



**Union of  
Concerned  
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Citizens and Scientists for Environmental Solutions

## **Davis-Besse's Five-Month Safety Cushion**

Years of unbelievable neglect by the FirstEnergy Nuclear Operating Company (FENOC) and the Nuclear Regulatory Commission (NRC) resulted in a gaping hole in the metal lid on the vessel housing the reactor core at the Davis-Besse nuclear plant in Ohio. A thin stainless steel liner, installed to protect the metal lid from corrosion but never intended to retain pressure, is all that kept water cooling the reactor from escaping within seconds. In other words, luck rather than skill saved the day.

The NRC recently issued a report showing how much luck was involved. The NRC's Office of Research, working in conjunction with scientists at National Laboratories, conducted experiments using materials intended to emulate the metal lid configuration at Davis-Besse. Their conclusion – the stainless steel liner would have burst open had Davis-Besse operated for two to thirteen more months with the most likely time being five months.

Five months is not much of a safety cushion in nuclear time. FENOC runs Davis-Besse on a two-year operating cycle, meaning that the reactor shuts down every 24 months for refueling and maintenance. Plant owners typically schedule the refueling outages in the spring or fall when electricity demands are lower than in summer and winter peak demand periods. FENOC had Davis-Besse slotted for spring outages. It came down for refueling in the spring of 1996, 1998, 2000, and 2002. The following two scenarios illustrate that five months was a very thin cushion.

### **Scenario 1 – Workers at Oconee Do Not Detect CRDM Nozzle Cracking**

Workers at Oconee, a sister nuclear plant in South Carolina, found unexpected cracks and leaks in tubes called control rod drive mechanism (CRDM) nozzles passing through the reactor's metal lid in the spring of 2001. The NRC reacted to that surprise discovery by requiring owners of potentially vulnerable plants to inspect their CRDM nozzles for cracks. Workers performing this non-routine inspection during Davis-Besse's 2002 refueling outage discovered the gaping hole in the reactor lid. Absent that fortuitous discovery, it is questionable whether the hole would have been otherwise found. It has been established that FENOC failed to follow its own procedures for cleaning and inspecting the reactor lid during the 1996, 1998, and 2000 refueling outages. Thus, they could have easily missed it again during the 2002 refueling outage. Had Davis-Besse restarted from its spring 2002 refueling outage without discovering the gaping hole, the NRC's report indicates that the stainless steel liner would have burst open two to thirteen months later. In other words, Davis-Besse could not have operated to its next scheduled refueling outage in spring 2004. The most likely timing of the disaster would have been five months after restart, or the October 2002 timeframe.

### **Scenario 2 – Davis-Besse Refuels in Odd Rather Than Even Years**

FENOC was bringing Davis-Besse offline in the spring of even years (e.g., 1996, 1998, 2000, 2002, 2004, etc.) for refueling. But past performance of the plant could just as easily have placed the reactor into an odd-year refueling window (e.g., 1997, 1999, 2001, 2003, 2005, etc.). For example, Toledo Edison might not have taken so long to bring Davis-Besse back online following its June 1985 near-miss or if the company could have transitioned from 12-month to 24-month refueling outages differently. Had that been the case, Davis-Besse would have been refueling in spring 2001 around the same time workers at Oconee made their surprise discovery. The NRC did not require owners of potentially vulnerable

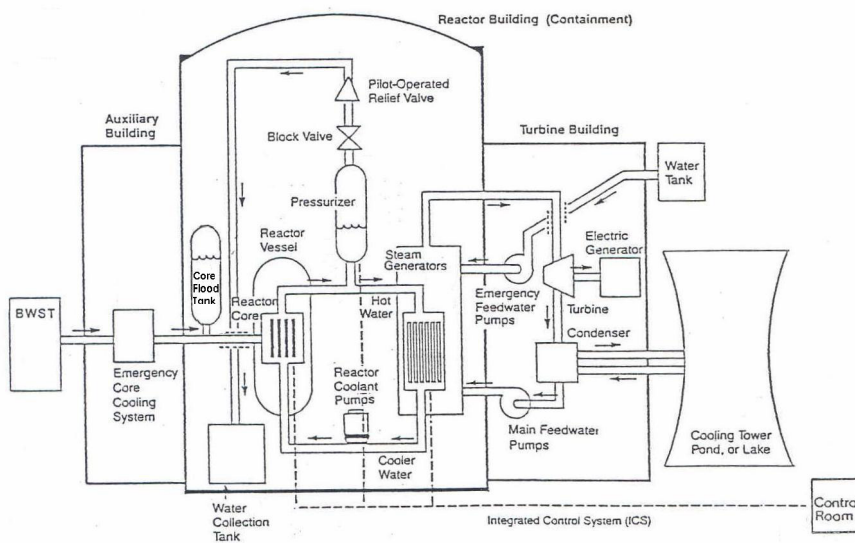
plants to inspect CRDM nozzles for cracks until August 2001 – after FENOC would have restarted Davis-Besse in spring of 2001. Assuming that NRC would have lacked the wherewithal to compel FENOC to shut down Davis-Besse for the required inspections (a fairly safe assumption given that the NRC demonstrated wherewithal deprivation on November 28, 2001, by deciding not to issue the shutdown order it had prepared for Davis-Besse), the stainless steel liner would have likely burst open in August 2003.<sup>1</sup> The irony is that the liner may have failed during the electrical grid blackout caused, in large part, by FENOC's other performance problems.

### What Would Have Happened?

To outline what might have happened had either scenario occurred, the Union of Concerned Scientists (UCS) reviewed results from evaluations of potential accidents conducted by Davis-Besse's owner as described in the plant's Updated Safety Analysis Report and documents cited at the end of this report.

### Background

The Davis-Besse reactor core has 177 fuel assemblies forming a cylinder roughly 12 feet tall and 11 feet in diameter. The reactor core contains about 84 metric tons of uranium fuel. The NRC licensed Davis-Besse for a maximum output of 2,772 megawatts of thermal energy (Mwt). When the plant operates at full power, nearly 23 million gallons of water cycles back and forth between the reactor vessel and two steam generators every hour to cool the reactor core. This water is heated to 608°F by the reactor core but does not boil because it is kept at nearly 2,200 pounds per square inch pressure. The very hot, pressurized water enters the steam generators where it flows inside tubes. Heat passes through the tubes' thin walls to boil water outside the tubes. The water exits the tubes at about 557°F and returns to the reactor vessel helped along by the reactor coolant pumps.



The steam from the water boiling outside the tubes within the steam generators passes through large pipes to spin blades within the turbine. The turbine is connected to an electrical generator providing nearly 900 megawatts of electricity (Mwe) to the grid when Davis-Besse operates at full power.

The steam leaving the turbine enters a large box called the condenser. Tubes inside the condenser circulate water drawn from the lake between the condenser and the cooling tower. The steam is cooled down until it turns back into water. The main feedwater pumps return the water to the steam generators. The Davis-Besse plant is only one-third efficient. For every watt of electricity produced, nearly two watts of waste heat are discharged to the environment.

<sup>1</sup> The NRC's five month estimate is added to February 2002 which marked the starting point for the NRC's experiments. An additional month is added to represent the refueling outage period in spring 2001 for this scenario.

When Davis-Besse is operating, the emergency core cooling system and the emergency feedwater pumps are in standby mode for use in event of an accident.

#### Stainless Steel Liner Rupture

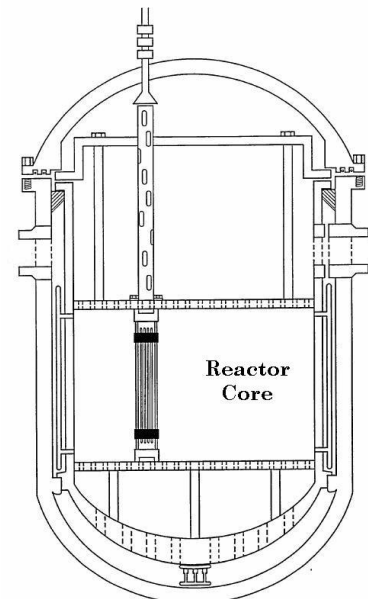
The stainless steel liner, already cracked and bulging outward under normal pressure and lacking the structural support from the missing portion of the reactor lid, breaks wide open causing a loss of coolant accident (LOCA). The ensuing LOCA has four distinct phases: (1) blowdown, (2) refill, (3) reflood, and (4) recirculation.

During the blowdown phase, the reactor vessel rapidly depressurizes as water jets out through the large hole in the reactor's lid into the containment. The hot water flashes to steam as its pressure drops upon exiting the hole. The blowdown phase ends within tens of seconds when the pressure inside the containment rises to balance that inside the emptied reactor vessel. The surface temperature of the fuel rods inside the reactor core nearly doubles during the blowdown phase to about 1,200°F.

Even though the reactor core automatically shut down within seconds of the blackout, it continues to generate considerable amounts of heat. Thirty minutes after shut down, the reactor emits nearly two (2) percent of the heat it generated at full power. Two percent may not sound like much, but it's around 180,000,000 British Thermal Units (BTUs) per hour. A single BTU is defined as the heat needed to increase the temperature of one pound of water by one degree Fahrenheit at atmospheric pressure. Two percent of Davis-Besse's rated output can heat one million pounds of water from 32°F to 212°F in an hour. Even twenty (20) hours after the blackout, the reactor produces nearly 60,000,000 BTU per hour. The reactor's decay heat must be removed to protect the nuclear fuel from damage caused by overheating.

As pressure inside the reactor vessel plummets during the blowdown phase, three parts of the emergency core cooling system (ECCS) automatically engage: (1) the core flood tanks, (2) the high pressure injection (HPI) pumps, and (3) the low pressure injection/decay heat (LPI/DH) pumps. The core flood tanks provide the first response. The HPI and LPI/DH responses are delayed by the time needed for idle pumps to start up and move stagnant water from the Borated Water Storage Tank to the reactor vessel.

The two core flood tanks are partially filled with water and the remaining space is filled with nitrogen gas pressurized to about 800 pounds per square inch (psi). When reactor vessel pressure falls below 800 psi during the blowdown phase, the nitrogen gas pressure "pushes" the water from the core flood tanks into the reactor vessel. In the latter moments of the blowdown phase and early moments of the refill phase of the LOCA, the water entering the emptied reactor vessel from the core flood tanks refills its lower domed area. Throughout the refill phase, the reactor core receives very little cooling as the water from the core flood tanks runs down the sides of the vessel to its bottom. The uncovered reactor core sits and bakes – the fuel rods experience near adiabatic heat-up (meaning the reactor's decay heat goes into the fuel rod with very little heat going elsewhere). As the fuel rods' temperature rises above 1,400°F, a chemical reaction between the zirconium metal of the fuel rod and the water vapor occurs. This reaction is exothermic, meaning it produces heat to "boost" the fuel rods' temperature closer to its melting point of over 2,200°F.



When the water level inside the reactor vessel reaches the bottom of the reactor core, the reflood phase of the LOCA begins. As the rising water level recovers the exposed reactor core, decay heat boils some of the water. The steam cools the exposed upper regions of the reactor core.<sup>2</sup> The reflood phase stops the temperature rise of the fuel rods as the water or steam removes the decay heat being produced by the reactor core. The fuel rods' temperature reached approximately 2,100°F, retaining a small but sufficient margin to the 2,200°F melting point. At this temperature, the fuel rods may be a little blistered from the heat, but they are largely intact.

After the reactor core is once again covered and the reactor vessel refilled with water, the reflood phase of the accident ends. Until now, the water entering the reactor vessel to compensate for the lost inventory came from the core flood tanks and the Borated Water Storage Tank (BWST) via the high pressure injection and/or low pressure injection/decay heat pumps. The water lost from the reactor vessel drained down into the bottom of the containment building. The first 200,000 gallons or so of the spilled water fills nooks and crannies in the basement to the point where water starts spilling over into the containment sump.

The BWST is a large tank containing 500,100 gallons of water. As the level inside the BWST drops to only nine (9) feet remaining, automatic alarms warn the operators in the control room. At this level, more than 360,000 gallons of water have been transferred from the BWST into the reactor vessel and through the hole in its lid to the containment, flooding the building two (2) feet above the top of the sump. By procedure, the operators respond to the warning by flipping switches that remotely open valves in the auxiliary building to permit the HPI and LPI/DH pumps to draw water from the containment sump instead of the BWST. As the containment sump valves open, the BWST valves automatically close as the recirculation phase of the accident begins.

In theory, the recirculation phase features the LPI pumps taking the water expelled from the reactor vessel and collected in the containment sump and returning it to the reactor vessel. In practice, this essential function is soon lost at Davis-Besse. The thousands of gallons of water sprayed through the reactor vessel's lid during the blowdown phase of the accident scoured piping and components in its path ripping away insulation, layers of paint, and other protective coatings. Debris falls to the containment floor and is carried by the water draining to the containment sump. Only a very small percentage of the debris generated during the blowdown phase needs to make it to the containment sump to clog the mesh screens covering the sump. The debris blocks the containment sump screens, depriving the HPI pumps, the LPI pumps, and the containment spray pumps of water they need.

The operators know about the trouble. Plenty of gauges, chart recorders, and alarms in the control room tell them about the water shortage problem plaguing the emergency core cooling system pumps. At the same time, the BWST is empty or very nearly so. What are their options?

They cannot send anyone inside the containment to clean the containment sump screens because of the high temperature, pressure, and radiation conditions. Even if someone makes a suicide run, once the flow of water through the cleaned screens resumes, the water carries more debris in to re-block the screens. On to Plan B.

There's a fairly large lake nearby. The operators use it to refill the BWST, then they swap the pumps back to taking water from it. It works fine – for awhile. Davis-Besse was designed to accommodate the

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<sup>2</sup> Steam cooling is not an intuitive concept but recall that the fuel rods at this point are greater than 1,200°F and the steam temperature at this point is around 250°F.

amount of water inside containment from the BWST, a flood level of a couple of feet above the containment sump. Pumping Lake Erie into the containment carries a toll of about 8 pounds per gallon. Every 125,000 gallons of lake water entering containment adds one million pounds of weight and increases the flood level by nearly a foot. What gives way first? Does containment structure fail due to the added weight? Or does vital electrical equipment stop working because the flood submerged it?

It's a rhetorical question. Either answer being 'yes' causes the premature end of the recirculation phase of the accident and the unexpected arrival of a fifth phase: meltdown. Once the jury-rigged, lake-aided recirculation flow ends, the meltdown clock starts. The water inside the reactor vessel boils away and drops closer and closer to uncovering the reactor core. It takes time, maybe 2 to 5 hours, to boil off enough water to uncover the core and allow fuel rod temperatures rise to the melting point.

### Aftermath

In a series of post-mortem inquiries, Congress presses the NRC for answers to questions like: Why was Davis-Besse allowed to operate for so long with so many safety problems, some known and others suspected? Why has the NRC allowed pressurized water reactors like Davis-Besse to operate for decades with containment sumps known to be impaired? Congress allocates barrels of money to the NRC to finance all the reforms needed to reassure the American public that it won't happen again.

But why must the Congress wait for a disaster to seek the reforms NRC so desperately needs today? Whatever measures that Congress deems prudent and necessary after the next nuclear plant accident would seem to be even more vital now. After all, taking those steps **now** could prevent the next meltdown, leaving us one meltdown ahead in the safety race. And even if a meltdown occurred, at least members of Congress could tell their surviving constituents that they'd taken every reasonable step to protect them – something they could not claim today.

Among the first steps that Congress must ensure NRC takes is the expeditious resolution of the containment sump problem at pressurized water reactors. Had this vital safety equipment not been broken at Davis-Besse, the failure of the reactor lid's stainless steel liner would not likely have damaged the reactor core or caused the significant release of radioactivity to the atmosphere. Davis-Besse has now fixed this key safety system, but 68 other pressurized water reactors operating in the United States today have not yet done so. These reactors are one broken pipe away from turning this narrative into a tragic prophecy. Congress must ensure this clear and present danger is removed before the luck runs out.

### Sources:

1. Nuclear Regulatory Commission, NUREG/CR-5640, "Overview and Comparison of U.S. Commercial Nuclear Power Plants: Nuclear Power Plant System Sourcebook," September 1990.
2. Letter dated April 19, 2000, from Guy G. Campbell, Vice President – Nuclear, FirstEnergy, to Nuclear Regulatory Commission, "Notification of Change in the Analysis of Record for both Large Break and Small Break Loss of Coolant Accident and of the Resulting Change in Peak Clad Temperature in Accordance with 10 CFR 50.46(a)(3)."
3. Letter dated November 15, 2000, from Guy G. Campbell, Vice President – Nuclear, FirstEnergy, to Nuclear Regulatory Commission, "Revision 22 to the Davis-Besse Nuclear Power Station (DBNPS) Unit 1 Updated Safety Analysis Report (USAR)."
4. Nuclear Regulatory Commission, NUREG-1350 Vol. 14, "Information Digest: 2002 Edition," Appendix A, "U.S. Commercial Nuclear Power Reactors."
5. BWX Technologies, Inc., "Final Report: Examination of the Reactor Vessel (RV) Head Degradation at Davis-Besse," June 2003.