Evaluation of Exposures to Styrene during Cured-in-place Pipe Liner Preparation and during Pipe Repairs using Hot Water and Steam

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Introduction

Request

We received a management request for a health hazard evaluation at cured-in-place pipe (CIPP) installations using hot water and steam curing techniques and also at a facility where liners are prepared (wet-out facilities) before being shipped to installation sites. The company was interested in characterizing and controlling styrene exposures to employees during preparation and installation of the liners. Styrene is classified as a probable carcinogen and has been associated with adverse health outcomes in exposed workers, including but not limited to hearing loss, balance and concentration problems, tiredness, and altered vision. Inhalation of styrene has also been associated with the development and worsening of respiratory illnesses.

Workplace

We assessed multiple workplaces during this evaluation. For the wet-out facility, four employees were working inside one facility where the resins were mixed and combined with the liners prior to shipment to the installation sites. An administrative building was within walking distance of the wet-out facility but was not assessed during our site visit. For installations, the workplaces were outside at seven installation sites where employees repaired underground sewer and storm drain lines (pipes) using liners containing resin cured with steam or hot water. Six to eight employees were present at each installation site.

The following lists are brief process descriptions for the preparation of liners and installation of liners using hot water or steam curing.

CIPP liner preparation at the wet-out facility

- Liner laid out on pinch roller assembly.
- Catalyst mixed with styrene and then combined with resin.
- Resin mixture injected at front end of the liner and squeezed through the liner using the pinch roller.
- Vacuum used to help distribute the resin throughout the liner.
- Liner sometimes manually manipulated to distribute the resin evenly throughout the liner.
- Finished liner containing resin folded and placed onto a refrigerated truck.

CIPP liner installation

- Liner transported to the job site on refrigerated truck to reduce unwanted curing.
- Damaged pipe scoped using closed-circuit television (CCTV), and pipe cleaned with high-pressure water (jet-cleaning).
- Employees positioned liner above upstream manhole and prepared for inversion.

- Liner inverted through damaged section of pipe using compressed air or water pressure, which also kept the liner pressed against the inner walls of the pipe.
- Liner cured in place using heat from steam or near-boiling water. The temperature required to cure the liner depended on the catalyst used.
- Employees entered upstream and downstream manholes to manually cut away excess sections of cured liner. During steam-cured installations, employees sometimes cut away excess sections of the cured liner outside the manhole.
- Cured liner scoped by CCTV truck operator to ensure successful installation.
- Laterals remotely cut into cured liner using a robotic cutting tool, if necessary.

The water-cured CIPP process installations were sub-contracted to the company for the Mississippi Department of Transportation (MDOT) to rehabilitate storm drains on a highway. The steam-cured CIPP process installations were used to repair smaller, 8-inch diameter residential waste water pipes, and the water-cured CIPP process was used to repair 24-inch diameter non-residential waste water pipes. The company reported the health and safety of employees was their number one priority and wanted to proactively protect their employees by requesting that NIOSH assess workers' exposure to styrene.

To learn more about the workplace, go to Section A in the Supporting Technical Information

Our Approach

We visited the wet-out facility and water- and steam-cured CIPP installation sites on one occasion for each process to learn more about how the work was conducted and assess employee exposures to styrene and other volatile organic compounds (VOCs). We conducted opening and closing meetings with employees and management to discuss NIOSH, why we were there, and what to expect. Employees at the company were not represented by unions. At the opening meetings, we also collected employees' contact information if they wanted to receive their personal sampling results. At the closing meetings, we provided immediate feedback to employees and management on observations during the visit and opportunities for improvement. We shared preliminary results with the company by phone as soon as they were available after each site visit.

The following is a list of what we did during our site visits:

- We observed the work process, including tasks and activities conducted by the employees, to better understand the process and the risk factors for exposure and emissions. We also observed the use of personal protective equipment (PPE).
- We assessed exposures and emissions of styrene and other VOCs during preparation and installation of CIPP liners to understand how much and where these were occurring to determine if control measures were needed.

- We collected air samples from some employees' breathing zones during specific tasks at the CIPP installation sites and the wet-out facility and during the workday (full-shift) at the wet-out facility to measure personal exposures to styrene.
- We measured process emissions at various area locations.
- We measured personal exposures to and area process emissions of total volatile organic compounds (TVOCs).
- We collected bulk and cured process materials during surveys to measure styrene emission rates.

- We collected safety data sheets for process ingredients during the site visits to identify hazardous ingredients and confirm that adequate control measures, including PPE, were used.

To learn more about our methods, go to Section B in the Supporting Technical Information

Our Key Findings

Company took a proactive approach to employee safety and health

- The company submitted a health hazard evaluation request to assess whether styrene exposures to employees were concerning.
- The company was receptive to initial recommendations aimed at reducing styrene exposure to employees.
- The company was vigilant about traffic safety on a busy highway during CIPP installations.

Employees did not always follow permit-required confined space entry protocols

- We did not observe continuous monitoring of toxic gases before and during entry into a confined space.
- We observed employees who did not tie off before entering storm drains. We observed employees wearing a harness attached to a rope. The rope was not always attached to a winch on the tripod. In the event of an emergency, the top man would have to pull the worker out of the hole.
- We observed attendant employees break contact with the employee in the hole to get tools or help somewhere else on the site for brief periods of time.
- Not all confined spaces were permit-required confined spaces. Some manholes/access grates were not deep enough to require the employee to be tied off.

Employees were exposed to styrene emissions from cured liner and other process materials

- One employee's exposure to styrene during steam "pre-cure" was 105.5 parts per million (ppm) and exceeded the NIOSH short-term exposure limit (STEL) for styrene of 100 ppm and the American Conference of Governmental Industrial Hygienists (ACGIH) STEL of 20 ppm.

- One employee's exposure to styrene during "inversion" tasks was 33.6 ppm, which exceeded the ACGIH STEL of 20 ppm.
- One employee's exposure while checking thermocouples during steam-cured cooldown reached an elevated concentration of 1,125 ppm TVOCs (this value was adjusted for styrene based on a response factor provided by the instrument manufacturer).
- The highest styrene exposures occurred when employees were near cured liner or wet (uncured) liner. For steam, these high exposure tasks were during "pre-cure", "inversion", and "cutting the cured liner". For water, the only high exposures were during "cutting the cured liner."
- Styrene air concentrations downwind of the process were higher than upwind.

Worksite conditions and unexpected process difficulties increased employee exposure to the wet liner.

- Employees entered the refrigerated truck to place or remove liners containing resin and styrene, or to cool down during hot temperatures.
- One employee placed their torso into a cured liner section to remove the tie back.
- When the liner did not make the turn into a degraded pipe, employees manually maneuvered and used lift equipment to assist the transition of the liner into the host pipe. We note the wet liner still emits styrene even though it has a polyethylene outer lining.

To learn more about our results, go to Section B in the Supporting Technical Information

Our Recommendations

The Occupational Safety and Health Act requires employers to provide a safe workplace.

Benefits of Improving Workplace Health and Safety:

↑ Improved worker health and well-being	↑ Improved image and reputation
↑ Better workplace morale	↑ Better products, processes, and services
↑ Better employee recruiting and retention	↑ Could increase overall cost savings

The recommendations below are based on the findings of our evaluation. The company was receptive to these recommendations. The company reported a "safety first" mentality to protecting worker health, and this culture was observed during our investigation. For each recommendation, we list a series of actions you can take to address the issue at your workplace. The actions at the beginning of each list are preferable to the ones listed later. The list order is based on a well-accepted approach called the "hierarchy of controls." The hierarchy of controls groups actions by their likely effectiveness in reducing or removing hazards. In most cases, the preferred approach is to eliminate hazardous materials or processes and install engineering controls to reduce exposure or shield employees. Until such controls are in place, or if they are not effective or feasible, administrative measures and personal protective equipment might be needed. Read more about the hierarchy of controls: https://www.cdc.gov/niosh/topics/hierarchy/.

We encourage the company to use a health and safety committee to discuss our recommendations and develop an action plan. Both employee representatives and management representatives should be included on the committee. Helpful guidance can be found in "Recommended Practices for Safety and Health Programs": https://www.osha.gov/shpguidelines/index.html.

Recommendation 1: Reduce employee exposure to styrene and other process emissions

Why? Styrene is emitted into the air during preparation of the liner at the wet-out facility and during curing of the liner with steam and hot water. Controlling styrene emissions at the source is one of the most effective control strategies. You can remove or reduce styrene emissions by using local exhaust ventilation or dilution ventilation.

We measured high employee exposures to styrene during cutting the cured liner. Depending on work site conditions, styrene emitted into the air while cutting the cured liner could create a safety hazard and unnecessarily expose employees to high styrene concentrations for a short period of time. In 2017, an employee died at a CIPP installation site in Illinois because the employee entered a liner section they thought was cured. That employee got stuck and became incapacitated. These types of work-related deaths are preventable. Styrene and styrene-adjusted TVOCs (as measured by real-time photoionization detectors) air concentrations should not exceed the OSHA ceiling limit of 200 ppm and should be below the NIOSH immediately dangerous to life or health limit of 700 ppm.

We measured an employee's exposure to styrene in excess of the NIOSH short-term exposure limit for styrene of 100 ppm and a peak exposure to TVOCs of 1,125 ppm. Exposures to styrene and other process emissions could be reduced by implementing recommendations outlined here to reduce employee exposure to styrene and other process emissions.

How? At your workplace, we recommend these specific actions:

Substitute process ingredients for ones that do not contain styrene or have less styrene

- Investigate the use of process ingredients that do not have styrene or have less styrene.

Continuously operate ventilation blower fans before and during entry to access holes after curing

- Ventilate access holes after curing and before the employee enters the hole to cut the cured liner to reduce the styrene air concentration in the hole. Also, check real-time stryene air concentrations before the employee enters the hole to make sure it is safe to enter (less than 200 ppm/if feasible, less than 100 ppm/if 15 minutes or more, less than 50 ppm).
- After curing, continuously ventilate access holes and monitor confined space atmosphere including TVOC air concentratons while the employee is in the hole.
- If feasible, flush the cured liner with forced air to decrease the styrene concentration before entering the confined space.

Continuously operate ventilation wall fans at wet-out facility during working hours to reduce styrene air concentrations

- Ventilate wet-out facility during the work day while employees are present in the production space and the liner wet-out process is occurring to reduce the styrene air concentrations from process emissions.

Ventilate the reefer truck at wet-out facility and at liner installation sites

- Use ventilation to dilute air in refrigerated truck:
  - While loading the truck with liner at the wet-out facility, and
  - Before entering the truck to remove the liner at CIPP installation site, and
  - Any time an employee needs to enter the refrigerated truck when uncured or cured liner is being stored in the truck.
- Ensure VOC air concentrations are safe in the truck before entry (less than 200 ppm/if feasible, less than 100 ppm/if 15 minutes or more, less than 50 ppm).

Educate employees on the dangers of placing head or torso into pipe with freshly cured liner

- Warn employees about safety and health concerns related to placing their head or torso into pipe with freshly cured liner. Employees might get stuck in uncured liner if curing is not complete. Employees might be exposed to high concentrations of styrene immediately after curing.

Close or cover containers of process ingredients to reduce emissions at wet-out facility

- Close container lids or cover open containers of process ingredients when not in use to reduce emissions at wet-out facility.

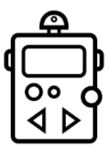
Minimize the amount of time the employee interacts with cured liner, liner that is curing, or process materials

- Employees' exposure to hazardous process emissions can be reduced by limiting the amount of time spent around material that emits styrene or other VOCs.

Recommendation 2: Monitor employee exposure to styrene during short-term tasks

Why? We measured one employee exposure to styrene that exceeded the NIOSH recommended short-term exposure limit of 100 ppm during steam "pre-cure", where the process temperature needed to activate curing had not been reached. We encourage you to continue to periodically monitor employee exposures for short durations when they work near or handle process materials. Additionally, changes in process emissions and potential employee exposures can be caused by different environmental and work conditions on site, changes to the process or process materials, different employee behaviors, and use of source control measures like ventilation. Additional consideration should be given to monitoring employee exposures especially after process changes, material changes, or changes to environmental and work conditions.

How? At your workplace, we recommend these specific actions:



Conduct personal sampling in employee's breathing zone for short duration tasks that require close interaction with cured or uncured liner process materials

- Use sorbent tube air sampling (OSHA method Org-89) to monitor employee exposures to styrene for short duration task lasting for more than one minute.
- Use evacuated canister air sampling (NMAM 3900) or length of stain indicator tubes to monitor employee exposures to styrene for short duration tasks lasting for less than one minute.
- Additional information for air sampling methods (OSHA method Org-89 and NMAM 3900) can be found in the Supporting Technical Information on page B-5 of this report.
- If styrene exposures exceed occupational exposure limits after ventilation, employees will need respiratory protection equipped with organic vapor cartridges as part of a comprehensive respiratory protection program that meets the requirements of OSHA's Respiratory Protection standard (29 CFR 1910.134) and includes medical evaluations, fit testing, maintenance, and training. Some states have applicable Federal OSHA-approved State plans.

Recommendation 3: Continue to educate employees on safe work practices for confined space entry according to established company protocols

Why? A confined space is defined as a space large enough to enter, difficult to exit, and not designed for continuous occupancy. A permit-required confined space is defined as a confined space that has or can develop a hazardous atmosphere, has material that can engulf a person, has a configuration that can trap or cause asphyxiation of a person, or contains any other serious safety and health hazards. Work-related injuries and deaths during confined space entry are preventable. Unsafe air concentrations of styrene might develop in the manhole or storm drain access hole because of the amount of styrene emitted into this small space during the process.

We observed that employees did not always follow confined space entry protocols. Although confined space entry was not the focus of this evaluation, this health and safety issue should be addressed.

How? At your workplace, we recommend these specific actions:

Encourage employees to follow established company safety procedures to protect employees during confined space entry.

- Monitor the confined space atmosphere in the manhole/access point hole for styrene in addition to using a 4-gas meter to monitor oxygen, carbon monoxide, hydrogen sulfide, and the lower explosive limit before and during entry to ensure the atmosphere is safe for occupancy throughout the installation process.
- For styrene, real-time or instantaneous styrene air concentrations may be estimated using colorimetric gas detector tubes or a photoionization detector that measures total VOCs which can be adjusted based on response factors for styrene provided by the manufacturer. Do not enter the space until the concentration is below the OSHA ceiling limit of 200 ppm for styrene. If feasible, wait until the concentration is below 100 ppm. If the employee is expected to spend more than 15 minutes in the space, wait until the concentration is below 50 ppm, which is one-half the NIOSH short-term exposure limit.
- Begin continuous forced air ventilation to the access point holes using ambient air dilution to reduce styrene air concentration before entering to cut cured liner. Do not stop the forced air ventilation until the employee exits the confined space.
- Before entering the confined space, employees should tie off to a tripod with a winch that can assist and quickly pull up the employee should an unsafe condition arise.
- Always have a top man monitoring the employee in the hole. If the top man must break contact with the employee in the hole, make sure there is another person present to monitor the employee in the hole before leaving.

- Educate employees on the company's permit-required confined space program and ensure the program aligns with OSHA permit-required confined space entry regulations. For further guidance, see 29 CFR 1926.1200-1213 and this OSHA publication https://www.osha.gov/Publications/OSHA3825.pdf.

Recommendation 4: Continue to educate employees on the safety and health hazards associated with process ingredients

Why? We reviewed safety data sheets of process ingredients provided by the company. We found process ingredients that could be hazardous if employees are exposed to them in sufficient quantities including styrene, tetrohydrofuran, resins, and initiators. Initiators are chemicals or chemical mixtures that help the resin mixture begin to harden or cure. OSHA's Hazard Communication Standard, also known as the "Right to Know Law" [29 CFR 1910.1200] requires that employees are informed and trained on potential work hazards and associated safe practices, procedures, and protective measures.

How? At your workplace, we recommend these specific actions:

Ensure workers understand potential hazards in the workplace and how to protect themselves

- Conduct initial and periodic training with employees to share information on potential hazards from process ingredients, the actions the company is taking to protect employees from exposures, and how employees can protect themselves from exposure.
- Use process ingredients that are inhalational hazards such as styrene and other VOCs in well-ventilated areas.
- Supply employees with non-latex gloves (nitrile or Viton™ gloves) and remind them to wear them when working with the liner, resin, or other cured and uncured process materials that contain styrene and other chemicals.
- Storage areas and confined spaces should be adequately ventilated before entering.
- Employees should not eat, drink, or smoke in areas where process materials are used.
- Employees should wash their hands and face before eating.
- Wear hearing protection when indicated; we did not formally assess noise during our visits. A noise survey would be necessary to determine the need or level of hearing protection and inclusion in a hearing conservation program.

Recommendation 5: Implement a Smoking Cessation Program for Employees

Why? In workplaces with risk of occupational lung disease, prevention of smoking-related lung disease is important and makes the detection of work-related adverse effects easier.

The Centers for Disease Control and Prevention offers tools and resources for setting up smoking cessation programs at https://www.cdc.gov/tobacco/stateandcommunity/index.htm.

Supporting Technical Information

Evaluation of Exposures to Styrene during Cured-in-place Pipe Liner Preparation and during Pipe Repairs using Hot Water and Steam

HHE Report No. 2019-0080-3379
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Section A: Workplace Information

Wet-out Building

Size: 11,100 square feet (approximate)
Floors: One-story

Employee Information

of employees at time of evaluation: 4-8 employees depending on process
Length of shift: 8-10 hours depending on process
Union: No
Mean age: Not determined
Mean tenure at job: Not determined

History of Issue at Workplace

Request basis: Company expressed the desire to proactively protect employees by characterizing employees' exposure to styrene and implement recommendations to control process emissions, when appropriate.
Previous issues: None

Process Description

Cured-in-place Pipe Liner Preparation

The purpose of liner preparation is to impregnate a length of cured-in-place pipe (CIPP) liner with a liquid resin-catalyst mixture. Liner preparation took place inside a large rectangular warehouse fitted with four general exhaust fans and two large garage doors. During our sampling campaign, two of the four exhaust fans were broken. The two operational fans were run at the suggestion of the NIOSH staff members during second and third days of the visit. The resin-catalyst mixture was prepared by mixing styrene, resin, and catalyst using a resin-pump static mixer machine (Figure A1).

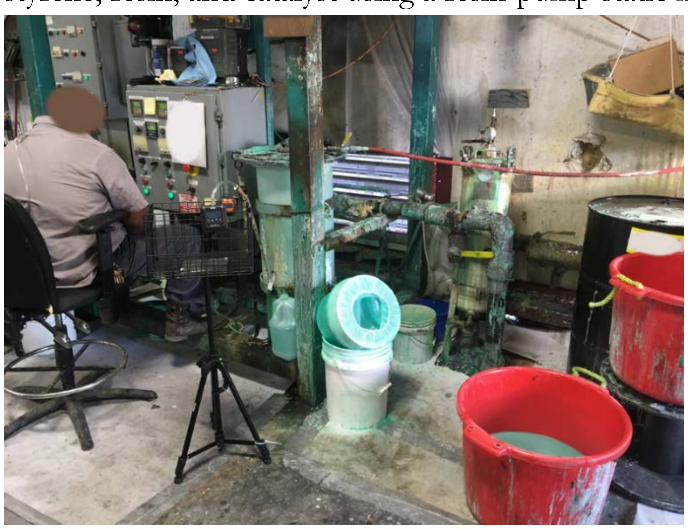


Figure A1. Employee sitting at controls of resin-pump static mixer station at wet-out facility. The red buckets contained styrene and catalyst. The white bucket with a filter on top was used to transfer styrene-catalyst mixture to the hopper of the resin-pump static mixer, located to the immediate right of the controls, December 2019. Photo by NIOSH.

Proportions of resin, catalyst, and styrene used in the mixture were dependent upon the length of liner to be "wetted." Employees laid out a dry length of liner along a roller assembly and pulled it through a pinch roller. The resin mixture was injected into the liner using the resin-pump static mixer and an injection port attached to the pulled-out front end of the liner. Employees attached vacuum lines to multiple points along the length of the liner on the roller assembly to remove excess air from the liner, facilitating the spread of the resin mixture throughout the inner section of the liner. Employees manually cut holes into sections of the liner to attach the vacuum lines. Before these sections of the liner could be impregnated with the resin-catalyst mixture, the holes were patched using a tetrahydrofuran-based adhesive. Employees maintained uniform spread of the resin mixture across the length of the liner. This was primarily accomplished by the pinch roller, but employees occasionally had to use hand tools or physically mount the liner on the roller assembly to spread the mixture using their body weight (Figure A2).

Figure A2. Employee at wet-out facility using body weight to spread resin mixture in liner and holding vacuum tube with right hand, December 2019. Photo by NIOSH.

For very long liners, the resin mixture was sometimes injected into multiple sections of the liner simultaneously. Once the liner was fully impregnated with the resin mixture, employees folded and situated these "wetted" sections into a refrigerated semi-trailer (reefer truck). The final section of the liner was not impregnated with the mixture and marked as "dry" to allow the field installation teams to attach the liner to equipment used to invert the liner into a damaged underground pipe. The resin-pump static mixture was cleaned by flushing thoroughly with acetone. Any excess resin, catalyst, or acetone was placed into a waste bin located outside the rear door of the facility. Employees typically but not always wore nitrile or latex gloves and safety goggles during the wet-out process (Figure A3).

Figure A3. Employee repairing hole in completed liner at wet-out facility, December 2019. Photo by NIOSH.

CIPP Installation: General Process Overview

Refrigerated trucks transported resin-impregnated felt liners to job sites to reduce unwanted curing. Equipment on the job site included a closed-circuit television (CCTV) camera truck, jetter truck, a refrigerated truck, a combination inversion/boiler truck, and a one-ton general purpose truck with an air compressor for hand-held power tools. Installation crews consisted of five to six general laborers, a CCTV truck operator, jetter truck operator, combination inversion and boiler truck operator, foreman, and superintendent. On-site work was directed by the foreman and supervised by the superintendent. Upon arriving on site, employees scoped the damaged pipe with a CCTV robot. The pipe was cleaned with pressurized water using a device called a jetter. Employees positioned the liner above the upstream manhole in preparation for inverting the liner through the damaged pipe. The liner was inverted through the pipe using pressure from compressed air or water, which also held the liner tight against the walls of the damaged pipe. Once inverted through the pipe, the liner was cured in-place using heat from steam or hot water. The liner was cured at a proprietary temperature for a predetermined duration depending upon the length, thickness, and diameter of the liner. One general laborer was tasked with installing thermocouples, wherever it was possible to access the liner and monitor the temperature of the liner during curing. After curing, the liner was cooled using air or water. Once the liner was cool enough to handle, employees entered the upstream and downstream manholes and manually cut away excess sections of cured liner with power tools. Sometimes, a blower ventilator fan was used to provide dilution ventilation to the manholes while employees were inside. Finally, the newly cured liner was scoped via CCTV to ensure successful installation, and a remotely controlled robot cut out lateral connections, if necessary. Employees wore hard hats, safety goggles, disposable gloves, long pants, high visibility gear, and hearing protection. When cutting the cured liner, employees also wore disposable coveralls. On-site specifics for liner installation and for the water and steam curing process are described in the respective sections below.

Water Cured-in-place Pipe

The water-cured liner installation process is typically used to repair host pipes 24 inches in diameter or larger. The installations took place between the hours of 6:00 p.m. and 6:00 a.m. with around an hour at the beginning and end of the repairs to close or open one lane of traffic in each direction. Most installations were conducted in 10-hour shifts. Once on site, the jetter truck operator cleaned the host pipes with high pressure water prior to liner installation. The CCTV truck operator collected and monitored video of the host pipes during the initial cleaning. General laborers then unloaded the upstream, felt end of the cold liner from the refrigerated truck and secured it to a large hydraulic lift on the inversion/boiler truck (Figure A4).

Figure A4. Employees removing liner from refrigerated truck during water-cured CIPP installation, March 2019. Photo by NIOSH.

Concurrently, other general laborers attached a long, thin line called a "lay flat" to the downstream end of the liner. The lay flat line was used to recirculate water from the liner back to the boiler truck during liner inversion and curing. Once the lay flat was in place with the liner attached to the lift, the inversion/boiler truck operator inverted the liner through itself and into the host pipe using water pressure. The liner inversion process typically required general laborers to manually manipulate the liner as it was inverted into the host pipe (Figure A5).

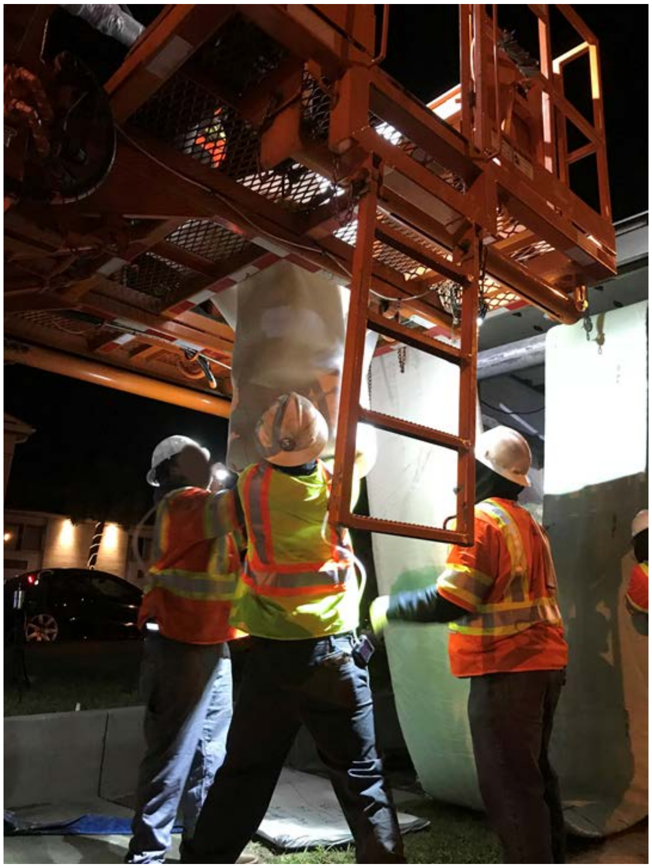


Figure A5. Employees pulling dry liner through itself under lift on boiler truck during water-cured CIPP installation, March 2019. Photo by NIOSH.

Once liner inversion was complete, the inversion/boiler truck operator introduced hot water to the recirculating liner and lay flat system to begin the curing process. The duration of curing was based on the length, thickness, and diameter of the liner but varied depending on site conditions such as temperature and the presence of standing water in the pipes. During the curing process, one employee monitored the temperature at positions along the length of the liner using thermocouples, while the inversion/boiler truck operator monitored water temperature. Once the liner reached a predetermined temperature along its entire length, curing was deemed complete. The liner was then cooled down by recirculating cold water. Once the liner was cool enough to handle, employees on the upstream side began cutting and tearing the felt section of liner away from inversion/boiler truck lift. At the same time, an employee on the downstream side descended into the manhole and manually cut out excess cured liner with hand-held power tools (Figure A6).

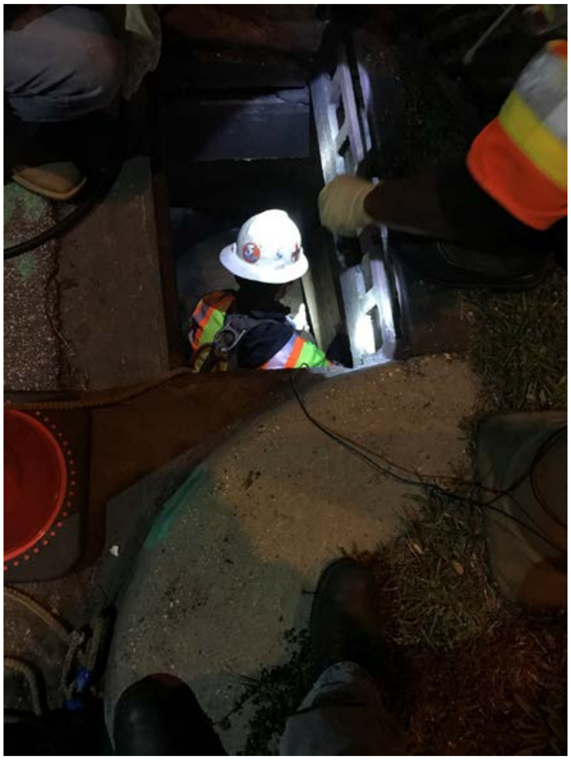


Figure A6. Employee cutting water-cured liner inside of access hole at CIPP installation, March 2019. Photo by NIOSH.

After completing the tear down of the felt section of liner from the inversion/boiler truck lift, an employee descended into the upstream manhole to also cut out excess cured liner with hand-held power tools. Employees wore hard hats, safety goggles, disposable gloves, long pants, high visibility gear, and hearing protection. When cutting the cured liner, employees also wore disposable coveralls.

Steam Cured-in-place Pipe

The steam-cured liner installation process is typically used to repair host pipes 24 inches in diameter or smaller. The installations took place between the hours of 7:00 a.m and 7:00 p.m. with most conducted in 10-hour shifts. Once onsite, the jetter truck operator cleaned the host pipes with high pressure water prior to liner installation. The CCTV truck operator collected and monitored video of the host pipes during the initial cleaning. After the host pipe had been cleaned and scoped, the refrigerated truck containing the cold liner, the boiler truck, large air compressor, and inversion machine called a "shooter" were positioned near the upstream manhole. The shooter was positioned directly above the upstream manhole with the refrigerated truck as close as possible. Then general laborers entered the refrigerated truck bed to manually remove the cold liner and attach it to the shooter using a manifold called a "can." Occasionally, the upstream manhole was not close to an access road, requiring the employees to manually drag the entire length of the liner from the refrigerated truck to the manhole. With the liner in place, employees attached an air hose from the large air compressor to the shooter. The combination inversion-machine and boiler truck operator then used levers on the shooter to introduce compressed air in bursts into the liner to invert it through itself and into the host pipe. During this process, general laborers were tasked with manually feeding the liner into the shooter. Occasionally, the inversion-machine operator would lubricate the liner by adding mineral oil or water to ease the liner movement through the host pipe. Once the liner reached the downstream manhole, inversion was complete. Compressed air was continually supplied to the liner to keep it inflated against the inner walls of the host pipe. On the downstream side, employees trimmed excess uncured liner and attached an exhaust line to the end of the liner using metal clamps. The exhaust line terminated in an automotive muffler to reduce the level of sound generated during the curing process. With the exhaust line attached, employees on the upstream side removed the shooter, leaving the liner attached to the can and compressed air line with the assembly hanging from a tripod directly above the upstream manhole. The boiler truck operator then introduced steam into the liner to begin curing. Once curing was completed, the steam line at the upstream manhole was replaced with a compressed air line to cool the liner. When the liner was cool enough to handle, one employee at each manhole used powered hand tools to cut away excess sections of cured liner. Employees either entered or reached into the manhole to cut the cured liner depending on the size of the manhole (Figures A7–A9). Employees wore hard hats, safety goggles, disposable gloves, long pants, high visibility gear, and hearing protection. When cutting the cured liner, employees also wore disposable coveralls.

Figure A7. Employee cutting steam-cured liner partially inside of manhole at CIPP installation, June 2019. Photo by NIOSH.

Figure A8. Employee cutting excess section of steam-cured liner outside of manhole at CIPP installation, June 2019. Photo by NIOSH.

Figure A9. Employee cutting steam-cured liner fully inside of manhole at CIPP installation, June 2019. Photo by NIOSH.

Section B: Methods, Results, and Discussion

Methods: Observations of Work Processes, Practices, Conditions, and Personal Protective Equipment

We observed the work process, including tasks and activities conducted by employees and their use of personal protective equipment (PPE). We visited the wet-out facility over three days in December 2019, water-cured CIPP installation sites over four days in March 2019, and steam-cured CIPP sites over three days in June 2019.

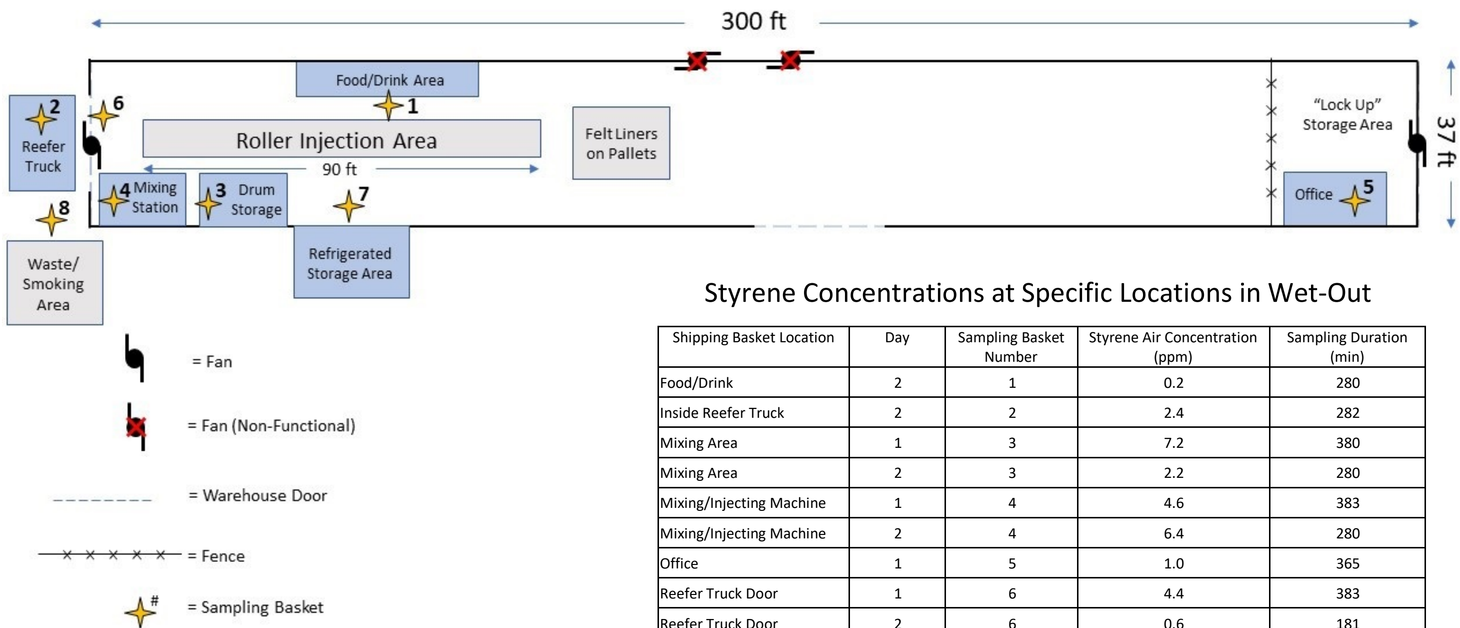
Results: Observations of Work Processes, Practices, Conditions, and Personal Protective Equipment

Facility Layout, Site Information, and Work Practices

Wet-out Facility

- General information
  - Administrative offices were situated in another building at the same complex as the wet-out facility building.
  - The designated eating and drinking area was in the same wet-out facility building without any separation from the process area.
  - The foreman had an enclosed office that lacked ventilation. The office was located on the opposite end of the facility from the process (Figure B1).
  - The duration of the process and amount of the materials used to wet the liner depended on the dimension of the liner. Specific proportions of styrene, catalysts, and resin were mixed to produce a desired amount of resin mixture to infuse in the liner.
  - Excess resin-catalyst mixture was drained from the liner by cutting holes in the liner along its length. Once drained, holes were manually sewn shut and covered with a patch using an adhesive containing tetrahydrofuran.
  - Excess resin, catalyst, and acetone was placed in the waste disposal area outside close to the rear door of the facility, which was also the smoking area.
  - Employees did not always wear gloves to protect against dermal exposure to chemical process ingredients.
  - During liner rolling, two employees were present inside the refrigerated truck to fold and place the finished liner containing resin.
  - All the containers used to prepare resin-catalyst mixture were cleaned using acetone.
  - Four employees, including a foreman and three general laborers, were present for sampling on both days. The four employees and vice president of the company attended the opening meeting on the second day.
- On the first day at the facility, we conducted a walkthrough survey of the facility, set up equipment for sampling on the next day, met with employees, and learned about the wet-out process.

  - See Figure B1 for a diagram of the liner “wet-out” facility showing building dimensions, work areas, ventilation fans, and air concentrations of styrene at area sampling locations.
  - No samples were collected on the first day.
- On the second day, the facility did not have wall ventilation fans operating or the large overhead door open.
  - Two pounds of styrene were used to prepare the resin-catalyst mixture for the liner.
  - Employees produced a liner that was 43-linear feet long with an 18-inch diameter and 9-millimeter (mm) thickness.
- On the third day, ventilation fans were turned on and outside doors were opened based on our recommendation.
  - 106 pounds of styrene were used to prepare the resin-catalyst mixture for the liner.
  - Employees produced a liner that was 538-linear feet long with a 23.25-inch diameter and 11-mm thickness.
  -



Styrene Concentrations at Specific Locations in Wet-Out

Shipping Basket Location	Day	Sampling Basket Number	Styrene Air Concentration (ppm)	Sampling Duration (min)
Food/Drink	2	1	0.2	280
Inside Reefer Truck	2	2	2.4	282
Mixing Area	1	3	7.2	380
Mixing Area	2	3	2.2	280
Mixing/Injecting Machine	1	4	4.6	383
Mixing/Injecting Machine	2	4	6.4	280
Office	1	5	1.0	365
Reefer Truck Door	1	6	4.4	383
Reefer Truck Door	2	6	0.6	181
Refrigerated Storage Area	1	7	1.2	381
Refrigerated Storage Area	2	7	0.2	280
Waste/Smoking Area	1	8	1.9	446

Figure B1. Diagram of liner wet-out facility showing building dimensions, work areas, ventilation fans, and air concentrations of styrene at area sampling locations, December 2019.

Steam-cured CIPP Installation Sites

- General Information
  - One steam-cured liner was installed each day. The duration of a steam-cured installation depended on the length of the liner and ease of access to the damaged pipe at each location.
  - Seven workers, including a foreman, were present at steam-cured installation sites each day.

- There were five work trucks on the installation site, including a reefer truck, a water (jetter) truck, a boiler truck, a CCTV truck, and a heavy pickup with an air compressor for cutting tools. An inversion machine called the "shooter" was positioned directly above the inlet manhole to facilitate inverting the liner through the damaged pipe using air pressure.
- Inversion of the liner through the damaged pipe was a loud process and not all employees were wearing hearing protection.
- After inversion, the precure process began, during which the liner was inflated and preliminarily heated using the air compressor. When a certain temperature threshold was reached, the boiler was turned on to add more heat to approximately 140 degrees Fahrenheit, at which point the catalyst helps initiate polymerization and hardening of the resin.
- Many processes during steam-cured installation were conducted manually without gloves and contributed to employees' dermal exposure to styrene.
- We observed employees entering the manhole/access grates to cut excess liner. Employees did not test the atmosphere prior to entering the confined space of the manhole. Entry into the manhole to cut the cured liner was sometimes necessary depending on the depth of the manhole. We observed some employees coughing after exposure to process emissions when they entered the manhole to place thermocouples before curing began.
- All steam-cured liners had diameters of 8 inches. Additional liner and site information and environmental conditions are presented in Table 1.

- Day 1 installation occurred between a residential backyard and golf course. The inlet manhole was approximately 5 feet deep. Employees cut cured liner in two minutes on inlet side.
- Day 2 installation occurred between backyards in a residential area while it was raining. The inlet manhole was approximately 10 feet deep, which allowed an employee to enter the manhole to cut the cured liner. Mineral oil was used as a lubricant to facilitate liner entry into the degraded pipe because it was raining during inversion. Employees lifted liner above their heads to feed into the inversion machine (shooter).
- Day 3 installation occurred in a commercial area with direct on-street access. The outlet manhole was approximately 3 feet deep. A second site installation was attempted but stopped because of incorrect liner dimensions. No air samples were collected from the second site.

Water-cured CIPP Installation Sites

- The company was subcontracted by a general contractor to perform storm drain repairs for Mississippi Department of Transportation (MDOT).
- MDOT inspectors were present each day to monitor and facilitate work.
- General observations for all sites and days included:
  - One water-cured liner was installed each day. The duration of a water-cured installation depended on the length of the liner, ease of access to the damaged pipe at each location, and the ease with which the liner made the turn into the damaged pipe in the manhole.

- Installations occurred on a busy four-lane coastal highway with a median with two lanes in each direction. The coastal highway had an occasional turning lane, and some areas with a pull off for parking on the coast side.
- A public restroom was available at one installation site near pull off area and at local businesses.
- Process water was obtained from a company water truck or fire hydrants depending on accessibility.
- There were five work trucks at the installation sites including a reefer, water (jetter), boiler/lift, TV truck, and heavy pickup truck with an air compressor for cutting tools.
- Seven workers were present on the first day including a foreman, a superintendent, and five general laborers. Eight workers, including a foreman, a superintendent, and six general laborers were present on Days 2–4.
- The liner was 24 inches in diameter and 9 mm thick but variable in length depending on the day. The liner entered the storm drain through manholes with a diameter of 2.0 feet or access grates with dimensions of 3.5 feet by 4.5 feet, with a variable depth that was approximately 6 feet to 7 feet.
- Water pressure from raising the liner 20 feet while adding water to the liner was used to force the liner into the manhole and through sections of degraded pipe.
- Curing was conducted for 1 hour to 1.5 hours. The curing was checked with thermocouples added at each manhole/access grate along the liner. Small rocks were also thrown at the cured liner to check for a hard sound indicating that the liner was starting to cure. At the end of curing, an employee would throw a heavy metal bar with a pointed end that was attached to a rope at the cured liner while listening for a "crack" to indicate the cure was complete. The metal bar was also used to release water from the liner at the end of curing.
- We observed employees entering the manhole/access grates to cut the excess liner. Employees did not always adhere to company safety protocols for confined space entry. Some employees wore a harness with a rope attached that was not properly secured to a tripod winch, while other employees entered the manhole/access grates with no harness or rope. Sometimes, the tripod winch was used to hoist large pieces of liner out of the manhole, while the employee was still in the hole.
- Employees cut the excess cured liner using pneumatic- or electrical-powered chainsaws and angle grinders with a cutting blade. The bottom of cured liner in access grates between inlet and outlet was occasionally left uncut, but inlet and outlet ends were completely cut and trimmed. Dust generated during cutting was noticeably less when water was present on the bottom cuts than when cutting the top or sides of the liners.
- Blower ventilation fans (8-inch diameter, 615 cubic feet per minute of free air) were used frequently, but not always, to reduce styrene vapors using ambient dilution air during cutting and grinding.
- Additional site information and environmental conditions are presented in Table C1.

- Day 1 installation occurred between the inlet located at the outside of the pull-off area toward the coast and the outlet located at the inside of the turning lane at the median between the two inside lanes of opposing traffic. Two access grates were located between the inlet and the outlet. During pre-cure, rainwater that accumulated in the storm drain had to be pumped out while the water temperature was approaching its set point. This environmental issue slowed down the process and increased the time required to reach an adequate cure temperature.

- Day 2 installation occurred between the inlet access grate located inland and the outlet manhole located on the boardwalk off the access road by the coast.
- Day 3 installation occurred between the inlet access grate located inland and the outlet access grate located on the outside of the highway by the coast. A problem was encountered with getting the liner to make the turn during inversion. Employees had to lower and raise the lift and remove/add water to get the liner to make the turn.
- Day 4 installation occurred between the inlet located on the outside of the turning lane to enter the access road toward the coast and the outlet located at the inside of the median inland. Wooden boards were placed at the outlet to stop the liner from continuing through the downstream storm drain.

Personal Protective Equipment

At CIPP installations, we observed employees and MDOT personnel onsite wearing long pants, hardhats, steel-toed shoes, reflective vests, hearing protection, and safety glasses. Hearing protection was not always used. When cutting, most employees wore chemically resistant coveralls (Lakeland Polyethylene-coated ChemMax®1 suits with hoods) and latex gloves. At the wet-out facility, we observed employees wearing safety glasses and occasionally wearing latex gloves. Respiratory protection was not required or worn at any process location.

Smoking

We noticed that some employees smoked cigarettes, which can contribute to lung disease.

Methods: Exposure Assessment

We assessed exposures and emissions of styrene and other volatile organic compounds (VOCs) during preparation and installation of CIPP liners. We collected air samples from some employees' breathing zones during specific tasks at the CIPP installation sites and the wet-out facility and during the full workday at the wet-out facility. Breathing zone air samples were collected to measure task-based and full-shift personal exposures to styrene using sorbent tubes and OSHA method ORG-89 [OSHA 1991]. For sorbent tubes, coconut shell charcoal tubes impregnated with t-butylcatechol (Part No. 226-73, SKC, Inc.) were attached to a personal air sampling pump (SKC Pocket Pump) flowing at 50 milliliters per minute. No adjustments were made to the full-shift exposures to account for time not sampled. The sampling strategy for task-based samples was not designed specifically for comparison to exposure limits, but when the samples were collected for 15 minutes, we directly compared them to applicable short-term exposure limits to determine whether occupational exposure limits had been exceeded.

Sorbent tube samples were analyzed for styrene in accordance with OSHA method ORG-89 [OSHA 1991]. A limit of detection is the lowest mass that can be measured by an analytical method. The limit of detection was 0.9 microgram (µg) per sample for styrene, corresponding to 0.3 parts per million (ppm) for a sample duration of 15 minutes. Limit of quantitation was 3.0 µg per sample for styrene, corresponding to 0.9 ppm for a sample duration of 15 minutes. Limits of detection expressed as air concentration (in ppm) will vary depending on the sampling volume. Data were log-transformed before further analyses because environmental data are often log-normally distributed. We summarized styrene air concentration estimates using geometric means and geometric standard deviation by process and either task or location. We conducted a statistical comparison among processes using an ANOVA with Tukey's post-hoc analysis on log-transformed personal task exposures to styrene with a significance level of 0.05.

We measured process emissions at various area locations using the same sorbent tube method described above and instantaneous evacuated canisters (NMAM 3900) [NIOSH 2018]. The evacuated canister sampling setup consisted of a 450-mL evacuated canister equipped with an instantaneous flow controller designed for a short sampling duration of less than 30 seconds. The limits of detection were 0.0003 ppm for acetone and 0.0005 ppm for styrene based on a 1.5 times dilution but will vary depending on sample pressure and injection volume. The limits of quantitation were 0.0010 ppm for acetone and 0.0018 ppm for styrene. We measured real-time personal exposures to and area process emissions of total volatile organic compounds using photoionization detectors with a 10.6 eV lamp (Tiger Cub for personal samples and Tiger for area samples; resolution 0.001 ppm). We collected near real-time air concentrations of styrene using a fourier-transform infrared spectrometer (Model DX4040, Gasmet Technologies) at the water-cured installation but the instrument failed. We did not use the spectrometer during the two additional surveys, and no spectrometer results are presented here. We collected bulk and cured process materials during surveys to measure styrene emission rates using a micro-chamber thermal extractor (Markes International, Inc., Sacramento, CA) and thermal desorption tubes (Universal tubes with inert coating, Markes International, Inc.).

Personal full-shift air sampling for styrene using sorbent tubes at the wet-out facility

We collected four personal full-shift samples using sorbent tubes and OSHA method ORG-89 for styrene on the second day of our survey at the wet-out facility.

Area full-shift air sampling for styrene using sorbent tubes at the wet-out facility

We collected 12 area full-shift air samples using sorbent tubes and OSHA method ORG-89 for styrene on the second and third day of our survey at the wet-out facility.

Personal task air sampling for styrene using sorbent tubes during all processes

We collected a 109 personal task samples using sorbent tubes and OSHA method ORG-89 for styrene during all process assessments. Nine samples were collected at the wet-out facility on the third day. Over three days, 46 samples were collected from steam-cured installations sites. Over four days, 54 samples were collected from the water-cured installation sites.

- To summarize data, we grouped tasks by primary task or combined tasks with similar exposure potential or proximity to the source. Some task groups included multiple types of tasks. "Assisting cutting cured liner" task included one sample where the employee also cut the cured liner; six samples (one water and five steam) where the employee assisted with tearing down the work site after liner installation had been completed, and two samples for water-curing where the employee was also supervising the installation. "Cutting cured liner" task included nine samples for steam-curing where the employee assisted with tearing down the worksite after liner installation. "Inversion" task samples were only collected during inversion of the liner. "Other tasks" included assisting or directly tearing down the lift. For water-curing, "pre-cure/cure/cooldown" task included three samples with only pre-cure occurring and six samples including all three tasks. For steam-curing, "pre-cure/cure/cooldown" task included one sample when only pre-cure and cure were occuring at the time and two samples when all three tasks were occurring.

Area air sampling for styrene using sorbent tubes upwind and downwind of source

We collected 127 area air samples for styrene using sorbent tubes and OSHA method ORG-89 upwind and downwind of emission source at the steam- and water-cured installation sites.

Area air sampling for styrene and acetone using instantaneous canisters at or around source

We collected 27 area task air samples for styrene and acetone upwind and downwind of source at wet-out facility and steam- and water-cured installation sites using instantaneous canisters and NMAM 3900 [NIOSH 2018].

Real-time personal and area monitoring for total volatile organic compounds using photoionization detectors

We measured 124 real-time personal and area monitoring of total volatile organic compounds (TVOCs) at wet-out facility and steam- and water-cured installation sites using photoionization detectors.

Styrene emission from cured liner and other process materials

We measured styrene emission rates from seven samples of bulk process material or cured liner including one sample of steam-cured liner, one sample of water-cured liner, and five samples of process materials from the wet-out facility. In the emission chamber, the temperature ranged from 22.9 degree Celsius (°C) to 25.6°C, and the humidity ranged from 36% to 47% relative humidity (RH).

Results: Exposure Assessment

Personal full-shift air sampling for styrene using sorbent tubes at the wet-out facility

All four personal full-shift air samples were well below the NIOSH REL of 50 ppm styrene. Personal full-shift samples had a geometric mean of 4.7 ppm styrene and geometric standard deviation of 1.3. The range of exposures to styrene was 3.4 ppm to 6.0 ppm collected over 355 minutes (5.9 hours) to 372 minutes (6.2 hours).

Area full-shift air sampling for styrene using sorbent tubes at the wet-out facility

Styrene concentrations in area full-shift air samples at the wet-out facility ranged from 0.2 ppm to 7.2 ppm (Figure B1). Sampling durations ranged from 280 minutes (4.7 hours) to 446 minutes (7.4 hours). The highest area air concentration of 7.2 ppm styrene was measured at the mixing area on the first day when wall ventilation fans were not operating. On the second day in the same location, we measured an area air concentration of 2.2 ppm styrene when wall ventilation fans were operating. In the refrigerated storage area, we also observed a reduction in air concentration from 1.2 ppm styrene on the first day to 0.2 ppm styrene on the second day.

Personal task air sampling for styrene using sorbent tubes during all processes

We collected 46 personal task samples for styrene during steam-cured CIPP installations (Table C2). Three of these samples were collected for 16 minutes, of which one employee exposure measured 105.5 ppm during a "pre-cure" task. During this sample, the employee was banding together the end of a liner and also entered the manhole to place a thermocouple. This sample was the highest measured exposure to styrene of all three industrial hygiene surveys and exceeded the NIOSH 15-minute short-term exposure limit (STEL) of 100 ppm styrene and the ACGIH STEL of 20 ppm. The other two personal task exposures for styrene were 33.6 ppm and 8.5 ppm, both collected during "inversion" tasks, and one was above the ACGIH STEL of 20 ppm The remaining 43 personal task exposures during steam-cured installations were sampled for durations shorter or longer than 15 minutes. All remaining exposures during steam-cured installations were below 43.4 ppm styrene, which was collected during an "inversion" task for a sample duration of 32 minutes.

The highest geometric mean for task samples collected during steam-cured installations occurred during "inversion" tasks (9.3 ppm styrene, maximum 43.4 ppm styrene) followed by "cutting cured liner" tasks (2.2 ppm styrene, maximum 29.6 ppm styrene). Of the 54 personal samples collected during water-cured CIPP installations, the highest geometric mean for task samples occurred during "cutting cured liner" tasks (19.2 ppm styrene; maximum 55.3 ppm styrene) followed by "assisting cutting cure liner" tasks (0.9 ppm styrene; maximum 7.2 ppm styrene). The geometric mean for task samples collected at the wet-out facility was 4.1 ppm styrene for "all tasks." The maximum styrene concentration of 12.5 ppm at the wet-out facility occurred when an employee was getting process ingredients from a refrigerated storage area for 18 minutes. The geometric mean for styrene concentrations measured during steam-cured processes was 23 times higher than for water-cured processes, indicating possible exposure differences in the process or increased dilution of ambient air during sampling of water-cured tasks. An ANOVA with Tukey's post-hoc analysis on log-transformed personal task measurements for styrene revealed a significant difference in mean exposures across processes with wet-out facility and steam ($p=0.69$) having higher exposures than water processes ($p<0.05$).

Task sampling durations for steam processes were generally shorter than water processes. For example, "cutting cured liner" tasks had a median duration of 19 minutes for steam-cured versus 89 minutes for water-cured. This difference in task sample durations was likely because of the liner dimensions and complexity of the installation sites. Additionally, "inversion" task sample durations for steam-cured processes was generally shorter than for water-cured processes (median 50 minutes versus 108 minutes).

Area air sampling for styrene using sorbent tubes upwind and downwind of source

We observed higher air concentrations for styrene downwind of the manhole/grate in most area samples (Table C3). As an example, we measured less than 0.04 ppm styrene upwind of an access grate and 1.5 ppm styrene downwind during cutting the cured liner at a water-cured liner installation site (Figure B2).

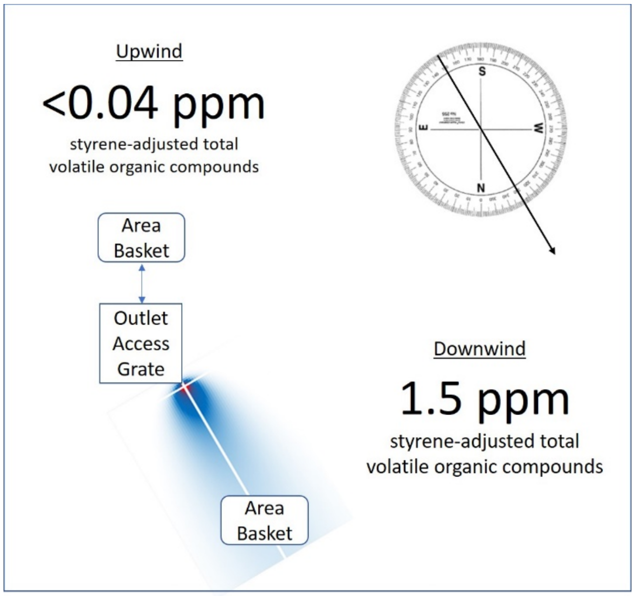


Figure B2. Representative diagram showing chemical plume (blue shading) of total volatile organic compounds (TVOC) downwind of access grate during water-cured CIPP installation, March 2019. TVOC air concentrations in parts-per-million (ppm) were adjusted for styrene using a response factor from the manufacturer. Low TVOC air concentrations measured upwind of access grate compared to high TVOC air concentrations measured downwind of access grate. Black line with arrow in compass depicts wind direction. Red center with blue outer regions and white cross hairs depicts chemical plume showing higher TVOC concentrations next to the access grate that get lower as the chemical emissions travel downwind or crosswind from the access grate.

For the steam-cured process, the geometric mean for styrene air concentration downwind of the outlet manhole/grate was 0.4 ppm (maximum 6.2 ppm), which was more than 0.2 ppm (maximum 3.3 ppm) upwind. For the water-cured process, the geometric mean for styrene air concentration downwind of the outlet manhole/grate was 0.7 ppm (maximum 13.6 ppm), which was higher than 0.2 ppm (maximum 0.3 ppm) upwind. The highest geometric mean for styrene air concentrations was 4.3 ppm (maximum 10.6 ppm) and occurred close to the face of the manhole/grate.

Area air sampling for styrene and acetone using instantaneous canisters at or around source

For source sampling using instantaneous canisters, we observed the highest air concentrations of styrene at the door of the reefer truck when the employee opened it (253.3 ppm, 215.9 ppm, and 135.3 ppm) during steam-cured process (Table C4). One sample collected at the door of the reefer truck during a steam-cured process measured 0.2 ppm styrene; this sample was likely an outlier and presumably sampled upwind of the truck door or before the air in the reefer truck had a chance to migrate out of the truck door. We did not collect source samples at the door of the reefer truck during water-cured processes. For area sampling, the highest air concentration was 35.9 ppm styrene on day 3 of water-cured process, upwind of the inlet during cutting the cured liner. The next highest air concentrations of styrene were 24.7 ppm and 23.4 ppm at the door to the refrigerated storage area of the wet-out facility. The highest air concentration for acetone was 42.5 ppm at the pinch roller during injection of liquid in the liner at the wet-out facility, followed by 37.3 ppm at breathing height in the refrigerated storage area and 35.6 ppm at breathing height in the mixing area of the wet-out facility.

Real-time personal and area monitoring for total volatile organic compounds using photoionization detectors

We performed real-time personal exposure and area monitoring of TVOCs using photoionization detectors (PID). The resultant concentrations were styrene-adjusted using the PID instrument manufacturer's styrene correction factor of 0.45. We collected 136 total samples at the wet-out facility and steam- and water-cured CIPP installation sites.

For real-time PID area monitoring during CIPP installations, styrene-adjusted TVOC concentrations were generally highest near the outlet manhole. The highest observed styrene-adjusted TVOC concentration of 142.3 ppm was measured just downwind of the face of the outlet manhole during a "pre-cure" task of a water-cured installation (Figure B3), in contrast to upwind of the inlet where styrene-adjusted TVOC air concentrations were low (<0.2 ppm).

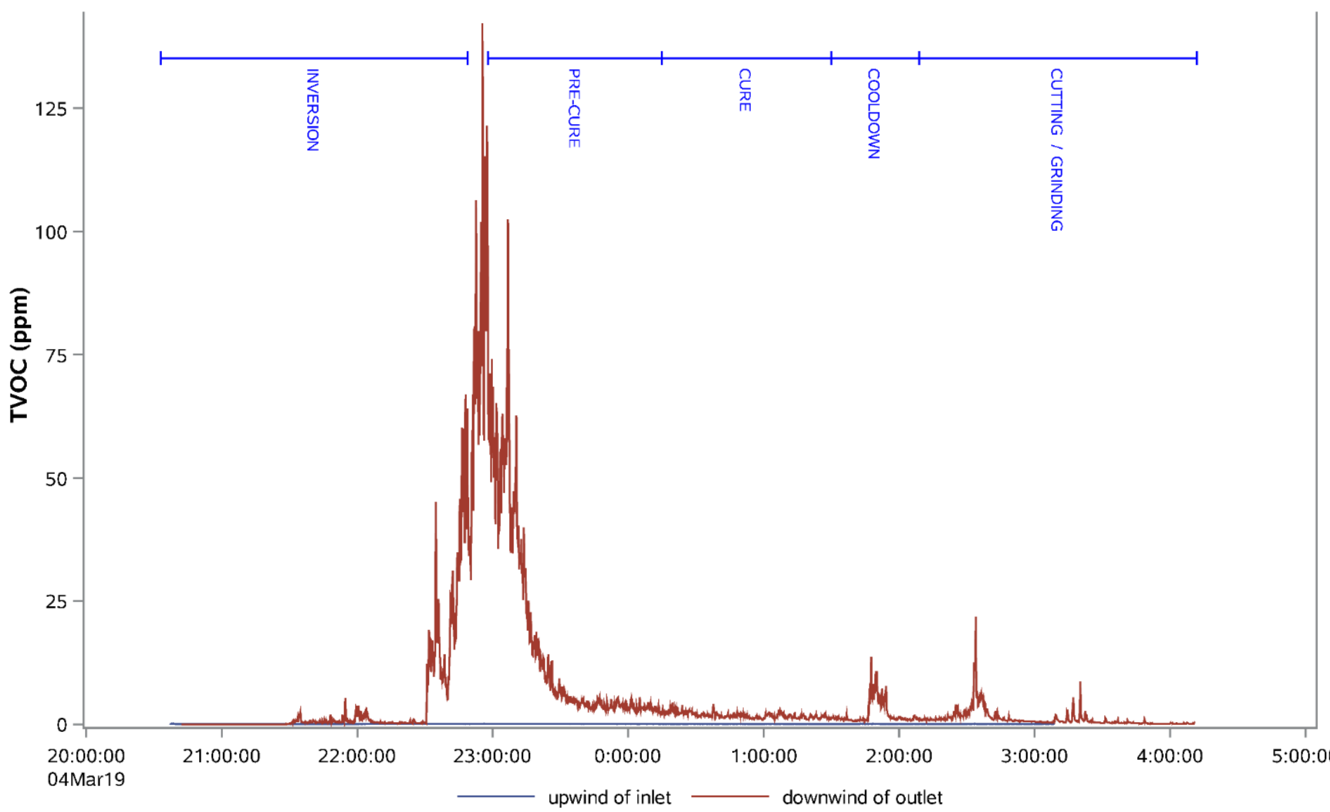


Figure B3. Area air sample collected during a water-cured CIPP installation using a real-time photoionization detector showing total volatile organic compound (TVOC) concentrations in parts per million (ppm) adjusted for styrene. Concentrations were higher downwind of the outlet manhole (red line) compared to upwind of the inlet manhole (blue line—almost indiscernible from the x-axis and fluctuating around the detection limit of the instrument), March 2019.

The highest real-time area monitoring styrene-adjusted TVOC concentration measured during a steam-cured CIPP install was 44.1 ppm and was collected three meters downwind of the outlet manhole at the end of a "pre-cure" task and the beginning of a "cure" task (Figure B4). For CIPP installation area monitoring, styrene-adjusted TVOC concentrations were generally higher during "pre-cure" and "cure" tasks near and, particularly, downwind of the outlet manhole (Figures B3 and B4).

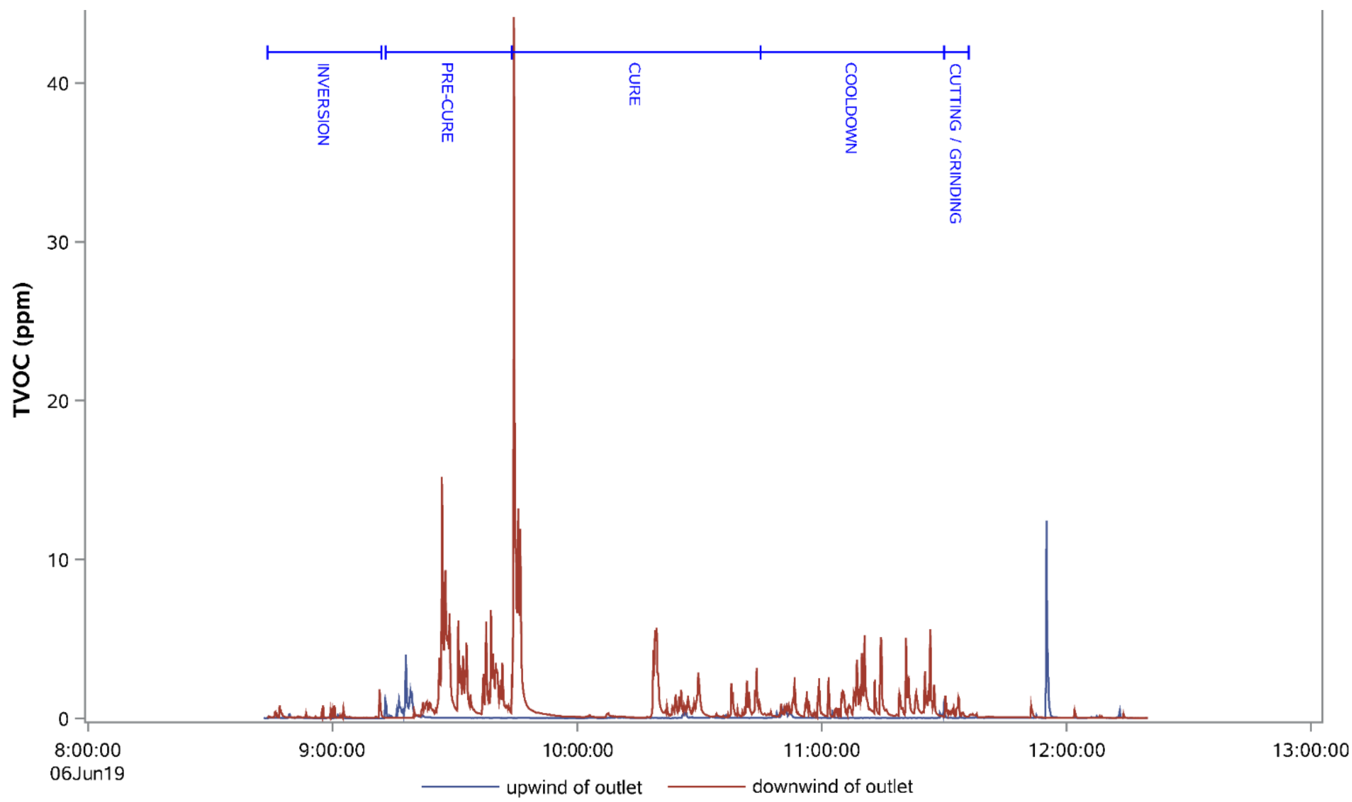


Figure B4. Area air samples upwind (blue line) and downwind (red line) of the outlet manhole collected during a steam-cured CIPP installation using real-time photoionization detector showing total volatile organic compound (TVOC) concentrations in parts per million (ppm) adjusted for styrene, June 2019.

For real-time PID personal monitoring during CIPP installations, the highest styrene-adjusted TVOC concentration of 1,125 ppm was observed as an employee was checking thermocouples near the outlet manhole of a steam-cured install during a “cooldown” task (Figure B6). The highest styrene-adjusted TVOC concentration observed during water-cured CIPP installations was 117.6 ppm and occurred when general laborer-a was inside an outlet manhole performing a “cutting cured liner” task (Figure B4). Real-time styrene-adjusted TVOC personal monitoring results demonstrated that proximity to the liner was a driving factor for potential exposure to higher styrene concentrations before and during “inversion” tasks. In Figure B5, there are styrene-adjusted TVOC concentration spikes as both general laborer-a and general laborer-b were manually handling uncured sections of liner prior to an “inversion” task. Similarly, close proximity to the inlet and outlet manholes during “pre-cure,” “cure,” “cooldown,” and “cutting cured liner” tasks can lead to higher concentrations of personal styrene exposures. In Figure B6, styrene-adjusted TVOC concentration peaks are observed when employees were setting or checking thermocouples close to manhole openings during “pre-cure” and “cooldown” tasks.

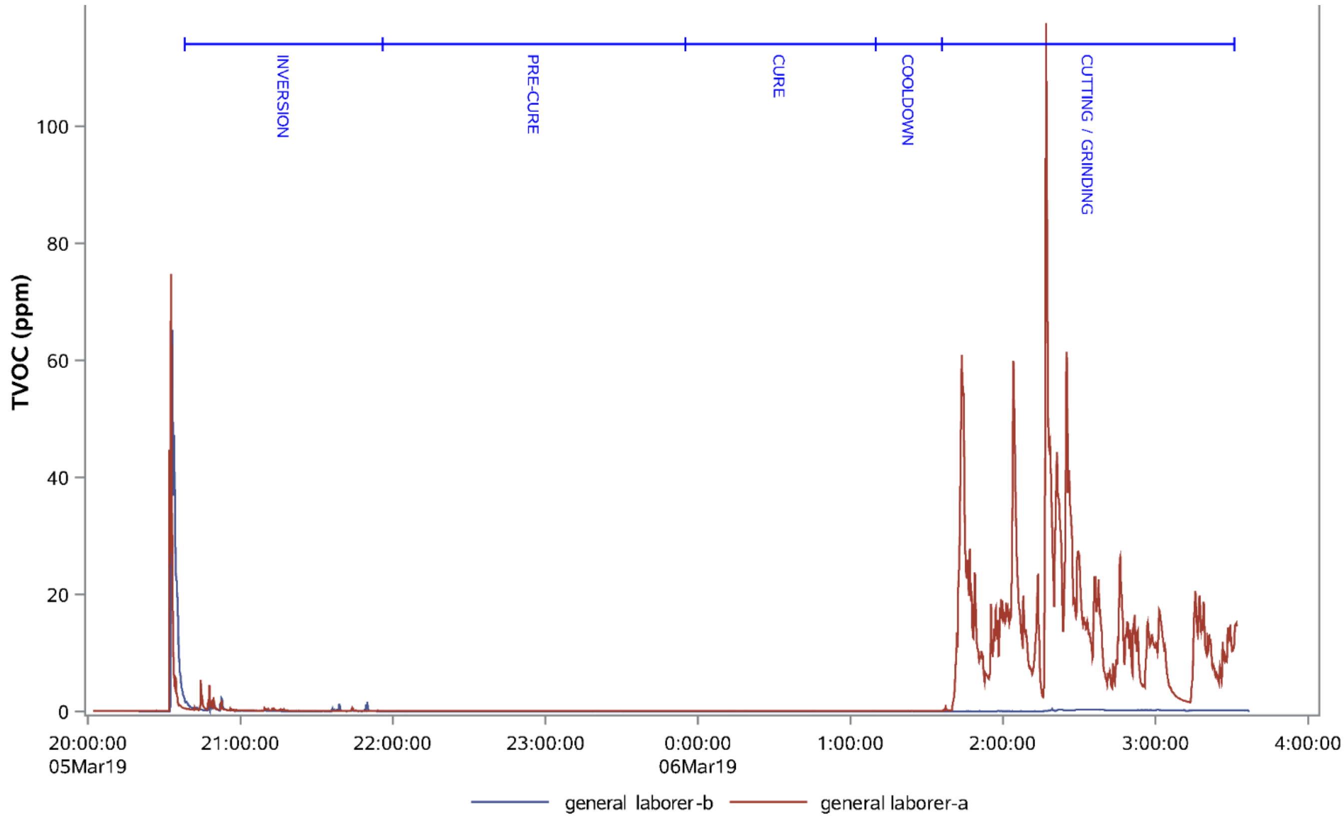


Figure B5. Personal air samples collected from employees during water-cured CIPP using real-time photoionization detector showing total volatile organic compound (TVOC) concentrations in parts per million (ppm) adjusted for styrene, March 2019.

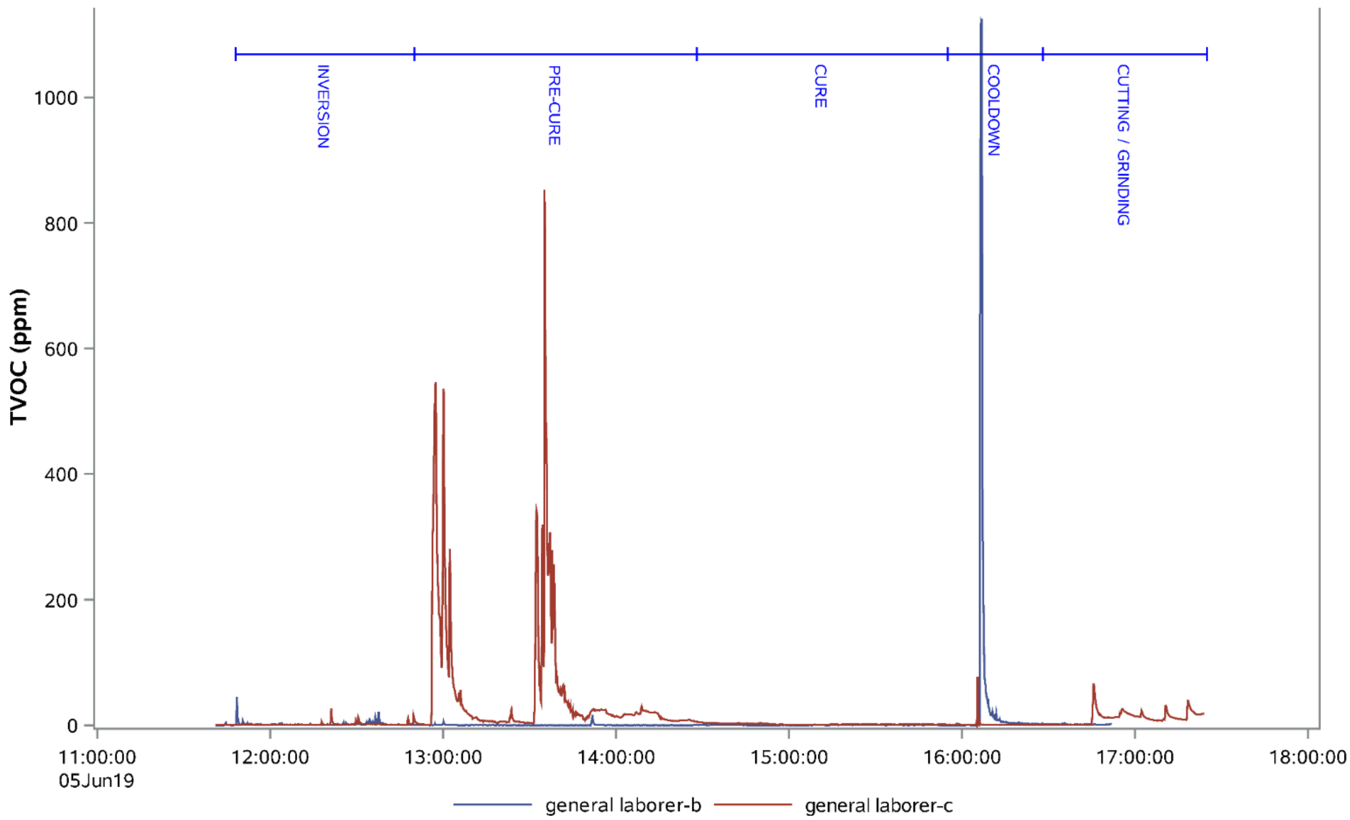


Figure B6. Personal air samples collected from two employee during steam-cured CIPP using real-time photoionization detector showing total volatile organic compound (TVOC) concentrations in parts per million (ppm) adjusted for styrene, June 2019.

Real-time PID TVOC monitoring was also conducted at the CIPP liner wet-out facility. A diagram of approximate locations of area-sampling baskets containing PID monitors can be seen in Figure B1. Overlaid plots of real-time, styrene-adjusted PID TVOC concentrations in different areas of the wet-out facility on 12/04/2019 can be seen in Figure B7. The highest styrene-adjusted TVOC area concentration of 821.8 ppm was observed in the mixing area while an employee cleaned the resin-pump static mixer machine with acetone after wetting of a liner (Figure B7). Additional concentration peaks were observed in the mixing area and near the resin-pump static mixer during rolling of a wetted liner (Figure B7). For personal exposure monitoring, the highest styrene-adjusted TVOC concentration of 1,067 ppm was observed when an employee cleaned the resin-pump static mixer machine with acetone (Figure B8). Additional elevated TVOC concentrations were observed for tasks including retrieving catalyst and styrene from the refrigerated storage area, injecting resin mixture into the liner, and liner rolling. Similar to trends during CIPP liner installations, close proximity to open containers of solvents (e.g., acetone) and the wetted liner can lead to higher levels of TVOC exposure.

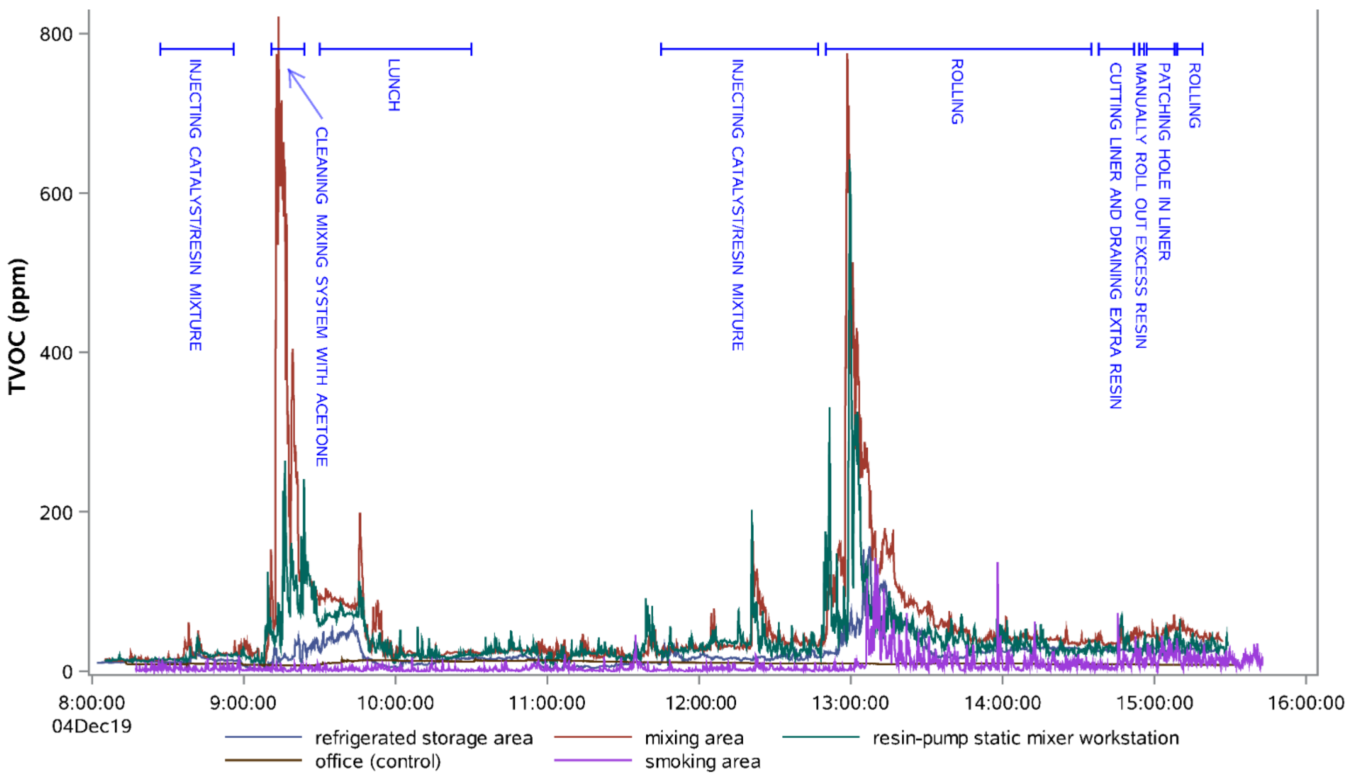


Figure B7. Area air samples from the wet-out facility collected using real-time photoionization detector showing total volatile organic compound (TVOC) concentrations in parts per million (ppm) adjusted for styrene, December 2019.

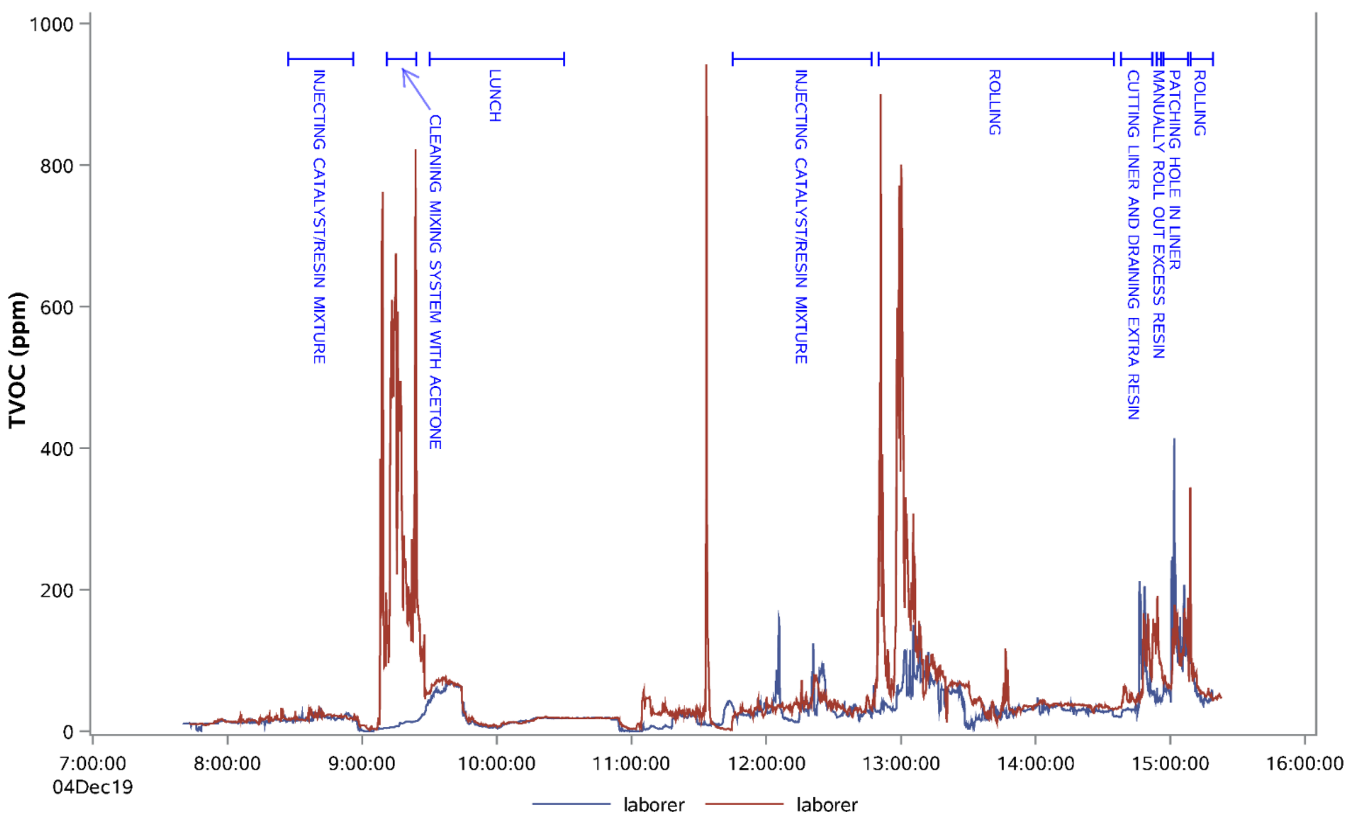


Figure B8. Personal air samples from two employees at the wet-out facility collected using real-time photoionization detector showing total volatile organic compound (TVOC) concentrations in parts per million (ppm) adjusted for styrene, December 2019.

Styrene emission from cured liner and other process materials

We collected samples of cured liner and process material ingredients from the wet-out facility and both CIPP installation sites to estimate styrene emission rates. Emission factors for the steam-cured liner ranged from 3.7 to 47 mg styrene/kg material/hour (Table C5). Emission factors for the water-cured liner were much higher and ranged from 150 to 222 mg styrene/kg material/hour. The uncured resin catalyst mix emitted the lowest amount of styrene (89 mg styrene/kg material/hour) from the wet-out facility. The day 3 liner mixture containing styrene, resin, and catalyst emitted the highest amount of styrene (153,004 mg styrene/kg material/hour). The number of days since the sample was collected to the time it was tested ranged from 19 days to 152 days.

Methods: Review of safety data sheets

We collected safety data sheets (SDSs) to review process ingredients used during the site visits.

Results: Review of safety data sheets

We reviewed the SDSs, which contained information on styrene, tetrahydrofuran, resins, and polymerization initiators. Styrene content of resins was less than or equal to 40% by weight. Most of the process ingredients including styrene, tetrohydrofuran, resins, catalysts, and initiators were flammable. Most of the process ingredients were respiratory, dermal, and eye hazards. Exposure to styrene and tetrohydrofuran can affect the central nervous system. Direct contact of process ingredients such as initiators may result in eye damage and skin irritation. Some of the process ingredients also contained a hazard statement on reproductive toxicity because it may affect fertility or cause damage to unborn children.

Discussion

Employees in the vicinity of pipe rehabilitation might be exposed to a number of potentially hazardous substances, including irritants, carcinogens, flammable gases, and respirable and inhalable dusts. Our assessment focused on VOCs, specifically styrene, listed in the health hazard evaluation request. Additionally, we observed standard employee practices, workplace conditions, and the use of PPE. Our observations and results from the exposure and workplace assessments are further discussed below.

Workplace Observations

We observed considerable differences in employee exposures between the two sampling days at the wet-out facility. On the first sampling day, wall ventilation fans in the facility were not operating, which was normal for the plant during the winter season depending on outside temperature. Not operating the fans contributed to higher measured concentrations of styrene in some full shift area samples. On the second sampling day, we sampled the same areas with the doors to the outside open and wall ventilation fans operating, which reduced some area air concentrations of styrene compared to the first sampling day. Continuously operating the wall ventilation fans at the wet-out facility during production could reduce area air concentrations in the facility and thereby reduce the overall burden of styrene exposures to employees.

Additionally, the potential for dermal exposure to process chemicals was observed. Employees manually conducted some tasks such as cutting and resealing the liner where dermal exposure to styrene and other process chemicals could be prevented with the use of chemically-resistant gloves. Nitrile or Viton™ gloves are recommended because latex gloves can cause allergic reactions in some individuals [NIOSH 2009] and are poor protection against solvents like styrene. Gloves should be frequently replaced and when broken or soiled. Employees were eating food and drinking coffee in the facility around the liner wetting out site. An outside smoking area was located next to the process waste collection area which contained excess resin mixture, acetone, and other solvents. Additionally, open containers in the process area held ingredients used to prepare the resin mixtures. These ingredients and the final products emit various VOCs during the work shift.

Steam-cured (liner diameter typically 24 inches or less) and water-cured (liner diameter typically 24 inches or more) installations were performed outside at different locations and times depending on work orders and traffic conditions. Steam-cured installations during our visits were conducted during the daytime while water-cured installations were conducted during the nighttime. Low air flow and high humidity conditions made the work environment challenging, especially in enclosed spaces like the manhole that contained cured liner. Occasionally, weather conditions such as rain prolonged the processes, resulting in a longer duration of exposure. We observed employees coughing after exposure to process emissions (e.g., styrene and other chemical vapor emissions). This exposure occurred after entering the manhole to place thermocouples before curing began. Water- and steam-curing processes might have a number of differences that influence employee exposures.

Exposure Assessment

Airborne exposure assessments are discussed below for styrene and other VOCs at wet-out liner preparation and two liner installations methods: steam-cured and water-cured.

Personal and area full-shift styrene concentrations at the wet-out facility

We conducted a limited characterization of employee full-shift exposures to styrene at the wet-out facility. The four full-shift measurements to styrene (3.4–6.0 ppm) were well below the NIOSH REL of 50 ppm styrene. The full-shift measurements were similar despite employees having different roles in the process, possibly indicating a well-mixed environment. The highest area air concentrations of styrene were at the mixing station and mixing/injecting machine, followed by the reefer truck door. The use of wall ventilation fans appeared to be effective at reducing styrene air concentrations in the facility. General dilution ventilation should be used to control temperature and humidity for occupant comfort and to control air concentrations of non-hazardous pollutants. We note that dilution ventilation is less effective than local exhaust ventilation at controlling source emissions and should not be used exclusively to control hazardous source emissions.

Personal task-based and area styrene concentrations at the CIPP installations

We characterized employee task-based exposures to styrene at the wet-out facility and at both CIPP installations to guide recommendations for controlling styrene emissions. The highest exposures occurred when employees were performing tasks in close proximity to process ingredients or resin-impregnated liners. For the wet-out facility, the highest measurement (12.5 ppm) occurred when a employee was getting styrene and catalyst from a refrigerated storage area. For water processes, the highest measurements (55.3 ppm) occurred during "cutting the cured liner" tasks when employees were in the access hole after the liner had been cured. For steam processes, the highest measurements (105.5 ppm) occurred when employees were doing tasks that generally occurred outside of the hole such as "inversions", "pre-cure" and "cutting cured liner" tasks. The steam-cured repairs we observed were performed on sewer drain systems that limited or prohibited employee entry into the small access holes and also required more manual handling of the liner than the water-cured process. When the cured liner was cut, it released styrene trapped in the liner material and increased the air concentration in the access holes and breathing zone of the employees. Local exhaust ventilation equipped to the cutting tools may be effective at capturing dust and chemicals emitted from the cured liner when it is cut. A qualified ventilation engineering firm should be consulted when attempting to implement local exhaust ventilation to control source emissions. If styrene exposures exceed occupational exposure limits after ventilation or administrative controls, employees will need respiratory protection equipped with organic vapor cartridges as part of a comprehensive respiratory protection program that meets the requirements of OSHA's Respiratory Protection standard (29 CFR 1910.134) and includes medical evaluations, fit testing, maintenance, and training.

Steam-cured installations occurred in residential settings; whereas, water-cured installations occurred in highway settings near the gulf. This difference in location was the major factor for differences in wind speed: minimal air movement for steam-cured compared to moderate wind speeds for water-cured processes. Low wind speeds promote higher concentrations around the source of styrene from process emissions, while higher wind speeds dilute and carry away the styrene concentrations downwind of the source. Some of the upwind concentrations might have been higher than the downwind concentration because of changing wind directions and low wind speed. Standing upwind or to the side when downwind so that employees are not directly downwind could reduce worker exposure.

<u>Area air sampling for styrene and acetone at or around sources using instantaneous canisters</u>

We observed opportunities to control source emissions of styrene and acetone at the reefer truck door, at the refrigerated storage door, and during the task of cutting cured liner. These opportunities are important places in the process to control exposures. All instantaneous sampling results (0.001–253.3 ppm) were well below the NIOSH Immediately Dangerous to Life or Health (IDLH) of 700 ppm for styrene. Ventilating the reefer truck space with ambient air before employees enter the truck might reduce peak exposures. Limiting the time spent in the reefer truck will also reduce exposures. Ventilating the refrigerated storage area at the wet-out facility and the confined space at CIPP installations with ambient air before entering might reduce process emissions, thereby reducing the chance for employee exposure to styrene and other VOCs. We expected to observe low concentrations upwind of the process emissions, but this was not always the case. On rare occasions, we measured higher concentrations upwind compared to downwind because of wind direction changes and local disturbances to wind direction from highway traffic, but in general, employees should stand upwind of the manholes whenever possible to reduce exposures to process emissions.

Real-time personal exposure and area monitoring for total volatile organic compounds using photoionization detectors

Physical proximity to the CIPP liner and the inlet and outlet manholes was the driving factor for increased TVOC exposure measurements during CIPP liner installation. The closer an employee was to the liner or the inlet and outlet manholes, the higher the likelihood of elevated TVOC concentrations. Physical contact with the liner should be avoided when possible. Time spent near the liner should be minimized when maintaining distance is not possible or practical. Prolonged contact or proximity to the uncured liner before and during “inversion” can lead to elevated personal exposures to TVOCs.

Wind direction plays a major role in air concentrations of styrene around manholes during CIPP installations. Specifically, higher concentrations are present immediately downwind of the inlet and outlet manholes, with concentrations around the outlet manhole typically being higher than those around the inlet manhole. Employee exposures to TVOCs during the “pre-cure”, “cure”, and “cooldown” phases of CIPP liner installation can be reduced if employees remain aware of wind direction and their relative proximity to the inlet and outlet manholes.

Time spent setting up and monitoring thermocouples near manholes should be minimized as we observed the highest styrene-adjusted TVOC concentration of 1,125 ppm during this task. Consider incorporating an automated means of measuring thermocouple temperatures to reduce employee levels of TVOC exposure during temperature monitoring during the “pre-cure,” “cure,” and “cooldown” phases of CIPP liner installation. Entering a manhole to engage in “cutting cured liner” was the task with the greatest potential for high exposures to TVOC concentrations, likely driven by styrene. Time spent in the confined space of the manhole should be minimized when possible. The manhole should be ventilated with a blower ventilator fan every time an employee enters the manhole and for the entire duration of the employee’s stay within the confined space.

For the wet-out facility, time spent in proximity to open containers of solvents such as styrene and acetone, time spent in enclosed spaces such as the refrigerated storage area or the reefer truck, and time spent in close proximity to the wetted liner were the main factors associated with higher concentrations of personal TVOC exposures. To lower the potential for exposure during the wet-out process, consider ventilating the refrigerated storage area and reefer truck trailer before and during occupancy by employees, while also minimizing the amount of time spent inside. Additionally, capping mixing buckets and solvent buckets when not in use can lower ambient levels of TVOCs within the facility. Because contact with the wetted liner is sometimes required during the wet-out process, potential for TVOC exposure can be reduced by minimizing time in contact with the liner and resin mixer, and also by wearing appropriate PPE such as nitrile gloves and safety glasses.

Styrene emission from cured liner and other process materials

We measured emission factors from cured liner and other process materials in the laboratory. Emission factors can be used to estimate styrene air concentrations when ventilation and room or space volume is known, but these estimated air concentrations should be confirmed with air sampling. Emission factors generally decrease over time as the amount of styrene in the material decreases at the boundary between the material and the air. In our tests, the emission factors did not always decrease with storage time because of variability in the technique and heterogeneity of the sample. The emission factors generated in these tests are worst-case emission estimates that are not realistic of real conditions where surface area available for emission is limited.

Emission factors for styrene from the cured and uncured process materials showed the potential for emission of styrene from materials. Much of the styrene in the uncured liner is consumed by the polymerization process or emitted into the atmosphere during the curing process, but some remains in the cured liner and can slowly emit over time. Steam-curing appeared to be more efficient at cooking off styrene as can be seen from the lower emission factors, but only one sample was tested for each curing method. Additional testing of styrene emission factors from cured liners should be conducted to assess the effectiveness of curing technique on emission factors. Flushing the freshly cured liner after curing, as well as before and during cutting the cured liner, might reduce employee exposures.

Safety Data Sheets

The Occupatonal Safety and Health Administration's (OSHA's) Hazard Communication Standard, also known as the "Right to Know Law" [29 CFR 1910.1200] requires that employees are informed and trained on potential work hazards and associated safe practices, procedures, and protective measures. SDSs provide information on hazardous chemicals used in products but might not list all hazardous ingredients [LeBouf et al. 2018]. The SDS describes the material properties as well as the physical, health, and environmental hazards for each hazardous chemical used in the workplace. In addition, the SDS provides information on how to safely handle and store hazardous chemicals. The SDS must be easily available to all employees or provided to the employee when requested. Sometimes SDS are kept as a hard copy in a binder, other times they may be on a computer. All SDSs must contain the following sections: information on the chemical such as product identifiers, common names, or synonyms, contact information for the manufacturer, a description of intended use and any restrictions on use, hazard classification and warning information associated with the hazards, composition, safe handling practices, storage information, emergency control measures, physical and chemical properties, stability and reactivity information, toxicological information, exposure limits, required engineering controls, personal protective measures, and other information including the date of preparation or last revision [OSHA 2012a,b].

SDSs for process ingredients indicated hazardous chemicals with inhalation and dermal exposure routes that can be controlled with ventilation and chemically resistant gloves. Employees should not eat, drink, or smoke in areas where these materials are used. Employees should wash their hands and face before eating. The precautions and safety information in these sheets reinforce our recommendations to increase ventilation of enclosed and confined spaces, especially for styrene, and to wear nitrile or Viton™ gloves when handling cured and uncured process materials. Latex gloves are not recommended because they are not as protective against styrene. Also, for some workers, exposure to latex can result in latex allergies [NIOSH 2009]. Gloves should be replaced often and when they break or become soiled.

Health Effects of Process Chemicals

Styrene

Styrene is a VOC with a sweet, pungent odor. Styrene is a component of the resin used in the CIPP liner. Exposure to styrene can occur by breathing air containing styrene or when skin comes into contact with resin containing styrene. Some health effects associated with styrene exposure are changes in color vision, tiredness, feeling drunk, slowed reaction time, concentration problems, balance problems, or hearing loss [ATSDR 2010; Campo et al. 2014; Estill et al. 2016]. Styrene exposure is also a potential risk factor for non-malignant respiratory disease among workers in industries using styrene [Nett et al. 2017a]. Respiratory diseases such as asthma and obliterative bronchiolitis have been reported among styrene-exposed workers [Culliman et al. 2013; Moscato et al. 1987]. The International Agency for Research on Cancer (IARC) has classified styrene as probably carcinogenic to humans based on limited evidence in humans and sufficient evidence in experimental animals for carcinogenicity [IARC Monographs Vol 121 Group]. "Probably carcinogenic" is the second of five categories that range from "carcinogenic to humans" to "probably not carcinogenic to humans" as defined by IARC [IARC 2019].

Obliterative Bronchiolitis

Obliterative bronchiolitis is a serious, often disabling, lung disease that involves scarring of the very small airways (i.e., bronchioles). Symptoms of this disease can include cough, shortness of breath on exertion, and/or wheeze, that do not typically improve away from work [NIOSH 2012]. Occupational obliterative bronchiolitis has been identified in styrene-exposed workers in a variety of industries, including boat manufacturing, automotive repair, military aviation, and others [Cullinan 2013, Nett 2017a, Nett 2017b].

Work-Related Asthma

Work-related asthma refers to asthma brought on by ("occupational asthma") or made worse by ("work-exacerbated asthma" or "work-aggravated asthma") workplace exposures [NIOSH 2017; Tarlo 2016; Tarlo and Lemiere 2014; OSHA 2014; Henneberger et al. 2011]. It includes asthma because of sensitizers, which cause disease through immune (allergic) mechanisms, and irritants, which cause disease through non-immune mechanisms. Symptoms of work-related asthma include episodic shortness of breath, cough, wheeze, and chest tightness. The symptoms may begin early in a work shift, towards the end of a shift, or hours after a shift. The symptoms often improve or remit during periods away from work, such as on weekends or holidays. Styrene has been demonstrated in multiple cases to cause occupational asthma in exposed individuals [Fernandez-Nieto 2006; Moscato 1987; Hayes 1991].

Acetone

Exposure to acetone in the air can irritate the upper respiratory tract and eyes and cause gastrointestinal and central nervous system health effects. Workers regularly exposed to acetone are less likely to experience irritation effects than workers without repeated exposures [ATSDR 2011; Dalton et al. 1997]. Human carcinogenicity for acetone has not been classified by the American Conference of Governmental Industrial Hygienists (ACGIH), IARC, or the National Toxicology Program. Significant acetone exposure (>500 ppm) can upregulate metabolic enzymes that can increase the cancer-causing potential of other chemicals like chloroform and benzene [ACGIH 2021].

Polyester Resin

Polyester resins can vary in composition, but typically contain a styrene monomer to reduce viscosity and thin the mixture [Zaske and Goodman 1998]. An acrylate is frequently included to promote the formation of chemical bonds (polymers) and increase the durability and strength of the final material. Health effects of composite materials like resin are difficult to assess unlike those of single materials like styrene or acetone. However, it has been known for many years that dermal exposure to polyester resin can cause skin irritation and chemical sensitization [Bourne and Milner 1963]. Recent research on CIPP emissions have determined that styrene, benzaldehyde, phenol, and many other substances are often present in the air during the curing process [Teimouri Sendesi et al. 2017]. Samples of these emissions have been shown to be harmful to lung cells, potentially predisposing exposed workers to the development or worsening of conditions such as fibrosis, obstructive pulmonary disease, and cancer [Kobos et al. 2019].

Catalysts/Initiators

Resin initiators, often referred to as catalysts, are used to start the series of chain reactions (polymerization) that allow the resin to cure [Kamath and Gallagher 1980]. Organic peroxides are thermally unstable chemicals, which can decompose while producing heat, and some compounds may react violently with other substances [OSHA 2013]. Organic peroxides are some of the most commonly used polymerization initiators. Acyl peroxide, benzoyl peroxide, cumyl peroxide, di-t-butyl peroxide, and methyl ethyl ketone peroxide are examples of peroxide initiators [Su 2013; CCOSH 2009]. Peroxide initiators, like resins, are frequently composite materials, meaning that their health effects are not as well understood as individual chemicals. These initiators might also have hazardous decomposition products. Depending on the composition of the initiator, dermal exposure can cause irritation and chemical burns. Based on a review of a catalyst SDS available online, components or decomposition products of an initiator might cause drowsiness, dizziness, or respiratory irritation. Inhalation, swallowing, or direct eye exposure can result in permanent damage [United Initiators, 2020].

Smoking

Smoking is a risk factor for lung disease. Evidence indicates that smoking can act in combination with hazardous agents to produce or increase the severity of a wide range of adverse health effects. We recommend implementing a smoking cessation program to assist employees to stop smoking. The Centers for Disease Control and Prevention offers tools and resources for setting up a smoking cessation program [CDC 2020].

Limitations

We measured employees exposures and process emissions for a limited number of days. Exposures may be different on different days because of changes in the environment or work site conditions. We suggest further sampling of employee exposures at multiple installation sites across a variety of environmental conditions and whenever changes to the process are implemented that could affect exposures. We designed the exposure assessment to focus on task-based exposures because employees preparing liner or conducting CIPP installations were intermittently exposed to emissions from process ingredients. Task samples varied in duration and did not frequently enable direct comparison to STELs, which are set for 15-minute sample durations.

Conclusions

The company proactively requested assistance from NIOSH to characterize and make recommendations to control employee exposures to styrene. Employees should follow confined space entry protocols outlined by the company and pursuant to OSHA regulations, including monitoring of hazardous atmospheres such as styrene air concentrations generated during the installation process. We identified locations and tasks such as the refrigerated storage area, the reefer truck, and cutting cured liner that are sources of styrene emissions and can be controlled using engineering and administrative controls. One employee's exposure exceeded the NIOSH STEL for styrene during "pre-cure" at a steam-cured CIPP installation site. Respiratory protection with organic vapor cartridges may be needed if exposures to styrene above OELs cannot be controlled with substitution, ventilation, or administrative controls. Cured liner continues to emit styrene after installation, and the process of cutting the cured liner increases emissions. Ventilation fans should be operated continuously during production in the wet-out facility and during access of enclosed and confined spaces at CIPP installation sites. In the future, exposure monitoring should focus on personal STEL (15-minute duration) and ceiling (instantaneous) sampling at the wet-out facility and CIPP installation sites to ensure employee health is protected by remaining below occupational exposure limits. At the wet-out facility, we observed full-shift personal sampling exposures to styrene well below the NIOSH REL. We conducted limited full-shift sampling and exposures are affected by environmental and process conditions at the time of sampling. For these reasons, additional full-shift exposure monitoring should be conducted periodically at the wet-out facility to ensure exposures remain below occupational exposure limits.

Section C: Tables

Table C1. Environmental and site conditions during sampling at water-cured CIPP installation sites (March 2019) and steam-cured CIPP installation sites (June 2019)

Process	Day	Number of Manholes/ Access Grates	Liner Length (feet)	Humidity Range (%RH)	Temperature Range (°F)	Wind Speed Range (mph)	Wind Direction Range*
Water	1	4	53	68.5–100.0	37.1–41.7	1.4–8.0	NNE to NNW
ater	2	3	39	52.8–86.3	41.5–48.7	1.2–5.0	NNE to NNW
Water	3	4	101	51.1–95.4	35.4–44.5	<0.1–4.2	S to N
Water	4	2	38	80.0–92.4	57.9–60.1	1.3–7.9	SSE to ESE
Steam	1	2	464	53.9–70.9	89.7–100.5	<0.1–0.8	SSW to S
Steam	2	2	464	90.6–99.3	70.3–77.8	<0.1–2.0	S to SSE
Steam	3	2	288	70.9–99.3	70.3–89.7	<0.1–2.3	N to W

Note: CIPP=cured-in-place pipe; RH=relative humidity; °F=degrees Fahrenheit; mph=miles per hour, S=South; N=North; W=West; NNE=North North East, NNW=North North West; SSW=South South West; SSE=South South East.
*Wind directions from local measurements during water-cured installations and from regional airport data during steam-cured wind direction.

Table C2. Task-based personal breathing zone air sampling for styrene during tasks at water-cured CIPP installation site (March 2019), steam-cured CIPP installation site (June 2019), and wet-out facility (December 2019)

Process	Task Name*	Number of Samples	Number of Workers	Geometric Mean Styrene Air Concentration (ppm)	Geometric Standard Deviation	Styrene Air Concentration Range (ppm)	Median (range) Sampling Duration (minutes)	Number (percentage) of Samples below the LOD
Steam	ASSISTING CUTTING CURED LINER[†]	7	5	0.2	2.7	(<0.07–0.8)	28 (5 – 64)	6 (86%)
Steam	CUTTING CURED LINER[§]	9	5	2.2	5.0	(<0.21–29.6)	19 (2 – 26)	2 (22%)
Steam	INVERSION[¶]	21	6	9.3	5.0	(<0.07–43.4)	50 (4 – 70)	1 (5%)
Steam	PRE-CURE/CURE/COOLDOWN**	9	7	0.4	16.1	(<0.02–105.5)	211 (16 – 281)	3 (33%)
Water	ASSISTING CUTTING CURED LINER	13	6	0.9	3.3	(0.1–7.2)	116 (55 – 156)	0 (0%)
Water	CUTTING CURED LINER	6	3	19.2	3.1	(2.2–55.3)	89 (58 – 118)	0 (0%)
Water	INVERSION	23	8	0.4	3.8	(<0.02–2.4)	108 (68 – 235)	3 (13%)
Water	OTHER TASKS	9	5	0.4	2.0	(0.1–0.9)	110 (11 – 157)	0 (0%)
Water	PRE-CURE/CURE/COOLDOWN[††]	3	1	0.2	1.1	(0.2–0.2)	181 (155 – 225)	0 (0%)
Wet-out	ALL TASKS	9	4	4.1	2.3	(1.4–12.5)	97 (12 – 167)	0 (0%)
NIOSH Short-Term Exposure Limit value (ppm)						100		

Note: CIPP=cured-in-place pipe; ppm=parts per million; LOD=limit of detection, which is the smallest mass that can be measured by the analysis method.
*Some task samples included additional tasks but were grouped by primary task or combined into a larger task group with similar proximity to source or exposure potential.
[†]ASSISTING CUTTING CURED LINER included one sample where the employee also cut the cured liner (5.0 ppm), six samples (one water and five steam) where the worker assisted with tearing down the work site after liner installation had been completed (maximum concentration 0.7 ppm), and two samples for water-curing where the worker was also supervising the installation (maximum concentration 0.6 ppm).
[§]CUTTING CURED LINER included nine samples for steam-curing where the worker assisted with tearing down the worksite after liner installation.
[¶]INVERSION samples were only collected during inversion of the liner. OTHER TASKS included assisting or directly tearing down the lift.
**For steam-curing, PRE-CURE/CURE/COOLDOWN included one sample with only pre-cure and cure happening and two samples including all three tasks. Employee task exposure of 105.5 ppm over 16-minute sample duration exceeded the ACGIH 15-minute short-term exposure limit (STEL) of 20 ppm and likely exceeded the NIOSH 15-minute STEL limit of 100 ppm.
[††]For water-curing, PRE-CURE/CURE/COOLDOWN included three samples with only pre-cure happening and six samples including all three tasks.

Table C3. Area air sampling for styrene during water-cured CIPP processes (March 2019) and steam-cured CIPP processes (June 2019)

Process	Basket Location Relative to Manhole/Grate*	Location	Number of Samples	Geometric Mean Area Styrene Air Concentration (ppm)	Geometric Standard Deviation	Area Styrene Air Concentration Range (ppm)	Median (range) Sampling Duration (minutes)	Number (percentage) of Samples below the LOD
Steam	DOWNWIND	INLET	10	0.2	3.1	(<0.05–1.2)	52 (8–200)	6 (60%)
Steam	UPWIND	INLET	22	0.3	5.0	(<0.04–8.7)	43 (6–147)	15 (68%)
Steam	DOWNWIND	OUTLET	16	0.4	4.5	(<0.08–6.2)	42 (5–157)	8 (50%)
Steam	UPWIND	OUTLET	16	0.2	3.3	(<0.08–3.3)	51 (6–101)	8 (50%)
Water	DOWNWIND	INLET	11	0.5	2.2	(0.2–1.5)	78 (23–174)	0 (0%)
Water	UPWIND	INLET	14	0.1	3.0	(<0.02–2.0)	78 (17–214)	10 (71%)
Water	DOWNWIND	MIDDLE	8	0.8	5.8	(0.1–5.6)	87 (43–127)	0 (0%)
Water	DOWNWIND	OUTLET	19	0.7	4.5	(0.1–13.6)	90 (32–133)	0 (0%)
Water	FACE	OUTLET	4	4.3	2.1	(2.0–10.6)	119 (44–128)	0 (0%)
Water	UPWIND	OUTLET	7	0.2	1.4	(0.1–0.3)	82 (35–120)	0 (0%)

Note: CIPP=cured-in-place pipe; ppm=parts per million; LOD=limit of detection, which is the smallest mass that can be measured by the analysis method.
*Location relative to wind direction are approximate because of variability in wind direction during sampling.

Table C4. Instantaneous source and area air sampling for styrene and acetone at water-cured CIPP processes (March 2019), steam-cured CIPP processes (June 2019), and wet-out facility (December 2019)

Process	Day	At Source or Area Basket Orientation Relative to Manhole/Grate	Task	Sample Description	Instantaneous Styrene Air Concentration (ppm)	Instantaneous Acetone Air Concentration (ppm)
Steam	3	UPWIND	CURE	At breathing height 2.7 meters from inlet	0.001	0.002
Steam	2	UPWIND	CUTTING CURED LINER	At breathing height 2.3 meters from outlet	0.2	0.01
Steam	3	UPWIND	CUTTING CURED LINER	At breathing height 2.6 meters from inlet	0.1	0.02
Steam	1	SOURCE	OPENING REEFER TRUCK	At door when employee opened reefer truck	253.3*	<0.002
Steam	2	SOURCE	OPENING REEFER TRUCK	At door when employee opened reefer truck	215.9*	2.7
Steam	3	SOURCE	OPENING REEFER TRUCK	At door when employee opened reefer truck	0.2[†]	0.007
Steam	3	SOURCE	OPENING REEFER TRUCK	At door when employee opened reefer truck	135.3	0.3
Steam	3	UPWIND	REMOVING LINER	At breathing height 2.4 meters from inlet	5.2	<0.002
Water	1	SOURCE	CURE	At face of outlet manhole	16.7	0.004
Water	1	SOURCE	CUTTING CURED LINER	At face of outlet manhole	12.1	<0.002
Water	2	UPWIND	CUTTING CURED LINER	At breathing height 3.0 meters from inlet	0.1	<0.002
Water	3	DOWNWIND	CUTTING CURED LINER	At breathing height 1.0 meters from outlet	16.6	<0.002
Water	3	DOWNWIND	CUTTING CURED LINER	At breathing height 2.0 meters from middle grate	0.4	<0.002
Water	3	SOURCE	CUTTING CURED LINER	At face of inlet manhole	35.9	<0.002
Water	4	UPWIND	CUTTING CURED LINER	At breathing height 2.3 meters from inlet	0.3	<0.002
Water	4	UPWIND	CUTTING CURED LINER	At breathing height 3.1 meters from outlet	9.8	0.004
Water	2	DOWNWIND	INVERSION	At breathing height 1.2 meters from outlet	0.1	0.003
Water	1	DOWNWIND	PRE-CURE	At breathing height 2.1 meters from inlet	0.3	<0.002
Water	2	SOURCE	PRE-CURE	At grate face between inlet and outlet sides	0.1	<0.002
Wet-out	1	SOURCE	AT DOOR TO REFRIGERATED STORAGE	At door after worker opened refrigerated storage area	23.4	10.5
Wet-out	1	SOURCE	INJECTING LIQUID IN LINER	At pinch roller	3.6	42.5
Wet-out	1	SOURCE	MIXING RESIN WITH STYRENE AND CATALYST	At breathing height in mixing area	16.0	35.6
Wet-out	1	SOURCE	NO TASK[§]	At breathing height in refrigerated storage area	8.0	35.5
Wet-out	1	SOURCE	NO TASK[¶]	At breathing height in refrigerated storage area	6.3	37.3
Wet-out	1	SOURCE	OPENING DOOR TO REFRIGERATED STORAGE	At door when employee opened refrigerated storage area	24.7	12.1

Table C4. Instantaneous source and area air sampling for styrene and acetone at water-cured CIPP processes (March 2019), steam-cured CIPP processes (June 2019), and wet-out facility (December 2019) ***(continued)***

Process	Day	At Source or Area Basket Orientation Relative to Manhole/Grate	Task	Sample Description	Instantaneous Styrene Air Concentration (ppm)	Instantaneous Acetone Air Concentration (ppm)
NIOSH Immediately Dangerous to Life and Health (IDLH) value (ppm)					700	2500
Occupational Safety and Health Administration Ceiling value (ppm)					200**	

Note: NIOSH=National Institute for Occupational Safety and Health; OSHA=Occupational Safety and Health Administration; ppm=parts per million; "NA" =not applicable because OSHA does not have a ceiling value for acetone.

*Two samples exceeded the OSHA ceiling limit value while an employee was opening the reefer truck door indicating the potential for overexposure during this task. However, exposure limits above OSHA or NIOSH limits are not directly applicable to instantaneous canister samples in table because the samples were not collected in the breathing zone of an employee.

†Measured concentration of 0.2 ppm seems low considering the sample was collected at the face of a refrigerated truck as an employee opened the door. Other samples collected during the same activity on different days were much higher (253.3 ppm and 215.9 ppm).

§Employee entered area 14 minutes before sample to get styrene and catalyst.

¶Employee entered area 16 minutes before sample to get styrene and catalyst.

**600 ppm 5-minute maximum in any 3 hour period

Table C5. Styrene emission factors for cured liners and process materials from wet-out facility and CIPP installations

Process	Description	Test Number	Days since sample collected	Emission Factor (mg/kg/h)	Mass (g)	Temperature (°C)	Humidity (%RH)
Steam	Cured liner	1	19	6.8	1.7	20.6	63
Steam	Cured liner	2	26	47	1.1	20.7	63
Steam	Cured liner	3	36	3.7	1.5	20.7	63
Steam	Cured liner	4	61	8.2	1.2	20.3	63
Water	Cured liner	1	20	222	0.88	22.3	58
Water	Cured liner	2	32	155	1.3	22.6	61
Water	Cured liner	3	152	150	1.5	20.7	67
Wet-out	Uncured Resin Catalyst Mix	1	37	89	1.0	23.9	47
Wet-out	Day 1 liner mixture containing styrene and uncured resin catalyst mix	1	55	88,200	0.31	22.9	46
Wet-out	Day 2 liner mixture containing styrene and uncured resin catalyst mix	1	82	66,145	0.25	23.7	41
Wet-out	Day 3 liner mixture containing styrene and uncured resin catalyst mix	1	53	153,004	0.26	25.6	47
Wet-out	Liner plus liner mixture (solidified naturally during storage)	1	97	102	0.25	23.9	36

Note: CIPP=cured-in-place pipe; mg/kg/h=milligrams styrene per kilogram of material per hour; g=grams; °C=degrees Celsius; RH=relative humidity.

Section D: Occupational Exposure Limits

NIOSH investigators refer to mandatory (legally enforceable) and recommended occupational exposure limits (OELs) for chemical, physical, and biological agents when evaluating workplace hazards. OELs have been developed by federal agencies and safety and health organizations to prevent adverse health effects from workplace exposures. Generally, OELs suggest concentrations of exposure that most employees may be exposed to for up to 10 hours per day, 40 hours per week, for a working lifetime, without experiencing adverse health effects.

However, not all employees will be protected if their exposures are maintained below these levels. Some may have adverse health effects because of individual susceptibility, a pre-existing medical condition, or a hypersensitivity (allergy). In addition, some hazardous substances act in combination with other exposures, with the general environment, or with medications or personal habits of the employee to produce adverse health effects. Most OELs address airborne exposures, but some substances can be absorbed directly through the skin and mucous membranes.

Most OELs are expressed as a time-weighted average (TWA) exposure. A TWA refers to the average exposure during a normal 8- to 10-hour workday. Some chemical substances and physical agents have recommended short term exposure limits (STEL) ceiling values. Unless otherwise noted, the STEL is a 15-minute TWA exposure. It should not be exceeded at any time during a workday. The ceiling limit should not be exceeded at any time.

In the United States, OELs have been established by federal agencies, professional organizations, state and local governments, and other entities. Some OELs are legally enforceable limits; others are recommendations.

- The U.S. Department of Labor OSHA permissible exposure limits (PELs) (29 CFR 1910 [general industry]; 29 CFR 1926 [construction industry]; and 29 CFR 1917 [maritime industry]) are legal limits. These limits are enforceable in workplaces covered under the Occupational Safety and Health Act of 1970. OSHA STELs are the legal maximum average exposure for a 15-minute time period. Some chemicals also have an OSHA ceiling value that represents concentrations that must not be exceeded at any time.
- NIOSH recommended exposure limits (RELs) are recommendations based on a critical review of the scientific and technical information and the adequacy of methods to identify and control the hazard. RELs as TWA concentrations that should not be exceeded over an 8 or 10-hour work shift, during a 40-hour workweek [NIOSH 2020]. NIOSH also provides STELs that are 15-minute TWAs. For some chemicals, NIOSH has Immediately Dangerous to Life or Health (IDLH) values. An IDLH value is a concentration of an air contaminant that can cause death or immediate or delayed permanent adverse health effects or prevent escape from such an environment. NIOSH RELs are published in the NIOSH Pocket Guide to Chemical Hazards [NIOSH 2020]. NIOSH also recommends risk management practices (e.g., engineering controls,

safe work practices, employee education/training, personal protective equipment, and exposure and medical monitoring) to minimize the risk of exposure and adverse health effects.

- Other OELs commonly used and cited in the United States include the threshold limit values (TLVs®), which are recommended by ACGIH, a professional organization. The ACGIH TLVs are developed by committee members of this professional organization from a review of the published, peer-reviewed literature. TLVs are not consensus standards. They are considered voluntary exposure guidelines for use by industrial hygienists and others trained in this discipline "to assist in the control of health hazards" [ACGIH 2021]. ACGIH provides TLV-TWA guidelines that are concentrations that should not be exceeded during any 8-hour workday of a 40- hour workweek. ACGIH also provides TLV-STEL guidelines that are 15-minute exposure concentrations that should not be exceeded during a workday.

Outside the United States, OELs have been established by various agencies and organizations and include legal and recommended limits. The Institut für Arbeitsschutz der Deutschen Gesetzlichen Unfallversicherung (Institute for Occupational Safety and Health of the German Social Accident Insurance) maintains a database of international OELs from European Union member states, Canada (Québec), Japan, Switzerland, and the United States. The database, available at http://www.dguv.de/ifa/GESTIS/GESTIS-Stoffdatenbank/index-2.jsp, contains international limits for more than 1,500 hazardous substances and is updated periodically.

OSHA requires an employer to furnish employees a place of employment free from recognized hazards that cause or are likely to cause death or serious physical harm [Occupational Safety and Health Act of 1970 (Public Law 91–596, sec. 5(a)(1))]. This is true in the absence of a specific OEL. It also is important to keep in mind that OELs may not reflect current health-based information.

When multiple OELs exist for a substance or agent, NIOSH investigators generally encourage employers to use the lowest OEL when making risk assessment and risk management decisions.

Occupational Exposure Limits for Styrene and Acetone

Occupational Safety and Health Administration (OSHA) [Mandatory]
For styrene, the OSHA PEL is 100 ppm, and the OSHA ceiling value is 200 ppm [OSHA 2019]. OSHA does not have a STEL for styrene. Further, there is a limit of 600 ppm 5-minute maximum peak in any 3 hours, meaning that a 5-minute exposure above the ceiling value, but never above the maximum peak, is allowed in any 3 hours during an 8-hour workday [OSHA 2019].

For acetone, the OSHA PEL is 1000 ppm [OSHA 2019].

American Conference of Governmental Industrial Hygienists (ACGIH) [Recommended]
For styrene, the ACGIH TLV is 10 ppm, and the ACGIH STEL is 20 ppm [ACGIH 2021]. In January 2020, ACGIH reduced the previous TLV of 20 ppm and STEL of 40 ppm by half and added designations of ototoxicant (hearing hazard) and A3 carcinogen, which is a "confirmed animal

carcinogen with unknown relevance to humans" [ACGIH 2021]. These changes were made after the last site visit associated with this health hazard evaluation request in December 2019.

For acetone, the ACGIH TLV is 250 ppm and STEL 500 ppm [ACGIH 2021].

<u>National Institute for Occupational Safety and Health (NIOSH) [Recommended]</u>
For styrene, the NIOSH REL is 50 ppm, the NIOSH STEL is 100 ppm, and the IDLH is 700 ppm.

For acetone, the NIOSH REL is 250 ppm, and IDLH is 2500 ppm [NIOSH 2020]. Raleigh et al. mentioned symptoms such as headache, lightheadedness, and irritation in eye, nose, and throat among workers exposed to acetone concentrations higher than 1000 PPM [Raleigh et al. 1972]. For safety considerations, IDLH for acetone was set at 2500 ppm as 10% of the lower explosive limit of 2.5% [NIOSH 2020].

Section E: References

Health Effects of Styrene

ATSDR [2010]. Toxicological profile for styrene. U.S. Department of Health and Human Services, Public Health Service, Agency for Toxic Substances & Disease Registry, https://www.atsdr.cdc.gov/toxprofiles/tp53.pdf.

Campo P, Venet T, Thomas A, Cour C, Brochard C, Cosnier F [2014]. Neuropharmacological and cochleotoxic effects of styrene. Consequences on noise exposures. Neurotoxicol Teratol *44*:113-120, https://doi.org/10.1016/j.ntt.2014.05.009.

Cullinan P, McGavin CR, Kreiss K, Nicholson AG, Maher TM, Howell T, Banks J, Newman Taylor AJ, Chen CH, Tsai PJ, Shih TS, Burge PS [2013]. Obliterative bronchiolitis in fibreglass workers: a new occupational disease? Occup Environ Med *70*(5):357-359, https://doi.org/10.1136/oemed-2012-101060.

Estill CF, Rice CH, Morata T, Bhattacharya A [2016]. Noise and neurotoxic chemical exposure relationship to workplace traumatic injuries: A review. J Safety Res *60*:35-42, https://doi.org/10.1016/j.jsr.2016.11.005.

Fernández-Nieto M, Quirce S, Fraj J, del Pozo V, Seoane C, Sastre B, Lahoz C, Sastre J [2006]. Airway inflammation in occupational asthma caused by styrene. J Allergy Clin Immunol 117(4):948–950. https://doi.org/10.1016/j.jaci.2005.12.1350.

Hayes JP, Lambourn L, Hopkirk JA, Durham SR, Taylor AJ [1991]. Occupational asthma due to styrene. Thorax *46*(5):396-397, https://doi.org/10.1136/thx.46.5.396.

Henneberger PK, Redlich CA, Callahan DB, Harber P, Lemière C, Martin J, Tarlo SM, Vandenplas O, Torén K; ATS Ad Hoc Committee on Work-Exacerbated Asthma [2011]. An official American Thoracic Society statement: work-exacerbated asthma. Am J Respir Crit Care Med *184*(3):368–378, https://doi.org/10.1164/rccm.812011ST.

IARC [2019] Agents classified by the IARC monographs, volumes 1–123. Lyon, France: International Agency for Research on Cancer, https://monographs.iarc.fr/agents-classified-by-the-iarc/.

IARC Monographs Vol 121 Group [2018]. Carcinogenicity of quinoline, styrene, and styrene- 7,8-oxide. Lancet Oncol *19*(6):728-729, https://doi.org/10.1016/S1470-2045(18)30316-4.

Nett RJ, Cox-Ganser JM, Hubbs AF, Ruder AM, Cummings KJ, Huang YT, Kreiss K [2017a]. Non-malignant respiratory disease among workers in industries using styrene-A review of the evidence. Am J Ind Med *60*(2):163-180, https://dx.doi.org/10.1002%2Fajim.22655.

Nett RJ, Edwards NT, Ruder AM, Bertke SJ, Keumala I, Cox-Ganser J, Cummings KJ. [2017b]. Deaths from nonmalignant respiratory disease in styrene-exposed workers: does oblierative bronchiolitis contribute to mortality? Ann Am Thorac Soc *14*(5):810-811, https://doi.org/10.1002/ajim.22655.

NIOSH [2012]. Flavoring-related lung disease. Information for healthcare providers. Department of Health and Human Services, Centers for Disease Control and Prevention, DHHS (NIOSH) Publication No. 2012-148 (supersedes 2012-107), http://www.cdc.gov/niosh/docs/2012-148/.

Moscato G, Biscaldi G, Cottica D, Pugliese F, Candura S, Candura F [1987]. Occupational asthma due to styrene: two case reports. J Occup Med *29*(12):957-960.

NIOSH [2017]. Work-realted asthma, National Insititute for Occupational Safety and Health, https://www.cdc.gov/niosh/topics/asthma/default.html.

OSHA [2014]. OSHA Fact sheet: Do you have work-related asthma? A guide for you and your doctor. Washington, D.C.: U.S. Department of Labor, Occupational Safety and Health Administration, https://www.osha.gov/Publications/OSHA3707.pdf.

Tarlo SM, Lemiere C [2014]. Occupational asthma. N Engl J Med *370*:640-649, https://doi.org/10.1056/NEJMra1301758.

Tarlo SM [2016]. Update on work-exacerbated asthma. Int J Occup Med Environ Health *29*(3):369-374. https://doi.org/10.13075/ijomeh.1896.00676.

Health Effects of Acetone

ATSDR [2011]. Addendum to the toxicological profile for acetone. Atlanta, GA: U.S. Department of Human Services, Centers for Disease Control and Prevention, Agency for Toxic Substances and Disease Registry, https://www.atsdr.cdc.gov/toxprofiles/acetone_addendum.pdf.

Dalton P, Wysocki CJ, Brody MJ, Lawley HJ [1997]. Perceived odor, irritation, and health symptoms following short-term exposure to acetone. Am J Ind Med *31*(5):558-69, https://doi.org/10.1002/(sici)1097-0274(199705)31:5%3C558::aid-ajim10%3E3.0.co;2-y.

Raleigh LR, McGee WA [1972]. Effects of short, high-concentration exposures to acetone as determined by observation in the work area. J Occup Med *14*(2):607-610.

Health Effects of Polyester Resin

Bourne LB, Milner FJM [1963]. Polyester Resin Hazards. Br J Ind Med *20*(2):100-109, https://dx.doi.org/10.1136%2Foem.20.2.100.

Kobos L, Teimouri Sendesi SM, Whelton AJ, Boor BE, Howarter JA, Shannahan J [2019]. In vitro toxicity assessment of emitted materials collected during the manufacture of water pipe plastic linings. Inhal. Toxicol *31*(4):131-146, https://doi.org/10.1080/08958378.2019.1621966.

Teimouri Sendesi,SM, Ra K, Conkling EN, Boor BE, Nuruddin M, Howarter JA, Youngblood JP, Kobos LM, Shannahan JH, Jafvert CT, Whelton AJ [2017]. Worksite chemical air emissions and worker exposure during sanitary sewer and stormwater pipe rehabilitation using cured-in-place-pipe (CIPP). Environ. Sci. Technol. Lett *4*(8):325-333, https://doi.org/10.1021/acs.estlett.7b00237.

Zaske OC, Goodman SH [1998]. Unsaturated Polyester and Vinyl Ester Resins. In Goodman SH (Ed). Handbook of Thermoset Plastics Second Edition (pp 97-168). Westwood: Noyes Publications.

Health Effects of Catalyst/Initiators

CCOSH [2009]. OSH answers fact sheets: organic peroxides – hazards. Canadian Centre for Occupational Health and Safety, https://www.ccohs.ca/oshanswers/chemicals/organic/organic_peroxide.html.

Kamath VR and Gallagher RB [1980]. Initiator systems for unsaturated polyester resins. In Pritchard G (Ed). Developments in Reinforced Plastics—1 (pp 121-144). Essex: Applied Science Publishers.
OSHA [2013]. 29 CFR 1910.1200 Hazard communication standard, Appendix B. Washington, DC: U.S. Department of Labor, Occupational Safety and Health Administration, https://www.osha.gov/laws-regs/regulations/standardnumber/1910/1910.1200AppB

Su W-F [2013]. Chapter 7: Radical Chain Polymerization. In Su W-F (Ed). Principles of Polymer Design and Synthesis (pp 137-183). Berlin: Springer Berlin Heidelberg.

Latex Allergies

NIOSH [2009]. Latex allergies. National Institute for Occcupational Safety and Health, https://www.cdc.gov/niosh/topics/latex/.

Smoking

CDC [2020]. Smoking & tobacco use – tobacco control plans. Centers for Disease Control and Prevention, https://www.cdc.gov/tobacco/stateandcommunity/tobacco_control_programs/index.htm.

Methods

NIOSH [2018]. Volatile organic compounds, C1 to C10, Canister method: Method 3900. Cincinnati, OH: U.S. Department of Health and Human Services, Public Health Service, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health, https://www.cdc.gov/niosh/nmam/pdf/3900.pdf.

OSHA [1991]. OSHA Method ORG-89: divinylbenzene, ethylvinylbenzene, styrene. Occupational Safety and Health Administration, https://www.osha.gov/dts/sltc/methods/organic/org089/org089.html.

Occupational Exposure Limits

ACGIH [2021]. 2021 TLVs® and BEIs®: threshold limit values for chemical substances and physical agents and biological exposure indices. Cincinnati, OH: American Conference of Governmental Industrial Hygienists.

NIOSH [2020]. NIOSH pocket guide to chemical hazards, National Institute for Occupational Safety and Health, https://www.cdc.gov/niosh/npg/.

OSHA [2019]. Permissible exposure limits – Annotated OSHA Z-1 and Z-2 Table, Washington, DC: U.S. Department of Labor, Occupational Safety and Health Administration, https://www.osha.gov/dsg/annotated-pels/index.html.

Confined Space Entry

OSHA [2015a] 29 CFR 1926 Construction industry confined space standard, subpart AA, sections 1200-1213. Washington, DC: U.S. Department of Labor, Occupational Safety and Health Administration, https://www.osha.gov/laws-regs/regulations/standardnumber/1926/1926SubpartAA.

OSHA [2015b]. Protecting construction workers in confined spaces: Small entity compliance guide. Washington, DC: U.S. Department of Labor, Occupational Safety and Health Administration, https://www.osha.gov/Publications/OSHA3825.pdf.

Safety Data Sheets

OSHA [2012a]. OSHA brief - hazard communication standard: safety data sheets. Occuypational Safety and Health Administration, https://www.osha.gov/sites/default/files/publications/OSHA3514.pdf.

OSHA [2012b] CFR 1910.1200 Appendix D safety data sheets (mandatory), U.S. Department of Labor, Ocupational Safety and Health Administratoin, https://www.osha.gov/laws-regs/regulations/standardnumber/1910/1910.1200AppD.

LeBouf RF, Hawley B, Cummings KJ [2018]. Potential hazards not communicated in safety data sheets of flavoring formulations, including diacetyl and 2,3-pentanedione. Ann Work Exp Health *63*(1):124-130, https://doi.org/10.1093/annweh/wxy093.

United Initiators [2020]. NOROC-MEKP-925 Material safety and data sheet. https://www.united-initiators.com/files/NOROX%C2%AEMEKP-925/United_Initiators_NOROX%C2%AEMEKP-925_MSDS_CN_EN.pdf

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