Equipment Fracture and Fatal Hydrogen Chloride Release at Wacker Polysilicon North America

U.S. Chemical Safety and Hazard Investigation Board

Charleston, TN | *Incident Date: November 13, 2020* | **No. 2021-01-I-TN**

Investigation Report

Published: June 2023

Key Issues:

- Written Procedures
- Control of Hazardous Energy
- Simultaneous Operations
- Means of Egress

U.S. Chemical Safety and Hazard Investigation Board

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The November 13, 2020, equipment fracture and hydrogen chloride release at Wacker Polysilicon North America fatally injured Jesus Jared Aguilar Montes.

CONTENTS

ABBREVIATIONS

ANSI	American National Standards Institute
ASSP	American Society of Safety Professionals
CFR	Code of Federal Regulations
CSB	U.S. Chemical Safety and Hazard Investigation Board
EPA	Environmental Protection Agency
HCl	Hydrogen Chloride, Hydrochloric Acid
IBC	International Building Code
ICC	International Code Council
IFC	International Fire Code
NDT	Non-destructive testing
NFPA	National Fire Protection Association
NIOSH	National Institute for Occupational Safety and Health
OEM	Original equipment manufacturer
OSHA	Occupational Safety and Health Administration
PHA	Process Hazard Analysis
PPE	Personal protective equipment
PSM	Process Safety Management
PTFE	Polytetrafluoroethylene
RMP	Risk Management Program
SEM	Scanning electron microscope
SIMOPs	Simultaneous Operations
SOP	Standard Operating Procedure

TOSHA	Tennessee Occupational Safety and Health Administration

EXECUTIVE SUMMARY

On November 13, 2020, a graphite heat exchanger cracked during maintenance activities, releasing gaseous hydrogen chloride (HCl) at the Wacker Polysilicon North America (Wacker) facility in Charleston, Tennessee. The incident occurred on the fifth floor of an equipment access structure when a contractor pipefitter applied excessive torque to flange bolts on a heat exchanger outlet pipe containing HCl, causing the pipe to crack and release HCl.

At the time of the incident, seven workers from two contract firms were present on the fifth-floor platform, which was equipped with a single staircase for access and egress. Three of the workers, tasked with bolt torquing, wore full-body chemical-resistant suits. The four other workers, who were from the other firm, were tasked with insulating equipment and wore only standard flame-resistant clothing. The location of the release and the workers' inability to clearly see their surroundings in the white cloud created by the releasing HCl prevented all the workers from being able to access the staircase to exit the platform. To escape from the HCl release, three of the contractor workers who were not wearing full-body chemical-resistant suits began climbing down piping on the side of the structure, located approximately 70 feet above the ground. While attempting to climb down, all three workers fell to the ground. One worker was fatally injured from the fall, and the other two sustained serious injuries. After the release stopped, the four workers still remaining on the fifth-floor platform used the staircase to evacuate the area and reach the ground.

In addition to the fatality and the serious injuries, the Wacker site sustained $214,000 in property damage.

SAFETY ISSUES

The CSB's investigation identified the safety issues below.

- **Written Procedures.** Wacker tasked contractor pipefitters with torquing flange bolts on a live piping segment equipped with multiple bolts with differing torque requirements. Wacker did not have a written procedure to execute the torquing task and instead relied on the piping manufacturer's equipment manual to communicate the torque requirements to the contractors. The manual, however, did not include the torque requirements for the bolts that were over-torqued. The resulting lack of clarity of the differing torque requirements led to the inadvertent over-torquing of the flange bolts on live operating equipment, the equipment fracture, and the release of HCl. (Section 4.1)

- **Control of Hazardous Energy.** Wacker did not treat torquing operations on equipment containing hazardous chemicals as a line break or as an activity that required isolation of hazardous energy since it did not involve the intentional opening of a line. As such, Wacker did not perform a risk analysis to determine whether the torque task could be safely performed on operating equipment, nor did it implement precautions to mitigate the risk of torquing bolts on operating equipment prior to issuing a safe work permit to the pipefitters, which could have restricted the insulators from being present in the area and prevented their harm. (Section 4.2)

- **Simultaneous Operations (SIMOPs).** When the incident occurred, four workers from a separate contractor company were performing an unrelated pipe insulation task on the structure, as permitted by

Wacker, and were present on the fifth-floor platform near the pipefitter work crew. Wacker did not have a policy or procedure for evaluating SIMOPs, a situation in which two or more operations occur together at a time and place. In addition, there is a general lack of industry and regulatory guidance on SIMOPs considerations available to companies such as Wacker. As a result, Wacker did not evaluate the risks associated with the simultaneous work tasks, and the contract workers not involved in the torquing task were unnecessarily exposed to the HCl release. (Section 4.3)

- **Means of Egress.** During the incident, seven workers were present on the fifth-floor platform, which was equipped with only a single point of egress. Wacker designed the equipment access structure with a single point of egress based on building code requirements for an “unoccupiable equipment platform”. The CSB found that the current International Building Code and National Fire Protection Association building requirements do not provide for sufficient means of egress from elevated work platforms used for accessing equipment containing hazardous materials. Additionally, three months before the incident during the Process Hazard Analysis, Wacker employees identified the need for a second point of egress, but Wacker did not take any action to address this recommendation before the incident. (Section 4.4)

CAUSE

The CSB determined the cause of the incident was the inadvertent over-torquing of bolts on an HCl piping flange connection to a heat exchanger, which resulted in the fracture of the heat exchanger outlet piping and a release of gaseous HCl in the vicinity of seven contract workers. Wacker’s lack of written procedures and lack of control of hazardous energy contributed to the occurrence of the event, and Wacker’s lack of a SIMOPs program and the absence of regulatory and published industry guidance on SIMOPs contributed to the severity of the event. Wacker’s limited means of egress from the equipment access structure and the absence of regulatory guidance and standards on means of egress from open-air industrial structures also contributed to the severity of the event.

RECOMMENDATIONS

<u>Previously Issued Recommendations Superseded in This Report</u>

To Occupational Safety and Health Administration (OSHA)

2020-07-I-NC-R2 (from the Evergreen Packaging Paper Mill - Fire During Hot Work report)

Require Owner/Operators to ensure the coordination of simultaneous operations involving multiple work groups, including contractors. Include in the requirement for Owner/Operators to ensure the following activities occur:

- Identification of potential simultaneous operations;
- Identification of potential hazardous interactions;
- Evaluation and implementation of necessary safeguards to allow for safe simultaneous operations;
- Coordination, including shared communication methods, between the simultaneous operations; and

- Inclusion of emergency response personnel or services in the planning and coordination of the simultaneous operations.

As necessary, seek the regulatory authority to promulgate this requirement.

*Superseded by **2021-01-I-TN-R1** to OSHA below.*

New Recommendations

To Occupational Safety and Health Administration (OSHA)

2021-01-I-TN-R1 (Supersedes 2020-07-I-NC-R2 from the CSB's 2020 Evergreen Packaging report)

Promulgate a standard or modify existing standards to require employers to ensure the coordination of simultaneous operations (SIMOPs) involving multiple work groups, including contractors. Ensure that the requirements of this standard or standards apply to both general industry and construction activities and are not limited to activities occurring within confined spaces. Include in the standard requirements for Employers to ensure that the following activities occur:

a. Identification of potential SIMOPs;

b. Identification of potential hazardous interactions;

c. Evaluation and implementation of necessary safeguards to allow for safe SIMOPs;

d. Coordination, including shared communication methods, between the SIMOPs; and

e. Inclusion of emergency response personnel or services in the planning and coordination of the SIMOPs.

2021-01-I-TN-R2

Develop a safety product providing guidance on the coordination of simultaneous operations (SIMOPs) involving multiple work groups, including contractors, that is not limited to confined space or construction. Provide guidance on the following activities:

a. Identification of potential SIMOPs;

b. Identification of potential hazardous interactions;

c. Evaluation and implementation of necessary safeguards to allow for safe SIMOPs;

d. Coordination, including shared communication methods, between the SIMOPs; and

e. Inclusion of emergency response personnel or services in the planning and coordination of the SIMOPs.

To Wacker Polysilicon

2021-01-I-TN-R3

Develop detailed maintenance procedures for torquing activities which:

a. Clearly communicate differing equipment torque specifications, such as those for bolts installed at PTFE-to-PTFE and PTFE-to-graphite connections through visual means such as annotated photographs, signage, physical differentiation, and other methods, as appropriate;

b. Include procedural requirements for all torquing activities conducted on equipment containing hazardous material to perform an engineering and risk analysis and implement safeguards as a result of the risk analysis, per American Society of Mechanical Engineers (ASME) PCC-1-2019 *Guidelines for Pressure Boundary Bolted Flange Joint Assembly* and ANSI/ASSP Z244.1-2016 *The Control of Hazardous Energy Lockout, Tagout and Alternative Methods;*

c. Ensure that terms such as "hot torque" are clearly defined and employees and contractors are trained on these terms; and

d. Ensure that procedures and training conform to the mechanical integrity requirements of the Process Safety Management (PSM) standard found in 29 CFR 1910.119(j) and the Risk Management Program (RMP) rule found in 40 CFR 68.73.

2021-01-I-TN-R4

Develop policy requirements to ensure that torquing activities performed on equipment containing hazardous energy are performed safely, such as through de-inventorying equipment or restriction of nonessential personnel and ensuring that essential workers wear proper personal protective equipment (PPE). Document these requirements in procedures, such as *Lock, Tag and Try; First Line Break – Return to Service;* or other procedures as applicable. Ensure employees and contractors are trained on these procedures in accordance with the Process Safety Management (PSM) standard requirements found in 29 CFR 1910.119(f)(4) and 29 CFR 1910.119(g) and the Risk Management Plan (RMP) rule found in 40 CFR 68.69(d) and 40 CFR 68.71.

2021-01-I-TN-R5

Develop and implement a formalized Simultaneous Operations (SIMOPs) program addressing planned and/or permitted co-located work tasks including:

a. Identification of potential SIMOPs;

b. Identification of potential hazardous interactions;

c. Evaluation and implementation of necessary safeguards to allow for safe SIMOPs;

d. Coordination, including shared communication methods, between the SIMOPs; and

e. Inclusion of emergency response personnel or services in the planning and coordination of the SIMOPs.

Ensure relevant staff are trained on execution of the SIMOPs program.

2021-01-I-TN-R6

Install additional means of egress for the T230 desorption tower platforms and other multi-floor equipment structures on-site. After completing these installations, ensure workers are made aware of exit locations from the structure platforms through training, drills, or other techniques as appropriate.

To Tennessee Occupational Safety and Health Administration (TOSHA)

2021-01-I-TN-R7

Promulgate a standard or modify existing standards to require employers to ensure the coordination of simultaneous operations (SIMOPs) involving multiple work groups, including contractors. Ensure that the requirements of this standard or standards apply to both general industry and construction activities and are not limited to activities occurring within confined spaces. Include in the standard requirements for Employers to ensure that the following activities occur:

a. Identification of potential SIMOPs;

b. Identification of potential hazardous interactions;

c. Evaluation and implementation of necessary safeguards to allow for safe SIMOPs;

d. Coordination, including shared communication methods, between the SIMOPs; and

e. Inclusion of emergency response personnel or services in the planning and coordination of the SIMOPs.

To Center for Chemical Process Safety (CCPS)

2021-01-I-TN-R8

Develop and publish a safety product on Safe Work Practices, including detailed and practical guidelines for evaluating simultaneous operations (SIMOPs). The product, at a minimum, should:

a. Address the content found in CCPS's website resource for implementing Safe Work Practices; and

b. Discuss guidelines for a SIMOPs life cycle, including:

   1. methods to identify SIMOPs;
   2. methods to conduct a SIMOPs hazard assessment;
   3. safeguards and controls pertaining to SIMOPs;
   4. preparation for SIMOPs; and
   5. SIMOPs execution.

In developing this safety product, consider the findings presented in the CSB report titled *Fire During Hot Work at Evergreen Packaging Paper Mill* and this CSB report, titled *Equipment Fracture and Fatal Hydrogen Chloride Release at Wacker Polysilicon North America*.

To International Code Council (ICC)

2021-01-I-TN-R9

Amend the International Building Code (IBC) to address conditions that may require multiple means of egress from elevated equipment platforms used for accessing equipment containing materials that pose physical and health hazards, such as the one used at Wacker in this incident. Specify the minimum number of egress points to increase the likelihood of worker escape in the event of a hazardous material release.

To National Fire Protection Association (NFPA)

2021-01-I-TN-R10

Revise NFPA 101 *Life Safety Code*, NFPA 55 *Compressed Gases and Cryogenic Fluids Code*, or NFPA 400 *Hazardous Materials Code* to address conditions which may require multiple means of egress from elevated industrial structures containing hazardous materials posing physical and health hazards, regardless of their combustibility, burn rate, or likelihood of explosion. The guidance should address egress situations for workers on unwalled, elevated structures in the presence of materials posing physical and health hazards. Specify the minimum number of egress points to increase the likelihood of worker escape in the event of a hazardous material release.

1 BACKGROUND

1.1 WACKER

Wacker Polysilicon North America LLC (Wacker) began production operations in Charleston, Tennessee, in 2016. Wacker manufactures silicones and hyperpure[a] polycrystalline silicon (polysilicon) used in the production of electronics processors and photovoltaics for solar panels. In 2019, Wacker also began producing pyrogenic silica,[b] which is used in the manufacturing of silicone rubber, paints, coatings, toothpaste, and tomato ketchup [1]. Wacker employs approximately 700 workers at the Charleston, Tennessee, site.

1.2 CONTRACTORS

1.2.1 JAKE MARSHALL

Jake Marshall, LLC (Jake Marshall) is a general mechanical contractor located in Chattanooga, Tennessee, and provides piping and equipment fabrication, maintenance, and pipefitting, as well as other services [2]. Wacker contracted Jake Marshall to provide maintenance and pipefitting services.

1.2.2 PEN GULF

Pen Gulf Inc. (Pen Gulf) is a contract company specializing in industrial coatings and insulation, as well as other services. It is headquartered in Pensacola, Florida, with a regional office in Charleston, Tennessee [3]. Wacker contracted Pen Gulf to provide insulation maintenance on process piping.

1.3 HYDROGEN CHLORIDE AND HYDROCHLORIC ACID

The polysilicon manufacturing operations at the Wacker facility require the use of hydrogen chloride (HCl). Gaseous HCl is a colorless, corrosive gas with a sharp, irritating odor. Gaseous HCl is a vapor at atmospheric temperature and pressure. Exposure to gaseous HCl can cause injuries ranging from mild irritation of the eyes, lungs, and skin, to severe burns, inflammation of the respiratory tract, accumulation of fluid in the lungs, and death [4].

When HCl is dissolved in water, it forms hydrochloric acid. Hydrochloric acid is corrosive and can cause serious injuries in the event of a release [5]. Specifically, hydrochloric acid exposure can cause damage to the eyes, skin, and mucous membranes. Skin exposure to hydrochloric acid can cause severe burns, ulceration, and scarring [6].

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[a] Wacker defines “hyperpure” as elemental silicon containing impurities on the order of parts per trillion.

[b] Pyrogenic silica, also called fumed silica, is an amorphous silica made from byproducts of the hyperpure polysilicon process [1].

1.4 HYDROGEN CHLORIDE AND MATERIALS OF CONSTRUCTION

Gaseous HCl and hydrochloric acid are highly corrosive to most metal and metal alloy materials of construction commonly used for industrial piping and equipment [7]. To prevent equipment damage from corrosive HCl, the equipment in direct contact with HCl at the Wacker facility is designed with graphite[a] interiors or polytetrafluoroethylene (PTFE)[b] lining.

1.5 HEAT EXCHANGER AW234

The incident occurred when gaseous HCl released from a crack that formed in the vapor outlet nozzle of a heat exchanger in HCl service (referred to by Wacker as heat exchanger AW234) after a contractor pipefitter inadvertently over-tightened (torqued) flange bolts installed on the heat exchanger. The heat exchanger consisted of a carbon steel shell (which contained cooling water) and a graphite tube bundle (which contained HCl). A photograph of the heat exchanger is shown in Figure 1.

Figure 1. Heat exchanger AW234. (Credit: CSB)

The heat exchanger was equipped with a graphite outlet nozzle[c] from which gaseous HCl exited. As shown in **Figure 2**, the piping equipment connected to the graphite nozzle was constructed of PTFE and PTFE-lined carbon steel,[d] which was Wacker's preferred material of construction for HCl service.

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[a] Graphite, a crystalline form of carbon, is inherently corrosion resistant with good chemical stability, good thermal conductivity, and low permeability [35]. It is widely used in the manufacturing of heat exchangers, often as a composite material impregnated with a resin to form graphite that has excellent heat transfer characteristics that can withstand temperature and pressure fluctuations, as well as mechanical stresses encountered in normal industrial-process applications [36]. However, graphite is a brittle material with little plastic deformation, so material constructed of graphite must be designed such that tensile and shear stresses are avoided [41, p. 646].

[b] The Wacker Charleston facility utilizes a polytetrafluoroethylene (PTFE)-lined carbon steel piping.

[c] The gaseous HCl outlet nozzle was a four-inch diameter nozzle constructed of resin-impregnated graphite.

[d] The graphite vapor outlet nozzle was connected to a PTFE-lined spool piece using a carbon steel backing ring and blue-colored PTFE-coated fasteners. The spool piece was connected to a PTFE expansion joint, required by the exchanger manufacturer on all graphite nozzle connections to the exchanger (the tube side inlet nozzle as well as the vapor and liquid tube side outlet nozzles). The use of expansion joints on graphite heat exchangers minimizes stress loading applied to the graphite nozzles by connected piping and prevents damage to the graphite material caused by pipe loading stresses. The expansion joint was connected to a PTFE flange spacer, and the downstream piping was constructed of PTFE-lined carbon steel. The PTFE lining on the carbon steel is required to significantly reduce corrosion when in direct contact with HCl.

The bolts that were used to connect the nozzle equipment to the PTFE-lined carbon steel pipe required various tightening (torque) requirements, based on the materials of construction of the equipment being connected and the properties of the bolts. The heat exchanger manufacturer indicates that the recommended bolt torque for bolts connecting equipment to the graphite heat exchanger (the blue bolts in **Figure 2**) is 15-foot pounds (ft-lbs). By contrast, the torque requirement for connecting PTFE-lined carbon steel piping components (shown in **Figure 2**) is significantly higher, at 40 to 67 ft-lbs.

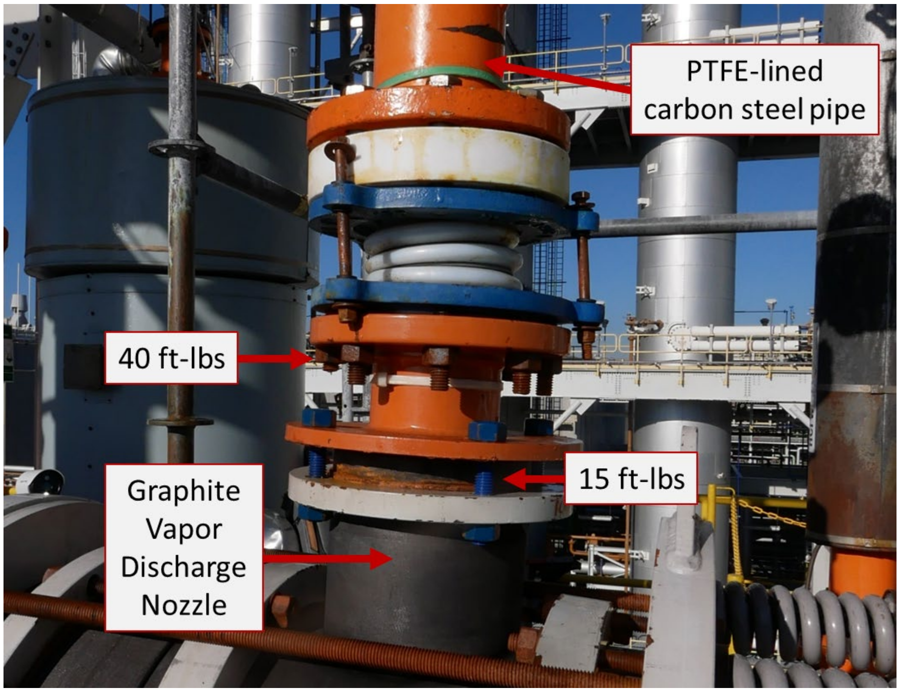

Figure 2. AW234 vapor discharge piping configuration. (Credit: CSB)

1.6 Retorquing Requirements

PTFE-lined piping, such as the equipment installed in the HCl regeneration unit, requires a retorquing of flange bolts to minimize leakage from bolt relaxation. The retorquing involves bringing the process unit to operating temperature, allowing it to cool to ambient temperatures, and retorquing to the set value. As the original equipment manufacturer (OEM) describes:

> A retorque should be applied within 24 hours of the initial torque or after the first thermal cycle. This allows for seating of the plastic and for relaxation of the bolts. If the system is to perform at elevated temperatures, it is recommended that hot water be circulated at the maximum operating temperature of the process (if possible) for a minimum of 24 hours. This allows for the pipe system to experience one thermal cycle. After cool-down, retorquing of the system should be done.[a]

[a] Excerpt from PTFE-lined piping OEM installation and operation manual.

Some Wacker personnel would refer to this method of retorquing PTFE-lined fittings as “hot torquing”, while others used the term to mean a torque of flanges at live operating conditions. This term was not documented in any official Wacker policy or procedure but was used as vernacular among Wacker personnel.

1.7 Equipment Access Structure

The AW234 heat exchanger was located on a fifth-floor platform, shown in **Figure 3**. The fifth-floor platform was equipped with a single staircase, visible in **Figure 3**, for access and egress. The platform was approximately 70 feet above the ground.

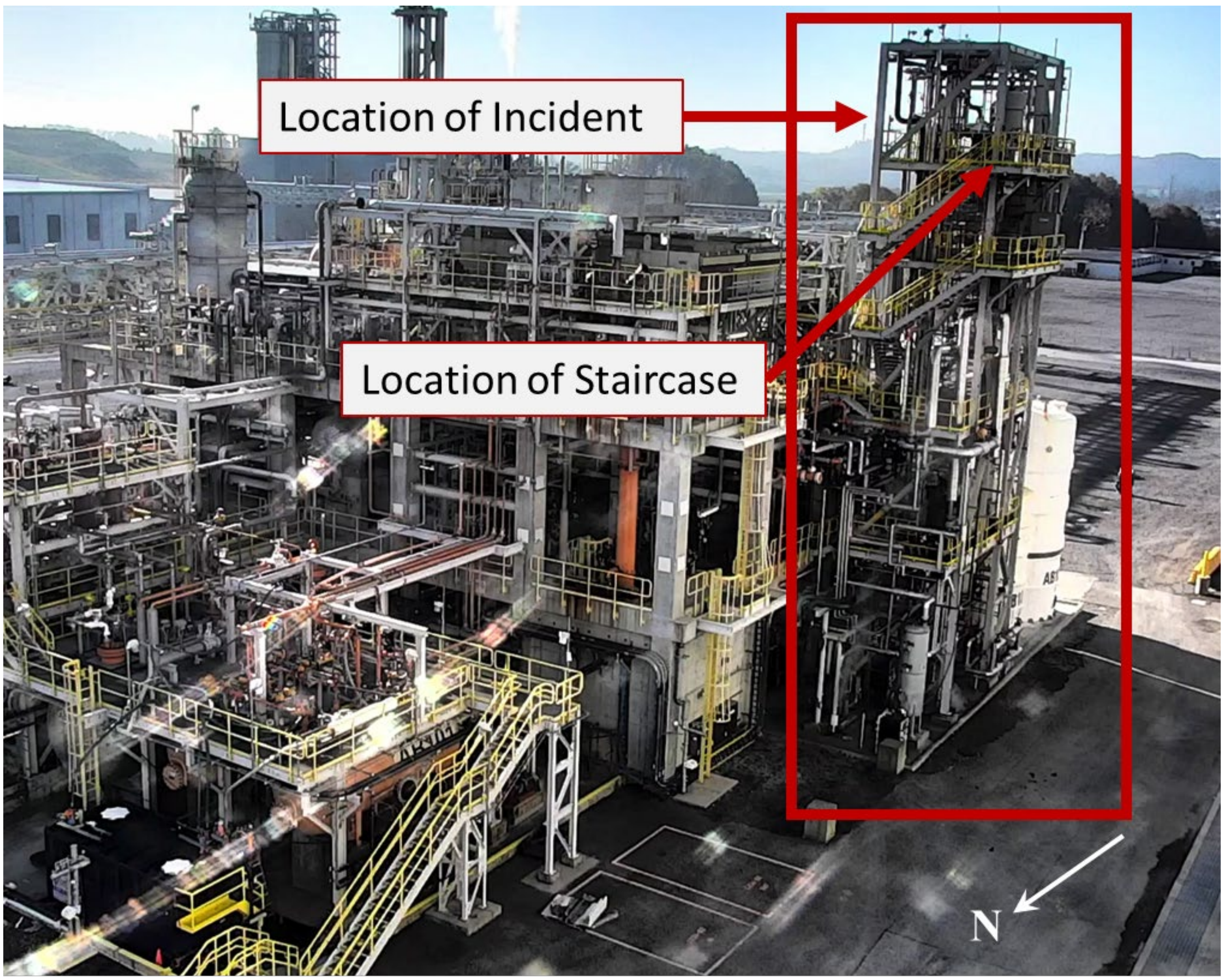

Figure 3. Equipment access structure where incident occurred. Directional arrow is approximate. (Credit: Wacker, annotations by CSB)

Scaffolding had been assembled on the fifth floor (**Figure 4**) to support scheduled maintenance activities. An emergency safety shower (**Figure 5**) was also located on the fifth-floor platform.

Figure 4. Scaffolding located near the release obstructing movement on the platform. (Credit: CSB)

Figure 5. Fifth-floor safety shower. (Credit: CSB)

1.8 Regulatory Coverage

Wacker is regulated by the U.S. Occupational Safety and Health Administration (OSHA) Process Safety Management (PSM) Standard (29 CFR 1910.119) and the U.S. Environmental Protection Agency (EPA) Risk Management Program (RMP) Rule (40 CFR 68) for its processing of highly hazardous chemicals and extremely hazardous substances, including HCl [8, 9]. The Tennessee Occupational Safety and Health Administration (TOSHA) oversees an OSHA-approved state plan and is responsible for PSM compliance in Tennessee.

1.9 Description of Surrounding Area

Figure 6 shows the Wacker Polysilicon facility and depicts the area within one, three, and five miles of the facility boundary. The surrounding area within one mile of the facility is rural, with approximately 10 residences, and includes other industrial facilities. **Table 1** summarizes the demographic information for census blocks immediately surrounding the facility.[a] Detailed demographic data are included in **Appendix B**.

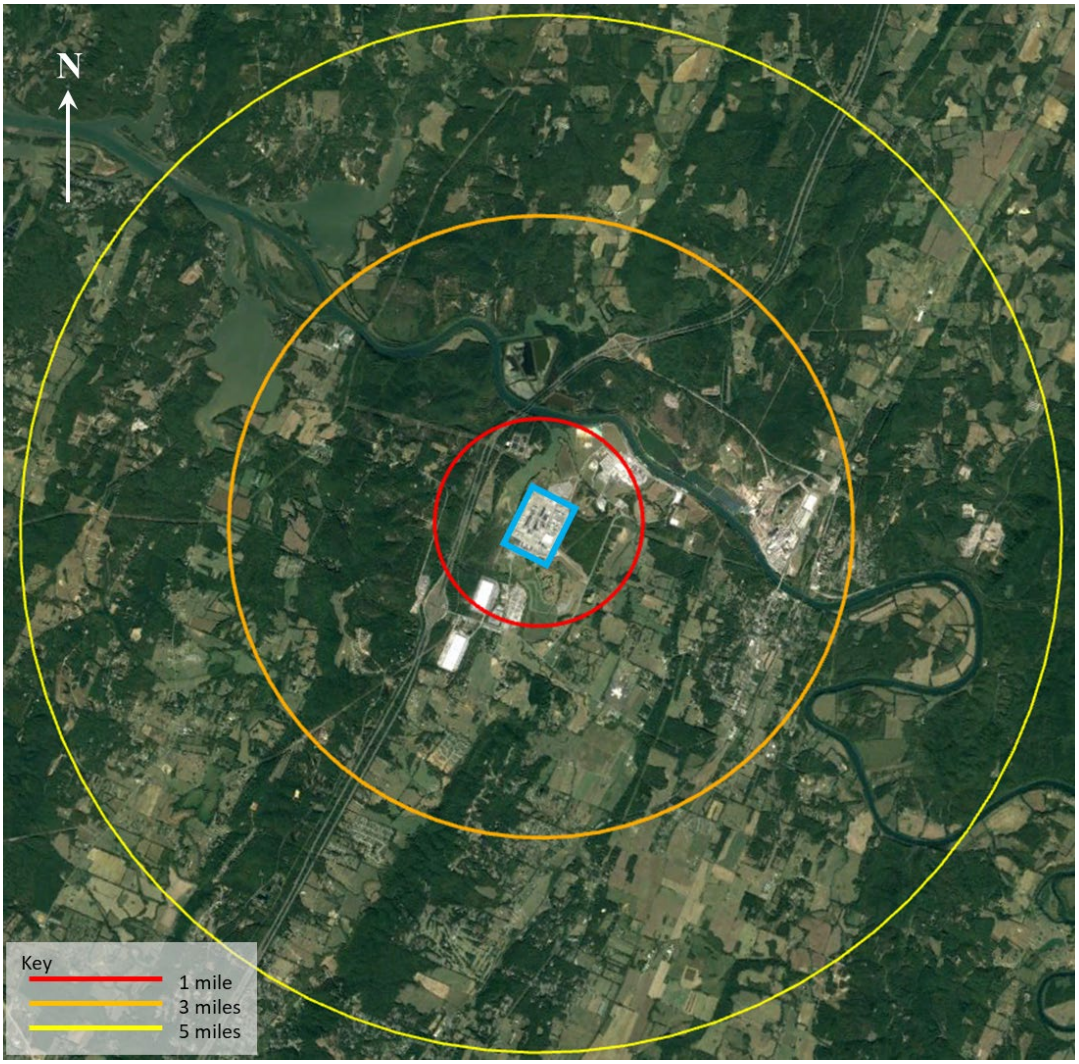

Figure 6. Overhead satellite image of the Wacker Polysilicon facility (blue) and the surrounding area. (Source: Google, annotations by CSB)

[a] The smallest census data breakdown includes populations up to 5 miles from the facility.

Table 1. Summarized demographic data for census blocks in the direct vicinity of the Wacker Polysilicon facility. (Source: Census Reporter [10])

Race & Ethnicity		Per Capita Income[a]	Number of Housing Units	Types of Housing Units	
White	85%	$29,608	2,621	Single Unit	78%
Black	5%			Multi-Unit	6%
Native	0%			Mobile Home	15%
Asian	1%			Boat, RV, Van, etc.	0%
Islander	0%				
Other	0%				
Two+	3%				
Hispanic	6%				

[a] The Census Bureau reports that the 2021 per capita income for the United States is $41,285 [40].

2 INCIDENT DESCRIPTION

On November 2, 2020, Wacker initiated a scheduled two-week outage, called a turnaround, of the HCl regeneration unit to perform routine maintenance, equipment upgrades, and equipment repairs. During this turnaround, Wacker replaced segments of the AW234 heat exchanger.

During the night shift on November 12, 2020, Wacker operators restarted the HCl regeneration unit, introduced acid into the system, and brought the unit to operating temperatures and pressures. At approximately 7:00 a.m. on November 13, 2020, the unit reached normal operating conditions.

At 8:00 a.m., Wacker issued Jake Marshall a work permit to perform a "hot torque" of heat exchanger AW234, whereby Jake Marshall was tasked with checking the torque on all the bolts on the heat exchanger vapor outlet piping (**Figure 7**). The Wacker permit authorizer and the Jake Marshall foreman then toured the work area and reviewed the permit and equipment to be torqued. The Wacker permit authorizer also provided the Jake Marshall foreman with an information packet containing the piping installation and operation manual, which included manufacturer-recommended torque values for PTFE-to-PTFE piping connections, but not for graphite connections such as that of the graphite heat exchanger nozzle. The manual included torque specifications for four-inch piping, which was the size of the piping installed on the AW234 nozzle and discharge line. The packet included torque specifications for PTFE-coated bolts as 24–40 ft-lbs, and non-PTFE-coated bolts as 40–67 ft-lbs. The information provided in the packet pertained only to PTFE-to-PTFE connections. The packet provided to Jake Marshall did not contain information indicating the 15 ft-lb torque recommendation for bolts connected to the graphite heat exchanger nozzle. Prior to the date of the incident,[a] Wacker had provided Jake Marshall with the heat exchanger design drawing, which specified the 15 ft-lb torque requirement. The design drawing was posted in a nearby meeting trailer. However, on the date of the incident, Jake Marshall workers performing the torquing task were not in possession of the design drawing.

At 8:10 a.m., the Wacker permit authorizer left the area and the Jake Marshall foreman led one journeyman and two apprentices to the AW234 heat exchanger to review the tasks and indicate the specific piping connections they were to torque. Once verbal instructions were provided, the workers returned to ground level to prepare for the work, and the foreman left the area.[b]

Around 9:15 a.m., Pen Gulf workers arrived on the fifth floor and began preparing for insulation activities. Unaware of the planned permitted torquing work, Pen Gulf employees were wearing the minimum personal protective equipment (PPE) required by Wacker: flame-resistant clothing, steel-toe safety boots, and hard hats, with escape respirators and safety harnesses in their possession, as well as safety glasses and gloves.

[a] The CSB was unable to determine the exact date in which Wacker provided the heat exchanger design drawing to Jake Marshall.

[b] The foreman was the supervisor of the Jake Marshall pipefitters. The journeyman is a licensed plumber in the state of Tennessee [37]. Apprentices are workers enrolled in a local apprenticeship training program through the U.S. Department of Labor, Bureau of Apprenticeship and Training [38]. In execution of the hot torquing task, the foreman supervised the activities of all of the Jake Marshall workers, and the journeyman pipefitter oversaw the activities of the apprentice pipefitters.

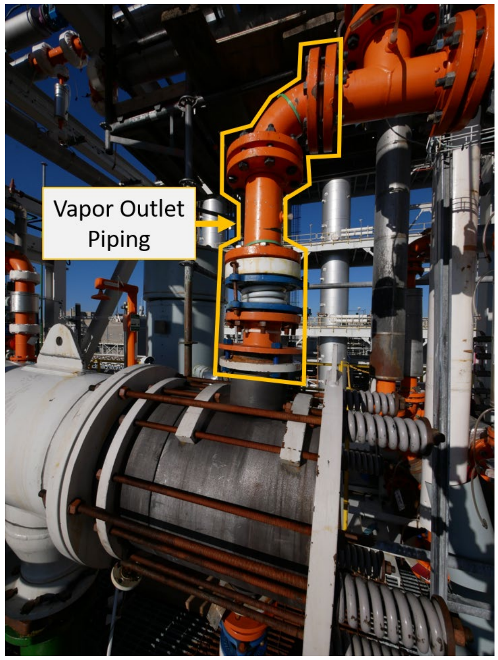

Figure 7. HCl vapor outlet piping on the AW234 heat exchanger vapor outlet nozzle. (Credit: CSB)

Some time before 10:00 a.m., the Jake Marshall journeyman and apprentice pipefitters returned to the fifth floor of the structure wearing full-body chemical-resistant suits, rubber boots and gloves, and full-face respirators with acid-gas cartridges as required by an internal Jake Marshall policy covering work involving piping containing hazardous chemicals.[a] Before they began the work, the Jake Marshall journeyman instructed an apprentice on which bolts to torque on the AW234 vapor outlet line, which included both PTFE-to-PTFE flanged connections requiring a 40 ft-lb torque, and PTFE-to-graphite flanged connections, which according to the manufacturer, required a 15 ft-lb torque (see Section 1.5 and **Figure 2**), although the journeyman and apprentice were not in possession of any documentation indicating the 15 ft-lb torque requirement. The journeyman instructed the apprentice to contact the Jake Marshall foreman for further instructions once initial torquing was complete. The journeyman provided the apprentice with a torque wrench set to 40 ft-lbs and moved to overview work in another location in the area.

When the Pen Gulf workers encountered the Jake Marshall workers preparing to begin the torquing task wearing chemical protective clothing and respirators, they questioned the Jake Marshall workers as to whether they (the Pen Gulf employees) were allowed to be in the area. A Jake Marshall employee told the Pen Gulf workers that they could remain in the area since the Jake Marshall workers were not working with chemicals. At this time

[a] Wacker set the minimum PPE requirements for the facility. However, Jake Marshall chose to implement more protective PPE requirements for the torquing task. Following a previous chemical release incident in July 2020 at Wacker in which Jake Marshall employees sustained severe chemical burns, Jake Marshall implemented an internal company policy requiring employees working on piping containing a hazardous chemical to wear chemical suits. In addition, Jake Marshall completed a hazard assessment checklist for the day's hot torquing work that required Jake Marshall workers to wear chemical boots, chemical suits, and respiratory protection (full-face respirators with acid-gas cartridges) in addition to Wacker's minimum PPE requirements.

there were three Jake Marshall and four Pen Gulf employees on the platform,[a] located in the approximate areas shown in **Figure 8**.

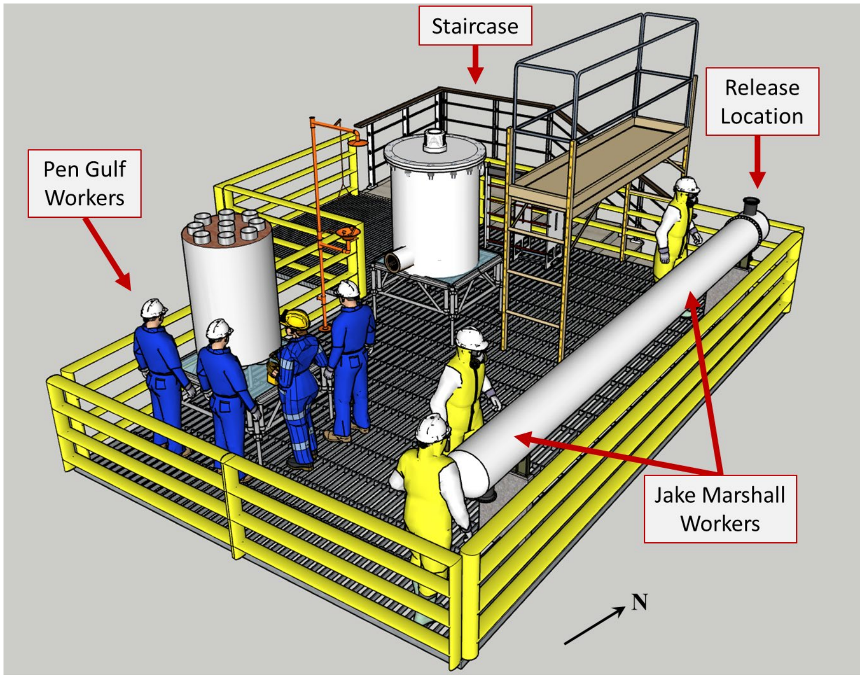

Figure 8. Pen Gulf and Jake Marshall work locations. Figure is not to scale and is intended to provide a general spatial representation of workers and equipment. (Credit: CSB via SketchUp)

Just after 10:00 a.m., the Jake Marshall apprentice pipefitter used the torque wrench set at 40 ft-lbs to check the torque on the blue-colored bolts (shown in **Figure 9**), which have a manufacturer-recommended torque value of 15 ft-lbs. At 10:04 a.m., the excess torque applied to the blue-colored bolts caused the graphite heat exchanger AW234 to crack, releasing gaseous HCl (**Figure 10**).

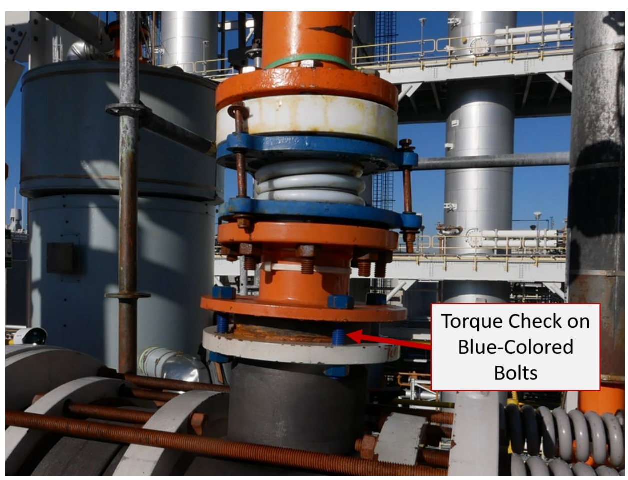

Figure 9. Torque check location. A Jake Marshall employee was checking the bolts connecting the graphite flange when the release occurred. (Credit: CSB)

[a] The fifth floor is approximately 70 feet above ground level and measures 19 feet wide and 38 feet long.

Figure 10. Image of HCl release at the time of release (left) and 15 seconds after release (right). (Credit: Wacker)

A white gaseous HCl cloud filled the area within 15 seconds (**Figure 10**), preventing the workers on the platform from being able to see their surroundings. When the Jake Marshall apprentice pipefitter attempted to move away from the release, his chemical suit was snagged and tore open, allowing HCl to enter the suit and cause chemical burns to his skin. While engulfed in the white HCl cloud, he also bumped into equipment on the platform, which knocked off his respirator. Due to the breach of his PPE and location of the release, the apprentice pipefitter was unable to escape to the single staircase to exit the platform. He moved to the opposite side of the platform where the other Jake Marshall and Pen Gulf employees had been working (**Figure 11**). Jake Marshall workers placed the injured worker in the adjacent safety shower to protect him from the release (**Figure 5**).

Three of the four Pen Gulf employees put on their escape respirators. Realizing they would have to walk through the chemical release to access the sole platform staircase to escape the area, these three Pen Gulf workers began climbing down piping on the side of the structure, approximately 70 feet above the ground. While climbing down, all three workers fell to the ground. One worker was fatally injured from the fall, and two sustained serious injuries.

The remaining Pen Gulf worker received assistance putting on her escape respirator from a Jake Marshall worker, who, wearing chemical-resistant PPE, also attempted to shield her from the release. The release continued for approximately three minutes, until all gaseous HCl had escaped from the system. After the release stopped at approximately 10:07 a.m., the three Jake Marshall workers and one Pen Gulf worker used the staircase to evacuate the area and reach the ground.

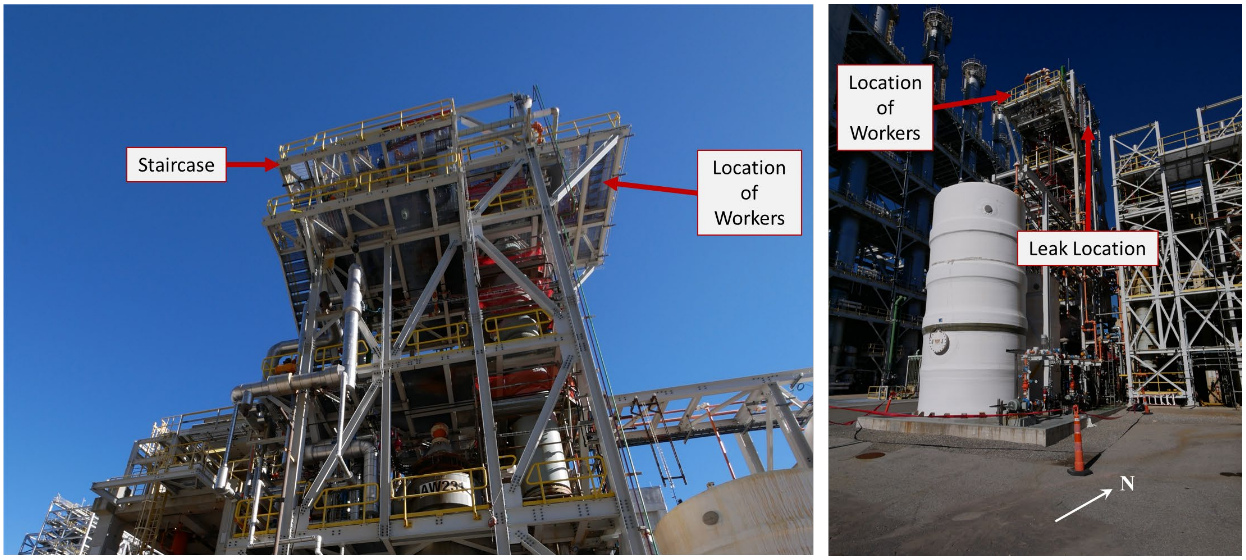

Figure 11. Location of trapped workers. When the release occurred, two Jake Marshall employees and four Pen Gulf employees were working on the south end of the platform. Directional arrow is approximate. (Credit: CSB)

3 Technical Analysis

A leak test was conducted on the heat exchanger involved in the incident to determine the approximate location of the failure. The test identified a leak on the heat exchanger vapor outlet nozzle. The leak was under the carbon steel ring that was connected to the blue bolts that the Jake Marshall employee was torque checking (**Figure 12**).

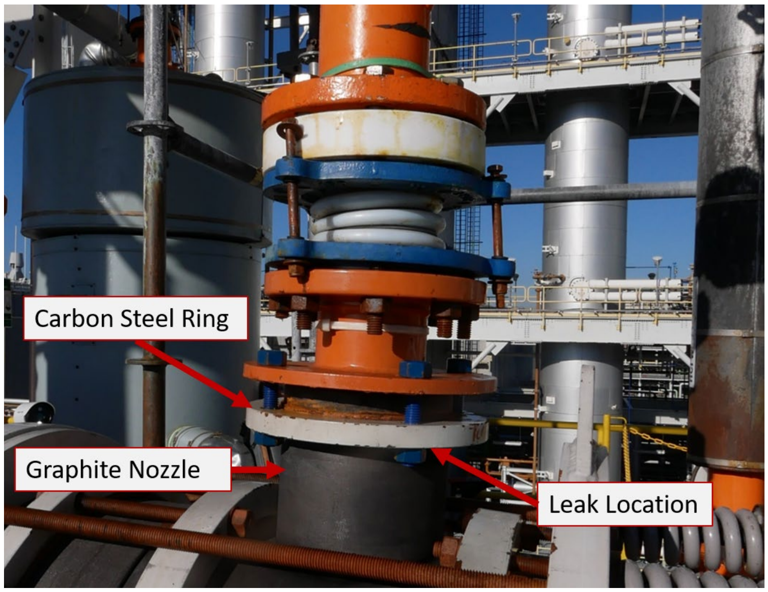

Figure 12. Location of leak. Leak tests on the heat exchanger revealed a leak from the graphite nozzle underneath a carbon steel ring used to attach the nozzle to carbon steel piping. (Credit: CSB)

Following the incident, Wacker commissioned testing and failure analysis of the AW234 graphite nozzle, which included laboratory analysis; non-destructive testing (NDT); fractography; scanning electron microscopy (SEM); and tensile, flexural, and thermal expansion testing. The graphite AW234 heat exchanger nozzle was found to have failed from a full circumferential fracture on the top flange, as shown in **Figure 13**. Destructive testing indicated that the nozzle fracture was consistent with brittle overload. The U.S. Chemical Safety and Hazard Investigation Board (CSB) concludes that the failure of the graphite heat exchanger nozzle was due to over-torquing the bolts connecting the graphite nozzle to PTFE-lined equipment.

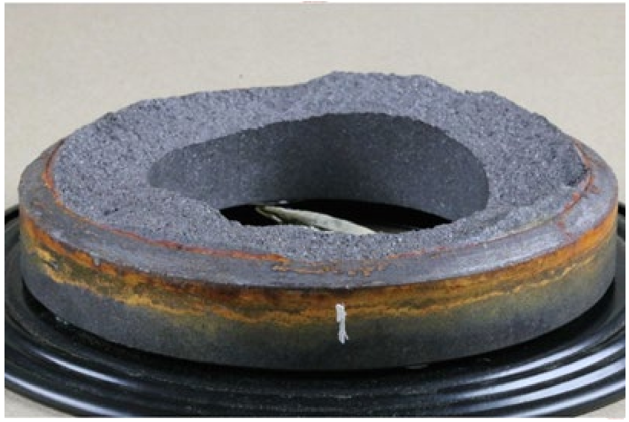

Figure 13. AW234 graphite nozzle fracture. (Credit: Wacker)

Further analysis identified potential radial misalignment between the AW234 nozzle and the outlet piping (as shown in **Figure 14**). Misalignment could have imposed external loading that resulted in stresses within the graphite nozzle. While misalignment stresses may typically be mitigated by the present expansion joint, it is possible that if sufficient torque had been applied to the flanged connection to initiate cracks, the misalignment stresses could have provided the driving force to complete the nozzle fracture.[a]

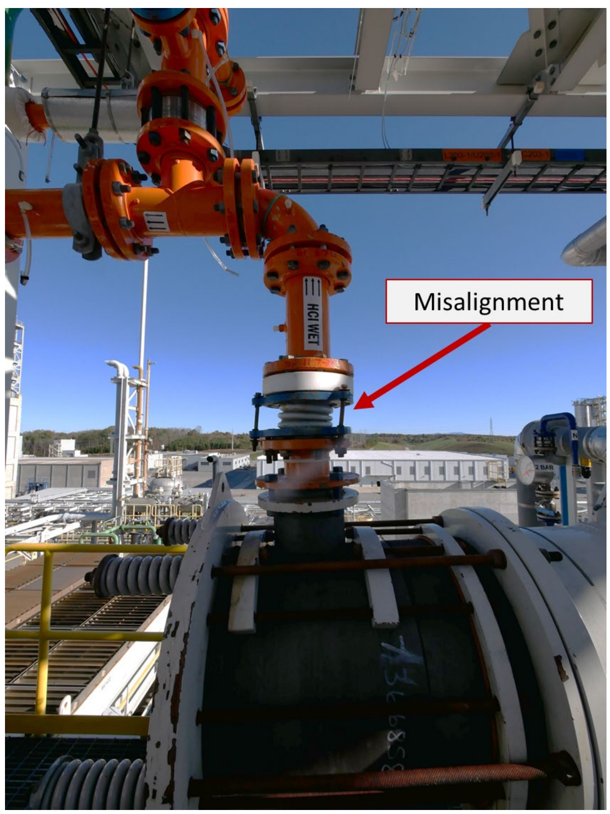

Figure 14. Possible radial misalignment on AW234 outlet piping. (Credit: CSB)

[a] While the misalignment may have exacerbated the fracture, the CSB did not consider misalignment of the vapor outlet piping causal to the nozzle failure, and therefore, piping misalignment is not detailed in this report.

4 Safety Issues

The following sections discuss the safety issues contributing to the incident, which include:

- Written Procedures
- Control of Hazardous Energy
- Simultaneous Operations (SIMOPs)
- Means of Egress

4.1 Written Procedures

4.1.1 Regulatory Requirements and Industry Guidance

The PSM Standard and RMP Rule require Wacker to implement maintenance procedures [8, 9].[a] The Center for Chemical Process Safety's (CCPS's) *Guidelines for Writing Effective Operating and Maintenance Procedures* specifies elements of effective procedures, which include [11, pp. 57-77]:

- All information necessary for performing the procedure is included in the procedure or referenced.
- Procedure steps are written in short, concise sentences.
- Procedure steps that must be performed in a fixed sequence are identified as such.
- Operating or maintenance limits or specifications are written in quantitative terms.
- Procedures should provide instructions for all reasonable contingencies. If contingency instructions are used, the contingency statement precedes the action statement.
- If conditions or criteria are used to help the user make a decision or recognize a condition, the conditions precede the action.
- Conditional instructions should be easy to understand.
- Graphs, charts, and tables in procedures are designed so that values can be easily and accurately extracted and interpreted.

In addition, CCPS provides the following consideration for maintenance procedures [11, pp. 55-56]:

> Maintenance procedures require special consideration depending upon the type of maintenance force your site maintains. If your site uses cross-trained maintenance personnel, your facility may need maintenance procedures that are

[a] 29 CFR § 1910.119(j), 40 CFR § 68.73

written to a very high level of detail. The increased use of contract maintenance personnel at facilities presents a similar problem.

Referencing vendor manuals is a choice that maintenance managers can use to keep numbers of procedures manageable, but it implies another level of document control. If you reference vendor manuals in maintenance procedures, your site must possess these documents and ensure they are accessible, up to date, and accurate.

Vendor manuals often do not provide the application-specific cautions, warnings and level of detail that your site may need. Vendor manuals are usually written generically in terms of the process application and for generic models of equipment. Your maintenance procedures may need to augment this information in order to reflect your site needs accurately.

4.1.2 Verbal Instructions

Verbal instructions for the AW234 retorquing task were communicated through multiple levels of staff, from the Wacker permit authorizer to the contractor performing the task, as follows: (1) the Wacker permit authorizer provided verbal instructions for the AW234 torquing task to the Jake Marshall foreman, along with the piping installation and operation manual, (2) the Jake Marshall foreman provided verbal instructions to the Jake Marshall journeyman and apprentice pipefitters, and (3) the journeyman set the torque wrench to 40 ft-lbs and provided verbal instructions to the Jake Marshall apprentice pipefitter. The CSB found that none of these communications relayed the 15 ft-lb torque requirement for the graphite heat exchanger nozzle. Based on interview accounts, each person believed they were communicating and understanding the torque requirements correctly. However, the CSB concludes that Wacker's and Jake Marshall's reliance on verbal instructions, communicated sequentially by three separate people without a detailed task-specific procedure, increased the likelihood of miscommunication or misunderstanding of the task steps and precautions.

KEY LESSON

Language, vernacular, and jargon, when undefined and undocumented, can result in different interpretations of the same terminology. It is important that localized terminology referring to actions and tasks on process equipment be officially defined in a site-specific policy or procedure.

The reliance on verbal communications also resulted in Wacker personnel using inconsistent vernacular for "hot torque." As detailed in Section 1.6, the piping installation and operation manual provides instructions to execute a thermal cycling retorquing protocol of PTFE-to-PTFE piping following the restart of process equipment. Based on interviews with Wacker and Jake Marshall employees, some staff used the term "hot torque" to mean a retorque at cooled conditions following a thermal cycle, as described in the piping installation and operation manual, while others used the term to mean a torque of flanges at live operating conditions.[a] This second

[a] At the same time the AW234 torquing task was being executed, other Jake Marshall workers were also tasked with "cold torquing" heat exchanger AW232, a different heat exchanger on the bottom floor of the tower. The instructions Wacker provided to Jake Marshall for "cold torquing" was consistent with the retorque method detailed in the piping installation and operation manual.

definition is more consistent with the American Society of Mechanical Engineers (ASME) PCC-1-2019 *Guidelines for Pressure Boundary Bolted Flange Joint Assembly*, which indicates that "hot torque" is a synonym for "start-up retorque," which it defines as "tightening all bolts on a joint while the unit is coming up to operating temperature in a circular pass until the nuts no longer turn. Start-up retorque (also referred to as hot torque) is performed to increase the residual operational stress on the gasket (to recover initial gasket relaxation), to minimize the likelihood of leakage" [12, p. 35] (emphasis added).

The CSB concludes that the development of documentation and training defining different types of torquing requirements, such as "hot torquing" as applicable, could have helped to eliminate the inconsistent vernacular at the Wacker facility. The CSB recommends that Wacker ensure that terms such as "hot torque" are clearly defined in a documented policy or procedure and employees and contractors are trained on these terms.

4.1.3 Lack of Procedure

The piping manual provided to Jake Marshall workers was not a maintenance procedure; rather, it was a manual of OEM instructions for the installation and operation of lined piping. As shown in **Figure 15**, the OEM provides ranges of recommended torque values pertaining to certain types of piping connections, such as PTFE-to-PTFE connections, based on piping size and bolts used.

While the information in the manual provides important guidelines for applying proper torque values and retorquing methods, the information is not specific to the AW234 heat exchanger or its connected piping, which included PTFE-to-graphite connections that were not covered in the manual. Rather, torque requirements for the graphite heat exchanger were contained in the manufacturer's drawing of the exchanger, which the Jake Marshall workers on the structure did not have in their possession.

The piping manual and verbal instructions did not properly constitute an effective written maintenance procedure for the AW234 torquing task. The CSB concludes that Wacker did not establish, implement, or adhere to detailed and job-specific maintenance procedures relating to torquing tasks on the AW234 heat exchanger. Instead, Jake Marshall contractors were provided unclear and undocumented instructions for torquing the bolts on the heat exchanger. The CSB also concludes that had Wacker used the information from the piping installation and design manual and the manufacturer's drawing of the heat exchanger to develop specific torquing procedures for the HCl regeneration unit and the AW234 heat exchanger, it is likely that the contractors would have applied the correct torque values to the AW234 heat exchanger PTFE-to-graphite connections, which would have prevented the incident. In addition, equipment design features that would require the use of different tools would be consistent with the concept "Prevention through Design." NIOSH defines Prevention through Design as "…anticipating and designing out or eliminating safety and health hazards in facilities, work methods, and operations, processes, equipment, tools, products, new technologies, and the organization of work" [13]. The CSB recommends that Wacker update its maintenance policies to

KEY LESSON

Written procedures are a critical tool for ensuring safe operations and maintenance activities. Procedures consolidate information required to execute a given task into easy-to-understand step-by-step instructions, with specific reference to safety precautions and crucial actions. Written procedures for hazardous operations should be prepared as part of robust safe work practices, including on temporary or ancillary maintenance activities.

require detailed maintenance procedures for torquing activities that clearly communicate differing torque specifications through visual means.

ASME B16.5 Class 150 Systems - Lightly Oiled A193 Gr. B7 Bolts and A194 2H Nuts									
Pipe Size NPS (DN)		Bolt Torque, ft-lb per Bolt (Nm per bolt)							
		PP		PVDF/ETFE		PTFE		PFA	
		Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.
1/2	(15)	- -	- -	- -	- -	6 (9)	11 (15)	9 (13)	14 (19)
3/4	(20)	- -	- -	- -	- -	9 (13)	16 (22)	14 (19)	20 (28)
1	(25)	13 (18)	17 (24)	17 (24)	21 (29)	8 (11)	13 (18)	12 (17)	17 (24)
1 1/2	(40)	31 (43)	41 (56)	41 (56)	50 (68)	19 (26)	31 (43)	28 (38)	41 (56)
2	(50)	65 (89)	85 (116)	85 (116)	104 (142)	39 (53)	65 (89)	59 (81)	85 (116)
3	(80)	103 (140)	134 (182)	134 (182)	165 (224)	62 (85)	103 (140)	93 (127)	134 (182)
4	(100)	67 (91)	88 (120)	88 (120)	108 (147)	40 (55)	67 (91)	61 (83)	88 (120)
6	(150)	124 (169)	161 (219)	161 (219)	199 (270)	75 (102)	124 (169)	112 (152)	161 (219)

ASME B16.5 Class 150 - PTFE-Coated A193 Gr. B7 Bolts and A194 2H Nuts									
Pipe Size NPS (DN)		Bolt Torque, ft-lb per Bolt (Nm per bolt)							
		PP		PVDF		PTFE		PFA	
		Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.
1/2	(15)	- -	- -	- -	- -	4 (6)	6 (9)	6 (9)	8 (11)
3/4	(20)	- -	- -	- -	- -	6 (9)	9 (13)	9 (13)	12 (17)
1	(25)	8 (11)	10 (14)	10 (14)	13 (18)	5 (7)	8 (11)	7 (10)	10 (14)
1 1/2	(40)	19 (26)	25 (34)	25 (34)	30 (41)	11 (15)	19 (26)	17 (24)	25 (34)
2	(50)	39 (53)	51 (70)	51 (70)	62 (85)	23 (32)	39 (53)	35 (48)	51 (70)
3	(80)	62 (85)	80 (109)	80 (109)	99 (135)	37 (51)	62 (85)	56 (76)	80 (109)
4	(100)	40 (55)	53 (72)	53 (72)	65 (89)	24 (33)	40 (55)	36 (49)	53 (72)
6	(150)	75 (102)	97 (132)	97 (132)	119 (162)	45 (62)	75 (102)	67 (91)	97 (132)

Figure 15. PTFE-lined piping OEM bolt torque specifications for PTFE-to-PTFE piping connections. (Top) Red, solid box indicates minimum and maximum values for non-coated, lightly oiled bolts for the size of piping connected to the AW234 heat exchanger. (Bottom) Purple, dashed box indicates minimum and maximum values for PTFE-coated bolts for the size of piping connected to the AW234 heat exchanger. (Credit: OEM design manual)

4.2 Control of Hazardous Energy

Wacker managed the control of hazardous chemical energy through procedures titled *Lock, Tag and Try* and *First Line Break – Return to Service*. The procedures present precautions and requirements for performing work on equipment containing hazardous chemical energy, including development of an energy isolation plan, methods for energy isolation, PPE requirements, personnel restrictions, and barricading.

While torquing activities may involve work on equipment containing hazardous chemicals, Wacker does not define or treat such activities as line breaks, which it defines as an activity in which process equipment is opened in preparation for maintenance or repair. In addition, the safe work permit issued to Jake Marshall to perform the hot torque activities did not consider the hazardous energy control precautions, as shown in **Figure 16**, since it did not involve the intentional opening of a line.[a]

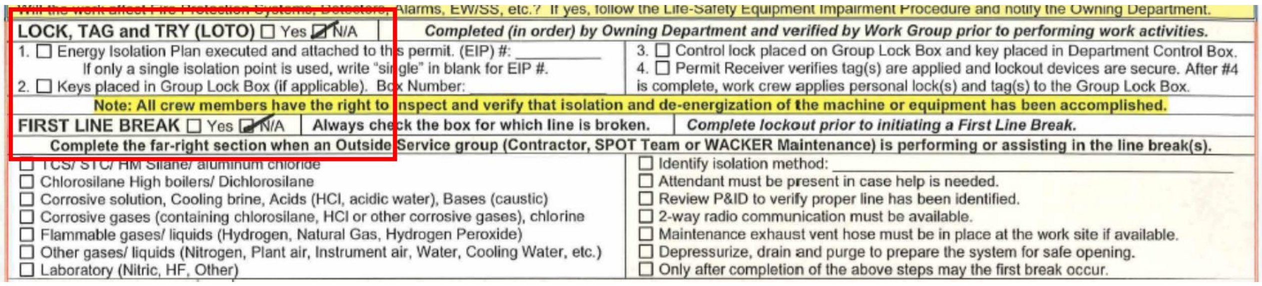
Alarms, EW/SS, etc.? If yes, follow the Life-Safety Equipment Impairment Procedure and notify the Owning Department.
LOCK, TAG and TRY (LOTO) ☐ Yes ☑ N/A | *Completed (in order) by Owning Department and verified by Work Group prior to performing work activities.*
1. ☐ Energy Isolation Plan executed and attached to this permit. (EIP) #: ______
If only a single isolation point is used, write "single" in blank for EIP #.
2. ☐ Keys placed in Group Lock Box (if applicable). Box Number:
3. ☐ Control lock placed on Group Lock Box and key placed in Department Control Box.
4. ☐ Permit Receiver verifies tag(s) are applied and lockout devices are secure. After #4 is complete, work crew applies personal lock(s) and tag(s) to the Group Lock Box.
Note: All crew members have the right to inspect and verify that isolation and de-energization of the machine or equipment has been accomplished.
FIRST LINE BREAK ☐ Yes ☑ N/A | Always check the box for which line is broken. | *Complete lockout prior to initiating a First Line Break.*
Complete the far-right section when an Outside Service group (Contractor, SPOT Team or WACKER Maintenance) is performing or assisting in the line break(s).
☐ TCS/ STC/ HM Silane/ aluminum chloride
☐ Chlorosilane High boilers/ Dichlorosilane
☐ Corrosive solution, Cooling brine, Acids (HCl, acidic water), Bases (caustic)
☐ Corrosive gases (containing chlorosilane, HCl or other corrosive gases), chlorine
☐ Flammable gases/ liquids (Hydrogen, Natural Gas, Hydrogen Peroxide)
☐ Other gases/ liquids (Nitrogen, Plant air, Instrument air, Water, Cooling Water, etc.)
☐ Laboratory (Nitric, HF, Other)
☐ Identify isolation method: ______
☐ Attendant must be present in case help is needed.
☐ Review P&ID to verify proper line has been identified.
☐ 2-way radio communication must be available.
☐ Maintenance exhaust vent hose must be in place at the work site if available.
☐ Depressurize, drain and purge to prepare the system for safe opening.
☐ Only after completion of the above steps may the first break occur.

Figure 16. Excerpt from safe work permit to hot torque the AW234 heat exchanger with Lock, Tag and Try and First Line Break marked "N/A" (Not Applicable). (Credit: Wacker, annotations by CSB)

The American National Standards Institute (ANSI)/American Society of Safety Professionals (ASSP) Standard Z244.1-2016 (R2020) *The Control of Hazardous Energy Lockout, Tagout and Alternative Methods* provides requirements for the control of hazardous energy and covers activities such as repairing, adjusting, troubleshooting, servicing, and maintaining equipment or processes in which the unexpected release of stored energy or the actions of persons could result in harm [14, p. 15]. The standard states that "the control of hazardous energy includes isolation, de-energization and verification, and shall take into consideration the impacts of residual energy [14, p. 29]." When energy isolation methods are not used, the standard requires that users demonstrate that an alternative method will provide effective protection after hazards have been assessed and risks documented through a risk assessment[b] [14, p. 39].

In addition, ASME PCC-1-2019 *Guidelines for Pressure Boundary Bolted Flange Joint Assembly* states that "[a]n engineering and risk analysis of the proposed [hot torque] operation shall be carried out to establish that the operation can be performed safely" [12, p. 9].

The CSB concludes that Wacker did not perform a risk analysis to determine whether the hot torque task could be safely performed on operating equipment, nor did it implement precautions to mitigate the risk of torquing bolts on operating equipment prior to issuing a safe work permit to Jake Marshall workers. Had Wacker implemented the same precautions undertaken as part of a first line break, namely methods for energy isolation, PPE requirements, personnel restrictions, and barricading, it is likely that injuries to the Pen Gulf workers could have been prevented.

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[a] Wacker's Safe Work Permit procedure did not require the work permit preparer, approval authority, or work crew to perform a hazard assessment, except in the case of exceptions not requiring a safe work permit. Regardless, prior to performing the torquing task, Jake Marshall performed a checklist-based hazard assessment that identified the hazard of working around chemicals and required chemical boots, chemical suits, and respirator protection. The hazard assessment also identified the need for barricades; however, this was as a precaution to protect workers on the lower levels from overhead hazards, such as falling tools, not to restrict access to the fifth floor. As described in Section 2, the Pen Gulf workers may have already been present on the fifth floor when the Jake Marshall workers arrived. The hazard assessment did not consider hazardous energy isolation. The CSB notes that checklist-based hazard assessments relate to personal worker safety and not process safety.

[b] ANSI/ASSP Z244.1-2016 (R2020) provides methods for completing a risk assessment. The standard states: "The critical part of the risk assessment is to make certain that the hazards and failure modes are known prior to using the alternative method… A risk assessment should be performed to be certain that the tasks and hazards are identified, understood and addressed to reduce the risks to an acceptable level" [14, p. 46].

The CSB recommends that Wacker develop policy requirements to ensure that torquing activities performed on equipment containing hazardous energy are performed safely, such as through de-inventorying equipment or restriction of nonessential personnel and ensuring that essential workers wear proper PPE. Document these requirements in procedures, such as *Lock, Tag and Try; First Line Break – Return to Service*, or other procedures as applicable.

In addition, the CSB recommends that Wacker include procedural requirements for all torquing activities conducted on equipment containing hazardous material to perform an engineering and risk analysis and implement safeguards as a result of the risk analysis, per ASME PCC-1-2019 *Guidelines for Pressure Boundary Bolted Flange Joint Assembly* and ANSI/ASSP Z244.1-2016 *The Control of Hazardous Energy Lockout, Tagout and Alternative Methods*.

KEY LESSON

The control of hazardous energy should be considered whenever equipment containing hazardous energy is repaired, adjusted, serviced, and maintained, not only in situations in which equipment is intentionally opened. Prior to working on equipment containing hazardous energy, a risk assessment should always be performed to evaluate the need for energy isolation or other protective measures.

4.3 Simultaneous Operations (SIMOPs)

SIMOPs occur when two or more operations occur together at a time and place, and may interfere with each other, increase the risk of either activity, or introduce new risks to one or more of the operations [15]. As described below, while Wacker had in place work practices that *could have* identified SIMOPs and associated hazards, these work practices were not designed to formally evaluate SIMOPs and, as a result, did not identify the SIMOPs and the potential for increased risk to the Pen Gulf crew on the day of the incident.

4.3.1 Wacker Work Practices

4.3.1.1 Safe Work Permitting Process

Wacker documents its work permitting process in a Standard Operating Procedure (SOP) titled *Safe Work Permit*. Wacker defines the scope of the procedure as "…activities and conditions related to dangerous work activities, mechanical work (includes electrical, construction, etc.), maintenance, repair or construction work performed by Wacker personnel or contractors."

The *Safe Work Permit* SOP assigns "Owning Department Representatives" the responsibility to review all safe work permits for their department and verify that all hazards and safety precautions have been considered. These reviews are typically office based. The *Safe Work Permit* SOP then assigns additional tasks to a second individual, the permit authorizer, that, in some situations, *could* identify SIMOPs and prevent hazardous interactions, including the following:

1. "Inspecting the work area personally, to be certain that conditions are safe for the work to be done" and "Notifying appropriate personnel working in the area about the work that will be done under the permit, before allowing that work to begin," and

2. "Posting a copy of … the Safe Work Permit in the Control Center … as a communication tool."

The CSB found, however, that these precautions did not prevent or control the SIMOPs on the fifth floor of the equipment access structure on the day of the incident, as described below.

Failure to Identify SIMOPs During Permit Authorizer's Work Site Inspection

On November 10, 2020, the Wacker Owning Department Representative signed the safe work permit for the Pen Gulf reinsulation work. This permit was scheduled to last for three days, expiring on November 13, 2020 (the day of the incident). The Owning Department Representative's review was limited to ensuring that the hazards and associated precautions for the insulation task were properly evaluated. On November 13, 2020, the same Owning Department Representative signed the safe work permit for the Jake Marshall AW234 heat exchanger retorquing task. Again, his review was limited to ensuring that the hazards and associated precautions specific to the retorquing task were considered. Although he signed, and therefore was aware of, both safe work permits for both jobs, the Owning Department Representative did not consider in his review any SIMOPs.

Per the Wacker *Safe Work Permit* SOP, the best opportunity to identify SIMOPs was during the permit authorizer's work site inspection. However, when the Wacker permit authorizer "inspect[ed] the work area personally, to be certain that conditions are safe for the work to be done" and was to "notif[y] appropriate personnel working in the area about the work that will be done under the permit," the Pen Gulf work crew had not yet arrived onto the fifth-floor platform. As such, the permit authorizer did not realize that there was the potential for the Jake Marshall work task to hazardously impact another work crew. As the Wacker Owning Department Representative described:

> [The permit authorizer for the Jake Marshall retorquing task] walked the system down and I think just the timing of it, [he and the permit authorizer for the Pen Gulf reinsulation task] missed each other. Because once, you know, 8:00 comes around, 8:30, [8]:40, whatever time it was, they're getting their tools together to go up and do the job.

A separate Wacker permit authorizer reviewed the Pen Gulf work area on the morning of the incident prior to the Pen Gulf work taking place. During his walk-through, he did not encounter the permit authorizer for the Jake Marshall work or the Jake Marshall crew itself. As the Wacker permit authorizer overseeing the Pen Gulf work described to the CSB:

> Well, when I authorized this [Pen Gulf] permit none of [the Jake Marshall] work was going on. When I was out there none of this was going on. There was nobody else [on the structure] working when I walked through with [Pen Gulf].

Failure to Identify SIMOPs from Control Center

The *Safe Work Permit* SOP required the permit authorizer to "post a copy of … the Safe Work Permit in the Control Center … as a communication tool." The Control Center's permit board allowed the control room operators and others not involved in the day's permitted activities to understand the work being executed around the facility. As a Wacker permit authorizer described:

> [The permit board is] to show what work's being done out there. And so if, a lot of times, we're in the control room, we don't know exactly what's going on out there […]. […] But if we need, if we have somebody that wants to walk through mechanical integrity, for instance… Well, let me see the board and see what work's going on right now. And, well, I see this work's being done and there's a first break involved. Maybe you should wait until it's done.

This incident, however, occurred during the COVID-19 pandemic, and Wacker had implemented practices to reduce personnel in areas of crowding. To limit foot traffic in the control room, Wacker began permitting some tasks in the area manager's office, and copies of those permits were placed on the area manager's desk. Under this practice, some permits were posted in the control room, and some permits were placed on the area manager's desk (**Figure 17**), and there was no organized tracking system for Wacker employees to find which permits were in what location. While the CSB could not determine where the Pen Gulf and Jake Marshall safe work permits were displayed before the incident, this new, somewhat disorganized permit posting method in response to the COVID-19 pandemic may have contributed to the permit authorizers not realizing that two separate crews were scheduled to work on the fifth-floor platform on the day of the incident.

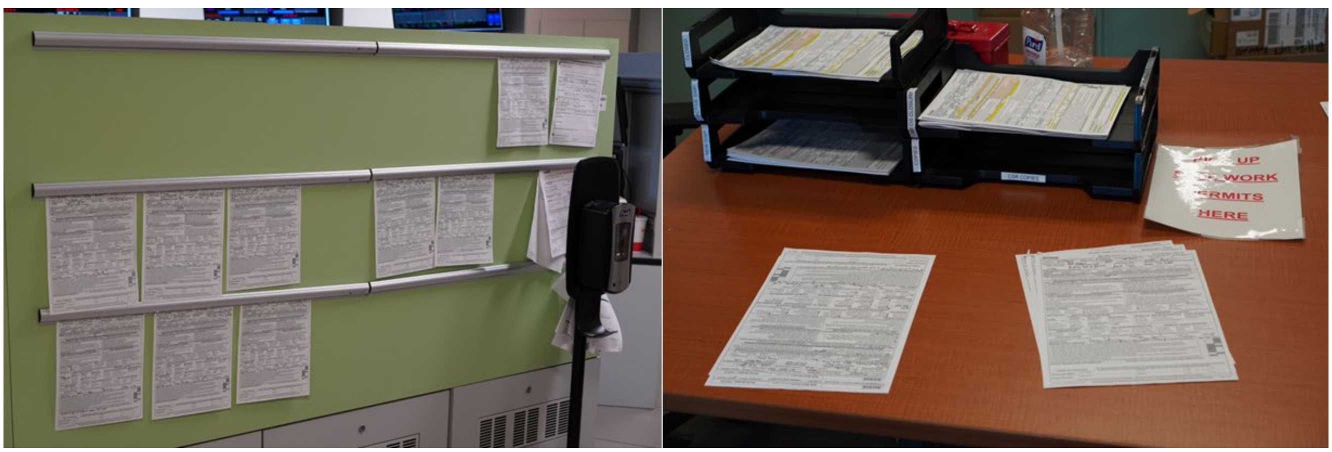

Figure 17. Active work permits posted on a board in the control room (left). Work permits on a table in the area manager's office (right). (Credit: CSB)

4.3.1.2 Wacker Simultaneous Operations Practices

It was not uncommon for multiple work crews to work simultaneously at Wacker. For example, during previous jobs, Wacker often issued safe work permits to Pen Gulf in work areas where other crews were working. The CSB identified the following conditions that contributed to Wacker's failure to identify and control the Jake Marshall and Pen Gulf SIMOPs on the day of the incident:

- Wacker did not have a SIMOPs policy or procedure, and therefore had no defined practice for identifying and controlling SIMOPs.

- Wacker's maintenance management culture often allowed for the co-location of several unrelated work crews supporting maintenance tasks or turnaround efforts.

- Wacker's safe work permit process did not explicitly require SIMOPs considerations and relied on the knowledge and decisions of the specialists authorized to sign and issue the work permits to the work crews.

- Wacker's permitting practice allowed any available specialist to serve as authorized signer of a work permit, regardless of their familiarity with the work or other activities planned in the same location. For example, the Wacker specialists who were authorized to issue work permits lacked awareness of other work ongoing in the same location. In addition, Wacker's COVID-19 restrictions made it difficult to post and review active work permits for a given area, resulting in further missed opportunities to identify SIMOPs.

- There are limited publicly available and published technical guidelines, industry standards, or regulations outlining the steps in a SIMOPs life cycle and execution of a SIMOPs review, hazard analysis, and risk assessment specific to stationary source chemical processes. Therefore, Wacker lacked the appropriate industry knowledge necessary to implement a successful SIMOPs program. More information on publicly available guidance on SIMOPs can be found in Section 4.3.2 below.

KEY LESSON

Owners and operators should always consider how simultaneous operations, or SIMOPs, could impact a given operation, whether by influencing a hazard or affecting the risk of the operation. SIMOPs should be identified and controlled via a hazard assessment prior to commencing a given operation or task. An established system to manage work permits can also identify risks associated with SIMOPs before they occur. A well-established system must be able to document the specific task to be executed, readily coordinate the issued permits, and identify scenarios of potential interaction between permitted work groups.

The CSB concludes that Wacker lacked a formalized SIMOPs process, failed to properly identify hazards introduced by co-located permitted work, and used an ineffective safe work permitting process, which resulted in the co-location of Jake Marshall and Pen Gulf work crews during the hot torquing and insulation work on the fifth floor of the equipment access structure. Consequently, Pen Gulf workers lacked awareness of the hazards and were unable to take precautions, such as delaying the reinsulation task or donning chemical-protective PPE, and as a result were unnecessarily exposed to the hazards of the hot torquing task.

The CSB recommends that Wacker develop and implement a formalized SIMOPs program addressing planned and/or permitted co-located work tasks that addresses:

- Identification of potential SIMOPs;

- Identification of potential hazardous interactions;
- Evaluation and implementation of necessary safeguards to allow for safe SIMOPs;
- Coordination, including shared communication methods, between the SIMOPs; and
- Inclusion of emergency response personnel or services in the planning and coordination of the SIMOPs.

4.3.2 SIMOPs Standards and Guidelines

Industry guidance directly concerning practices for recognizing and controlling SIMOPs has largely been restricted to offshore processing, such as oil and gas drilling, in response to the Piper Alpha disaster in 1988[a,b] [16, p. 6]. At the time of this report's publication, the CSB was unable to identify codes, standards, or regulations specifically relating to the identification and control of SIMOPs for maintenance activities conducted on stationary source chemical processes. The subsections below present an overview of currently available SIMOPs guidance and regulations (international and from the United States) identified by the CSB.

4.3.2.1 International Guidance

International Marine Contractors Association (IMCA)

The IMCA is an international trade association that promotes improvements in quality, health, safety, environmental, and technical standards in the offshore, marine, and underwater engineering fields [17]. The IMCA publication *Guidance on Simultaneous Operations (SIMOPS)* provides industry guidelines for a SIMOPs life cycle, which includes the following [17, p. 3]:

- Identify SIMOPs
- Kick-off meeting identifying scope of work
- Each party prepares work-specific dossiers
- SIMOPs assessment review
- Develop SIMOPs interface document
- Preparation for SIMOPs

[a] On July 6, 1988, an explosion on the Piper Alpha offshore platform in the North Sea resulted in 167 fatalities and loss of the platform. The failure of a condensate pump resulted in a standby pump being returned to service while offline for maintenance. The relief valve protecting the standby pump had been removed. Condensate and gas escaped and ignited, triggering a chain of fires and explosions on the platform. Divers were performing maintenance on the platform's supporting structures near the fire pump inlets, so the fire protection was disabled to protect the divers. Once the diving work was completed, the deluge system was not reinstated. The spread of the fire prevented crew members from activating the local pump controls, increasing the severity of the incident [39, pp. 44-45].

[b] The United Kingdom (UK) Health and Safety Executive (HSE) identified SIMOPs-related issues in the Piper Alpha permit-to-work system, including the lack of cross-referencing permits, deviation from procedures, lack of permit display, permits kept in multiple locations, and lack of communication between work crews [16].

- Carry out SIMOPs
- Change/deviation
- Closeout

United Kingdom (UK) Health and Safety Executive (HSE)

The UK HSE is Britain's regulatory authority for workplace health and safety [18]. HSE's *Guidance to Permit-to-Work Systems* provides guidelines for ensuring SIMOPs are addressed as part of safe work practices [16]:

> Essential features of permit-to-work systems are […] clear and standardised identification of tasks, risk assessments, permitted task duration and supplemental or simultaneous activity and control measures [16, p. 7].
>
> A permit-to-work system aims to ensure that proper consideration is given to the risks of a particular job or simultaneous activities at a site. Whether it is manually or electronically generated, the permit is a detailed document which authorises certain people to carry out specific work at a specific site at a certain time, and which sets out the main precautions needed to complete the job safely [16, p. 7].
>
> Sites and installations should give particular attention to the permit-to-work system during combined or simultaneous operations to ensure that work undertaken does not compromise safety, for example by a mobile drilling unit or support vessel. Combined operations may require the interface of electronic permit-to-work systems with paper-based systems to enable permits to be transmitted or authorised by remote sites [16, p. 10].
>
> It is essential that a competent person […] is appointed to co-ordinate and control the issue and return of permits. That person should have an overview of all operations under way and planned on site to avoid hazards caused by simultaneous activities. The site or installation manager is normally responsible for ensuring this co-ordination and control, either by controlling the issue and return of permits themselves […], or by appointing an appropriate responsible person (or people) with sufficient authority to carry out this function on their behalf [16, p. 18].

Government of Western Australia, Department of Mines, Industry Regulation and Safety

The Government of Western Australia, Department of Mines, Industry Regulation and Safety document *Petroleum safety and major hazard facility – guide, Bridging documents and simultaneous operations (SIMOPS)* provides information on the requirements of legislation and details of good practice on SIMOPs for onshore and offshore hazardous facilities in Western Australia [19]. The guide provides the following information:

- A SIMOPs project needs to be clearly defined as early as possible. Operators must identify and arrange early consultation with all members of a SIMOPs project, including operators of the facilities involved, contractors, and service providers [19, p. 4].
- SIMOPs documentation, also called bridging documents, combines various safety cases into one SIMOPs safety management plan. The facility operators should have a system in place to manage review and update of bridging documents in the course of SIMOPs [19, p. 4].
- The SIMOPs project team should comprise experienced members who can participate in hazard identification and risk assessments for the SIMOPs. The results of hazard identification and risk assessments will feed into the bridging document [19, p. 4].
- A project-specific emergency response plan should be developed that identifies the various parties to the SIMOPs, contains examples of emergency scenarios that may occur during the project, specifies emergency response equipment available to the project and where it is located, and identifies evacuation routes and muster points for the project personnel, including alternate routes available [19, p. 11].

4.3.2.2 U.S. Chemical Processing Guidance

OSHA Regulatory Guidance

OSHA regulatory guidance on SIMOPs is limited to work conducted within confined spaces.[a,b] There are no other OSHA requirements to consider SIMOPs for maintenance activities performed on chemical processes.

Process Safety Progress Article

The American Institute of Chemical Engineers (AIChE) publishes a quarterly periodical titled *Process Safety Progress*. In the March 2017 edition, the AIChE published an article titled "Simultaneous Operation (SIMOP) Review: An Important Hazard Analysis Tool [15]." The author defines SIMOPs as:

> …situations where two or more operations or activities occur close together in time and place. They may interfere or clash with each other and increase the risks of the activities or create new risks resulting in undesired events … with adverse impacts on … process safety. SIMOPs often involve work in the same area by multiple … workers whose work may overlap and/or interact.

The author outlines a six-step process for analyzing SIMOPs [15, pp. 64-65]:

1. Identify potential SIMOPs

[a] 29 CFR 1910.146(d)(11) states: "Develop and implement procedures to coordinate entry operations when employees of more than one employer are working simultaneously as authorized entrants in a permit space, so that employees of one employer do not endanger the employees of any other employer."

[b] 29 CFR 1926.1204(k) states: "Develop and implement procedures to coordinate entry operations, in consultation with the controlling contractor, when employees of more than one employer are working simultaneously in a permit space or elsewhere on the worksite where their activities could, either alone or in conjunction with the activities within a permit space, foreseeably result in a hazard within the confined space, so that employees of one employer do not endanger the employees of any other employer."

2. Collect information on those activities
3. Identify interactions
4. Identify consequences
5. Identify existing safeguards
6. Identify missing risk controls

Center for Chemical Process Safety Website Resource

The CCPS maintains a website resource for safe work practices applicable to process industries [20]. CCPS provides guidelines for identifying potential hazards and consequences, strategies and practices to manage and mitigate hazards, and common practices for several safe work practices, including the field review of permits and line opening [20]. CCPS provides the following guidance concerning the field review of permits:

- Facilities need to maintain a sense of vulnerability by asking the question, "Do systems exist that would provide sufficient time for Permit roles to identify Task and Location specific Hazards, and to consider other ongoing work or simultaneous operations (SIMOPS) ongoing in the area?" [21]
- Permit pre-authorization field inspections should confirm that there are no SIMOPs planned around the job location during execution of the safe work permit [22].
- A designated Area Authority, such as a Shift Supervisor, should be responsible for conducting an initial field inspection of the area, identifying and ensure precautions are in place before permitting, reviewing where there may be impact from SIMOPs, and ensuring field conditions are safe before issuing a permit [23].
- "The condition of ongoing plant processes and other nearby activities should be considered when scheduling work. Good practice is to have a matrix of allowable simultaneous operations or 'SimOps' and those which are prohibited." [24]

Plant Design and Operations

Plant Design and Operations by process safety author Ian Sutton is a compiled reference book on safe operations and maintenance best practices for offshore facilities, chemical plants, oil refineries, and pipelines [25]. The book presents the following best practices for managing SIMOPs [25, pp. 289-292]:

- "The various groups who are conducting normal operations, maintenance, and construction work at a location need to be aware of one another's existence and what they are doing. Hence there needs to be one person who is aware of all activities that are taking place at the facility, and who has the authority to change or stop those activities. This person is sometimes referred to as the [p]erson in [c]harge. …the [person in charge] will appoint a SIMOPs coordinator."
- "The SIMOPs coordinator needs to learn from each of the groups doing the […] work […] the different types of hazards analysis that have been carried out, and the recommendations and actions from each,

[…] escape route identification, [and] [c]ommunications between the work leaders, the other work groups, and the SIMOPs coordinator."

- "Once the various SIMOPs activities have been identified, a kickoff meeting should be arranged so that the various work activities can be discussed by the affected parties in order to understand how they may affect one another." The meeting should:
    - Summarize the work to be done in a step-by-step manner.
    - Identify all the SIMOPs activities.
    - Identify constraints affecting each activity.
    - Ensure preparation of emergency response strategies and escape routes.

4.3.2.3 Other Incidents Involving SIMOPs Issues

The CSB has investigated at least five other incidents involving SIMOPs, all of which led to the injuries or deaths of individuals uninvolved in the event that initiated the incident, as detailed in **Table 2**.

Table 2. Other incidents investigated by the CSB involving SIMOPs issues.

Incident Title	Date of Incident	SIMOPs Applicability	Severity
Fire During Hot Work at Evergreen Packaging Paper Mill [26]	September 21, 2020	Two contract companies were performing simultaneous maintenance work inside two connected process vessels in the pulp bleaching unit when a heat gun ignited flammable resin, causing a fire. The crew using the heat gun did not warn or communicate its use to the other work crew.	2 fatalities
Ethylene Release and Fire at Kuraray America, Inc. EVAL Plant [27]	May 19, 2018	An ethylene release from a pressure-relief system ignited, injuring 23 workers during process startup. None of the contract workers near the pressure-relief system were essential to the startup, nor were they responding to the upset process conditions that led to the emergency release. The welding work they were performing likely supplied the ignition source that created the fire.	23 injuries

Incident Title	Date of Incident	SIMOPs Applicability	Severity
Allied Terminals Fertilizer Tank Collapse [28]	November 11, 2008	A two-million-gallon liquid fertilizer tank catastrophically failed, seriously injuring two workers, flooding an adjacent residential neighborhood, and releasing at least 200,000 gallons of unrecovered liquid fertilizer to the environment. During the filling of the tank, a welder and his helper were sealing leaking rivets on the tank. The collapsing tank wall injured the welder and his helper.	2 injuries; 200,000 gallons of liquid fertilizer released to environment
BP America (Texas City) Refinery Explosion [29]	March 23, 2005	During startup, a distillation tower was overfilled, resulting in the release of flammable liquids, which led to an explosion near office trailers housing workers not involved in the startup.	15 fatalities 180 injuries
Georgia-Pacific Corp. Hydrogen Sulfide Poisoning [30]	January 16, 2002	Hydrogen sulfide gas leaked from a sewer manway, injuring eight people and fatally injuring two contract workers. Contractors were working on a construction project near a tank truck unloading station that contained spilled sodium hydrosulfide. To clear the area for the workers, the sodium hydrosulfide was drained to the acid sewer. While the construction workers were working, sulfuric acid was added to the acid sewer to control the pH, which reacted with the sodium hydrosulfide to form hydrogen sulfide, which leaked from the sewer manway in the presence of the contract workers.	2 fatalities 8 injuries

4.3.2.4 Industry Standards Conclusions

The CSB concludes that while there is some published guidance from various sectors on SIMOPs, there is limited industry and regulatory guidance on proper SIMOPs considerations for chemical process facilities and other stationary sources in the United States. The CSB also concludes that while CCPS's current website resource on SIMOPs is a beneficial start to prompting facilities to consider SIMOPs when permitting work, additional practical guidance, such as in a CCPS *Guidelines* book or monograph publication, is needed to help facilities develop SIMOPs evaluation programs. Such a publication, outlining the steps in a SIMOPs life cycle, including the SIMOPs review, hazard analysis, and risk assessment specific to stationary source chemical processes, could help drive important improvements to safe work practices in the United States.

The CSB recommends that CCPS publish guidelines on safe work practices, including detailed and practical guidelines for evaluating SIMOPs. The guidelines, at a minimum, should address the content found in CCPS's website resource for implementing safe work practices. In addition, the publication should discuss guidelines for a SIMOPs life cycle, including methods to identify SIMOPs, methods to conduct a SIMOPs hazard assessment, safeguards and controls pertaining to SIMOPs, preparation for SIMOPs, and SIMOPs execution. In developing this guidance, consider the findings presented in the CSB report titled *Fire During Hot Work at Evergreen Packaging Paper Mill* and this CSB report, titled *Equipment Fracture and Fatal Hydrogen Chloride Release at Wacker Polysilicon North America*.

In addition, the CSB supersedes recommendation 2020-07-I-NC-R2 to OSHA, originally published in the CSB report titled *Fire During Hot Work at Evergreen Packaging Paper Mill*. The CSB recommends that OSHA require employers to ensure the coordination of SIMOPs involving multiple work groups, including contractors. Ensure that this requirement applies to all activities and not only to confined space. Include in the requirement for Employers to ensure that the following activities occur:

- Identification of potential simultaneous operations;
- Identification of potential hazardous interactions;
- Evaluation and implementation of necessary safeguards to allow for safe simultaneous operations;
- Coordination, including shared communication methods, between the simultaneous operations; and
- Inclusion of emergency response personnel or services in the planning and coordination of the simultaneous operations.

The CSB also issues this same recommendation to Tennessee OSHA.

In addition, the CSB recommends that OSHA develop a safety product providing guidance on the coordination of SIMOPs involving multiple work groups, including contractors, that is not limited to confined space or construction. Provide guidance on the following activities:

- Identification of potential SIMOPs;
- Identification of potential hazardous interactions;
- Evaluation and implementation of necessary safeguards to allow for safe SIMOPs;
- Coordination, including shared communication methods, between the SIMOPs; and
- Inclusion of emergency response personnel or services in the planning and coordination of the SIMOPs.

4.4 Means of Egress

4.4.1 Wacker Employees' Identification of Egress Gap in PHA

Wacker performed a Process Hazard Analysis (PHA), dated August 11, 2020—three months before the incident—which assessed the availability of only a single exit on the fourth and fifth floors of the equipment access structure from which the HCl release occurred. Scenario (1) of the PHA specifically questioned "What if there is an HCl leak from the [tower structure] while personnel are on the 4th or 5th-floors of the unit such that they must move through the cloud to get down the stairs, which are on the North end of the platform?" The PHA team provided a recommendation to install a ladder with an enclosed cage, or some other means of egress, on the opposite end of the structure for personnel to use in the event that the path to the existing stairs is blocked. Wacker assigned the action to address the installation of alternate means of egress to the Manager of Process and Facilities Engineering, but the PHA did not include a timeline or due date for implementation. No such secondary form of egress was installed prior to the date of the incident.

KEY LESSON

The Process Hazard Analysis (PHA) is an important tool for identifying, evaluating, and controlling process- and facility-specific hazards. While building codes are an important foundation in facility design, they do not necessarily consider the specific hazards posed by a given process. Owners and operators should prioritize the implementation of PHA recommendations and employee input to control hazards that have been identified by those closest and most familiar with facilities and operations.

Wacker also maintained an online safety suggestion system in which employees could submit safety-related feedback. During the CSB's interviews with support specialist staff in the HCl area, multiple employees mentioned either discussing with management or submitting online feedback concerning the need for a secondary means of egress on the tower structure. However, interviews with Wacker employees indicated a perception among the workers that management deferred employee concerns regarding secondary egress because of management's understanding that the building was designed per code. As one Wacker employee described:

> We… all were pushing to have an emergency exit out there, a new ladder. And for whatever reason, I mean the building is within [standards]. And that was basically the answer that we got when we were wanting to have a secondary means of exit for the building… But it's hard to argue with the standards…

The CSB concludes that, based on the PHA recommendation and worker statements, Wacker was aware of the risks posed by a single point of egress on the tower structure. However, the risk was documented in the PHA three months prior to the occurrence of the incident and had not yet been addressed. In addition, Wacker did not see an immediate need to install a second point of egress since Wacker considered the structure to be compliant with applicable building codes and standards and had received a certificate of occupancy by the local building code permitting authority. Had Wacker implemented the PHA recommendation and worker suggestion for a secondary means of egress before the incident, it is possible that the workers affected by the HCl release would have had access to a safer egress route and been able to exit the fifth floor, preventing the fatality and serious injuries of the Pen Gulf workers.

4.4.2 Wacker's Application of the International Building Code

As part of the design effort for the equipment access structure, Wacker considered several building and construction codes, including the 2012 International Building Code (IBC).[a] Per the 2012 IBC, Wacker designated the equipment access structure as "an unoccupiable equipment platform. Grating floors and mezzanines are considered maintenance access platforms to the process equipment…." The 2012 edition of IBC defines an equipment platform as an "unoccupied, elevated platform used exclusively for mechanical systems or industrial process equipment, including the associated elevated walkways, stairs, alternating tread devices and ladders necessary to access the platform" [31, p. 19]. Because of the designation of the structure as an unoccupiable equipment platform, Wacker concluded that IBC did not require multiple points of egress, and the access stairwell was determined to be sufficient as a means of egress.[b] Further, the structure was inspected and permitted by the Bradley County Tennessee Department of Building Inspections and found to be compliant with the relevant local building codes.[c]

4.4.3 Gap in Means of Egress Codes and Standards

Open-air, normally unoccupied industrial structures, such as the one in use by Wacker, are common throughout industrial facilities, chemical plants, and refineries. As part of its investigation, the CSB identified several gaps and opportunities for improvement for the codes and standards applicable to open-air industrial structures.

International Building Code

IBC offers requirements for several industrial occupancies depending on the building use and expected occupant load. Below are examples of IBC occupancies that may be applicable for processes such as those at Wacker:

- *Factory Industrial Group F occupancy* – Building or structure, or a portion thereof, for assembling, disassembling, fabricating, finishing, manufacturing, packaging, repair or processing operations [31, p. 42].

- *High Hazard Group H occupancy* – Building or structure, or a portion thereof, that involves the manufacturing, processing, generation, or storage of materials that constitute a physical or health hazard in quantities defined in IBC [31, p. 43].

- *Utility and Miscellaneous Group U* – Buildings and structures of an accessory character and miscellaneous structures not classified in any specific occupancy shall be constructed, equipped and

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[a] Wacker also considered the 2012 International Fire Code (IFC) and 2012 NFPA 101 Life Safety Code.

[b] The 2012 IBC requires two exits for certain occupiable spaces. IBC defines an occupiable space as "A room or enclosed space designed for human occupancy in which individuals congregate for amusement, educational, or similar purposes or in which occupants are engaged at labor, and which is equipped with means of egress and light and ventilation facilities meeting the requirements of this code [31, p. 29]." Equipment platforms, such as the structure at Wacker, are not considered by the 2012 IBC as an occupiable space requiring two exits.

[c] Bradley County adopted in the 2012 IBC as the local building code.

> maintained to conform to the requirements of this code commensurate with the fire and life hazard incidental to their occupancy [31, pp. 50-51].

While these occupancy classifications offer guidance for these industrial structures, the relevant provisions do not apply to normally unoccupied equipment structures. For each of these occupancies, IBC requires the structure to include at least two means of egress at the third story and above [31, p. 267]. Since the structure at the Wacker facility was designated as an unoccupied equipment platform, however, this requirement did not apply.

OSHA Exit Routes and Emergency Planning

OSHA provides requirements for means of egress in 29 CFR 1910.34 to 1910.40. For exit routes and emergency planning, OSHA requires that "the number of exit routes must be adequate"[a] and at least two exit routes must be available,[b] except where the number of employees, the size of the building, its occupancy, or the arrangement of the workplace is such that all employees would be able to safely evacuate[c] [32]. While this requirement offers a means of citation when the means of egress is proved to be inadequate, it lacks specific definitions and expectations, making it difficult for building designers and facility employers to employ the necessary degree of judgement when attempting to apply these requirements to open air industrial structures found in chemical processing plants. The requirements of 29 CFR 1910.36(b) include a note to consult NFPA 101-2009 for assistance in determining the number of necessary exit routes. The requirements of NFPA 101 are discussed below.

National Fire Protection Association (NFPA) Life Safety Code

The NFPA 101 *Life Safety Code* addresses means of egress requirements for industrial occupancies [33, p. 365]. The goal of NFPA 101 is to provide an environment for the occupants that is reasonably safe from fire [33, p. 40]. As such, the code requires the number of means of egress based on the classification of hazardous contents, which is determined based on combustibility, burn rate, and likelihood of explosion [33, p. 52]. The 2018 edition of NFPA includes an additional goal to provide reasonable life safety during emergency events involving hazardous materials,[d] with an objective to provide fundamental safeguards to "reasonably prevent or mitigate events involving hazardous materials to allow the time needed to evacuate, relocate, or defend in place occupants" [33, p. 40]. However, with regard to the number of means of egress, the code requires that hazardous materials must be also classified as high-hazard contents [33, p. 90], or "those likely to burn with extreme rapidity or from which explosions are likely" [33, p. 52], in order to require multiple means of egress.[e]

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[a] 29 CFR 1910.36(b)

[b] 29 CFR 1910.36(b)(1) states: "Two exit routes. At least two exit routes must be available in a workplace to permit prompt evacuation of employees and other building occupants during an emergency, except as allowed in paragraph (b)(3) of this section. The exit routes must be located as far away as practical from each other so that if one exit route is blocked by fire or smoke, employees can evacuate using the second exit route."

[c] 29 CFR 1910.36(b)(3) states: "A single exit route. A single exit route is permitted where the number of employees, the size of the building, its occupancy, or the arrangement of the workplace is such that all employees would be able to evacuate safely during an emergency."

[d] NFPA 101 defines "Hazardous Material" as "A chemical or substance that is classified as a physical hazard material or a health hazard material, whether the chemical or substance is in usable or waste condition" [33, p. 34]. This definition is inclusive of gaseous HCl.

[e] See NFPA 101-2018 §§ 7.12.1 and 7.11.4.

Otherwise, the code permits a single point of egress [33, p. 367], regardless of the physical or health hazards of the contents.[a]

National Institute for Occupational Safety and Health (NIOSH)

NIOSH published the *Criteria for a Recommended Standard for Emergency Egress of Elevated Workstations* in 1975, which identified a gap in emergency egress guidance and standards [34]. The publication evaluates means of egress references from OSHA, NFPA, ANSI, and state entities, and calls for a standard specific to emergency egress:

> [W]orker egress from elevated workstations has been subordinated in importance by the standards-producing and standards-adopting agencies. The need for definitive standards on the subject has not been demonstrated by the amassing and analysis of relevant statistics. Specific language relating to the subject has, in some cases, been dropped during the standards-adopting process because of the technical nature of the requirements, their economic impact, or their potential for generating negative reaction on the part of factions within the labor/management arena. When the subject has been included in consensus standards, it has been treated as an adjunct to the general concern of the standard… [34, p. 49].

The NIOSH criteria also identified that among the codes and standards evaluated, "[t]here are no present standards which specify training requirements for egress from high places" [34, p. 30].

Conclusions

The CSB concludes that the current IBC and NFPA building requirements do not provide for sufficient means of egress from elevated work platforms used for accessing equipment containing hazardous materials.

The CSB recommends that the International Code Council (ICC) amend the IBC to address conditions that may require multiple means of egress from elevated equipment platforms used for accessing equipment containing materials that pose physical and health hazards, such as the one used at Wacker in this incident. Address egress locations to increase the likelihood of worker escape in the event of a hazardous material release.

The CSB also recommends that NFPA revise NFPA 101 *Life Safety Code*, NFPA 55 *Compressed Gases and Cryogenic Fluids Code*, or NFPA 400 *Hazardous Materials Code* to address conditions that may require multiple means of egress from elevated industrial structures containing hazardous materials posing physical and health hazards, regardless of their combustibility, burn rate, or likelihood of explosion. The guidance should address egress situations for workers on unwalled, elevated structures in the presence of materials posing physical and health hazards. Address egress locations to increase the likelihood of worker escape in the event of a hazardous material release.

[a] See NFPA 101-2018 § 40.2.4.1.2.

5 CONCLUSIONS

5.1 FINDINGS

1. The failure of the graphite heat exchanger nozzle was due to over-torquing the bolts connecting the graphite nozzle to PTFE-lined equipment.

Written Procedures

2. Wacker's and Jake Marshall's reliance on verbal instructions, communicated sequentially by three separate people without a detailed task-specific procedure, increased the likelihood of miscommunication or misunderstanding of the task steps and precautions.

3. The development of documentation and training defining different types of torquing requirements, such as "hot torquing" as applicable, could have helped to eliminate the inconsistent vernacular at the Wacker facility.

4. Wacker did not establish, implement, or adhere to detailed and job-specific maintenance procedures relating to torquing tasks on the AW234 heat exchanger. Instead, Jake Marshall contractors were provided unclear and undocumented instructions for torquing the bolts on the heat exchanger.

5. Had Wacker used the information from the piping installation and design manual and the manufacturer's drawing of the heat exchanger to develop specific torquing procedures for the HCl regeneration unit and the AW234 heat exchanger, it is likely that the contractors would have applied the correct torque values to the AW234 heat exchanger PTFE-to-graphite connections, which would have prevented the incident.

Control of Hazardous Energy

6. Wacker did not perform a risk analysis to determine whether the hot torque task could be safely performed on operating equipment, nor did it implement precautions to mitigate the risk of torquing bolts on operating equipment prior to issuing a safe work permit to Jake Marshall workers. Had Wacker implemented the same precautions undertaken as part of a first line break, namely methods for energy isolation, PPE requirements, personnel restrictions, and barricading, it is likely that injuries to the Pen Gulf workers could have been prevented.

Simultaneous Operations

7. Wacker lacked a formalized SIMOPs process, failed to properly identify hazards introduced by co-located permitted work, and used an ineffective safe work permitting process, which resulted in the co-location of Jake Marshall and Pen Gulf work crews during the hot torquing and insulation work on the fifth floor of the equipment access structure. Consequently, Pen Gulf workers lacked awareness of the hazards and were unable to take precautions, such as delaying the reinsulation task or donning chemical-protective PPE, and as a result were unnecessarily exposed to the hazards of the hot torquing task.

8. While there is some published guidance from various sectors on SIMOPs, there is limited industry and regulatory guidance on proper SIMOPs considerations for chemical process facilities and other stationary sources in the United States.

9. While CCPS's current website resource on SIMOPs is a beneficial start to prompting facilities to consider SIMOPs when permitting work, additional practical guidance, such as in a CCPS *Guidelines* book or monograph publication, is needed to help present facilities develop SIMOPs evaluation programs. Such a publication, outlining the steps in a SIMOPs life cycle, including the SIMOPs review, hazard analysis, and risk assessment specific to stationary source chemical processes, could help drive important improvements to safe work practices in the United States.

Means of Egress

10. Wacker was aware of the risks posed by a single point of egress on the tower structure. However, the risk was documented in the PHA three months prior to the occurrence of the incident and had not yet been addressed. In addition, Wacker did not see an immediate need to install a second point of egress since Wacker considered the structure to be compliant with applicable building codes and standards and had received a certificate of occupancy by the local building code permitting authority. Had Wacker implemented the PHA recommendation and worker suggestion for a secondary means of egress before the incident, it is possible that the workers affected by the HCl release would have had access to a safer egress route and been able to exit the fifth floor, preventing the fatality and serious injuries of the Pen Gulf workers.

11. The current IBC and NFPA building requirements do not provide for sufficient means of egress from elevated work platforms used for accessing equipment containing hazardous materials.

5.2 Cause

The CSB determined the cause of the incident was the inadvertent over-torquing of bolts on an HCl piping flange connection to a heat exchanger, which resulted in the fracture of the heat exchanger outlet piping and a release of gaseous HCl in the vicinity of seven contract workers. Wacker's lack of written procedures and lack of control of hazardous energy contributed to the occurrence of the event, and Wacker's lack of a SIMOPs program and the absence of regulatory and published industry guidance on SIMOPs contributed to the severity of the event. Wacker's limited means of egress from the equipment access structure and the absence of regulatory guidance and standards on means of egress from open-air industrial structures also contributed to the severity of the event.

6 Recommendations

To prevent future chemical incidents, and in the interest of driving chemical safety excellence to protect communities, workers, and the environment, the CSB makes the following safety recommendations:

6.1 Previously Issued Recommendations Superseded in This Report

6.1.1 Occupational Safety and Health Administration (OSHA)

2020-07-I-NC-R2 (from the Evergreen Packaging Paper Mill - Fire During Hot Work report)

Require Owner/Operators to ensure the coordination of simultaneous operations involving multiple work groups, including contractors. Include in the requirement for Owner/Operators to ensure the following activities occur:

- Identification of potential simultaneous operations;
- Identification of potential hazardous interactions;
- Evaluation and implementation of necessary safeguards to allow for safe simultaneous operations;
- Coordination, including shared communication methods, between the simultaneous operations; and
- Inclusion of emergency response personnel or services in the planning and coordination of the simultaneous operations.

As necessary, seek the regulatory authority to promulgate this requirement.

*Superseded by **2021-01-I-TN-R1** to OSHA in Section 6.2.1 below.*

6.2 New Recommendations

6.2.1 Occupational Safety and Health Administration (OSHA)

2021-01-I-TN-R1 (Supersedes 2020-07-I-NC-R2 from the CSB's 2020 Evergreen Packaging report)

Promulgate a standard or modify existing standards to require employers to ensure the coordination of simultaneous operations (SIMOPs) involving multiple work groups, including contractors. Ensure that the requirements of this standard or standards apply to both general industry and construction activities and are not limited to activities occurring within confined spaces. Include in the standard requirements for Employers to ensure that the following activities occur:

a. Identification of potential SIMOPs;

b. Identification of potential hazardous interactions;

c. Evaluation and implementation of necessary safeguards to allow for safe SIMOPs;

d. Coordination, including shared communication methods, between the SIMOPs; and

e. Inclusion of emergency response personnel or services in the planning and coordination of the SIMOPs.

2021-01-I-TN-R2

Develop a safety product providing guidance on the coordination of simultaneous operations (SIMOPs) involving multiple work groups, including contractors, that is not limited to confined space or construction. Provide guidance on the following activities:

a. Identification of potential SIMOPs;

b. Identification of potential hazardous interactions;

c. Evaluation and implementation of necessary safeguards to allow for safe SIMOPs;

d. Coordination, including shared communication methods, between the SIMOPs; and

e. Inclusion of emergency response personnel or services in the planning and coordination of the SIMOPs.

6.2.2 Wacker Polysilicon

2021-01-I-TN-R3

Develop detailed maintenance procedures for torquing activities which:

a. Clearly communicate differing equipment torque specifications, such as those for bolts installed at PTFE-to-PTFE and PTFE-to-graphite connections through visual means such as annotated photographs, signage, physical differentiation, and other methods, as appropriate;

b. Include procedural requirements for all torquing activities conducted on equipment containing hazardous material to perform an engineering and risk analysis and implement safeguards as a result of the risk analysis, per American Society of Mechanical Engineers (ASME) PCC-1-2019 *Guidelines for Pressure Boundary Bolted Flange Joint Assembly* and ANSI/ASSP Z244.1-2016 *The Control of Hazardous Energy Lockout, Tagout and Alternative Methods;*

c. Ensure that terms such as “hot torque” are clearly defined and that employees and contractors are trained on these terms; and

d. Ensure that procedures and training conform to the mechanical integrity requirements of the Process Safety Management (PSM) standard found in 29 CFR 1910.119(j) and the Risk Management Program (RMP) rule found in 40 CFR 68.73.

2021-01-I-TN-R4

Develop policy requirements to ensure torquing activities performed on equipment containing hazardous energy are performed safely, such as through de-inventorying equipment or restriction of nonessential personnel and ensuring that essential workers wear proper PPE. Document these requirements in procedures, such as *Lock, Tag and Try; First Line Break – Return to Service;* or other procedures as applicable. Ensure employees and contractors are trained on these procedures in accordance with the Process Safety Management (PSM) standard requirements found in 29 CFR 1910.119(f)(4) and 29 CFR 1910.119(g) and the Risk Management Program (RMP) rule found in 40 CFR 68.69(d) and 40 CFR 68.71.

2021-01-I-TN-R5

Develop and implement a formalized Simultaneous Operations (SIMOPs) program addressing planned and/or permitted co-located work tasks including:

a. Identification of potential SIMOPs;

b. Identification of potential hazardous interactions;

c. Evaluation and implementation of necessary safeguards to allow for safe SIMOPs;

d. Coordination, including shared communication methods, between the SIMOPs; and

e. Inclusion of emergency response personnel or services in the planning and coordination of the SIMOPs.

Ensure relevant staff are trained on execution of the SIMOPs program.

2021-01-I-TN-R6

Install additional means of egress for the T230 desorption tower platforms and other multi-floor equipment structures on-site. After completing these installations, ensure workers are made aware of exit locations from the structure platforms through training, drills, or other techniques as appropriate.

6.2.3 Tennessee Occupational Safety and Health Administration (TOSHA)

2021-01-I-TN-R7

Promulgate a standard or modify existing standards to require employers to ensure the coordination of simultaneous operations (SIMOPs) involving multiple work groups, including contractors. Ensure that the requirements of this standard or standards apply to both general industry and construction activities and are not limited to activities occurring within confined spaces. Include in the standard requirements for Employers to ensure that the following activities occur:

a. Identification of potential SIMOPs;

b. Identification of potential hazardous interactions;

c. Evaluation and implementation of necessary safeguards to allow for safe SIMOPs;

d. Coordination, including shared communication methods, between the SIMOPs; and

e. Inclusion of emergency response personnel or services in the planning and coordination of the SIMOPs.

6.2.4 Center for Chemical Process Safety (CCPS)

2021-01-I-TN-R8

Develop and publish a safety product on Safe Work Practices, including detailed and practical guidelines for evaluating simultaneous operations (SIMOPs). The guidelines, at a minimum, should:

a. Address the content found in CCPS's website resource for implementing Safe Work Practices; and

b. Discuss guidelines for a SIMOPs life cycle, including:

1. methods to identify SIMOPs;
2. methods to conduct a SIMOPs hazard assessment;
3. safeguards and controls pertaining to SIMOPs;
4. preparation for SIMOPs; and
5. SIMOPs execution.

In developing this safety product, consider the findings presented in the CSB report titled *Fire During Hot Work at Evergreen Packaging Paper Mill* and this CSB report, titled *Equipment Fracture and Fatal Hydrogen Chloride Release at Wacker Polysilicon North America*.

6.2.5 International Code Council (ICC)

2021-01-I-TN-R9

Amend the International Building Code (IBC) to address conditions that may require multiple means of egress from elevated equipment platforms used for accessing equipment containing materials that pose physical and health hazards, such as the one used at Wacker in this incident. Specify the minimum number of egress points to increase the likelihood of worker escape in the event of a hazardous material release.

6.2.6 National Fire Protection Association (NFPA)

2021-01-I-TN-R10

Revise NFPA 101 *Life Safety Code*, NFPA 55 *Compressed Gases and Cryogenic Fluids Code*, or NFPA 400 *Hazardous Materials Code* to address conditions which may require multiple means of egress from elevated industrial structures containing hazardous materials posing physical and health hazards, regardless of their combustibility, burn rate, or likelihood of explosion. The guidance should address egress situations for workers on unwalled, elevated structures in the presence of materials posing physical and health hazards. Specify the minimum number of egress points to increase the likelihood of worker escape in the event of a hazardous material release.

7 KEY LESSONS FOR THE INDUSTRY

To prevent future chemical incidents, and in the interest of driving chemical safety excellence to protect communities, workers, and the environment, the CSB urges companies to review these key lessons:

1. Written procedures are a critical tool for ensuring safe operations and maintenance activities. Procedures consolidate information required to execute a given task into easy-to-understand step-by-step instructions, with specific reference to safety precautions and crucial actions. Written procedures for hazardous operations should be prepared as part of robust safe work practices, including on temporary or ancillary maintenance activities.

2. Language, vernacular, and jargon, when undefined and undocumented, can result in different interpretations of the same terminology. It is important that localized terminology referring to actions and tasks on process equipment be officially defined in a site-specific policy or procedure.

3. The control of hazardous energy should be considered whenever equipment containing hazardous energy is repaired, adjusted, serviced, and maintained, not only in situations in which equipment is intentionally opened. Prior to working on equipment containing hazardous energy, a risk assessment should always be performed to evaluate the need for energy isolation or other protective measures.

4. Owners and operators should always consider how simultaneous operations, or SIMOPs, could impact a given operation, whether by influencing a hazard or affecting the risk of the operation. SIMOPs should be identified and controlled via a hazard assessment prior to commencing a given operation or task. An established system to manage work permits can also identify risks associated with SIMOPs before they occur. A well-established system must be able to document the specific task to be executed, readily coordinate the issued permits, and identify scenarios of potential interaction between permitted work groups.

5. The Process Hazard Analysis (PHA) is an important tool for identifying, evaluating, and controlling process- and facility-specific hazards. While building codes are an important foundation in facility design, they do not necessarily consider the specific hazards posed by a given process. Owners and operators should prioritize the implementation of PHA recommendations and employee input to control hazards that have been identified by those closest and most familiar with facilities and operations.

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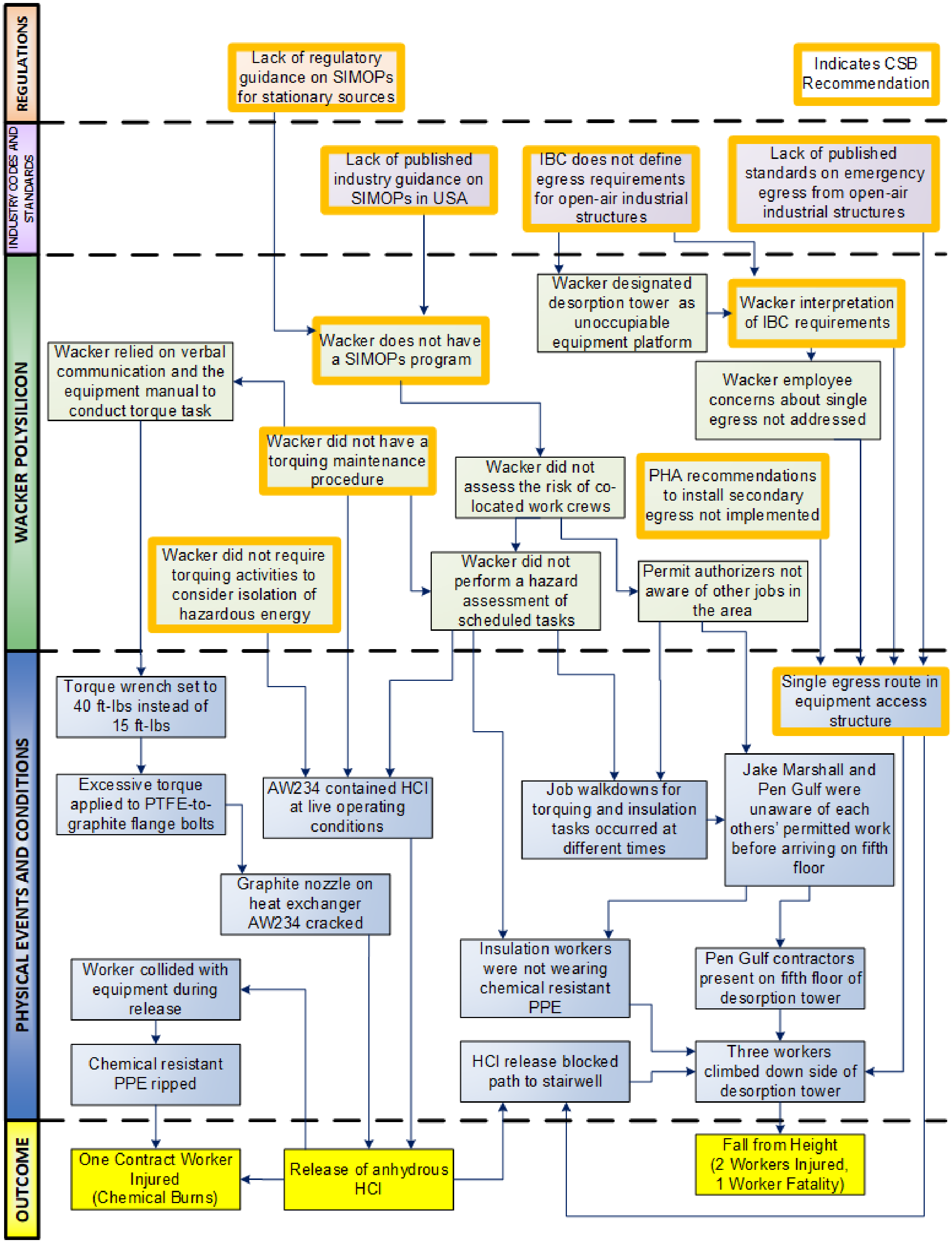
Appendix A—Causal Analysis (AcciMap)



APPENDIX B—DESCRIPTION OF SURROUNDING AREA

Figure 18 shows the census blocks immediately surrounding Wacker Polysilicon. The numbered blocks shown in **Figure 18** and presented in **Table 3** and **Table 4** present data from the smallest census blocks available, which include populations up to five miles away from the facility.

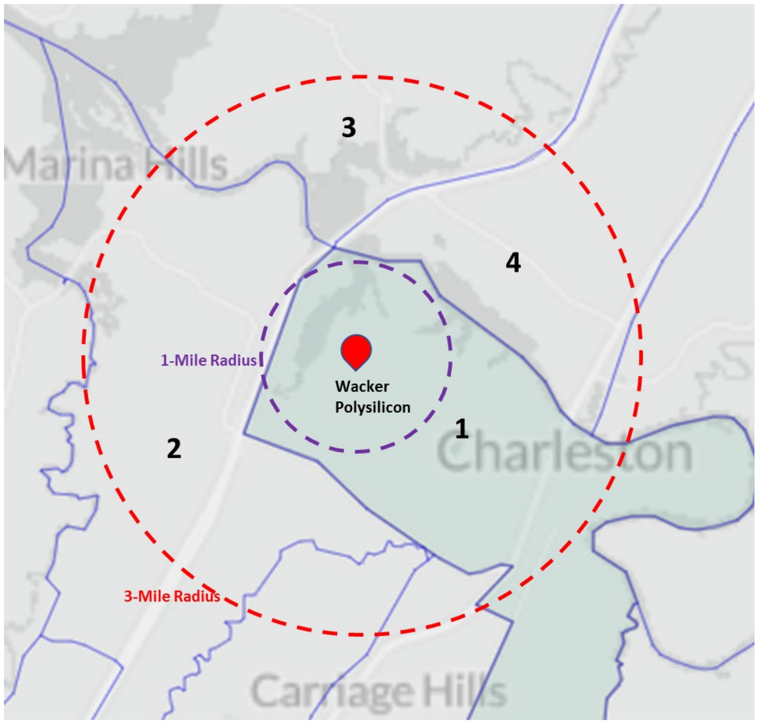


Figure 18. Census blocks in an approximately three-mile distance from Wacker Polysilicon. (Source: Census Reporter [10], annotations by CSB)

Table 3. Summarized demographic data for the populations within the census blocks shown in **Figure 18**. (Source: Census Reporter [10])

Population	Race & Ethnicity		Per Capita Income	Number of Housing Units	Types of Housing Units	
6,583	White	85%	$29,608	2,621	Single Unit	78%
	Black	5%			Multi-Unit	6%
	Native	0%			Mobile Home	15%
	Asian	1%			Boat, RV, Van, etc.	0%
	Islander	0%				
	Other	0%				
	Two+	3%				
	Hispanic	6%				

Table 4. Tabulation of demographic data for the populations within the census blocks shown in **Figure 18**. (Source: Census Reporter [10])

Tract Number	Population	Median Age	Race & Ethnicity		Per Capita Income	Number of Housing Units	Types of Housing Units	
1	1,291	46.8	82.1%	White	$23,464	627	78%	Single Unit
			5.6%	Black			13%	Multi-Unit
			0.0%	Native			9%	Mobile Home
			0.0%	Asian			0%	Boat, RV, van, etc.
			0.0%	Islander				
			0.0%	Other				
			4.3%	Two+				
			8.0%	Hispanic				
2	2,932	39.6	88.0%	White	$32,557	918	93%	Single Unit
			7.1%	Black			0%	Multi-Unit
			0.0%	Native			7%	Mobile Home
			0.0%	Asian				Boat, RV, van, etc.
			0.0%	Islander				
			0.5%	Other				
			4.4%	Two+				
			0.0%	Hispanic				
3	1,241	46.4	80%	White	$24,940	475	60%	Single Unit
			0%	Black			0%	Multi-Unit
			0%	Native			37%	Mobile Home
			0%	Asian			3%	Boat, RV, van, etc.
			0%	Islander				
			0%	Other				
			1%	Two+				
			19%	Hispanic				
4	1,119	52.1	84%	White	$34,148	601	71%	Single Unit
			3%	Black			11%	Multi-Unit
			3%	Native			18%	Mobile Home
			5%	Asian			0%	Boat, RV, van, etc.
			0%	Islander				
			0%	Other				
			0%	Two+				
			6%	Hispanic				

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