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Photo: Dominion Energy

Dominion Energy's Surry Power Station.

Surry's safety-related pipeline upgrade

A seven-year project to renew safety-related piping picks up an industry award as it prepares Surry for long-term operation.

By Janean Sealey and Anna Pridmore

During the spring 2018 refueling outage at Unit 1 of Dominion Energy's Surry nuclear power plant, an innovative, first-of-a-kind upgrade of a safety-related piping system began, using a carbon fiber–reinforced polymer (CFRP) system to improve reliability. The first phase of this long-term project was completed successfully, and subsequent phases will take place through 2025.

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The CFRP upgrade has garnered significant industry attention as well, as it received the Nuclear Energy Institute's Best-of-the-Best Top Innovation Practice (TIP) Award at the 2019 Nuclear Energy Assembly, held earlier this year in Washington, D.C. (*NN*, July 2019, p. 10). When asked about the TIP Award, a Surry spokesperson commented, "We were honored to receive the TIP Best-of-the-Best, and to have the opportunity to share this unique solution to an ongoing challenge across the nuclear industry." Upon completion in 2025, the CFRP upgrade is expected to deliver significant operational risk avoidance, savings, and a full structural upgrade to several Surry-1 and -2 critical, large-diameter safety-related piping systems.

Companies that operate U.S. nuclear energy facilities have partnered on a multiyear strategy to transform the industry and ensure its viability for consumers, as well as its essential role in protecting the environment. This strategic plan, called "Delivering the Nuclear Promise," is designed to strengthen the industry's commitment to excellence in safety and reliability and ensure future viability through efficiency improvements. Dominion Energy believes the Surry safety-related piping upgrade with CFRP aligns with nuclear industry efforts to deliver that promise by encouraging innovation and improving operational efficiency while enhancing reactor safety and maintaining a focus on reliability.

The Surry plant is located in Surry County in southeastern Virginia, near the town of Smithfield. The power station lies on an 840-acre site adjacent to the James River. Surry-1 and -2 are Westinghouse-designed pressurized water reactors and have both entered their period of extended operation under a renewed license. The circulating water and service water system

Photo: Dominion Energy

The condition of Surry's metallic pipelines required routine repair work, driving the desire for a long-term CFRP upgrade.

piping has been in service since commercial operation began at Unit 1 in 1972 and at Unit 2 in 1973. Each reactor produces over 800 MWe, for a combined plant output of about 1.6 GWe.

Over the past several years, routine inspections required by American Society of Mechanical Engineers (ASME) Boiler & Pressure Vessel Code (B&PVC) Section XI, "In-Service Inspections of Nuclear Power Plant Components," identified significant corrosion on the interior surfaces of the circulating water and service water carbon steel piping. During refueling outages, this piping has been routinely drained, cleaned, inspected, welded, and coated with a ceramic-epoxy coating system. These maintenance activities have proved very costly and have often impacted the refueling outage critical path. Meanwhile, the overall condition of the carbon steel piping has continued to degrade, increasing the possibility of an unplanned outage. After many years of addressing pipe degradation during every outage, Surry needed to find a long-term solution for the affected pipelines.

Options considered

To address this challenge, the Surry team had to complete a thorough options analysis process and prioritize the pipelines. The options considered included the following:

- *Replacement*—requiring excavation and placement of new piping.
- *Steel slip-lining*—requiring insertion of a new steel pipe within the existing pipe.
- *Long-term coating systems*—requiring surface preparation and installation of nonstructural system.
- *CFRP*—requiring surface preparation and installation of fully structural system.

Replacement of the pipe segments was ruled out as an option due to their size, locations, and the lengthy outage that would be required. Slip-lining was not feasible due to bends and location complicated for excavation. Coating systems last five to six years in brackish water environments like that at Surry, and even high-end coating systems were ruled out due to the frequent maintenance they would require.

After the extensive options analysis, Surry chose the trenchless, fully structural repair, utilizing a CFRP system to address the distressed sections of piping because it offered a 50-year service life, completion of repairs within an outage window with no excavation required, and limited hydraulic loss because of the minimal thickness of the lining system, coupled with an improved coefficient of friction over the original pipe conditions.

Dominion partnered with engineering firm Simpson, Gumpertz & Heger (SGH) and Structural Technologies LLC to plan the CFRP installation. This was a long-term effort that began in 2014 with the application of CFRP in non-safety piping and evolved to an approach for safety-related lines and subsequent development of an alternative request package for the Nuclear Regulatory Commission, which was submitted in 2016 and approved in late 2017.

CFRP system background

The project team for the Surry pipeline upgrade designed, manufactured, and installed the structural upgrade for the circulating water and service water safety-related piping using Structural Technologies' V-Wrap CFRP System. CFRP is a lightweight, high-strength composite material applied to the interior of the pipe using existing access points.

CFRP pipe-lining systems are effective in the internal repair or renewal of buried pipes 30 inches in diameter and larger, and can be used in limited scenarios down to a 24-inch diameter. Prior to the safety-related pipeline upgrade project, the CFRP method had previously been used at Surry for multiple repairs on non-safety metallic piping, including 30-inch, 42-inch, and 96-inch diameters.

Fiber-reinforced polymer systems are comprised of high-strength carbon fiber fabrics and glass fiber fabrics fully saturated in a two-part epoxy matrix. (While a glass fiber-reinforced polymer system is referred to as a GFRP system, the acronym CFRP is used both generically for any fiber-reinforced polymer system and specifically for a carbon fiber–reinforced polymer system.) The epoxy materials are volatile organic compound (VOC) compliant, which means the use of organic cartridge respirators is not required during the installation.

Layers of carbon and glass fabric, saturated in epoxy, are installed on the prepared interior surface of the pipe, forming a structural lining within the pipe. This lining can serve as a structural replacement of the existing pipe for the life of the repair, except at the repair termination points.

The CFRP system typically includes a structural reinforcing fabric consisting of unidirectional carbon fiber applied circumferentially and longitudinally as a strengthening component; a nonstructural fabric consisting of glass, which provides a dielectric barrier (for metallic pipelines), an intermediate layer, and a water barrier; and termination materials—corrosion-resistant stainless-steel expansion rings with rubber gaskets—used to mechanically press the CFRP system against the pipe at the end of the repair.

Project scope

The spring 2018 safety-related CFRP upgrade at Surry covered a total of about 260 lineal feet of piping, including 96-inch circulating water inlet piping from the intake canal to the main steam condenser isolation valves and 24-, 30-, 36-, 42-, and 48-inch service water pipe headers, leading from the circulating water system to the recirculation spray system piping and component cooling heat exchangers supply lines.

The upgraded piping was made of carbon steel encased in concrete and buried, and was originally designed to meet specifications from ASME, the American Society of Testing and Materials, and the American Water Works Association.

Use of a CFRP system for pipe applications is a technology improvement that was not available in the 1960s or 1970s, and accordingly it is not included in Surry's Final Safety Analysis Report. There are currently no provisions in ASME standards for installing CFRP systems as a Section XI repair for Class 3 piping.

Pursuant to the requirements of 10 CFR 50.55a, "Codes and Standards," Dominion submitted an ISI Alternative Material Request to the NRC requesting approval to use the V-Wrap CFRP System for the safety-related service water and circulating water pipe upgrades. The proposed Alternative Material Request to the ASME Section XI requirements was subsequently approved by the NRC.

The installation of the CFRP system in safety-related piping at Surry was governed by strict adherence to the NRC-approved design, material manufacturing, and installation requirements, and in accordance with all relevant codes and standards.

Implementation

One of the most important aspects of CFRP system installations is the preplanning process, and that process at Surry began months prior to the implementation phase. The project team had numerous site meetings, as well as weekly conference calls to plan all aspects of the installation. Project pre-planning for nuclear installations consists largely of contingency planning for multiple scenarios that could arise during implementation, including the following:

- Mitigating safety factors, such as the atmosphere within the pipe.
- Material preparation issues, such as improper epoxy-to-fabric weight ratios.

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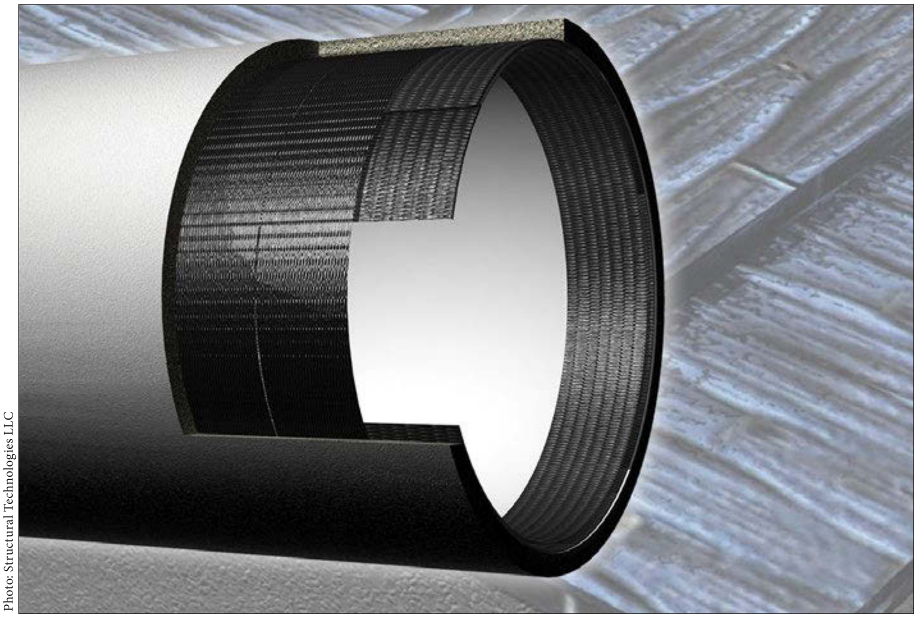

Photo: Structural Technologies LLC

Structural Technologies' V-Wrap CFRP System received approval from the NRC for an upgrade of safety-related pipelines at Surry.

Photo: Structural Technologies LLC

Quality control inspections were ongoing during the CFRP installation process as part of the pipeline upgrade.

- Unforeseen pipe conditions.
- Addressing chloride levels in the pipe in the event of high chloride levels.
- Extended epoxy cure times in the event of lower-than-anticipated air temperature.
- Coordination with other work activities within the station.

All these scenarios, and more, were worked through and contingency plans put in place prior to implementation, in preparation for the project. The contingency plan was then discussed in detail with all relevant parties.

Prior to the pipeline outage period, crews arrived at the site to set up the laydown area, equipment, and material handling, and to implement safety aspects of the project. The first step in the on-site construction activity was dewatering and gaining access to the pipeline(s), and for the Surry project, this was coordinated by Dominion.

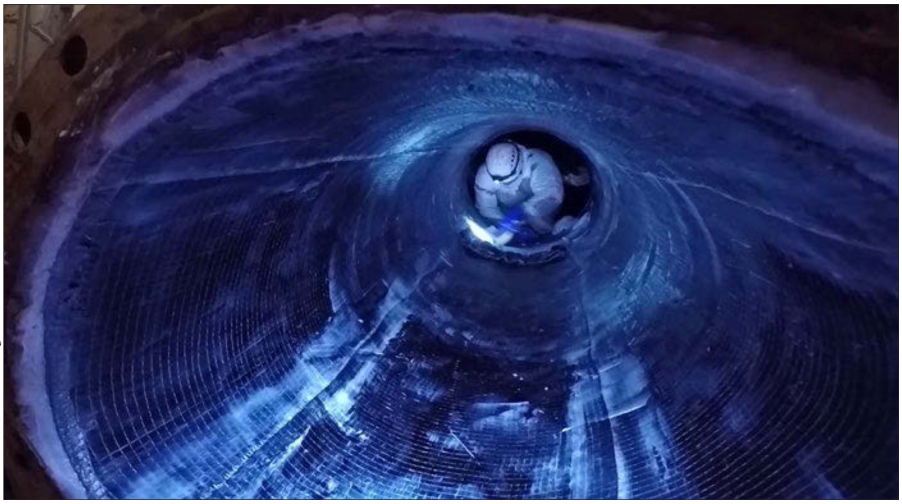

Photo: Structural Technologies LLC

A trained and certified technician, meeting Surry specification requirements, installs the CFRP system in a 30-inch segment of piping.

A CFRP system installation requires two separate work sites: topside and in-pipe. A main component of the topside site is the mixing, saturation, and storage area, which is temperature-controlled to meet quality control requirements. At the mixing and saturation area the epoxy is mixed and applied to the fabric using a mechanical saturator, which is a critical step in the process because saturation should be even throughout the fabric.

Worker safety is the most important aspect of all pipeline projects, and it is especially important for the in-pipe activities, given that the work takes place in a confined space with limited access and egress availability. For the Surry project, the team was focused on this aspect throughout, and there were zero Occupational Safety and Health Administration recordable events during the implementation phase at Surry.

Ensuring that crews within the pipe have adequate air supply is critical, and environmental control equipment is staged topside and utilized during in-pipe activities. Environmental controls utilized for safety include a dust collector to reduce dust during the surface preparation phase of the project and dehumidification units with in-line heaters to provide for air movement and temperature and humidity control during installation of the CFRP system and its termination points.

The installation of the CFRP system takes place in a continuous manner and

Photo: Structural Technologies LLC

Custom-designed termination points are critical to the long-term performance of the CFRP lining system.

Photo: Structural Technologies LLC

Specialized access systems were required for safety during the CFRP upgrade of sloped pipe segments.

is staged to avoid contact with the material until it has cured, which takes about 72 hours in ambient temperatures. In the 96-inch piping upgraded at Surry, a temporary platform was installed to allow for continued access and completion of the CFRP installation process.

The saturated CFRP is applied to the inside surface of the host pipe in what is called a “wet lay-up process.” The fabric, fully saturated with epoxy, is pressed to the inside surface of the host pipe to achieve intimate contact. Any air trapped between layers is released or rolled out without wrinkling of the carbon fiber. The installed CFRP is oriented in the directions indicated on the design drawings, with no greater than a five-degree misalignment of the fabrics allowed from the specified direction.

Following the installation of the CFRP system at Surry, the termination points were installed. The termination points of the CFRP liner are a critical point of the lining system, and they are designed so internal water pressure is not able to migrate behind the CFRP system. If the CFRP is not properly sealed at termination points and pressure is allowed to build up behind the liner, the CFRP lining will be structurally ineffective. In addition, a topcoat of thickened epoxy is added as the final layer across the entire installed CFRP system. Following these steps, the CFRP system is cured and the installation is complete, following quality control (QC) sign-off.

The QC procedures in place for the safety-related CFRP upgrade at Surry were robust, setting a standard for the industry. For documentation of the CFRP repair, separate QC forms were created for each segment of pipe repaired. This included identifying the location and specifics of the rehabilitation, design and as-built information, and as-found conditions, such as previous repairs. Each individual QC form documented the complete lining installation process, including the date of completion, inspection/verification of the installation process, lot numbers of materials used, notes regarding unique field conditions, and the personnel involved in the QC documentation process.

Verification of the installation process consisted of a series of tests conducted throughout the installation phase, including saturator roller calibration, a weight ratio test to verify epoxy saturation, testing of the bond and the tensile strength of the CFRP, and cure testing to verify that the CFRP system is fully cured prior to placing the piping back into service.

In addition, to meet QC requirements, a host of environmental conditions are measured and documented throughout the implementation period. Throughout the installation process, Surry, Structural Technologies, and SGH collaborated

Photo: Structural Technologies LLC

Quality control inspectors carry out a detailed post-installation examination of the installed CFRP lining system.

on the detailed QC process to ensure the long-term performance of the CFRP repair.

Compounded innovation

Surry and its owner, Dominion Energy, embarked on a first-of-a-kind pipe repair project that is also the first project approved as part of Dominion's pursuit of subsequent license renewal for the plant. The safety-related CFRP upgrade project has several benefits for the plant, first and foremost being improving reactor safety and operational performance.

Innovation began long before the safety-related CFRP upgrade project was initiated. Implementing an asset management program, such as the one that led to the pipe repair decision, requires several key components and a complex decision tree. In-service inspections are the primary building blocks of any asset management program related to safety-related piping. Collecting and evaluating data to determine risk level, perform engineering analysis, and identify replacement or repair strategies are also important steps.

In the case of Surry's safety-related systems, pipe failure could lead to potential life-safety issues, challenges to reactor safety, and damage to safety-related structures, components, or equipment. The potential for a forced shutdown was real, and if it had occurred, it would have led to unplanned demands on safety systems, considerable loss of revenue, and additional regulatory oversight. A unique, first-of–a-kind failure modes and effects analysis (FMEA) for the use of a CFRP system in safety-related piping was performed. The FMEA demonstrated that the benefits, risk profile management, and proposed installation of the CFRP system were achievable and met performance and reliability objectives established by Surry. Based on the consequences of failure, the FMEA identified key quality attributes and required mitigating actions.

All these steps led to the award-winning safety-related CFRP upgrade project and constitute a series of ongoing innovations by a team at Surry that was determined to end the cycle of ongoing inspections and piping repairs that impacted every refueling outage. The safety-related CFRP upgrade was a textbook case of proactive asset management, and an example of identifying and implementing a long-term solution for an ongoing challenge.

Project impact

The implementation of the CFRP system is expected to yield direct and indirect cost savings to Surry and enhance its economic outlook as it operates past 60 years for two decades of subsequent license renewal. The project eliminates recurring costs and schedule impacts during refueling outages from tag-out, draining, cleaning, inspecting, welding, and coating tasks for circulating water and service water piping. In the past, the inspect-and-repair process has often been critical path during refueling outages and has caused significant schedule risk due to the unknown number of required repairs.

The direct cost savings are estimated to be significant. The indirect benefits, however, may be even more meaningful. Personnel previously engaged in the inspection and repair process for piping, including work management, planning, engineering, support services, operations, and maintenance, can all perform tasks on other systems and ultimately further improve the plant's overall performance during each refueling outage.

Also, because the CFRP upgrade project is being performed under quality assurance programs maintained by the engineering and contracting companies, demands on the time of Surry personnel are further reduced.

The use of the CFRP system is currently being evaluated at several other U.S. nuclear plants to address similar reliability and performance opportunities in large-diameter pipelines. The project that won Surry and Dominion Energy NEI's Best-of-the-Best TIP Award is applicable to safety-related and non-safety-related systems across the nuclear power industry. NN