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BEFORE THE MINNESOTA OFFICE OF ADMINISTRATIVE HEARINGS
600 North Robert Street, St. Paul, MN 55101

FOR THE MINNESOTA PUBLIC UTILITIES COMMISSION
121 7th Place East, Suite 350, 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
In re the Review of the 2013-14 Annual Automatic Adjustment Reports for All Electric Utilities	MPUC Docket No. E-999/AA-14-579
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

DIRECT TESTIMONY OF RICHARD A. POLICH

ON BEHALF OF

THE MINNESOTA DEPARTMENT OF COMMERCE
DIVISION OF ENERGY RESOURCES

June 16, 2023

PUBLIC DOCUMENT

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Abbreviations Used in Testimony

Commission	Minnesota Public Utilities Commission
EPRI	Electric Power research Institute
GDS	GDS Associates, Inc.
GE	General Electric
HP	High-Pressure
hr	Hour
IP	Intermediate Pressure
lb	Pounds
LP	Low-Pressure
MPI	Magnetic Particle Inspection
MVa	Megavolt Amperes
NERC	National Electric Reliability Council
NSP	Northern States Power
O&O	Ownership and Operation Agreement
psig	Pounds per square inch gage pressure
RCA	Root Cause Analysis
SCC	Stress Corrosion Cracking
Sherco 3	Xcel Sherco Unit 3 Power Plant
SMMPA	Southern Minnesota Municipal Power Agency
TIL	General Electric Technical Information Letter

I. Introduction

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

A. My name is Richard A. Polich, P.E. I am a Managing Director with GDS Associates, Inc. (GDS). My business address is 1850 Parkway Place, Suite 800, Marietta, Georgia, 30067.

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 (Department).

Q. What is your assignment in this proceeding?

A. My assignment is to assist Department of Commerce personnel in conducting an evaluation of the Xcel Energy's (Xcel) operation of its Sherburne County Generating Station Unit 3 (Sherco 3) generator, 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). In particular, it is my understanding that the Minnesota Public Utilities Commission (Commission) has commenced this proceeding for the purpose of considering whether Xcel's Sherco 3 maintenance and operating practices led to the steam turbine failure and if the costs of purchasing replacement power during the time that the Sherco 3 was out of service were prudently and reasonably incurred.

Q. What is your educational and professional background?

A. I received a Bachelor of Science Mechanical Engineering in 1979, a Bachelor of Science Nuclear Engineering in 1979, and a Master of Business Administration in 1990, all from the University of Michigan in Ann Arbor, Michigan. I am a registered Professional Engineer in the State of Michigan but am not licensed or certified as a Professional Engineer in the State of Minnesota. I have over 40 years of experience in the utility industry and energy sector, performing duties and services for myriad companies and organizations, and representing the interests of private and public constituencies throughout the world.

In May 1978, I joined Gilbert-Commonwealth Associates, Inc., located in Jackson, Michigan, as a Graduate Engineer and worked on several plant modification projects, new nuclear plant construction projects and in the information technology department. In May 1979, I joined Consumers Power Inc., (now called Consumers Energy), located in Jackson, Michigan, as an Associate Engineer in the Plant Engineering Services Department. While in this department, I provided plant engineering design, project oversight and engineering trouble shooting on the company's existing and new construction power generation fleet. In April 1980, I transferred to the Midland Nuclear Project and progressed through various job classifications to Senior Engineer. I also participated in the initial design evaluation of the Midland Cogeneration Plant. Between 1987 and 1998, I worked in Consumers Power Marketing and Rates Department, progressing to Manager of Rates.

I joined Nordic Energy, an independent power producer and retail/wholesale power marketer, in 1998 as Vice President. In 2003, I began my consulting career when forming Energy Options & Solutions, based in Ann Arbor, Michigan, as a consulting firm focused on providing engineering services and regulatory support. During my consulting career, I have provided a variety of testimony on rates, cost of service, and engineering problems in various state regulatory commissions and the Federal Energy Regulatory Commission. I also have provided project development expertise on wind, solar and various fossil generation projects. In 2015, I joined GDS Associates, Inc. (GDS).

Q. What portion of your engineering project experience relates directly to evaluation of the cause of the Sherco 3 steam turbine failure?

A. Throughout my career, I have participated in and performed failure analysis of multiple types of equipment and systems, many of which have involved utility power generation systems. I have provided power generation asset management services for several clients which involved oversight of power generation facilities in which they are a minority owner of the plant. The asset management function for minority owners includes review of plant operation and management, equipment failure root cause analysis, and maintenance and repair options analysis of power generation equipment. While working on power plant failure analysis or root cause analysis, I have performed evaluations of equipment failures associated with stress corrosion cracking (SCC), water chemistry induced corrosion, metallurgical damage and failure, impact of thermodynamics on systems causing failures and other types of events leading to equipment failures. A copy of my resume is contained in Schedule 1 of my direct testimony.[1]

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

A. A list of utility regulatory proceedings in which I have filed testimony is set forth in Schedule 2.[2] Regulatory proceedings in which I provided testimony specifically on equipment failures and owner maintenance and operating practices include:

- Indiana Utility Regulatory Commission, Case No. 38707 FAC111-S1;
- Florida Public Service Commission, Docket No. 2019001-EI;
- Minnesota Public Utility Commission, Docket No. E999/AA-20-171; and
- Minnesota Public Utility Commission, Docket No. G-002/CI-21-610.

Q. Do you have an opinion regarding whether replacement power costs incurred because of the November 19, 2011 accident at Sherco 3 were reasonably and prudently incurred?

A. Yes. The accident originated in one of Sherco 3's two low pressure (LP) turbines due to L-1 set of buckets separating from to the LP turbine rotor, causing significant damage to the turbine, generator and exciter. The LP turbine is part of the turbine-generator

[1] DOC Ex. __, RAP-D-1 (Polich Direct) (Professional Resume).
[2] DOC Ex. __, RAP-D-2 (Polich Direct) (List of Prior Testimony)

package which turns steam into electricity. Figure 1 shows a cutaway view of a steam turbine that would be similar to Sherco 3's steam turbine but not identical. The LP

Figure 1 - Example Steam Turbine

turbines are the ones with the long blades, called buckets, located on the right side of Figure 1. The turbine buckets separated because the LP turbine rotor disk holding the L-1 turbine buckets cracked due to SCC. It is my opinion that Xcel would have prevented this accident if it had not delayed the inspection of the LP turbine and had followed industry guidelines on the timing of proper LP turbine inspection. Thus, the replacement power costs were ***not*** reasonably and prudently incurred because Xcel failed to operate and maintain Sherco 3 in a manner that was consistent with good utility practice. This opinion is based on the following:

- Xcel failed to perform maintenance on the Sherco 3 steam turbine in accordance with good utility practice.
- Xcel personnel had in their possession documentation that identified the potential for steam turbine failure and provided recommended plant maintenance and inspection practices to avoid such a failure.

- Xcel personnel were well aware of stress corrosion cracking problems in low pressure turbines long before the November 19, 2011 catastrophic failure at Sherco 3.
- Xcel knowingly and unreasonably risked delaying inspections of the Sherco 3 steam turbine even though manufacturer and other utility industry knowledge contained recommendations to perform the inspections earlier and even though it knew that this delay increased the risk of failure.

It is my opinion that, had Xcel followed good utility practice it likely would have discovered the metallurgical condition – SCC – that resulted in the steam turbine failure that put Sherco 3 out of service for approximately 23 months. Thus, if Xcel had acted prudently, the November 19, 2011 Sherco 3 accident, and the resulting costs, would have been avoided.

Q. You have used the phrase "good utility practice." In your professional opinion, what do you consider to be good utility practice?

A. "Good Utility Practice" means any of the practices, methods, and acts engaged in or approved by a significant portion of the electric utility industry during the relevant time period, or any of the practices, methods, and acts which, in the exercise of reasonable judgment in light of the facts known at the time the decision was made, could have been expected to accomplish the desired result at a reasonable cost consistent with good business practices, reliability, safety and expedition.[3]

"Good Utility Practice" is not intended to be limited to the optimum practice, method, or act, to the exclusion of all others, but rather to refer to acceptable practices, methods, or acts generally accepted in the region in which the Project is located. "Good Utility Practice" includes, but is not limited to, LP turbine inspection and maintenance criteria of the turbine manufacturer General Electric (GE), recommendations of the Electric Power Research Institute, (EPRI), the North American Reliability Corporation (NERC) criteria, rules, guidelines, and standards, Federal Energy Regulatory Commission criteria, rules, guidelines, and standards, and Minnesota Public Utilities Commission criteria, rules, guidelines, and standards, where applicable, and as they may be amended from time to time, including the rules, guidelines, and criteria of any predecessor or successor organization to the foregoing entities.

II. Overview of Sherco 3

Q. Please describe the allocation of Sherco 3 responsibilities between Xcel and Southern Minnesota Municipal Power Agency (SMMPA).

A. Sherco 3 is 41 percent owned by the Southern Minnesota Municipal Power Agency (SMMPA), which is a municipal power agency serving retail municipal power companies.

[3] This definition is generally consistent with that used in the industry. *See, e.g.*, DOC-__, RAP-D-4 (Polich Direct) (*United States v. Exelon Corp.*, Case: 1:11-cv-02276, Final Judgment (D.D.C. May 23, 2012)) and DOC-__, RAP-D-5 (Polich Direct) (Northern States Power Open Access Transmission Tariff excerpts).

Although SMMPA owns a large portion of Sherco 3, Xcel is 100% responsible for all plant operation, maintenance, and other decisions associated with the plant. Responsibility and cost allocation for Sherco 3 is governed by the Sherburne County Generating Unit 3 Ownership and Operating Agreement (O&O) dated January 10, 1983, between NSP and SMMPA, as amended. Under the O&O, Xcel Energy has the responsibility to manage the plant. The O&O directs those costs be shared between Xcel and SMMPA on a fixed or variable cost basis, as appropriate.[4]

Q. Please provide a description of Sherco 3.

A. Sherco 3 was initially placed in service in November 1987 and is the largest of the three coal fired units at Sherco located in Sherburne County, Minnesota. Units 1 and 2 are 750

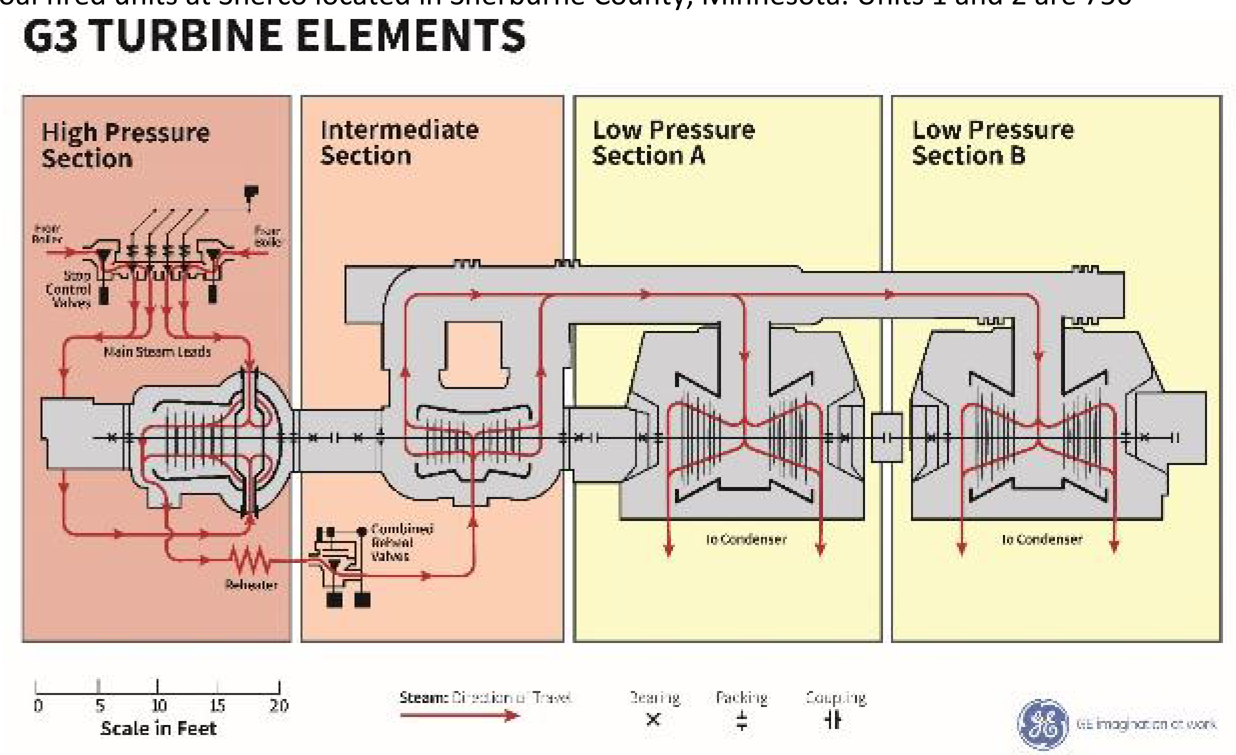

Figure 2- Sherco 3 Steam Turbine, Generator and Exciter General Configuration

[4] In the Matter of the Application of Northern States Power Company for Authority to Increase Rates for Electric Service in Minnesota, Docket No. E002/GR-13-868, Direct Testimony of Ronald L. Brevig at 7. (eDocket No. 201311-93272-05)

megawatts (a megawatt (MW) a quantity of electricity and is equal to 1,000 kilowatt (kW)) each and Sherco 3 is 900 MW. Unit 3 has a Babcock & Wilcox drum boiler capable of producing 6,150,000 lb/hr of main steam at 1,007˚F and 2,640 psig. Reheat design steam flow is 5,632,000 lb/hr at 1005˚F. The steam turbine model G3 was manufactured by General Electric (GE) and is composed of one seven-stage high pressure (HP) section, a double flow six-stage intermediate pressure (IP) section and two double-flow, six-stage, low pressure turbines. Figure 2 is a general depiction of the Sherco 3 steam turbine. The term "stage" in a steam turbine is used to define a row of steam turbine buckets which remove energy from the steam, converting it to horsepower, resulting in a reduction in steam pressure and temperature.

Q. Please explain the difference between a "drum boiler" and a "once through boiler."

A. A drum boiler is designed with a large drum at the top of the boiler, which is used for multiple purposes, one of which is to separate steam from water in the steam production process. The boiler feedwater in a power generation plant like Sherco enters the boiler through an economizer section which performs the initial water heating. From the economizer, the feedwater typically enters the steam drum. The drum is

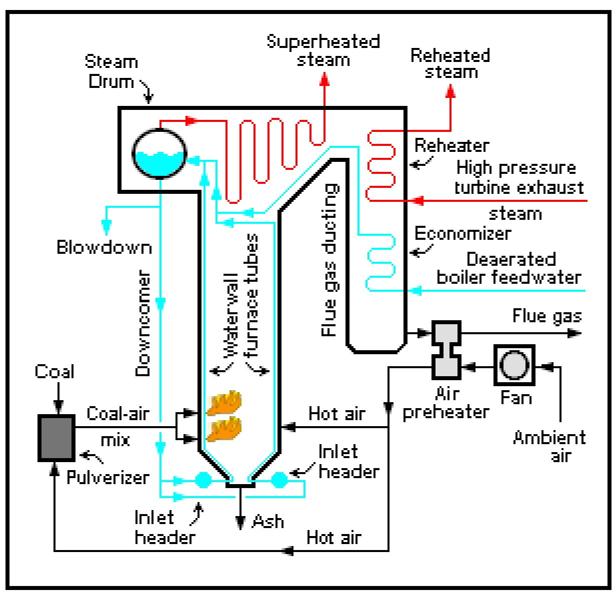

Figure 3 - Drum Boiler Schematic.

designed with tubes on the bottom which circulate water down the water walls (vertical sections of tubing) of the boiler and tubes on the top which extract steam from the drum and send it to the superheater for additional heating. The water from the bottom of the drum circulates down through the walls of the boiler and then back to the drum, gaining sufficient heat to turn the water into saturated steam (steam containing water droplets). The drum separates the water from the steam and sends it to high temperature sections of the boiler where it is superheated and sent to the steam turbine. Figure 3 is a simplified schematic of a drum boiler.

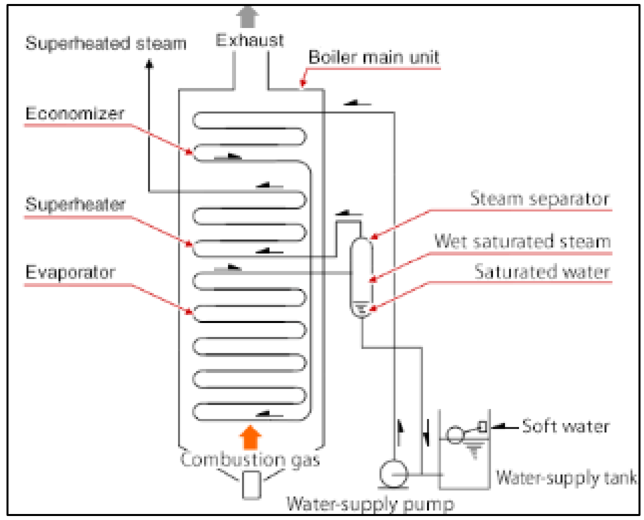

Figure 4 – Once-Through Boiler Schematic

Once-through boilers do not have a steam drum and the process of heating the water into superheated steam typically occurs in a continuous flow, single pass through the boiler. The water enters the boiler through the economizer section and then flows through the boiler water walls for additional heating. Next the water enters an evaporator section where it is all converted to steam. After the evaporator section, the steam is heated further into the superheat region in the boiler and sent directly to the steam turbine. Figure 4 is a simplified diagram of water and steam flow through a once-through boiler. Please note that not all once-through boilers have a steam separator.

Q. Please describe how the LP turbine is constructed and functions.

A. As shown in Figure 2, the Sherco 3 steam turbine has two LP turbines. Each LP turbine is a double-flow turbine in which the steam enters the center of the turbine

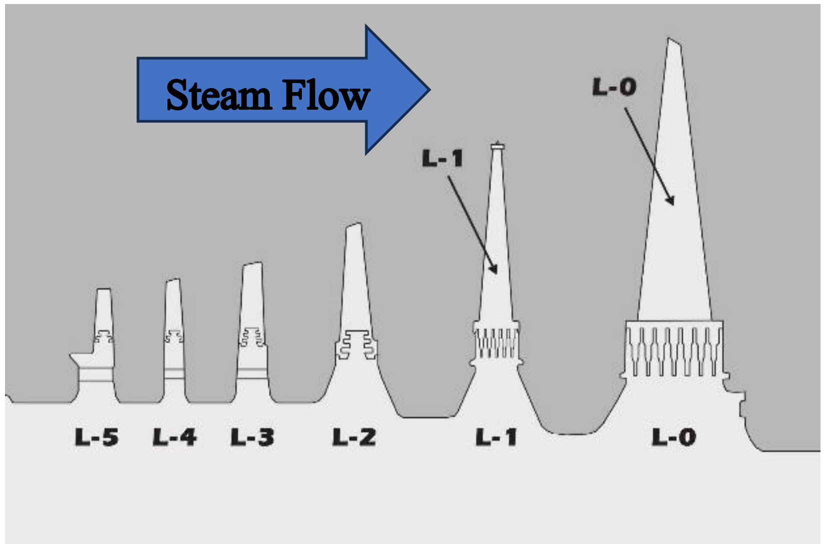

Figure 5 - Sherco 3 LP Turbine Blade Stages

and flows in opposite directions, exiting the last set of buckets and entering the condenser. There are six stages of buckets (sometimes referred to as "buckets") on each side of the LP turbine, identified as stages L-5 through L-0 in Figure 5. The steam entering the turbine first encounters the nozzles which help the steam to be distributed around the entire 360 degrees of the turbine and change its flow direction to maximize its impingement on the first stage of turbine buckets, shown as the L-5 buckets in Figure 5. There are nozzles

Figure 6 - LP Turbine Rotor

between each set of buckets that also change steam flow direction prior to the next stage of buckets. As the steam exerts force on the turbine buckets, the buckets convert the energy of the steam to horsepower in the turbine shaft that is used to power the generator. As the steam passes through each stage of buckets, the steam pressure drops and expands so it is necessary to increase the length of the buckets to maximize the conversion of steam energy to horsepower. The low-pressure turbine L-0 buckets are over 33 inches long as measured from the base to the tip and does not include the turbine rotor disk.[5] Figure 6 is a picture of an LP turbine rotor.

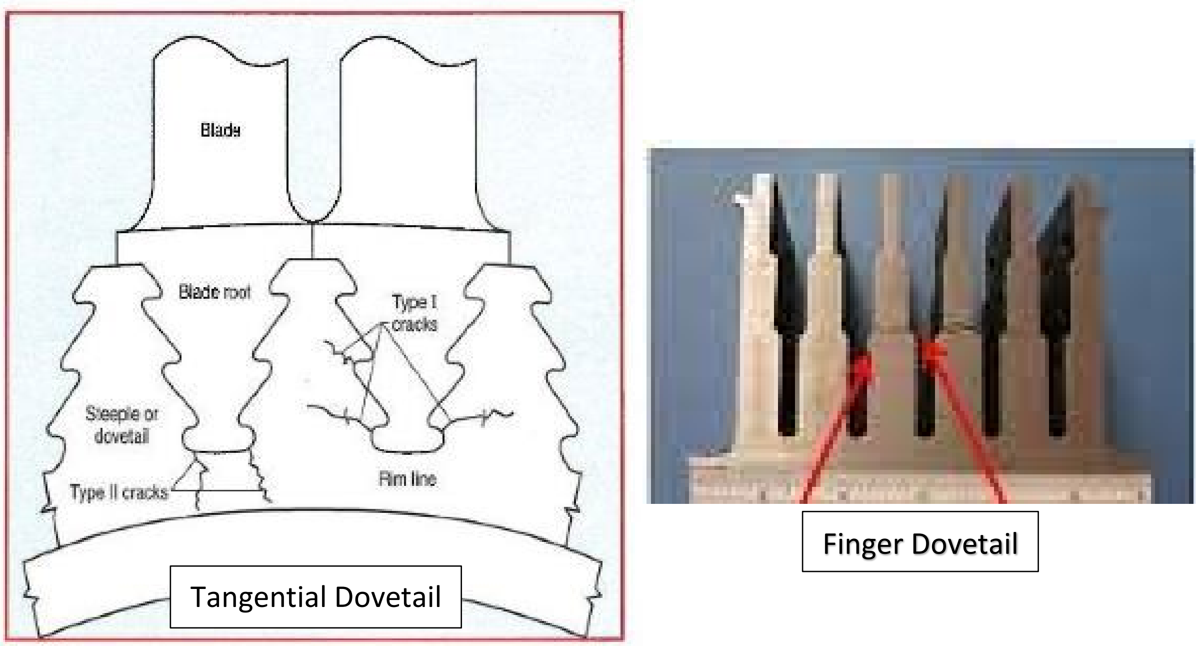

Figure 7 -Sherco LP bucket Attachment Types

The turbine buckets are connected to the turbine rotor through a disk at the base of the buckets. The Sherco 3 LP turbine section uses two different types of connections between the buckets and the disk, tangential dovetail and finger dovetail (see Figure 7). The finger dovetail is held to the turbine rotor by several pins inserted into the rotor disk. The L-0 and L-1 stages are connected to the rotor with finger dovetails and the L-2, -3, -4, and -5 stages are connected with tangential dovetails.

[5] DOC Ex. __, RAP-D-6 (Polich Direct) (Xcel Response to DOC IR S39).

III. Sherco 3 November 19, 2011 Steam Turbine Accident.

Q. Please provide a description of the failure of the Sherco 3 turbine that occurred on November 19, 2011?

A. Xcel Energy had completed a maintenance outage and was in the process of startup testing of Sherco 3. One of the tests included verification that the turbine trip sequences function properly to shut down the turbine in the event the turbine exceeds certain RPM rates, called an overspeed test. During the overspeed test, the LP turbine disk in row L-1 catastrophically failed, throwing the turbine buckets through the turbine shell. This caused a mass imbalance in the turbine rotor, causing significant vibration and fracturing the generator shaft, fracturing the exciter shaft in three places, and causing extensive steam turbine damage, a fire, and damage to various auxiliary systems. At the time of the accident, Sherco 3 had been in operation for approximately 24 years.

Q. Describe the extent of damage caused by the accident?

A. The damage to the steam turbine- generator was extensive. When the LP turbine rotor B stage L-1 turbine disk failed, several buckets were thrown through the turbine housing, damaging equipment outside of the turbine. Imagine a piece of equipment that is over six feet in diameter, spinning at over 3,600 rpm and having a piece weighing several pounds flung off. This caused a significant imbalance in the turbine rotor, causing vibrations which induced bearings failure and caused fractures in the generator shaft and five fractures in the exciter shaft. Oil systems and the generator hydrogen cooling system ruptured and were ignited by overheating bearings. A 200 lb part of the exciter was thrown across the turbine floor and into an operator's room (see figure 8).[6] In comments filed with the Commission, Xcel described the accident as "catastrophic" and expressed gratitude that there were no injuries.[7]

Figure 8 - Photograph of liberated exciter collector which came to rest in operator's room.

The LP turbines sustained the most damage. This damage included damage to the outer exhaust hoods, inner casings, inner shells, and diaphragms at interface points to each turbine component, cracks in the original fabrication welds, damage from flying

Figure 9 - Damaged LP Turbine Blades

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[6] DOC-__, RAP-D-7 at p. 55 (Polich Direct) (GE Litigation, Dep. Ex. 656, Thielsch Report).
[7] In the Matter of the Application of Northern States Power Company for Authority to Increase Rates for Electric Service in the State of Minnesota, Docket No. E-002/GR-12-961, et al., Xcel Reply Comments (Jan. 27, 2021) (eDockets No. 20211-170360-05).

debris, and out of specification clearances to mating components. The rotors sustained large amounts of bucket damage including loss of buckets as described above. The inner casings sustained the most damage of all the LP components and took the longest to repair.

Q. How long was Sherco 3 out of service?

A. Unit 3 was out of service until October 2013, almost two years.

Q. Did Xcel incur additional costs for the power that replaced the power Sherco 3 would have produced during the almost two-year outage?

A. Yes, to replace Sherco 3's output, Xcel Energy bought both replacement power and additional fuel for other Xcel-owned generators; these costs were passed on to ratepayers through Xcel's fuel clause adjustment mechanism. Department witness Matt King will address the replacement power costs.

IV. Procedural History

Q. When did the cost of the Sherco 3 steam turbine November 19, 2011 catastrophic failure first come before the Commission?

A. Xcel's costs for Sherco 3 repairs for the November 19, 2011 event were included in its November 2013 general rate case.[8] Xcel also requested recovery of replacement power costs associated with the outage through the Company's Fuel Clause Adjustment mechanism.[9]

Q. Did Xcel take any other action in November 2013 to recover costs of the Sherco 3 steam turbine November 19, 2011 catastrophic failure?

A. Yes, in November 2013, Xcel, SMMPA, and their insurers initiated a lawsuit against the turbine manufacturer, General Electric Company (GE), for damages associated with the turbine failure and outage.

Q. What steps did the Commission take next in regard to cost recovery?

A. In the Xcel 2013 Rate Case, the Commission referred the issues of prudency, recoverability and ratemaking treatment of replacement power and additional fuel costs to the annual fuel-clause adjustment dockets.[10] The Commission issued additional guidance in a subsequent order that required Xcel Energy to include Sherco 3 insurance

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[8] In the Matter of the Application of Northern States Power Company for Authority to Increase Rates for Electric Service in Minnesota, Docket No. E002/GR-13-868, Direct Testimony of Ronald L. Brevig at 1 (eDocket No. 201311-93272-05).

[9] *Id.* at 47.

[10] In the Matter of the Application of Northern States Power Company for Authority to Increase Rates for Electric Service in Minnesota, Docket No. E002/GR-13-868, FINDINGS OF FACT, CONCLUSIONS, AND ORDER at 47 (May 8, 2015) (eDockets No. 20155-110264-01).

proceeds as an offset to its rate base.[11] On June 2, 2016, the Commission, in ruling on Xcel's 2013-2014 annual fuel adjustment filing, decided to wait until the conclusion of the litigation regarding legal liability for the accident before deciding whether Xcel's energy replacement costs were prudently incurred and recoverable from ratepayers.[12]

Q. Did Xcel reach a settlement with GE?

A. Yes, on September 20, 2018, Xcel reached a settlement with GE resulting in a payment to Xcel, which Xcel indicated would be credited in its entirety to ratepayers.[13] On December 3, 2018, Xcel submitted an update stating that it planned on returning the settlement payment as a credit to customers through the monthly fuel clause adjustment for the month beginning February 1, 2019.[14] By its order dated April 11, 2019, the Commission authorized Xcel to refund the GE settlement proceeds to customers.[15]

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[11] In the Matter of the Application of Northern States Power Company for Authority to Increase Rates for Electric Service in Minnesota, Docket No. E002/GR-13-868, ORDER REOPENING, CLARIFYING, AND SUPPLEMENTING MAY 8, 2015 ORDER at pp. 12-13 (August 31, 2015) (eDockets No. 20158-113661-01).

[12] In the Matter of the Review of the 2013-2014 Annual Automatic Adjustment Reports for All Electric Utilities, Docket No. E-999/AA-14-579 ORDER ACTING ON ELECTRIC UTILITIES' ANNUAL REPORTS AND REQUIRING ADDITIONAL FILINGS, at p. 5-6 (June 2, 2016) (eDockets No. 20166-121943-03).

[13] In the Matter of the Application of Northern States Power Company for Authority to Increase Rates for Electric Service in the State of Minnesota, Docket No. E-002/GR-12-961, et al., Sherco Unit 3 Litigation Update (Nov. 2, 2018) (eDockets No. 201811-147564-08).

[14] In the Matter of the Application of Northern States Power Company for Authority to Increase Rates for Electric Service in the State of Minnesota, Docket No. E-002/GR-12-961, et al., Sherco Unit 3 Litigation Update (Dec. 3, 2018) (eDockets No. 201812-148208-12).

[15] In the Matter of the Application of Northern States Power Company for Authority to Increase Rates for Electric Service in the State of Minnesota, Docket No. E-002/GR-12-961, et al, Order

Q. What was the outcome of the lawsuit against GE by Xcel's insurers?

A. At the close of the evidence, the trial judge found that no reasonable jury could find that Xcel was unaware of the risk of harm and, accordingly, dismissed the insurers' claim against GE alleging that GE had failed to warn Xcel of the potential SCC problems in the Sherco 3 LP turbine sections after the sale of the turbine to Xcel.[16] By its answers to the questions put to it on the special verdict form, the jury found that Xcel was negligent in its operations and maintenance of Sherco 3, and this negligence was a direct cause of the property loss.[17] The jury further found Xcel to be 48% at fault and GE to be 52% at fault. The court held, however, that because the jury had not found GE to be willfully and wantonly negligent or grossly negligent, Xcel's insurers had failed to prove a necessary element of their remaining claims and, accordingly, ruled in favor of GE as a matter of law.[18]

Q. What issues relating to the Sherco accident remain unresolved?

A. The Commission's July 13, 2022, order found that all issues had been resolved except the prudency of replacement power costs.[19] The Commission's order commenced a

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Authorizing Sherco Unit 3 Ratepayer Refund Amount and Method and Requiring Compliance Filing (Apr. 11, 2019) (eDockets No. 20194-151886-02).

[16] DOC Ex. __, RAP-D-8 at pp. 33-35 (Polich Direct) (GE Litigation, Trial Transcript).

[17] DOC Ex. __, RAP-D-9 (Polich Direct) (GE Litigation, Findings of Fact, Conclusions of Law and Order for Judgment, Nov. 7, 2018).

[18] Id. See also DOC Ex. __, RAP-D-10 (Polich Direct) (GE Litigation, Order Denying Plaintiffs' Motion for Judgment as a matter of Law or Alternatively for a New Trial, March 3, 2019).

[19] In the Matter of the Application of Northern States Power Company for Authority to Increase Rates for Electric Service in the State of Minnesota, Docket No. E-002/GR-12-961, et al, Notice and Order for Hearing (July 13, 2022) (eDockets No. 20227-187362-07).

contested case in which Xcel bears the burden of proof that its Sherco 3 energy replacement costs were prudently incurred and that it is just and reasonable to recover those costs from ratepayers (or to deny a refund of costs previously recovered).

V. Cause of Sherco 3 LP Turbine November 19, 2011 Accident

Q. Did Xcel perform a Root Cause Analysis (RCA) of the steam turbine failure?

A. Yes. Xcel retained an engineering firm, Thielsch Engineering, to perform a root cause analysis of the accident. Thielsch stated the cause of the failure was ***pre-existing*** SCC in the LP turbine rotor disk finger dovetail of the L-1 row of turbine buckets, likely caused by sodium hydroxide.[20] This was not the root cause, it was simply a contributor to the rotor disk failure, it was the condition that caused the buckets to be liberated from the turbine. I will discuss the true root cause of the failure later in my testimony.

Q. What is the purpose of a root cause analysis?

A. The purpose of performing a root cause analysis of equipment failures is to determine the major contributing problems and events of the failure and determine the primary reason the failure occurred. In performing a RCA, the investigators do not look at only at the physical properties of the failure but include actions by companies and personnel which may have resulted in identification of the problem prior to failure. Identification of physical properties of a failed piece of equipment reviews the engineering, materials,

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[20] DOC-__, RAP-D-7 at p. 93 (Polich Direct) (GE Litigation, Dep. Ex. 656, Thielsch Report).

equipment life cycle, operational environment, and other aspects of the equipment failure, determines why and how the part failed. The physical properties in the case of Sherco 3 LP turbine disk failure would be the LP turbine disk material, operational history, chemical properties of steam, forces on the disk, etc.

The second part of the RCA involves identification of actions by various parties with involvement in the piece of equipment, such as the manufacturer, the equipment installer, equipment owner's staff, and outside consultants, which could have identified, contributed to or prevented the failure. This would include GE notification to Xcel of SCC problems with LP turbine disks, Xcel inspection procedures and timing, Xcel water chemistry standards, operating personnel performance of Xcel procedures and testing requirements, Xcel personnel knowledge of SCC in LP turbines, and Xcel maintenance of the LP turbines. This portion of the RCA determines if the failure was the result of failure to take action to identify the potential problems and prevent failure from occurring.

A proper RCA will incorporate the information into an analysis that assesses the physical failure mechanism of the equipment and if actions by various entities contributed to the failure or failed to prevent the failure. For example, poor boiler water chemistry control can be a contributing factor in an RCA but not the root cause if actions, such as delaying an inspection that would have discovered damage caused by poor water chemistry, occur. In this example the root cause would have been a combination of the SCC, poor water chemistry and failure to perform timely inspections with the delay of the inspection being the leading contributor to the actual failure because it could have detected the SCC prior to the failure occurring.

Q. Why do you say that SCC was not the true cause of the accident?

A. Based on the sequence of events leading to the Sherco 3 LP turbine failure, SCC was a cause of the LP turbine disk fracture, but it was not the true root cause of the accident because, with proper inspection of the LP turbines, the November 19, 2011 accident would not have occurred. Thus, SCC was not the true or "root cause" of the accident, rather, Xcel's failure to timely inspect the LP turbine rotor disk dovetails, in accordance with good industry practice for the maintenance and operation of the Sherco 3 steam turbine, was the root cause of the accident. The potential for SCC to occur in LP turbine rotor disks was well known in the utility industry prior to the Sherco 3 November 2011 event. Xcel personnel knew the water chemistry used at Sherco 3 could contribute to SCC, there was prior evidence of chemical deposits on the LP turbine components, and yet Xcel chose to delay the 2011 critical inspection of the LP turbine. There is ample evidence that if Xcel had performed the inspection in 2011 or earlier and in accordance with various industry recommendations, the SCC in the LP turbine rotor disks would have been found and the November 2011 accident would not have occurred. Xcel's decision to delay inspection of the LP turbine rotor disk dovetail was the true root cause of the November 19, 2011 accident.

Q. What is stress corrosion cracking?

A. Stress corrosion cracking, or SCC, is a phenomenon in which a material will start to crack well below its design strength, called yield strength, when the material is placed under stress. SCC typically requires three components to occur, susceptible material, corrosive environment, and high stress. The corrosion typically occurs when a chemical, such as sodium hydroxide, penetrates a steel part and works its way into the grain boundaries of the steel (see Figure 11). Over time the steel grain boundary separates forming a crack in the metal. These cracks will typically propagate in a high stress location of a part, such as a corner or notch. An example of typical SCC locations is shown in Figure 7 where the cracks are in the corner of the tangential dovetail joint. A picture showing SCC in the Sherco 3 LP turbine, stage L-1 disk finger dovetail is shown in Figure 10.[21]

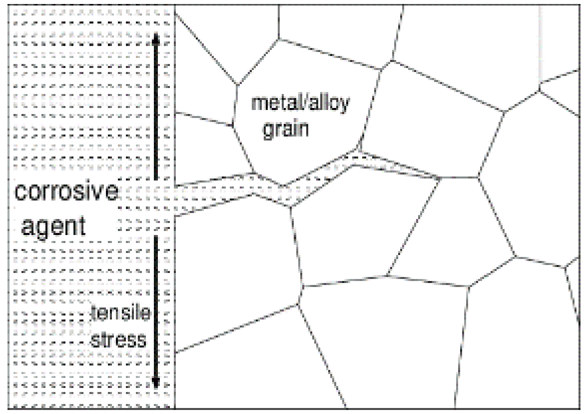

Figure 11 - Intergranular SCC

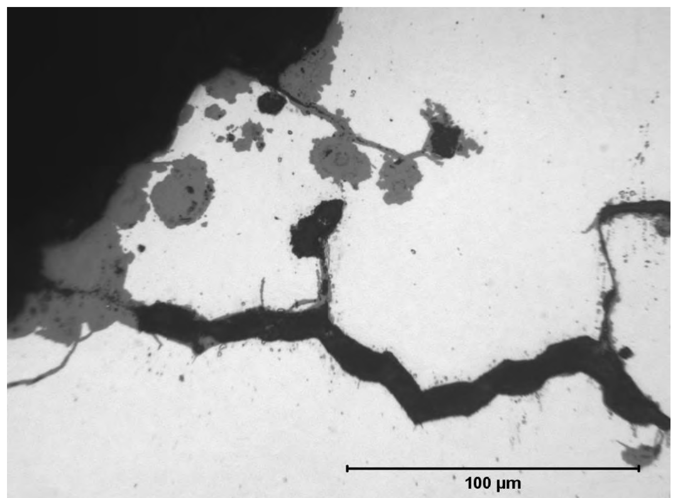

Figure 10 - Photo Micrograph of Portion of Sherco LP Turbine Disk Showing SCC

[21] DOC-___, RAP-D-7 at p. 222 (Polich Direct) (GE Litigation Dep. Ex. 656, Thielsch Report).

Q. What non-destructive inspection methods are used to detect SCC in steam turbine components?

A. Typical inspection methods to detect SCC in turbine components include visual inspection, dye penetrant testing, magnetic particle inspection (MPI), and ultrasonic testing (UT). GE recommends either MPI or UT as appropriate inspection methods for detection of SCC.

Q. Please describe magnetic particle inspection (MPI).

A. MPI is a method of detecting surface anomalies in iron and steel parts by using magnetic fields induced in the part to cause iron part particles around the parts surface anomalies. When the magnetic field encounters the surface cracks, it distorts the magnetic field and the iron particles will collect at the magnetic field distortion. However, the magnetic flux will only leak out of the material if the discontinuity is generally perpendicular to its flow. If the discontinuity, such as a crack, is parallel to the lines of magnetic flux, there will be no leakage and therefore no indication observed. To resolve this issue, each area needs to be examined twice. The second examination needs to be perpendicular to the first so discontinuities in any direction are detected.

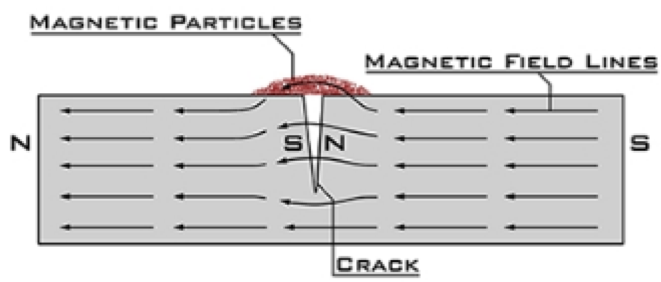

Figure 12 - MPI Showing magnetic Field Distortion

Q. Is MPI a type of inspection that is commonly used in the utility industry?

A. Yes, MPI is an inspection method used for detecting cracks or other anomalies in a variety of ferrous parts in the utility industry. For example, this was one of the inspection methods used for testing the hot-reheat piping at Minnesota Power's Boswell plant that was discussed in Docket E999/AA-20-171. MPI is one of the commonly used non-destructive testing mechanisms that Xcel would have used in testing other components in their generation facilities.

Q. Please describe ultrasonic testing of parts for anomalies.

A. Ultrasonic inspection is a method of non-destructive testing to detect flaws in the metallurgy of parts. A transmitter/receiver induces ultrasonic waves through the part and when those waves encounter a crack or anomaly, the waves are reflected back to the receiver. There are different forms of ultrasonic testing, some only detect surface flaws while others can be used to detect flows deep within a part. Ultrasonic testing provides the ability to detect flaws in parts below the surface due to the penetration of the ultrasonic waves deep into the part and the reflection off cracks in the material. It is often used to detect SCC deep within a part.

Q. Please explain the structural failure which resulted in the Sherco 3 LP turbine November 19, 2011 accident.

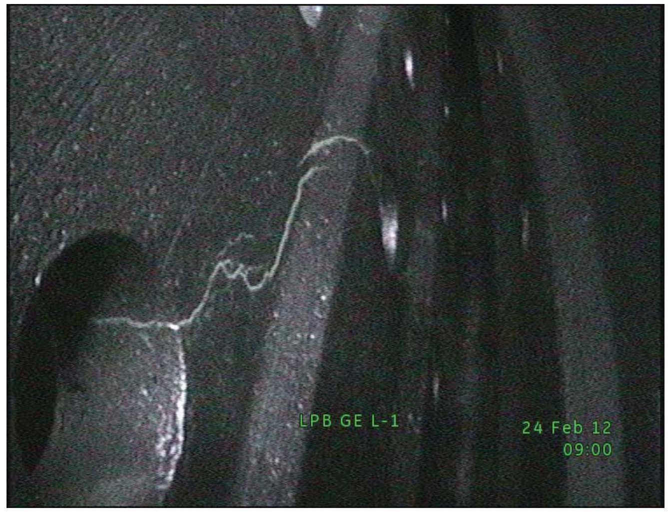

Figure 13 - LP Turbine "B" L-1 Blade Disk Cracking

A. The Sherco 3 LP turbine "B" rotor disk holding the L-1 buckets failed due to SCC in the pin holes, ledges and base of the finger dovetail joints. It needs to be noted that the failed L-1 disk was on the end of the "B" LP turbine closest to the generator, commonly called the "Generator End". The image in Figure 13 is blacklight photograph of low-pressure turbine "B" L-1 disk rim showing the cracks in finger-root attachment that were revealed with MPI.[22] The image in Figure 14 is a portion of the LP turbine L1 buckets liberated during the November 19, 2011, event which has a portion of the turbine rotor disk still attached.[23] The MPI performed after the event shows that the cracking was prevalent throughout the LP turbine rotor disk that attach the L-1 buckets to the LP turbine rotor, and would have been found if Xcel had


Figure 14 - Liberated L-1 Turbine bucket with Fractured Rotor Disk Attached

[22] DOC-__, RAP-D-7 at p. 143 (Polich Direct) (GE Litigation Dep. Ex. 656, Thielsch Report).
[23] Id., p. 131, Fig. 62.

performed non-invasive inspection during the 2011 maintenance outage. Although SCC was the structural failure mechanism that resulted in the November 19, 2011 catastrophic failure, it was not the root cause of the failure.

Engel Metallurgical Ltd., a metallurgical engineering firm retained by Xcel's insurers to determine the cause of the failure, performed a metallurgical evaluation of both of Sherco's LP turbines. The testing revealed that not only did the "B" LP turbine rotor L-1 disk on the generator end have SCC, but the turbine end of the "B" LP turbine L-1 turbine rotor disk and both "A" LP turbine rotor L-1 disks also had SCC. This report states:" *"The severity of the corrosion observed on the stress corrosion cracks indicates that the cracks have been present in the LP-B and LP-A rotors for a significant period time in excess of five years.*[24] **NONPUBLIC INFORMATION BEGINS** [redacted]

NONPUBLIC INFORMATION ENDS[25]

Q. What are the contributing causes of SCC in steam turbine rotors?

A. Stress corrosion cracking has consistently been identified as being among the main causes of outages caused by low pressure turbines in the utility industry. There is a

[24] DOC Ex. __. RAP-D-11 at p 4-5 (Polich Direct) (GE Litigation, Dep. Ex. 638, Engel Report).
[25] DOC Ex. __, RAP-D-12 at p. 6 (Polich Direct) (GE Litigation, L. Engel Dep. Transcript).

significant amount of literature addressing SCC problems in low pressure turbines, the causes of SCC in low pressure turbines, and modeling to estimate SCC damage. One of the reasons SCC is so prevalent in LP turbines is the nature of the steam pressure and temperature. As the steam flows through the LP turbine, its pressure decreases and the temperature falls, resulting in saturated steam or steam which contains water droplets in the steam. The Electric Power Research Institute (EPRI) research in turbine bucket failures find the vast majority of failures occur in the LP turbine (see Figure 15)[26]. Chemical impurities in the steam will collect in those water droplets and attach to metal surfaces in the steam turbine. These chemical impurities often contain chemicals such as sodium hydroxide, chlorides, sulfides, sulfates, carbonate-bicarbonate, CO_2, and other acids, which contribute to corrosion. These chemicals attack the grain boundaries in the metal when stress exposes the grain boundaries to the chemical and causes an anodic dissolution propagates the crack. SCC typically begins in areas of high stress where parts have locations of stress concentration such as corners.

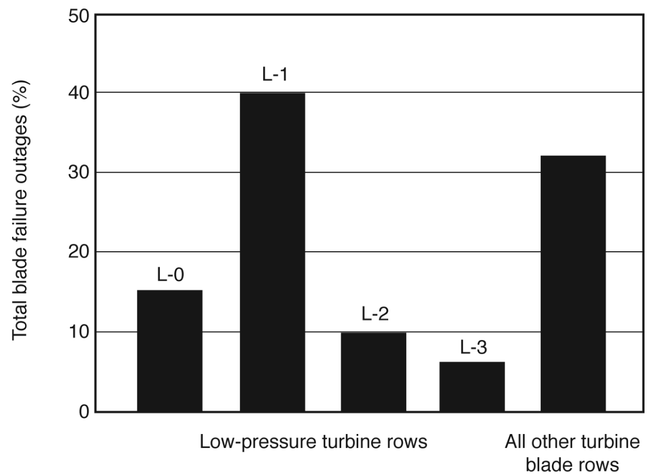

Figure 15 - Distribution of Blade Failures in U.S. Fossil Turbines by Row

[26] DOC Ex. __. RAP-D-13 at p.18 (Polich Direct) (Low-Pressure Steam Turbine Corrosion Mechanisms and Interactions: State of Knowledge 2010, EPRI).

Boiler water chemistry is a critical factor in mitigation of SCC in steam turbines because impurities in boiler water are carried over into the steam and then these impurities are often deposited on the LP turbine as the steam flows through the steam turbine. Steam turbine manufacturers provide owners with specific steam chemistry standards, often updating them through the life of the steam turbine. Attached to my testimony as DOC-1, RAP-D-15 is a copy of a GE document sent to Xcel which contains GE's steam chemistry recommendations for all GE steam turbines.[27]

Last, since SCC acts over time in weakening a component, the age of the steam turbine is also a factor in SCC induced failures. GE found that steam turbines with over 200,000 hours of operation (approximately 20-25 years) are likely to develop SCC issues. Nuclear LP turbines have experienced disk cracking after only 6.5 years of operation.

Q. For how long has the utility industry known about SCC in LP turbines?

A. As the design and size of steam generation facilities increased in the 1960s and 1970s, the temperatures of steam, size and complexity of steam turbines started to push the envelope. By the late 1970s, forced outages caused by steam turbines climbed, prompting the utility industry to investigate the cause of steam turbine forced outages. The utility industry, working through EPRI held one of the first workshops on steam turbine bucket failure in 1978.[28] SCC was identified in this workshop as one of the

[27] DOC Ex.-__, RAP-D-15 (Polich Direct) (GE Litigation, Tr. Ex. 1019, The Effect of Water Chemistry on the Reliability of Modern Large Steam Turbines).
[28]DOC-__, RAP-D-36 (Polich Direct) (Workshop Proceedings 1980).

causes of steam turbine bucket failure. Southwest Research Institute published an EPRI report in September 1980 on the metallurgical analysis of rim cracking in LP turbine discs. That report found that SCC was the primary cause of disk cracking.[29] There is a significant amount of literature on SCC in steam turbines and it is a phenomenon in which good utility practice dictates that utilities need to be concerned and perform periodic inspections to determine if SCC is an issue in their steam turbines. The EPRI report, *"Low-Pressure Steam Turbine Corrosion Mechanisms and Interactions: State of Knowledge 2010",* includes references to 50 articles on steam turbine failures, many of which discuss SCC.[30] Thus, Xcel had significant information available from sources outside of GE that provided evidence that the Sherco 3 turbine was highly susceptible to SCC.

Q. What is EPRI?

A. EPRI is American independent, nonprofit organization that conducts research and development related to the generation, delivery, and use of electricity to help address challenges in the energy industry, including reliability, efficiency, affordability, health, safety, and the environment. It was founded in 1972 after the 1965 Great Northeastern Blackout which left over 30 million people without electricity. Although EPRI is an

[29] DOC-__, RAP-D-16 at p iii (Polich Direct) (Metallurgical Analysis of Rim Cracking in an LP turbine Disc, Southwest Research Institute).
[30] DOC Ex. __. RAP-D-13 (Polich Direct).

independent organization, it is strongly linked with the utility industry and many of its research projects are funded by the utility industry.

Q. Did Xcel employees involved in the operation of Sherco 3 participate in EPRI activities that included discussion of SCC?

A. Yes, Xcel participated in several EPRI activities in which information on SCC problems in steam turbines was presented. Many of the EPRI publications referenced in my testimony were produced by Xcel in discovery in the prior civil litigation.

Q. Are you aware of evidence that that Xcel employees involved in the operation of Sherco 3 were aware of the risks associated with SCC?

A. As an operator of an electricity generating plant, Xcel had a responsibility to be aware of conditions that could adversely affect the reliability and safety of its generator fleet. A presentation by GE in 2006 to Xcel employees included a diagram which indicates three factors that affect the development of SCC.[31]

- Operating environment (Chemistry, steam properties, temperature),
- Material properties (strength, material composition, toughness), and
- Design of the part (including nominal stress, stress concentrations and temperature).

[31] See DOC Ex. __, RAP-D-14 at 24 (Polich Direct) (GE Litigation, Trial Ex. 1036, GE Turbine Maintenance and Reliability Presentation).

An Xcel internal email in 2008 stated: "Attached are draft recommendations regarding turbine rotor wheel inspections for stress corrosion cracking. These recommendations are intended to address the stress corrosion cracking issues that are now becoming more apparent on units ***with drum boilers***."[32] The document attached to the email contains detailed discussions of Xcel experience with SCC and steps taken at several of its facilities to inspect for SCC and repairs to steam turbines with SCC induced cracks. Further, evidence presented at the civil trial makes clear Xcel employees were well aware of SCC.

VI. Sherco 3 LP Turbine Inspection and Maintenance History

Q. What is your data source for Sherco 3 steam turbine maintenance and outage history?

A. My primary data source for Sherco 3 steam turbine maintenance and outage history is the previously cited Thielsch Engineering report "*Root Cause Analysis Steam Turbine Generator Event of November 19, 2011 Unit No. 3 Sherburne County Xcel Energy Becker, Minnesota.*" According to the report, Xcel provided maintenance and outage records.[33]

Q. Based on your review of these inspection reports, when was the last inspection of Sherco 3 LP turbine rotor disks L-0, L-1 and L-2 dovetails that used any testing that could have potentially detected SCC?

[32] See DOC Ex. __, RAP-D 31 at p 2 (Polich Direct) (GE Litigation, Trial Ex. 133, Draft Recommendations for Steam Turbine Wheel Inspections).
[33] DOC-__, RAP-D-7 at p. 68 (Polich Direct) (GE Litigation, Dep. Ex. 656, Thielsch Report).

A. First, the importance of inspection of the L-0, L-1 and L-2 LP turbine disk dovetails is because this is the area of the steam turbine in which steam because "wet" steam and water droplets condense on the buckets, leaving chemical deposits on the turbine rotor disk. It appears the last inspection of the Sherco 3 LP turbine rotor disks L-0, L-1 and L-2 dovetails that involved MPI or UT inspection was 1999, 12 years prior to the 2011 accident. This time between inspections of the LP turbine rotor disks L-0, L-1 and L-2 dovetails exceeds all industry standards for such inspections. This is especially true in light of the potential for substantial property damage, personal injury, and even death that may result from a failure of a turbine of the kind experienced at Sherco 3.

Q. Before summarizing Sherco 3's maintenance and outage history, what is a "major outage"?

A. A major outage is one that lasts more than three weeks and is typically 9-12 weeks in duration. A steam turbine major outage typically includes opening the turbine up to inspect various portions of the steam turbine and can include major inspections of the generator.

Q. When was the first steam turbine major outage performed on Sherco 3 and what work was performed on the LP turbine?

A. The Thielsch report cited a steam turbine major outage that was performed in February 1989 and did not include any earlier steam turbine outages.[34] Based on this report, I assumed it was the first steam turbine major outage. During this outage, the following work was performed on "A" LP turbine:

1. Turbine rotors removed, sand-blasted and non-destructive inspection which did not identify any issues.
2. L-1 bucket tie wire end sleeves repaired.
3. L-1 stage pins (pins holding bucket dovetails to turbine rotor disk) were ultrasonically inspected and no issues reported.

The following work was performed on the "B" LP turbine:

1. Turbine rotors were removed, sand blasted, and non-destructive inspection was performed which did not identify any issues.
2. All diaphragms were removed, sand blasted and inspected. Minor damage on the L-5 stage diaphragm was repaired.
3. L-1 bucket tie wire end sleeves repaired.
4. L-1 stage pins (pins holding bucket dovetails to turbine rotor disk) were ultrasonically inspected and no issues reported.

The Thielsch report did not identify any inspection of the LP turbines rotor disks using MPI, UT or other non-destructive testing.

[34] Id., p. 68.

Q. When did the next maintenance occur on the LP turbines and what work was performed?

A. The Thielsch report next recorded LP maintenance in March 1993.[35] During this outage, the following work was performed on "A" LP turbine:

1. Turbine rotors removed blasted and non-destructive inspection. The tendons on the one bucket of a five-bucket group of the L-1 stage was cracked and the bucket cover was bent and worn away. This bucket group was replaced, and a new cover installed. Additional L-1 stage covers were found damaged requiring an additional bucket and two covers to be replaced.
2. All diaphragms were removed, sand blasted, and inspected. Several diaphragms were straightened and repaired.
3. Fifty L-0 stage bucket pins were identified as cracked by ultrasonic inspection and replaced.

The following work was performed on the "B" LP turbine:

1. Turbine rotors removed sand blasted and non-destructive inspection were performed which did not identify any issues.
2. All diaphragms were removed, sand blasted and inspected. Several diaphragms were straightened and repaired.
3. L-0 stage pins (pins holding bucket dovetails to turbine rotor disk) were ultrasonically inspected and 17 pins were replaced.

[35] Id., pp. 71-72.

The report does not identify any inspection of the LP turbines rotor disks using MPI, ultrasound or other non-destructive testing.

Q. When did the next maintenance occur on the LP turbines and what work was performed?

A. The Thielsch report next recorded LP maintenance in March 1996.[36] The primary purpose of this outage was to inspect the L-1 bucket tie wire cracking. Both LP turbines were disassembled and all L-1 buckets removed. Blade tie wires were removed, rotors blasted, and non-destructively inspected of tie wire holes found no issus nor tie wires cracked. The bucket tendons were also ultrasonically inspected with no issues reported. Other minor repairs were performed on the LP turbines. The reports do not identify any inspection of the LP turbines rotor disks using MPI, ultrasound or other non-destructive testing.

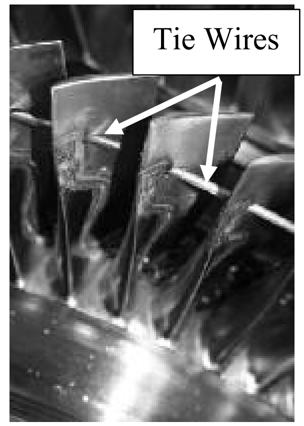

Figure 16 - Turbine Blade Tie Wire

Q. When did the next maintenance occur on the LP turbines and what work was performed?

A. The Thielsch report next recorded LP maintenance in February 1999.[37] During this outage, the following work was performed on "A" LP turbine:

1. Turbine rotors removed blasted and non-destructive inspection.

[36] Id., pp. 72-73.
[37] Id., pp. 73-76.

2. The turbine rotor bore was inspected by MPI, radial and axial beam borescope[38], and periphery and axial ultrasonic testing. No issues were found.
3. Dovetail ultrasonic testing and MPI of L-2 and L-3 stage buckets was performed. Point source, non-continuous circumferential indications were detected in both L-2 stages. No action taken.
4. The L-1 stage turbine buckets were replaced with a new GE design.
5. A total of 203 L-0 stage bucket pins were identified as cracked by ultrasonic inspection and replaced.

The following work was performed on the "B" LP turbine:

1. Turbine rotors removed blasted and non-destructive inspection.
2. The turbine rotor bore was inspected by MPI, radial and axial beam borescope, and periphery and axial ultrasonic testing. No issues were found.
3. Dovetail ultrasonic testing and MPI of L-2 and L-3 stage buckets was performed. Point source, non-continuous circumferential indications were detected in both L-2 stages. No action taken.
4. The L-1 stage turbine buckets were replaced with a new GE design.
5. A total of 55 L-0 stage bucket pins were identified as cracked by ultrasonic inspection and replaced.

[38] Borescope is a fiberoptic camera housed in a small, flexible cable that allows the see inside of a machine without disassembly. The user snakes the borescope into the area of interest and observes a picture on a video screen.

The outage report indicates the L-1 finger pinned bucket attachments were inspected by MPI with no indications found.

Q. When did the next maintenance occur on the LP turbines and what work was performed?

A. The Thielsch report next recorded LP maintenance three years later, in March 2002 in which the low-pressure turbine hood expansion bellows replacement, and low-pressure turbine hood spray and steam seal system.[39] Borescope inspection of the LP L-0 buckets were found to have heavy water droplet erosion and the L-1 stage buckets were found to have light water droplet erosion.

Q. What maintenance work was performed on the LP turbine during the October 2005 major turbine outage?[40]

A. The only reported work on the LP turbines was ultrasonic examination of the L-2 and L-3 stage tangential dovetails with no reported indications.

Q. Did you review the 2005 outage report?

A. Yes. The 2005 steam turbine outage work was performed by Mechanical Dynamics and Analysis (MDA) of New York. This inspection report contains only minimal information and did not include any inspection of the L-1 or L-2 stage rotor disks. The report did

[39] Id., pp. 76-77.
[40] Id., pp. 77-78.

indicate there were chemical deposits on the buckets of the LP turbines. These deposits are an indication that additional chemical deposits are likely to occur in the turbine rotor disk to bucket attachment finger dovetail joint of the L-1 stage.

Q. What turbine inspections were performed during a 2008 scheduled maintenance outage?

A. Xcel apparently made a visual inspection of the last stage blades in 2008 but the inspection method was not specified in the Thielsch report.[41]

Q. What maintenance work was performed on the Sherco 3 steam turbine during the September 2011 major turbine outage?[42]

A. Xcel installed new HP and IP turbine rotors and diaphragms. The LP turbine was originally scheduled for a major inspection, but Xcel deferred the work until a future outage that was planned for 2014.

VII. GE Documentation Regarding LP Turbine Maintenance Practices

Q. Which documents provided by GE as part of the Steam Turbine Owner's Manual specifically discuss steam turbine maintenance and inspection?

A. There are two portions of the GE Owner's manual which address steam turbine maintenance and Inspection:

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[41] Id., p. 78.
[42] Id., pp. 79-80.

1. GEK-63355: Turbine Generator Inspections[43]
2. GEK-46354: Maintenance and Inspection of Turbine Rotors and Buckets[44]

Q. What are the key inspection requirements in GEK-63355 (Turbine Generator Inspections) that pertain to the Sherco 3 LP turbine failure?

A. This document recommends inspections of LP turbines every three to five years by removing the inner turbine shell and inspecting for wear, erosion, deposits, distortions, misalignment, thermal or fatigue cracking, and mechanical damage.

Q. What are the key inspection requirements in GEK-46354 (Maintenance and Inspection of Turbine Rotors and Buckets) that pertain to the Sherco 3 LP turbine failure?

A. This document identifies the methods for inspecting the steam turbine, especially the L-2, L-1 and L-0 buckets, which components to inspect, what to look for, and types of testing.

Q. What is the recommended frequency of major turbine inspections?

A. GE recommends three-to-five-year service interval for major turbine inspections.

Q. What is involved in a steam turbine major service inspection?

[43] DOC-__, RAP-D-17 (Polich Direct) (GE Litigation, Trial Ex. 131, GEK 63355, Turbine Generator Inspections).

[44] DOC-__, RAP-D-18 (Polich Direct) (GE Litigation, Trial Ex. 132, GEK 46354, Maintenance and Inspection of Turbine Rotors and Buckets).

A. A typical steam turbine major service inspection is a comprehensive inspection of the entire steam turbine and generator system. A steam turbine major inspection includes removal of the turbine inner shells to expose the steam turbine HP, IP and both LP rotors for inspection. Often all rotors are removed for additional inspection, measurement of bearing surfaces, checking for bowing of the rotor, sandblasting of deposits, and access to the lower internals of the steam turbine. It is during these inspections that testing for SCC will occur.

Q. Has GE provided further guidance on LP turbine inspection and testing?

A. Yes, GE provided the following Technical Information letters:

1. TIL 1121-3AR1: Inspection of Steam Turbine Rotor Wheel Finger Dovetails, February 1, 1993;[45]
2. TIL 1277-2: Inspection of Low-Pressure Rotor Wheel Dovetails on Steam Turbines with Fossil Fueled Once-Through Boilers, December 2, 1999.[46]

Q. What instructions are contained in TIL 1121-3AR1 (Inspection of Steam Turbine Rotor Wheel Finger Dovetails) that pertain to the Sherco 3 LP turbine failure?

A. This document contains recommendations for how to perform MPI inspection of rotor wheel finger dovetails, similar to those on Sherco 3 LP turbine stages L-0 and L-1, on GE

[45] DOC Ex. __, RAP-D-19 (Polich Direct) (GE Litigation, Trial Ex. 6. TIL 1121-3AR1, Inspection of Steam Turbine Rotor Wheel Finger Dovetails).
[46] DOC Ex. __, RAP-D-20 (Polich Direct) (GE Litigation, Trial Ex. 56, TIL 1277-2, Inspection of Low Pressure Rotor Wheel Dovetails on Steam Turbines with Fossil-Fueled Once-Through Boilers).

steam turbines to detect SCC. This document was produced by GE to improve the MPI testing procedure. This document recommended that *all* GE steam turbines that have been in service for more than ten years have the rotor wheels with finger dovetail joints inspected, with the buckets removed, using MPI. If SCC is discovered in the finger dovetail joints, repairs should be completed using GE approved procedures before the unit returns to service. This inspection should be part of the major turbine inspection.

Although this document references once through boilers, Xcel was aware of SCC problems in finger dovetail joints, as evidenced in Mr. Murray's March 8 email[47] and the draft recommendations for turbine rotor wheel inspection for SCC.

Q. What recommendations are contained in TIL 1277-2 (Inspection of Low-Pressure Rotor Wheel Dovetails on Steam Turbines with Fossil Fueled Once-Through Boilers) that pertain to the Sherco 3 LP turbine failure?

A. First, this document was initially only applicable to steam turbines with once-through boilers because the problems with SCC in finger dovetail joints were first found in LP turbines that used steam produced by once-through boilers. **NONPUBLIC INFORMATION BEGINS** [redacted]

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[47] DOC-__, RAP-D-31 (Polich Direct) (GE Litigation, Trial Ex. 133, Draft Recommendations for Steam Turbine Wheel Inspections).

[redacted]. **NONPUBLIC INFORMATION ENDS**[49] This GE document recommends careful monitoring of water chemistry and maintaining steam chemistry within GE requirements. It also recommends that all LP turbines in operation for more than 10 years, with disks using finger dovetails, should be inspected with buckets removed, using MPI.

Q. Did Xcel adopt a schedule for overhaul of the Sherco 3 LP turbines?

A. Yes, in a System Health Report prepared by Xcel and dated February 1, 2005, the "green" condition rating of the LP turbines was "[c]ontingent on maintaining current levels of maintenance and a 6-year T.B.O [i.e., time between overhauls]" The report also describes risks associated with a yellow or red designation as follows: "Risks associated with wheel cracking involve wheel failure and buckets departing the rotor. Resulting collateral damage could be severe (i.e., due to mass imbalance)."[50]

Q. What would've been involved in overhauling the Sherco 3 LP turbines

A. The overhaul of the LP turbine would typically involve inspection, cleaning and refurbishment of various components of the LP turbine. The work starts with removal of the turbine inner and outer shells to and upper shaft bearings for initial inspection.

[48] DOC-__, RAP-D-34 (Polich Direct) (GE Litigation, Dep. Ex. 109, Murphy-Bird email exchange).
[49] DOC-__, RAP-D-35 at 6 (Polich Direct) (GE Litigation, Dep. Ex. 673, Sirois Report).
[50] DOC Ex. __, RAP-D-21 at p. 1 (Polich Direct) (GE Litigation, Trial Ex. 8, Sherco Unit 3 LP Turbine System Health Report).

Items such as bearing and rotor wear, rotor alignment, oil seals and initial turbine nozzle and bucket inspections are performed at this point. Typically the rotor is removed for cleaning and inspections of the various bucket attachments, end caps, tie wires and other components of the rotor. Depending on the manufacturer recommendations and good industry practice, the inspection may include bucket removal for joint and attachment inspections. As damage or other degradation of components are found, various methods of refurbishment or parts replacement is performed. The inspections can include various non-destructive examination methods such as MPI, die penetrant, and ultrasonic testing to search for cracking of LP turbine components.

Q, Did Xcel maintain a six-year overhaul cycle?

A. No. A System Health Report prepared by Xcel and dated December 7, 2010,[51] noted that "These LP's [sic] also experience dovetail pin cracking problems, erosion damage and may suffer from an industry-wide problem with rotor wheel cracking. However, rotor wheel phased array testing in 2005 did not detect any cracking issues. GE recommends TBO of 5 years. Increasing inspection interval adds risk. Currently scheduled for a 8 1/3 year TBO this cycle." The report goes on to state "Risks associated with wheel cracking involve wheel failure and buckets departing the rotor. Resulting collateral damage could be severe (i.e. due to mass imbalance and projectiles.)"[52] The risks identified in this

[51] Id. at p. 18.
[52] Id. at pp. 18-19. See also DOC Ex. __, RAP-D-8 at pp. 13-16 (Polich Direct) (GE Litigation, Trial Transcript, testimony of M. Kolb).

report ultimately came to fruition on November 14, 2011. Wheel is another term often used for the disk.

If Xcel had followed an 8 1/3 year overhaul schedule, it would've performed an overhaul of the LP turbines as part of the planned outage that took place in November 2011. However, as I note above, Xcel decided to defer the overhaul to 2014.[53] It is noteworthy that Lester Engel, a metallurgical engineer retained by Xcel's insurers concluded, based on his review of GE documents, Xcel documents and the Theilsch Report, that one of the root causes of the failure of the LP turbine was "inadequate or improper inspection of the L-1 low pressure turbine wheels, Proper magnetic particle inspection would have detected the stress corrosion cracking prior to rotor failure. This would have prevented the present catastrophic failure of the unit."[54]

VIII. Sherco Water Chemistry Impact on SCC

Q. Was water chemistry a likely contributor to the LP turbine rotor L-1 disk SCC failure?

A. Yes. **NONPUBLIC INFORMATION BEGINS** [redacted]

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[53] DOC Ex. __, RAP-D-8 at pp. 7-9 (Polich Direct) (GE Litigation, Trial Transcript, testimony of T. Murray).

[54] DOC Ex. __, RAP-D-11 (Polich Direct) (GE Litigation, Dep. Ex. 638, Engel Report).

[55] DOC Ex. __, RAP-D-22 (Polich Direct) (GE Litigation, Dep. Ex., 705, ChemStaff Report).

[redacted] **NONPUBLIC INFORMATION ENDS**

Q. Did Xcel follow good utility practice with respect to monitoring steam chemistry at Sherco 3?

A. No. One example is the failure to monitor reheat steam. EPRI recommended continuous monitoring of the reheat steam for sodium and cation conductivity, which are described as "core parameters."[56] Duane Wold, who was responsible for water and steam chemistry at Sherco 3, testified that he understood that EPRI identified core parameters as the minimum required for routine chemistry monitoring and also acknowledged that Xcel did not monitor reheat steam at Sherco 3 for any parameter.[57]

Q. What is the reheat steam and how can it contribute to SCC?

A. The Sherco 3 steam path flows from the IP turbine through the reheat section of the boiler to raise the steam temperature prior to entering the LP turbine. Upon exiting the boiler reheat section, water is injected into the reheat steam to keep steam temperatures below the GE temperature limits of the LP turbine. The water chemistry of

[56] DOC Ex.__, RAP-D-23 at p. 7 (Polich Direct) (GE Litigation, Dep. Ex. 1047, Cycle Chemistry Guidelines for Fossil Plants: All-volatile Treatment, EPRI); RAP-D-22 at p. 21 (Polich Direct) (Dep. Ex. 705, ChemStaff Report).
[57] DOC-Ex.__, RAP-D-24 at pp. 2-3 (Polich Direct) (GE Litigation, Wold Trial Dep. Transcript).

the injected water should be tightly controlled and monitored so that chemicals that cause SCC are not introduced into the LP turbine.

Q. Are there other examples of Xcel's failure to adequately monitor steam chemistry at Sherco 3?

A. Yes. **NONPUBLIC INFORMATION BEGINS** [redacted]

[58] DOC-Ex. __, RAP-D-22 at p. 21 (Polich Direct) (GE Litigation, Dep. Ex. 705, ChemStaff Report).

[redacted]

8. [redacted] **NONPUBLIC INFORMATION ENDS**

Q. What documentation was available to Sherco 3 staff that described good utility practice for water chemistry requirements?

A. Good utility practice for boiler water chemistry can be found in multiple documents, including the following:

1. *Turbine Steam Purity*, General Electric, GEK-63430, March 1978.[59]
2. *Interim Consensus Guidelines on Fossil Plant System Chemistry*, Electric Power Research Institute (EPRI), Palo Alto, CA, CS-4629, June 1986.[60]
3. *Cycle Chemistry Guidelines for Fossil Plants: Oxygenated Treatment*, Electric Power Research Institute (EPRI), Palo Alto, CA, TR-102285, December 1994.[61]
4. *Cycle Chemistry Guidelines for Fossil Plants: All-Volatile Treatment*, Electric Power Research Institute (EPRI), Palo Alto, CA, TR-105041, April 1996.[62]

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[59] DOC Ex. __. RAP-D-25 (Polich Direct) (GE Litigation, Tr. Ex. 288, GEK-63430, Turbine Steam Purity).
[60] DOC Ex. __. RAP-D-26 (Polich Direct) (GE Litigation, Trial Ex. 350, Interim Consensus Guidelines on Fossil Plant System Chemistry, EPRI).
[61] DOC Ex. __. RAP-D-27 (Polich Direct) GE Litigation, Dep. Ex. 50, Cycle Chemistry Guidelines for Fossil Plants, Oxygenated Volatile Treatment, EPRI).
[62] DOC Ex. __. RAP-D-28 (Polich Direct) (GE Litigation, Trial Ex. 349, Cycle Chemistry Guidelines for Fossil Plants, All-Volatile Treatment, EPRI).

5. *Cycle Chemistry Guidelines for Fossil Plants: All-Volatile Treatment: Rev. 1*, Electric Power Research Institute (EPRI), Palo Alto, CA, 1004187, November 2002.[63]
6. *Steam Purity Recommendations for Utility Steam Turbines*, General Electric, GEK-72281c, April 2004.[64]

In addition, Xcel's internal requirements for water chemistry were not followed at Sherco 3.[65] This document contains the following requirement:

"Review and implement, if not already in compliance, the latest OEM or EPRI turbine steam purity recommendations (Cycle Chemistry Guidelines for Fossil Plants: Phosphate Continuum and Caustic Treatment, EPRI, Palo Alto, CA: 2004, 1004188 and Cycle Chemistry Guidelines for Fossil Plants: Oxygenated Treatment, EPRI, Palo Alto, CA: 2005, 1004925), whichever is more stringent, and including monitoring of reheat steam."[66]

Q. How does water chemistry impact on steam impurities differ between once through boilers and drum boilers?

A. A description of the difference in how steam is produced by once-through versus drum boilers is provided on Section II of my testimony. In a once-through boiler, the

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[63] DOC Ex. __. RAP-D-29 (Polich Direct) (GE Litigation, Trial Ex. 324, Cycle Chemistry Guidelines for Fossil Plants: All-Volatile Treatment, Rev. 1, EPRI).
[64] DOC Ex. __. RAP-D-30 (Polich Direct) (GE Litigation, Trial Ex. 65, GEK-72281c, Steam Purity Recommendations for Utility Steam Turbines).
[65] DOC Ex. __, RAP-D-31 (Polich Direct) (GE Litigation, Trial Ex. 22 Steam Turbine Rotor Wheel Inspection Recommendations for Stress Corrosion Cracking).
[66] Id, at p. 3.

feedwater entering the boiler is turned to steam and flows directly to the steam turbine. Thus, 100% of all chemical impurities present in the boiler feedwater are transported into the steam that flows thru the steam turbine. Upon reaching the Wilson line, these chemical impurities will concentrate in the water droplets and be deposited on the LP turbine components. Some of these water droplets migrate in between turbine parts, such as between the turbine bucket attachment to the turbine rotor. When these droplets dry, they leave behind the chemical impurities contained in the feedwater and the deposits build-up over time. These are the chemical deposits which contribute to SCC. The reason that GE first encountered SCC in once-through boilers steam turbine generation facilities was due to the higher level of impurities in the steam causing higher amounts of chemical deposits in the LP turbine components.

Drum boilers do not pass 100% of chemical impurities contained in the feedwater to the steam because the water in the boiler drum acts as a filter to collect feedwater impurities. The feedwater chemical impurities have a tendency to stay in aqueous solution because of the chemical attraction to water. Still, a portion of the chemical impurities will transfer into the steam exiting the steam drum, but in lower quantities than in once-through boilers. Thus, steam turbines of drum boiler power generation facilities will still have steam containing chemical impurities, flowing thru the turbine. The low-pressure turbine will still have water droplets containing those impurities, condensing on LP turbine components. As with once through boilers, these droplets will deposit the chemicals on turbine components, just at a slower rate. Thus, LP turbines of generation facilities using drum boilers are still susceptible to SCC cracking caused by chemical impurities in the feedwater system.

Q. What were ChemStaff's findings in regard to Sherco 3's water chemistry practices?

A. **NONPUBLIC INFORMATION BEGINS** [redacted]

[67] DOC Ex. __, RAP-D-22 at p. 22 (Polich Direct) (GE Litigation, Dep. Ex. 705, ChemStaff Report).
[68] DOC Ex. __, RAP-D-8, p. 22-25 (Polich Direct) (GE Litigation, Trial Transcript, Allmon testimony).
[69] Id. at p. 26-29.

[redacted]

NONPUBLIC INFORMATON ENDS

Q. Did Thielsch report contain an evaluation of Sherco 3 water chemistry history?

A. Yes. Thielsch review of Sherco 3 water chemistry concluded that the Xcel had operated the unit with GE and EPRI guidelines for water chemistry. Thielsch's conclusions are not valid because they assumed the monitoring of water chemistry at Sherco 3 was being performed properly, the water chemistry monitoring and testing equipment was properly calibrated, and data was obtained at the correct points in the feedwater and

[70] DOC Ex. __, RAP-D -22 at p. 30 (Polich Direct) (GE Litigation, Dep. Ex. 705, ChemStaff Report).

steam cycle. Thielsch also did not review the American Society for Testing and Materials (ASTM) standard D4191-97, published in 1997 regarding accuracy of Flame Atomic Absorption Spectroscopy (AAS) used at Sherco for measuring sodium.[71] The standard indicates that prior to 2008, the AAS is not accurate below 200 ppb sodium concentration levels. **NONPUBLIC INFORMATION BEGINS** [redacted] **NONPUBLIC INFORMATION ENDS** Thus, Thielsch conclusions regarding Sherco 3 water chemistry meeting GE and EPRI guidelines are without merit. In addition, as pointed out by ChemStaff witness Mr. Allmon, there were multiple problems with Sherco 3 equipment calibration and the locations in which Sherco 3 was monitoring water chemistry.[75] Thielsch never verified the water chemistry monitoring practices or equipment calibration practices of Sherco 3.

Q. What is your conclusion regarding the impact of Sherco 3's water chemistry program on the SCC failure of the LP turbine rotor L-1 disk?

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[71] DOC-__, RAP-D-33 (Polich Direct) (ASTM standard D4191-97).
[72] DOC-__, RAP-D-22 at p. 22 (Polich Direct) (GE Litigation, Dep. Ex. 705, ChemStaff Report).
[73] DOC-__, RAP-D-25 (Polich Direct (Trial Ex. 288, GEK-63430, Turbine Steam Purity).
[74] DOC Ex. __. RAP-D-28 (Polich Direct) (GE Litigation, Trial Ex. 349, Cycle Chemistry Guidelines for Fossil Plants, All-Volatile Treatment, EPRI).
[75] DOC-__, RAP-D-8 at pp. 26-33 (Polich Direct) (GE Litigation Trial Transcript, Allmon testimony.

A. Sherco 3 failed to monitor and control water chemistry within GE and EPRI guidelines in accordance with good utility practice. This resulted in chemical higher concentrations of caustic chemicals in the steam flowing through the LP turbine and increased accumulation of SCC inducing chemicals on the L-2 – L-0 stages of the LP turbine. Xcel also failed to perform recommended inspections of the LP turbine rotor disks in accordance with industry standards based upon the level of chemicals in Sherco 3's steam. Xcel should have performed the LP rotor inspection and inspected the LP turbine rotor L-1 disk finger dovetails using MPI in 2011, which would have discovered the high level of SCC and avoided the accident.

IX. Assessment of Responsibility for November 19, 2011 LP Turbine Failure

Q. What is the real root cause of the November 19, 2011 Sherco 3 LP turbine accident?

A. The real root cause of the November 19, 2011 Sherco 3 LP turbine accident was Xcel's failure to properly maintain and operate the steam turbine in accordance with good utility practice. Xcel failed to maintain proper water chemistry during the period of 1999 through the 2011 outage. Xcel failed to perform timely inspections of the LP turbine for SCC. Xcel failed to recognize the potential for SCC to occur in the LP turbine despite the widespread industry knowledge of the potential for SCC to occur in the LP turbine disk of both the tangential and finger style dovetail joints that connected the buckets to the turbine rotor. Xcel's excuse was that GE did not provide Xcel with proper guidance on SCC potential in the joints between the buckets and the rotor disk, ignores well known and understood information and evidence on the potential for SCC to occur in the

Sherco 3 steam turbine. Nor was cost a justifiable reason for not performing the proper inspections for SCC in the LP turbine buckets connections in light of the cost of the catastrophic failure and resulting replacement power costs.

Q. Could Xcel have prevented the November 19, 2011 LP turbine accident?

A. Yes. Xcel decision to postpone the 2011 inspection of the LP turbine and not remove the buckets with finger dovetail joints for MPI inspection was the root cause of the November 19, 2011 LP turbine accident.

Q. Based on your review of the information available to Xcel, did Xcel apply good utility practice in regard to maintenance of the Sherco 3 LP turbine?

A. No. Xcel did not follow GE guidelines on inspection timing nor procedure for inspection of the LP turbine. GE recommends inspection of the turbine rotor for problems like SCC should be performed every three to five years. The inspection for SCC induced cracks in the LP rotor disk requires removal of the buckets from the rotor. Xcel did not perform this type of inspection within the recommended time period. GE specifically states the buckets need to be removed from the rotor to test for SCC. Engle Metallurgical, Ltd, performed an RCA of the Sherco 3 LP turbine failure and stated SCC

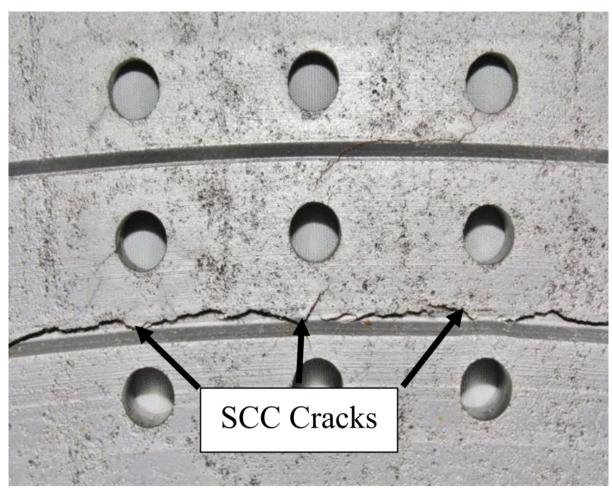

Figure 17 - Photo of L-1 Rotor Disk Finger Dovetail Joint Showing Cracks

cracks would have been evident up to five years prior to the failure.[76] As can be seen in Figure 17, these cracks were visible with the naked eye and would have been easily detected using the GE recommended testing procedures[77]. These same type of SCC cracks were also found in the both stage L-1 turbine rotor disk of LP turbine A and the generator end stage L-2 disk of LP turbine A. [78] Thus, if Xcel had performed the turbine rotor inspection during the 2011 outage, they would have discovered the extent of the SCC cracking and repaired the rotor prior to restarting the unit. This would have avoided the November 19, 2011 catastrophic event.

Q. Did the Xcel have ample evidence that SCC occurrence in the last few stages of the LP turbine was a major problem?

A. Yes. In addition to GE, EPRI and others had published numerous articles on the occurrence and problems with SCC in LP turbines. Xcel's claims that GE did not explicitly tell Xcel to inspect the finger dovetail joints for SCC as the reason for not doing so does not follow good utility practice. Xcel knew of the potential for SCC in the LP turbine rotors, chose to take the risk of delaying inspection and proper testing of the turbine rotor disk finger dovetail joints, and ignored previous outage evidence of chemical deposits on the LP turbine rotor components and water chemistry history at Sherco 3.

[76] DOC-__, RAP-D-11 at pp. 4-5 (Polich Direct) (GE Litigation, Dep. Ex. 638, Engel Report).
[77] DOC-__, RAP-D-7 at p. 306 (Polich Direct) (GE Litigation, Dep. Ex. 656, Thielsch Report).

Q. Please summarize why the November 19, 2011 accident at Sherco 3 was preventable.

A. Xcel personnel had ample information on the potential for SCC to occur in the LP turbine finger dovetails of Sherco 3. Xcel personnel had discussions with GE regarding SCC in LP turbine dovetails of drum boiler plants as early as 2008. Xcel had performed inspections of Sherco 1 and 2 in 2007 and 2008 but chose not to do so for Sherco 3. Xcel chose to delay the scheduled 2011 LP turbine to 2014 and instead installed new HP and IP turbine rotors to improve plant efficiency. All of the information available to Xcel should have raised a red flag and compelled Xcel to follow good utility practice by performing the proper inspection and testing of the turbine rotor disk finger dovetail joints. As such, The November 19, 2011 accident of the Sherco 3 LP turbine was a direct result of Xcel not employing good utility practice of inspection of the LP turbine dovetail joints in a timely manner. This opinion is based on the following:

- Xcel failed to perform maintenance on the Sherco 3 steam turbine in accordance with good utility practice.
- The catastrophic failure of the Sherco 3 low pressure turbine on November 19, 2011 was caused by SCC in the low pressure ("LP") turbine rotor disk that held the L-1 buckets.
- Xcel personnel had in their possession documentation that identified the potential for steam turbine failure and provided recommended plant maintenance and inspection practices to avoid such a failure.
- Xcel personnel were well aware of SCC problems in low pressure turbines long before the November 19, 2011 catastrophic failure at Sherco 3.

- Xcel was well aware of the importance of water chemistry and the potential for poor water chemistry to cause stress corrosion cracking in portions of the LP turbine.
- Xcel did not maintain water chemistry in accordance with industry recommended practices that resulted in sodium induced SCC in the LP turbine rotor L1 disk.
- Xcel had previous evidence of chemical deposits around the LP turbine L-1 rotor disk prior to the scheduled outage in 2011 and should have performed magnetic particle inspection of the L-1 disk dovetail connections to the L-1 buckets, as recommended by industry experts.[79]
- Xcel knowingly and unreasonably risked delaying inspections of the Sherco 3 steam turbine even though manufacturer and other utility industry knowledge contained recommendations to perform the inspections earlier and even though it knew that this delay increased the risk of failure.
- Xcel did not follow manufacturer recommendations for inspection of the LP turbine rotor dovetail connections to the turbine buckets nor did they follow internal inspection guidelines.
- Xcel knew of the potential for the type of steam turbine failure that occurred at Sherco 3 well in advance of its decisions to delay the inspections previously planned for November 2011.

[79] DOC Ex. __, RAP-D-3 at p. 227 (Polich Direct) (GE Litigation, Trial Ex. 1266, Xcel Energy Sherburne County Unit #3 Inspection Report).

- Xcel had experience with steam turbine equipment which had the same type of damage as that which led to the Sherco 3 steam turbine failure.
- The planned inspection of the LP turbine disk dovetails in 2011 would have discovered the extent of the SCC in the LP turbine L-1 rotor disk and Xcel's decision to delay that inspection to 2014 was directly responsible for the accident.

Q. Does this conclude your direct testimony?

A. Yes.