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NOTE TO: Jim Wiggins
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FROM: Bob Spence **/RA/**

DATE: May 22, 2000

SUBJECT: RESONANCE VIBRATIONS IN STEAM GENERATOR TUBES DURING STEAM LINE BREAK DEPRESSURIZATION

The steam generator tube rupture analyses I have reviewed so far in preparing for our DPO Panel work have discounted or not addressed the resonance vibrations that may be established in steam generator tubes during steam line breaks of various sizes. Resonance vibrations may add to the differential pressure across the tubes as an initiator to open existing tube cracks as the steam generator depressurizes. Tube and tube sheet plate movement will vary based on the magnitude and timing of pressure pulsations, size of steam line break, main steam isolation valve position, feed water operation, length of depressurization, and size of existing steam generator tube cracks, leaks, and ruptures. I believe the DPO panel should consider the accuracy of the dismissal of resonance vibrations in the steam generator, because if affects the validity of the steam generator tube leak and rupture analyses.

Steam line breaks occurred at Turkey Point on December 1991[1] and Robinson 2 on April 1970.[2] I recommend that the Panel obtain as much information about these two events as possible, including licensee and Westinghouse reports, results of eddy current testing in the affected steam generator before and after the event, and propagation of cracks and leaks, and tube plugging in the affected steam generator versus the other steam generators, from the event until the steam generators were replaced. Comparison of how these, and other steam generator tube rupture and dryout events that may have affected steam generator tubes will provide necessary operating experience to support our decisions on the analyses in the DPO on Steam Generator Integrity Issues.

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[1] No. 34 “Safety Valve Header Failure - Equipment Damage - Personnel Injuries” and No. 1 “Circumferential Pipe Rupture - Blowdown, Injuries” Nuclear Power Experience (attached).

[2] No. 1 “Circumferential Pipe Rupture-Blowdown, Injuries” Robinson 2 - Apr 70 (hot functional testing), Nuclear Power Experience (aatached).

Turkey Point 3 Steam Line Break

The Turkey Point 3 steam line break on December 1971 during hot functional testing is briefly described in Nuclear Power Experience. However, this summary did not describe the magnitude of resonance vibrations it caused.

I personally experienced this steam line break closer than anyone as the midnight-shift Startup Engineer. I had climbed onto the steam line platform less than 10 seconds before the break, only to see and hear a main steam code safety valve sizzling louder by the second. The valve had a wispy steam cloud below it where it didn't belong. I immediately recognized the high energy steam leak and scrambled down the ladder to go to the control room, just before the safety valve branch line ruptured. I heard an initial "whomp," and then a few seconds later felt throughout my entire body the loudest noise I ever experienced. I covered my ears, but it did nothing to abate the pain. Fortunately, I was protected by the concrete wall beside the open turbine deck and the steam blew over my head. I looked up to see a safety valve rise through the steam cloud above the containment, then fall back to earth like a failed rocket.

The escaping steam started choked flow cycling, at a primary frequency and many secondary frequencies. The main booms settled into a slow rhythmic beat, while the air was beating at a higher frequency. Equipment vibrated at their own frequencies. I tried, but could not run across the turbine deck. My first step found the deck higher than I expected, and my next step hit the deck lower than I expected. I staggered with great effort, as fast as I could, to reach the more solid footing by the turbine pedestal area near the turbine front standard, then raced towards the control room. As I opened the controlled-access door, I glanced back to see the part of the operating deck I had just come from undulating like the "Galloping Gurdy" Tacoma Narrows bridge, with the steam plume rolling above the containment into the sky.

It had taken me maybe 20 seconds to reach the control room. As I entered, I ran into a reactor operator on his way out to see what happened, and I pushed him in with me. I found the operators clustered around the steadily falling steam generator level indicator (reading somewhere > 60%). When the Operations Superintendent asked what was happening, I could barely hear him. The control room door, floor, and the plastic ceiling tiles were each resonating to their own beat. It surprised me that the booms continued at the same frequency for what seemed like an interminable period of time (maybe 5 to 10 minutes?), even as the steam generator level fell below zero. Finally, a series of louder, lower pitched, more spaced out booms ended in quiet.

After we could hear again and had accounted for personnel, the Operations Superintendent asked me to take a reactor operator and inspect the turbine building for damage. In addition to the damage described in Nuclear Power Experience, we found the supports on the main steam line in the mezzanine level angled away from the containment. Insulation damage and new rust scrapes indicated steam lines had moved back and forth by less than a foot. We saw a piece of steam line insulation 400 feet away near the Startup trailer, and many smaller pieces of shrapnel in between.

After reporting back what had happened, the Operations Superintendent asked us to "volunteer" to make a containment entry to inspect for damage before they restarted the reactor coolant pump on the damaged train. We were concerned about the fate of the steam generator and the reactor coolant pumps.   Very surprisingly, we found no steam leaks and little visible damage in the containment. The penetration weld, seismic supports, and spring hangers were effective in limiting piping damage inside the containment.

I recall concern about the steam generator tube integrity and a discussion about eddy current testing the tubes in the affected steam generator again, but I was not involved in that.

Event Analysis

I cannot explain my experience with the magnitude of these resonance vibrations, pressure pulsations, and the ½" carbon steel they sheared, because no one can really understand this unless they have been there. I cannot relate how much more powerful this was than a full-power scram because of the steam chugging vibrations. Safety valves are tuned for sonic steam velocities, while the jagged edges of pipe breaks are not. The break area in the Turkey Point event was about 40% of the area of a main steam line - much larger than a stuck open safety valve and it did not take long for the leak-before-break portion of the event to complete its process. Westinghouse either knew or should have known the magnitude of the vibrations in this event. A few days after the event, it became common knowledge to us in the Florida Power & Light engineering staff, that this event was considered outside the design basis of the plant.

Although the blow down oscillations had started earlier, they were similar in shape to Dr. Ward's Figure C3 in the DPO,[3]   reflecting the many vibratory frequencies and water hammers, even though it wasn't the same scenario.

An NRC ASP analysis would have imposed normal operating conditions on this event instead of hot functional testing. Had this event occurred during operation, fuel would have been in the vessel, and a much worse event would have happened during the full power scram test. Every branch line, with safety valves, on each main steam line would have ruptured simultaneously and all three steam generator levels would have fallen together. The reactor vessel would have exceeded its cool down rate. Further RCS cooling would have had to be by bleed and feed. Emergency core cooling systems would have been employed for real, regardless of steam generator tube leaks or ruptures.

Based on my Turkey Point experience, I believe a steam line break near main steam isolation valves in a closed turbine building may render some of them inoperable, as occurred in the open-air turbine building at Turkey Point. Shrapnel could destroy an isolation valve or its operator. Vibration could open or close limit switches or effect the torque switches preventing operation. The steam environment may overheat wiring, controls, or the motor before an operator could close the valves in accordance with the EOPs.

[3] DPO Attachment I, Dr. Ward, INEL, memo to Dr. Hopenfeld, "Draft Results of Steam Generator Tube Ruptures Concurrent with Steam Line Break Outside Containment Calculation - LWW-05-92", Figure C3. "Main Steam Line Break Flow. 5 DEG Tube Breaks"