briefing

Davis-Besse: The Reactor with a Hole in its Head

The reactor core at the Davis-Besse nuclear plant sits within a metal pot designed to withstand pressures up to 2,500 pounds per square inch. The pot -- called the reactor vessel -- has carbon steel walls nearly six inches thick to provide the necessary strength. Because the water cooling the reactor contains boric acid that is highly corrosive to carbon steel, the entire inner surface of the reactor vessel is covered with 3/16-inch thick stainless steel. But water routinely leaked onto the reactor vessel's outer surface. Because the outer surface lacked a protective stainless steel coating, boric acid ate its way through the carbon steel wall until it reached the backside of the inner liner. High pressure inside the reactor vessel pushed the stainless steel outward into the cavity formed by the boric acid. The stainless steel bent but did not break. Cooling water remained inside the reactor vessel not because of thick carbon steel but due to a thin layer of stainless steel. The plant's owner ignored numerous warning signs spanning many years to create the reactor with a hole in its head.

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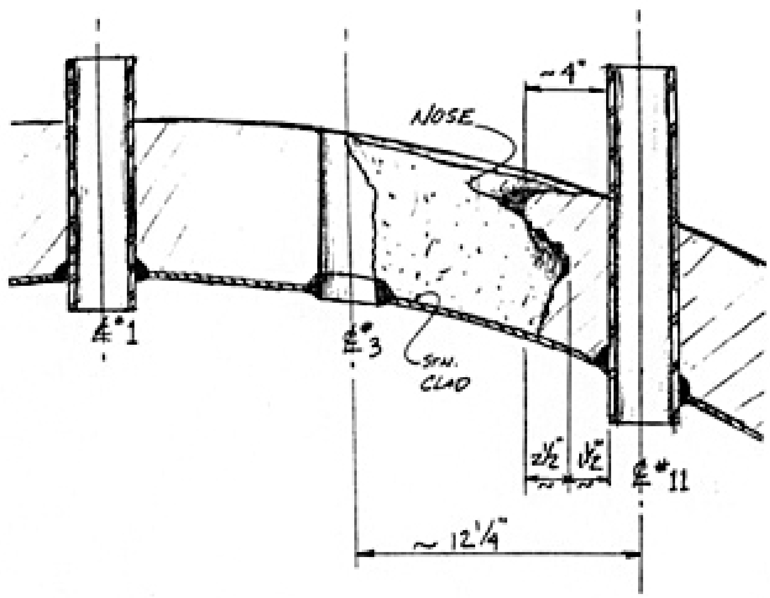
What happened?

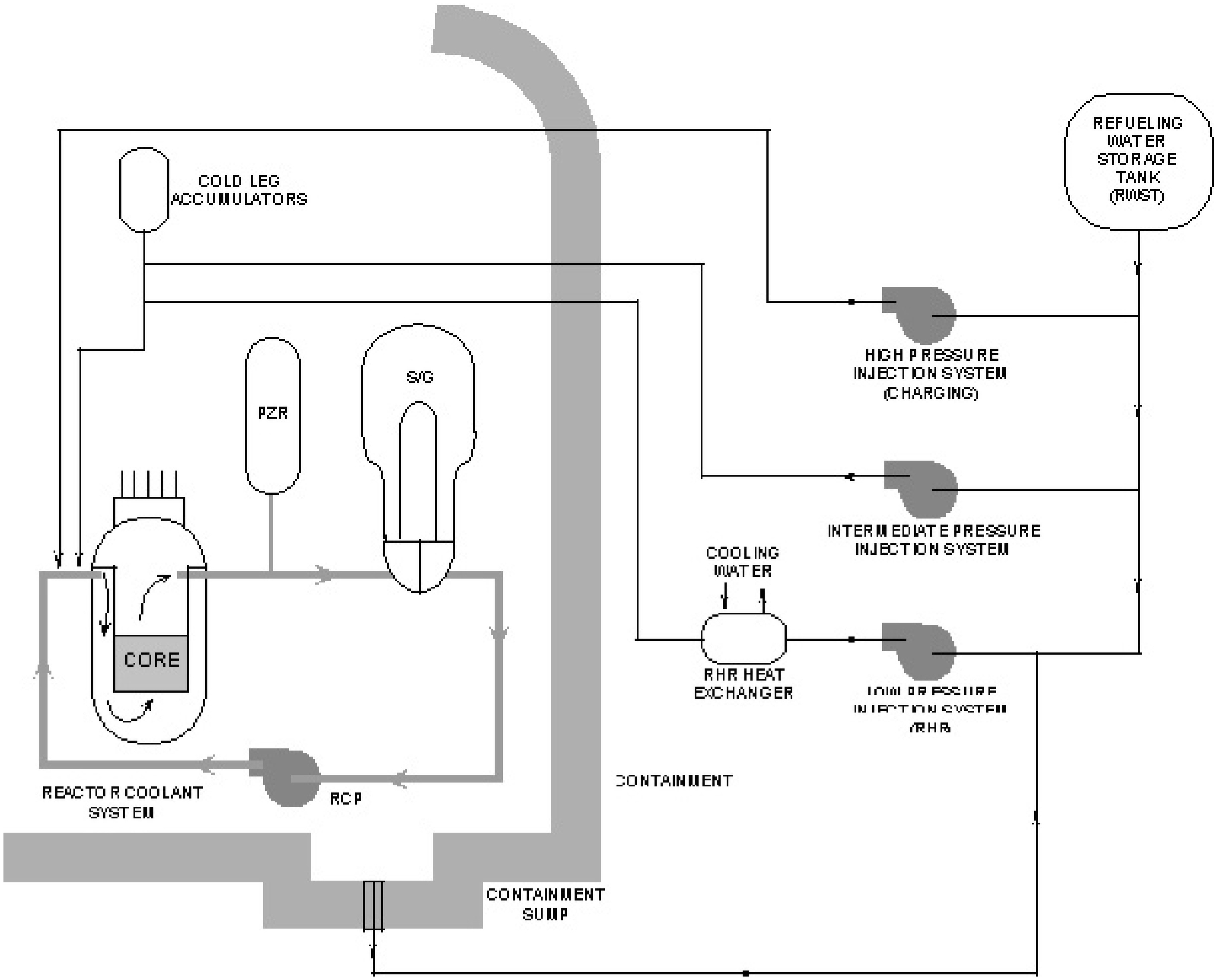


Workers repairing one of five cracked control rod drive mechanism (CRDM) nozzles at Davis-Besse discovered extensive damage to the reactor vessel head. The reactor vessel head is the dome-shaped upper portion of the carbon steel vessel housing the reactor core. It can be removed when the plant is shut down to allow spent nuclear fuel to be replaced with fresh fuel. The CRDM nozzles connect motors mounted on a platform above the reactor vessel head to control rods within the reactor vessel. Operators withdraw control rods from the reactor core to startup the plant and insert them to shut down the reactor.

The workers found a large hole in the reactor vessel head next to CRDM nozzle #3. The hole was about six inches deep, five inches long, and seven inches wide. The hole extended to within 1-1/2 inches of the adjacent CRDM nozzle #11. The stainless steel liner welded to the inner surface of the reactor vessel head for protection against boric acid was at the bottom of the hole. This liner was approximately 3/16-inch thick and had bulged outward about 1/8-inch due to the high pressure (over one ton per square inch) inside the reactor vessel.

What could have happened?

A loss-of-coolant accident (LOCA) occurs if the stainless steel liner fails or CRDM nozzle #3 is ejected. The water cooling the reactor core quickly empties through the hole into the containment building. The containment building is made of reinforced concrete designed to withstand the pressure surge from the flow through the break.



To compensate for the reactor water exiting through the hole, water inside the pressurizer (PZR) and the cold leg accumulators flows into the reactor vessel. This initial makeup is supplemented by water from the Refueling Water Storage Tank (RWST) delivered to the reactor vessel by the high, intermediate, and low pressure injection pumps. The makeup water re-fills the reactor vessel and overflows out the hole in the reactor vessel head.

Approximately 30 to 45 minutes later, the RWST empties. Operators close valves between the pumps and the RWST and open valves between the low pressure injection (RHR) pumps and the containment sump. Water pouring from the broken reactor vessel head drains to the containment sump where the RHR pumps recycle it to the reactor vessel. A cooling water system supplies water to the RHR heat exchanger shown to the left of the RHR pump to remove heat generated by the reactor core.

On paper, that's how the safety systems would have functioned to protect the public. But the following examples suggest that things might not have gone by the book:

- The Three Mile Island nuclear plant experienced a loss of coolant accident in March 1979. Emergency pumps automatically started to replace the water flowing out the leak. Operators turned off the pumps because instruments falsely indicated too much water in the reactor vessel. Within two hours, the reactor core overheated and melted, triggering the evacuation of nearly 150,000 people.

- At the Callaway nuclear plant in 2001, workers encountered problems while testing one of the emergency pumps. Investigation revealed that a foam-like bladder inside the RWST was flaking apart. Water carried chunks of debris to the pump where it blocked flow. The debris would have disabled all the emergency pumps during an accident.

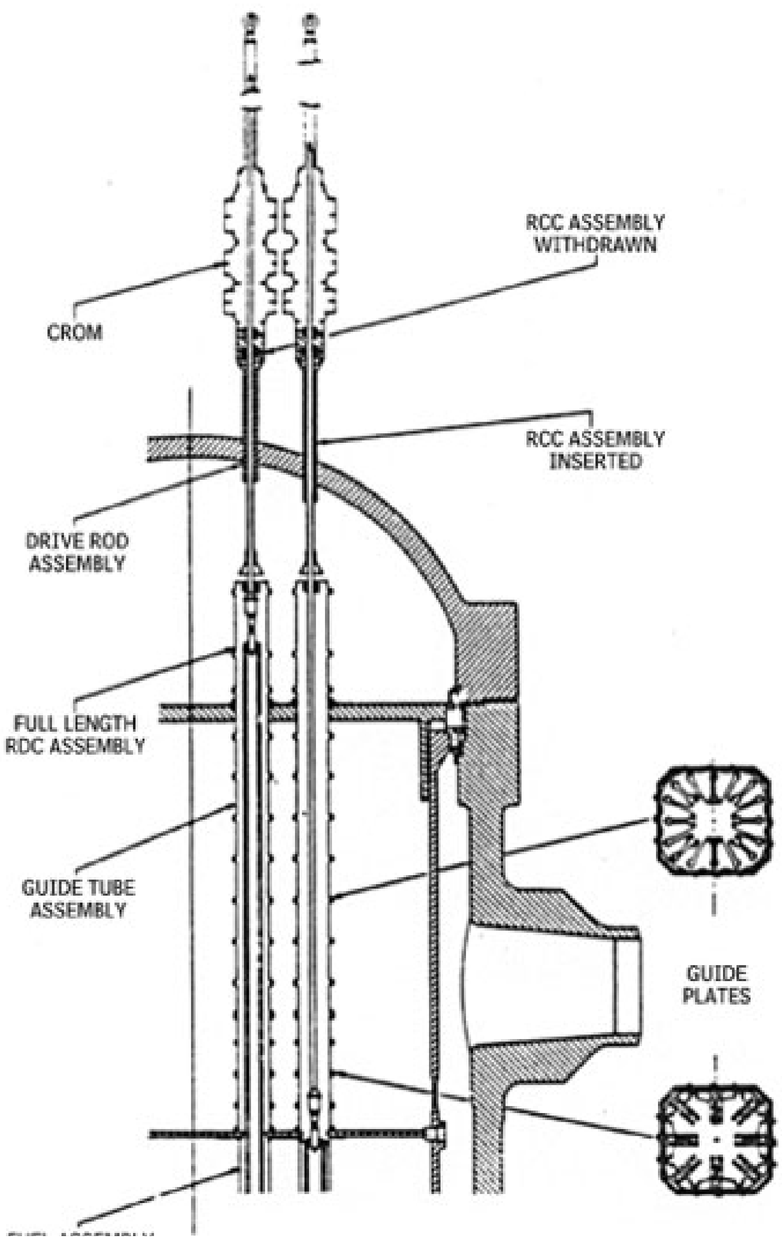
- At the Haddam Neck nuclear plant in 1996, the NRC discovered the piping carrying water from the RWST to the reactor vessel was too small. It was long enough but it was not wide enough to carry enough water during an accident to re-fill the reactor vessel in time to prevent meltdown. The plant operated for nearly 30 years with this undetected vulnerability.

- At several US and foreign nuclear power plants, including the Limerick nuclear plant 8 years ago, the force of water/steam entering the containment building during a loss of coolant accident has blown insulation off piping and equipment. The water carried that insulation and other debris into the containment sump. The debris clogged the piping going to the emergency pumps much like hair clogs a bathtub drain. According to a recent government report, 46 percent of US nuclear plants are very likely to experience blockage in the containment sumps in event of a hole the size found at Davis-Besse opens up. For slightly larger holes, the chances of failure increase to 82 percent.[1]

Thus, events at Davis-Besse may have gone by the book had the stainless steel failed or would have become the subject of many books on the worst loss of coolant accident in US history.

What caused the hole in the reactor head?

According to the plant owner[2], a crack developed in CRDM nozzle #3 in 1990. By 1995, the crack grew all the way through the nozzle. Boric acid from the water leaking through the crack began attacking the reactor vessel head. By 1999, the reactor vessel head corrosion was bad enough that iron oxide (e.g, rust particles) was being detected in the containment atmosphere. Once it opened, the hole widened by nearly two inches per year.



FUEL ASSEMBLY

Workers did not discover the damage during visual inspections of the reactor vessel head in 1998 and again in 2000. Boric acid crystals coated the reactor vessel head masking the metal surface. The boric acid crystals came from reactor water leaking from the flanges connecting the CRDM nozzles to the CRDMs above the reactor vessel head.

What REALLY caused the hole in the reactor head?

Complacency on the part of the plant's owner and the NRC really caused the hole in the reactor head. Evidence of complacency by the plant's owner includes:

- When problems with leaking CRDM flanges surfaced years agon, workers at Davis-Besse proposed a modification that would enable better inspections of the reactor vessel head. Management approved this modification, but then deferred its implementation.

- When boric acid crystals were repeatedly found coating the outer surface of the reactor vessel head, workers at Davis-Besse merely tried cleaning them away. The plant's design required all components coming into contact with reactor water to be made of corrosion-resistant materials or to be clad with a protective layer of stainless steel. The outer surface of the reactor vessel head was neither corrosion-resistant nor coated with stainless steel. Management tolerated a degraded condition prohibited by the plant's design.

Boric acid crystals on the outer surface of a reactor vessel head at a plant similar to Davis-Besse.

- Armed with knowledge about leaking CRDM flanges at Davis-Besse causing the outer surface of the reactor vessel to be coated with boric acid crystals, about the high likelihood that one or more CRDM nozzles would be cracked, and about elevated iron oxide levels within the containment building, management begged the NRC in fall 2001 to allow it to skip the reactor vessel head inspection mandated by the end of the year.

Evidence of complacency by the NRC includes:

- Less than two years after another similarly skipped inspection contributed to an accident at the Indian Point 2 nuclear plant, the NRC allowed Davis-Besse to skip the mandated 2001 year-end inspection.

- After CRDM nozzle cracking was reported at Bugey Unit 3 in 1991, the NRC initiated a research program to examine the issue for US reactors. As the NRC research program was plodding along, Greenpeace International petitioned the NRC on March 24, 1993, to require inspections of CRDM nozzles at all US reactors and to make the inspection results publicly available. Greenpeace also sought to shut down all reactors with cracked nozzles. The NRC denied Greenpeace's requests nearly two years later.[3]

- NRC denied Greenpeace's petition in large part because of a research report prepared by the Idaho National Engineering Laboratory for the NRC. This report, released in October 1994, concluded "CRDM nozzle cracking is not a short-term safety issue. All the detected cracks on the nozzle inside surface are axially oriented. ...Some analyses have shown that short, circumferential cracks on the outside surface are possible; however, these cracks are not expected to grow through-wall...." At the time of this conclusion, a grand total of one (1) US nuclear plant (Point Beach Unit 1in Wisconsin) had been inspected for CRDM nozzle cracking.[4]

- After large, through-wall, circumferential cracking was found on the outside surface of two CRDM nozzles at Oconee Unit 3 in August 2001, the NRC asked plant owners to write them about inspections of CRDM nozzles and the extent of identified cracking. In essence, the NRC only did *part* of what Greenpeace asked eight years earlier.

- After a huge gaping hole was found in the reactor head at Davis-Besse, the NRC finally sought the inspections that Greenpeace requested nine years earlier.

What should the reactor with a hole in its head teach us?

Company and NRC officials were quoted as being surprised by the nature and extent of the damage to the reactor vessel head at Davis-Besse. There were similar statements of surprise last summer about the nature and extent of damage to the CRDM nozzles at the Oconee nuclear plant, about the nature and extent of the damage to the steam generator tube at the Indian Point 2 nuclear plant in February 2000, about the nature and extent of the damage to the hot leg piping at the Summer nuclear plant later in 2000, about the nature and extent of the damage to the core shroud at the Nine Mile Point nuclear plant in 1997, and so on. Child-like wonderment is endearing on Christmas morning. It is dangerously irresponsible when consistently applied to nuclear safety.

To be surprised or not to be surprised, that's the question NRC must answer (hopefully right this time)

The NRC must stop allowing plant owners to conduct fewer inspections and to defer inspections for economic reasons. It would be a huge surprise for the NRC to someday put safety ahead of financial considerations. But that's a far better surprise than the surprise from finding a gaping hole in a reactor vessel head. It's a sure bet that there are nuclear power plants operating today with safety equipment degraded by aging. Will NRC surprise these gremlins or will they surprise NRC, again?

Notes:

[1] D. V. Rao, B. Letellier, C. Shaffer, S. Ashbaugh, and L. Bartlein, Los Alamos National Laboratory, Draft Technical Letter Report, "GSI-191: Parametric Evaluations for Pressurized Water Reactor Recirculation Sump Performance," July 2001.

[2] S. A. Loehlein, Root Cause Team Leader, FirstEnergy, to H. W. Bergendahl, Vice President -- Nuclear, FirstEnergy, "Probable Cause Summary Report for CR2002-0891, Significant Degradation of the Reactor Vessel Head Pressure Boundary," March 22, 2002.

[3] Nuclear Regulatory Commission, Director's Decision under 10 CFR 2.206, DD-95-02, January 26, 1995.

[4] V. N. Shah, A. G. Ware, and A. M. Porter, Idaho National Engineering Laboratory, "Assessment of Pressurized Water Reactor Control Rod Drive Mechanism Nozzle Cracking," NUREG/CR-6245, October 1994.