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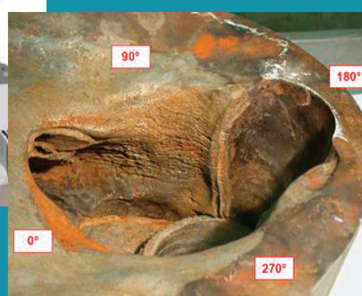


Davis-Besse Reactor Pressure Vessel Head Degradation

Overview, Lessons Learned, and NRC Actions Based on Lessons Learned

Davis-Besse Reactor Pressure Vessel Head Degradation: Overview

Background

The reactor pressure vessel (RPV) heads of pressurized water reactors (PWR) have penetrations for control rod drive mechanisms and instrumentation systems made from nickel-based alloys (e.g., Alloy 600) and related weld metals **(Figure 1).** Primary coolant and the operating conditions of PWR plants can cause cracking of these nickel-based alloys and weldments through a process called primary water stress corrosion cracking (PWSCC). In response to the detection of PWSCC at several plants, the NRC issued NRC Bulletin 2001-01, "Circumferential Cracking of Reactor Pressure Vessel Head Penetration Nozzles," which requested information related to licensees' programs for inspection of vessel head penetration (VHP) nozzles.

Through-Wall Cracking Detected

On February 16, 2002, in response to Bulletin 2001-01, the Davis-Besse Nuclear Power Station (DBNPS), located in Oak Harbor, Ohio, began a refueling outage with the intent to perform work that included remotely inspecting the VHP nozzles from underneath the head focusing on the control rod drive mechanisms (CRDM). The licensee found that three CRDM nozzles had indications of through-wall axial cracking. Specifically, the licensee found these indications in CRDM nozzles 1, 2, and 3, which are located near the top of the RPV head.

Repair Attempts

The repair of these nozzles was performed remotely from underneath the head. On March 6, 2002, the licensee terminated the repair process on CRDM nozzle 3 to determine the cause of unusual equipment operation, and removed the machining apparatus from the nozzle. During the removal, the nozzle tipped in the downhill direction until it rested against an adjacent CRDM. If structurally sound, the surrounding steel should have held the nozzle in place.

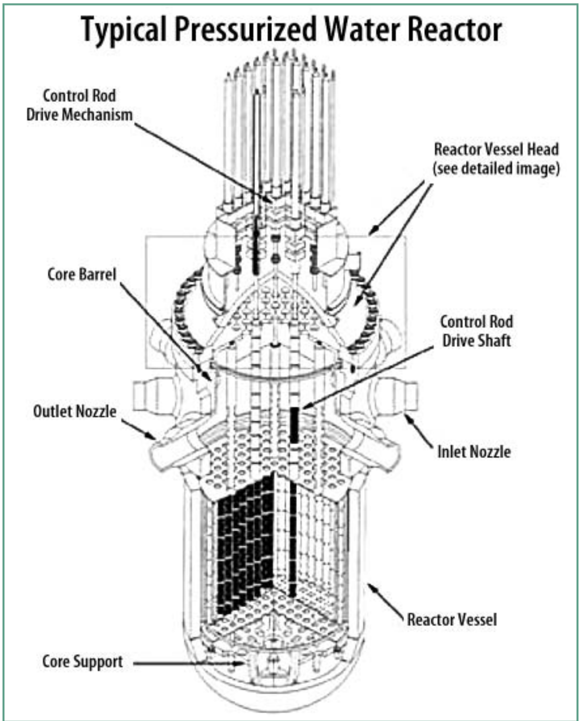


Figure 1a. Typical pressurized water reactor

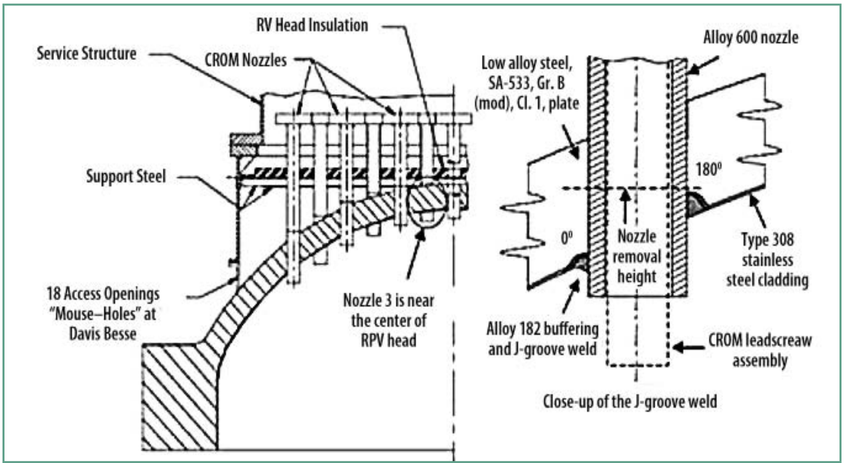


Figure 1b. Detail of vessel head penetration nozzles

Investigation

The licensee investigated the condition of the RPV head surrounding CRDM nozzle 3. The investigation included removing the CRDM nozzle and removing boric acid deposits from the top of the RPV head. Upon completing the boric acid removal on March 7, 2002, the licensee conducted a visual examination of the area and identified a large cavity in the RPV head on the downhill side of CRDM nozzle 3 **(Figure 2).** The corrosion was caused by borated water that leaked from the reactor coolant system onto the vessel head **(Figures 3 and 4)** through cracks in the nozzle and the weld that attached nozzle 3 to the RPV head **(Figures 5 and 6).** The remaining thickness of the RPV head in the wastage area was found to be approximately 3/8 inch. This thickness consisted of the thickness of the stainless steel cladding on the inside surface of the RPV head, which is nominally 3/8 inch thick. The stainless steel cladding is resistant to corrosion by boric acid, but it is not intended to provide structural integrity to the vessel. Failure of the stainless steel cladding would have resulted in a loss-of-coolant accident (LOCA). The LOCA would have resulted in actuation of the plant's emergency systems.

NRC Actions

NRC issued a confirmatory action letter that required the plant to remain shut down until the situation could be satisfactorily addressed and invoked the process outlined in Inspection Manual Chapter 0350, "Oversight of Reactor Facilities in a Shutdown Condition Due to Significant Performance and/or Operation Concern." This process establishes guidelines for the oversight of licensee performance during the shutdown. The process requires that specific criteria must be met before the plant can restart, to ensure that the plant is operated in a manner that provides adequate protection of public health and safety.

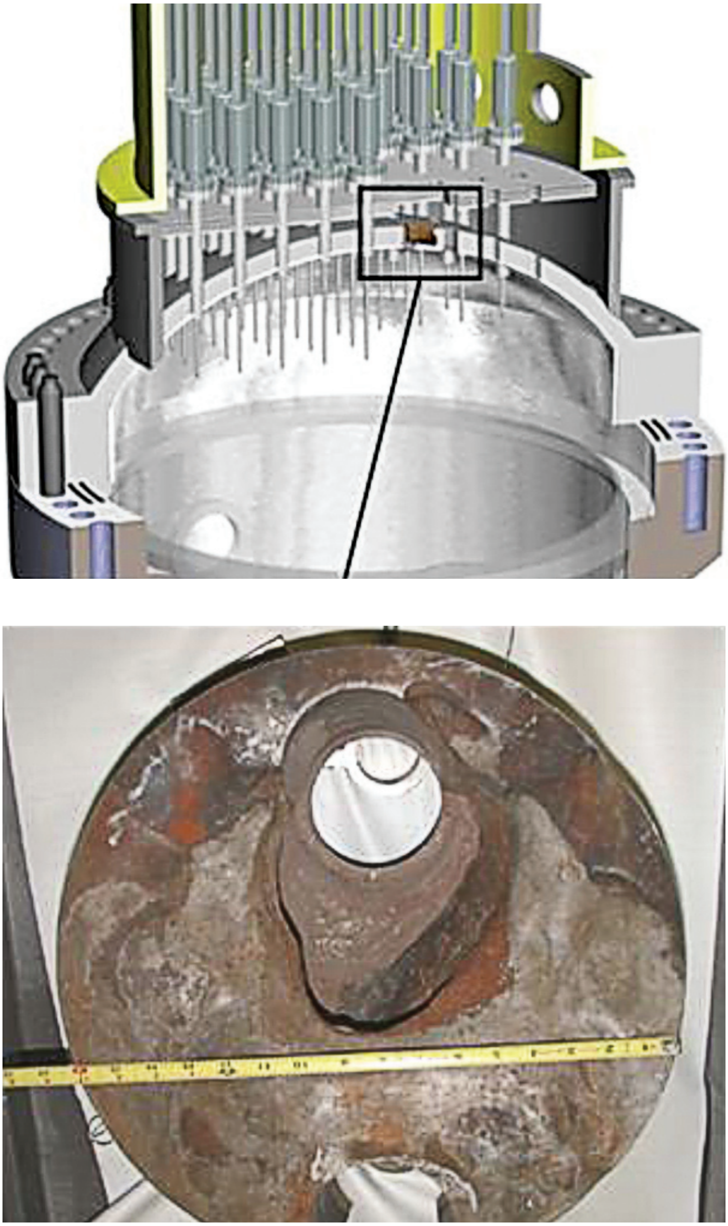


Figure 2. Region of the vessel head depicted by the model and photo of the cavity after it was removed from the vessel head

Davis-Besse Reactor Pressure Vessel Head Degradation: Lessons Learned

Operational Experience

During the early 1990's, the NRC and industry recognized the potential for boric acid corrosion of an RPV head. In 1993, the industry and NRC specifically addressed the possibility of extensive RPV head wastage stemming from undetected VHP nozzle leaks involving axial cracking caused by PWSCC. The industry concluded and the NRC agreed that the likelihood of this happening was low because VHP nozzle leaks would be detected before significant RPV head degradation could occur. Nevertheless, in spite of this awareness and contrary to this conclusion, the DBNPS event occurred.

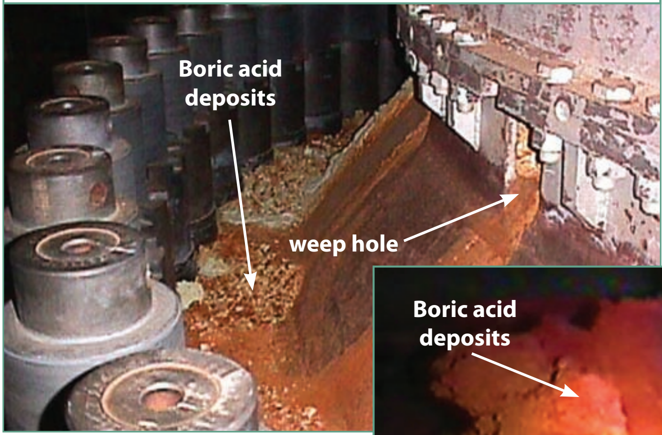
Lessons Learned Task Force

The NRC's Executive Director for Operations (EDO) directed the formation of an NRC task force in response to the issues associated with the DBNPS event. The objective of this task force was to independently evaluate the NRC's regulatory processes related to assuring RPV head integrity in order to identify and recommend areas for improvement that may be applicable to either the NRC or the nuclear industry. Consistent with its charter, the task force reviewed five general areas, including: (1) reactor oversight process issues; (2) regulatory process issues; (3) research activities; (4) international practices; and (5) the NRC's Generic Issues Program.

Task Force Conclusions

The lessons learned task force (LLTF) concluded that the DBNPS VHP nozzle leakage and RPV head degradation event was *preventable.* While this review was primarily introspective, this question could not be answered without considering industry activities and DBNPS's performance. At DBNPS, early indications of RPV corrosion were missed such as radiation element system filters being clogged by boric acid and corrosion fines, the build up of boric acid deposits on containment air cooler fins and large amounts of boric acid deposits on the RPV head. The task force concluded that the event was not prevented because: (1) the NRC, DBNPS, and the nuclear industry failed to adequately review, assess, and follow-up on relevant operating experience, (2) DBNPS

Figure 3a. RPV head flange area showing significant amounts of boric acid deposits (photo taken during the 2000 refueling outage at DBNPS)



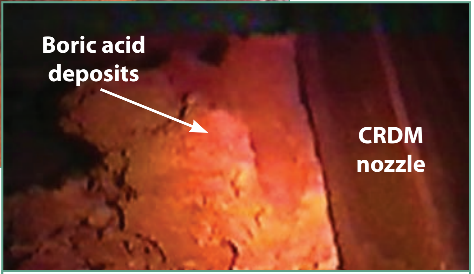


Figure 3b. Boric acid deposits accumulating near a CRDM nozzle (still photo of video taken during the 2000 refueling outage at DBNPS)

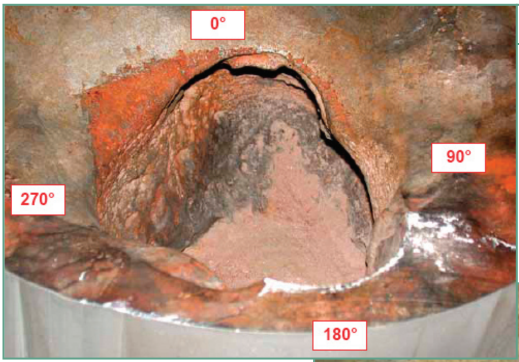


Figure 4a. Close-up view of the cavity

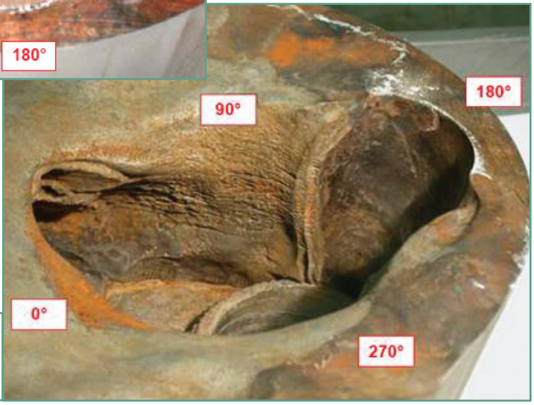


Figure 4b. Oblique view of the cavity partially showing the J-groove weld at the bottom of the cavity

failed to assure that plant safety issues received appropriate attention, and (3) the NRC failed to integrate known or available information into its assessments of DBNPS's safety performance. Furthermore, an NRC investigation concluded that DBNPS did not adequately execute the boric acid corrosion control program in response to an NRC Generic Communication, and the NRC did not adequately review the industry implementation of long term commitments, such as the commitment to maintain a boric acid corrosion control program.

NRC Actions

As a result of its review, the task force determined that the NRC should take specific actions to address contributing factors that led to the DB-NPS event. The recommendations made involved the following areas: 1) stress corrosion cracking, 2) reactor coolant pressure boundary integrity, 3) operational experience and 4) inspection and program management. Select examples of NRC actions taken to address recommendations of the LLTF in these areas are described in a later section.

Davis-Besse Reactor Pressure Vessel Head Degradation: NRC Actions Based on Lessons Learned

The LLTF developed recommendations in key technical and programmatic areas. Examples of some of the actions taken by the NRC to address the recommendations of the task force in the areas of stress corrosion cracking, operating experience, and inspection and program management are discussed below.

Stress Corrosion Cracking

NRC Order EA-03-009 was issued requiring all licensees with plants susceptible to RPV head degradation to visually inspect the reactor vessel head surface area for indications of leakage and boric acid accumulation, as well as inspect head penetrations using methods to detect cracks before leakage starts.

The NRC worked with the American Society of Mechanical Engineers (ASME) to develop Code Case N-729-1 to develop long-term inspection

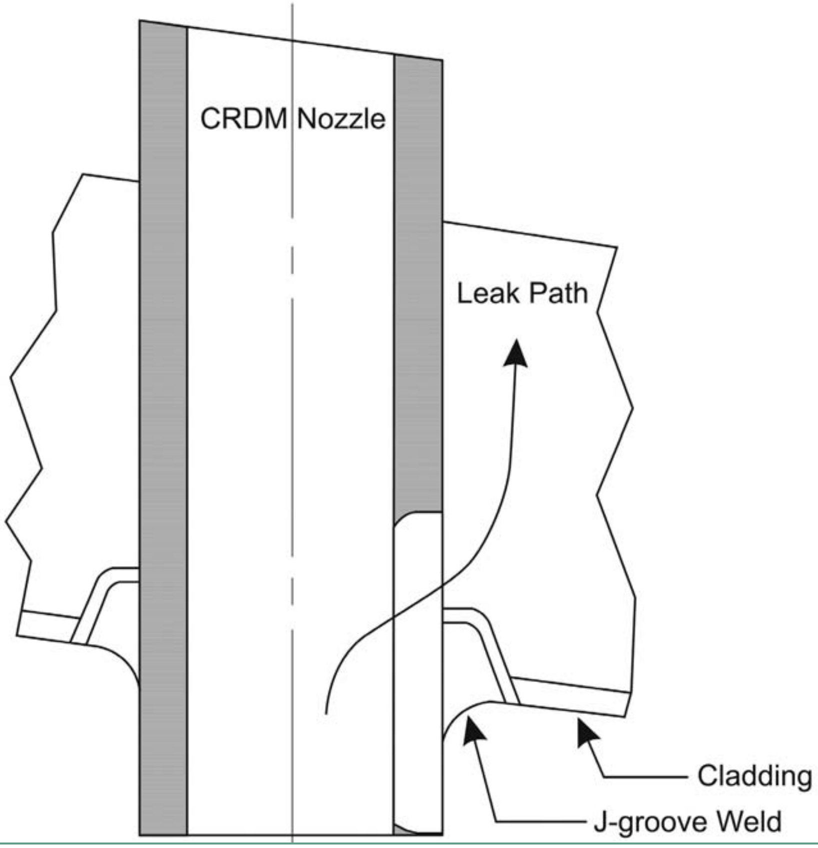


Figure 5. Schematic of the nozzle penetration cross section showing the leak path of the reactor coolant

Top View of J-Groove Weld

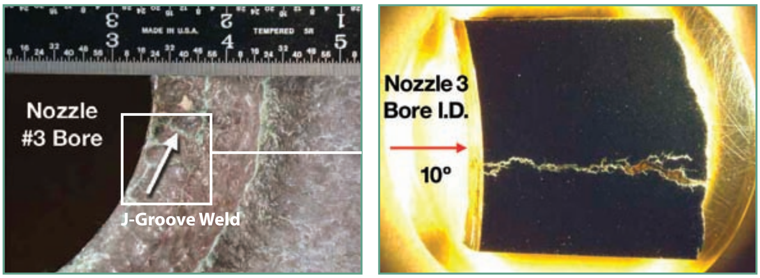


Figure 6. Top photo: Top view of the J-groove weld with an arrow pointing to a crack
Top-right photo: Polished cross section of the area shown in the top photo showing the through-wall crack in the J-groove weld

requirements of RPV heads into the ASME Code. The finalized inspection requirements will be incorporated into 10 CFR 50.55a and allow the rescission of NRC Order EA-03-009.

Operating Experience

In December 2004, the NRC codified a new operating experience program in Management Directive 8.7, "Reactor Operating Experience Program," to systematically collect, communicate and evaluate operating experience information, including foreign operating experience. The program makes significant use of information technology to make operating experience information available to internal users and members of the public through a single Web access page.

An organization within the NRC was established to act as a clearinghouse that collects, communicates and evaluates operating experience and applies the lessons learned to the core regulatory functions of oversight, licensing, rulemaking, and incident response. It also conducts a daily screening meeting at which incoming event reports and other operating experience items are reviewed. There is a new powerful database for managing all reported events, as well as a new operating experience information gateway that consolidates a large collection of individual databases and Web sources of information onto a single Web access page.

The NRC developed a new communication tool to promptly notify NRC staff of developing operating experience in their areas of expertise or practice. Users may also use this tool to examine recent or developing operating experience in their respective areas.

To ensure plant experience is adequately considered in licensing decisions, new or revised expectations were established with regard to the duration of a licensing Project Manager assignment to a specific plant, frequency of site visits, communication with the resident inspector staff and maintaining a questioning safety attitude about plant events.

Inspection and Program Management

The staff made several changes to the process to enhance the NRC's ability to detect declining plant performance, including the specific issues identified at the DBNPS. For example, the review of the event indicated the deteriorating condition had been underway for several years and that the planned inspection, maintenance, and modification activities that could have prevented, or enabled earlier discovery of the condition were frequently deferred.

The NRC increased the evaluation of licensees' programs and actions relating to long-standing unresolved problems. In addition, the NRC now audits the licensees' commitment management programs every three years by assessing the adequacy of the licensees' implementation of a sample of commitments made to the NRC in past licensing actions and activities.

The NRC inspector training program has been enhanced by a Web-based system to provide more timely dissemination of information to the inspection staff, and a method for individual study. New training modules were developed to address lessons learned from the DBNPS event, such as the effects of boric acid corrosion and the importance of maintaining a questioning attitude toward safety.

Safety culture weaknesses at Davis-Besse were determined to be one of the root causes of the reactor vessel head degradation event. Therefore, the NRC took significant steps within the Reactor Oversight Process to strengthen the ability to detect a weak safety culture in our inspections and performance assessments. In this context, safety culture is defined as "that assembly of characteristics and attitudes in organizations and individuals which establishes that, as an overriding priority, nuclear plant safety issues receive the attention warranted by their significance." The NRC continues to seek ways to improve this and other aspects of its oversight processes.

The program management aspects of the Reactor Oversight Process have been enhanced. For example, the guidance for managing NRC resources devoted to plants in an extended shutdown as a result of performance issues was revised to ensure less impact on routine oversight at other plants. Also, to ensure continuity of regulatory oversight, the staff developed and issued a site staffing metric to monitor gaps in permanent resident and senior resident staffing at reactor sites, and established the criterion of maintaining a minimum of 90-percent coverage.

NUREG/BR-0353, Rev. 1
August 2008