refer to 10:00 am entry). Subsequent analysis of pressurizer level responses during this period from 10:28 am indicate a loss of RCS water inventory. Temperatures through this period remained relatively constant. Incore temperatures indicated ≈281°F, Loop T_H indicated ≈276°F with the Loop T_C indicating ≈275°F (Ref. 59, 63, 16, 55, 57).
12:23 pm	LPSI pump 1A on	A marked increase in LPSI system flow and pressure indicated the addition of inventory to the RCS from the Refueling Water Tank (Ref. 54, 59, 6) Appendix RAD.
12:26 pm	LPSI pump 1A off	Ref. 6, 54, 59.
12:27 pm	LPSI pump 1A on LPSI pump 1B off	Pressurizer level response indicated that the RCS system inventory was being replaced (Ref. 6, 59, 54).
12:30 pm	Subcooled conditions were reached in the pressurizer	Ref. 1
12:34 pm	LPSI pump 1B on	Shutdown cooling using the LPSI system was re-established. Pressure in the LPSI system was increased to ≈260 psi with the two LPSI pumps running. 1A LPSI pump had supplied the inventory and pressure needed in the RCS while the 1B LPSI pump and heat exchangers provided cooling in the RCS. (Ref. 54, 59, 16, 6, 55, 57, 1).

Time	Event	Remarks and References
12:34 pm (approx.)	Recorded pressurizer level indication went off scale on the high end.	Ref. 63.
1:30 pm	Saturated conditons were restored in the pressurizer	The water in the pressurizer had been heated to saturated conditions through the use of pressurizer heaters. (Ref. 1).
1:57 pm	LPSI pump 1A off	The following plant conditions were recorded: Pressure in the LPSI system was indicating ≈385 psi at a flow rate of ≈3300 gpm. Loop T_H was indicating ≈220°F, Loop T_C was ≈205°F, with incore temperature of ≈225°F. Pressurizer pressure was recorded at 260 psi at a temperature of 410°F which represent saturated conditions in the pressurizer (Ref. 6, 1, 59, 54, 55, 57, 16).
2:50 pm (approx.)	Recorded Pressurizer Level indication returned to the indicating range displaying a downward trend	Letdown from the RCS had been established at a flow rate greater than the flow rate of the charging pumps. This action was taken to get pressurizer level in its normal recorded range. (Ref. 63, 16).
3:45 pm (approx.)	The downward trend indicated on the recorded pressurizer level instrumentation was stopped at an indicated level of 58%	Charging into the RCS loops using two charging pumps was initiated. Pressurizer level indication responded with an upward trend. This trend is anticipated when the RCS is full of water with a bubble in the upper portion of the pressurizer. Prior to this time, charging into the loops brought a decreasing pressurizer level indication signaling that steam existed at some other location in the RCS in addition to the steam in the pressurizer. (Ref. 63, 11).
4:20 pm	RCS degasification procedure was commenced	Ref. 50

Plant status:

The plant had been shutdown and was being cooled using the LPSI system in the shutdown cooling mode of operation.

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APPENDIX T/H

NATURAL CIRCULATION AND PLANT COOLDOWN

APPENDIX T/H

NATURAL CIRCULATION AND PLANT COOLDOWN

The reactor was manually tripped at 2:33 am. All reactor coolant pumps were tripped by 2:35 am. The 1B1 reactor coolant pump was restarted at 2:38 am, and was run for about one minute, then stopped. All reactor coolant pumps remained stopped to eliminate any risk of pump seal failure from operation without seal water cooling. Pump operation was not resumed even after cooling water had been restored, about 1-1/2 hours after it had been lost.

The reactor coolant pumps were manufactured by Byron Jackson and have a three stage mechanical seal plus a vapor seal. Seal water is supplied only from the reactor coolant system, the water first being cooled by a heat exchanger integral with the pumps. It was reported that the seals did not experience greatly increased leakage during the plant cooldown. However, intermittent RCP seal alarms recurred throughout the cooldown.

Natural Circulation

Natural circulation of reactor coolant and continued heat transfer from the reactor system to the steam generators occurs as a consequence of the higher elevation of the steam generator relative to the reactor. A temperature differential between the hot legs and cold legs of the system is required to sustain natural circulation. The coolant flow can be estimated by comparing the measured temperature differential to the full power temperature differential, knowing the decay heat at any given time after trip.

Natural circulation cooling worked well throughout the cooldown using the steam generators. Temperature differentials between T_{hot} and T_{cold} ranged from 20-40°F (Figures T/H-1 and 2), compared with 44°F during power operation. With core power in the 1-2% range, the temperature differential corresponded to a reactor coolant flow rate of 2-3% of full flow.

The higher coolant flow rate under natural circulation occurred soon after reactor trip, corresponding to the higher decay heat production. At about 7:00 am, during the time that evidence of the first drawing of the steam bubble under the reactor head appeared, the temperature difference between T_{hot} and T_{cold} was about 20°F. With decay heat just under 1%, the coolant flow rate is estimated to have been near 2% of full flow. Throughout the time that the steam generators were used to cool the unit with a steam bubble under the head, the coolant temperatures indicated that about 2% of rated flow was being maintained.

After shutdown cooling was initiated at about 11:00 am, the steam generators continued to be functional for a few hours, assisting in the removal of heat from the reactor coolant system.

From the time of reactor trip until initiation of shutdown cooling (2:33 am -11:00 am), the coolant subcooling ranged from 67°F at the moment of trip to as high as 225°F at 5:30 am, based on the highest core exit thermocouple reading or T_{hot} instrumentation located in the hot legs. The T_{hot} instrumentation reached the low end of its range (515°F) at 3:20 am and was not useful for about 2-1/2 hours, until it had been re-ranged by an I&C technician. Below 515°F, the core exit thermocouples were used to indicate the amount of coolant subcooling. From 5:30 am, coolant subcooling fell slowly, reaching a low of 55°F at 12:23 pm, just prior to raising coolant inventory and pressure through operation of Low Pressure Safety Injection (LPSI) pump 1A in the safety injection mode.

At no time did the T_{hot} instrumentation indicate a transfer of hot water from the reactor vessel head region into the hot legs as the steam bubble formed. However, flow from the upper vessel and head region into the hot legs each time the steam bubble formed was always a small fraction of coolant flow though the core and loops. Between 11:05 am and 11:25 am hot water flowing from the pressurizer during a relatively low water level dip was indicated by the T_{hot} instrumentation which by that time was being recorded (Ref. 55).

Steam Formation during Cooldown

Cooldown on natural circulation, by feeding the steam generators and dumping steam to the condenser, began at about 3:00 am. Natural circulation of reactor coolant had been well established by the time the cooldown started. The cooldown progressed at an average 60°F per hour until about 6:00 am. Shortly after that, an attempt was made to cool the pressurizer and reduce pressure through the use of auxiliary spray from the charging pumps. Between 6:15 am and 7:15 am the water level in the pressurizer rose unexpectedly, much more than could be explained by the volume of water being pumped into the reactor coolant system (Figure T/H-3). The pressure at 6:15 am, when the steam bubble apparently first started to form under the head of the reactor vessel, was somewhere between 1140 and 690 psig, the pressure log entries at 6:00 am and 6:30 am respectively (Figure T/H-4). Saturation temperature at 6:15 am corresponding to the mean pressure between 6:00 am and 6:30 am was 535°F, likely very nearly the temperature of the reactor vessel head and its contents at the beginning of bubble formation. The cold leg temperature was 320°F at this time, so a temperature differential of about 200°F existed in the reactor vessel between the top of the flange and the coolant nozzles. From the observed level rise in the pressurizer, the coolant shrinkage from cooling, and estimated charging and letdown, the size of the first steam bubble expansion is estimated to have been somewhat larger than the head volume down to the closure flange, but well short of the hot leg nozzle (Figure T/H-5).

It is not possible to estimate reliably the inventory of reactor coolant during the cooldown since the charging flow indicator was out of service, starting and stopping of the charging pumps may not have been noted always, (the operator's written logs had no entries on charging pump operation) and the letdown flow was variable and not recorded. However, from the hourly log entries, it appears the letdown flow, in response to the rapidly rising pressurizer level, may have been slightly higher than charging flow (auxiliary spray) during the drawing of the initial steam bubble. A slow loss of inventory apparently continued in response to higher than desired pressurizer level until 8:15 am, when letdown was reported to have been stopped for 40 minutes. As many as 3 charging pumps may have been operated for several minutes during this interval, affording an increase in coolant inventory. At 9:00 am, charging was evidently back to the flow of one pump (about 44 gpm), and letdown flow was 30 gpm. The charging flow appeared to have continued at 44 gpm past 3:00 pm Letdown flow was stopped shortly after 10:00 am, remaining off until sometime between 2:00 pm and 3:00 pm, when it was re-initiated at about 80 gpm. Between 9:00 am and 12:30 pm the charging flow was alternated several times between the reactor loops and pressurizer auxiliary spray, causing rapid pressurizer level transients, as the steam bubbles in the pressurizer and the reactor head alternately swelled and shrank in opposite directions. (Fig. T/H-3)

Coolant Flow to Refueling Water Tank

At 10:28 am the isolation valves between the reactor coolant system and the shutdown cooling loop 1B (LPSI-1B) were opened, in order to start shutdown cooling. Pressurizer pressure was indicating 235 psi. It was reported that the suction relief valve on the shutdown cooling loop lifted at this time, and the discharge relief valve lifted at 10:33 am upon starting the Low Pressure Safety Injection

(LPSI) pump 1B. The LPSI pump 1B was then stopped, and initiation of shutdown cooling delayed until system pressure decayed another 20 psi.

Upon opening the valves to the shutdown cooling loop at 10:28 am, the pressurizer level transient, which was then trending down, exhibited a distinctly different response than the previous downward movements (Figure T/H-3). Whereas the previous two downward legs of the pressurizer level transient indicated an exponential decay of the steam bubble under the head, once the shutdown cooling loop isolation valves were opened, steeply falling levels were experienced each time the charging flow was switched from pressurizer spray to reactor loop injection. Since letdown had been shut off shortly after 10:00 am, and reactor coolant average temperature was nearly constant from 9:30 am until noon, a steadily rising reactor inventory resulting from the charging flow would have been expected. However, a generally downward pressurizer water level trend was experienced. Analysis of the pressurizer level and system inventory indicate that a reactor coolant leak was in progress. Further evidence of this leak appeared on the Refueling Water Tank level strip chart recording (Reference 26). From the RWT strip chart, the leak appears to have been about 5000 gal up to 12:23 pm. Averaged over the time period from 10:28 am to 12:23 pm, the leak rate would have been about 45 gpm. However calculation of coolant inventory over that time period based on pressurizer level response, assuming letdown shutoff, charging in-flow from one pump (44 gpm) and reactor coolant pump seal out-flow of 4 gpm, gives an estimated leak flow of about 60 gpm. The net loss from the Reactor Coolant System was somewhere in the range of 5-20 gpm. Evidently the transfer of reactor coolant to the Refueling Water Tank occurred through a partially open valve in the recirculation line from LPSI pump 1B. The orifice in this line is rated at 50 gpm at pump shutoff head (200 psi). Leakage of reactor coolant to the Refueling Water Tank is discussed further in Appendix RAD.

Noting that pressurizer pressure had decreased to 115 psi and pressurizer water level had repeatedly dropped below the reference value, Low Pressure Safety Injection Pump 1A, which had been aligned for safety injection, was started at 12:23 pm in order to increase pressure. LPSI pump 1B was turned off for several minutes while pump 1A was injecting, lowering the pressure in the common LPSI pump discharge header, thus permitting LPSI pump 1A to raise reactor pressure to the pump shutoff head, about 200 psi. About 5000 gallons of refueling water was pumped into the reactor system between 12:23 pm and 12:34 pm, at which time LPSI pump 1B was re-started, raising the discharge header pressure well above the shutoff head of the 1A pump.

At 12:23 pm, just prior to starting LPSI pump 1A to inject water into the reactor, the steam bubble under the head had been allowed to decay to a small, but unknown size, while water flowed from the pressurizer to replace the decaying bubble. From rough coolant inventory calculations, the steam bubble is estimated to have been no larger than a few hundred cubic feet at that time. Operation of LPSI pump 1A, injecting water and raising pressure would have reduced the bubble size by half. Complete collapse of the steam bubble in the reactor vessel head is estimated to have occurred within minutes of the repressurization.

Once the pressurizer water level (Figure T/H-3) had been raised above 100% (indicated) on the hot calibrated level recorder at 12:34 pm (above 67% corrected for temperature), the pressurizer steam space was compressed, and the water in the pressurizer was then subcooled. The pressurizer heaters were energized to raise the water temperature, so that the pressurizer could be used to maintain pressure above 200 psi. The heaters had raised the temperature of the water to saturation at 175 psi by 1:15 pm and continued to raise pressure, reaching 260 psi by 2:00 pm. Pressure was then maintained near 260 psi for several hours, preventing any reappearance of a steam bubble under the reactor vessel head.

After the reactor inventory and pressure had been increased through operation of LPSI pump 1A at 12:34 pm, and shutdown cooling had resumed using LPSI pump 1B, the 1A pump continued to operate in the injection mode. The 1A pump was merely recirculating water back to the Refueling Water Tank through its miniflow recirculation line, as the pressure in the discharge header was too high to permit further injection to the reactor coolant system. Leakage from the shutdown cooling system to the Refueling Water Tank continued until 1:57 pm at which time the 1A pump was stopped and the recirculation lines from both pumps were isolated from the Refueling Water Tank. From 12:34 pm until 1:57 pm, it is estimated that approximately 5000 gallons of reactor coolant leaked to the Refueling Water Tank. During this time period the letdown was secured, and most likely one charging pump was operated continuously. The net rate of loss from the reactor system is estimated to have been 20 gpm.

By 2:00 pm the pressurizer had been heated sufficiently to restore the reactor coolant pressure to 260 psi, and the slow coolant leak had been stopped. The coolant inventory was now slowly increasing from continuous charging flow. It was reported that at 2:32 pm letdown flow was re-initiated at about twice the charging flow rate. The pressurizer steam space expanded slowly, bringing the water level indication back on scale on the recorder (hot calibrated channel, Figure T/H-3) by 2:50 pm. At about 3:45 pm charging was increased to a higher flow rate than letdown, and the pressurizer water level exhibited a normal slow rise in response over a 45 minute period. Conditions had been restored to normal.

The 1977 Natural Circulation Cooldown

During 1977, the St. Lucie plant conducted a cooldown under natural circulation conditions. The possibility that a steam void had been formed under the reactor vessel head during that event had not been recognized. The pressurizer water level transient during that cooldown has now been examined (Figure T/H-5), and anomalous behavior similar to the recent transient has been confirmed. The cooldown prior to the time of the first rise in pressurizer level was about 2 hours longer in 1977 than in 1980. Additional training and understanding, which came as a result of the TMI accident, enabled operations personnel to recognize the significance of the pressurizer level behavior in 1980.

The 1977 transient pressurizer water level response did not exhibit any evidence of a loss of coolant inventory during the event. Shutdown cooling was not initiated until approximately 7-1/2 hours after the first sharp rise in pressurizer level, compared with 4 hours to initiation of shutdown cooling in 1980. Delaying the reduction of reactor system pressure to permit initiation of shutdown cooling gave the reactor vessel head and its contents more time to cool, lessening the tendency to form a large steam bubble.

Inventory Control Procedure

An analysis of plant behavior during the time period between 8:00 am and 9:00 am suggests a procedure that could be used to determine inventory of reactor coolant if alternate drawing of a vessel bubble and collapsing of it is determined to be an acceptable operating method for cooling the reactor vessel head area during a natural circulation cooldown. During this period of time charging flow was directed to the reactor coolant loop and the pressurizer level fell. By 8:30 am the steam bubble in the head had virtually collapsed, as evidenced by pressurizer level which had bottomed out, turned around, and was rising at a rate consistent with charging and letdown flows. At this time (Fig. T/H-3) pressurizer level properly compensated for temperature, would have been a good indicator of coolant inventory. Note how the rounded off character of pressurizer level turning around and starting to rise was different from the rest of the curve, where the head bubble was not fully collapsed and the turnaround of level indication was char-

acteristically a sharp sawtooth shape. These later water level turnarounds (caused by spraying the pressurizer) exhibited rates of level rise much faster than that consistent with charging and letdown flows. From 8:30 am until 9 am, pressurizer level was a good indicator of coolant inventory. Pressurizer level did not properly indicate coolant inventory again until shortly after 12:34 pm, when it is estimated that the reactor vessel steam bubble finally collapsed. It would be practical for operators conducting a natural circulation cooldown to repeat periodically the procedure which was used by the St. Lucie operators at about 8:30 am, in order to obtain correct indication of coolant inventory. The essential rule to follow to provide proper indication is to cause the pressurizer water level transient to bottom out and start to rise slowly while continuing to charge to the coolant loop.

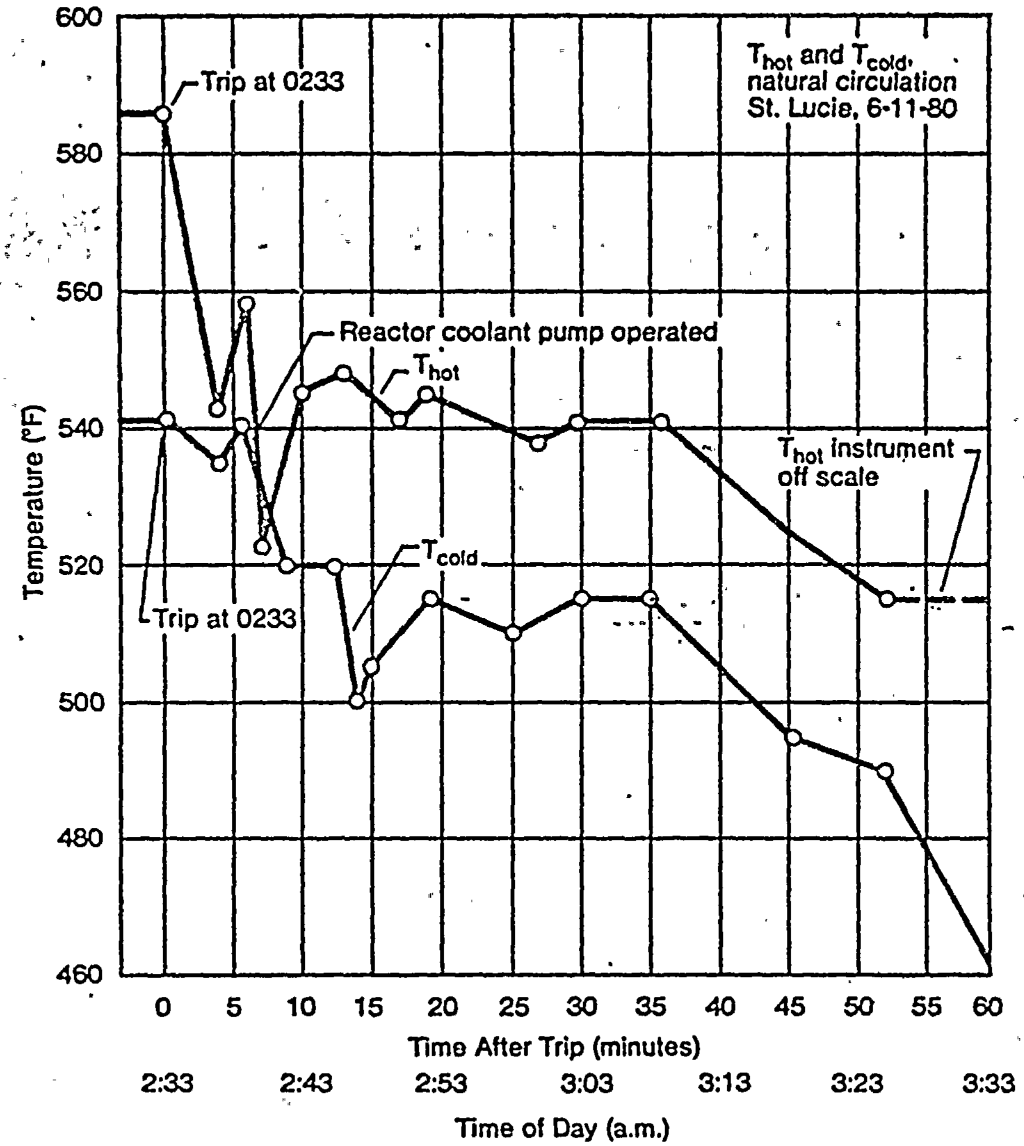

Figure T/H-1. Reactor Coolant Temperatures First Hour After Trip

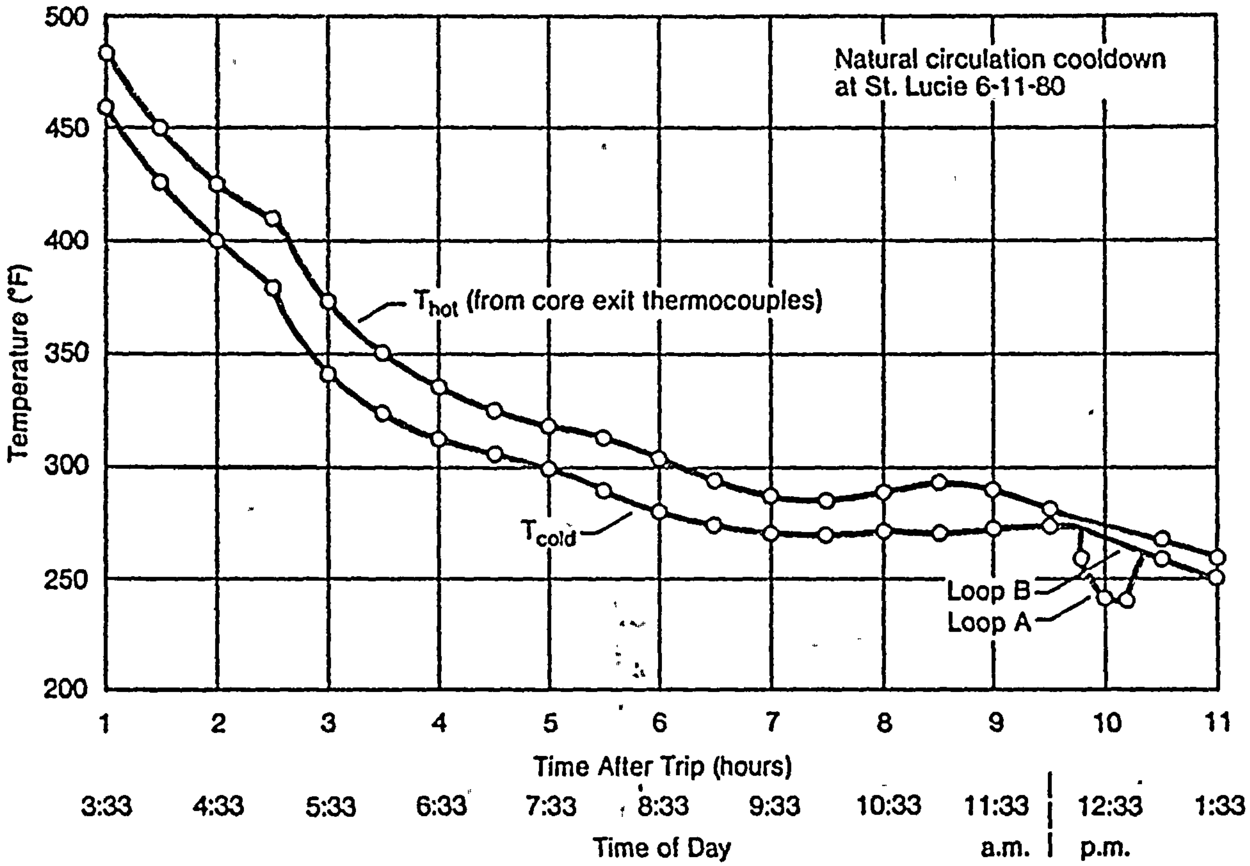

Figure T/H-2. Reactor Coolant Temperatures During Cooldown

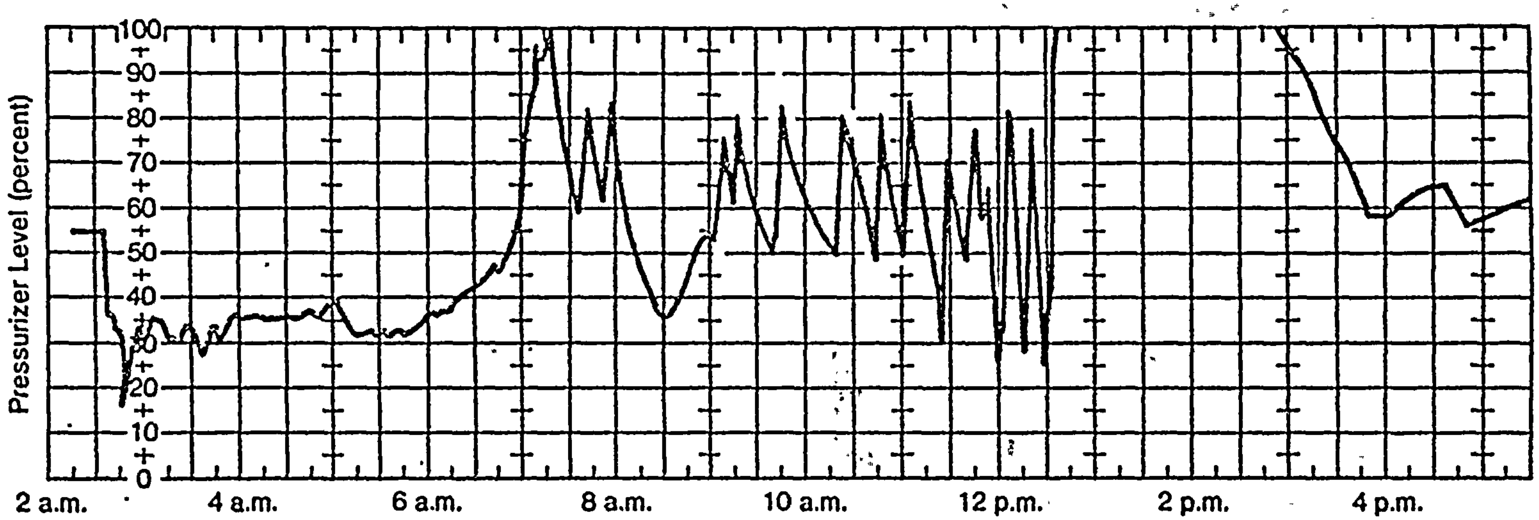

Figure T/H-3. Pressurizer Level (hot calibrated) St. Lucie 6-11-80

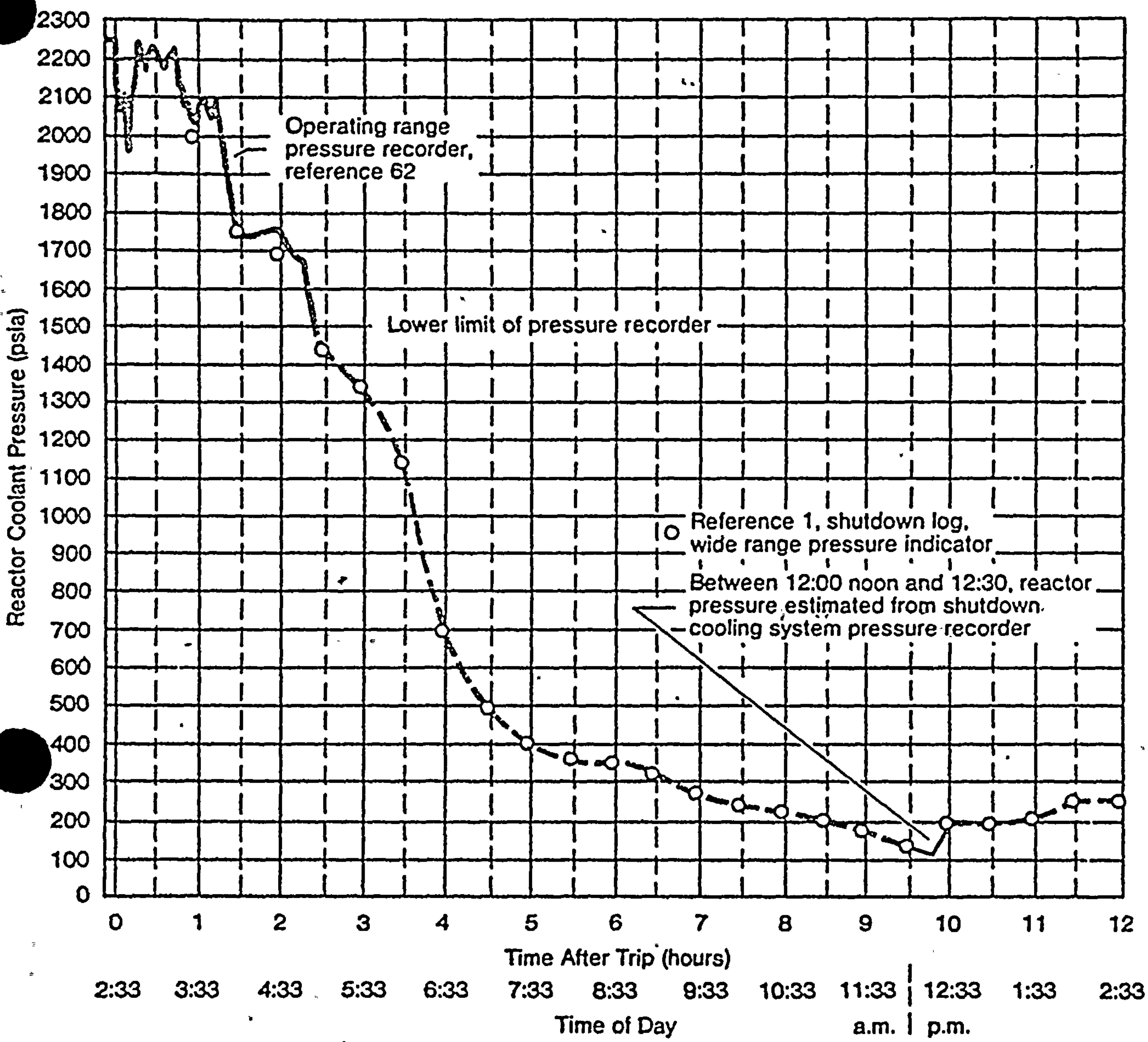

Figure T/H-4. Reactor Pressure

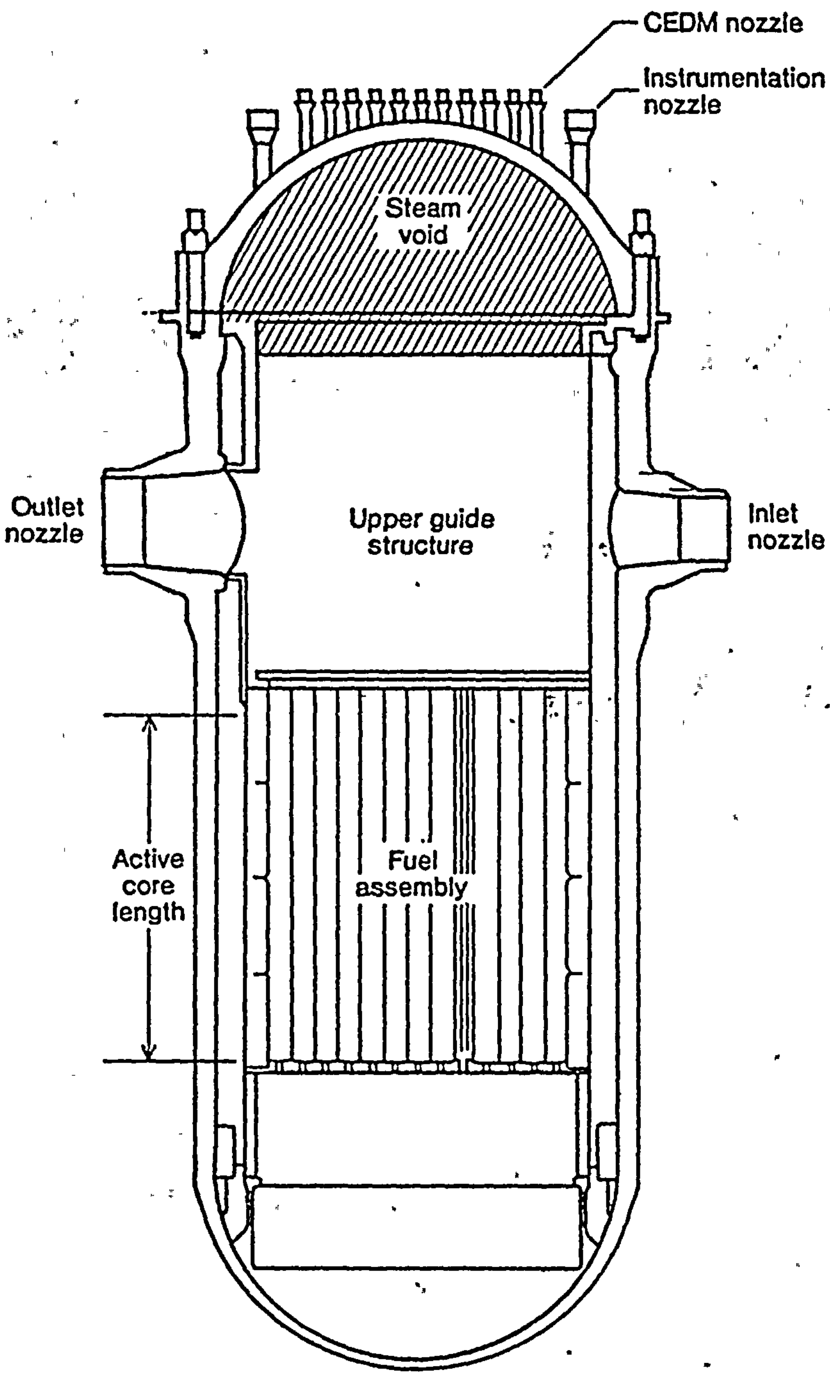

Figure T/H-5. Estimated Size of Initial Steam Bubble

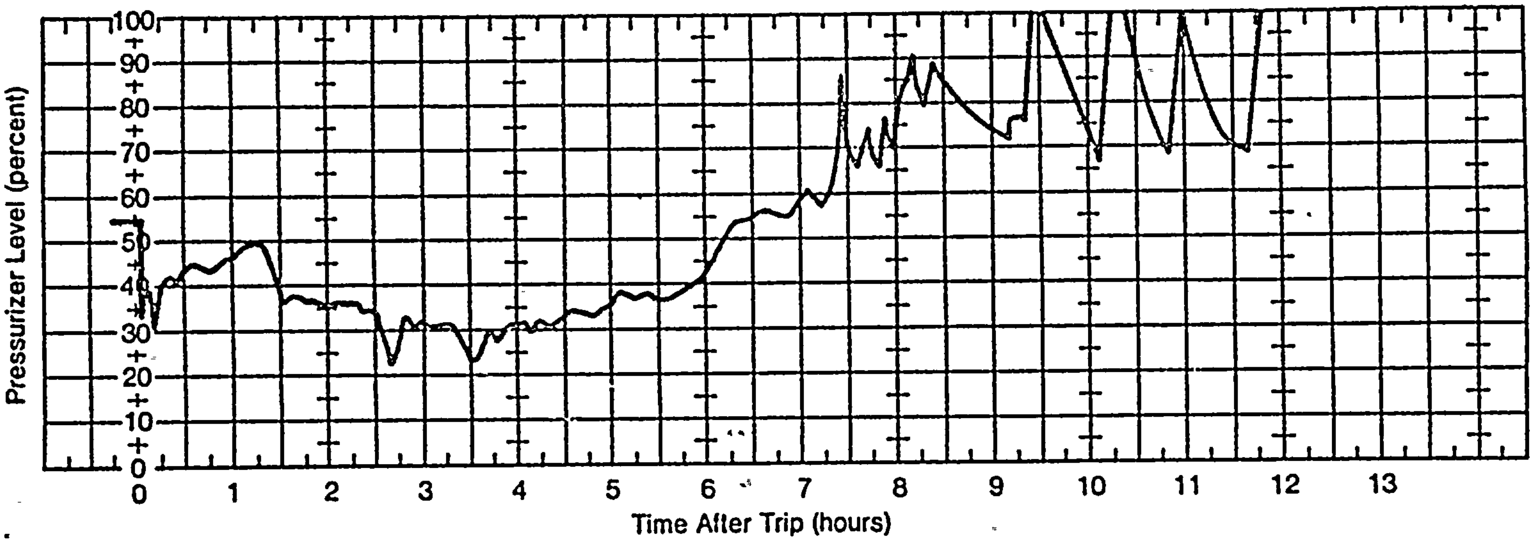

Figure T/H-6. Pressurizer Level, 1977 St. Lucie Natural Circulation Cooldown

APPENDIX RAD

RADIOCHEMISTRY AND RADIOACTIVE EFFLUENTS

APPENDIX RAD

RADIOCHEMISTRY AND RADIOACTIVE EFFLUENTS

At ~10:28 am on 6/11/80, after previously heating up the water in the shutdown cooling lines, shutdown cooling loop 1B isolation valves to the reactor coolant system were opened in preparation for initiating shutdown cooling using the 1B low pressure safety injection (LPSI) pump. A gradual increase in the Refueling Water Tank (RWT) level began at this time. The most probable pathway that reactor coolant took to reach the refueling water tank was through the 1B LPSI pump mini-flow recirculation valve (V-3205) which may have been at least partially open while the system was operating in the shutdown cooling mode. (See Figure RAD-1). This allowed the transfer of approximately 5000 gallons of reactor coolant to the refueling water tank between 10:28 am and 12:23 pm at which time the 1A LPSI pump was turned on to fill the reactor coolant system and repressurize back to 200 psi. About 5000 gallons of refueling water was tranferred back to the reactor coolant system at this time. The 1B LPSI pump was turned off at 12:27 pm and restarted at 12:34 pm and left on thereafter in the shutdown cooling mode. The 1B LPSI pump mini-flow recirculation valve (V-3205) remained open during this time allowing the continued transfer of an additional 5000 gallons of reactor coolant to the refueling water tank until 1:57 pm when all mini-flow was isolated using the motor operated valves on the LPSI pumps mini-flow header outlet line (V-3659 and V-3660). Although the 1A LPSI pump remained in operation until 1:57 pm, its head was sufficient to pump water from the refueling water storage tank to the reactor coolant system only when the pressure in the pump discharge line was below 200 psi. Once reactor pressure had been restored to 200 psi (~12:30 pm) and the 1B LPSI pump restarted (12:34 pm), pressure in the common discharge line was too high to permit further return of coolant from the refueling water tank to the reactor.

Samples of the reactor coolant taken in this period (1:45 pm on 6/11/80) contained specific activity levels of approximately 10×10^{-2} microcuries/ml. The transfer of a total of 10,000 gallons of reactor coolant containing specific activity of 10×10^{-2} microcuries/ml to the refueling water tank represents the inadvertent transfer of approximately 3.8 curies of activity from the reactor coolant system to the refueling water tank.

Plant vent gaseous, particulate and iodine activity levels remained steady before and throughout the transient with plant vent gaseous activity maintaining approximately 200-300 counts per minute. Subsequent to 6/11/80, Florida Power & Light conducted a containment purge and three releases from the gas decay tanks also without any abnormal releases of activity.

There may have been a small off-site release of gaseous radioactive material from the refueling water tank external vent due to the transfer of reactor coolant to the refueling water tank. A reactor coolant sample taken at 1 pm on 6/11/80 contained noble gaseous activity of 1.35×10^{-2} microcuries/ml. Isotopic analysis of this sample showed this gaseous activity to be composed of greater than 90% Xe-133, 8% Xe-135 with the remainder (less than 2%) Kr-85. If as much as 10,000 gallons of reactor coolant had been transferred to the refueling water tank this would have resulted in the transfer of 0.51 curies of noble gas activity. The allowable environmental limit for unplanned or uncontrolled release of noble gas is approximately ten times this amount.

A small fraction of the 0.51 curies of noble gas actually transferred to the refueling water tank would be expected to have outgassed from the relatively cool refueling water tank prior to the decay of the xenon fraction in the tank to non-volatile cesium.

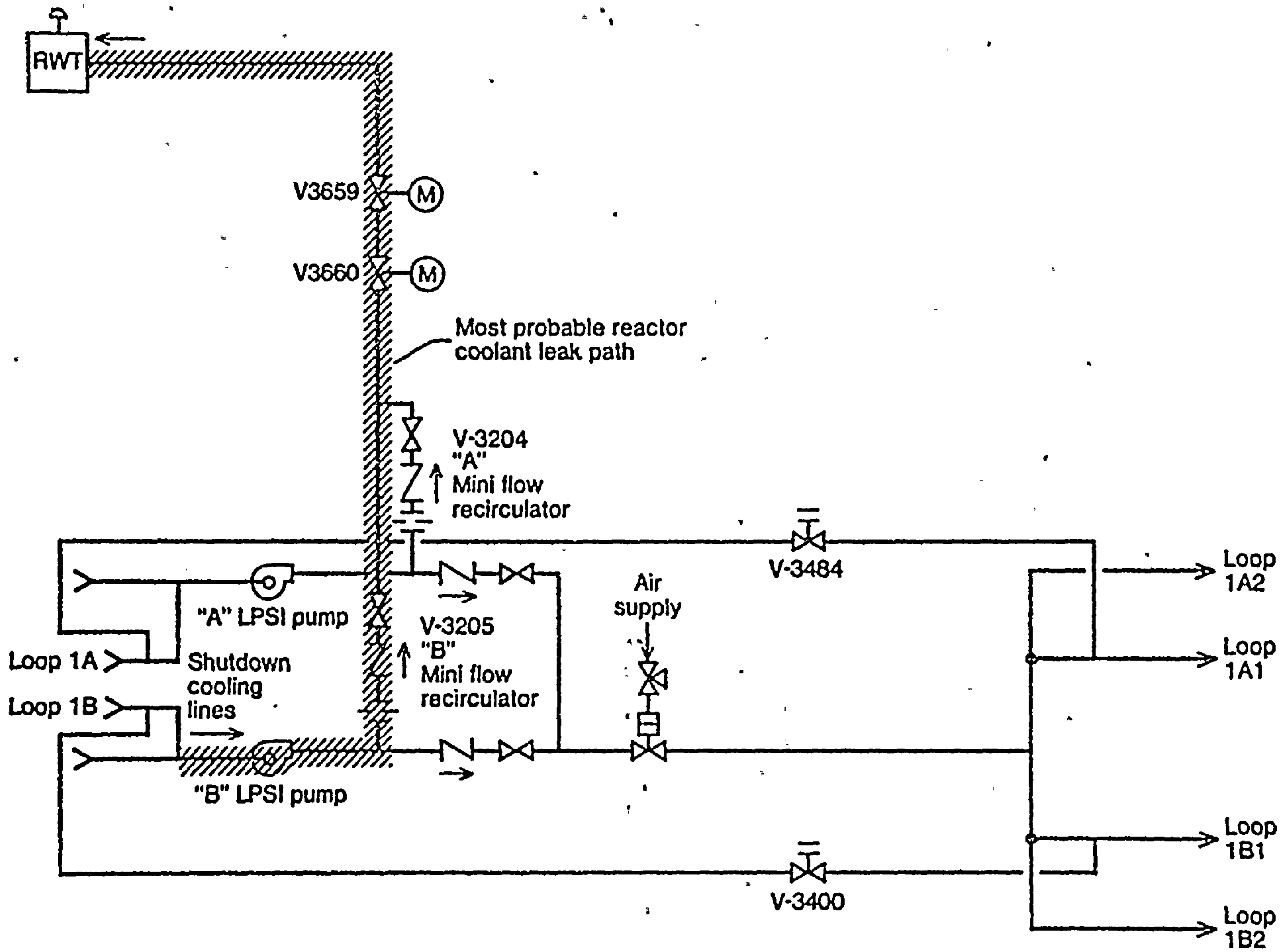
RWT
V3659
M
V3660
M
Most probable reactor coolant leak path
V-3204
"A"
Mini flow recirculator
V-3484
Loop 1A2
"A" LPSI pump
V-3205
"B"
Mini flow recirculator
Air supply
Loop 1A1
Loop 1A
Loop 1B
Shutdown cooling lines
"B" LPSI pump
Loop 1B1
V-3400
Loop 1B2

Figure RAD-1.

APPENDIX OPS

PLANT PROCEDURES AND OPERATION

APPENDIX OPS
PLANT PROCEDURES AND OPERATION

1.0 Objective

Relevant plant procedures in effect at the time of the cooldown were reviewed to ascertain if they were adequate and properly applied in placing the plant in a shutdown and cooled condition. Procedure revisions made after the cooldown were also reviewed.

2.0 Scope

The scope of this review covered the following: Emergency operating procedures, Off-normal operating procedures, sequence of events, operator logs, related drawings, and discussions with various FP&L personnel.

3.0 Discussion

FP&L had three major procedures that were applied during this transient and that will be commented on in this appendix:

1. Off-normal Operating Procedure - Reactor Coolant Pump
2. Emergency Operating Procedure - Loss of Reactor Coolant Pump Flow/Natural Circulation
3. Operating Procedure - Reactor Plant Cooldown-Hot Standby to Cold Shutdown.

Off-normal Operating Procedure - Reactor Coolant Pump

The applicable section of this procedure addresses the action to take if the alarm "Reactor Coolant Pump Low Cooling Water Flow" occurs on all Reactor Coolant Pumps at the same time. It states that if component cooling water cannot be established within 10 minutes, trip the reactor, turbine, and all four reactor coolant pumps. Also, it discusses a method for reopening the supply and return header valves to the reactor coolant pumps, if any of these have failed.

In this event, one of the return header valves (HCV-14-6) failed closed. (See Figure OPS-1). Reopening of this failed valve took approximately 1 1/2 hours. The procedure was followed which tripped the reactor, turbine and all four reactor coolant pumps. Plant responses to this event indicate that operators took actions

prescribed by the procedure, and the procedure was adequate for placing the plant into a hot standby condition.

Since the 6/28/80 cooldown, FP&L has provided quick connect fittings to these four valves and a nitrogen supply which would allow them to be reopened more quickly in the event of an electrical or pneumatic failure. Those design changes have been reflected in a revised reactor coolant pump off-normal operating procedure.

Emergency Operating Procedure - Loss of Reactor Coolant Pump Flow/Natural Circulation.

The procedure had an introductory discussion of natural circulation including various sources that can be used to determine subcooling margin. It specifies appropriate steam generator levels (65%), operation of the steam dumps, an administrative cooldown rate (max. 75° F/hr), subcooling margin (>20°F), maintenance of plant pressure, loop ΔT (< full power) and T_H and T_C response. It also references a procedure to continue plant cooldown to cold shutdown if the reactor coolant pumps cannot be restarted within a few minutes.

A step in this natural circulation procedure specifies that an I & C technician will install wide range T_{hot} for a Digital Data Processing System (DDPS) display on the control panel to allow continued monitoring of T_H. The normal indicator/recorder for T_H is narrow range and does not read below 515°F. Also, the same T_{hot} narrow range temperature transmitter inputs the subcooling meter, resulting in an invalid reading from the subcooling monitor when T_{hot} is below 515°F. Consequently, the operator must consult the steam tables when T_H is below 515°F to determine subcooling margin. Plant responses indicated that the procedure was followed and was adequate to establish and maintain natural circulation while in a hot standby condition.

Operating Procedure - Reactor Plant Cooldown Hot Standby to Cold Shutdown

This procedure provides instructions for the cooldown of the Reactor Coolant System (RCS) from a hot standby to a cold shutdown condition. These instructions include cooldown rates for the RCS (<75° F/hr.) and pressurizer (<190° F/hr.). Temperature differential limits are provided between pressurizer water phase temperature and pressurizer spray water temperature (350°F). The RCS temperature and corresponding allowable pressure relationships are determined through the use of a figure. The procedure also directs the operators in placing various safety and RCS support systems in a shutdown or standby condition. Additionally these procedures detail actions to take when sequentially stopping Reactor Coolant Pumps (RCPs). Finally, instructions are provided for placing the Low Pressure Safety Injection System (LPSI) in operation for use in the shutdown cooling mode.

In this event, cooldown was started approximately half an hour after the reactor shutdown. Cooldown using natural circulation proceeded smoothly for about an hour and a half at which time component cooling water was restored to the Reactor Coolant Pumps. The decision was made not to restart the RCPs. It was reported that three factors led to this determination:

1.) There was concern that the RCP restart could cause a seal failure

2.) A previous successful natural circulation cooldown had been accomplished in 1977.

3.) At the time the cooling water to the RCPs was restored, (approximately 1-1/2 hours after event initiation), cooldown using natural circulation was progressing smoothly.

The cooldown limits prescribed by the procedure were not exceeded in this event. However, use of the procedure produced voiding in the reactor vessel head area indicating that the procedure needed to be changed.

Component Cooling Water

The component cooling water system provides cooling to numerous components both essential and non-essential. The four reactor coolant pump lube oil and seal coolers are considered non-essential loads supplied through a common header and return line (see Figure OPS-1). The supply header and return lines penetrate containment. Therefore, the supply valves (HCV-14-1, 14-7) and return line valves (HCV-14-2, 14-6) are essential to containment isolation.

At St. Lucie 1 an electrical short from moisture removed power from the solenoid on the return line isolation valve (HCV-14-6) causing it to close. This stopped component coolant water flow through the reactor coolant pump seal coolers. At St. Lucie 1, a loss of component coolant water to the reactor coolant pump necessitates stopping the affected reactor coolant pump within 10 minutes to minimize risk of seal damage.

FP&L has provided a temporary fix to allow the four isolation valves to be re-opened quickly in the event of an electrical or pneumatic failure. This includes a nitrogen header to replace the air and quick connect fittings to allow bypassing the pilot valve. Long term modifications are being considered that will provide an additional cooling water header from the containment coolers supply as a backup to the normal supply of component cooling water to the reactor coolant pumps.

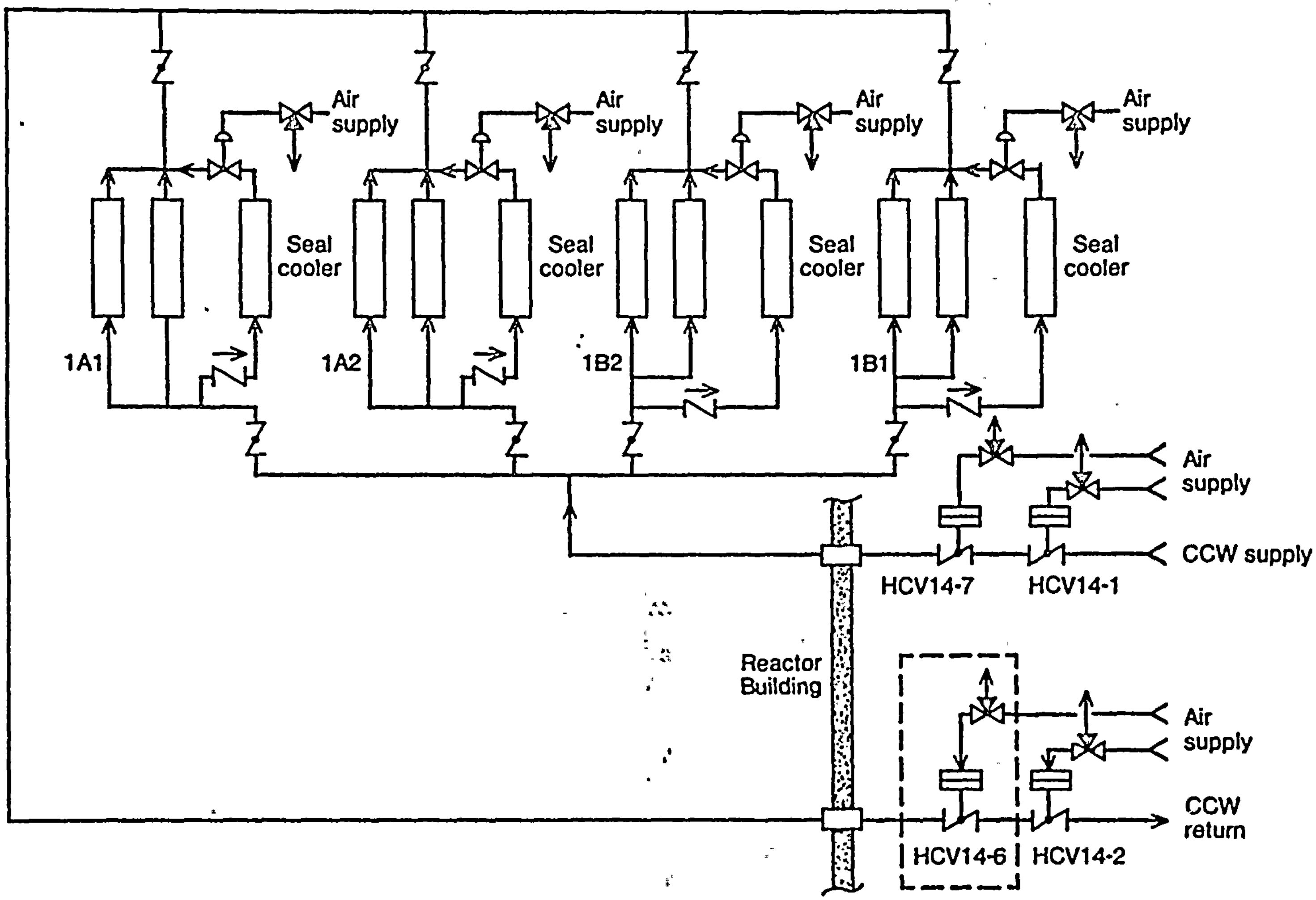
Air supply
Air supply
Air supply
Air supply
Seal cooler
Seal cooler
Seal cooler
Seal cooler
1A1
1A2
1B2
1B1
Air supply
CCW supply
HCV14-7
HCV14-1
Reactor Building
Air supply
CCW return
HCV14-6
HCV14-2

Figure OPS-1.

APPENDIX NCC

OPERATIONS DURING NATURAL CIRCULATION/COOLDOWN

APPENDIX NCC

OPERATIONS DURING NATURAL CIRCULATION/COOLDOWN

This appendix identifies conditions that may exist during natural circulation which are different from those existing during forced circulation by Reactor Coolant Pumps (RCPs). These conditions are considered in two plant evolutions:

1. Hot standby using natural circulation
2. Plant cooldown using natural circulation

This appendix could be used in the review of current procedures or the development of new procedures.

Hot Standby Using Natural Circulation

The natural circulation capability of the plant provides a means of decay heat removal when the RCPs are unavailable. Natural circulation flow rates are governed by the amount of decay heat, component elevations, primary to secondary heat transfer, loop flow resistance and voiding. The conditions discussed in this section relate to maintaining adequate primary to secondary heat transfer and the potential effects on the primary system of volumes of hot fluid which do not take part in natural circulation.

While in natural circulation, adequate heat transfer and coolant flow are dependent on adequate inventory in both the primary and secondary systems.

The number of steam generators required to support primary to secondary heat transfer and coolant flow is less than the number of steam generators provided with each plant. However, when conditions call for the use of natural circulation for extended periods, heat removal should be accomplished through the use of all available steam generators. The use of all steam generators under natural circulation conditions will provide a more even heat removal in the overall plant and eliminate additional pockets where higher temperature fluids can exist. Volumes of fluid which do not take part in natural circulation may be subject to voiding during depressurization. Furthermore, non-flowing volumes do not mix when borating for shutdown, and the later dilution must be considered.

The steam generator water level required to support heat transfer varies with each type of steam generator installed. Maintaining water level above the tubes on the secondary side of the "U" tube steam generator and high on the tubes of the once through steam generator can aid in condensing voids and continuing natural circulation in the primary system should depressurization or loss of inventory take place. Therefore, maintaining the water level above the tubes or high on the tubes should be considered. Overcooling transients are more a function of feed rate than they are of steam generator water level.The rate that steam generator secondary water level is increased should be limited to prevent exceeding the maximum cooldown rate allowed for the plant. While making level changes in low mounted, once through steam generators, the resulting RCS temperature change may momentarily interrupt the natural circulation flowrate. If the water inventory is adequate on the primary and secondary sides of the steam generators, natural circulation will resume.

Voiding in the primary system is dependent on the temperature and pressure of the coolant and the amount of coolant inventory in the system. Regions where natural circulation is not occurring (idle steam generators or reactor vessel head) can become hot spots that reach saturation conditions when system pressure is reduced during cooldown. Most plants do not measure temperature in the regions most likely to reach saturation. Increasing pressure, additions of charging water, and maintaining levels in the steam generators as previously described combine to reduce or eliminate voids which may be formed inadvertently.

Loss of subcooling and increase in ΔT would warn of an impending loss of flow. T_{hot} would provide the first indication of a loss of subcooling resulting from the rapid expansion of hot water into the flowing loops from the reactor vessel head region. Core exit thermocouples would not see this change.

Confirmation of flow while in natural circulation is accomplished through the use of temperature indications. Those indications are T_{cold} (T_c) and Loop ΔT ($T_h - T_c$). T_c should attain a value which is a few degrees higher than the saturation temperature of the secondary inventory. The loop ΔT should attain a value which is less than the full power ΔT. Examples of the values for ΔT at St. Lucie are shown in Figures T/H-1 and 2. The value for ΔT may decrease slightly with time during a subsequent cooldown as the values of decay heat and system temperatures fall (Figure T/H-1 and 2). When T_c and Loop ΔT attain the values described above, flow and heat transfer have been achieved.

T_h and T_c are two parameters which need to be indicated over the full range while in natural circulation or cooldown using natural circulation because of the inputs they provide to Loop ΔT and the subcooling monitor. Further, T_h provides the first indication of a loss of subcooling and potential voiding in the flow stream at the highest elevation in the loops.

Cool Down Using Natural Circulation

In addition to the considerations discussed under natural circulation, the following items impact plant status during cooldown more than at hot standby conditions:

1. Boration
2. Cooldown rate
3. Reactor coolant inventory control
4. Venting the reactor vessel head
5. Safety system operations
6. Condensate inventory requirements.

Boration

Low coolant flow rates and stagnant regions of coolant impair the ability to achieve equilibrium boron conditions throughout the Reactor Coolant System (RCS). The reduced flowrates experienced during natural circulation increase the time it takes to achieve boron equilibrium throughout the system. Reactivity changes which occur upon shutdown and cooldown, particularily xenon and temperature, should be anticipated in advance through early boration.

Any non-flowing regions, such as the coolant in the reactor vessel above the nozzles, should be considered in terms of the dilution which will occur when these regions eventually mix with the previously borated flowing regions. Idle steam generators as well as the reactor vessel head can contain volumes of water with boron concentrations that were used during at-power conditions.

The conditions discussed above should be considered in the coolant sampling practices used during natural circulation. Until final mixing of all regions has taken place, sampling from all flowing regions of the

reactor coolant system should give a higher than expected boron content. Sample source locations and frequency should be increased over those used during forced coolant circulation.

Cooldown rate

Under forced circulation, cooldown of the reactor coolant system is relatively even throughout. The cooldown rate is limited by consideration of the transient temperature differential across the wall of the reactor vessel. Cooldown under natural circulation causes an additional transient temperature differential in the vertical direction in the reactor vessel wall between the top of the vessel flange and the coolant nozzles. Consideration of the increased thermal stresses produced by the natural circulation cooldown may result in setting a slower rate of cooldown than allowed under forced circulation. In addition, a maximum temperature differential between the top of the vessel and the cold leg may be imposed.

Prior to forming a steam bubble under the reactor vessel head at St. Lucie, the cooldown of the head region was much slower than the rest of the reactor coolant system. Most likely at least some amount of coolant at the temperature T_{hot}, 585°F, remained under the reactor vessel head after the trip, as the continued operation of the reactor coolant pumps after trip lasted but a few minutes. At 6:15 am it appeared that the steam bubble under the head first started to form. The pressure at that time was 900 psia, corresponding to a saturation temperature of 532°F. By this method the cooldown rate of the upper head region over the first 3.7 hours after trip is estimated to have been 14°F/hr. Other assumptions on the initial temperature of the head region and the time of initial bubble formation may be made, which yield estimates of the head region cooldown rate ranging from 10 to 20°F/hr.

At St. Lucie, the system pressure should be reduced to about 200 psig before bringing the shutdown cooling loop into operation. Consequently the head region would need to be lower than 387°F to prevent forming a steam bubble. If in fact a 14°F/hr. cooldown of the head region would occur without the formation of a steam bubble, then about 14 hours of cooldown using steam generators would be required prior to initiating shutdown cooling. Should the system cooldown rate and/or the temperature differential allowed between the vessel flange and nozzles be reduced from

the St. Lucie event, then cooldown of the head region would require more time than the example above.

Reactor coolant inventory control

Should a steam bubble form in the reactor coolant system while reducing pressure, a rise in pressurizer level would result. If charging and/or letdown were to remain under automatic control, coolant inventory would be reduced as the control system attempted to correct the rising level. Consequently, manual control of charging and letdown should be used. Generally, charging should exceed letdown by an amount equal to the coolant shrinkage rate. The plant operators should keep track of inventory needs, additions, and subtractions throughout the cooldown.

Pressurizer level anomalies resulting from steam formation hinder the operators' ability to detect leakage or a loss of coolant from the system. Once system depressurization has begun, and the automatic initiation of safety injection has been blocked, pressurizer level and loss of subcooling are the primary parameters left to the operators to detect a loss of coolant. Since level anomalies can occur during the cooldown under natural circulation, it is important that subcooling relative to T_{hot} and core exit thermocouples be monitored. Should a steam bubble form under the head while spraying the pressurizer, spray should be discontinued, directing charging to the loops. Charging to the loops should be continued at least until the falling pressurizer water level stops or reverses. Only at that point can the operators use pressurizer water level as an indicator of system inventory. Falling pressurizer water level should not be reversed by spraying the pressurizer.

In order to minimize the rate of depressurization, and thereby minimize the size of potential coolant loss which could be masked by anomalous pressurizer water level change, the auxiliary spray rate used should generally be no more than the design minimum charging flow for the system. In addition, auxiliary spray should usually be heated by letdown flow in order to meet the maximum temperature differential allowed betwen the pressurizer and the spray flow (at least in systems which include a regenerative heat exchanger). Should inventory control dictate stopping the letdown flow to conserve reactor coolant system inventory, then pressurizer spray should be temporarily discontinued as well to stop the depressurization and allow the pressurizer water level to give a more reliable indication of system inventory.

Venting the reactor vessel head

Plants which have a vent installed from the reactor vessel head to the pressurizer should open the vent while reducing system pressure. The higher water level of the pressurizer will push steam generated under the reactor vessel head into the pressurizer, where it may be condensed by auxiliary spray. Cooling of the reactor vessel head region will result from the generation and drawing off of steam. By coordinating the system depressurization with the system cooldown, the vessel head region may be cooled simultaneously, speeding up the overall cooldown evolution.

Safety system operations

In cooldowns using forced circulation, safety systems are taken out of operation based on coolant temperature and pressure. In natural circulation cooldown the operator may not know the temperature of the hottest point in the system (under the reactor vessel head). Consideration should be given to taking safety systems out of operation at lower indicated temperatures than those used during normal forced circulation cooldown.

Condensate inventory requirements

The amount of condensate inventory required to support a cooldown using natural circulation can increase significantly over the amount required to support a normal cooldown. The event which led to the natural circulation condition may also render the normal heat sink and the inventory replacement system unavailable (e.g., loss of off-site power). Therefore, the use of the atmospheric steam dump system may become the only method of heat removal and will deplete available inventory. Condensate availability may limit the amount of time that a plant can maintain hot shutdown conditions before starting a natural circulation cooldown. The time that the plant remains at a hot shutdown condition before starting the cooldown using natural circulation and the longer cooldown time suggest that a review be made to ensure that existing condensate storage capacity is sufficient for natural circulation cooldown. As long as twenty hours of cooldown while dumping steam may be required to cool from hot standby to hot shutdown where the shutdown cooling system may be used.

REFERENCE LIST

REFERENCE LIST

I. OPERATING LOGS

Reference #	Title
1.	Appendix A to Operating Procedure No. 0030127 Rev. 19 -- Pressurizer Temperatures and Pressures 3:30 am - 3:00 pm.
2.	Chemistry Logs for the RCS and RWT 6/1/80 -- 6/30/80.
4.	Pressurizer/Heatup/Cooldown Curve - 6/11/80 Plotted cooldown curve for RCS and pressurizer.
5.	Shutdown Cooling Log Sheet - 6/11/80 12:00 pm - 11:00 pm.
9.	Log Sheet for Power Operation 6/11/80 VCT, Charging, letdown - 12:00 am - 11:00 am.
10.	NCCO Log Sheet #2 for Power Operation 6/11/80 Pressurizer pressure, Steam Generator Levels and Pressures - 12:00 am - 11:00 am.
11.	N.O. (Nuclear Operator) Log Sheet #4 (3 pages) Miscellaneous temperatures and pressures for various coolers and pumps - 12:00 am - 10:00 pm.
29.	N.O. (Nuclear Operator) Log Sheet #1-4&6 (5 pages) Plant support systems including CCW 12:00 am - 10:00 pm.
30.	N.O. (Nuclear Operator) Log Sheet #1-$&6 (5 pages) Plant Support Systems including CCW and RWT levels for 6/12/80 - 12:00 am - 10:00 pm.
49.	Control Room Operator's Log - 6/11/80 (2 pages).
50.	Watch Engineer's Log - 6/11/80 (2 pages).
72.	N.O. Log Sheet - 6/11/80-6/13/80 (2 pages).

II. COMPUTER PRINT-OUTS

6.	Sequence of Events 10:49 pm - 6/10/80 through 16:37 pm - 6/11/80.
16.	Digital Data Processing System (DDPS) 02:00 - 16:00, 6/11/80 - Calorimetric points, Incore detectors, Incore Thermocouples and major equipment starts and stops.

III. PLANT PROCEDURES

22.	Emergency Operating Procedure 0120040 Rev. 4 Loss of Reactor Coolant Pump Flow/Natural Circulation.

23. Emergency Operating Procedure -120040 Rev. 5 Loss of Reactor Coolant Pump Flow/Natural Circulation.

24. Off-Normal Operating Procedure 0120034 Rev. 7 Reactor Coolant Pump - Off-Normal Operation.

71. Operating Procedure - 0120021 Rev. 5 Reactor Coolant System Draining.

73. Operating Procedure - 0030127 Rev. 19 Reactor Plant Cooldown - Hot Standby to Cold Shutdown.

74. Off-Normal Operating Procedure 0120034 Rev. 6 Reactor Coolant Pump - Off-Normal Operation.

75. Off-Normal Operating Procedure 0310030 Rev. 10 Component Cooling Water - Off Normal Operation

IV. SYSTEM DESCRIPTIONS AND P&ID

System Descriptions:

34. Reactor Internal Structures #3 (Calvert Cliffs).

35. Reactor Coolant System #5 (Calvert Cliffs).

36. Chemical Volume and Control System #6 (Calvert Cliffs).

37. Safety Injection System #7 (Calvert Cliffs).

System P&ID St. Lucie:

39. Chemical and Volume Control System
Figure 9.3-3.

40. Chemical and Volume Control System
Figure 9.3-5.

41. Chemical and Volume Control System
Figure 9.3-4.

42. Reactor Coolant Pump
Figure 5.5-7.

43. Safety Injection System
Figure 6.3-1.

44. Safety Injection System
Figure 6.3-2.

45. Component Cooling Water
Figure 9.2-2.

46. Reactor Coolant System
Figure 5.1-3.

47. Containment Spray and Refueling Water System Figure 6.2-28.

65. Shutdown Cooling Flow Operational Mode Diagram Figure 9.3-6.

V. SYSTEM STRIP CHART RECORDINGS

19. Reactor Makeup Water (RMW) Flow

20. Shutdown Cooling Heat Exchanger Inlet Temperature SI Low Pressure Header Temperature.

26. Refueling Water Tank (RWT) Level

28. Activity Levels
    1.) Plant vent particulate
    2.) Plant vent gaseous
    3.) Plant vent iodine
    4.) Containment gaseous.

31. "B" Auxiliary Feedwater Flow

32. "A" Auxiliary Feedwater Flow

48. Steam Generator IA and 1B Pressure/Turbine Inlet Pressure.

51. Boric Acid Flow

52. Boron Concentration

53. Wide Range Log Nuclear Instrumentation

54. LPSI Flow

55. Loop "A" and "B" Hot Leg Temperature.

56. Tave and Tref Temperatures (RRS #2)

57. Loop "A" and "B" Cold Leg Temperature

58. Tave and Tref Temperatures (RRS #1)

59. LPSI Pump Discharge Pressure

60. Process Radiation Monitor (Gross Coolant Activity)

61. Flowrate from Reactor Cavity.

62. Pressurizer Pressure

63. Pressurizer Level

64. Steam Generator 1A and 1B Level

66. Feedwater and Steam Flow for Steam Generator 1A

67. Pressurizer Level (1977 Transient)

VI. MISCELLANEOUS REFERENCE MATERIAL

17. DDPS Calorimetric Log Instrument Point Definition Sheet.

18. DDPS Calorimetric Log Instrument Identification Log.

38. Containment Penetration Pipe I.D. Plan.

68. Recorded pressurizer level temperature compensation curves.

69. St. Lucie - Plant Transient Report.

70. Photograph - Repaired Flange.

GLOSSARY OF TERMS, ABBREVIATIONS AND ACRONYMS

GLOSSARY OF TERMS

CEA	-	Control Element Assemblies
CCW	-	Component Cooling Water
FP & L	-	Florida Power and Light
gpm	-	Gallons per minute
HCV	-	Control Valve
LPSI	-	Low Pressure Safety Injection
Microcuries/ML	-	Microcuries per milliliter
MSIV	-	Main Steam Isolation Valve
PSI	-	Pounds per square inch
RCP	-	Reactor Coolant Pump
RCS	-	Reactor Coolant System
ΔT	-	$T_H - T_C$
T_H or T_{HOT}	-	Hot Leg Temperature
T_C or T_{COLD}	-	Cold Leg Temprature