## Generic Training on INPO SOER 02-4

**Course Title:** Generic Training on INPO SOER 02-4  
**Course Owner:** Jim Caulk

### Revision History

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*Note: This lesson plan includes all training content. It does not include graphics, videos, interactive exercises, or review questions.*
NANTeL
Generic Training on INPO SOER 02-4

Reactor Pressure Vessel Head Degradation at Davis-Besse Nuclear Power Station

Estimated Time to Complete: 30 minutes

Revision 09.00

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Purpose

This course describes the causes of the Davis-Besse reactor vessel head degradation event. The course covers the generic training elements of Recommendation 1 in the SOER, including the technical causes and organizational contributors to the event and key lessons learned. Additional site-specific training is still required to address how the factors in this event apply to processes and cultures at individual stations.

Objectives

Upon completion of this course, the student will be able to do the following from memory:

1. DESCRIBE what physically caused the CRDM nozzle crack and the subsequent degradation of the reactor pressure vessel head.

2. DESCRIBE what led to the organization’s inability to identify and correct the situation, including the organizational factors that influenced how decisions were made.

3. SUMMARIZE the missed opportunities to prevent the event.

4. STATE the organizational factors at Davis-Besse that resulted in excessive emphasis on production and less emphasis on nuclear safety.

Why Take This Training

INPO Significant Operating Experience Report (SOER) 02-4 recommends periodic training on what caused the Davis-Besse reactor vessel head degradation event. After completing this lesson you should be able to describe the main causes.
This training satisfies the generic requirements in Recommendation 1 of the SOER. Additional site-specific training is required to address how the factors in this event apply to processes and culture at your own station.

How This Course Is Organized

This course is divided into three sections:

- Event description (What happened?)
- Lessons Learned (What caused the event and what actions could have prevented it?)
- Review and Summary (What are the key aspects you need to remember?)

The event description includes animations with sound, so be sure your computer sound is turned on. You also might want to have headphones available if you are in a computer lab with other learners.

The Event

During a refueling outage on March 6, 2002, workers at the Davis-Besse Nuclear Power Station discovered a cavity in the head of the reactor pressure vessel (RPV). The cavity was alongside control rod drive mechanism (CRDM) nozzle three.

The technical cause of the event was primary water stress corrosion cracking (PWSCC) in the nozzle, which allowed boric acid to leak onto the head. However, the root cause was a shift in focus at all levels of the organization from pursuing high standards to justifying minimum standards. This shift - driven by a focus on production goals - caused behaviors that undermined the station's safety culture.

Event Timeline

The Davis-Besse event unfolded over a long period of time with warning signs along the way. Click each date below to see key events.

1990 Refueling Outage 6
The Nuclear Regulatory Commission issues a warning on primary water stress corrosion cracking. Video inspection reveals boric acid on the Davis-Besse RPV head from a CRDM flange leak. Around this same time, an undetected crack begins in the number three CRDM nozzle.

1991 Refueling Outage 7
Excessive boric acid deposits are found on the RPV head and the containment air coolers. The unit starts up with six known leaks in CRDM flanges.
1994 Refueling Outage 9
An inspection of the RPV head reveals eight CRDM flange leaks. The station chooses not to perform a complete head inspection because of the difficulty accessing the top. This is accepted because a complete inspection is "not an NRC commitment."

1996 Refueling Outage 10
An undetected crack extends through the wall of CRDM nozzle three. Indications of leakage would have been visible on the reactor vessel head if a full head inspection had been completed.

1998 Refueling Outage 11
Clumps of boric acid are found at the base of CRDM flanges and classified as flange leakage. The unit starts up with known packing leakage in a pressurizer spray valve. As a result, several bonnet nuts become severely corroded during the operating cycle.

1999
The containment air coolers are cleaned 17 times in one year. This far exceeds what is normal. Additionally, the reactor coolant system leak rate increases significantly. The station is unable to adequately pinpoint the cause of these two significant trends.

2000 Refueling Outage 12
Red, rusty boric acid is found coming out of mouse holes in lava-like flows more than 1-inch thick. The head is only partly cleaned and the unit is re-started. The work order for cleaning the head is signed off as completed without exception.

2002 Refueling Outage 13
Boric acid deposits as high as four inches are found flowing out of the mouse holes on the reactor head. Nozzle number three tilts during outage maintenance. This leads to the discovery of a large cavity in the head, followed by a two-year extended outage that costs $600 million.

The Reactor Head
In the next four screens you will learn about four aspects of the reactor pressure vessel head as it relates to this event:

- Design
- Insulation
- Leakage
- Boric Acid Corrosion Damage

Design
The Davis-Besse RPV head is made from six-inch carbon steel with a stainless steel liner on the inside.
The head has 69 nozzle penetrations:
- 61 CRDMs
- 7 spares (empty)
- 1 vent

The nozzles are each about 4 inches wide and are spaced about 12 inches apart. They attach to the head using a partial penetration J-groove weld.

**Insulation**

The reactor head is covered by metal reflective insulation. At its center, the horizontal sheet of insulation sits about 2 inches from the top of the reactor head.

The space between the insulation and the reactor is large enough to allow visual inspection of the nozzles through 18 small openings at the bottom of the insulation support structure. These openings, known as "mouse holes," allow small cameras to be inserted for inspection.

**Leakage**

Over the years, visual inspections showed an uneven layer of boric acid deposits scattered over the RPV head.

White streaks on the outside of the nozzles indicated that the boric acid flowed down from leakage in the CRDM nozzle flanges.

These leaking flanges were repaired by replacing the gaskets and machining the flange faces to ensure a better seal.

Later, visual inspections found new boric acid deposits on the RPV head.

Management continued to attribute this to leaking flanges. They tolerated the condition, believing that mechanical joint leaks were manageable and boric acid leakage on the head was harmless.

Management's acceptance of this condition and the decision not to analyze the cause masked the real problem. A crack had formed in a CRDM nozzle wall, endangering the safety system integrity.

**Boric Acid Corrosion Damage**

On March 6, 2002, while conducting an ultrasonic inspection of a CRDM penetration, workers discovered a cavity in the head alongside nozzle 3.

Boric acid from the crack in the nozzle corroded a hole about 7 inches long and six inches wide. At its deepest, it extended through the base metal of the head all the way to
the stainless steel liner, which was about 3/8 of an inch thick. The liner had bowed outward under the 2200 pounds of pressure inside the vessel.

Lessons Learned

This section describes the lessons learned about how this event occurred and how it could have been prevented.

Warning Flags

This event involved many of the warning flags described in a 1998 INPO study of long-term regulatory shutdowns:

1. Event significance was unrecognized or underplayed, and reaction to events is not aggressive.
2. Effects of organization and staff changes were not fully considered.
3. Self-assessment processes did not find or address problems.
4. Important equipment problems lingered or were postponed while the plant stayed on line.
5. Senior managers were not involved in operations and did not exercise accountability or follow-up.
6. Employees were not involved or listened to by management, and raising problems was not valued by the organization.
7. The "numbers" were good, and the nuclear staff was living off past successes.

These warning flags are highlighted in the left margin of your screen as you go through this next section on lessons learned from the event.

Missed Opportunities to Prevent the Event

For years, the station had signs of system leakage, but the RPV head was overlooked as a likely source. A proper evaluation of the symptoms might have prompted a thorough inspection of the head.

Leak Rate

Between 1995 and 1998, the average unidentified leakage from the reactor coolant system was less than 0.1 gallons per minute. This increased to 0.8 in 1998 through mid-1999.

The change in leak rate was attributed to a pressurizer relief valve and safety valve discharge lines. These issues were corrected, but the leak rate remained above the baseline rate of 0.1 gpm until the 2002 refueling outage.
Station personnel unsuccessfully tried to determine the source of the leak and continued plant operation assuming it was associated with CRDM flanges.

**Rad Monitor Filters**
The station normally replaced the containment atmosphere radiation monitor filters monthly. In 1999, the filters began clogging more frequently with boric acid and iron oxide deposits.

Between May 1999 and April 2001, the filters were changed about every one to three weeks. Sometimes they were cleaned as often as every one to three days.

Analysis of the iron oxide particles indicated active localized corrosion of a carbon steel component. This information was not used to focus personnel on the possible source.

A more thorough inspection of areas not easily accessible during previous inspections may have led to the conclusion that the source was somewhere on the RPV head.

**Containment Air Coolers**
Between 1992 and 1998, the containment air coolers did not require cleaning from boric acid fouling. Then, between November 1998 and May 1999, the coolers had to be cleaned 17 times. This continuous fouling did not raise concerns about the system's ability to operate.

The station assumed that flange leaks caused the boric acid deposits. Yet previous flange leaks had not fouled the coolers, and flange leakage was reduced after 1996. The deposits were generally described as white, but some work orders indicated they were rust-colored. This was attributed to the age of the boric acid.

This justification was incorrect because the air coolers were cleaned five times in 2000 and four times in 2001, indicating that the deposits had built up during one operating cycle and were relatively fresh.

**Organizational Contributors**

While organizational weaknesses did not directly cause the CRDM nozzle leak, they did prevent the station from finding, evaluating, and correcting the problem before the head was seriously damaged. SOER 02-4 groups the contributors into several categories:

- ineffective management and oversight
- inadequate use of the corrective action and boric acid corrosion control programs
- justification and acceptance of degraded conditions, especially boric acid deposits on the RPV head

**Ineffective Management and Oversight**

A variety of weaknesses in management and oversight contributed to this event.
Management Involvement

Good historical performance convinced senior managers that problems were being identified and corrected at lower levels in the organization. They assumed issues would be raised up to higher levels if necessary.

Frequent management changes put new managers in charge of programs that they had little experience with. As a result, they provided little oversight.

As its experience base eroded, management did not ask questions; it did not recognize the need to investigate symptoms of corrosion; and it did not understand the risks of continued operation. Boric acid leakage became accepted.

Senior managers were unaware of the worsening conditions inside the containment building.

Independent Oversight

The independent oversight function did not identify the extent of condition on the RPV head. Neither Quality Assurance (QA) nor the Nuclear Safety Review board effectively identified the abnormal trend.

A QA audit report written in 2000 noted no adverse trends in the previous two years. During this same period, the color and consistency of boron acid on the head began to change; unidentified leakage in the reactor coolant system increased; and boron acid and corrosion products began accumulating in the containment air coolers and radiation monitor filters.

Another QA audit credited engineering personnel with aggressively removing boron acid deposits from the RPV head. The audit did not address the boron acid that was left on the head or the lack of an acid corrosion evaluation.

Excessive Focus on Production

Until 1996, safety was the largest contributor to the incentive compensation program at all levels of the organization. In 1997, that began to change. Over time, incentive programs at the higher levels of management became based on short-term production goals more than on safety. This caused a misalignment of priorities and inhibited a safety-first philosophy.

In combination with other incentives, such as rewards for meeting or exceeding outage goals, these production incentives led management to defer important work that did not affect generation.

This was especially true for tasks associated with RPV head cleaning. Station managers consistently assumed the best-case scenario about the boron deposits. They failed to consider and plan for the worst-case scenario.
Management Engagement

Station managers were unaware of the actual condition of the RPV head or that conditions had worsened in recent years. When problems like the 1998 pressurizer spray valve leak were identified, management encouraged engineering personnel to justify continued operation rather than correcting the problems.

Open, candid discussions about potential problems were rare and not encouraged. Management's participation in problem solving was generally limited to reliability issues.

When station personnel reported symptoms of leakage and corrosion to managers, there was little questioning to determine extent or causes.

Management did not recognize the effect of these conditions on other components and did not insist on placing "eyes on the problem."

Inadequate Use of Station Programs

The Corrective Action Program and Boric Acid Corrosion Control Program lacked effective oversight. Neither station management nor station oversight groups verified that the programs were performing their intended functions to high standards.

Corrective Action

Corrective action (CA) reports were not reviewed for recurring problems, and long-standing issues were left uncorrected. Managers generally did not verify if corrective actions were completed in a timely manner. When completion dates were extended, managers did not always ensure that potential consequences were evaluated.

A 1996 CA report identified that the RPV head was not inspected adequately to ensure that nozzles were not leaking and the head was not corroding. The report was later downgraded and closed without a root cause analysis because the licensing department felt the station had no NRC commitment to inspect the nozzles.

Corrective actions were sometimes closed out by referencing actions to another CA document that did not fully address the original actions.

Boric Acid Corrosion Control

The station's Boric Acid Corrosion Control Program (BACCP) stated that areas of boric acid buildup should be inspected for signs of corrosion. It also stated that this process required the removal of the deposits to expose bare metal. Still, large deposits of boric acid were left on the RPV head after the 1994, 1996, 1998, and 2000 outages.

The RPV head and CRDM nozzles were inspected under the in-service inspection (ISI) program instead of the BACCP. Boric acid deposits found by the ISI were not properly documented, evaluated, or corrected by the BACCP.
The station did not properly evaluate the extent of the boron deposits on the head, and it made no effort to verify that inspections were done to determine the head's actual condition.

**Justification and Acceptance of Degraded Conditions**

Despite the inability to examine the CRDM nozzles at the top center of the head, the station accepted the boric acid deposits and justified not removing them based on several assumptions. Click the button to see what they were.

Management accepted inconclusive industry studies indicating that CRDM nozzle leakage was unlikely, and that significant corrosion of the head by boric acid would allow ample time for detection.

Management believed that the station's age made it less susceptible to nozzle cracking.

Analyses predicted that peripheral nozzles were more likely than center nozzles to crack. The Davis-Besse crack was in a nozzle near the center of the head.

Inaccurate or misleading data indicated that the operating temperature range of the RPV head would limit the possibility of corrosion from boric acid buildup.

**The Safety Culture Connection**

Davis-Besse conducted a root cause analysis that provided this summary statement of the event:

*Over time, the plant appeared to become complacent. In many areas, a minimum compliance standard existed in management and thus throughout the Davis-Besse organization.*

In contrast, the INPO document *Principles for a Strong Nuclear Safety Culture* provides this definition of a strong safety culture:

*An organization's values and behaviors - modeled by its leaders and internalized by its members - that serve to make nuclear safety the overriding priority.*

**Summary**

1. The primary technical cause of the event was primary water stress corrosion cracking of a CRDM nozzle.

2. The crack in the nozzle allowed boric acid to leak onto the RPV head and corrode the carbon steel.

3. The event developed over many years. During that time the station missed multiple opportunities to identify the problem and prevent the event. These included an
increased leakage rate that couldn't be identified, as well as boric acid deposits that covered the RPV head, clogged the radiation monitor filters, and fouled the containment air coolers.

4. A major contributor to the event was the station's shift in focus from implementing high standards to justifying minimum standards.

5. Organizational and station incentive programs were aligned to production goals, undermining sensitivity to nuclear safety.

6. Organizational factors that contributed to poor decision-making included ineffective management and oversight; inadequate use of the station's CA and BACCP programs; and justification and acceptance of degraded conditions.

Acknowledgements

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Documents

SOER 02-4, Rev. 1, "Reactor Pressure Vessel head Degradation at Davis-Besse Nuclear Power Station"

SER 2-02, "Undetected Leak in Control Rod Drive Mechanism Nozzle and Degradation of Reactor Pressure Vessel Head"