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PRESSURE BOUNDARY DEGRADATION DUE TO PUMP SEAL FAILURE AT ARKANSAS NUCLEAR ONE

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ABSTRACT

Arkansas Nuclear One, Unit 1 (ANO-1) was operating at 86% of full power on May 10, 1980, when a reactor coolant pump shaft seal failed. The reactor coolant pressure boundary was breached and approximately 227,000 liters (60,000 gallons) of coolant was leaked to the containment. The leak rate varied from 0.32 to 19 liters/second (5-300 gallons/minute). The reactor was rapidly shut down in an orderly manner and no abnormal offsite radiological releases resulted.

The ANO-1 event was significant because it revealed that the failure of one seal stage can lead to a total loss of seal integrity. The leakage rate from the failed seal was larger than previously predicted, although well within the installed system capabilities for reactor coolant inventory recovery. A subsequent analysis of various seal failure events has led to the preliminary determination that because of the frequency of seal failures in operating reactors, the probability of small break loss-of-coolant events is larger than previous estimations.

1.0 DESCRIPTION OF THE EVENT

Arkansas Nuclear One, Unit 1 (ANO-1) is a pressurized water reactor located in Russellville, Arkansas. The nuclear steam supply system was designed by the Babcock and Wilcox Company and licensed by the Nuclear Regulatory Commission to operate at a power level of 2565 MWt (850 MWe). The reactor coolant system (RCS) employs two recirculation coolant loops. Each loop utilizes a single line (hot leg) to direct flow to a once-through steam generator and two lines (cold legs) with a reactor coolant pump (RCP) in each line to return coolant to the reactor pressure vessel. The RCP was manufactured by Byron Jackson Pump Division, Borg-Warner Corporation. Prior to the event on May 10, 1980, the unit was operating at approximately 86% of full power without any major operational activities in progress.

The first indication that an RCS pressure boundary degradation and inventory loss occurred was when the operators observed a rapid decrease (a step change) in the RCS makeup tank level. The reactor coolant pump (RCP) seal instrumentation confirmed that a problem existed with the shaft seal or associated cooling water piping. Since the leak rate exceeded the plant technical specifications, a power reduction was initiated in preparation for reactor shutdown. The initial rate of power reduction was 5% per minute, and increased to 20 to 30% per minute, in response to the leak rate increasing from 0.32 to 1.3 liters/second (5-20 gallons/minute).Subsequently, the RCP was stopped; the leak rate then immediately increased to an estimated 16 to 19 liters/second (250-300 gallons/minute). The operators started and stopped the RCP bearing lift pumps four times in succession and the leak rate decreased. The reactor was manually tripped from approximately 10% power. The safety injection system was manually actuated (before any automatic initiation setpoint was reached) during the event to restore pressurizer level. After the trip, containment pressure increased from 101 to 105 kilopascal (14.7 to 15.2 psig). Approximately 227,000 liters (60,000 gallons) of water accumulated inside containment during the event.[1/] More than 28°C (50°F) subcooling was maintained during the event.

During the controlled system depressurization, the operators decided to avoid discharging the core flood tanks to the RCS. But the RCS pressure decreased to below 4.2 megapascal (600 psig) and some water from the core flood tanks entered the RCS before containment entry could be made to isolate the tanks. No nitrogen cover gas entered the RCS, however, from the core flood tanks. At this plant, the electrical breakers for the isolation valves between the core flood tanks and the RCS are located inside primary containment and were not operable from outside containment at the time of the event.

Approximately seven hours after initiation of the event, the cooldown was completed with the residual heat removal system in service and all four reactor coolant pumps secured.

Examination of the RCP seal revealed that it had experienced catastrophic destruction which resulted in an unexpected high leak rate. It is believed that the upper (third) stage assembly failed first and that damage to the other stages was a direct result of a stationary carbon ring failure in the upper stage. The cause of the failure could not be positively determined. The postulated causes are: one, excessive wear of the carbon ring may have caused it to break apart; or two, possible excessive axial movement or improper seating of the seal cartridge, caused the carbon ring to fail in compression. Either cause of failure can result in the loss of seal axial integrity and a loss-of-coolant accident (LOCA).

2.0 EVALUATION OF THE OCCURRENCE

2.1 Reactor Coolant System Response

The operators received early indication of RCP seal problems because operation personnel were obtaining RCS leak rate data at the time of the event and observed a step decrease in the makeup tank level. Further investigation revealed that RCP seal cavity pressure, temperature and flow were indicating abnormal conditions. The operators implemented the procedures for a small break loss-of-coolant event and initiated a power reduction to achieve cold shutdown. The reactor coolant system cooldown rate was accelerated to 41.7C(75°F)/hour. The technical specification limit is 55.6°C(100°F)/hour.

The main turbine-generator was taken off line approximately 62 minutes after power reduction was initiated and the affected RCP was tripped one minute later. The leak rate increased immediately to 16-19 liters/second (250-300 gallons/minute) at this time, which exceeded the flow rate of the makeup pump. After the RCP bearing lift pumps were started and stopped four times by the operators, the leak rate decreased. The safety injection system was manually initiated in response to the decreasing RCS level and pressure due to the leak and reactor coolant shrinkage (volume decrease) from cooldown following the reactor trip. Normal reactor coolant drainage flow (letdown) and RCP seal coolant return flow were isolated by the operators. The increasing primary containment building pressure and radiation levels confirmed that the leak was located in the containment area.

The RCS responded as expected and all safety systems performed satisfactorily. However, the inability to isolate the core flood tanks from outside primary containment was identified as a design deficiency although it had no adverse effect during this event. As a result of the fast cooldown rate and depressurization, some inventory from the tanks entered the RCS before containment entry and breaker closure could be achieved. Failure to isolate the core flood tanks during an RCS depressurization below 4.2 megapascal (600 psig) could become a problem if nitrogen was introduced into the RCS after the tanks empty. The licensee has subsequently relocated the core flood tank isolation valve breakers outside of containment.

2.2 Analysis of RCP Seal Failure

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 such 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 this failed seal, 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. The licensee has postulated that either excessive axial movement or improper seating of the seal cartridge lead to wear or failure by compression. In general, RCP rotor vibration is a common cause of RCP seal failures. Prior to the event, however, there were no indications of unusual vibration or pending seal degradation.

3.0 SAFETY SIGNIFICANCE OF RCP SEAL FAILURE*

The reactor coolant pump seal provides for discrete pressure and temperature decreases from the high reactor coolant pressure and temperature conditions to near atmospheric conditions by means of controlled flow or leakage of coolant through the seal cartridge. The principal safety issue is that the catastrophic failure of an RCP seal results in a loss of primary reactor pressure-boundary integrity, which leads to a small loss-of-coolant event and a challenge to the safety systems. Other areas of concern are the equivalent break size and the frequency of RCP seal leaks compared to previously estimated small break loss-of-coolant probabilities.

Since an equivalent break size for the event was not accurately known, the method for relating the consequences of the seal failure to previous LOCA analyses was through a comparison of leakage rates. For example, in the Reactor Safety Study,[2/] the "s ll-small" LOCA (S_2) is defined as an RCS rupture between 1.3 and 5.1 centimeters (0.5 to 2 inches) equivalent diameter. This break size opening corresponds to a leak rate of 3 to 50 liter/second (50-800 gallons/minute). Therefore, the ANO-1 event is considered similar to the "small-small" LOCA category of the Reactor Safety Study since the average leak rate was not exceeded.

A review of RCP shaft seal failure events reported to the NRC was conducted to assess their frequency for comparison with the prob-bility estimated in the Reactor Safety Study. The operational data on RCP seal leakage events

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*Basis for reporting to the NEA Incident Reporting System (IRS) as a significant event.

for all RCP types were used in determining the event frequency and in estimating the probability of small loss-of-coolant events.[3/] The NRC study covered over 200 seal leakage events reported since 1967. An initial conclusion of the study indicated that the probability of small break LOCAs from RCP seal failures appears to be an order of magnitude higher than the "small-small" LOCA probability obtained in the Reactor Safety Study.

The RCP shaft seal configuration was designed by Byron Jackson to limit leakage in the event of a seal failure. However, the ANO-1 event seems to have exhibited leakage rates greater than usually observed or anticipated after seal failure occurs. The simultaneous failure of all three stages was similarly an unexpected occurrence. This raises a safety question relative to whether the design can reasonably be expected to limit the leak rate to a predetermined value. Important factors affecting seal integrity such as normal wear, the number of RCP starts and stops, seal cooling, and operation with some seal degradation have not been quantified to assess their impact on the design basis of the seal. Studies are in progress to assess the operational history of RCP seals and other factors in order to improve reliability of RCP seals.

REFERENCES

1. Licensee Event Report 80-015/01X-2, Arkansas Power and Light Company, Docket 50-313, April 13, 1981.

2. U.S. Nuclear Regulatory Commission, "Reactor Safety Study - An Assessment of Accident Risks in U.S. Commercial Nuclear Power Plants," WASH-1400 (NUREG-75-014), October 1975.

3. Memorandum, T. E. Murley, NRC to D. G. Eisenhut, NRC, Subject: Reactor Coolant Pump Seal Failure, dated March 27, 1981.