Cured-In-Place-Pipe (CIPP) Lining Safety-Related Installation

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As nuclear plants renew operating licenses and extend operational life, the cost of replacing piping systems can be substantial, especially for buried piping. Several solutions exist to rehabilitate buried safety-related piping. One of them is lining with Cured-In-Place-Pipe (CIPP). CIPP has been used worldwide to rehabilitate commercial pipelines.

CIPP mitigates deterioration, providing an internal corrosion barrier while maintaining the pressure boundary integrity of the host pipe. It is used extensively to rehabilitate buried piping systems in-situ without requiring excavation or disturbance of adjacent systems or components. CIPP is an economical option for piping difficult or impossible to replace. The Electric Power Research Institute (EPRI) has prepared a technical report for CIPP, TR-103992, “Recommended Practices: Cured-in-Place Pipe Liner for Rehabilitation of Service Water Piping” [1]. This report, which was developed during a CIPP service water system project at the Millstone 2 Nuclear Station, contains guidance to address relevant issues at nuclear generating facilities.

Initial Pipe Condition

Installed CIPP Liner

OVERVIEW OF CIPP

CIPP was first introduced in the United Kingdom in the early 70’s with the first patent [2] granted February 22, 1977. Since then, it has become a standard method to rehabilitate piping for municipalities and commercial industries. CIPP materials consist of a liner with resin impregnated layers. After resin curing, the resultant product is a form-fitted, structurally reinforced resin pipe within the existing host pipe. CIPP can be designed as a standalone pipe capable of meeting design requirements, including internal and external pressure and seismic loads [3, 4].

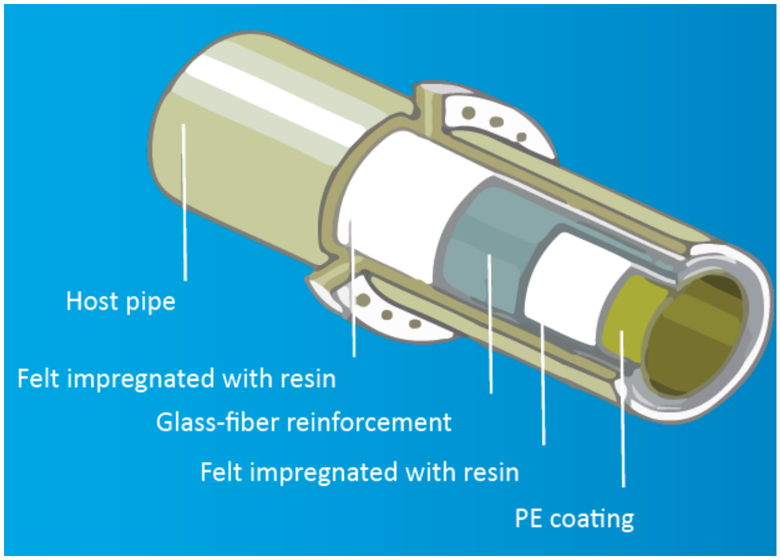
CIPP Liner

In pressure applications, the liner is usually a combination of four layers:

1- A barrier film (i.e. Polyethylene (PE) coating) forming the new inside diameter (ID) of the rehabilitated pipe
2- A first layer of resin impregnated felt

3- Fiber reinforcement layer(s)

4- A second layer of resin impregnated felt next to the host pipe



Schematic of an installed CIPP liner in a pipe [5]

The barrier film provides an impermeable layer to protect the resin and the rehabilitated pipe from water intrusion. Polyethylene (PE) is a good choice for this application and it is widely used for water pipe. The PE liner is resistant to saltwater as well as to common water treatment chemicals, such as sodium hypochlorite. PE is not a nutrient source for bacteria, fungi, spores, etc. and eliminates microbial induced corrosion (MIC) of the host pipe ID. The smooth surface will not promote biofouling.

The use of glass fiber reinforcement in polymer composites has been practiced for decades and is still the most common reinforcement fiber for plastics. The tensile strength of glass fiber per unit density exceeds that of steel, while its tensile modulus is similar [6]. Glass fiber is less brittle than carbon fiber and more chemically resistant than aramid or nylon fibers. The glass fibers are woven both in the longitudinal and transversal directions to provide reinforcement and are sandwiched between two layers of resin impregnated felt.

CIPP Resin

The resin choice will impact the mechanical characteristics and lifetime of the final product. Resin selection also determines installation processes selection. There are currently three main chemical families of resins available for CIPP installation: Polyester, Vinyl Ester, and Epoxies. Each chemistry has its advantages and inconveniences. Table 1 summarizes the resin characteristics.

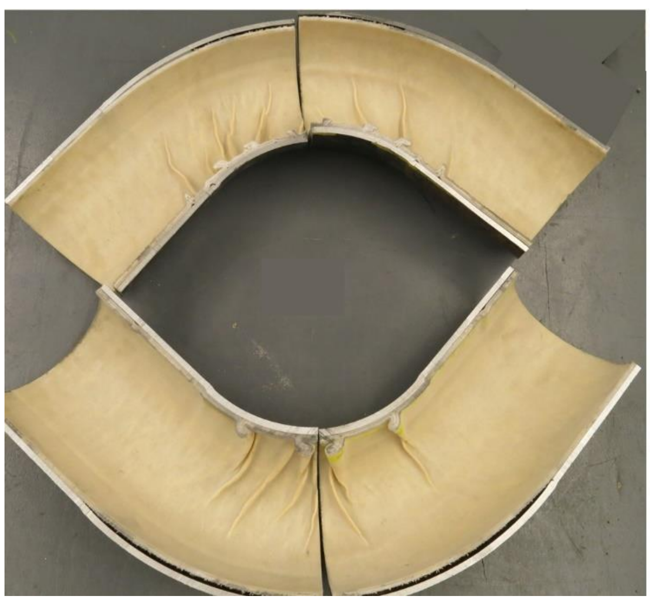
Table 1 Resin Characteristics for CIPP Installation

Characteristics	Polyester	Vinyl Ester	Epoxies
Safety	Initiator: Peroxide	• Initiator: Peroxide • Styrene	No major concern.
Mixing - Ingredient proportion	Not critical	Not critical	Critical

Pot Life	Long for temperature below reaction initiation	Long for temperature below reaction initiation	Shorter than polyester and vinyl esters. Duration increased by cooling .
Reaction	Exothermic Self-accelerating	Exothermic Self-accelerating	Exothermic
Cure	Multiple heating levels	Water inversion recommended.	Heating or room temperature (several days).
Properties	• Lower mechanical properties. • Lower chemical resistance. • Shrinkage ~ 7%	• Improved mechanical properties • High impact resistance • Improved chemical resistance • Shrinkage < 7%	• High strength • High chemical resistance • Lower impact resistance • Shrinkage < 3%

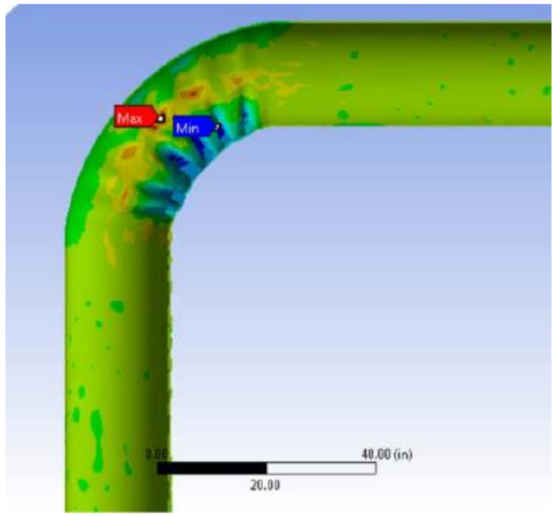
CIPP Elbows

Reduction of the flow can be a concern when installing CIPP due to pipe ID reduction and elbow wrinkles. Wrinkles at the elbow (i.e., due to the difference in intrados and extrados length) in combination with the smooth liner have been evaluated by Imperia [7] through a full-size mock-up. The CIPP installation of an actual plant configuration mocked up 80 ft of 20 Nominal Pipe Size (NPS) concrete lined pipe with seven 45^0 and one 90^0 elbow. CIPP improved fluid hydraulic resistance in the straight pipe due to reduced friction factor of the liner compensated for reduction in ID and increased resistance of the elbows.



Cut Out of a 90º Elbow (8” NPS) Lined with CIPP

Detailed analyses have shown that CIPP improves critical mechanical properties of lined piping. ANSYS Finite Element Analysis (FEA) techniques were utilized to evaluate the Stress Intensification Factor (SIF) and critical buckling (i.e. collapse) pressure of CIPP elbows. Based on bending moment analysis, the SIF is reduced for wrinkled elbows due to thickening of the ID as shown below. The buckling analysis eigenvalue solution demonstrated that wrinkles stiffen the elbow by reducing flexibility and increasing the critical circumferential buckling pressure.

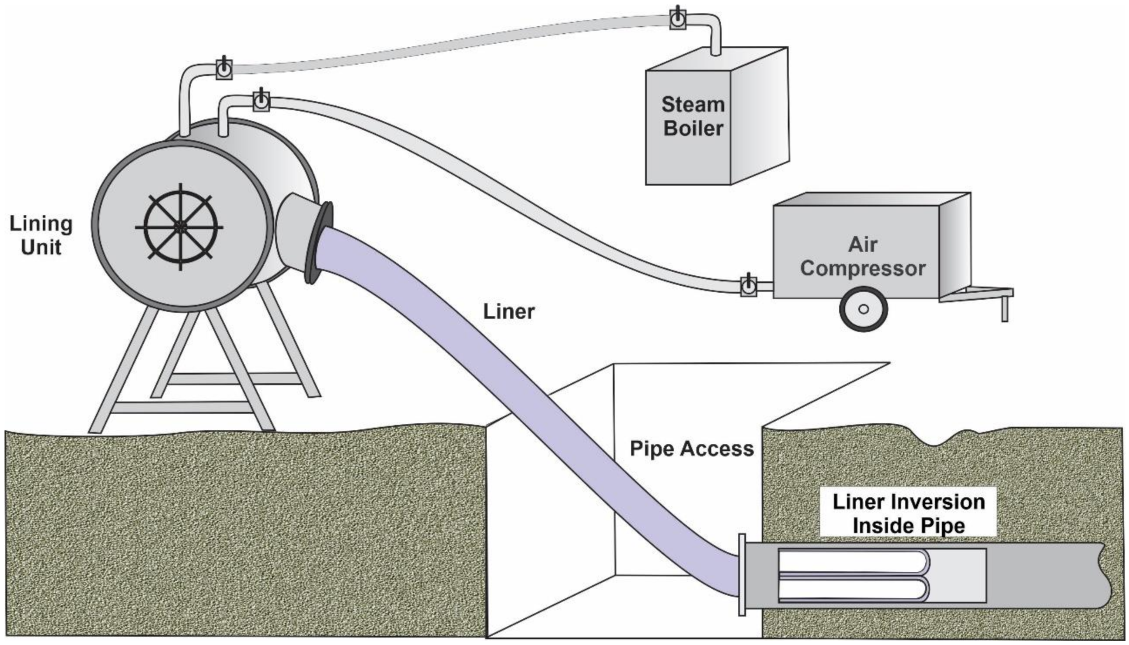


Bending Moment Analysis - Wrinkled CIPP Elbow

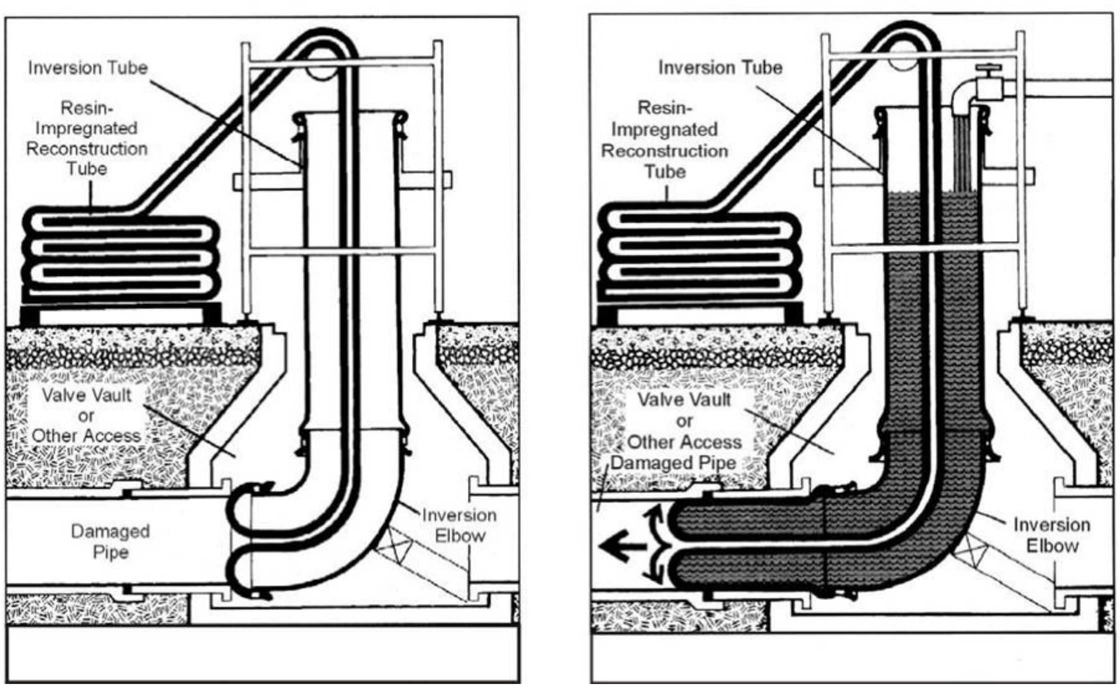
INSTALLATION

Prior to installation, the pipe is cleaned to remove sharp edges, protrusions, or any other surface features that would adversely affect the liner. Cleaning is usually done by hydrolazing and/or by mechanical cleaning. After cleaning of the host pipe and evacuating standing water, there are four main steps to proceed to liner installation:

1. Liner Preparation - During this step, the liner is impregnated with the mixed resin. Pot life and temperature are important monitoring parameters to assure a smooth installation and to achieve the expected properties. The proper resin wetting (saturation) of the entire liner length is an important criterion.
2. Impregnated Liner Installation - Installation is an inversion process achieved with either compressed air or water head pressure.
3. Resin Curing - Curing is achieved by steam or hot water circulating inside the installed liner.

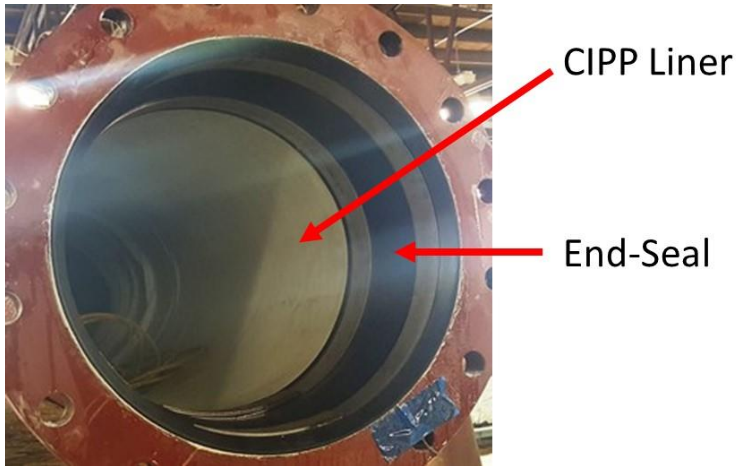


Schematic of CIPP Installation with Air



Schematic of CIPP Installation with Water [1]

4. Seal Installation – Seals are Installed at each end of the CIPP liner to prevent the infiltration of water in the annular space between the CIPP OD and the host pipe ID. Rubber seals cover the termination of the CIPP and host pipe. Retaining bands are installed to apply pressure on the rubber seal to secure it and prevent water infiltration.



End-Seal Installation

INSTALLATION EXAMPLE

In May 2017, safety-related CIPP rehabilitation of Train A Service Water to Emergency Feedwater cross connect piping at V. C. Summer was completed. Lessons learned prior were incorporated from the successful performance of the B Train installation in 2011.

Proposed Pipe for Rehabilitation

Over the service life of the 8-inch NPS Schedule 40 pipe, it experienced corrosion providing a source of corrosion products that could potentially be displaced, become foreign material and interfere with proper system function.

The installation was challenging as the pipe is buried underneath the Intermediate Building in the Radiological Controlled Area (RCA). One access point is above the floor; the other required confined space personnel entry through a 20-inch pipe with a short 90º drop to the 24-inch service water supply header.

Imperia provided the following support to V. C. Summer for a turnkey and seamless installation of the CIPP in the Spring of 2017.

Installer Selection

The installer selection was a two-step process done in close collaboration with the plant. Imperia issued a scope of work and technical requirements document. A pre-bid meeting was organized including work area walkdown. The Imperia and V. C. Summer team witnessed installations performed by each of the competing companies. AquaRehab was selected. They brought a long history of experience and the ability to adapt successfully to the demanding installation for the V. C. Summer configuration.

Engineering Support

Under its QA Program, Imperia supported V. C. Summer with the engineering calculations necessary to assure that the CIPP lined 8-inch NPS pipe satisfied the design requirements in the following areas:

- Material selection
- Liner thickness Determination
- End seal assemblies Evaluation
- Seismic qualification
- Effect of elbow geometry

Furthermore, safety considerations outlined in EPRI report TR-103992 [1] were evaluated.

Commercial Grade Dedication (CGD) Plan

A CGD Plan requirements were developed to utilize commercially purchased materials for safety-related installation. Acceptance criteria for the critical characteristics were established, including the mechanical properties of the cured installation, verification of the materials prior to installation (chemistry, configuration, etc.), and qualification of the installers and installation process. After the second mock-up was completed, a Commercial Grade Dedication Package was prepared to document the results and accept the utilization of the commercially purchased materials.

Laboratory Evaluation

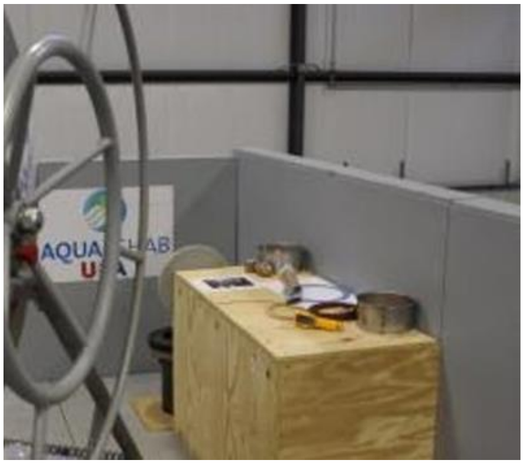
Liner materials used for the installation were tested by Imperia's Materials Engineering Laboratory throughout the process. Testing was performed (1) at the onset of the project for initial design input (2) after one of the mock-up installations to qualify the materials to be used, and (3) from samples made during the installation at VC Summer to confirm liner performance (See Table 2).

Table 2 Mechanical Performance of Cured Liner

Sample Orientation	Tensile Test		Flexural Tests	
	Tensile [psi]	Modulus [psi]	Flexural Stress (5% deflection) [psi]	Flexural Modulus (0.5%-1% deflection) [psi]
Axial	13,900	1,451,000	14,860	471,530
Hoop	19,340	1,277,340	19,200	575,130
ASTM F1216 [8]	**3,000**	NA	**4,500**	**250,000**

Mock-up Installations

Three mock-up installations were held to facilitate installation. All mock-ups were performed using a setup as close as possible to the plant conditions including pipe size, pipe configuration, and modeling of obstructions near the access points.



Mockup Installation at the plant

Pipe Access Point for Start of Inversion

The first mock-up established significant steps in the installation procedure. It enabled proof of concept testing for improved tooling and installation methods. The mock-up provided an opportunity to familiarize AquaRehab employees with the safety, quality, and demanding Nuclear Industry requirements. The second mock-up served as materials and installation team qualification in support of the Commercial Grade Dedication. Members of the rescue team observed the simulation of the confined space entry. The plant's Quality Control engineer finalized QC Hold Points based on the mock-up. The last mock-up provided a final check of the installation procedure and issue resolution assurance. The last mockup was located close to V. C. Summer to allow observation by key plant stakeholders. Time was also allocated for confined-space rescue team practice.

Installation

The CIPP installation started on April 30th, 2017 and finished on May 2nd, 2017. Because of the preparation done ahead of time and the experienced team from Imperia and AquaRehab, the installation went very smoothly.

Confined Space Rescue Personnel at Pipe Access Point

AquaRehab Personnel Inside V.C. Summer Pipe

CIPP AT A GLANCE

Critical Installation Characteristics	**Comments**
Pipe Diameter	2 to 110 inches
Pipe Length	< 800 ft in one lining Considerations: resin chemistry, liner construction, and host pipe configuration.
Branch Connections	Solutions exist.
Elbows	45^0 / 90^0 elbows accommodated Elbow SIF decreases and circumferential buckling pressure increases [7].
Hydraulic Characteristics [7]	ID reduction is compensated by improved flow resistance.
Pipe Orientation	Horizontal / Vertical
Pipe Access	Access required at both ends (e.g., manhole) Accommodation for installation equipment – one end
Installation Time	Outage schedule accommodated
Mechanical Characteristics	Pressure ≤ 200 psi

Critical Installation Characteristics	Comments
	Critical Buckling Pressure < straight pipe
Rehabilitated Pipe	Superior corrosion performance, reduced biofouling, CIPP standalone design possible.
CIPP service life	> 40 years
Cost of rehabilitation	20-30% of direct replacement.

REFERENCES

1. EPRI-TR-103992, Recommended Practices: Cured-in-Place Pipe Liner for Rehabilitation of Service Water Piping, Final Report, December 1994
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3. EPRI 3002005334, Guidelines for Relief Request for Use of Nonmetallic Repairs of ASME Class 2 and 3 Piping, August 2015
4. EPRI 1019179, Capacity Testing of Cured-in Place Pipe, December 2009
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6. D.C. Slivka, T.R. Steadman, V. Bachman, “High Performance Fibers II”, Battelle, 1987, p.ii
7. EPRI BPIG – Imperia Presentation, “Cured-in-Place Piping Elbows: Fluid Flow & Structural Integrity, Norfolk, VA., July 20 – August 1, 2019
8. ASTM F1216-05, Standard Practice for Rehabilitation of Existing Pipelines and Conduits by the Inversion and Curing of a Resin-Impregnated Tube