Pressurized Thermal Shock Potential at Palisades

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History of Embrittlement of Reactor Pressure Vessels in Pressurized Water Reactors

Irradiation embrittlement of the reactor pressure vessels (RPVs) may be the single most important factor in determining the operating life of a PWR. PWR vessels are generally constructed from eight inch thick steel plates, formed and welded to create the vessel structure. The major age-related mechanism associated with this component is embrittlement. Embrittlement is the loss of ductility, i.e., the ability to withstand stress without cracking, in the metals which make up the reactor pressure vessel. Embrittlement is caused by neutron bombardment of the vessel metals and is contingent upon the amount of copper and nickel in the metal and the extent of neutron exposure or fluence. In an unirradiated vessel the metal loses its ductility at about 40 degrees F. As the vessel becomes embrittled, the temperature at which it loses its ductility rises. This change in the mechanical properties of the metal from ductile to brittle is characterized as the reference temperature for nil ductility transition or Rtndt. Thus as the reactor ages and RPV is exposed to more radiation the Rtndt can shift from its original 40 degrees F to as much as 280-290 degrees F or more in extreme cases. (Server, Odette, Ritchie, "Pressurized Water Reactor Pressure Vessels" Vol. 1, NUREG/CR-4731)

Embritllement is of even greater concern to those plants constructed prior to 1972. The reason for this is that there is copper in the walls of older vessels. The use of copper was also extensive in the welds of the vessel walls in older reactors. Copper coated wire was routinely used to weld together the large plates which make up the RPV. Palisades began construction in 1967 and went commercial in 1972. (Edelson, "Thermal Shock-New Nuclear Reactor Safety Hazard?", Popular Science, June 1983, p.55-63)

The significance of reactor pressure vessel embrittlement is the increased susceptibility to Pressurized Thermal Shock (PTS). Pressurized Thermal Shock occurs when the reactor pressure vessel is severely overcooled. As the PRV is overcooled, there is a drop in the pressure of the primary coolant loop. This rapid decrease in the pressure of the primary coolant causes the high pressure injection pumps in the emergency core cooling system to automatically inject coolant into the primary loop. As the injection of coolant repressurizes the RPV, the vessel is subjected to pressure stresses. The stresses placed on the reactor pressure vessel by overcooling and repressurization causes Pressurized Thermal Shock. (Sholly, "Pressurized Thermal Shock Screening Criteria", Report prepared for Nuclear Information and Resource Service, January 1984)

Pressurized Thermal Shock (PTS) can be initiated by a host of mishaps including: instrumentation and control system malfunctions; small-break loss-of-coolant accidents; mainsteam line breaks; feed water pipe breaks; and steam generator tub ruptures. Any of these incidents can initiate a PTS event. If the fracture resistance of the RPV is reduced through neutron bombardment, severe overcooling accompanied by repressurization could cause flaws in inner surface of the RPV to propagate into a crack which breaches the vessel wall. (Thadani, NRC Memorandum RE: Frequency of Excessive Cooldown Events Challenging Vessel Integrity, April 21, 1981)

Without the reactor pressure vessel surrounding the radioactive fuel it would be impossible to sufficiently cool the reactor core and a meltdown would ensue. (Ibid, Thadani) Pressurized Thermal Shock is a safety issue for every pressurized water reactor. (ibid, NUREG/CR-4731 p. 105)

The Nuclear Regulatory Commission has vacillated on the issue of Pressurized Thermal Shock for over twenty five years now. Rtndt limits had been originally set at 200 degrees Fahrenheit. These limits were reached in the early to mid 1980's, the NRC began developing new limits within the framework of the PTS rule. In 1982, the NRC considered Rtndt limits of 230 and 250 degrees F for longitudinal and circumferential welds respectively. By 1985, the NRC sought to amend its regulations on Pressurized Thermal Shock. New reference temperatures established limits of 270 degrees F for plate materials and axial welds and 300 degrees F for circumferential welds.
(Ibid, Edelson)

The Commission (NRC) attempted to gloss over the fact that an increase in the Rtndt translated into a decreased margin of safety. An NRC press release said the rule constituted "further protection from Pressurized Thermal Shock". (Demetrios L. Basdekas, Letter to New York Times, 1985) To cope with the most severely embrittled reactors the NRC has allowed some plants to redesign the configuration of the fuel rods so that fewer neutrons bombard the RPV wall.

(The above text has been excerpted from Chapter IV of: "The Aging of Nuclear Power Plants: A Citizens Guide to Causes and Effects" Nuclear Information and Resource Service, August 1988 authored by James Riccio and Stephanie Murphy. Use granted by James Riccio.)

Embrittlement at Palisades

As early as July of 1981 the NRC identified the Palisades reactor as one of fourteen pressurized water reactors (PWR) with serious embrittlement problems. These fourteen embrittled plants are especially troublesome at high pressures and low temperatures, and can cause the pressure vessel to crack like hot glass dunked in cold water. At normal operating temperatures embrittlement poses no problem. But with a rapid drop in coolant temperature, caused by a very common scram or transient, the pressure vessel 's insides try to contract. The outside of the vessel is still very hot and the temperature differential creates enormous tensile stresses. (Excerpts from Not Man Apart, Nov. 1981, published by Friends of the Earth)

According to Public Citizen Nuclear Lemons report (July 8, 1993) Palisades has experienced nine scrams in the previous three years ranking it the tenth worst in the nation (1993). As noted above these are precisely the conditions which can lead to pressure vessel rupture if embrittlement is present. Embrittlement at Palisades in 1981 was reported to occur at temperatures of between 190 and 220 degrees F. (Ibid, excerpts from Not Man Apart) As noted earlier the NRC had originally set reference temperature for nil ductility transition (Rtndt) at 200 degrees F. As early as 1981 Palisades had exceeded these original Rtndt limits.

Very little can be done to forestall or avoid the problem; it is a process of aging. A number of fuel rods can be reconfigured and operating temperatures reduced; this simply slows the rate of embrittlement and substantially reduces the output of the reactor. This reduces the efficiency or capacity factor of the reactor. (Ibid, excerpts from Not Man Apart) Redesign of the configuration of the fuel rods at the Palisades plant is precisely what has been done in attempts to mitigate the ever increasing embrittlement of the Palisades reactor pressure vessel.

The following is a synopsis of a Consumers Power Company document dated May, 1990 entitled: "Analysis of the Reactor Pressure Vessel Fast Neutron Fluence and Pressurized Thermal Shock Reference Temperatures for the Palisades Nuclear Plant" authored by the Reactor Engineering Department at Palisades.

In a cover letter dated May 17, 1990 discussing the May report it is concluded that the Pressurized Thermal Shock (PTS) screening criteria will be exceeded at the axial welds (vertical welds) in September of 2001. Also, "that the flux reductions achieved in the Cycle 8 and 9 core loading patterns are, by themselves, insufficient to allow plant operation to the current expected end of life in (the year) 2011"... "Further measures, eg, greater flux reduction, Regulatory Guide 1.154 analysis, vessel shielding etc, are necessary to allow plant operation to the nominal end of plant life and beyond."

Initiated with fuel cycle 1 and continuing through fuel cycle 7 core loading patterns were typical of out-in fuel management, in that fresh fuel was placed on the core periphery. This approach results in the maximum overall core neutron leakage and flux to the reactor pressure vessel. This is the neutron bombardment which leads to embrittlement, this took place from 1971 through approximately 1987. Beginning with fuel cycle 8 thrice used fuel assemblies with stainless steel shielding rods were located near the axial weld locations on the core periphery. These are the locations where embrittlement is of the most concern. With the fuel cycle 8 reconfiguration flux reduction of a factor of two were reported at the axial weld locations. Similar measures will be incorporated in fuel cycle 9. (Ibid, May 1990 p.1) However as noted in July of 1981 the Palisades plant was already experiencing embrittlement problems. (Ibid, Not Man Apart)

The old adage "like closing the barn door after the horse is out" comes to mind.

Operation beyond the end of cycle 8 (September 1990) was assumed to occur at 75% capacity. With no flux reduction utilized, the PTS screening criteria would be exceeded at the axial welds in 1995. With flux reduction incorporated in cycle 9 and beyond, the PTS limit would be exceeded at the axial welds in September, 2001. These predicted dates are far short of the assumed nominal plant operating license expiration date of March, 2011. (Ibid, May 1990 p. 4) In order to get to the year 2001 before exceeding PTS limits it is assumed that the plant will not exceed 75% capacity factor after cycle 8. (Ibid. May 1990 p. 12)

The models for determining vessel flux and fluence calculations are extrapolations. The last actual measurement data (from the suspect axial welds) that was taken for comparison from an analysis of radiometric dosimeters irradiated in the W-290 vessel wall surveillance capsule was removed at the end of cycle 5. (ibid, May 1990 p. 8) There are methodological uncertainties with the reliance on proxy indicators of energy generation data, and reactor power history to determine the level of vessel embrittlement. The computer models employed to estimate the level of flux and fluence and ultimately vessel embrittlement are subject to "GIGO". That is garbage in, garbage out, they are at best estimates based on many assumptions, they are not actual analysis of the metal.

Specifically the problem axial welds identified which would limit the life of the Palisades reactor are located at 0 degrees and 30 degrees. It is not clear if these are the only axial welds that are suspect. In the methodology section 3.3 Geometry it is stated that the Palisades reactor exhibits 1/8 th core symmetry, thus only a zero to 45 degree sector has been included in the DOT model. Are there suspect axial welds in the remaining 7/8 th's of the vessel? Are there suspect circumference welds?

Consumers Power Company (Now CMS) acknowledges a calculational uncertainty of + / - 25% is estimated in the calculated vessel wall fluence, this is said to be typical of current neutron transport methodology uncertainties. Considering the consequences of a core meltdown the + / - 25% margin of error is not acceptable.

Consumers Power Company goes on to discuss other means to maximize vessel lifetime including areas of greater flux reduction; waiting for the NRC to again relax PTS standards; data manipulation and use of other estimating models; vessel annealing (artificially overheating the vessel to bring back the ductility); and shielding actions to reduce the accumulated vessel embrittlement rate. (Ibid, May 1990 p. 45) These are all measures that were never considered or conceived when the promise of "too cheap to meter" was the talk of the day.

As it stands the outside limit on the life of Palisades is the year 2001, running at a 75% capacity factor with a + / - 25% margin of error on neutron bombardment. These are serious economic constraints. All of this with the perpetual threat of loss of the containment due to Pressurized Thermal Shock coupled with the danger of storage of High Level Nuclear Waste on the shore of Lake Michigan. Consider the risk: The NRC commissioned a study from the Sandia Labs which was tho provide an assessment of a worst case accident at each U.S. nuclear power plant. The 1982 study concluded that there would be 52.6 billion dollars (1980 dollars) of damage at Palisades. 13,000 deaths due to cancer would occur. This study does not consider the loss of 20% of the world's surface fresh water.

Continued operation of the Palisades nuclear power plant constitutes poor economics and poor public policy. The day has come to shut down Palisades for economic, environmental, and safety reasons. The Coalition for a Nuclear Free Great Lakes calls on the Michigan Public Service Commission to hold public hearings concerning the viability of the Palisades plant and to place the onus upon Consumers Power Company to show cause as to why the plant should not be removed from operation.