

Pressure Equipment Integrity Incident Investigation

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Pressure Equipment Integrity Incident Investigation

1 Scope

1.1 General

The purpose of this document is to provide owner-operators with practices for developing, implementing, sustaining, and enhancing an investigation program for pressure equipment integrity (PEI) incidents. This recommended practice (RP) describes characteristics of how an effective investigation could be structured so organizations can learn from PEI failures, near-misses, or discoveries. This RP is not intended to define or supplement criteria for compliance with regulatory requirements for which companies already have defined investigation processes in place. Rather, API 585 provides a specific focus on investigating PEI failures as well as near misses or discoveries that are precursors to potential failures that could have significant impact on safety, health, and environment. As such, this RP can add value to process safety incidents/issue investigations by helping to focus specific investigative techniques that would enhance learning and enhance value from PEI incidents.

Significant pressure equipment mechanical integrity incidents are rarely the result of one isolated problem; there are almost always less severe precursors to an equipment failure. These precursors are frequently called near misses or discoveries when they are experienced. Additionally, this document highlights the value in recognizing these precursor occurrences and promotes investigating them to determine the immediate, contributing, and root causes. If these precursor occurrences are uncovered, investigated, and the contributing and root causes are resolved, then major catastrophic failures of pressure equipment could be minimized or prevented.

1.2 Industry Scope

The investigation principles and concepts that are presented in this RP are specifically targeted for application to pressure equipment in the oil, gas, refining and petrochemical industry but could be applied to other equipment and industries at the discretion of the owner-operator.

1.3 Flexibility in Application

Because of the broad diversity in an organization's size, culture, national, and/or local regulatory requirements, API 585 offers users the flexibility to apply the investigation methodology within the context of existing incident investigation practices and to accommodate unique local circumstances. API 585 is intended to promote the use of systematic investigations as a way to learn from unexpected leaks and equipment degradation or near misses associated with PEI.

As such, API 585 is intended to supplement owner-operator incident investigation procedures when the incident involves pressure equipment failures, near-misses, and discoveries such as those that involved one of the equipment damage mechanisms outlined in API 571. As indicated below in 1.4, API 585 offers information focused on PEI incidents that can enhance the typical features of process safety incident investigations. Referencing API 585 in owner-operator and site investigation procedures may help to bring the PEI focus to bear on such incidents.

Investigation methodologies consist of investigators collecting evidence and conducting an analysis of the evidence to determine the causes. Many types of investigation analysis methods exist and are used throughout the industry. This document is not intended to single out one specific analysis method for conducting investigations. This document highlights PEI issues for investigation and provides guidelines and work processes for PEI incident investigations.

1.4 Pressure Equipment Integrity (PEI) Focused

Investigation is a vital element for learning from unexpected discoveries or incidents (e.g. finding significantly more corrosion damage or other forms of deterioration than expected) and can be used in a continuous improvement process. Investigating and determining the causes of unexpected leaks, equipment degradation, or near misses

associated with pressure equipment may be used to improve mechanical integrity programs and management systems for maintaining PEI, such as design and construction procedures, maintenance and inspection practices, and operating practices including corrosion control documents (CCD) per API 970, Integrity Operating Windows (IOW) per API 584, and Risk-Based Inspection (RBI) planning per API 580. The API Committee on Refinery Equipment Subcommittees have produced a variety of codes and standards referenced in Table 1 to guide owners/users in maintaining PEI and reliability.

1.5 Types of Pressure Equipment Covered

Table 1 lists the types of equipment and associated components considered to be within the scope of this document. Other types of pressure equipment can be included at the discretion of the owner-operator.

Table 1—Types of Equipment and Components Within the Scope of RP 585

Type of Equipment	Components	API CRE Subcommittee	Example API Reference Documents
Pressure Vessels	all pressure-containing components	SCIMI	API 510, <i>Pressure Vessel Inspection Code</i> , RP 572, <i>Inspection Practices for Pressure Vessels</i>
Piping	pipe and piping components (valves, expansion joints, sight glasses)	SCOPV SCIMI	API 570, <i>Piping Inspection Code</i> , RP 574, <i>Inspection Practices for Piping System Components</i>
Storage Tanks	atmospheric, low pressure, and pressurized	SCAST SCIMI	Std 620, <i>Design and Construction of Large, Welded, Low-Pressure Storage Tanks</i> Std 650, <i>Welded Tanks for Oil Storage</i> Std 653, <i>Tank Inspection, Repair, Alteration and Reconstruction</i> RP 575, <i>Inspection of Atmospheric and Low Pressure Storage Tanks</i>
Rotating Equipment	pump and compressor cases and associated pressure-containing piping and pressure vessels, excluding seals.	SOME	Std 610, <i>Centrifugal Pumps for Petroleum, Petrochemical, and Natural Gas Industries</i> Std 617, <i>Axial and Centrifugal Compressors and Expander-compressors for Petroleum, Chemical, and Gas Industry Services</i> Std 618, <i>Reciprocating Compressors for Petroleum, Chemical, and Gas Industry Services</i>
Boilers and Heaters	pressurized components	SCHTE SCIMI	Std 538, <i>Industrial Fired Boilers</i> Std 560, <i>Fired Heaters for General Refinery Services</i> RP 573, <i>Inspection of Fired Boilers and Heaters</i>

Table 1—Types of Equipment and Components Within the Scope of RP 585 (Continued)

Type of Equipment	Components	API CRE Subcommittee	Example API Reference Documents
Heat Exchangers	shells, heads, channels, and pressure-containing components and tube bundles.	SCHTE SCIMI	Std 660, <i>Shell-and-tube Heat Exchangers</i> Std 661, <i>Petroleum, Petrochemical, and Natural Gas Industries—Air-cooled Heat Exchangers</i> Std 663, <i>Hairpin-type Heat Exchangers</i> Std 664, <i>Spiral Plate Heat Exchangers</i> API 510, <i>Pressure Vessel Inspection Code</i> RP 572, <i>Inspection Practices for Pressure Vessels</i>
Pressure-relief Devices		SCPRS SCIMI	Std 520, <i>Sizing, Selection, and Installation of Pressure-relieving Devices</i> Std 521, <i>Pressure-relieving and Depressuring Systems</i> Std 526, <i>Flanged Steel Pressure-relief Valves</i> Std 527, <i>Seat Tightness of Pressure Relief Valves</i> Std 2000, <i>Venting Atmospheric and Low-Pressure Storage Tanks (Nonrefrigerated and Refrigerated)</i> RP 576, <i>Inspection of Pressure-Relieving Devices</i>
Cooling Water Towers			Refer to OEM practices
Structural Systems	integral to supporting pressure-containing systems	SCIMI	API 510, <i>Pressure Vessel Inspection Code</i> RP 572, <i>Inspection Practices for Pressure Vessels</i> API 570, <i>Piping Inspection Code</i> RP 574, <i>Inspection Practices for Piping System Components</i>
Stacks and Flares		SCHTE SCIMI	Std 537, <i>Flare Details for General Refinery and Petrochemical Service</i> RP 573, <i>Inspection of Fired Boilers and Heaters</i>

1.6 Types of Equipment Excluded

The following non-pressurized equipment is not intended to be covered by this RP but could be included at the discretion of the owner-operator.

- Instrument and control systems.
- Electrical systems.
- Machinery components (except pump and compressor pressure-containing cases).
- Structural equipment not associated with a pressure-containing component or system.
- Pressure vessels or piping systems on movable structures, including piping systems on trucks, ships, barges, and other mobile equipment.

1.7 Target Audience

The primary audience for API 585 is the owner-operator and specifically personnel working in the PEI programs within refineries and petrochemical plants. However, investigations often require the involvement of various segments of the organization, such as engineering, maintenance, inspection, operations, and supervision. Corrective action and recommendations to address the causes may rest with more than one segment of the organization. Therefore, while the primary audience may be PEI personnel, it is suggested others within the organization who are likely to be involved in investigations become familiar with the concepts and principles embodied in this RP.

1.8 Organizational Responsibilities

Owners/users can incorporate PEI investigation into a broader incident investigation site program or develop a specific PEI incident investigation procedure that includes guidance provided in this document including roles, responsibilities, protocols, and specific activities to be performed by site personnel in the process of implementing this RP. Management demonstrates its commitment to this RP by allocating resources and assigning responsibilities to support the PEI incident investigation system.

2 Normative References

There are no documents considered to be normative for the application of this document. A bibliography can be found at the end of this document.

3 Terms, Definitions, Acronyms, and Abbreviations

3.1 Terms and Definitions

For the purposes of this document, the following terms and definitions apply.

3.1.1

bias

When people or groups use their experience or judgment to direct the evidence gathering and development of causes toward potentially incorrect conclusions or when investigators predetermine the cause of an incident and then look for confirming evidence and disregard disputing evidence.

3.1.2

chronic incidents

Frequent occurrences, especially when each occurrence alone typically has a low or minor consequence and is routine to fix.

NOTE Chronic incidents may happen routinely and may become expected and planned.

3.1.3

consequence

An undesirable outcome from an incident. There may be one or more consequences from an incident for different categories, such as safety, environmental, and/or economic. Consequences are always negative for integrity incident investigations.

3.1.4

contributing cause

A cause that increases the likelihood or consequence, or both, of an incident but is not the immediate or root cause. Eliminating the contributing causes will not by itself prevent reoccurrence but will likely reduce the frequency or consequence, or both, of any reoccurrence.

EXAMPLE An example of a contributing cause for a failure caused by corrosion under insulation (CUI) might be the plant has inadequate maintenance practices for maintaining coatings, insulation, and jacketing.

3.1.5

immediate cause

The most direct or primary contributor to the incident that if eliminated or avoided would have prevented the incident. Also known as the physical cause or direct cause.

EXAMPLE For a carbon steel pipe segment that developed a hole and leaked process fluid, the immediate cause was determined to be acid that unexpectedly came in contact with the carbon steel pipe and caused the pipe to corrode at an accelerated rate.

3.1.6

integrity operating window (IOW)

Established limits for process variables (parameters) that can affect the integrity of the equipment if the process operation deviates from the established limits for a predetermined amount of time. Reference API 584 for more information regarding IOWs.

3.1.7

investigation

The process of identifying the immediate, contributing, and root causes of incidents (failures, near misses or discoveries) and developing recommendations to prevent similar occurrences in the future.

3.1.8

investigator

The person or group that conducts the investigation by collecting the evidence, analyzing the evidence, determining the causes, and making recommendations.

3.1.9

owner-operator

An owner or user of pressure equipment who exercises control over the operation, engineering, maintenance, inspection, repair, and testing of the pressure equipment.

3.1.10

pressure equipment integrity

PEI

fixed equipment mechanical integrity

The state of pressure equipment when it has been and continues to be designed, fabricated, installed, operated, and maintained in a way to prevent loss of containment or loss of structural stability.

3.1.11

pressure equipment integrity failure PEI failure

fixed equipment failure

The termination of the ability of a pressure equipment system, structure, or component to perform its function of containment of the process fluid (i.e. a leak or loss of containment). Loss of containment due to misoperation of equipment and not involving material damage mechanisms is not considered PEI failure for the purpose of this RP. Within this document, the term “failure” is intended to refer to a PEI failure.

3.1.12

pressure equipment integrity incident

PEI incident

fixed equipment mechanical integrity incident

Refers to a PEI failure, a PEI near miss, or a PEI discovery. Within this document, the use of the term “incident” is intended to refer to a PEI incident.

3.1.13

pressure equipment integrity near miss

PEI near miss

fixed equipment mechanical integrity near miss

The discovery of equipment degradation or process operating conditions outside of acceptable limits that requires immediate or other unplanned action to shut down the equipment and/or perform repairs to avoid a loss of containment, usually the result of some form of damage mechanism such as those covered in API 571 but did not result in a loss of containment or structural stability. Within this document, the term “near miss” is intended to refer to a PEI near miss.

3.1.14**pressure equipment integrity discovery****PEI discovery****fixed equipment mechanical integrity discovery**

The discovery of unexpected conditions, damage, or deterioration that was not anticipated in the inspection planning process that causes some form of follow-up or unscheduled TA or maintenance work scope adjustment, but does not cause equipment shutdown or slowdown to make immediate repairs i.e. not a near-miss.

3.1.15**pressure equipment integrity personnel****PEI personnel****fixed equipment mechanical integrity personnel**

Personnel in an organization assigned to maintaining, developing, improving, and implementing the organization's PEI program.

EXAMPLE Positions or job titles such as inspector, authorized inspector, inspection engineer, inspection supervisor, pressure equipment engineer, piping engineer, reliability engineer, storage tank engineer, corrosion specialist, metallurgist, etc.

3.1.16**probable cause**

If, after thorough analysis of the evidence and facts, a cause cannot be fully proven but is determined to be very likely (more likely than not), then it is called a probable cause. A probable cause can be identified in any of the different causes (immediate, contributing, or root).

3.1.17**process safety incident**

An incident that resulted in, or could reasonably have resulted in, a catastrophic release of highly hazardous chemicals in the workplace as defined by the Occupational Safety and Health Administration's process safety management (PSM) regulation.

3.1.18**risk**

Combination of the frequency of an incident and its consequence. In some situations, risk is used to describe a deviation from the expected. When frequency and consequence are expressed numerically, risk is the product.

3.1.19**root cause**

A fundamental, underlying system or culture related reason why an incident occurred or allowed the immediate or contributing cause(s) to exist. There is often more than one root cause for every incident.

EXAMPLE An example of a root cause for a failure due to CUI might be there is a culture of only reacting to problems and not allocating resources to preventative maintenance activities.

3.1.20**sporadic incident**

An infrequent or very infrequent occurrence. These incidents tend to have an unusual combination of causes and could have a high consequence.

3.2 Acronyms and Abbreviations

The following acronyms and abbreviations are not found in the terms and definitions but are used in the document.

CCD	corrosion control document
CUI	corrosion under insulation
DCS	distributed control system
FA	failure analysis

NDE	nondestructive examination
P&ID	pipng and instrument diagram
PRD	pressure-relief device
PRV	pressure-relief valve
PSM	process safety management
RBI	risk-based inspection
RD	rupture disc
QA	quality assurance
QC	quality control
RCA	root cause analysis
SME	subject-matter expert

4 PEI Incidents

4.1 PEI Incident Types

PEI incidents are unexpected discoveries or occurrences relating to pressure equipment, usually involving loss of containment or the potential for loss of containment due to some form of damage mechanism such as those covered in API 571. This document will refer to PEI failures, PEI near misses and PEI discoveries, as defined in Section 3, as PEI incidents throughout.

The following are some examples of the three different types of PEI incidents as they relate to pressure equipment.

a) PEI Failures:

- flange leak of process fluid (not including environmental fugitive emissions leaks);
- equipment damaged from corrosion resulting in leak of process fluid;
- through-wall crack resulting in leak of process fluid;
- equipment rupture;
- structural failure (due to structural component deterioration or physical damage to the structure) resulting in pressure equipment leak or damage requiring repairs or rerating (e.g. deterioration of external support rings);
- a process pressure and/or temperature excursion or pH excursion resulting in loss of containment and/or damage to the process equipment requiring repairs;
- heat exchanger tube bundle leak or rupture causing a loss of primary containment (e.g. air cooler tube leak or a tube bundle leak into a cooling water system with detectable emissions to atmosphere at the cooling tower). For the purpose of this RP a tube failure that does not result in a loss of containment is not considered a failure.

b) PEI Near misses:

- corrosion or other damage/degradation that does not pass a Fitness-for-Service assessment and requires immediate repair or other corrective actions (e.g. preventative mechanical clamp, non-metallic wrap, lower operating conditions), but did not result in a leak;

- a damaged bolt or gasket that requires immediate repair/replacement, but before any failure or leak occurred;
- structural deterioration that is deemed not fit for continuing service (e.g. for static load support or during potential wind loading), but before a structural failure occurred;
- inspection or testing failure of a pressure-relieving device indicating that it would not have protected the equipment during an overpressure incident, but there was no incident that resulted in an overpressure or equipment failure;

c) PEI Discoveries:

- discovery of process chemistry or other operating condition that is found to be outside of an acceptable process or integrity operating window (IOW) for corrosion or other material degradation mechanism that was put in place to prevent leaks and failures.
- discovery of a compromised overpressure protection device (such as a closed block valve in the relief path or the wrong relief valve installed with a higher cold differential test pressure setting), but there was no incident that resulted in overpressure or equipment failure.
- discovery of corrosion or other damage/degradation that was beyond that expected in the inspection or maintenance planning process and thereby required unscheduled repairs/replacement during routine maintenance or turnarounds.
- discovery of the wrong gaskets or bolting being installed (e.g. B7 bolting installed where B7M was specified), but before being put in service or before there was a leak.
- discovery of the incorrect metallurgical component installed (e.g. CS fitting installed in a 5Cr-1/2Mo piping system), but before any significant damage or failure occurred;
- discovery of the incorrect specification piping or fitting installed but before any failure occurred (e.g. wrong schedule pipe or nipples installed or low Si pipe pup installed in an A106 piping system subject to sulfidation).

4.2 Other Determinates for Failures

When addressing PEI incidents, two aspects of further concern may be considered.

4.2.1 Announced or Unannounced Failures

PEI failures may be known or detected at the instant of occurrence (announced failure) or undetected at the instant of occurrence (unannounced failure). For example, a rupture of a pipe in a process plant or sudden decrease in pressure in the system is likely to be detected at the instant of occurrence and would be an announced failure. Examples of unannounced failures include a slow leak under insulation that may not be detected until a pool of fluid forms on the ground or someone notices a drip or wisp of vapor, or a slow leak from buried piping or small leak in a heat exchanger tube that may not be noticed until the next inspection.

4.2.2 Chronic or Sporadic Incidents

PEI incidents differ in the typical frequency of occurrence (chronic or sporadic) and the severity or consequence of the outcome. A chronic incident typically has ongoing common cause(s) that result in recurrence of the same or similar type of outcome over time. Examples of chronic incidents include reoccurring flange leaks, continuing discovery of CUI damage throughout a plant, multiple instances of finding the incorrect specification material or bolting during final inspection, and multiple cases of finding the incorrect schedule piping installed as nipples. Sporadic incidents tend to have an unusual combination of causes that result in an outcome of a certain type very infrequently or possibly only once in the life cycle of the pressure equipment. Any of the PEI failure examples

listed in 4.1 Item a) could be considered a sporadic incident. Valuable lessons can be learned from investigating both chronic and sporadic incidents, regardless of the outcomes.

4.3 Documenting PEI Incidents

PEI incidents, even low-consequence incidents, provide opportunities to learn through investigation to identify the causes and implement improvements to prevent a potential major failure. PEI personnel should report incidents discovered in pressure equipment, including unexpected discoveries during inspections, or monitoring of process operations. The tracking of PEI incident data provides opportunity to identify trends and improve PEI.

The reporting of PEI incidents should be done in a consistent manner and tracked so that the data can be more easily reviewed and analyzed. Annex A is an example of an incident reporting form that may be useful for such purpose. An incident report should be documented within a short period of time after the incident is recognized. The incident document should be reviewed to determine if an investigation is warranted. If trends are identified or suspected, then that grouping of PEI incidents can be investigated further to determine underlying common systemic causes. For example, it may be appropriate to investigate a grouping of chronic incidents (e.g. several instances of the wrong gasket being installed or several instances of a minor flange leak on a feed/effluent exchanger during start-up). Reporting could be computerized to facilitate analysis for systemic causes and to improve the ability to steward follow-up items to closure.

Some users have enhanced their reports by requiring specific, consistent data and codes depending upon the equipment type and failure mode. Examples of such data and codes are provided in ISO 14224, *Petroleum, petrochemical and natural gas industries – Collection and exchange of reliability and maintenance data for equipment, Annex B—Interpretation and notation of failure and maintenance parameters*. For example, ISO 14224 Annex B Table B.7 provides for failure reporting and analyzing purposes, standard failure mode categories per equipment type. Use of standardized data and codes may aid in analyzing data for common causes.

One way to implement this work process is to select a certain frequency, such as annually, to review reported PEI incidents to look for indications of common causes or similarities. The incidents that are similar or might have common causes could then be investigated as a group. The level of investigation used should be defined in the owner's/user's investigation classification system. The consequence used for classifying a grouping of incidents might be the sum of the individual consequences for each incident.

Investigation findings and results may be recorded in a standardized format such as those shown in Annex C, Annex G, and Annex H. This will help in collecting relevant data and enable trending of causes to look for common risk factors or common causes that reoccur over time so that more extensive development of corrective actions or PEI work process improvements can be identified and implemented.

4.4 Relationship of PEI Incident Types to API 754 Process Safety Performance Indicators

Any PEI incident like those indicated in 4.1 above that are not of a magnitude that deserve an investigation as an API 754 Tier 1 or 2 event should be investigated, recorded, and reported as a Tier 3 event using a Level 1 or 2 type investigation. In accordance with API 754, Tier 3 events include:

- A process parameter deviation that exceeds a safe operating limit (SOL). For PEI purposes those exceedances would include Critical IOWs, as defined in API 584. The owner-operator may also choose to include other exceedances which involve passing beyond an established barrier for reliable or potentially safe operation.
- An inspection or test finding that indicates that primary containment equipment has been operated outside acceptable limits. These findings typically trigger an action such as: replacement in kind, repairs to restore fitness for service, replacement with other materials, increased inspection or testing, or derating of process equipment. That definition could include all of the examples above of PEI failures, near-misses, and discoveries.
- A demand of a safety system designed to prevent a LOPC. For PEI purposes, that could include activation of a PRD not counted as a Tier 1 or 2 event. That means any challenge to a PRD including the rupture of a protective RD under a PRV would be counted as a Tier 3 event.

5 PEI Incident Causes

5.1 Types of Causes

PEI incidents are usually the result of multiple causes and may be categorized into different types. One particular way to categorize causes is into the following three different types (refer to Section 3 for the definitions):

- 1) immediate causes,
- 2) contributing causes,
- 3) root causes.

These causes are shown in the order of increasing depth of analysis:

- 1) identifying and correcting the immediate causes of an incident will only prevent an identical incident from occurring again on the same equipment, same type of equipment, or other equipment in the same part of the process;
- 2) identifying and correcting the contributing causes goes further in reducing the likelihood of future similar PEI incidents on other equipment throughout the process or facility;
- 3) identifying and correcting the root causes will result in improved PEI management systems and work culture and should prevent or reduce the likelihood of many other PEI incidents from occurring throughout the facility or company.

An effective investigation will determine not only the immediate cause of the incident but also the contributing causes and root causes. Thus, an investigation may reveal multiple contributing causes. Root causes are typically related to management systems or organizational cultural issues that need to be corrected to prevent other incidents from occurring. Conducting investigations and using a structured root cause analysis (RCA) methodology to determine the systems related causes will often reveal that there are multiple underlying causes. Determination of the true root causes of an incident takes a thorough investigation conducted by trained and experienced personnel and is generally best accomplished with a Level 3 investigation, described in 5.2.

5.2 Determining Causes

Determination of causes of an incident should be based on a systematic analysis of the evidence and facts collected. During the course of the investigation, the team will determine what happened leading up to the incident and the causes. There are intermediate analysis steps to prove or disprove theories of causes. Systematic analysis of evidence and use of fact-based reasoning are usually sufficient to prove or disprove causal theories. This RP describes three levels of PEI incident investigations.

- 1) Level 1 is a simple one- or two-person investigation on low-consequence PEI incidents that can be done in a fairly short period of time. Level 1 uses the evidence and the judgment and experience of the investigator to determine the causes. Level 1 investigations for PEI incidents may be initiated and staffed by the PEI group.
- 2) Level 2 is a more thorough investigation of medium-consequence PEI incidents that normally involves a small team and takes a bit more time to gather and analyze evidence and determine causes. The team may use casual factor or logic tree analysis techniques to determine the causes. Level 2 investigations for PEI incidents may be initiated and staffed by engineering or the PEI group.
- 3) Level 3 is a more detailed investigation of high-consequence PEI incidents that involves a team typically led by a trained/experienced root cause investigator. Level 3 investigations involve the gathering of much more evidence and conducting in-depth analysis and may take several weeks/months to complete depending upon the level of consequence. Level 3 should use a structured RCA methodology to determine the three