Pressurized Water Reactor
B&W Technology
Crosstraining Course Manual

Chapter 17.0

ANO-1 Seal Failure

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17.0 ANO-1 REACTOR COOLANT PUMP SEAL FAILURE

Learning Objectives:

1. Describe how control room instrumentation can be used to determine RCP seal failures.

2. Explain the different methods that can be used to initiate high pressure injection.

3. Explain why isolation of the core flood tanks is necessary during a plant cooldown.

17.1 Introduction

Arkansas Nuclear One, Unit 1 (ANO-1) is a 177 fuel assembly B&W designed plant with a core rating of 2568 Mwt. The unit is equipped with Byron Jackson reactor coolant pumps driven by 9000 hp, 6900vac, 3-phase induction motors. The design electrical output of the unit is 850 Mwe. Prior to the loss of the RCP seal, the unit was operating at 86% power with all parameters within their normal operating ranges.

17.2 Event Description

17.2.1 Seal Failure and Power Reduction

While performing an RCS inventory balance, the control room operators observed a step decrease in makeup tank level. Seal pressures and seal flows confirmed that a problem existed with the “C” RCP seal. Since the leak rate exceeded technical specification limits, an orderly shutdown of the plant was initiated. The initial rate of power reduction was 5%/minute, and the initial leak rate was between 10 and 20 gpm. During the power reduction, an increase in the leak rate was observed, and the rate of power decrease was increased to approximately 20 to 30% per minute. RCS letdown was isolated during the power reduction to minimize RCS inventory losses. Sixty-two minutes after the power reduction was started, the turbine-generator was removed from service. One minute later, the “C” RCP was stopped. Three minutes later, the reactor was manually tripped from 10% power.

17.2.2 Increased Seal Leakage and HPI Initiation

After the “C” RCP was stopped, the RCS leak rate increased to an estimated 250-300 gpm. Four actions were taken in response to the increased leakage. First, high pressure injection was manually placed in service by starting two makeup pumps, opening the four high pressure injection valves, and opening the suction valves from the borated water storage tank (BWST). Note that these actions could have been accomplished by pressing the manual initiation pushbuttons. However, all the ESF equipment associated with high pressure injection (e.g., diesel-generators, service water, LPI etc.) would also have been realigned. The second action that was taken was the operation of the RCP oil lift pumps. The lift pumps were started and stopped four times in an effort to change the radial alignment of the seal package. After the fourth lift pump start, a decrease in the RCS leak rate was observed. The next action was the isolation of the seal return path from the “C” RCP. The final action involved increasing the seal injection flow to the failed seal. This action was taken to quench the steam/water that was leaking by the seal. Reactor building pressure had increased from 14.7 psia to 15.2 psia, confirming the RCS leakage. The reactor building emergency coolers were placed in service to reduce containment pressure.

17.2.3 Plant Cooldown

After the seal leakage from the “C” RCP had been reduced, one of the operating makeup (HPI) pumps was stopped and the HPI valves were shut. Normal makeup was established from the BWST with two makeup pumps in service. The “A” RCP was stopped in preparation for a plant cooldown. A plant cooldown was initiated at a rate of 75°F/hour.

Due to the relatively high RCS cooldown rate, the operators did not reach the remote controls to bypass the steam line break instrumentation control (SLBIC) system prior to reaching the 600-psig setpoint on the “B” loop. When SLBIC actuated, the “B” MSIV closed and the steam driven emergency feedwater pump started. The “A” loop did not reach the SLBIC setpoint at this time. Steam header pressure was controlled by cycling the “B” loop MSIV. After raising the “B” loop steam pressure above 600 psig the SLBIC function was bypassed; however, the header pressure was increased to approximately 650 psig, which reset SLBIC and removed the bypass.

Consequently, “A” loop had SLBIC actuation when steam header pressure was decreased to the 600-psig setpoint. The steam header pressure was again increased and SLBIC reset. This time, SLBIC was successfully bypassed and the steam pressure was dropped below 600 psig without SLBIC actuation. About two and a half hours into the event, the emergency feedwater pump was stopped, and the auxiliary feedwater pump was placed in service.

As RCS pressure was decreased, a containment building entry was made to isolate the core flood tank (CFT) discharge valves. The entry was necessary to prevent the CFTs from discharging as the RCS pressure decreased below the 600 psig N2 pressure in the CFTs. However, some water discharged from the tanks during the time operators took to isolate the discharge valves. The RCS cooldown was essentially complete eight hours after the seal failure. Both DHR loops were placed in service, and all four RCPs were stopped. As a result of the seal failure and cooldown, approximately 60,000 gallons of water was collected in the reactor building basement.

17.3 Failure Analysis

The cartridge-type shaft seal consists of an upper, middle, and lower stage. These three stages are cooled by seal injection coolant provided by the normally operating RCS makeup pump and by the integral heat exchanger which is cooled by the component cooling water system. The stages are in series, and each stage is designed to be capable of withstanding RCS operating pressure so that a single stage failure could be detected and appropriate operator action completed in a timely manner without incident or consequential failure of the remaining two stages. On examination of the failed "C" pump seal package, however, all three stages were found to be severely damaged. The upper stage experienced the most damage. The stationary carbon ring had disintegrated; it appeared to have been ground into carbon particles and washed away. It is believed that this carbon ring breakdown was the initial failure; the loss of this ring probably resulted in the other two stages shifting upward, causing subsequent breakage of the carbon ring in each of the other two stages.

The failure of the upper stage carbon ring was postulated to have occurred from either excessive wear or fatigue due to compression. The mechanism or conditions leading to the ultimate failure of the ring are not positively known. It has been postulated that either excessive axial movement or improper seating of the seal cartridge led to wear or failure by compression.

17.4 Corrective Actions

First, all four RCP seal packages were replaced. The CFT isolation valve breakers were relocated to a motor control center outside of the reactor building. Finally, all leakage was reprocessed for use in the RCS, thus requiring no liquid releases as a result of the seal failure.

17.5 Similar Event - Oconee 2 (1/74)

A leak was discovered by an operator in the 1-1/2 inch seal injection line to reactor coolant pump 2A1 between the seal injection stop valve and the seal injection throttle valve. About three and a half hours later the seal injection flow to RCP 2A1 was secured to repair the leak. Due to boundary valve leakage, seal flow (~1.5 gpm) to RCP 2A1 continued, and the leak could not be repaired. The total seal flow control valve was closed to secure flow to all 4 RCP's and permit repair of the leak, but leakage continued.

After 9 hours, the seal injection flow was stopped completely by closing a manually operated isolation valve. The following events were recorded by the plant computer over the next 16 min. period: RCP 2B2 Seal Inlet Temp. Hi. (217.14°F), RCP 2B2 Seal Leakoff (Return) Flow Hi (1.75 gpm), Quench Tank Press. Hi, RCP 2B2 Seal Leakoff Flow 1.28 gpm, RCP 2B2 Seal Inlet Temp. 344.31°F, RCP 2B2 Off, RCP 2B2 Seal Return Closed, RCP 2B2 Seal Inlet Temp. 363.91°F, etc. RCP 2A1 Seal Inlet Temp. Hi 186.65°F, RCP Motor 2B2 LWR Air Temp. Hi 187°F, Quench Tank Level Hi 90.05 in., RCP Seal Filter DP

Hi, RCP 2A1 Leakoff 1.4 gpm, RCP Motor 2B2 Upper Air Temp. Hi 188.32°F, and Reactor Manual Trip. In addition, alarms were received from the reactor building (RB) fire monitor, RCP 2B2 oil catch tank level, RCP 2B1 oil catch tank level (overflow from 2B2), and on the loose parts monitor (RCP 2B2) prior to shutdown of RCP 2B2.

Three minutes after the manual isolation of seal flow, the operator commenced a load reduction from 22% power. The turbine was taken off the line within 12 minutes. The reactor was manually tripped from 15% full power and system cooldown was started.

Fourteen minutes after the reactor trip, an operator entered the RB to investigate the cause of the fire monitor and RCP oil catch tank level alarms. He reported steam blowing around the RCP 2B2 seals and no visual indication of fire. Fire monitor, oil catch tank level and quench tank high pressure alarms were due to this leaking steam.

Fourteen hours from the discovery of the seal leak, a unit cooldown was in progress, with the RCS pressure at ~700 psig. Depressurization of the core flood tanks was initiated by bleeding the nitrogen to the quench tank instead of to the vent header or waste gas filter, as is normally done. Venting to the waste gas filter or vent header would have required operation of 2 valves located in the RB basement, and these valves were inaccessible due to the seal leakage collecting there. In the process of venting the core flood tanks to the quench tank, the quench tank became overpressurized and its rupture disk blew out, severing the impulse line on pressurizer level instrumentation, bending the stem on the impulse line root valve, thus preventing isolation of the leak, and damaging the insulation on the bottom and side of the pressurizer.

When the RCP seal failed, it allowed primary coolant water to flow to the floor of the containment building. The leakage persisted for ~10 to 12 hours at a rate of ~90 gpm, resulting in a total leakage of ~50,000 gal. In order to reclaim the water rather than process it as waste, they allowed it to flow to the containment floor where it reached a maximum depth of ~12 inches. Equipment was to be examined for possible damage prior to plant startup.

Radioactivity in the water was 7×10^{-3} mCi/ml gross beta and 5×10^{-3} mCi/ml gross gamma. Reactor water level was maintained with one of the available makeup pumps, each of which has a capacity of 300 gpm, and no difficulty was encountered with the plant cooldown.

17.6 PRA Insights

The failure of reactor coolant pumps seals is one of the leading contributors to core melt frequencies at ANO1. According to their PRA, the contribution to core melt frequency from this initiator is 4.4 E-6/Rx-yr.

<u>RCP Seal Failure Sequence</u>

This sequence is initiated by a reactor coolant pump seal rupture or a rupture in the RCS in the break range of 0.38 inches in diameter to a break diameter of 1.2 inches, followed by failure of the high pressure injection system. Containment failure is predicted by one of the following: (a) containment overpressure due to hydrogen burning, (b) penetration leakage, or (c) base mat melt-through.

This sequence assumes a small LOCA occurs followed by a failure of the high pressure injection system (HPI). Containment systems would operate as designed to control the atmosphere, but failure of the core cooling system would lead to boil off of the water covering the core.

The dominant failure mode of the HPI is predicted to be failure of the operator to initiate the system. Information received from Babcock and Wilcox indicates an engineered safeguards HPI actuation signal due to low RCS pressure may not be generated following some LOCAs < 1.2 inches in diameter. This sequence assumes an ESFAS signal will not be generated prior to core uncovery, and the operator must initiate the system.

An important insight realized from the analysis of this sequence is that a possibility exists for failing one of the three HPI pumps, given a LOCA of 1.2 inches in diameter. During normal operation, one of the pumps is operating and takes a suction from the makeup tank to perform the function of makeup and purification. (This same pump is realigned to take suction from the BWST upon an ESFAS signal to perform ECCS functions.) Upon a small LOCA, the pressurizer level and pressure would begin to decrease, and automatic control actions will cause the makeup flow control valve to go fully open and the pressurizer heaters to turn on. Calculations indicate that the pressurizer heaters will remain covered for an extended period and thus maintain RCS pressure well above the ESFAS actuation setpoint. The calculations also indicate that the makeup tank would empty prior to uncovering the pressurizer heaters. The makeup tank is estimated to empty within approximately 14 minutes after LOCA initiation or about 10 minutes after the low makeup tank alarm. Upon dryout of the makeup tank, it is assessed that the operating HPI pump will fail in a short time.

APPENDIX - Sequence of Events

ANO-1 RCP Seal Failure - May 10, 1980

Initial Conditions

The unit was operating at 86% with all parameters in their normal range.
An inventory balance of the RCS was in progress.

Time	Event
0145 (0)	The reactor operator observes a step decrease in makeup tank level. RCP “C” Seal Failure diagnosed. RCS Leakage ~10-20 gpm. Power reduction at 5%/min. initiated.
0214 (+29 min)	Unit loads transferred to offsite power.
0220 (+35 min)	Letdown isolated.
0225 (+40 min)	Extra operations staff called in to aid in placing the unit Cold Shutdown
0227 (+42 min)	NRC Emergency Response Center and resident inspector notified. Increase in leak rate observed. Increased reduction rate to 20%-30%/min.
0247 (+62 min)	Generator off line.
0248 (+63 min)	RCP “C” stopped. RCS leakage increases to ~250-300 gpm.
0250 (+65 min)	Reactor manually tripped from 10% power. Manually started 2 additional makeup pumps. Opened all HPI MOVs. Cycled “C” RCP lift pumps four times. After 4th start of lift pumps, RCS leakage decreases. Started RCS cooldown
0254 (+69 min)	Isolated RCP “C” seal return. Increased seal injection flow to quench steam from failed seal. RB pressure increases from atmospheric pressure to 15.2 psia.
0256 (+71 min)	Placed RB emergency coolers in service.
0301 (+76 min)	Stopped RCP “A”.

APPENDIX - Sequence of Events (continued)

Time	Event
0305 (+80 min)	Stopped “C” makeup pump, closed all HPI MOVs, established normal makeup with 2 makeup pumps with suction supply from BWST.
	“B” OTSG Steamline Break Isolation and Control (SLBIC) actuation at 600 psig due to high RCS cooldown.
	Steam driven EFW pump starts. Raised header pressure to >600 psig. Bypass SLBIC. Steam pressure>650 psig, SLBIC automatically resets. SLBIC actuated on low pressure (<600 psig) Raised header pressure to >600 psig. SLBIC successfully bypassed.
0320 (+95 min)	Steam driven EFW pump stopped. Aux. Feedwater pump placed in service.
0800 (+375 min)	Containment entry to power up and close CFT outlet valves. CFTs inject some water prior to isolation.
0900 (+435 min)	Unit in cold shutdown

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