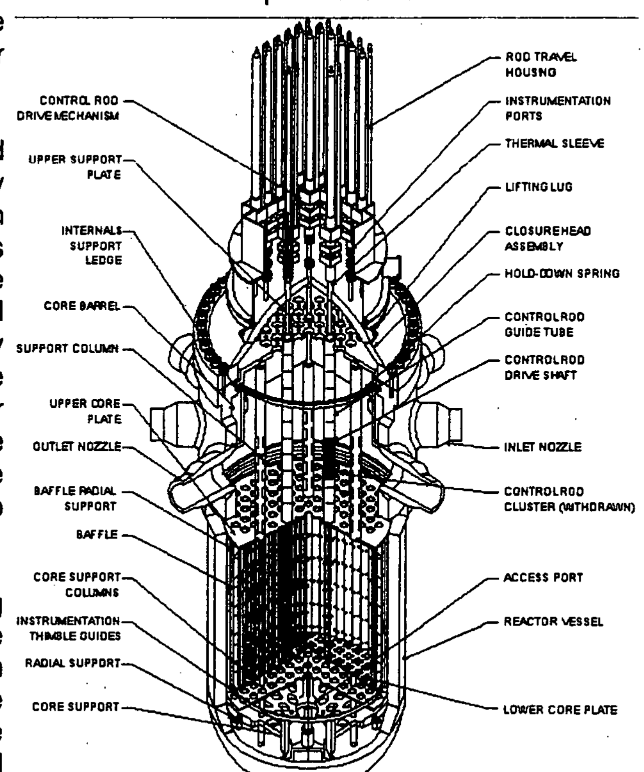
Union of Concerned Scientists
Citizens and Scientists for Environmental Solutions
issue brief

Not-So-Happy Anniversary: 10 Years of Band-Aid Fixes for CRDM Nozzle Cracking

Workers testing the integrity of the reactor vessel at France's Bugey Unit 3 in September 1991 found something that had never been seen before — cracks extending completely through the wall of a control rod drive mechanism nozzle that permitted reactor cooling water to leak out. Subsequent examinations discovered cracks of up to two inches long.[1] Nearly ten years later, the U.S. Nuclear Regulatory Commission is seeing what it said would not be seen — even more serious cracking of CRDM nozzles at nuclear reactors in the United States. And we are belatedly seeing what should have been seen at least six years ago — efforts by the NRC to address this nuclear safety hazard. But we have not yet seen what foreign countries have done to solve CDRM nozzle cracking — replacement of the reactor vessel heads.

What is a CRDM Nozzle?

In pressurized water reactors like Bugey and roughly two-thirds of the nuclear plants operating in the United States, control rods enter the reactor core from the top. The control rods are withdrawn when the plant is operating, but can be fully inserted within seconds to stop the nuclear chain reaction and shut down the reactor.



Each control rod is attached to its own control rod drive mechanism (CRDM). The CRDM is basically a long pole and equipment that is used to position the control rod. The pole is so long that it extends through the domed metal enclosure head to the reactor vessel. Above the vessel head, CRDM equipment moves the long pole. By sequentially energizing a number of electromagnets, the pole can be lifted or lowered, which in turn withdraws or inserts the attached control rod. If the electromagnets are de-energized, their grip on the pole is released and the control rod drops fully into the reactor core by gravity.[2]

The holes cut in the metal vessel head for the long poles receive special attention because the pressure inside the reactor vessel during operation exceeds 2,000 pounds per square inch. The CRDM nozzles are hollow tubes containing the long poles. The upper end of the nozzle is capped while the lower end, located inside the reactor vessel, is open. The nozzles, made of steel called Alloy 600, are welded to the vessel head. The reactor vessel and the nozzles form the reactor coolant pressure boundary.

[1] 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.
[2] The University of California at Berkeley, System Training Guide A-3a, "Rod Control System," 1996.

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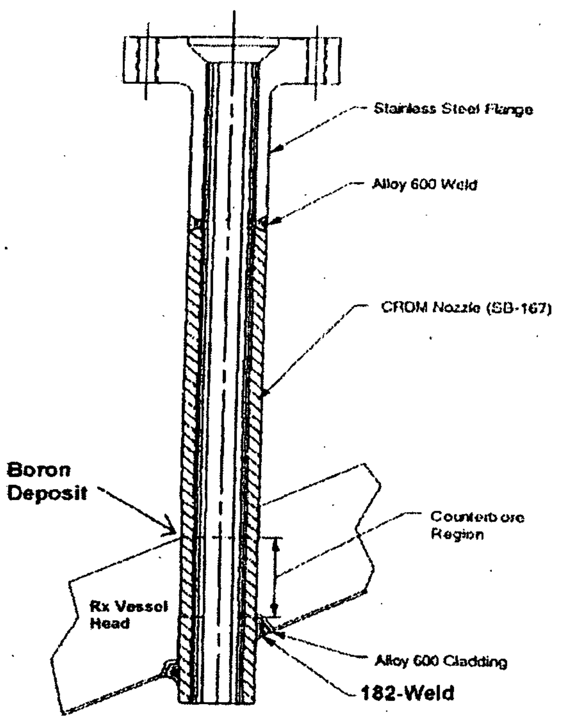
Why are the CRDM Nozzles Cracking?

CRDM nozzles are susceptible to degradation by Primary Water Stress Corrosion Cracking (PWSCC). The PWSCC occurs when stress causes material imperfections to get "pulled." High temperatures of up to 600ºF during reactor operation create stress. Metal expands as its temperature increases. The reactor vessel is not at the same temperature because some parts are closer to the reactor core and air conditioning flow outside the reactor vessel is different. Temperature differences create stress as parts of the reactor vessel expand at different rates. Stress can cause a crack at any minor imperfection in the metal leftover from the manufacturing or installation processes. Once a crack develops, stress causes it to grow larger.

What Happens When CRDM Nozzles Crack?

CRDM nozzle cracking can lead to rupture of the nozzle followed by ejection of the CRDM/control rod or leakage of reactor water onto the unprotected outer surface of the vessel head causing its failure.

In April 2001, the owner of Oconee Unit 3 in South Carolina reported finding through-wall leaks on nine of sixty-nine CRDM nozzles. Workers found the leaks after observing boron deposits at the base of the CRDM nozzle as shown in the figure. Boron deposits are clear signs that borated reactor water is leaking out. The cracking extended nearly 45 percent of the way around the circumference of nozzle-to-vessel head welds on two CRDM nozzles.[3]



At some point, cracks can grow so large that the CRDM nozzle no longer remains intact with over 2000 pounds per square inch pressure inside and zero pressure outside. The catastrophic rupture of the CRDM nozzle causes a loss-of-coolant accident. In addition to the reactor water pouring out the hole, the CRDM could be ejected, pulling its control rod out of the reactor core.

The inner surface of the reactor vessel head is covered by stainless steel (represented in the figure by the thin gray region at the bottom edge). The stainless steel protects the reactor vessel head from corrosion by borated water (i.e., dilute boric acid). The outer surface of the reactor vessel head is unprotected. Borated water can weaken the reactor vessel metal through corrosion, particularly when evaporation causes the boron concentration to increase. If the weakened reactor vessel fails, water may leak out faster than the emergency systems can replace it.

[3] Duke Energy, Licensee Event Report No. 50-287/2001-001 Rev. 0, April 18, 2001, and Nuclear Regulatory Commission, Bulletin No. 2001-01, "Circumferential Cracking of Reactor Pressure Vessel Head Penetration Nozzles," August 3, 2001.

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What Has the NRC Done About CRDM Nozzle Cracking?
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.[4]

The NRC's denial was based in large part on the 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.[5]

After large, through-wall, circumferential cracking was found on the outside surface of 2 CRDM nozzles at Oconee Unit 3, the NRC asked plant owners to write them about inspections of CRDM nozzles and the extent of identified cracking. In essence, the NRC is doing *part* of what Greenpeace asked eight years ago.

What Should the NRC Do About CRDM Nozzle Cracking?
After the NRC's letter collecting campaign is out of the way, the NRC should take real steps to protect public health and safety. As a bare minimum, the NRC should do what has already been done in foreign countries to protect non-Americans from CRDM nozzle cracking:[6]

1. "In Japan, the three most susceptible vessel heads are being [have been] replaced because of safety considerations, even though no cracks were found in the nozzles of these heads."

2. "In France, EDF has found it economical to replace the vessel heads having defective nozzles; several heads have been replaced or are planned to be replaced."

3. "In Sweden, replacement of the Ringhals 2 vessel head is planned."

4. "Removable insulation on the vessel head and N-13 monitoring systems are installed at French and Swedish plants for early detection of leakage from through-wall cracks in the nozzle wall." "Installation of a N-13 leak monitoring system can provide a continuous and accurate monitoring of a leak as small as 0.2 L/h (0.001 gpm) from a cracked CRDM nozzle."

What Will the NRC Probably Do About CRDM Nozzle Cracking?
It is highly unlikely that the NRC will require any of the safety measures that already have been taken at foreign reactors; at least not until after an accident at a US reactor demonstrates that the band-aid fix experiments are inadequate.

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[4] Nuclear Regulatory Commission, Director's Decision under 10 CFR 2.206, DD-95-02, January 26, 1995.
[5] 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.
[6] 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.