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Reactor Pressure Vessel Issues

Background

Reactor pressure vessels are thick steel containers that hold nuclear fuel when the reactors operate. The vessels provide one of several barriers that keep radioactive material out of the environment. NRC regulations describe how U.S. nuclear power plants must inspect, maintain and repair reactor pressure vessels. Several technical issues must be addressed as the vessels operate over a nuclear power plant's lifetime.

Embrittlement

Reactor operation generates subatomic particles called neutrons. Some of these neutrons hit atoms in the steel as they leave the core. These neutron impacts can reduce the steel's ability to withstand cracking and handle the stresses of operation. This "embrittlement" is generally most significant in a vessel's middle section, closest to the reactor fuel.

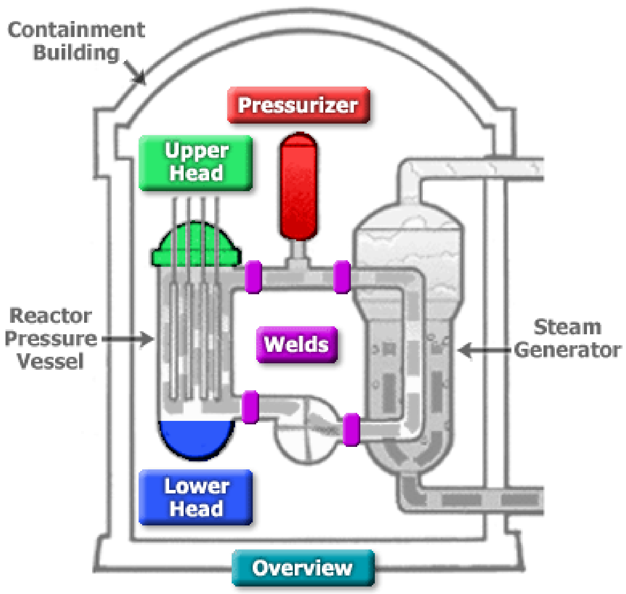
Pressurized-water reactors operate with a higher rate of neutron impacts and their vessels therefore tend to experience a greater degree of embrittlement than boiling-water reactor vessels. Many pressurized-water reactors design their cores to reduce the number of neutrons hitting the vessel wall. This slows the vessel's embrittlement. The chemical makeup of the vessel materials also affects a vessel's embrittlement rate. The NRC's regulations address embrittlement in 10 CFR Part 50, Appendix G, "Fracture Toughness Requirements" and Appendix H, "Reactor Vessel Material Surveillance Program Requirements."

Pressurized-water reactors also take embrittlement into account because of potential events called pressurized thermal shock, or PTS. In this accident scenario, cold water enters a reactor while the vessel is pressurized. This rapidly cools the vessel and places large thermal stresses on the steel. The NRC created 10 CFR Part 50.61 and 50.61a – the "PTS rule" and "alternate PTS rule" – to ensure the vessel's steel remains strong enough to protect the vessel's integrity. These rules require additional evaluations or other actions if embrittlement reaches certain limits. While PTS doesn't affect boiling-water reactors, there are very limited conditions where those vessels could overpressurize at low temperatures.

The NRC summarized these issues in an October 2000 supplement to "Reactor Pressure Vessel Status Report." As U.S. nuclear power plants comply with the regulations described above, they demonstrate their reactors will maintain adequate toughness throughout their operating lives.

Cracking of Upper Reactor Vessel Head Nozzles

Reactor vessels include a cap, or "head," which is removed for loading fuel or doing maintenance inside the vessel. The heads at pressurized-water reactors include access nozzles for devices such as rods that control the nuclear reaction. These nozzles are welded to the head. The reactors' combination of high temperature, pressure and chemicals in the water can lead to cracks in the welds. This could lead to safety issues, since a nozzle with enough cracking could break off during operation. Such a gap in the reactor vessel would bypass one of three primary barriers that keep radioactive material out of the environment. A broken nozzle could also eject a control rod and damage other safety systems.



The NRC's approach to dealing with this issue began in 2001, with a Bulletin to U.S. pressured water reactors asking about nozzle structural integrity. The plants responded with plans for inspecting their nozzles and the outside of the vessel heads to spot any cracked or leaking nozzles. Plant inspections later that year found nozzle cracking at four plants, all of which repaired their nozzles.

In 2002 the NRC issued another Bulletin that suggested plants might need supplemental machine-based examinations of vessel heads. The Bulletin asked pressurized-water reactors about their inspection programs, as well as any plans to supplement visual inspections. U.S. pressurized-water reactors described their immediate inspection plans, with many plants saying their long-term inspections would follow guidance from an industry research effort, the Materials Reliability Program.

Many pressurized-water reactors repaired vessel head nozzle and weld cracking after their 2002 inspections. Most plants also purchased new vessel heads made of an alloy much less susceptible to cracking. Based on the amount of cracking found, in February 2003 the NRC ordered specific inspections of U.S. pressurized-water reactor vessel heads and associated nozzles. The NRC updated the Order in February 2004. In 2008, the NRC issued a rule requiring all pressurized-water reactors to follow the American Society of Mechanical Engineers' Boiler and Pressure Vessel Code Case N-729-1, with NRC conditions. The rule replaced the Order with long-term inspection requirements for vessel heads and associated nozzles and welds. Today approximately seven plants have vessel heads with repaired nozzles and approximately 40 U.S. pressurized-water reactors have replaced their vessel heads.

Reactor Vessel Head Damage at Davis Besse

In March 2002, while the Davis-Besse nuclear reactor in Ohio was responding to the 2001 Bulletin, the plant identified a football-sized cavity in the reactor vessel head. The cavity was next to a cracked, leaking nozzle, in an area of the vessel head covered with deposits from years of leaks. A few days after the discovery, the NRC issued a Confirmatory Action Letter to the plant owner, First Energy Nuclear Corporation. The letter ensured the plant would remain shut down until the company evaluated and resolved the vessel head damage. Later analysis concluded the cracked nozzle leaked borated water, which created boric acid that corroded the vessel head's steel and created the cavity.

The NRC's 2003 Bulletin addressed the generic implications of the Davis-Besse corrosion on the safe operation of U.S. pressurized-water reactors. The NRC reviewed the industry's responses to the Bulletin in order to ensure proper actions were taken. More information on the agency and industry response to the Davis-Besse corrosion is available on the NRC website.

Cracking of Lower Reactor Vessel Head Nozzles

In 2003, inspections at the South Texas Project Unit 1 pressurized-water reactor discovered small deposits of boron (found in reactor coolant) at the bottom of the reactor vessel. The deposits centered on two bottom-mounted instrumentation nozzles. Further examination of all bottom-mounted nozzles at the South Texas nuclear power plant confirmed only those two nozzles were cracked. The plant repaired the cracked nozzles and resumed normal operations later in 2003.

The South Texas plant reviewed the inspection results and analyzed a material sample from one of the leaking nozzles. The plant concluded the nozzles had small defects from their original construction. These defects most likely created conditions that allowed the reactor's high temperature, pressure and water chemistry to crack the nozzles.

In August 2003, the NRC issued an Information Notice and a Bulletin in order to address the generic safety implications of the South Texas cracking experience on operations of U.S. pressurized water reactors. Industry responses to the Bulletin are available on NRC's website.

In late 2013, inspections at the Palo Verde Unit 3 reactor in Arizona discovered small boron deposits on one bottom-mounted instrumentation nozzle. Further testing concluded the nozzle was the only one with flaws; it was repaired and the plant resumed normal operations.

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