SmartSignal
Predict the unpredictable

Early Warning of Reactor Coolant Pump Seal Degradation

APS PALO VERDE NUCLEAR GENERATING STATION USES SMARTSIGNAL *e*CM TO DETECT REACTOR COOLANT PUMP SEAL DEGRADATION MONTHS EARLIER THAN CONVENTIONAL TECHNIQUES

Arizona Public Service Company's Palo Verde Nuclear Generating Station uses SmartSignal Equipment Condition Monitoring™ (*e*CM) to help engineers monitor key components at the three Palo Verde electrical generating units. SmartSignal *e*CM provides Palo Verde engineers earlier warning of abnormal operating conditions than traditional monitoring techniques should an unlikely degradation in equipment performance begin. For example, traditional monitoring techniques require a 10 to 15 PSI shift in pump seal staging pressure to confirm the onset of seal degradation. SmartSignal empirical modeling techniques correctly identified a 5 PSI shift in the 1st stage seal staging pressure as an indication of the onset of seal degradation. This was nearly two months earlier than the traditional monitoring technique used for these seals.

Background and Description of System

The reactor coolant pumps — key components of the Combustion Engineering Pressurized Water Reactors used at Palo Verde — transfer high-pressure water from the reactor to the steam generators. At Palo Verde, the high flow, low head 8780 horsepower vertically oriented reactor coolant pumps utilize 30-inch suction and 30-inch discharge pipes to pump 114,625 gallons per minute.

Figure 1 shows the layout of the seal system on a typical Palo Verde reactor coolant pump. Located within the containment building, the pumps ensure safe and efficient operation of the nuclear power plant. Palo Verde's designers included many redundant systems to ensure continued safety should unexpected equipment degradation occur. For example, each reactor has four reactor coolant pumps to ensure adequate heat removal from the reactor. Furthermore, each reactor coolant pump uses a three-stage seal mechanism to contain water inside the reactor coolant system. Although the reactor coolant pumps do not produce high head, they operate at a suction pressure of approximately 2,500 PSI. Therefore the reactor coolant pump seals have a strenuous and important job.

Why Early Warning of Seal Degradation is Valuable

Since the reactor coolant pumps operate within the containment building, physical access to the pumps occurs only during refueling outages. Engineers depend on process variables transmitted to the control room and through the station's data historian to assess the pumps' condition during normal operation.

Pump and seal maintenance occurs only during refueling outages carefully planned months in advance. The sooner that maintenance work is scheduled, the more efficient are the planning, procurement, and logistics. The costly reactor coolant pump seals require a lengthy procurement process. Early warning of seal degradation allows more time to plan the replacement. If significant seal degradation occurs without warning and requires an unplanned outage, replacement costs increase ten fold or more.

Furthermore, accurate assessment of the pump condition also helps determine whether maintenance deferral is possible. For example, if the reactor coolant pump seals show no signs of degradation, Palo Verde could use the increased monitoring capability provided by SmartSignal to extend the replacement interval.

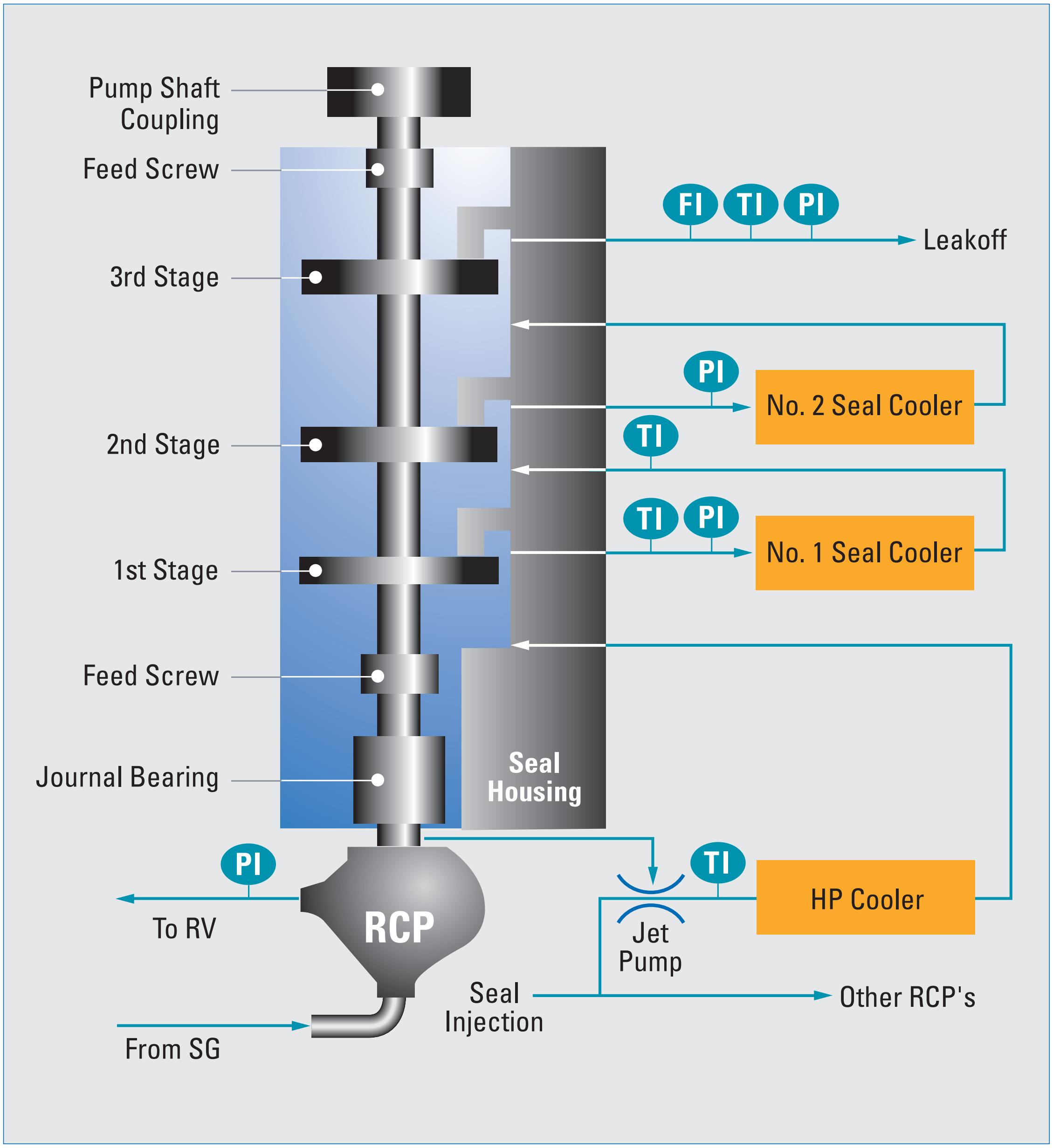

Figure 1 — Reactor Coolant Pump Shaft Seal Assembly. Seal cooling water leaves the high pressure cooler, enters the first stage seal housing, passes through seal cooler 1, enters the second stage seal housing, passes through seal cooler 2, then exits as controlled bleed-off flow. Note the positions of pressure, temperature and flow indicators.

How SmartSignal *e*CM Detects Reactor Coolant Pump Seal Degradation

The SmartSignal *e*CM software uses actual process variable measurements to construct empirical models of key equipment at Palo Verde. During the modeling process, engineers evaluate equipment functions and identify key failure modes. Using this information, empirical models are created from historical data to capture normal operational behavior. In real-time operation, the model uses actual measurements to generate estimates of expected values for normal operation. Residual signals are generated which is the difference between the actual and the estimated values. Statistically significant residual values imply abnormal deviations that can be linked to the associated failure modes.

The first column of Table 1 lists the eleven key process variable measurements for a typical reactor coolant pump seal that were identified during the modeling process. The independent variables — reactor coolant pump discharge pressure and seal water inlet temperature — describe the range of possible states for the reactor cooling pump seal stages. The SmartSignal *e*CM seal model accounts for normal variance in pump discharge pressure and seal water temperature to highlight the onset of seal mechanical degradation.

Table 1 maps one of the expected failure modes for the seals onto the eleven process variables. The table indicates a fault signature as process variables deviate from expected value in the high (+) or low (-) direction depending on fault type. For example, first stage seal degradation is indicated by a positive residual in Controlled Bleed-off Flow, Pressure and Temperature in addition to positive residuals in Seal Cooler 2 Inlet Pressure and Temperature.

SmartSignal engineers installed the reactor coolant pump seal models on Palo Verde computer systems to monitor all 12 reactor coolant pumps. The models accurately estimated the values for the process variables. However, in two out of twelve pumps, the seal models showed signs of statistically significant residual values indicating the onset of 1st stage seal degradation. In the first case, on Pump 1B in Unit 3, plant engineers had previously identified the onset of 1st stage seal degradation using traditional monitoring techniques. In the second case, on Pump 1B in Unit 2, the onset of a similar seal degradation is discussed. In this case, the model provided engineers with an earlier indication than the traditional monitoring techniques had allowed.

Tag Name	Tag Description	Seal Degradation First Stage
RCF166	Controlled Bleed-off Flow	+
RCP163	Controlled Bleed-off Pressure	+
RCT128P	Controlled Bleed-off Temperature	+
RCP161	Seal Cooler 1 Inlet Pressure	
RCT167	Seal Cooler 1 Inlet Temperature	
RCP162	Seal Cooler 2 Inlet Pressure	+
RCT191	Seal Cooler 2 Inlet Temperature	+
RCP190A	RCP Discharge Pressure	
RCT160	HP Cooler Inlet Temperature	
RCT161	HP Cooler Outlet Temperature	
RCT166P	RCP Upper Thrust Bearing Temperature	

Table 1 — List of Process Variables and Fingerprint Chart for the RCP Seal Model. Tag names, description, list of fault type, and deviation signature. The first column lists the process variables and the first row shows fault type. The table indicates a fault signature as process variables deviate from expected value in the high (+) direction depending on fault type.

Case 1: Unit 3 Pump 1B

SmartSignal *e*CM detected the onset of degradation for Unit 3 reactor coolant pump 1B, first stage seal. The Palo Verde engineers had detected this condition before the *e*CM software was installed, and had planned a replacement during the upcoming refueling outage. Since the reactor coolant pump seal package has three seal stages, some degradation of one stage does not compromise the integrity of the overall seal package. The agreement between the *e*CM model results and the plant engineering analysis confirms the model's seal degradation detection capability.

Figure 2 (Chart A) shows how the seal pressure (RCP162, Seal Cooler 2 Inlet Pressure) increased over the course of three months. Figure 2 (Chart A) shows the actual value (blue) plotted with the estimated value (green). Figure 2 (Chart D) shows the residual value for the same seal pressure (RCP162). The residual signal increases because the difference between the actual signal and the *e*CM estimate increases. The Seal Cooler 2 Inlet Pressure residual of 100 PSI clearly indicates a change in 1st stage seal staging pressure from the expected value. The remaining charts in Figure 2 display the two key independent variables — Reactor Coolant Pump Discharge Pressure (RCP190A in Figure 2 Chart B and Chart E) and the High Pressure Cooler Outlet Temperature (RCT161 in Chart C and Chart F) over the same time period.

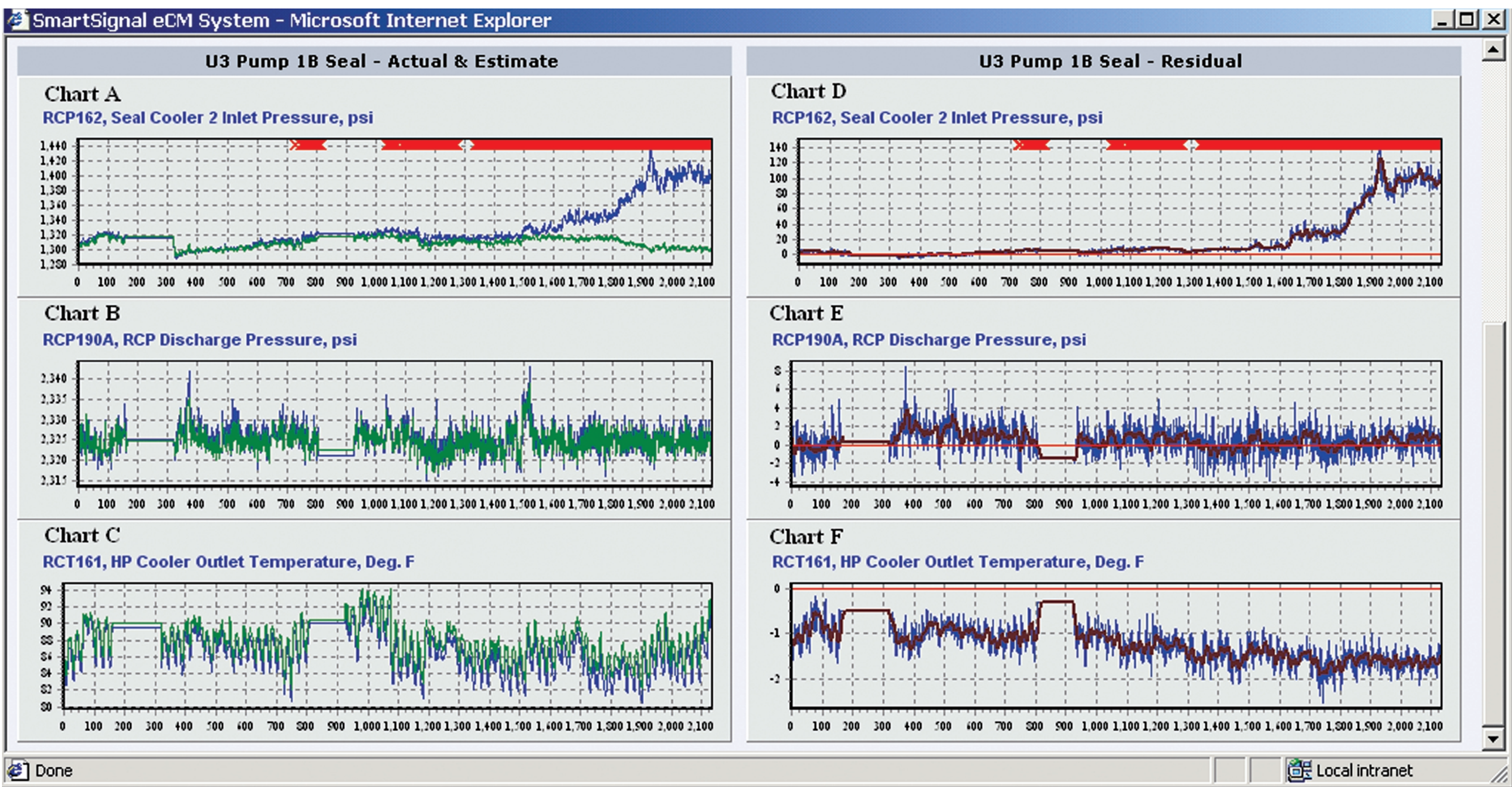

Figure 2 — SmartSignal *e*CM results for key Unit 3 Pump 1B variables for the period 10/5/02 to 1/05/03.

Chart A: RCP162, Seal Cooler 2 Inlet Pressure, in PSIG.
Chart B: RCP190A, RCP Discharge Pressure, PSI.
Chart C: RCT161 HP Cooler Outlet Temperature, Deg F.
Key: Actual (blue), Estimate (green), Alerts (red X).

Chart D: RCP162, Seal Cooler 2 Inlet Pressure, PSIG.
Chart E: RCP190A, RCP Discharge Pressure, PSI.
Chart F: RCT161 HP Cooler Outlet Temperature, Deg F.
Key: Residual (blue), Smoothed Residual (brown), Alerts (red X).

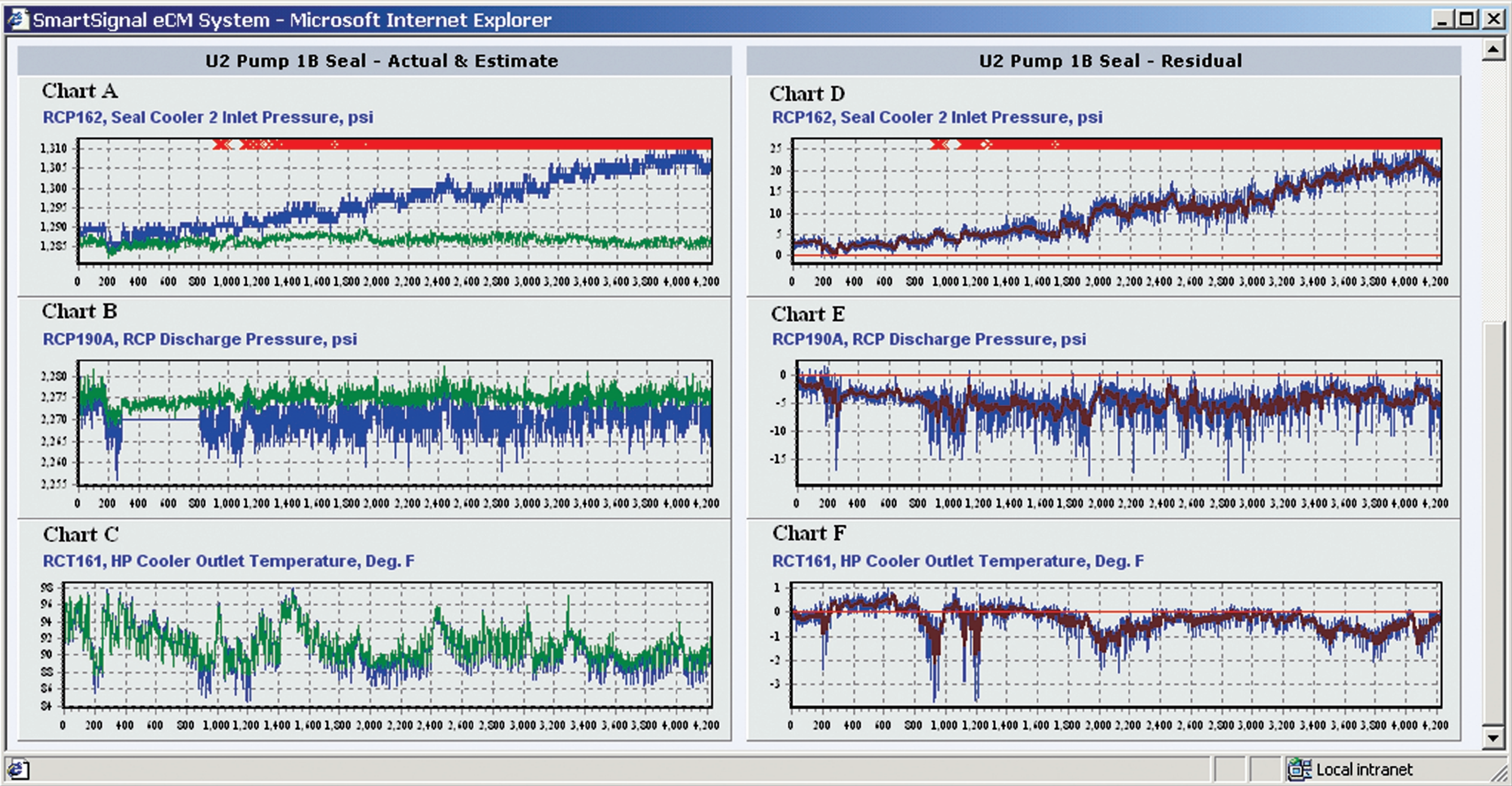

Figure 3 — SmartSignal *e*CM results for key Unit 2 Pump 1B variables for the period 9/25/02 to 3/25/03.

Chart A: RCP162, Seal Cooler 2 Inlet Pressure, in PSIG.
Chart B: RCP190A, RCP Discharge Pressure, PSI.
Chart C: RCT161 HP Cooler Outlet Temperature, Deg F.
Key: Actual (blue), Estimate (green), Alerts (red X).

Chart D: RCP162, Seal Cooler 2 Inlet Pressure, PSIG.
Chart E: RCP190A, RCP Discharge Pressure, PSI.
Chart F: RCT161 HP Cooler Outlet Temperature, Deg F.
Key: Residual (blue), Smoothed Residual (brown), Alerts (red X).

Case 2: Unit 2 Pump 1B

The SmartSignal *e*CM models also detected early signs of 1st stage seal degradation for Unit 2 pump 1B. The plant engineers had not seen the change in staging pressure prior to *e*CM implementation because the seal outlet pressure appeared to be within the normal variance of the system using the traditional monitoring techniques. Alerts in Figure 3 Chart A and Chart D show SmartSignal *e*CM early warning of the change in 1st stage staging pressure. Seal cooler 2 inlet pressure (RCP162, Seal Cooler 2 Inlet Pressure) exceeded the estimated pressure by only 5 PSI and was alerted by the *e*CM RCP models. The figures also show how the change advanced over a six-month period. SmartSignal *e*CM allowed engineers from SmartSignal and Palo Verde to carefully monitor this change.

Approximately two months after the *e*CM system first indicated the change in 1st stage seal staging pressure, the traditional monitoring technique also indicated the onset of pump 1B seal degradation as seal cooler 2 inlet pressure increased to the 10–15 PSI range. This confirms that SmartSignal *e*CM provided early warning of the onset of reactor coolant pump 1st stage seal degradation. The plant personnel feel confident that SmartSignal *e*CM detects early signs of seal degradation when the seal pressure deviates from the expected value by 5 PSI rather than 10–15 PSI, providing as much as two months earlier indication. This early warning could allow the plant to avoid additional expenditures associated with expedited emergency repairs.

Conclusion

The SmartSignal *e*CM technology is a powerful tool for monitoring the condition of reactor coolant pump seals. Experience at Palo Verde shows that SmartSignal *e*CM detects statistically significant deviations in pump seal staging pressure in the 5 PSI range that indicate the onset of seal degradation, where traditional techniques require at 10–15 PSI deviations. The high sensitivity of this technology provides as much as two months early warning compared to traditional methods. Early warning improves scheduling, reduces maintenance expenditures, and delivers exceptional value to nuclear power plants.

About SmartSignal

SmartSignal is a privately held technology company based in Lisle, IL. SmartSignal has thirty-six patents issued or owned and broad foreign coverage. SmartSignal has won the *Business Ledger's* "Annual Award for Business Excellence," *Control Engineering* Magazine's "Editor's Choice" new product award and a *Best of Sensors Expo* new product "Gold Award." More information about SmartSignal is available at www.smartsignal.com.

For more information on SmartSignal and our patented *e*CM technology, contact Brad True, General Manager — Power, Energy and Process at 630-829-4023, email us at info@smartsignal.com or visit our web site at www.smartsignal.com.

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