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BEFORE THE MINNESOTA OFFICE OF ADMINISTRATIVE HEARINGS
600 North Robert Street
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FOR THE MINNESOTA PUBLIC UTILITIES COMMISSION
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St Paul MN 55101-2147

In re the Matter of Sherco Unit 3 Energy Replacement Costs.	OAH Docket No. 65-2500-38476
In re the Application of Northern States Power Company for Authority to Increase Rates for Electric Service in the State of Minnesota, et al.	MPUC Docket No. E-002/GR-12-961
In re the Application of Northern States Power Company for Authority to Increase Rates for Electric Service in the State of Minnesota, et al.	MPUC Docket No. E-002/GR-13-868
In re the Review of the 2012-13 Annual Automatic Adjustment Reports for All Electric Utilities	MPUC Docket No. E-999/AA-13-599
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In re the Review of the 2015-16 Annual Automatic Adjustment Reports for All Electric Utilities	MPUC Docket No. E-999/AA-16-523
In re the Review of the 2016-17 Annual Automatic Adjustment Reports for All Electric Utilities	MPUC Docket No. E-999/AA-17-492
In re the Review of the 2017-18 Annual Automatic Adjustment Reports for All Electric Utilities	MPUC Docket No. E-999/AA-18-373

REBUTTAL TESTIMONY AND ATTACHMENTS OF STEPHEN KLOTZ

ON BEHALF OF

THE MINNESOTA DEPARTMENT OF COMMERCE
DIVISION OF ENERGY RESOURCES

SEPTEMBER 22, 2023

REBUTTAL TESTIMONY OF STEPHEN KLOTZ
In re the Matter of Sherco Unit 3 Energy Replacement Costs
MPUC DOCKET NOS. E-002/GR-12-961, et al.
OAH DOCKET NO. 65-2500-38476

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Abbreviations Used in Testimony

AE	Atomic Emission
AVT	All-Volatile
AVT-O	All-Volatile Oxidizing Treatment
AVT-R	All-Volatile Reducing Treatment
CPD	Condensate Pump Discharge
CPE	Condensate Polisher Effluent
DE	Demineralizer Effluent

DW	Drum Water
EI	Economizer Inlet
EPRI	Electric Power Research Institute
gpm	Gallons per Minute
HP	High Pressure
hr	Hour
HRSG	Heat Recovery Steam Generator
IP	Intermediate Pressure
ISO	International Organization for Standardization
lbs	Pounds
LP	Low Pressure
MPI	Magnetic Particle Inspection
MS	Main Steam
NSP	Northern States Power
OT	Oxygenated Treatment
psig	Pounds per Square Inch - Gauge
RH	Reheat Steam
SCC	Stress Corrosion Cracking
Sherco 3	Xcel Sherburne County Generating Station Unit 3
uS/cm	Microsiemens per Centimeter

I. Introduction

Q. Would you state your name, occupation, and address?

A. My name is Stephen E. Klotz. I am a retired Chemical Engineer, currently working as an independent consultant for GDS Associates, Inc. My address is 6771 Del Mason Rd, Bellaire, MI 49615.

Q. For what party are you presenting testimony in this proceeding?

A. I am presenting testimony on behalf of the Minnesota Department of Commerce, Division of Energy Resources.

Q. What is your assignment in this proceeding?

A. My assignment is to assist Department of Commerce personnel in conducting an evaluation of Xcel's operation of its Sherburne County Generating Station Unit 3 (Sherco 3) generating facility, which experienced a catastrophic failure of a steam turbine on November 19, 2011, that forced the unit to be out of service until October 2013 (approximately 23-month outage). My testimony focuses on issues relating to Xcel's practices with respect to the cycle chemistry of Sherco 3 and the relationship of cycle chemistry to the Sherco 3 LP steam turbine failure.

Q. Did you file direct testimony in this proceeding?

A. No, I did not. In this rebuttal testimony, I respond to the testimony of Xcel's expert witnesses, Mr. Sirois, regarding Xcel's "chemistry first" philosophy, and Mr. Daniels who discusses issues relating to steam cycle chemistry and offers opinions regarding the adequacy of steam cycle monitoring practices at Sherco 3.

Mr. Daniels opined that Sherco 3's plant chemistry was closely monitored, that the unit was prudently operated consistent with industry standards for steam cycle chemistry, and that he could find no evidence that the plant was operated in a condition that would have sent contaminated steam to the steam turbine.[1]

Q. Please summarize your response to Mr. Sirois's testimony.

A. I disagree with Mr. Sirois's opinion that the cycle chemistry practices in use at Sherco 3 before the turbine failure in November 2011 reflected a "chemistry first" philosophy.[2] Personnel responsible for maintaining the unit's cycle chemistry did not have a formal cycle chemistry review and improvement program, which is a basic, well-accepted practice for many utilities that are members of EPRI's cycle chemistry program.

Q. Please summarize your response to Mr. Daniels.

A. Based upon my review of the available evidence, it is my opinion, contrary to that expressed by Mr. Daniels, that Xcel failed to act prudently in connection with the steam cycle chemistry practices at Sherco 3, and those practices contributed to the stress

[1] See Xcel Ex. __ (DGD-1) (Daniels Direct) at 24.
[2] Xcel Ex. __ (HJS-1) at 7.

corrosion cracking (SCC) that cause the failure of one of Sherco 3's low pressure (LP) turbines as is discussed in more detail below.

Q. What is your educational and professional background?

A. I received a Bachelor of Science degree in Chemical Engineering in 1985 from Michigan Technological University in Houghton, Michigan. I have 21 years of professional experience in the chemical processing industry, 3 years of experience as a manufacturing process consultant, and another 12 years of experience in the utility industry as a corporate engineer focused on cycle chemistry program and performance management.

I worked for the Dow Chemical Company from 1985 until 2006. I spent my first 4 years with Dow as a Research Engineer working primarily on process scale-up. I worked in various Dow manufacturing facilities for the next 17 years progressing from Production Engineer to Production Supervisor to Plant Leader and to Site Leader.

In 2007, I joined Omni Tech International as an independent contractor supporting various clients with process evaluation services and ISO (International Organization for Standardization) environmental, safety and quality standard implementation and management services.

In 2009, I joined Consumers Energy as a corporate engineer overseeing cycle chemistry programs and performance for their fleet of fossil fuel generating plants. In this role, I developed cycle chemistry specifications and related programs for 16 different generating units. 14 of the 16 were coal-fired like Sherco 3. The chemistry programs at the coal-fired units included AVT (All-Volatile) boiler treatment, AVT-R (All-Volatile Reducing Treatment) feedwater treatment, AVT-O (All-Volatile Oxidizing Treatment) feedwater treatment, and OT (Oxygenated Treatment) feedwater treatment. These are the same treatment programs that were in place at Sherco 3 between 1999 and 2011.

As a part of my role with Consumers Energy, I evaluated unit performance against cycle chemistry specifications and program requirements on a regular basis and provided improvement recommendations and support for closing identified gaps. The results of these reviews were published broadly and reviewed with management on a regular basis. I also had system owner responsibilities for chemistry related equipment at 5 different generating units. 4 of these 5 units ran AVT-R followed by AVT-O feedwater chemistry treatment programs just like Sherco 3. The system owner role involved completing regular system health assessments along with developing and implementing improvement plans as appropriate. The results of these evaluations were also reviewed with management on a regular basis.

I retired from Consumers Energy in November of 2021.

Q. What portion of your engineering experience relates directly to your evaluation of Xcel's cycle chemistry practices prior to the Sherco 3 LP turbine failure?

A. I have participated in and performed root cause analysis for multiple types of events including equipment failures, personnel injuries, chemical spills, environmental releases, and product quality incidents. As a corporate cycle chemistry engineer for Consumers Energy, I have evaluated numerous metallurgical failure analysis reports and incorporated the results into root cause findings and corrective and preventative action plans. I also served as Consumers Energy's primary advisor for the EPRI (Electric Power Research Institute) cycle chemistry program (Program 64) from 2011 to 2021. In that role, I attended Program 64 advisory meetings twice a year to provide input on program research initiatives and to keep current on cycle chemistry related industry trends and best practices. I also attended several EPRI international cycle chemistry conferences and delivered a presentation on cycle chemistry specifications for a combined cycle plant using a neutralizing amine treatment program at the 2018 conference.[3] I attended several non-EPRI cycle chemistry conferences as well and presented a paper on converting mixed metallurgy plants to AVT-O feedwater chemistry at the Electric Utility Chemistry Workshop conference in 2016.[4] I was also one of the main advisory reviewers and contributors to the latest version (2020) of EPRI's comprehensive cycle chemistry guidelines for fossil plants and the latest version (2020) of EPRI's

[3] Proceedings: Twelfth International Conference on Cycle Chemistry in Fossil and Combined Cycle Plants with Heat Recovery Steam Generators (epri.com).
[4] See EUCW-2016-Brochure.pdf (illinois.edu).

comprehensive cycle chemistry guidelines for combined cycle/HRSG (Heat recovery steam generator) plants.

Q. In what proceedings have you previously testified before utility regulatory commissions?

A. I have not filed testimony in previous regulatory proceedings.

Q. Would you please define the term "cycle chemistry" and how it relates to water chemistry?

A. Cycle chemistry is a common and well-known term in the industry, and I use it throughout my testimony. Cycle chemistry refers to the chemistry associated with the boiler water and turbine steam cycle in fossil fuel electric generating plants. It is synonymous with the water chemistry (liquid water and steam) of the boiler water and turbine steam cycle.

EPRI publishes cycle chemistry guidelines that apply to fossil fuel electric generating plants. The International Association for the Properties of Water and Steam also provides cycle chemistry guidelines,[5] and General Electric provides steam chemistry recommendations for turbines.[6] The guidelines provided by these organizations are

[5] See http://iapws.org/techguide.html.
[6] See Exhibit DOC 1, RAP-D-30 (Polich Direct).

generally consistent with each other. Xcel used EPRI cycle chemistry guidelines, so I reference the EPRI guidelines throughout my testimony.

Q. Did the cycle chemistry practices at Sherco 3 contribute to the SCC failure of the LP turbine in November of 2011?

A. Yes, Xcel's cycle chemistry practices contributed to the SCC failure of the Sherco 3 LP turbine in November of 2011. The failure mechanism for the Sherco 3 LP turbine was determined to be transgranular SCC which is indicative of sodium hydroxide influenced corrosion.[7] Sodium hydroxide contamination was present at levels that were high enough to initiate and sustain ongoing SCC damage in both Sherco 3 LP turbines.[8] To the degree that sodium hydroxide concentrations were allowed to remain at these levels, Xcel's cycle chemistry practices failed to protect the Sherco 3 LP turbines from SCC damage.

My specific cycle chemistry areas of concern that relate to turbine SCC damage risk include steam drum mechanical carryover risk management, sodium monitoring, makeup water quality, and cycle chemistry performance review and improvement program practices.

[7] See Exhibit DOC-1, RAP-D-7 (Polich Direct) at 4; Exhibit DOC-4, SK-R-2 (Klotz Rebuttal) at 4-5 (GE Litigation Daniels Dep. Tr.) (Nonpublic).

[8] Exhibit DOC-1, RAP-D-7 (Polich Direct) at 4; Exhibit DOC-1, RAP-D-11 (Polich Direct) (Nonpublic) at 4.

II. Cycle Chemistry Performance Review and Improvement Program

Q. Would you please provide an overview of cycle chemistry review and improvement programs?

A. Cycle chemistry performance review and improvement programs comprise a set of formal activities that take place at a regular interval such as monthly or quarterly. At a high level, all cycle chemistry data for a given time interval is evaluated to determine compliance with established limits. Compliance gaps are identified, causes for the gaps are determined, and action plans are established to address the causes. Chemistry program requirements such as periodic mechanical carryover testing are also checked to ensure compliance with the requirements. A formal summary report of the evaluation is developed and distributed broadly within the organization to keep stakeholders well informed of performance, performance gaps, risks, action plans and progress against action plans. Performance reports are also reviewed with management to ensure issues, action plans and resource requirements are well understood. Repeating the evaluation, reporting, tracking, and reviewing process on a regular basis drives improvements in cycle chemistry performance and in the cycle chemistry program itself.

I followed the process described above nearly every quarter for 12 years at Consumers Energy. It was the most powerful tool that we had to drive cycle chemistry compliance and program improvement. It’s very easy to become complacent about cycle chemistry performance because compliance issues don’t typically translate into damage in the short term. The damage normally occurs long after the initial chemistry issues occur.

It's much more difficult to become complacent when plant personnel know that chemistry compliance performance will be analyzed, reported out broadly, and reviewed with management on a regular basis.

Based on my experience in the industry, it is my opinion that a prudent operator of a fossil fuel electric generation plant would have a formal cycle chemistry performance review and improvement program.

Q. Did you find evidence of a cycle chemistry performance review and improvement program at Sherco 3?

A. I did see evidence of informal evaluation and communication processes such as logbook entries, chemistry monitor checks, daily plant meetings, hallway discussions, e-mails, and phone calls where specific issues and day-to-day concerns could be identified and discussed or communicated.

I saw no evidence of regular comprehensive reviews of cycle chemistry performance, and I saw no evidence of a formal cycle chemistry performance improvement program.

Q. Were the informal processes that were used to evaluate and communicate chemistry issues sufficient to avoid the 2011 Sherco 3 SCC turbine failure?

A. No. Sherco's turbine experts, Timothy Murray[9] and Mark Kolb[10] testified that they were not aware of any steam chemistry excursions prior to the 2011 Sherco 3 LP turbine failure that would have made them consider MPI (magnetic particle inspection) of the Sherco 3 LP turbine finger dovetail connections. The informal evaluation and communication process that were in place prior to the 2011 LP turbine SCC failure were the only way they would have been aware of these types of steam chemistry excursions. They didn't hear anything, so they assumed that there were no steam chemistry related issues of significance. Not hearing anything is silence, and silence is a poor substitute for regular comprehensive evaluation, reporting, and reviewing of cycle chemistry performance.

If Sherco 3 had had a robust chemistry performance review and improvement program in place, I believe it is likely that their turbine experts would have had a much better understanding of the SCC turbine damage related risks that existed before the 2011 SCC turbine failure. If they were armed with this understanding, it is much more likely that they would have seriously considered MPI inspections of the Sherco 3 LP turbine finger dovetail connections.

Q. Did you complete an analysis of the cycle chemistry compliance performance of Sherco 3 prior to the 2011 SCC LP turbine failure?

[9] DOC Ex. 4, SK-R-7 (Klotz Rebuttal) at 5-10 (Trial Transcript).
[10] Id. at 15-17.

A. No. I attempted to evaluate the cycle chemistry compliance performance of Sherco 3 prior to the 2011 SCC LP turbine failure, but the hourly cycle chemistry data provided by Xcel was of such poor quality that I could not complete a meaningful compliance analysis.

Q. What quality issues did you discover with the hourly cycle chemistry data provided by Xcel?

A. I looked at the hourly cycle chemistry data that Xcel provided for 2002 through 2011.[11] There were significant gaps where no data was reported for several different cycle chemistry parameters.

There were also pervasive instances where the same number was reported for different parameters for multiple hours in a row. These numbers were reported to 10 significant digits. Having the exact same reading to 10 significant digits for multiple hours in a row just isn't possible. It's clear that these repeat duplicate results were not valid.

There were also pervasive instances where the change in different cycle chemistry parameters were the same for multiple hours in a row. The incremental change from hour to hour was exactly the same to 10 significant digits. Again, this just isn't possible. It's clear that these repeating duplicate increments from hour to hour were not valid.

[11] See XCEL_Sherco_09_0001231. Because the data is so voluminous (i.e., hourly data for nine years), I have not attached the data to my testimony.

Based on the data that I received, Xcel's process for maintaining accurate historical cycle chemistry data was seriously lacking for the nine years preceding the 2011 SCC LP turbine failure. Without valid hourly cycle chemistry data, it isn't possible to accurately evaluate steam and water chemistry history. It isn't even possible to accurately determine if EPRI recommended shutdown timing limits have been exceeded. I saw events in the data that looked like EPRI recommended shutdown timing limits had been exceeded, but I can't conclude that they were because of the data integrity issues described above.

Q. How do you respond to Mr. Daniels's testimony that, "A thorough review of historic record found no instance where records show feedwater, boiler, or steam were sufficient to create risk of caustic contamination." [12]

A. First, I did see events in the hourly data that could have created a risk of caustic contamination. However, the quality of the hourly cycle chemistry data provided by Xcel was so poor that I couldn't conclude that those events were valid. From that perspective, Mr. Daniels statement that he "found no instances where the records show feedwater, boiler, or steam were sufficient to create risk of caustic contamination" may be technically correct. The hourly chemistry data provided by Xcel didn't really show anything except that the data was either invalid or highly suspect. Because of this, Mr.

[12] Xcel Ex. __ (DGD-1) (Daniels Direct) at 31.

Daniels also wouldn't be able to find records showing that cycle chemistry conditions were not sufficient to create caustic contamination risk.

III. Steam Drum Mechanical Carryover

Q. Would you please provide an overview of steam drum mechanical carryover?

A. Water flows from the steam drum at the top of the boiler to the bottom of the boiler through downcomer lines. From the bottom of the boiler, the water flows back up to the steam drum through water wall tubing. The heat from the combustion of coal inside of the boiler converts part of the water in the waterwall tubing into steam as it travels back up to the steam drum. The steam/water mixture from the waterwalls enters the steam drum below the liquid level in the steam drum. Ideally, the liquid water would remain below the liquid level in the steam drum, and dry steam (steam without water droplets) would exit from the surface of the liquid in the steam drum before flowing through the steam path to the turbines. Unfortunately, liquid water droplets are entrained (i.e., carried along) in the flowing steam based on the velocity of the steam leaving the liquid surface and the density difference between the steam and the liquid water in the steam drum. Steam separation equipment is designed to knock out entrained water droplets before the steam enters the steam path, but the steam separation equipment is not 100% efficient. A certain amount of entrained water droplets will always exit the steam drum with the steam. The entrained liquid water that exits the drum in the steam is known as "*mechanical carryover.*"[13]

Q. How is steam drum mechanical carryover different from vaporous carryover?

A. Chemical contaminants that build up in the drum water have a degree of solubility in the steam that is generated in the boiler. Different contaminants have different solubilities in steam. For example, hydrochloric acid is more soluble in steam than sodium hydroxide. Contaminates of concern such as sodium, chloride, and sulfate become more soluble in the steam at higher drum pressures. There will be a certain amount of contaminants dissolved in the steam based on the steam solubility properties of the contaminants and the concentration of the contaminants in the drum water. This dissolved contamination in the steam phase is known as "*vaporous carryover.*" Total carryover is the vaporous carryover plus the mechanical carryover.[14]

Q. Why is steam drum mechanical carryover a significant concern in terms of the risk of SCC related steam turbine damage?

A. The main contaminants of concern for SCC related steam turbine damage are sodium, chloride, and sulfate.[15] The concentrations of these contaminants in drum water can be orders of magnitude greater than the concentrations dissolved in the steam via

[13] See Exhibit DOC-1, RAP-D-23 (Polich Direct).
[14] Ex. DOC 4, SK-R-1 (Klotz Rebuttal) at 77-78 (GE Litigation, Tr. Ex. 324).
[15] Id. at 102-105.

vaporous carryover. For example, the EPRI limit for sodium in steam is 2-ppb,[16] and the EPRI limit for sodium in drum water for a steam drum that operates at 2,850 psig is about 300-ppb.[17] The EPRI limits for sodium, chloride and sulfate in drum water are based on the steam solubility of the contaminants at the operating drum pressure plus a safety factor for mechanical carryover.[18] If drum contaminant limits are not exceeded, and mechanical carryover performance is within the acceptable range, the steam exiting the steam drum will meet or exceed EPRI's steam purity requirements. Maintaining drum water contaminate levels alone is not enough to assure steam purity. Mechanical carryover performance also needs to be maintained within acceptable limits.

Q. Was monitoring of mechanical carryover relevant to the operation and maintenance of the Sherco 3 plant?

A. Yes. Excessive mechanical carryover from the Sherco 3 steam drum would increase the amount of sodium, chloride, and sulfate contamination in the steam path to the turbines. This increased contaminant load to the LP turbines would increase the risk of SCC turbine damage.

Q. What methods are used to monitor and maintain mechanical carryover?

A. There are several ways to monitor mechanical carryover. Regular testing is the only

[16] Ex. DOC 4, SK-R-10 (Klotz Rebuttal).
[17] Ex. DOC 4, SK-R-1 (Klotz Rebuttal) at 118-126.
[18] Id. at 74.

direct method for determining mechanical carryover, and it is also the most reliable method. The alternatives to regular testing are indirect methods that are less reliable. Xcel used alternatives to regular mechanical carryover testing.

EPRI recommends regular mechanical carryover testing.[19] The test method involves taking saturated steam and drum water samples at the same time. The samples are analyzed for sodium using an analytical method with an appropriate detection limit. The ratio of the sodium in the saturated steam to the sodium in the drum water is indicative of total carryover. The vaporous carryover of sodium is determined based on the drum pressure and the drum water sodium level. The vaporous carryover is subtracted from the total carryover to determine the mechanical carryover.[20] A graph provided by EPRI is used to determine the acceptable mechanical carryover limit based on the steam drum operating pressure.[21] If the results are above the acceptable limit, the root cause for excessive mechanical carryover needs to be determined and addressed.

Continuous online measurement of steam cation conductivity and steam sodium is an indirect way of monitoring that could indicate an issue with mechanical carryover. Periodic steam grab sample analysis of sodium, chloride and/or sulfate is another indirect way that could indicate an issue with mechanical carryover.

[19] Id. at 118-121.
[20] Id. at 75-77.
[21] Id. at 75.

Periodic visual inspection of the steam drum internals including the steam separation equipment is another method to reduce the risk of excessive mechanical carryover. However, it is difficult to visually locate small gaps or cracks that would allow entrained water droplets to bypass the steam separation equipment, and internal steam drum inspections do not occur frequently.

Q. What is steam cation conductivity?

A. Steam cation conductivity is the conductivity of a condensed steam sample after it has passed through cation ion exchange resin. Steam cation conductivity is an indirect indicator of the chloride and sulfate concentration in the steam, which can lead to SCC.

The cation ion exchange resin is similar to the resin in a water softener. The purpose of water softener resin is to replace hardness cations (calcium and magnesium) in the water with sodium ions. The purpose of the cation ion exchange resin is to replace the cations (like sodium and calcium) in the water with hydrogen ions.

Q. How is cation conductivity measured?

A. The steam sample normally comes from the main steam line (between the superheater and the HP turbine) or from the reheat steam line (between the reheater and the IP turbine). The sample will typically flow from the steam line to a separate area that contains sample conditioning and sample analysis equipment. Sample conditioning equipment will condense the steam sample and adjust the sample pressure, temperature, and flow before the sample enters the analysis equipment. For cation conductivity, the cation ion exchange resin is located after the sample conditioning equipment and just before the conductivity measuring device.

A conductivity probe simply measures the electrical conductivity of water. Chemical species, like sodium chloride, ammonium hydroxide, and sodium hydroxide, that are dissolved in water form electrically charged ions. The conductivity of water increases as the concentration of electrically charged ions increases. So, the conductivity of a water sample is indicative of the concentration of chemical species that are dissolved in the water.

Q. Is measuring cation conductivity a reliable way to determine the concentration of chemical contaminants that could cause SCC?

A. No, cation conductivity is an indirect method for measuring chloride and sulfate concentration. Cation conductivity does not provide a measure of sodium hydroxide concentration.

The conductivity level of the steam at Sherco 3 is overwhelmingly influenced by the ammonia that is added to the cycle to control pH. Steam conductivity is a very reliable indicator of ammonia concentration and pH, but it is a poor indicator of chemical contaminant concentration because the concentration of ammonia is so much higher than normal contaminant levels.

Ammonia forms ammonium hydroxide when it is dissolved in water. Ammonium hydroxide forms water when the ammonium ion is exchanged with a hydrogen ion. So, the cation ion exchange resin removes the effect of ammonia on the conductivity reading.

Sodium chloride forms hydrochloric acid when the sodium ion is exchanged with a hydrogen ion. Sodium sulfate forms sulfuric acid when the sodium ion is exchanged. These acids are more conductive than the original sodium salts that entered the cation ion exchange resin.

In summary, the ion exchange resin removes the effect of ammonia and amplifies the effect of chloride and sulfate on the cation conductivity reading. However, there are also contaminants that do not pose a significant risk of SCC turbine damage that affect the cation conductivity reading. So, steam cation conductivity only provides an indirect indication of chloride and sulfate concentration.

Sodium hydroxide forms water when the sodium ion is exchanged for a hydrogen ion. This removes the effect of sodium hydroxide on the cation conductivity reading. *This is why cation conductivity does not provide an indication of sodium hydroxide concentration.*

Q. What does steam sodium measure?

A. Steam sodium is a measure of the concentration of sodium ions in the steam. Sodium from sodium hydroxide, sodium chloride and sodium sulfate would be included in the measurement. Sodium from chemical species that do not pose a significant risk of SCC turbine damage would also be included in the measurement. So, steam sodium is an indirect indicator of sodium hydroxide, chloride, and sulfate concentration in the steam.

Q. Please explain the differences between continuous monitoring and grab samples?

A. Continuous monitoring is monitoring that occurs on a continuous basis. A continuously flowing sample is routed to an instrument that provides a signal that continuously indicates the measurement of interest. Continuous monitoring provides a live reading of the measurement.

A grab sample is a sample that is taken at one point in time. The sample is collected and then analyzed. The results indicate the measurement of interest at a single point in time.

For monitoring of various chemistry parameters at certain locations in the steam cycle, EPRI recommendations specify whether the sampling method should be continuous monitoring or intermittent (i.e., grab samples).[22]

[22] Ex. DOC 4, SK-R-10 (Klotz Rebuttal).

Q. What methods were used at Sherco 3 to monitor and maintain mechanical carryover?

A. Sherco 3 did not follow EPRI's recommendation to regularly test mechanical carryover performance.[23] According to the Sherco 3 Chemistry Supervisor's testimony, mechanical carryover performance was never tested at Sherco 3, and he didn't have any idea how to complete the testing.[24]

Prior to 2008, Sherco 3 did not have a continuous online steam sodium analyzer in place.[25] They were analyzing steam grab samples for sodium on a weekly basis using an atomic emission (AE) method. [26] According to Xcel, the detection level for this AE method was 5-ppb which is 2.5 times above the EPRI limit for steam sodium.[27]

Sherco 3 had a continuous online steam cation conductivity analyzer in place. So, they did have an indirect way of possibly indicating excessive mechanical carryover. Mechanical carryover is a ratio of a contaminant's concentration in the saturated steam to that contaminant's concentration in the drum water. A high steam cation conductivity alone might indicate excessive mechanical carryover, but it might not if drum water contaminant concentrations are sufficiently high. Similarly, normal steam cation conductivity readings might indicate acceptable mechanical carryover

[23] Ex. DOC 4, SK-R-1 (Klotz Rebuttal) at 94.
[24] Exhibit DOC-4, SK-R-3 (Klotz Rebuttal) at 4-5.
[25] Id. at 7.
[26] Id. at 6.
[27] Id.; Ex. DOC 4, SK-R-1 (Klotz Rebuttal) at 120.

performance, but they might not if the drum water contaminant concentrations are sufficiently low.

In 2008, Sherco 3 installed a continuous online steam sodium analyzer.[28] From that point forward, they did have an additional indirect way of possibly indicating that there were mechanical carryover issues. Again, mechanical carryover is a ratio of a contaminant's concentration in the saturated steam to that contaminant's concentration in the drum water. A high steam sodium concentration alone might indicate excessive mechanical carryover, but it might not if the drum water sodium concentration is sufficiently high. Similarly, normal steam sodium concentration might indicate acceptable mechanical carryover performance, but it might not if the drum water sodium concentration is sufficiently low.

Xcel's process for managing mechanical carryover relied on visual inspection of the Sherco 3 steam drum internals, not performing mechanical carryover testing as recommended by EPRI. Again, it is difficult to visually locate small gaps or cracks that would allow entrained water droplets to bypass the steam separation equipment. Visual inspections of the Sherco 3 steam drum internals were infrequent, occurring only once every 3 years.[29]

[28] Exhibit DOC 4, SK-R-3 (Klotz Rebuttal) at 7.
[29] Exhibit DOC 4, SK-R-4 (Klotz Rebuttal).

Q. Were the mechanical carryover monitoring and maintenance practices at Sherco 3 sufficiently prudent to avoid the SCC turbine failure in November of 2011?

A. No. EPRI recommended regular testing of mechanical carryover performance. Xcel has never performed mechanical carryover testing on Sherco 3. EPRI recommended continuous online monitoring of steam sodium. Xcel did not have continuous online steam sodium monitoring until 2008. Xcel did continuously monitor steam cation conductivity, but this is an indirect measure of chloride and sulfate contamination that doesn't respond at all to sodium hydroxide contamination. Xcel's visual inspections of the steam drum internals were infrequent, occurring only once every 3 years, and it's difficult to visually locate small gaps or cracks that would allow mechanical carryover to bypass the steam separation equipment.

Contrary to Mr. Daniels, who stated that he "could find no evidence that the plant was operated in a condition that would have sent contaminated steam to the steam turbine,"[30] it is my opinion that mechanical carryover cannot be eliminated as a potentially significant cause for the 2011 LP turbine SCC failure.

IV. Sodium Monitoring

Q. Do you agree with Mr. Daniels's conclusion[31] that the steam chemistry monitoring practices at Sherco 3 were based on industry standards?

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[30] Xcel Ex. __ (DKD-1) at 24 (Daniels Direct).
[31] Id. at 32.

A. No. As discussed in detail below, I identified numerous ways in which monitoring at Sherco 3 failed to meet EPRI recommendations. EPRI recommendations represent prudent practices in the industry that Xcel professed to follow.

Q. Would you please describe how continuous sodium monitoring affects the potential for SCC related turbine damage?

A. Chloride, sulfate, and sodium are the key contaminants of concern for SCC related turbine damage.[32] Continuous sodium monitors measure the total sodium in the sample which includes sodium in sodium hydroxide and sodium associated with chloride and sulfate. The total sodium measurement also includes sodium associated with other contaminants that are not a significant concern for SCC turbine damage. So, sodium monitors provide an indirect indication of chloride, sulfate and sodium hydroxide contamination which is a significant concern for SCC turbine damage.

Cation conductivity monitors also give an indirect indication of chloride and sulfate contamination, but these monitors do not give any indication of sodium hydroxide contamination. It's critical to properly monitor sodium levels on a continuous basis in the steam cycle to reduce the risk of sodium hydroxide related SCC turbine damage.

Q. Prior to 2011, did EPRI make any recommendations regarding continuous sodium monitoring?

[32] DOC Ex. 4, SK-R-1 (Klotz Rebuttal) at102-105.

A Yes, EPRI's Cycle Chemistry Guidelines, published in 2002, which are attached to my rebuttal testimony as Schedule 1 and which I've referenced throughout my testimony, also address the importance of continuous online sodium monitoring.

Please refer to Figure 1 directly below as an aid to the discussion that follows.[33]

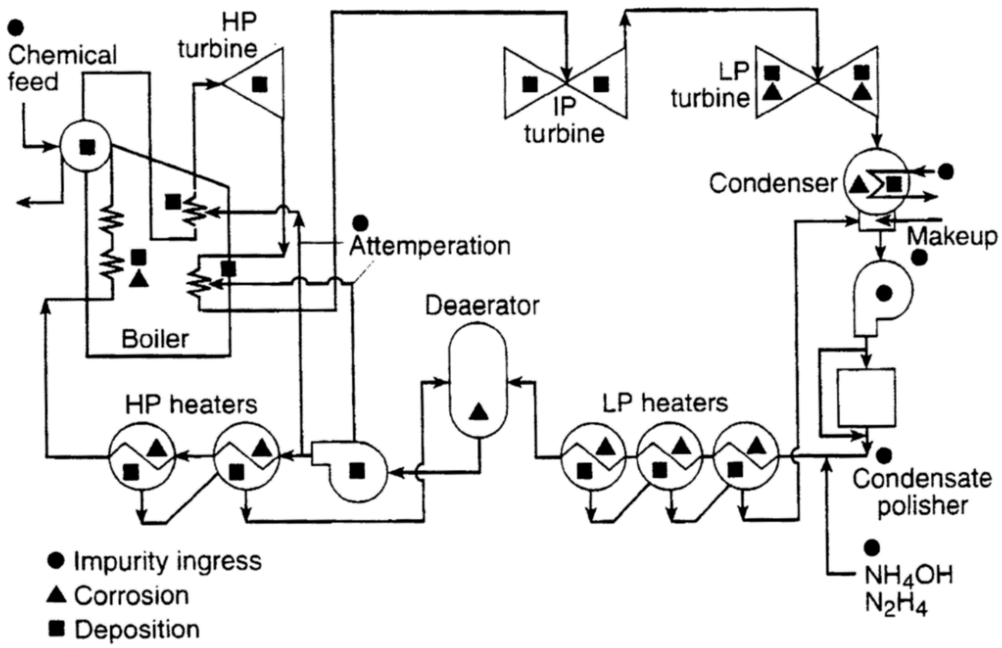

Figure 1

Key EPRI recommended sodium sampling points that relate to the potential for SCC turbine damage are listed below:

- Condensate pump discharge (CPD): Condensate pumps take water from the condenser hot well and pump it through the condensate polishers and then to

[33] Ex. DOC 4, SK-R-1 (Klotz Rebuttal) at 73.

the deaerator. Elevated sodium at this sample point is most likely an indication of a condenser tube leak. To a lesser extent, elevated CPD sodium can indicate contaminated makeup water. The flow rate of makeup water is about 1% of the flow rate of condensate at the CPD,[34] so makeup water would have to be severely contaminated to identify the issue based on the CPD sodium analyzer reading.

- Condensate polisher effluent (CPE): The CPE is located between the polishers and the deaerator. Sherco 3 used an ammoniated cation resin in their condensate polishers. Sodium isn't readily exchanged by this form of cation resin. Sodium essentially passes directly through the polisher without being exchanged. This just means that the concentration of sodium at the inlet of the polishers will be very close to the concentration at the outlet of the polishers.
- Economizer inlet (EI): Boiler feed pumps move water from the deaerator to the EI. The economizer is a heat exchanger that transfers heat from the flue gas to the feedwater before the feedwater enters the steam drum. The sodium concentration at the EI should be very close to the concentration at the CPE. Because the Sherco 3 condensate polishers don't really remove sodium, the sodium concentrations at the CPD, CPE and EI should all be very similar.

[34] Xcel Ex. __ (DGD-1, Schedule 3) (Daniels Direct) (Sherco 3 had capacity to generate 6350k/lbs/hr of steam); Exhibit DOC 4, SK-R-3 (Klotz Rebuttal) at 2 (normal makeup water flow is 50 to 100 gpm.) 100 gpm equals approximately 50k lbs/hr. 50k lbs. per hour is less than 1% of 6350k lbs. per hour.

- Drum water (DW): The DW sample is taken from downcomer lines that transport water from the steam drum at the top of the boiler to the bottom of the boiler. Elevated DW sodium is likely indicative of condenser tube leaks or contaminated makeup water. A rapid increase in DW sodium is indicative of a significant contamination event like a large condenser tube leak or severely contaminated makeup water. A slow increase in DW sodium would indicate a small condenser leak or slightly contaminated makeup water.
- Main steam or reheat steam (MS/RH): The MS sample is taken from the steam line that is between the superheater and the HP (high pressure) turbine. The RH sample is taken from the steam line that is between the reheater and the IP (intermediate pressure) turbine. The level of sodium in the MS or RH sample indicates the amount of total sodium carryover (vaporous carryover + mechanical carryover) from the steam drum in addition to any sodium that is added to the steam path by attemperator sprays (see Figure 1 above). Attemperator sprays are feedwater that is sprayed into the steam path to reduce the temperature of the steam. Any chemical contamination contained in the feedwater will be injected directly into the steam path and will enter the steam turbine. Attemperator sprays are a common way in which chemical contamination enters the steam flow path. The MS sample includes the sodium addition from the superheater attemperator sprays (see Figure 1 above). The RH sample includes the sodium addition from the superheater attemperator sprays and from the reheater attemperator sprays (see Figure 1 above).

Elevated MS or RH sodium could be caused by elevated drum or feedwater sodium levels from condenser leaks or contaminated makeup water, or from excessive mechanical carryover.

- Demineralizer effluent (DE): This sample is located between the demineralizer system and the makeup water storage tanks. Elevated DE sodium could indicate that the cation resin in the system is spent and needs to be regenerated. Chronically elevated DE sodium would likely indicate that the demineralizer system is not functioning properly because of mechanical issues or because of poorly performing ion exchange resins for example. It is critical to continuously monitor DE sodium to avoid producing makeup water that is contaminated with excessive sodium and to avoid contaminating the makeup water storage tanks with excessive sodium. Contaminated makeup water is one of the possible sources of contamination entering the steam path to the turbines.

Q. Did Sherco 3 follow EPRI's recommendations for continuous online sodium monitoring?

A. From 1999 until the SCC turbine failure in 2011, Xcel followed some of EPRI's recommendations but not all of them:[35]

[redacted] **[NONPUBLIC INFORMATION BEGINS** [redacted]

[35] Ex. DOC 4, SK-R-10 (Klotz Rebuttal).

[redacted]

- [redacted] **NONPUBLIC INFORMATION ENDS**][36]
- DE sodium was continuously monitored.[37]

Q. Are there concerns related to SCC turbine damage associated with the failure to follow EPRI's online sodium monitoring recommendations[38] at Sherco 3?

A. Yes, there are:

- A significant amount of the sodium that enters the condensate polishers will exit as sodium hydroxide, which can contribute to SCC. The cation resin in the condensate polishers is in the ammoniated form. Ammonium and sodium have about the same affinity for the cation resin, so sodium essentially passes through the condensate polisher without being exchanged. The anion resin in the condensate polishers is in the hydroxide form. Anions like chloride and sulfate are exchanged with hydroxide when they pass though the condensate polisher. When sodium chloride and sodium sulfate enter the condensate polisher, the sodium is not exchanged, but the chloride and sulfate will be exchanged with hydroxide. Sodium chloride and sodium sulfate that enter the condensate polisher will exit as sodium hydroxide.

[36] DOC Ex. 1, RAP-D-22 at 22 (Nonpublic).
[37] DOC Ex. 4, SK-R-5 (Xcel Response to DOC IR S95).
[38] DOC Ex. 4, SK-R-10.

- CPE sodium was not continuously monitored: The main purpose of this sodium sample point is to determine if the cation resin in the polisher is exhausted. The Sherco 3 polishers use ammoniated cation resin, so they don't remove sodium to a significant extent. Monitoring CPE sodium won't indicate if the cation resin is exhausted. From that perspective, this exception to EPRI's recommendation is not significant.
- EI sodium was not continuously monitored: Because the Sherco 3 condensate polishers don't really remove sodium, the EI sodium monitor should essentially duplicate the CPD sodium monitor. Having this type of duplication is an important part of the rationale for EPRI's continuous sodium monitoring recommendations. If there's a significant mismatch between the duplicate monitors, that's an indication that there's an issue with at least one of the monitors. Addressing issues with monitors through maintenance and/or calibration is critical to ensuring acceptable steam purity.
- The sodium hydroxide that leaves the condensate polishers is forwarded to the feedwater which is the source of superheat and reheat attemperator sprays. The sodium hydroxide in these sprays bypasses the boiler and directly enters the steam path to the turbines.
- The remainder of the sodium hydroxide in the feedwater will be fed directly into the boiler where it will build up in concentration unless the boiler is blown down. If the boiler isn't blown down to remove the sodium hydroxide, it can build up

enough to cause excessive carryover of sodium hydroxide from the steam drum into the steam path to the turbines.

- Ensuring that sodium levels in the feedwater are below EPRI recommended limits is a critically important practice to minimize the risk of SCC turbine damage. Having redundant pre-boiler continuous online instrumentation is a prudent practice to ensure appropriate sodium levels in the feedwater. Sherco 3 did not have redundant pre-boiler continuous online sodium instrumentation.
- RH sodium was not continuously monitored, and MS sodium was not continuously monitored until 2008: It is critical to continuously monitor steam sodium. Continuous RH sodium monitoring is the best practice, but continuous MS sodium monitoring is sufficient if steam flow, attemperator spray flow and feedwater sodium levels are well monitored.
- From 1999 until 2008, neither MS nor RH steam sodium were continuously monitored: From a continuous monitoring perspective, Sherco 3 was blind to intermittently excessive mechanical carryover of sodium hydroxide from the steam drum into the steam path to the turbines during this timeframe.
- From 1999 until 2008 when there was no continuous steam sodium monitoring taking place, grab samples of steam were analyzed for sodium on a weekly basis. Weekly testing is not sufficiently frequent to safeguard against intermittently excessive mechanical carryover.
- The Sherco Chemistry Department was using an AE spectroscopy method for the weekly steam sample sodium analysis. According to Xcel, the detection limit for

this AE method is 5-ppb of sodium.[39] This is 2.5 times the EPRI action level 1 limit for steam sodium.[40] The 5-ppb sodium detection limit for the AE method that the plant was using is far from sufficient for the intended purpose of the test.

Q. Were the sodium monitoring practices at Sherco 3 sufficient to avoid the SCC turbine failure in November of 2011?

A. No. Xcel did not follow EPRI's recommendation to continuously monitor EI sodium, so they did not have redundant continuous sodium monitors in the pre-boiler section of the plant. Xcel did not follow EPRI's recommendation to continuously monitor steam sodium until 2008. Xcel did complete steam grab sample sodium testing on a weekly basis, but weekly testing is not frequent enough to provide protection from intermittently excessive sodium hydroxide carryover. Additionally, the grab sample sodium method that Xcel used had a detection limit of 5 ppb [41]which is 2.5 times the EPRI recommended steam sodium limit of 2 ppb.[42] *As a result, I conclude that sodium hydroxide contamination cannot be eliminated as a potentially significant cause for the 2011 SCC turbine failure.*

V. Makeup Water Quality

[39] Ex. DOC 4, SK-R-3 (Klotz Rebuttal) at 6.
[40] Ex. DOC 4, SK-R-10.
[41] Ex. DOC-4, SK-R-3 (Klotz Rebuttal) at 6.
[42] Ex. DOC 4, SK-R-10.

Q. Would you please provide an overview of makeup water quality as it relates to the risk of SCC turbine damage?

A. Makeup water is used to replace water and steam that leaves the boiler water and steam cycle. Losses of cycle water and steam occur for various reasons including leaking pipes, leaking seals, water for soot blowing, and take offs for chemistry samples.

The Sherco generating site produced makeup water for all 3 operating units from well water. Well water was processed through various pieces of equipment in the site's demineralizer system to purify the water for use in the generating plants. Purified water from the demineralizer system was forwarded to makeup storage tanks and then forwarded to the hot wells of the Sherco site's three operating units (not just Sherco 3) on an as needed basis.

Q. Has EPRI published recommendations regarding makeup water quality?

A. Yes. Makeup water quality is directly related to the amount of chemical contamination in the makeup water. Low quality makeup water means that the water contains higher levels of chemical contamination. High quality makeup water means that the water contains lower levels of chemical contamination. The key makeup water contaminants that relate to SCC turbine damage include chloride, sulfate, and sodium.[43] The EPRI recommended makeup water limit for each of these contaminants is 3-ppb. [44]

[43] Ex. DOC 4, SK-R-1 (Klotz Rebuttal) at 72-75.
[44] Ex. DOC 4, SK-R-10 (Klotz Rebuttal).

A significant amount of the sodium in the makeup water will be converted to sodium hydroxide in the condensate polishers. From the polishers, some of this sodium hydroxide will bypass the boiler and directly enter the steam path to the turbines via the attemperator sprays. The remainder of the sodium hydroxide will be fed directly into the boiler where it will build up in concentration unless the boiler is blown down. If the boiler isn't blown down to remove the sodium hydroxide, it can build up enough to cause excessive carryover of sodium hydroxide from the steam drum into the steam path to the turbines.

Q. Were the Sherco site's makeup water limits for chloride, sulfate, and sodium consistent with the EPRI recommended makeup water limits?

A. Based on my review of the Sherco Chemistry Department manual, the makeup water limits were considerable higher than the EPRI's recommended limits. According to the Sherco Chemistry Department manual, the limits for chloride, sulfate and sodium were as follows: **[NONPUBLIC INFORMATION BEGINS**

[redacted]

[45] Ex. DOC 4, SK-R-6 (Klotz Rebuttal) at 37 (NSP Sherburne County Generating Plant Chemistry Manual) (Nonpublic).

[redacted]

○ [redacted] **NONPUBLIC INFORMATION ENDS]**

Again, EPRI's recommended makeup water limit for each of these contaminants is 3-ppb.[47]

Q. Did you evaluate makeup water quality data for the Sherco site for the period of 1999 through 2011?

A. I was able to complete a limited evaluation. Xcel provided grab sample analysis results for the demineralizer effluent[48] and for the makeup supply line from the makeup storage tank.[49] The timeframe for the results that were provided was from March of 2004 through December of 2011. No data was provided from 1999 to March of 2004, so my evaluation did not include that timeframe. On average, grab samples were analyzed once every 2 to 3 weeks. Sample analysis was not performed frequently enough to be definitive about Sherco's makeup water quality from 1999 to 2011. Xcel did not provide any continuous online makeup water quality data.

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[46] Id. at 38.
[47] DOC Ex. 4, SK-R-10 (Klotz Rebuttal).
[48] DOC Ex. 4, SK-R-8 (Klotz Rebuttal) (Grab sample analysis, demineralizer effluent).
[49] DOC Ex. 4, SK-R-9 (Klotz Rebuttal) (Grab sample analysis, makeup storage tank).

Q. What were the results of your limited evaluation of Sherco's makeup water quality data?

A. For the demineralizer effluent grab samples, nearly all the sodium and silica results that were provided were reported simply as "< 5-ppb". Based on the grab sample results that Xcel provided, it's not possible to know if Sherco's makeup water consistently met the EPRI recommended limit of 3-ppb for sodium and silica.[50] Nearly all the demineralizer effluent specific conductivity grab sample results that were provided were in compliance with EPRI's recommended limit of 0.1 uS/cm.[51]

For the grab samples that were taken from the makeup water supply line to the hot well, nearly all the sodium and silica results that were provided were reported simply as "< 5-ppb."[52] Based on the results provided by Xcel, it's not possible to know if Sherco's makeup water consistently met the EPRI recommended limit of 3-ppb for sodium and silica.[53]

Xcel also provided demineralizer effluent pH grab sample results from March of 2004 through December of 2011. The pH results for 127 different grab samples across this time were provided. Almost 90% of the results indicated that the makeup water being sent from the demineralizer to the makeup storage tanks was acidic. In other words,

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[50] DOC Ex. 4, SK-R-10.
[51] Id.; DOC Ex. 8 (Klotz Rebuttal)
[52] DOC Ex. 4, SK-R-9 (Klotz Rebuttal).
[53] DOC Ex. 4, SK-R-10 (Klotz Rebuttal).

the pH was below 7 for 90% of the samples. The lowest pH result provided was 5.1, and the average pH result provided was 6.2.[54]

The Sherco demineralizer effluent pH results provided by Xcel were typically acidic. This indicates that anionic contaminants such as chloride, sulfate and bicarbonate were making it through the demineralizer system without being completely removed. If the pH of the demineralizer effluent was over 7, it would be basic rather than acidic. If it was basic, that would indicate that cationic contaminants like sodium and calcium were making it through the demineralizer without being completely removed.

Demineralizer systems are not perfect. Some anionic contaminants and some cationic contaminants are always going to pass through without being removed. Because the demineralizer effluent was normally acidic, more anionic contaminants were making it through the system without being removed than cationic contaminants. This could indicate that there was a performance issue with the anion removal portions of the demineralizer system. Chloride and sulfate are anionic contaminants that can contribute to SCC turbine damage. Xcel did not provide any chloride or sulfate analysis results for the makeup system.

Q. Was the Sherco site's makeup water quality sufficient to avoid the Sherco 3 SCC turbine failure in November of 2011?

[54] DOC Ex. 4, SK-R-8 (Klotz Rebuttal).

A. There wasn't enough data available to determine if the site's makeup water quality was sufficient to avoid the 2011 Sherco 3 SCC turbine failure.

The site's makeup water purity limits for chloride, sulfate and sodium as shown in the Sherco Chemistry Department manual were not set prudently. The EPRI recommended limits for those contaminants were considerably lower than the limits shown in the Sherco Chemistry Department manual. Running at or near the Sherco Chemistry Department manual limits for chloride, sulfate or sodium would represent a higher risk of SCC turbine damage than running at or near the EPRI recommended limits.

The demineralizer effluent was normally acidic which could indicate that there was a performance issue with the anion removal portions of the demineralizer system. Chloride and sulfate are anionic contaminants that can contribute to SCC turbine damage, and Xcel did not provide any chloride or sulfate analysis results for the makeup system.

In conclusion, *makeup water quality cannot be eliminated as a potential contributing cause for the 2011 Sherco 3 LP turbine failure.*

VI. Conclusions

Q. Would you please summarize your conclusions concerning the cycle chemistry practices at Sherco 3 for the period of 1999 to 2011?

A. The cycle chemistry practices at Sherco 3 contributed to the SCC failure of the Sherco 3 LP turbine in November of 2011.

Cycle chemistry related practices of concern that are related to the 2011 Shecro 3 LP turbine failure were detailed in my preceding testimony. A high-level summary of those concerns is captured below.

- Xcel's cycle chemistry performance review and improvement practices were not prudent:
  - The Sherco site did not have a formal cycle chemistry performance review and improvement program in place.
  - The site relied on informal cycle chemistry performance evaluation and issue communication practices. With informal systems like this, it's easy for important information and issues to slip through the cracks.
  - When Sherco's turbine experts didn't hear anything, they assumed that there were no steam chemistry related issues of significance on Sherco 3 prior to the 2011 SCC turbine failure.
  - Not hearing anything is silence, and silence is a poor substitute for regular comprehensive evaluation, reporting, and reviewing of cycle chemistry performance.
  - Based on the hourly chemistry data they provided, Xcel's process for maintaining accurate historical cycle chemistry data was seriously lacking for the nine years preceding the 2011 SCC LP turbine failure.

- It wasn't possible to complete a meaningful cycle chemistry compliance analysis of the hourly chemistry data provided by Xcel. Too much of the data was either missing, invalid, or highly suspect.

- Steam drum mechanical carryover risk management practices were not prudent:
  - The mechanical carryover performance of Serco 3 was never tested.
  - Prior to 2008, Sherco 3 did not have continuous online steam sodium monitoring.
  - Weekly sodium analysis of steam grab samples was not frequent enough to provide protection from intermittently excessive mechanical carryover.
  - The detection limit of the method used to analyze for sodium in the weekly steam grab sample was not low enough to provide protection from mechanical carryover.
- Sodium monitoring practices were not prudent:
  - Sherco 3 did not have continuous online steam sodium monitoring in place until 2008.
  - Periodic sodium analysis of condensate, feedwater and steam grab samples was not frequent enough to provide protection from intermittent sodium contamination.
  - The detection limit of the method used to analyze for sodium in the condensate, feedwater and steam grab samples was not low enough to provide protection from sodium contamination.

  - Sherco 3 did not have sufficient redundancy of continuous online sodium monitoring in place in the pre-boiler section of the plant.
  - Ensuring compliance with the feedwater sodium limit is critical because Sherco 3 feedwater contains sodium hydroxide.
  - Some of the sodium hydroxide in the feedwater bypasses the boiler and is injected directly into the steam path to the turbines.
  - The remainder of the sodium hydroxide in the feedwater is fed directly into the boiler where it will build up in concentration unless the boiler is blown down. If the boiler isn't blown down to remove the sodium hydroxide, it can build up enough to cause excessive carryover of sodium hydroxide from the steam drum into the steam path to the turbines.
- Makeup water quality cannot be eliminated as potential contributing cause for the 2011 SCC turbine failure:
  - The Sherco site makeup water limits for chloride, sulfate and sodium were not prudently set. The site's limits for these contaminants were considerably higher than the EPRI recommended limits.
  - Xcel did not provide enough data to determine if the site's actual makeup water quality was appropriate or inappropriate from the perspective of SCC related turbine damage risk.
  - The demineralizer effluent was normally acidic which could indicate that there was a performance issue with the anion removal portions of the demineralizer system.

- Chloride and sulfate are anionic contaminants that can contribute to SCC turbine damage, and Xcel did not provide any chloride or sulfate analysis results for the makeup system.

Q. Does this conclude your testimony?

A. Yes.