U.S.NRC
UNITED STATES NUCLEAR REGULATORY COMMISSION
Protecting People and the Environment

FACT SHEET

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Reactor Pressure Vessel Issues

Embrittlement

Reactor pressure vessels, which contain the nuclear fuel in nuclear power plants, are made of thick steel plates that are welded together. Neutrons from the fuel in the reactor irradiate the vessel as the reactor is operated. This can embrittle the steel, or make it less tough, and less capable of withstanding flaws which may be present. Embrittlement usually occurs at a vessel's "beltline," that section of the vessel wall closest to the reactor fuel.

Pressurized water reactors (PWRs) are more susceptible to embrittlement than are boiling water reactors (BWRs). BWR vessels generally experience less neutron irradiation and therefore less embrittlement. Many utilities owning PWRs use core designs that reduce the number of neutrons that reach the vessel wall. These design features therefore reduce the rate of embrittlement in the reactor vessels. Other factors also contribute to the degree to which a particular vessel material becomes embrittled. Steels with a higher proportion of copper and nickel will tend to be more susceptible to embrittlement, than are steels with lower proportions of these two elements. [Pertinent regulations that govern this phenomenon include 10 CFR Part 50, Appendix G "Fracture Toughness Requirements" and Appendix H, "Reactor Vessel Material Surveillance Program Requirements."]

Another reason reactor vessel embrittlement is more of a concern for PWRs is because PWRs may experience pressurized thermal shock (PTS). PTS can occur under some accident scenarios that introduce cold water into the reactor vessel while the vessel is pressurized. Introduction of cold water in this manner can cause the vessel to cool rapidly, resulting in large thermal stresses in the steel. These thermal stresses, along with the high internal pressure and an embrittled vessel, could lead to cracking and even failure of the vessel. The NRC has established a regulation (10 CFR part 50.61 – the "PTS rule") to address the potential for the reactor vessels of PWRs to be affected by PTS events. The PTS rule includes criteria that limit the amount of vessel embrittlement the NRC will permit without requiring additional evaluations or corrective actions. BWRs are not susceptible to PTS events. If cold water is pumped into a BWR vessel, the steam in the vessel will condense and reduce the internal pressure. BWRs may however be susceptible to overpressurization of the reactor pressure vessel at low temperatures under certain conditions.

NUREG-1511, "Reactor Pressure Vessel Status Report" discusses the issue of vessel structural integrity and provides a plant-by-plant status. Updates were published in October 1996 (Supplement 1) and in October 2000 (Supplement 2). All plants are expected to maintain adequate toughness throughout their operating lives.

Primary Water Stress Corrosion Cracking of Upper Reactor Vessel Head Penetration Nozzles in PWRS

Control rod drive mechanism nozzles and other vessel head penetration nozzles welded to the upper reactor vessel head are subject to another phenomenon – primary water stress corrosion cracking. The issue is a potential safety concern because a nozzle with sufficient cracking could break off during operation. This would compromise the integrity of the reactor coolant system pressure boundary – one of three primary barriers that protect the public from exposure to radiation. The break may also result in the ejection of a control rod, which could damage nearby components.

On August 3, 2001, the NRC issued Bulletin 2001-01, "Circumferential Cracking of Reactor Pressure Vessel Head Penetration Nozzles," to licensed holders of U.S. pressured water reactors (PWR) following the discovery of cracked and leaking nozzles in 2000 and 2001. In the bulletin, the staff requested information from PWR licensees about the structural integrity of these nozzles at their facilities. In response to the bulletin, licensees provided their plans for inspecting their nozzles and the outside surfaces of their upper reactor vessel heads to determine whether any nozzles were leaking. Inspections by licensees during the fall of 2001 revealed vessel head penetration nozzle cracks at Three Mile Island Unit 1, Crystal River Unit 3, North Anna Unit 1, and Oconee Unit 3.

On August 9, 2002, the NRC issued Bulletin 2002-02, "Reactor Pressure Vessel Head and Vessel Head Penetration Nozzle Inspection Programs." The bulletin suggested that visual inspections of upper reactor vessel heads and their nozzles may need to be supplemented with non-visual non-destructive examinations to assure that the structural integrity and leakage integrity of the nozzles is maintained. Bulletin 2002-02 requested that PWR licensees provide information about their inspection programs and plans to supplement existing visual inspections with volumetric and surface examinations. Licensees responded with descriptions of inspection plans for at least the first refueling outage following the issuance of the bulletin. Many did not offer any long-term inspection plans, but instead opted to follow guidance being developed by the Materials Reliability Program, which is an industry-sponsored research organization.

Inspections performed at several PWRs in 2002 including those performed at the Davis-Besse Nuclear Plant, found leakage and cracks in vessel head penetration nozzles or J-groove welds that have required repairs or prompted the replacement of the vessel head. As a result of continuing concerns regarding licensee inspection programs in this area, the NRC issued an Order on February 11, 2003, to all PWR licensees in the U.S. The Order requires specific inspections of the vessel head and associated penetration nozzles based on their susceptibility to primary water stress corrosion cracking. The Order may be accessed at the following address on NRC's website: http://www.nrc.gov/reactors/operating/ops-experience/vessel-head-degradation/vessel-head-degradation-files/order-rpv-inspections.pdf.

Twenty-six units were identified by the Electric Power Research Institute's Materials Reliability Program as having a high susceptibility to nozzle cracking. Inspections by licensees performed after issuance of the latest bulletin and order, revealed nozzle or J-groove weld cracks and/or leaks at Oconee Unit 2, North Anna 2, Arkansas Nuclear One Unit 1, St. Lucie Unit 2, Milestone Unit 2, and Beaver Valley Unit 1. The utilities owning the Oconee, Surry, Davis-Besse and North Anna nuclear stations have replaced or are in the process of replacing their upper reactor vessel heads. Approximately twenty other units have announced plans to have their upper reactor vessel heads replaced within the next few years.

Reactor Vessel Damage at Davis-Besse

In early March of 2002, during an inspection prompted by Bulletin 2001-01, Davis-Besse Nuclear Power Station identified a football-sized cavity in the units reactor vessel head. The cavity was next to a leaking nozzle with a through-wall crack and was in an area of the vessel head that had been covered with boric acid deposits for several years. Inspections at Oconee Unit 1 and Millstone Unit 2 also identified nozzle cracking. The discovery of leaks and nozzle cracking at Davis-Besse and other PWR plants called for more effective inspections of reactor pressure vessel heads and associated penetration nozzles.

On March 13, 2002, the NRC issued a Confirmatory Action Letter to First Energy Nuclear Corporation confirming the company's commitments to evaluate and resolve damage to the reactor pressure vessel head at the Davis-Besse Nuclear Power Station, which is located in Oak Harbor, Ohio. Inspections revealed a cavity in the top of the reactor pressure vessel head that may have been caused by corrosion from boric acid deposits. Two meetings were held – one with industry and one with the public – to discuss the generic implications of the problem.

On March 18, 2003, the NRC issued 2002-01, "Reactor Pressure Vessel Head Degradation and Reactor Coolant Pressure Boundary Integrity," to address the generic implications of the degradation at Davis-Besse on the safe operation of PWRs in the U.S. and on the health and safety of the public. NRC Bulletin 2002-01 and the NRC's review of the industry's responses to Bulletin 2002-01 may be accessed at the following addresses on NRC's website: http://www.nrc.gov/reading-rm/doc-collections/gen-comm/bulletins/2002/bl02001.html and http://www.nrc.gov/reactors/operating/ops-experience/vessel-head-degradation/plant-specific-information.html.

Primary Water Stress Corrosion Cracking of Lower Reactor Vessel Head Penetration Nozzles in PWRs

On April 12, 2003, the licensee for South Texas Project Unit 1 (STP 1) discovered small boron deposits around two of the unit's bottom mounted instrumentation penetration nozzles during a bare metal visual examination of the reactor pressure vessel (RPV) bottom head. Subsequent nondestructive examination of all 58 nozzles at the South Texas nuclear power plant confirmed the existence of leaking, axially-oriented flaws in the two nozzles. No flaws were found in any of the other 56 nozzles at the plant. The licensee repaired the two cracked nozzles using a method known as a "half-nozzle" repair and returned the unit to power operations in August 2003.

Based on the licensee's examination results and the information gained from a material sample obtained from one of the leaking nozzles, the licensee for South Texas 1 concluded that the observed cracking was due to primary water stress corrosion of the Inconel Alloy 600 nozzle material. The licensee also concluded that the most likely root cause of this cracking involved fabrication-related defects which may have created conditions that lead to initiation of this nozzle cracking.

Additional information on this experience may be accessed on NRC's web site at: http://www.nrc.gov/reactors/operating/ops-experience/bottom-head-penetration-leakage.html.

On August 13, 2003, the NRC issued NRC Information Notice 2003-11, "Leakage Found on Bottom-Mounted Instrumentation Nozzles," to inform members of the U.S. nuclear power industry and members of the public of this event. Information Notice 2003-11 may be accessed on NRC's web site http://www.nrc.gov/reading-rm/doc-collections/gen-comm/info-notices/2003/in200311.pdf.

On August 21, 2003, the NRC issued NRC Bulletin 2003-02, “Leakage from Reactor Pressure Vessel Lower Head Penetrations and Reactor Coolant Pressure Boundary Integrity,” in order to address the generic safety implications of the South Texas cracking experience on operations of pressurized water reactors in the U.S. and specifically as the operations relate to maintaining the health and safety of the public. The staff is currently in the progress of reviewing the industry’s responses to NRC Bulletin 2003-02. NRC Bulletin 2003-02 may be accessed on NRC’s web site at: http://www.nrc.gov/reading-rm/doc-collections/gen-comm/bulletins/2003/bl03002.pdf.

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