Clinton Power Station
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Clinton, IL 61727

U-604226
June 19, 2015

Regional Administrator, Region III
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U.S. Nuclear Regulatory Commission
2443 Warrenville Road
Lisle, Illinois 60532-4352

Clinton Power Station, Unit 1
Facility Operating License No. NPF-62
NRC Docket No. 50-461

Subject: Clinton Power Station Regulatory Conference Supplemental Information

References:
1. Letter from A. Boland (NRC) to B. Hanson (EGC), "Clinton Power Station – NRC Integrated Inspection Report 05000461/2015001 and Preliminary White Finding," dated May 13, 2015
2. Letter from M. Newcomer (EGC) to J. McGhee (NRC), "Response to NRC Integrated Inspection Report and Preliminary White Finding," dated May 22, 2015
3. Letter from J. McGhee (NRC) to B. Hanson (EGC), "Clinton Power Station – Regulatory Conference," dated June 5, 2015

In accordance with the referenced letters above, Exelon Generation Company, LLC (EGC) is providing, in the attachment to this letter, the supporting presentation materials for the Regulatory Conference to be held on June 25, 2015 at the NRC's Region III Office. This material is being submitted to you, prior to the Regulatory Conference, in an effort to provide additional facts and perspective related to the preliminary White finding discussed in Reference 1 and to ensure the upcoming conference is effective.

If you have any questions and/or concerns regarding this information, please contact Mr. Jeffrey Cunningham, Regulatory Assurance Manager, at (217) 937-2800.

Respectfully,

Mark M. Newcomer
Site Vice President
Clinton Power Station

JLP/cas

Attachments

cc: NRC Document Control Desk
NRC Project Manager, NRR – Clinton Power Station
NRC Senior Resident Inspector – Clinton Power Station

Regulatory Conference
Clinton Power Station
Division 3 SX Pump

June 25, 2015

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Agenda

- Purpose – Mark Newcomer, Site Vice President
- Background and Overview of Previous Material – Jacob Smith, Site Engineering Director
- Discussion of New Material – Michael Heger, Senior Manager Plant Engineering
- Conclusions – Mark Newcomer

Purpose

- Provide additional information on the failure mechanism of the Division 3 SX pump and present facts based on further analysis performed.
- Present new facts related to hardface failure mechanism.

Recap of Division 3 SX Pump Timeline

- Original pump design had nine rubber cutlass bushings with cooling water for the upper bushings being supplied from the pump discharge and the lower bushings supplied from the pump casing.

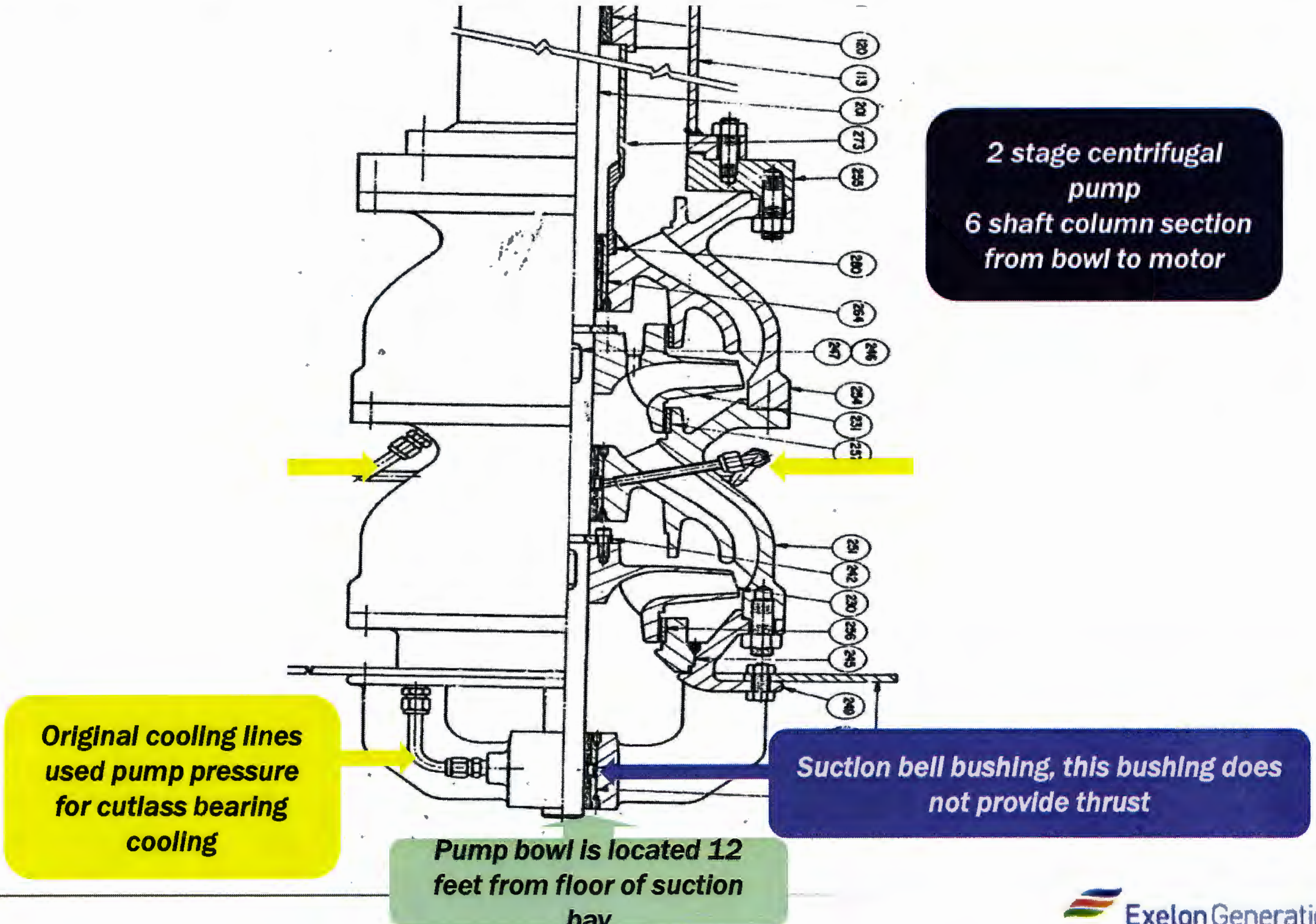
- August 1990 – incurred failure of this pump to start, found excessive amounts of silt in the bushings, inner tube and cooling flush lines. The silt was determined to be from the external cooling water supply depositing inside the enclosure tube and between bushing clearances. Pump was cleaned and restored with additional testing to monitor for degradation.

- 1991 – the station developed seven options to address the pump failure mechanism with input from various pump experts including Sulzer-Bingham, Byron Jackson and American Pump Co.

Recap of Division 3 SX Pump Timeline - continued

- May 1991 – Following rigorous research, the reasonable decision was made to replace pump with a modified design that removed the inner tube, removed the external supply of water and replaced the bushings with bronze bushings that were cooled with internal fluids. This course of action addressed the identified failure mechanisms. Other options were dismissed based on introduction of new failure modes. Resolution selected was common to input from the pump experts.
- August 1992 – ECN issued that authorized design for new pump and pump was ordered.
- October 1995 – new pump design installed and tested.
- Post October 1995 modification installation – testing performed weekly for an extended period of time until there was confidence in the new pump design and then returned to quarterly IST. IST is aligned with industry standards.
- October 1995 to September 2014 – no equipment failures occurred for the Division 3 SX pump.
- September 2014 – Division 3 SX pump failed to run.

Original Pump Construction



Summary of Preliminary White Finding (Inspection Report 05000461/2015001)

- Self-revealed finding
- Preliminarily determined to be of low to moderate safety significance
- Performance Deficiency – Apparent Violation of 10CFR50, Appendix B Criterion III -Design Control
  - High Level Assessment: "…the licensee's failure to verify the suitability of the design for the Division 3 SX replacement pump for conditions under which it was to be used…was a performance deficiency"
  - Detailed Assessment: "…the licensee failed to verify the design of the suction bell bushing for the replacement pump would pass sufficient cooling water flow to the pump internals without being affected by mud and silt from the lake water, resulting in failure of the pump"

Overview of Newly Determined Information

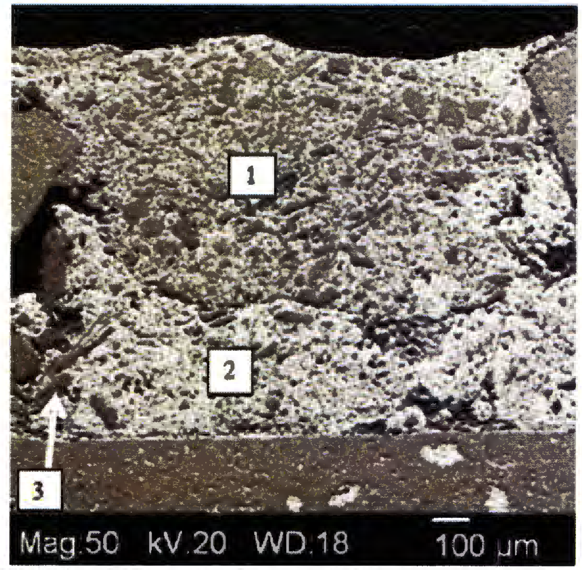
- Exelon reviewed and analyzed causes of the bushing failure based on internal and external challenges.
- The new information obtained through inspection of the failed assembly and other bushings on the shaft determined that silt and mud are not the cause of bushing failure.
- Further analysis and examination of the other bushings show that the hardface application is inadequate and hardface delamination is the cause. Corrective action products have been updated using the results of the investigation and analysis performed.

Overview of Newly Determined Information

- Through the use of additional inspections and metallurgical analysis of the failed bushing and the remaining bushings, the following observations have been made.
  - Hardface cracking occurred during normal operating conditions.
  - Hardface thickness is found to be a cause of hardface failure.
  - Corrosion and cracking of hardface occurred at column bushing locations.
  - Failed bushing cooling channel blockage was not due to silt.
- Analysis of bushing loads, flow rates, temperatures and stresses has been performed to support the causal conclusions.
  - Flow velocities in the cooling channels for all bushings are not directly dependent on flow external to the bushing.
  - Temperatures produced in a starved bushing are within the capabilities of the material.

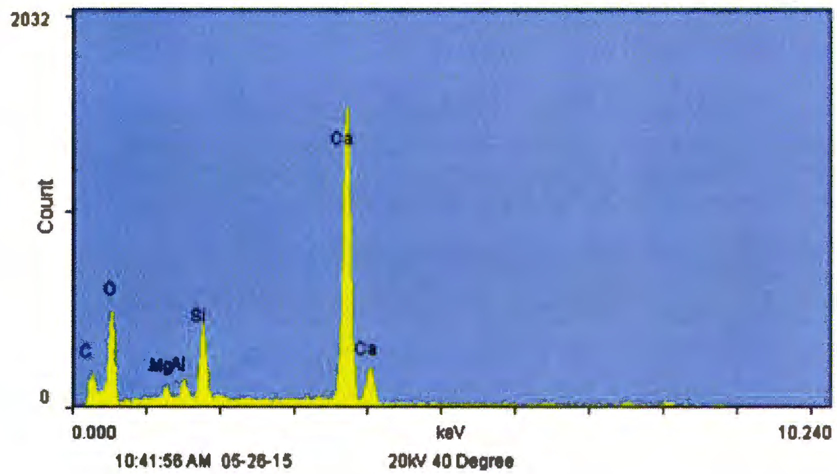
Cooling Channel Blockage

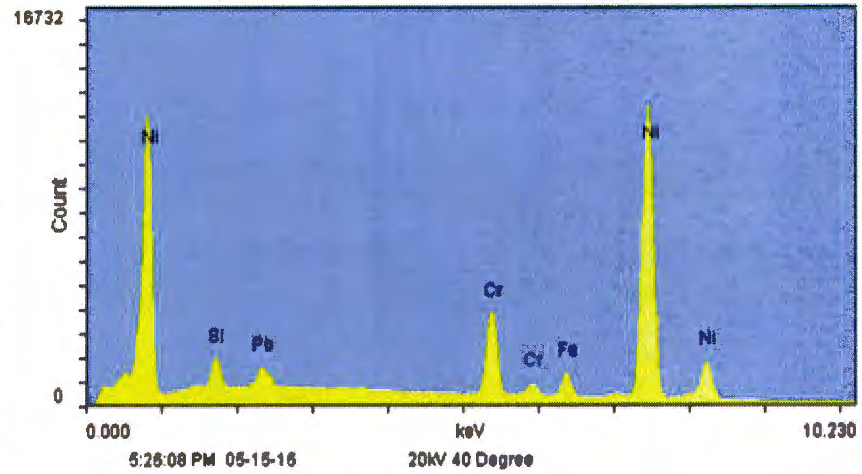
- Conclusion:
  - Plugging/blockage of cooling channel on failed bushing was a result of the bushing failure. The cooling channels were blocked with failed hardfacing material, not silt.
- Basis:
  - No evidence of silt in the cooling channels was found – Exelon PowerLabs re-performed Scanning Electron Microscopy (SEM) analysis of material in the cooling channel and concluded that silicon was present; however, this silicon was concluded to be from the hardfacing material (the hardfacing has 4.2% by weight silicon) as it was always found with other hardfacing constituents. No other minerals associated with silt were identified.
  - The suction bell bushing is no more likely to accumulate silt than some of the other pump bearings.
  - Remaining bushing cooling channels not blocked.



SEM photo of a metallurgical section of the failed bushing through a deformed and blocked cooling slot. Light areas 1 and 2 were examined and found to be mixtures of lead and hardfacing material. The spectrum from Dark Area 3 is shown on the next slide and it was also primarily hardfacing with a small amount of lead. No calcium or silicon rich sediment was detected. All the silicon in spectrum was associated with hardfacing.

Spectrum of Channel Debris & Representative Water Minerals





- This spectrum is from deposits on a bushing section that was part of the bushing pieces in an area that was outside normal contact zone.
- Example of water mineral deposits as evidenced by the high calcium and silicon peaks in the SEM-EDS spectrum

- This spectrum is from area three (previous slide) of the hardfacing debris in the cooling channel.
- Chromium and/or nickel were always present in large quantities with the silicon rich phases.

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Silt Accumulation

- Conclusion:
  - Silt is no more likely to accumulate at the suction bell bushing location than at the other locations.
- Basis:
  - The open design of the suction bell does not physically support silt accumulation.
  - Observations of large amounts of silt were noted at the lower column bushing locations and the areas surrounding the bowl bushings. The suction bell area was not noted to be packed with silt.
  - The area around the suction bell bushing is relatively open and ~12 ft. above the bottom of the suction bay, which limits preferential sites on which silt can build-up (as compared to column bushing or bowl bushings).

Suction bell bushing (during disassembly, picture rotated to show approximate orientation as installed) – note open design

Cooling Channel Flow Dependence

- Conclusion:
  - The suction bell bushing cooling channels are no more likely to accumulate silt than other bushing cooling channels.
  - Flow through the cooling channels is based on shaft rotation not pump flow.

- Basis:
  - The flow velocity through the cooling channel is predominantly driven by the shaft rotation, which is the same for all pump bushings. The flow velocity in the cooling channel does not have a strong dependence on flow conditions external to the bushing, as demonstrated by computational fluid dynamic analysis and further supported by flow theory for a spiral grooved bushing. Therefore, each bushing has the same ability to flush silt through the cooling channels.

Hardface Cracking in Other Column Bushings

- Conclusion:
  - Hardface cracking occurred during normal operating conditions.
  - Temperature and resulting thermal stresses resulting from a pump operating/shutdown cycle with completely starved bushing conditions are shown not to cause failure in a typical hardface application, assuming an industry standard strength and fatigue resistance of the shaft sleeve hardfacing.

- Basis:
  - Cracking was observed in five of the remainder of intact sleeves, including column bushing sleeves. The column bushings are lightly loaded and their cooling channels were stated to be free of silt upon disassembly. There was no evidence of high temperatures at these other locations.
  - Cyclic temperatures and stresses in the failed suction bell bushing due to pump operating/shutdown cycle were shown not to result in cracking of the hardface, even with no cooling water flows.
  - The bushing loads and heat generation are small. Thermal stress analyses performed assuming no cooling flow indicates peak thermal stresses are below the expected endurance strength of material based on published fatigue testing results of a similar hardface.

Other Sleeve Cracked with Wear Mark

- Representative photograph of cracks found on other bushing sleeves in pump assembly.
- This sample shows circular "polished" appearing surface area at intersection of sleeve cracks. This surface imperfection is not common.
- Metallurgical section shows delamination presumably contacting the bushing during operation.

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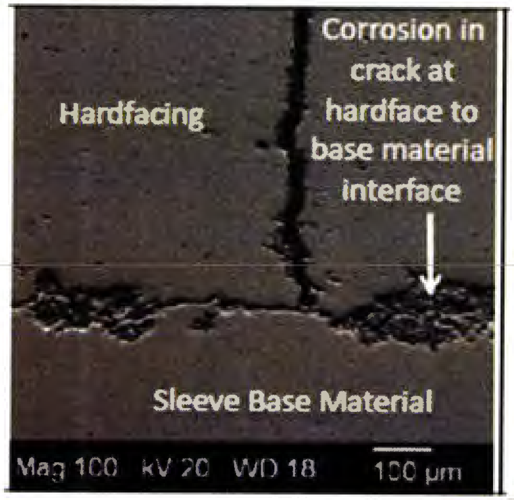
Hardfacing Thickness

- Conclusion:
  - The hardfacing thickness used (95 mils) is thicker than usual spray-on application and therefore increases the risk of hardfacing cracking compared to typical thickness applications.
- Basis:
  - The shaft sleeve hardfacing applied to the failed pump parts was applied by a thermal spray overlay process.
    - The exact process used is not known (proprietary to Sulzer).
    - The hardfacing thickness was 95 mils (0.095 inches).
  - Best practices for thermal spray-on overlay hardfacing:
    - Thermal spray thicknesses are generally in the 10 mil to 35 mil range.
    - Increased thickness increases potential for residual stresses during application process.
    - Increased thickness may increase the size and concentration of surface defects, which can be preferential fatigue crack initiation sites.
    - Increased thickness has been demonstrated to reduce hardfacing fatigue properties.
    - For a hardfacing thickness of >40 mils, weld overlay is the preferred application method.

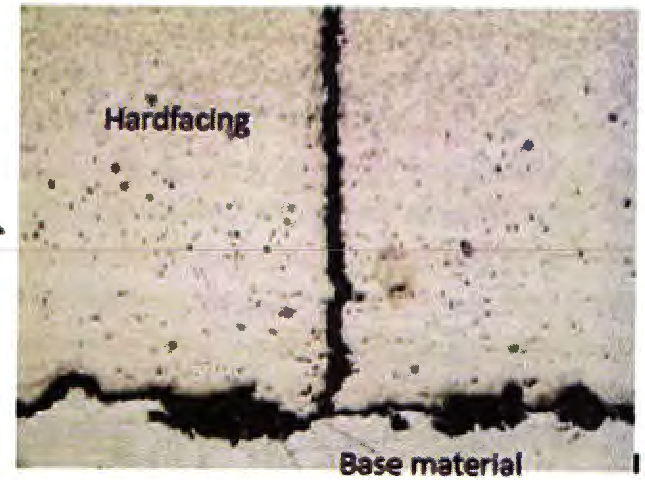
Corrosion and Cracking

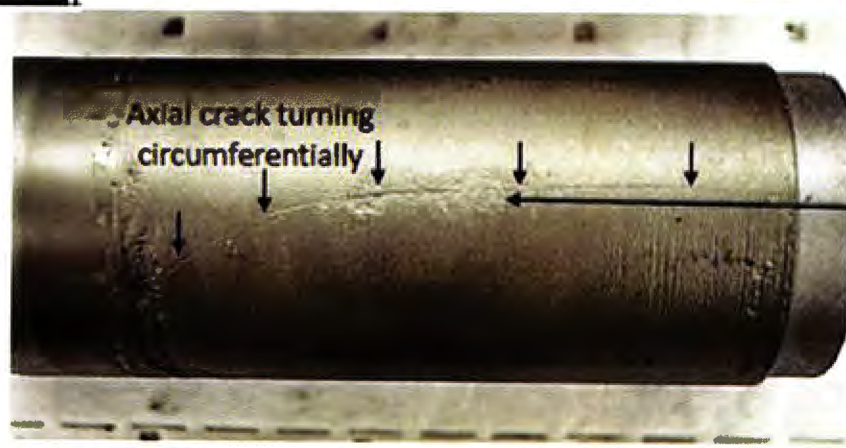
- Cracking found in the hardfacing on five of the sleeves in the pump above the failed sleeve.
  - Cracks were generally axial near the bottom; some cracks tended to become more circumferential near the top of the bushing mating area.
- Evidence of widespread, but shallow, surface corrosion on five of the pump sleeves was observed.
  - The corrosion is not considered significant enough to be the cause of crack initiation.
- Corrosion was evident in the cracks found on the sleeves, and at the hardface-base metal bond.
  - Corrosion accelerated and/or propagated bond degradation after the crack formed.

Representative Pictures – Cracking and Corrosion



Surface crack propagates radially inward to hardface bond, then follows hardface-to-base material interface circumferentially





Example of surface corrosion

Hardface Application

- The spray-on technique was the preferred method by the vendor at the time of fabrication. The thickness of the spray-on application and the resulting time-based impacts were not ideal. The vendor subsequently changed to a weld-on hardface application technique which is resilient to the concerns discussed.
- The Division 3 SX pump assembly was procured as a unit and the silting issue was a known concern where multiple pump manufacturers provided design options to rectify the original cutlass bearing issue.
- Research within and external to Exelon validated that it would be very uncommon for the purchaser to specify processes to a supplier of nuclear safety related equipment. The specification of hardface application does not appear in the vendor documents and as such is below the level of detail in the design.
- Exelon must rely on the qualified pump vendors to provide adequate fabrication.

Previous Conclusions No Longer Supported

- Original Failure Mechanism - Silting
  - The previous conclusion was silt buildup in the bushing cooling channels was the most likely cause of the hardfacing cracking and bearing failure. The additional information gathered through research, detailed inspection, and analysis no longer supports this conclusion.
    - Evidence of silt buildup in the cooling channels of the failed suction bell bushing was not found.
    - The suction bell bushing does not preferentially accumulate silt in the cooling channels – cooling channels for the column and bowl bushings were stated to be free of silt.
    - Hardface cracking was observed in column bushings for which there is no evidence of silting or thermal cycling.
    - Hardface cracking due to thermal cycling under postulated water-starved conditions is not supported by analyses.

Newly Determined Information Conclusions

- Failure Mechanisms:
  - Hardface delamination caused increased friction resulting in increased temperatures and eventual bushing failure.
  - Hardface thickness and corrosion:
    - The hardfacing thickness was significantly thicker than typical for thermal spray-on overlay hardfacing causing: residual stresses, preferential crack initiation sites, reduced fatigue properties.
    - Corrosion at the base of the cracks at the hardfacing bond interface accelerated delamination of hardfacing.
- Hardface Application
  - The spray-on hardface application has been changed to weld-on by the vendor. This change occurred after the failed bushing (pump assembly) was purchased and installed in 1995.
  - Application technique is below the level of detail of the design and not reasonable for Exelon to specify in a procurement specification.

Installed Pump Considerations

- The currently installed pump has welded hardfacing that is a metallurgical type bond with a bond strength equivalent to the base metal yield strength. The running clearances were evaluated for impact based on thermal expansion.

- April 2015 additional trending parameters established for monitoring during more frequent runs of Division 3 SX pump.

- Currently station is reviewing design and material for replacement options.

Conclusions

- The pump selected in 1995 was capable of performing the required design function for the environment.

- Through further analysis and investigation, Exelon has shown the hardface application was deficient leading to the failure of the bushing. The presence of mud or silt from the environment was not a contributor.

- Application technique is below the level of detail of the design and it is not reasonable for Exelon to specify in a procurement specification.

Additional Information

- *The following slides provide information for recovery and actual risk conditions.*

Risk Significance Determination

- Division 3 SX pump is important and risk-significant
- SDP result using Risk Assessment of Operational Events (*RASP) Handbook and SPAR* Model not in question
  - Guidance used to achieve consistent results
  - *SPAR* models reflect as-built, as-operated plant
  - Generally conservative estimate
  - Evaluate all inputs affecting significance of finding to inform an integrated risk-informed decision
- Refined causal analysis provides additional risk insights
- Sensitivity analysis of influential factors

Influential Factors

- Recovery of Division 3 SX Pump
  - Suction bell bushing not critical for operation
  - Mechanics demonstrated shaft movement

- Pump unavailability coincided with summer operation
  - No challenges to offsite power or switchyard
  - Few operational risk activities
  - Diesel generators and support systems fully available
  - High availability of key mitigating systems (e.g., RCIC)

- Associated risk driven by loss of offsite power scenarios

Pump Recovery

- Likelihood in 2-4 hour timeframe based on
  - Easily and quickly diagnosed
  - Pump internals and motor not degraded
  - Mechanics able to break shaft loose and rotate
  - 50% reduction in base case significance

- Suction bell bushing functions as guide during operation
- Recovery mitigates dominant (4-hour LOOP) cutsets
- Impacts long-term core cooling and offsite power recovery

Summer Operation

- LOOP initiating event frequency
  - Average value used in model is a distribution
  - Comprised of four categories: Plant-centered, Switchyard-centered, Grid-related and Weather (NUREG/CR-6890)
  - Summer operation on favorable end of distribution
  - 10-20 % reduction in base case significance

- Actual configuration risk
  - No major system outage windows
  - Higher availability (test/maintenance) than Baseline Model
  - 50% reduction in base case significance

LOOP Initiating Event

EVENT CATEGORY	FREQUENCY CONTRIBUTION [f]	SUMMER IMPACT	LIKELIHOOD OF RECOVERY [a]
Plant-Centered [b]	12%	Substantially reduced	95%
Switchyard Centered [c]	44%	Essentially eliminated	92%
Weather [e]	24%		60%
Grid-Related [d]	20%		80%

Notes

a. 4-hour values assumed in Clinton Full Power Internal Events Model using NUREG/CR-6890
b. Likelihood of SCRAMs reduced by avoidance of production risk activities
c. No routine maintenance impacting offsite power sources
d. ERAT and RATs available entire period; ring bus not subject to transmission line failures
e. Summer 2014 relatively cool with little/no challenge in terms of severe storms or grid stress
f. Detailed model for main switchyard and three 345 KV transmission lines

Equipment Unavailability (May-September 2014)

Component	Elapsed Hours Unavailable [a]	Unavailability [b] (hours per year)	Test and Maintenance Risk Contribution [c]
DIV 1 DIESEL GEN	< 1.0	1.01E-2 (88 hours)	12%
DIV 2 DIESEL GEN	< 1.0	1.01E-2 (88 hours)	10%
DIV 3 DIESEL GEN	< 1.0	1.01E-2 (88 hours)	N/A
RCIC	< 1.0	9.81E-3 (86 hours)	4%
LPCS	2.7	6.17E-3 (54 hours)	<1%
Div 1 (2) Charger	0	3.49E-3 (31 hours)	6%
Div 1 (2) SX	0	2.25E-3 (20 hours)	3%

Notes:

a. Actual component unavailability from control room logs (5/30/14 - 9/16/14)

b. Clinton Full Power Internal Events Model unavailability due to test/maintenance

c. Derived from Fussell-Vesely values and calculated for SDP case with SX "C" unavailable