Union of Concerned Scientists
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issue brief

HEADACHES AT PALISADES: BROKEN SEALS & FAILED HEALS

Like 68 other nuclear power reactors operating in the United States, the Palisades nuclear plant near South Haven, Michigan has a pressurized water reactor (PWR). Like thirteen other PWRs operating in the US, the reactor at Palisades was designed by the Combustion Engineering Company (CE). Like one other CE PWR operating in the US, the Palisades reactor has seals of a certain design installed around the metal shafts connecting the control rods inside the reactor core with their electrical motors located above the reactor vessel head. Unlike any PWR operating in the US, Palisades has experienced seal failures and failed fixes for decades. It appears the owner doesn't know how to fix this recurring problem, and that the Nuclear Regulatory Commission (NRC) has not been doing its job to ensure that the owner understands the cause of a recurring problem.

WHAT DO THE SEALS DO? OR RATHER, WHAT ARE THEY SUPPOSED TO DO?

Nuclear fuel assemblies within the reactor core produce the energy used to generate electricity. The core resides inside a large metal pot called a reactor vessel (see Figure 1). A lid, also called the reactor pressure vessel head, is bolted onto the reactor vessel during plant operation and removed during refueling to allow spent fuel assemblies to be replaced with fresh fuel assemblies. Each fuel assembly consists of vertical cylinders filled with uranium pellets. The Palisades reactor has 45 control rods, called control elements in the CE PWR design, interspersed among the fuel assemblies in the reactor core. Withdrawing the control rods increases the reactor's power level, while inserting control rods reduces the reactor's output. Figure 1 shows a control rod on the left that is fully withdrawn from the reactor core into a plenum region above the core, and a control rod on the right that is fully inserted. Control rods may also be partially withdrawn. Long metal shafts connect the control rods to electric motors located on top of the reactor pressure vessel head. The electric motors are used to withdraw or insert control rods. Because the pressure of the water inside the reactor vessel is high – over 2,000 pounds per square inch during operation – seals are installed around the metal shafts to prevent, or at least limit, water leaking from the reactor vessel.

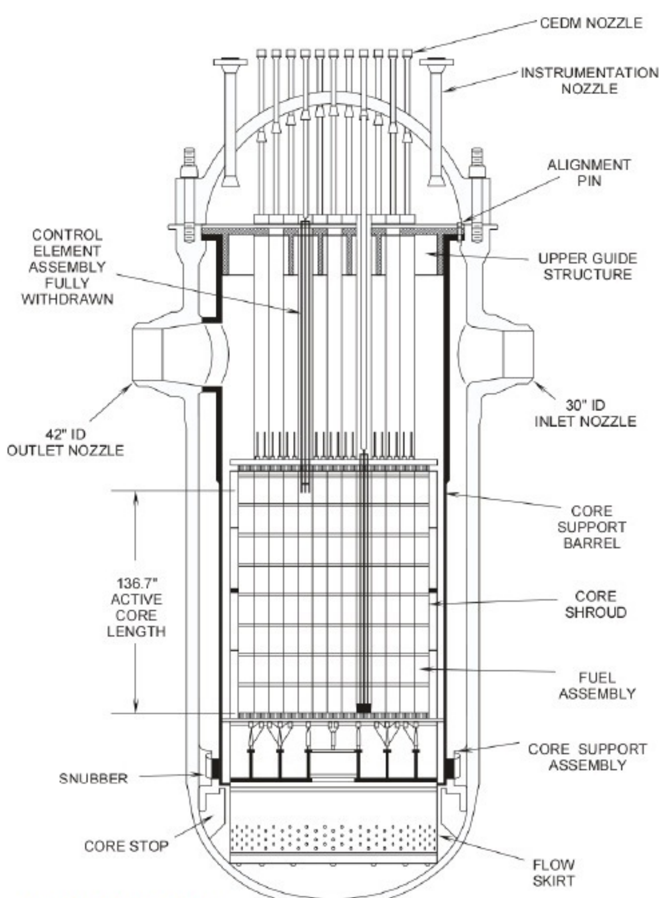

Figure 1 - Reactor Vessel
Source: Nuclear Regulatory Commission

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Figure 2 illustrates the seal design used at Palisades. The vertical blue piece in the center represents the metal shaft connecting an electric motor to a control rod. This shaft rotates when the electric motor operates to re-position the control rod, but this portion of the shaft does not move up or down. The bottom of this shaft is connected to another vertical metal shaft via beveled gears. As the blue shaft rotates, the gearing causes the parallel shaft to raise or lower to re-position the control rod. The red pieces toward the bottom are a cutaway view of what is a doughnut-shaped rotating seal that fits between the shaft and the outer metal tube (sometimes called the nozzle). Above this seal is a stationary seal, also doughnut-shaped and shown in orange. Below the seals, the nozzle is filled with

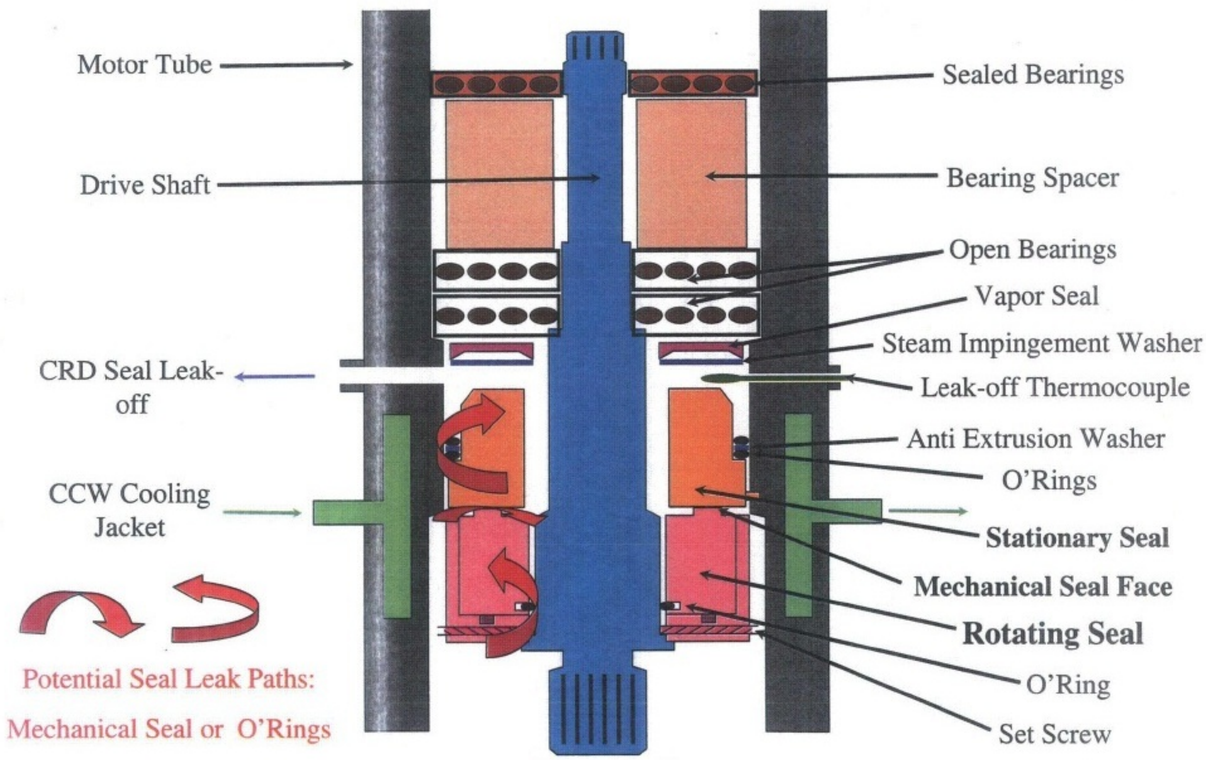


Figure 2: Control Rod Drive Seal
Source: Entergy (March 31, 2010, letter to NRC)

water at reactor pressure. The cushiony nature of the seals allows them to better fill the space between the shaft and the tube. However, the seal hardens and becomes less effective when heated above 250°F. Because the water is at a higher temperature (over 500°F), the region near the seals is supplied with cooling water from the component cooling water (CCW) system, shown in green in the figure. The seals prevent, or at least limit, water from leaking out of the reactor vessel. If water leaks past the seals, it is detected by a "leak-off" thermocouple (or thermometer) shown on the right side. The leaking water is routed to the containment sump via the control rod drive (CRD) seal leak-off line shown on the left side.

The operating license, or technical specifications, for Palisades permits water leakage of up to 10 gallons per minute (gpm) from all the seals combined. If the leak rate exceeds this limit, it must be reduced to below 10 gpm within 4 hours. The operator can move control rods with high seal temperatures to attempt to re-seat the seals and reduce the leak rates. If such efforts fail to reduce the leak rate below 10 gpm, the reactor must be shut down within the next 6 hours. Palisades has been there and done that many times.

The seals perform important safety functions. First and foremost, the seals protect against reactor core damage caused by overheating should too much cooling water escape from the reactor vessel. In addition, the seals protect the motors and associated components for the control rods from damage caused by moisture. (The electric motor is not shown in Figure 2, but is attached at the top of the blue drive shafts.) A motor failure could cause the control rods – the brakes for the nuclear chain reaction – to be impaired. These safety functions are the reason there is a tight limit on the overall leak rate from the seals and a requirement to promptly shut down the reactor when this limit is exceeded.

ABRIDGED HISTORY OF BROKEN SEALS

The Atomic Energy Commission (AEC), NRC's forerunner, issued an operating license for Palisades on February 21, 1971. The control rod seal problems began shortly afterwards:

Date	Event
10/23/1972	The operators shut down the reactor to repair a leaking control rod drive mechanism seal.
10/17/1974	The operators shut down the reactor to repair a leaking control rod drive mechanism seal and a fitting leak on a seal leak-off line.
06/20/1975	The operators shut down the reactor to repair a leaking control rod drive mechanism seal.
08/12/1975	" "
08/17/1975	" "
05/12/1976	" "
11/12/1976	" "
05/05/1977	" "
05/01/1978	" "
06/28/1978	" "
07/31/1978	" "
08/28/1978	" "
09/13/1978	" "
09/22/1978	" "
10/02/1978	" "
10/10/1978	" "
11/29/1978	" "

After a rough first decade, Palisades had two relatively trouble-free decades with respect to control rod seal problems. Then the problems returned:

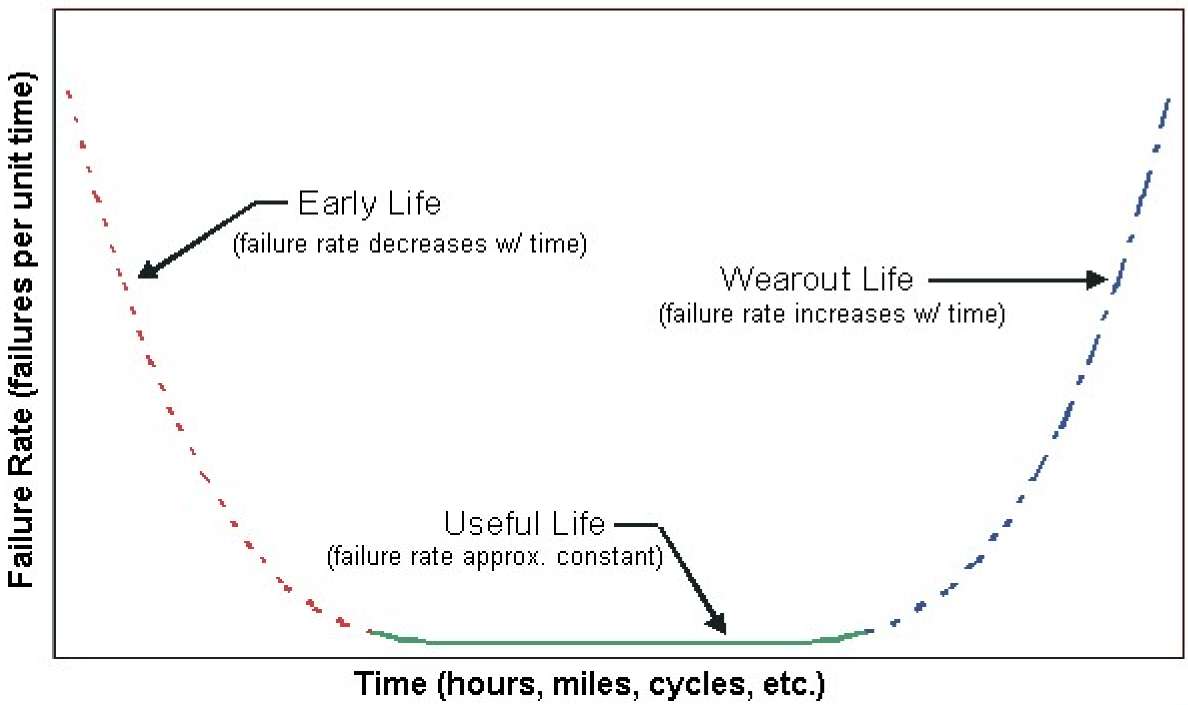
Date	Event
02/16/2000	The operators aborted an attempted startup and shut down the reactor due to excessive leakage from control rod drive mechanism seals. Workers rebuilt eight control rod drive mechanisms.
06/21/2001	Workers discovered leakage through the metal wall from one control rod drive mechanism.
08/10/2004	The operators shut down the reactor to repair leaking control rod drive mechanism seals.
12/31/2005	" "
02/17/2009	" "
06/24/2010	" "

For many types of products, it is common for early problems to be followed by a period of trouble-free operation and then a re-emergence of problems later in its operational lifetime. This experience is illustrated by the so-called bathtub curve, which shows how the failure rate varies with lifetime (see Figure 3).

Early in the lifetime of the product, the failure rate is high due to factors such as material defects, manufacturing flaws, and installation errors. As these problems are identified and fixed, the product experiences fewer failures in its mid-life. As it ages, materials rust or become brittle and failure rates rise during the end of its useful life.

The control rod seal problems during Palisades' operating lifetime can be explained by the bathtub curve. There's an annoying Catch-22 associated with the bathtub curve for consumable items like the control rod seals. When a seal wears out and leaks (i.e., is on the right side of the curve), its replacement starts out on the left side of the curve, and will also have a relatively high failure rate.

Figure 3: Bathtub Curve.



But the larger problem seems to be that the Palisades reactor has had a much higher seal failure rate than other reactors, particularly the other reactor with similar control rod seals. These other reactors have not had nearly as many control rod seal leaks as Palisades. The fundamental cause of the recurring control rod seal leak problems at Palisades has apparently eluded detection.

ABRIDGED HISTORY OF FAILED HEALS

The Palisades staff have made numerous attempts over the years to resolve the leaking control rod seal problem. In late 1972, about 18 months after the reactor was licensed by the AEC to operate, workers replaced the rotating seals (the red item in figure 2) on eleven of the 45 control rods with ones made from a different material. That attempt failed and workers replaced the seals on all 45 control rods in late 1974 with ones made from yet another type of material.

In 2001, workers replaced the housings and seals on all 45 control rods.

During the refueling outage in 2006, workers modified the ventilation to the upper head to increase cooling in the area occupied by the control rod drive mechanisms. By lowering the seal operating temperatures, the seals would not harden.

During the refueling outage in 2007, workers replaced the housings and seals on all 45 control rods.

In 2008, the company conducted an evaluation to identify the causes of recurring control rod seal leakage. The primary cause was attributed to inadequate seal area cooling. A secondary cause was poor quality of the rotating seals (the red item in the graphic on page 2) and fabrication-related material defects of the stationary seals (the orange item in the graphic on page 2).

During the refueling outage in 2009, workers replaced the seals on all 45 control rods. In addition, workers again modified the ventilation system to provide more cooling air flow to the region of the control rod drive mechanisms above the reactor vessel head.

The reactor shut down in June 2010 to allow a leaking control rod seal to be fixed, strongly suggesting that the true cause of the problem remains unidentified.

Palisades' owner has expended considerable time and effort in numerous attempts to resolve the control rod seal leak problem. The owner also lost revenue during reactor shut-downs required to address the leaking seals. But most significant, the nuclear safety problem remains unfixed. That's unacceptable.

NRC – MISSING IN ACTION

The NRC can and should do more than meekly monitor the repetitive failures to resolve the leaking control rod seal problems at Palisades. In June 1970 – roughly nine months before the operating license for Palisades was issued – the AEC implemented quality assurance regulations (Appendix B to 10 CFR Part 50). Criterion XVI imposed explicit requirements for correction actions:

> *Measures shall be established to assure that conditions adverse to quality, such as failures, malfunctions, deficiencies, deviations, defective material and equipment, and nonconformances are promptly identified and corrected. In the case of significant conditions adverse to quality, the measures shall assure that the cause of the condition is determined and corrective action taken to preclude repetition. The identification of the significant condition adverse to quality, the cause of the condition, and the corrective action taken shall be documented and reported to appropriate levels of management.*

The phrase "significant conditions adverse to quality" appears twice: once in requiring corrective action to prevent repeat offenses, and once in requiring causes to be identified. Are control rod seal leaks "significant conditions adverse to quality?" Considering that the reactor cannot continue to safely operate with such leaks and must be promptly shut down, it seems reasonable to conclude that they are indeed "significant conditions adverse to quality."

Corrective actions have often been taken at Palisades for control rod seal leaks. But the safety regulations require more than merely taking corrective actions – they require that corrective actions be taken "to preclude repetition."

Causes of "significant conditions adverse to quality" have often been identified at Palisades for control rod seal leaks. But the true cause(s) have either not been identified or the true cause(s) have not been corrected.

The regulatory requirement to find and fix causes of "significant conditions adverse to quality" has repeatedly been violated at Palisades due to the recurring control rod seal leaks. The NRC's job is to establish and enforce regulations to protect public health and safety. The NRC is only doing half its job. It has established the regulations. It's time for the NRC to enforce them as well. The NRC should sanction[1] Palisades' owner for repetitive violations of federal regulations that – ironically – protect against repetitive failures. Nuclear safety is not a "no blood, no foul" enterprise. Or, it must stop being one.

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[1] The NRC could impose a fine of up to $140,000 per day or issue an Order requiring the leaking control rod seals to be fixed – really fixed – by a certain date.