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Pressure Equipment Integrity Incident Investigation

API Recommended Practice 585

1st Ballot comment resolution
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1 Purpose and Scope

1.1 General

The purpose of this document is to provide owner/users with best practice guidelines and recommended practices for developing, implementing, sustaining and enhancing an investigation program for pressure equipment integrity incidents. This recommended practice describes characteristics of an effective investigation and how organizations can learn from pressure equipment integrity incident investigations. 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, this RP provides a specific focus on investigating pressure equipment with a specific focus on incidents caused by integrity failures of pressure equipment that are precursors to potentially significant incidents that could have the potential for significant impact on safety, health and environment catastrophically.

Catastrophic mechanical integrity incidents are rarely the result of one isolated issue; there are almost always less severe precursors to a major failure. These precursors are frequently called near-misses when they are found. Additionally, the intent of this document is to highlights the value in recognizing these precursor occurrences and promotes investigating them to determine the immediate, direct, 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 RP 585 are specifically targeted for application to process pressure equipment in the refining and petrochemical industry, but could be applied to other equipment at the owner/user discretion.

1.3 Flexibility in Application

Because of the broad diversity in organizations’ size, culture, and regulatory requirements, RP 585 offers users the flexibility to apply the investigation methodology within the context of existing incident investigation practices and to accommodate unique local circumstances. RP 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 pressure equipment integrity.
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 pressure equipment integrity (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. Typically the unexpected leaks, equipment degradation or near-misses associated with pressure equipment are not required to be investigated per the OSHA process safety management standard. However, by investigating and determining the causes of unexpected leaks, equipment degradation or near-misses associated with pressure equipment these PEI incidents, the determination of the causes can be used to improve mechanical integrity programs and management systems in maintaining PEI, such as design and construction procedures, maintenance and inspection practices and operating practices.

The Inspection, Corrosion/Materials, and Storage Tank Subcommittees of the API Committee on Refinery Equipment have produced a variety of codes and standards to guide owner/users in maintaining pressure equipment integrity and reliability, including:

- API 510 Pressure Vessel Inspection Code
- API 570 Piping Inspection Code
- API RP 571 Damage Mechanisms Affecting Fixed Equipment in the Refining Industry
- API RP 572 Inspection/Practices for Pressure Vessels
- API RP 573 Inspection of Fired Heaters and Boilers
- API RP 574 Inspection Practices for Piping System Components
- API RP 575 Methods for Inspection of Atmospheric and Low Pressure Storage Tanks
- API RP 576 Inspection of Pressure Relieving Devices
- API RP 577 Welding Inspection and Metallurgy
- API RP 581 Material Verification Program for New and Existing Alloy Piping Systems
- API RP 609 Fit for Use
- API RP 580 Risk - Based Inspection
- API RP 581 Risk - Based Inspection Technology
- API RP 582 Welding Guidelines for the Chemical, Oil and Gas Industries
- API RP 583 Corrosion Under Insulation (pending publication)
- API RP 584 Integrity Operating Windows (pending publication)
- API STD 653 Tank Inspection, Repair, Alteration and Reconstruction
- API Pub 932A A Study of Corrosion in Hydroprocess Reactor Effluent Air Cooler Systems
- API Pub 932B Design, Materials, Fabrication, Operation and Inspection Guidelines for Corrosion Control in Hydroprocessing Reactor Effluent Air Cooler (REAC) Systems
- API RP 939C Guidelines for Avoiding Sulfidation Corrosion Failures in Oil Refineries
1.5 Types of Pressure Equipment Covered

The following types of equipment are considered to be inside the scope of this document:

a) Pressure Vessels - all pressure containing components.

b) Piping - pipe and piping components (valves, expansion joints, sight glasses).

c) Storage tanks - atmospheric, low-pressure and pressurized.

d) Rotating equipment - (pump and compressor cases, pressure containing piping and pressure vessels associated with, excluding seals.)

e) Boilers and heaters - pressurized components.

f) Heat exchangers (shells, heads, channels and pressure containing components and tube bundles).

g) Pressure relief devices.

h) Structural systems - integral to supporting pressure containing systems.

i) Cooling water towers.

j) Stacks and Flares.

Other types of pressure equipment can be included at the owner/user’s discretion.

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/user.

a) Instrument and control systems.

b) Electrical systems.

c) Machinery components (except pump and compressor pressure containing cases)
d) Structural equipment not associated with a pressure containing component or system.

e) 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 RP 585 is the inspection and engineering 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 should become familiar with the concepts and principles embodied in this recommended practice, especially for level 3 PEI incident investigations that would involve the PSM organization.

1.8 Organizational Responsibilities

Owner/users can may should use incorporate PEI investigation into a broader existing incident investigation incident investigation site program or develop a site specific PEI incident investigation procedure or work process that includes guidance provided in this document the policy behind PEI incident investigations and defines the roles, responsibilities, protocols, and specific activities to be carried out by site personnel in the process of implementing this RP. Management demonstrates its commitment to this RP by allocating the adequate resources and assigning responsibilities to support the PEI incident investigation system.

2 Normative References

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

API Publication 510, Pressure Vessel Inspection Code: Maintenance Inspection, Rating, Repair, and Alteration

API Publication 570, Piping Inspection Code: Inspection, Repair, Alteration, and Rerating of In-service Piping Systems
API Recommended Practice 571, *Damage Mechanisms Affecting Fixed Equipment in the Refining Industry*

API Recommended Practice 572, *Inspection of Pressure Vessels*

API Recommended Practice 573, *Inspection of Fixed Heaters and Boilers*

API Recommended Practice 574, *Inspection of Piping System Components*

API Recommended Practice 575, *Guidelines and Methods for Inspection of Existing Atmospheric and Low-Pressure Storage Tanks*

API Recommended Practice 576, *Inspection of Pressure-relieving Devices*

API Recommended Practice 577, *Welding Inspection and Metallurgy*

API Recommended Practice 578, *Material Verification Program for New and Existing Piping Systems*

API Standard 579-1/ASME ¹ FFS-1, *Fitness-For-Service*

API Standard 653, *Tank Inspection, Repair, Alteration, and Reconstruction*

API Recommended Practice 580, *Risk-Based Inspection*

API Recommended Practice 584, *Integrity Operating Windows (pending publication)*


EPA 58 FR 54190 (40 CFR Part 68) ³ *Risk Management Plan, Rule Section 68.60 Incident Investigations*

NFPA 921M ⁴ *Guide for Fire and Explosion Investigations*

OSHA 29 CFR 1910.119 ⁵ *Process Safety Management of Highly Hazardous Chemicals*

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1. ASME International, 3 Park Avenue, New York, New York 10016-5990, [www.asme.org](http://www.asme.org)
2. Center for Chemical Process Safety of the American Institute of Chemical Engineers, 3 Park Avenue, New York, New York 10016-5991, [www.aiche.org/ccps](http://www.aiche.org/ccps)
4. National Fire Protection Association, 1 Batterymarch Park, Quincy, Massachusetts 02169-7471, [www.nfpa.org](http://www.nfpa.org)
3 Terms, Definitions, Acronyms and Abbreviations

3.1 Terms and Definitions

For purposes of this RP, the following terms, definitions, acronyms, and abbreviations shall apply.

3.1.1 Attorney work product investigation

AWP investigation
A particular set of legal rules for the purpose of assisting attorneys in providing legal advice or preparing for litigation that may apply to a serious incident investigation by legal counsel where legal proceedings are anticipated as the result of the incident. The rules generally allow the investigation to proceed in a manner that is privileged from discovery in litigation, but the rules may vary depending upon the jurisdiction.

3.1.2 bias

When people or groups use their past experience or judgment to direct the evidence gathering and development of causes towards potentially incorrect conclusions. This can be intentional or unintentional. Bias also happens when investigators predetermine the cause of an incident and then look for confirming evidence and disregard disputing evidence.

3.1.3 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.

3.1.4 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 investigation aspects.

3.1.5 contributing cause

A cause which increases the likelihood and/or consequence of an incident, but is not the immediate, direct, or root cause. Eliminating the contributing cause will not by itself prevent reoccurrence, but will likely reduce the frequency and/or consequence of any reoccurrence.
EXAMPLE: an example of a contributing cause for a failure caused by CUI - might be; the plant has poor maintenance practices for maintaining coatings, insulation and jacketing.

3.1.56

**Immediate cause**

**Direct cause**

**Physical cause**

The most direct or primary contributor to the incident that, if eliminated or avoided, would have prevented the incident.

EXAMPLE: a carbon steel pipe segment 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. A 304 stainless steel charge heater coil of a naphtha hydrotreater unit (NHT) was found to be extensively cracked following unit shutdown. The Direct Cause was determined to be: The internal metal skin temperature due to conduction was high enough to cause sensitization over time of the 304 stainless steel tubes and the soda ash neutralization procedures were not properly conducted.

3.1.6

**Immediate cause**

The mechanical mode and/or mechanism of failure e.g. rupture from thinning; localized corrosion, pin hole leak from pitting corrosion; leak from environmental cracking, flange leak from gasket deterioration, etc.

EXAMPLE: The immediate cause of the cracked 304 stainless steel charge heater coil was determined to be PASCC failure occurred in sensitized 304 stainless steel.

3.1.76

**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-RP-584 (pending publication) for more information regarding IOWs.

3.1.878

**Investigation**

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

3.1.989

**Investigator**

The person or group that conducts leads the investigation by collecting the evidence, analyzing the evidence and determining the causes and makes recommendations.
3.1.109 investigation classification matrix
A matrix used to guide the level and extent of an investigation.
EXAMPLE: Table 1 contains a sample matrix.

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

3.1.121 pressure equipment integrity
PEI
Mechanical integrity
The state of pressure equipment when it has been designed, fabricated, installed, operated and maintained in a way to prevent unexpected loss of containment or unexpected loss of structural stability.

3.1.132 pressure equipment integrity failure
PEI 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), or the discovery of equipment degradation that requires immediate action to shut down the equipment and/or perform repairs to avoid a loss of containment, usually as a result of some form of damage mechanism such as those covered in API RP 571. Loss of containment due to misoperation of equipment and not involving material damage mechanisms are not considered PEI failures for the purpose of this RP. Within this document the term “failure” is intended to refer to a PEI failure.

3.1.143 pressure equipment integrity incident
PEI incident
An unexpected PEI failure or an unexpected PEI near miss. Within this document, the use of the term “incident” is intended to refer to a PEI incident.

3.1.154 pressure equipment integrity near miss
PEI near miss
The discovery of significantly more equipment degradation or process operating conditions outside of acceptable limits that requires immediate 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 RP 571, but than expected or the discovery of process operating conditions outside of acceptable material degradation limits that did NOT result in a loss of containment or structural stability, but
corrective action is needed to prevent the progression to a PEI failure. Within this document, the term “near miss” is intended to refer to a PEI near miss.

3.1.165 pressure equipment integrity personnel

PEI personnel

People Personnel in an organization who have the direct responsibilities are assigned to for maintaining, developing, improving, and implementing the organization’s PEI program. EXAMPLES: 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.

3.1.176 probable cause

If, after thorough analysis of the evidence and facts, a cause can not 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 three categories of different causes (immediate, direct, contributing, or root).

3.1.187 process safety management incident

PSM 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 OSHA PSM regulation.

3.1.198 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.

3.1.201 root cause

A fundamental, underlying system or culture related reason why an incident occurred or allowed the immediate, direct 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.

3.1.212 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

API American Petroleum Institute
AWP attorney work product
CCPS Center for Chemical Process Safety
CUI corrosion under insulation
DCS Distributed control system
EPA Environmental Protection Agency
FA Failure Analysis
IOW Integrity Operating Window
JSA Job Safety Analysis
LOP Layers of Protection
NDE nondestructive examination
NFPA National Fire Protection Association
NPS National Piping Standards
OSHA Occupational Safety and Health Administration
PEI Pressure Equipment Integrity
P&ID Piping and Instrument Diagrams
QA quality assurance
QC quality control
PSM process safety management
RCA Root Cause Analysis
SME Subject Matter Expert

4 PEI Incident Tracking

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 RP 571. This document will refer to both failures and near-misses as PEI incidents throughout.

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

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

Near-Misses:
• Discovery of corrosion or other damage/degradation that does not pass a fitness for service assessment and requires immediate repair, but did not result in a leak
• Discovery of a damaged bolt or gasket before any failure or leak occurred, and requires immediate repair
• Structural deterioration that is found and deemed not fit for service (during potential wind loading, for example), but before a structural failure occurred
• Process chemistry or other operating conditions are found to be outside of an acceptable process IOW for corrosion or other material degradation mechanism, before failure or leak occurred and requires immediate inspection or repair
• 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 (for example, during shop pressure test the device did not function at 150% or greater of the cold differential test pressure)
• 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
• Discovered significantly more damage than expected upon a routine inspection
• Discovered the wrong metallurgical component installed but before any significant damage or failure occurred
• Discovered the wrong specification piping or fitting installed but before any failure occurred, i.e. wrong schedule nipples installed
• Discovered the wrong gaskets or bolting were being installed but before being put in service or before there was a leak

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.

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 are: reoccurring flange leaks, continuing discovery of CUI damage throughout a plant, multiple instances of finding the wrong specification material or bolting during final inspection, multiple cases of finding the wrong 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 items listed previously under Failures, could be considered a sporadic incident. Valuable lessons can be learned from investigating both chronic and sporadic incidents, regardless of the outcomes.

### 4.2 Documenting PEI Incidents

All PEI incidents, even low consequence incidents, should be viewed as opportunities to learn through investigation in order to identify the causes and implement improvements to prevent a potential major failure. PEI personnel should report all incidents discovered in pressure equipment, including unexpected discoveries during inspections or monitoring of process operation, even if they are not initially investigated individually. 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 from them can be more easily reviewed and analyzed. Annex A is an example of an incident reporting form that may be useful for such purpose. The incident report form should be filled out and documented within a short period of time after the incident is recognized, e.g. 24 hours. The incident document should be reviewed to determine if an investigation is warranted if trends are identified or suspected should be started immediately or if the incident should be recorded for trending and reviewed later with other similar incidents. If many PEI incidents are reported and enough relevant data collected, the reports can be reviewed and analyzed to identify similarities. If any similarities 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. This is one way that reporting, tracking and investigating PEI incidents can be used as a preventative tool and continuous improvement tool, by identifying and correcting causes before a failure occurs. Reporting could be computerized to facilitate analysis for systematic causes and to improve the ability to steward follow-up items to closure.
One way to implement this work process is to select a certain frequency, like every six months such as annually, to review all reported PEI incidents to look for indications of common causes or similarities. All of the incidents that are similar or might have common causes should then be investigated as a group. The level of investigation used should be defined in the owner/user’s investigation classification matrix 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 should also be collected in a standardized format such as those shown in Annex C & G. This will help in collecting all relevant data and enable trending of causes to look for common risk factors or common causes that reoccur over time such that more extensive development of corrective actions or PEI work process improvements can be identified.

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 four different types:

1. Immediate causes
2. Direct causes
3. Contributing causes
4. Root causes

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

1. Identifying and correcting the immediate and or physical direct 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 and direct cause of the incident but also the contributing causes and root 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 utilizing a structured RCA methodology to determine the systems related causes will often reveal that there are multiple underlying causes. Most investigations can determine many of the contributing causes. Determination of the true root causes of an incident takes a very thorough investigation conducted by trained and experienced personnel and is generally best accomplished with a level 3 investigation.

Any of the four types of causes (immediate, direct, contributing and root) can also include a probable cause. If, after thorough analysis, some causes can not be fully proven but are determined to be the most likely causes, then these are called probable causes. The investigation team, along with the investigation sponsor, should fully review these probable causes to assure they are based on sound reasoning and some evidence and not personal bias. Bias can be the result of intentional or unintentional predetermination of causes.

An example to illustrate the types of causes is as follows from this fictitious situation. A carbon steel pipe in a sulfuric acid alkylation unit failed and released alkylate. After a PEI incident investigation it was determined the loss of containment causes were the following:

Immediate Cause: The loss of containment occurred because sulfuric acid came in contact with the carbon steel pipe and rapidly corroded it to the point of failure.

Contributing Causes:
- There are inadequate operating controls to prevent acid carryover in the process.
- Operators did not recognize and properly react to the abnormal operating condition that caused the acid carryover.

Probable Root Causes:
- There is a mindset within the organization of making do with less than adequate leadership did not adequately address the lack of controls or information on process operations.
- Rigorous training of operators and retraining is not considered important to site management.

5.2 Determining Causes

Determination of causes of an incident should be based on a thorough 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. Analysis of evidence and use of fact-based reasoning are usually sufficient to prove or disprove cause 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.

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 could use casual factor or logic tree analysis techniques to determine the causes.

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 to complete. Level 3 should use a structured Root Cause Analysis (RCA) methodology to determine all the types of causes.

All three levels of investigation (which are described in more detail in section 6) are designed and intended to identify the immediate, direct causes and contributing causes, but level 2 or 3 investigations may be required to uncover the root causes of the incident.

Each investigation, at any level, should determine the exact immediate or physical and direct cause of the incident, based on evidence. If the immediate and direct cause cannot be determined, then the team or investigator should look for more evidence or consult with additional expertise or request a metallurgical failure analysis. Typically, when the immediate and direct cause cannot be determined, it means that some key evidence has been missed or is missing. If, after gathering more evidence or additional review of the evidence, the immediate and direct cause cannot be determined, then the most probable immediate and direct cause(s) of the incident should be defined and clearly documented, with both the known facts and assumptions identified.

Two of the main differences between the investigation levels are in the depth of the investigation and the precision used in determining the contributing and root causes. For the level 1 investigation, the investigator’s best knowledge of the organization and systems is used to identify the probable contributing causes and possible root causes. For level 1 investigations the identified root causes may not be true root causes based on detailed analysis of evidence, but are people’s opinion based on their experiences of the cultural and systemic issues within the organization. It is important to document these “root causes,” even if they are not too precise, so that ideas can be collected and grouped with other level 1 investigations to determine any trends in probable contributing and possible root causes. If enough level 1 investigations are conducted and the identified probable and possible causes are grouped, this will most likely identify real systemic or cultural issues that could then be addressed by the appropriate management or work group to determine corrective actions.

The level 2 investigations should be able to determine the immediate causes, direct causes, contributing causes and probable root causes of the incident based on analysis of the evidence and agreement between the team and the investigation sponsor. The level 2 investigation may not determine all the root causes due to factors such as the experience
of the investigation team and the depth of analysis. Identifying corrective actions for the causes that are identified and agreed to by the team and the investigation sponsor should help to prevent future incidents from occurring.

As discussed, because of the brevity or simplicity, level 1 or level 2 investigations may not be able to precisely define or prove all of the contributing and root causes. Based on the evidence and analysis, consideration should be given to making recommendations based on the probable causes to best mitigate the potential for additional incidents.

The level 3 investigations are typically conducted by trained and experienced root cause analysis personnel, and are thorough enough to identify all of the causes of the incident, including the root causes. Level 3 investigations will often be driven by others within the site organization, the PSM organization with PEI personnel involved.

6 PEI Incident Investigations

6.1 General

It is impractical and unnecessary to investigate every PEI incident to the same level of detail. As indicated in the foregoing, there are different degrees of consequence and complexity of incidents, warranting different levels of investigations. Generally, the more serious or potentially serious an incident, the greater the scope and depth the investigation should be. Every PEI incident should be reviewed to determine if an investigation is warranted and what level of investigation is appropriate. The consequences of the incident, both actual and potential, are typically used to determine the level of the investigation. When using potential consequences as a deciding factor in determining level of investigation, care should be taken to use only the most likely scenarios that might have occurred if one or possibly two other events had happened, but not more than two. The assumptions used for determining potential consequences should be clearly documented and agreed upon with the investigation sponsor.

EXAMPLE1: As an example, if a leak occurs and releases gasoline which forms a vapor cloud but does not cause a fire or explosion because an operator immediately saw the leak and turned on fire monitors, then it is reasonable to consider fire and explosion as a potential consequence and investigate based on that.

EXAMPLE2: But if the leak released diesel and a small pool fire results that is contained by the emergency response, it might be reasonable to say that the potential consequence would have been major equipment damage if the fire monitors weren’t working and the emergency shut down valves had not been activated. The assumptions used for determining potential consequences should be clearly documented and agreed upon with the investigation sponsor.
The RP defines three levels of investigation described in this RP. These levels differ in scope and depth of investigation and the amount and type of personnel involved. The owner/users may give guidelines defining the different levels of investigations and the circumstances under which they are used, should be defined by the owner/user in an investigation classification matrix. Table 1 is an example of defining the guidelines for PEI incident investigations in a classification matrix for PEI incidents. The guidelines herein will define the differences in the levels of investigation. These differences are mainly based on the personnel that are involved, including the qualifications and number of those personnel, the depth of analysis, the reporting requirements and the follow up.

### 6.2 PEI Investigation PEI Incident Investigation Levels

For the purpose of this RP, the highest level investigation, level 3, would be performed when a single PEI incident has a large actual or potential consequence. A level 2 investigation would be performed on a single PEI incident that had a medium actual or potential consequence. A level 2 investigation could also be conducted on a grouping of similar chronic PEI incidents that, when combined have a medium actual or potential consequence. A level 1 investigation would be performed on low consequence PEI incidents. These level 1 investigations are opportunities to learn and act on small incidents and proactively prevent similar chronic incidents or future larger incidents. Any PEI incident that results in a PSM incident should be investigated according to the company’s PSM incident investigation procedure.

Typically, the level of investigation is independent of the type of incident, but is determined by the consequence or potential consequence of the incident. For example, pressure equipment failures, depending on the consequence and/or specifics, might have a level 1, 2 or 3 investigation conducted. The starting point for near-misses is usually a level 1 or 2 investigation.

The following are examples of some specific PEI incidents that might warrant a level 1 investigation:

- Incorrect gasket installed and leaked without causing a fire.
- Short term corrosion rate discovered to have doubled over long term rate.
- Incorrect alloy discovered in valve before it was installed.
- Schedule 40 nipple installed where schedule 80 required in piping specification.
- Small bore piping threaded connection installed directly adjacent to a vibrating reciprocating compressor.
- Inspector discovers B7 bolting installed on exchanger floating head where specification called for B7M in sour service.
- Inspector discovers wrong weld rod being used by welder for Cr-Mo piping replacement.
- Inspector discovers utility hose being used for process drain hose.
- Thermography inspection finds 50 degree hot spot on radiant tube.
• small underground leak discovered of class 2 buried piping

The following are examples of some specific PEI incidents that might warrant a level 2 investigation:

• high pressure boiler tube rupture
• storage tank bottom leak
• inspection finds a process pipe in operation below minimum required thickness
• a feed/effluent heat exchanger flange leaks on start-up and causes a small hydrogen flame
• a process heater tube ruptures causing furnace fire that is blocked in and snuffed out without significant damage to the firebox
• a relief valve opens prematurely releasing a few hundred pounds of product before being blocked in
• a relief valve is discovered to be plugged during servicing
• piping vibration near a reciprocating compressor causes fatigue crack and product release requiring compressor station to be blocked in and taken off line
• a heat exchanger tube rupture causes heat exchanger to be blocked in and taken off line for inspection and repairs
• CUI leak causes side-stripper column to be blocked in and taken off line for repair
• a gasket blows out on a blocked in product line releasing a few hundred gallons of hazardous fluid,
• pinhole leak develops on a hydros-process line and ignites, but an operator is able to extinguish it and block it in, before major damage

6.3 PEI-Investigation PEI Incident Investigation Guidelines Classification Matrix

Owner/users may should develop an investigation guidelines classification matrix that clearly defines what consequences and what types of failures or near-misses trigger what level of PEI investigation. Their classification matrix guidelines typically includes the combinations of actual and potential consequences and frequency of occurrence for the different levels of investigation.

The investigation guidelines classification matrix includes the following:

a. Examples of incident types and consequences for each classification
b. Team leadership, team size and composition
c. Timing for investigation initiation
d. Management level of sponsorship

Table 1 is an example of an investigation guideline classification matrix for PEI type incidents and specifically does not define investigation characteristics, team make-up, or timing requirements for any particular regulatory requirement (e.g., OSHA PSM).
### 6.4 Initial Response to a PEI Incident

The owner/user may/should have a documented plan on how to promptly respond to PEI incidents, so that the need for investigations can be quickly recognized and initiated. This may be developed at the facility level or at a company level. The level of investigation and the timing of initiating the investigation may also be prescribed by governing jurisdictions agencies (e.g. OSHA, EPA, etc.), which is outside the scope of this RP. This RP is not intended to detail the emergency response or internal and external notifications. (For example purposes, the company should designate who should be notified immediately to determine the need to notify regulatory and insurance representatives, if necessary.)
As previously noted, the facility or company should have a written process that defines how information from PEI incidents should be reviewed to determine if an investigation is warranted and how it is initiated. When an incident occurs, it is important to begin collecting data and evidence as soon as safely possible. If collecting of data and evidence is not initiated immediately, some valuable information might be lost in repair and clean up activities. The most serious or highest consequence PEI incidents should have an investigation evidence gathering started soon after it occurs, but no later than 24 hours. It is important that accurate data on all PEI incidents is collected so that those incidents can be properly tracked and reviewed to determine the causes and corrective action.

The facility should have a work process to assign an investigation leader and team members immediately after a high or medium consequence incident is recognized (the incident may still be ongoing while the investigation team is identified and assigned). For PEI incidents that require emergency response, the lead investigator should be available to begin the gathering of physical evidence as soon as the area is secured by the emergency response team and released by regulatory authorities, if they are involved. If the lead investigator is not immediately assigned or available, then PEI personnel who have been trained in proper gathering of evidence can begin the evidence gathering, or at least taking steps to preserve the evidence.

For PEI incidents that do not require emergency response, the supervisor or PEI personnel closest to the equipment should begin collecting information as soon as the issue is recognized. Annex A is an example of a form that can be used to collect the initial information. Once the information is collected, it should be reviewed by the appropriate manager or supervisor to determine if an investigation should be conducted.

### 6.5 Types of Evidence

There are three basic types of evidence that are used for investigating PEI incidents:

1. **People**— interviewing people involved in the incident, eyewitnesses, or have knowledge of the system, process, or equipment design as an example.

2. **Physical**— photographic documentation of as-found conditions, examination of the mechanical parts that are deficient or failed, any equipment involved in the incident, chemical samples (e.g. corrosion and fouling material), stains, damaged equipment, appearances and observations, physical sizing and orientation of observed conditions, metallurgical analysis, secondary damage to surrounding equipment, valve positions, locations of fragments or debris, orientation of witness observations, and any other similar physical examples.
3. Records- paper and electronic records, including such items as operating logs, inspection records, prior engineering evaluations, design specifications, policies, procedures, alarm logs, test records, work orders and maintenance records, and training records. This would also include electronic format data, such as operating data recorded or correspondence (emails) pertaining to the system or equipment.

The three types of evidence listed above are in the order of what is typically the most time-sensitive to be gathered before recollections or physical conditions or orientations can be changed or affected by bias. This can be used as a guide on what evidence to start collecting first (i.e. start performing eyewitness interviews as soon as possible after the incident, followed by physical evidence gathering). Note that some electronic operating records such as distributed control system (DCS) data, disappear after a short specific time lapse so data from those systems should be immediately preserved.

7 Conducting PEI Investigation

7.1 General

This section provides general guidelines on how to perform the level 1, level 2, and level 3 PEI investigations. For the purposes of these guidelines, the levels are as described in Table 1. Any PEI related incidents that are also process safety PSM incidents may be governed by national regulations and/or jurisdictions having authority would fall under the PSM regulation (e.g. OSHA) and should be handled by the appropriate group responsible for PSM process safety incident investigations.

The main purpose of this section is to provide PEI personnel guidelines on how to conduct and support investigations. The CCPS, Guidelines for Investigating Chemical Process Incidents, 2003 referenced publication provides more detailed guidance on how to conduct investigations and could be used to build a comprehensive investigation program.

7.2 Performing Level 1 PEI Investigation

Level 1 investigations are recommended for failures with minor actual or potential consequences, near misses or unexpected discoveries concerning PEI. These investigations should involve a review of the facts and identification of appropriate corrective action items. Level 1 investigations are less resource intensive than level 2 & 3 investigations. When appropriate, level 1 investigations identify specific corrective action items assigned to individuals with deadlines and periodic follow-up, e.g., unit inspector. The analysis is limited to localized incidents, and contributing causes and root causes are generally not evaluated in depth. The 5-Whys process is an example of an
investigation method that can be used for Level 1 PEI incident investigations and is described further with an example in Annex B.

A level 1 investigation might start with the incident report filled out with the knowledge about the incident that is known at the time of occurrence and a clear statement of the problem that is being investigated. Although no specific format for level 1 investigations is prescribed in this RP, developing a form or guidelines for gathering and recording the information will be useful when reviewing these investigations for trends and further improvements.

The following are examples of some specific PEI incidents that might warrant a level 1 investigation:

- incorrect gasket installed and leaked without causing a fire.
- short term corrosion rate discovered to have doubled over long term rate.
- incorrect alloy discovered in valve before it was installed.
- schedule 40 nipple installed where schedule 80 required in piping specification.
- small bore piping threaded connection installed directly adjacent to a vibrating reciprocating compressor.
- inspector discovers B7 bolting installed on exchanger floating head where specification called for B7M in sour service.
- inspector discovers wrong weld rod being used by welder for Cr-Mo piping replacement.
- inspector discovers utility hose being used for process drain hose.
- thermography inspection finds 50 degree hot spot on radiant tube.
- small underground leak discovered of class 2 buried piping.

7.2.1 PEI Level 1 Investigation Personnel

The level 1 PEI investigation would be performed by one or two persons, typically the PEI personnel responsible for the equipment involved in the incident, e.g., inspector and/or engineer for the area where the PEI incident occurred. The following are guidelines on the type and role of personnel that could be involved in level 1 investigations.

1. PEI Incident Investigation Leader: PEI personnel responsible for the equipment involved in the incident. If trained and qualified, the person could be the one who discovered the problem or the one who reported the incident.

The investigation leader should have some sufficient training and knowledge to carry out the responsibilities for this level of investigation. This person may be the only one conducting the investigation and is responsible for collecting the evidence and analyzing the evidence in an unbiased way to determine the immediate, direct, contributing and possible root causes to the extent possible based on the evidence and facts. The investigation leader is then responsible for presenting the conclusions and
recommendations to the sponsor for approval and endorsement. Finally the investigation leader is responsible for completing the final documentation.

2. Team Members: Typically, this level of investigation is performed by a single person. If another team member is needed, their training and qualifications should be dictated by the type of PEI incident that occurred, and the need for assistance of the investigation leader. Others may be involved as needed to assist on an ad hoc basis with providing data/evidence, providing SME input or as interview witnesses regarding the incident.

3. Sponsor: These investigations might should be sponsored by the investigation leader’s immediate supervisor or a supervisor/manager of the unit or department involved with the equipment where the incident occurred. The role of the sponsor is to ensure the investigator has the time and skills to complete and document the investigation and to set a date by which it needs to be complete. The sponsor would also help guide the investigator to ensure they are conducting an appropriate level of investigation and analysis. The sponsor would also have the responsibility to assure that follow-up corrective actions from the investigation were completed in a timely manner.

7.2.2 Collecting/Examining Evidence

All three forms of evidence, people, physical, and records, would be gathered or examined by the investigator(s).

The investigator should consider interviewing eye witnesses (if there are any), people who work in the area, such as operators, process engineers, maintenance or reliability engineers, and any other PEI personnel involved with the equipment or incident. The investigator should collect and or examine any physical evidence or parts involved or damaged in the incident. The investigator should examine any relevant documentation for the equipment or system, such as past inspection records, process operating history, design records, purchasing records, and maintenance or repair records.

If needed, the investigator should ask for expert help in the examination of some evidence or determining what additional evidence to examine.

7.2.3 Analyzing Evidence and Determining Causes

The investigator should analyze all the evidence gathered, characterize what each piece of evidence is revealing about the causes of the incident.

The analysis includes looking at the evidence and determining, to the best of their ability, what the immediate, direct, contributing and possible root causes of the incident are. This may involve judgment and some subjective assessment. It is important to best determine the causes even if it is without 100% certainty, so that recommendations can be proposed for corrective actions to prevent a similar incident.
At times, it would be helpful if the investigator used a structured method, such as the 5-Whys, to determine the causes. In such cases, the investigator should be trained on the techniques or engage other knowledgeable experts. If the investigator cannot fully explain the immediate or direct causes from the evidence gathered, they may need to gather more evidence or ask for additional SME expertise to help determine the immediate and direct cause(s).

Level 1 investigations should identify the immediate and direct causes of the incident as a minimum. The investigation leader should also make a best effort at identifying contributing and possible root causes based on the investigator’s knowledge of the component failure mode or damage mechanism in conjunction with some specific information gathered about the particular incident, and the investigator’s knowledge of the facility’s systems and work processes. Level 1 investigations are usually not rigorous enough to identify all of the contributing and root causes.

7.2.4 Action Items

The level 1 investigation should include an understanding of the immediate and direct cause to identify what actions need to be taken to address the direct immediate cause to prevent a similar incident. The investigator would also try to understand the contributing and possible root causes, with special emphasis on issues that represent opportunities for improvement that are within the control of the investigator or the control of the investigation sponsor. The investigator with approval from the investigation sponsor would recommend determine what action items are assigned and to whom.

With the focus on PEI incidents, consideration might be given to what changes may be needed to improve the PEI program to prevent similar incidents.

Example: Action items might include improvements on how inspection plans are developed, or making improvements to the work process of how damage mechanisms are predicted and utilized in specifying on-stream NDE, or the investigation might reveal that additional process parameters should be monitored for IOWs.

7.2.5 Reports

Level 1 investigation results may be documented on a simple form or template such as that shown in Annex C. As a minimum, the report may document what happened, the immediate causes, the direct causes, the contributing causes and the corrective actions. These reports are important for both the incident being investigated and to have quality information to review for trends and broader improvements.
7.2.6 Determining effectiveness of Action Items

The identified contributing causes from many level 1 investigations, may should be reviewed over time to look for common or systemic causes, and to determine if they are being reduced and/or eliminated. If no improvement is shown, then this may be an indication that the follow up actions were not effective. In such a case, a review may should be conducted to determine how to more effectively address the reoccurring contributing causes, or to identify additional contributing and/or root causes that should be addressed. This might involve a level 2 investigation on a grouping of similar level 1 incidents.

7.3 Performing Level 2 PEI Investigation

Level 2 investigations are conducted on medium actual or potential consequence incidents, i.e., all that fall between level 1 and 3. It is assumed that level 2 PEI investigations would not involve incidents that rise to the level of requiring a PSM investigation. As previously discussed, the level 2 processes may also be used to further analyze information from multiple, similar level 1 investigations. Because Level 2 investigations typically involve higher risk incidents than those in level 1, they would typically have a two to three person multi-disciplined team to analyze the evidence and identify contributing causes and probable root causes.

7.3.1 Beginning the Level 2 PEI Investigation

Similar to the level 1 investigation, the level 2 investigation should start with the incident report filled out with the knowledge about the incident known at the time. Developing a form or guidelines for gathering and recording the incident information will be useful when reviewing these investigations for trends and further improvements. See Annex A for a simple example form. It is very important to properly define the problem that the investigation team is going to investigate. The incident might have caused multiple issues, such as loss of containment that then revealed improper fire monitor coverage or improper drainage when mitigating. These are different problems and should be investigated separately; the PEI incident investigation should address personnel would be responsible for investigating why the loss of containment occurred.

The owner/user’s investigation program should define how a PEI incident investigation team leader is assigned and how a team is formed for a level 2 investigation. The team composition should consider the type, size, consequences, and nature of the incident.

It is very important to collect all available and relevant evidence as soon as safely and reasonably possible to do so. As part of establishing a PEI incident investigation program, it is helpful to have one or more trained and designated team members with the
responsibility for arriving at the scene ready to collect and/or preserve evidence while the
evidence still exists. For example, if an incident involves loss of containment, evidence
gathering can begin outside the area even before the area is secured and safe to enter.
This person(s) can begin to collect eye-witness statements, if the eye witnesses are not
involved in the emergency response, and also downloading of DCS data. For level 2
investigations that did not involve loss of containment, the program should include
consideration on how to collect evidence at the scene immediately. For example, the
designated team member or investigation leader responsible for initial evidence gathering
should not be involved in the repair work that may be required due to the incident. This
will allow the person to concentrate on evidence/data gathering and not miss an
opportunity to collect data, such as while a piece of equipment is shutdown or before a
patch is installed over a corroded area, or before corrosion or fouling products are lost or
disposed of. More details about evidence gathering are in Section 7.3.3 Collecting
Evidence.

The following are examples of some specific PEI incidents that might warrant a
level 2 investigation:

- High pressure boiler tube rupture
- Storage tank bottom leak
- Inspection finds a process pipe in operation below minimum required thickness
- A feed/effluent heat exchanger flange leaks on start-up and causes a small
  hydrogen flame
- A process heater tube ruptures causing furnace fire that is blocked in and snuffed out without significant damage to the firebox
- A relief valve opens prematurely releasing a few hundred pounds of product
  before being blocked in
- A relief valve is discovered to be plugged during servicing
- Piping vibration near a reciprocating compressor causes fatigue crack and product
  release requiring compressor station to be blocked in and taken off line
- A heat exchanger tube rupture causes heat exchanger to be blocked in and taken off line for inspection and repairs
- CUI leak causes side stripper column to be blocked in and taken off line for repair
- A gasket blows out on a blocked in product line releasing a few hundred gallons of hazardous fluid,
- Pinhole leak develops on a hydroprocess line and ignites, but an operator is able to extinguish it and block it in, before major damage

7.3.2 PEI Level 2 Investigation Personnel

Defining the team composition requirements associated with a level 2 investigation
may be part of the PEI incident investigation program. The following are
guidelines on the type and role of personnel that would be involved in level 2 investigations.

1. **PEI Investigation PEI Incident Investigation Team Leader:** The investigation leader should be trained in the specific investigation methodology used. For level 2 investigations the investigation team leader is responsible for leading the investigation team through the entire investigation process. The investigation team leader responsibilities include the following:

   a) Managing the team’s safety concerns and coordinating investigation activities with any emergency response activities.

   b) Conducting the investigation by the specific company methodology.

   c) Defining the required resources or team members to help conduct the investigation.

   d) Leading the team in collecting the evidence and analyzing the evidence in an unbiased way to determine the immediate, contributing and root causes based on the evidence and facts.

   e) Presenting to appropriate management the conclusions and recommendations.

   f) Writing the final report.

2. **Team Members:** The investigation team leader may be assisted by at least two other team members. The size and complexity of the incident will determine the number of team members that are needed. The team may be comprised of a diverse mix of backgrounds from either the area where the incident occurred or another area within the facility in order to facilitate the thinking process from different perspectives. Either one team member or the team leader should include a PEI person from the area; this could be an inspector, pressure equipment engineer, inspection engineer, metallurgical/corrosion engineer or reliability engineer. The investigation team members are responsible for assisting in the investigation by collecting evidence and helping to analyze the evidence to determine the causes. Team members may also be needed to assist the team leader in writing the final report.

3. **Sponsor:** These investigations should be sponsored by the highest supervision over the area where the incident occurred. If the incident occurred in a process unit in a refinery or chemical plant, then the sponsor would typically be the process unit’s area manager or could be the engineering manager or project manager, depending upon the type of incident.

   The sponsor’s role is to ensure that the team has the time, resources and cooperation to conduct the investigation, but not to manage the activities of the investigation. The sponsor should convey to all those who will be assisting the investigation team, the importance of their corporate and honest participation in the investigation developing lessons learned and corrective actions. Without that lessons learned and corrective actions taken may be flawed. Additionally the sponsor would be responsible
for assuring that identified and approved corrective actions were implemented on a timely basis and that the lessons learned were communicated to affected individuals.

7.3.3 Collecting Evidence

The determination of immediate, direct, contributing and root causes are should always be based on evidence and expert knowledge of the contribution of the evidence. If not properly preserved or collected soon after the incident, some evidence can will be destroyed or lost, such as Distributed Control System data being overwritten, damaged components, failed parts, being thrown away or fracture surfaces improperly handled, if not properly preserved or collected immediately after an incident occurs. The priority for collecting data should be based on how perishable the data is. The more perishable or changeable data should be collected first. The team should begin collecting data without trying to solve why the incident occurred or determining the immediate, direct, contributing or root causes.

In PEI incidents that involve fires or toxic releases, once the area has been secured and it is safe for personnel to enter, the lead evidence gathering should begin or the investigation lead, the investigation lead will need to work with operations to control should have sufficient control over the scene until they determine that initial evidence gathering is complete. The area might should be roped off with designated for no unauthorized entry allowed.

Collection of physical evidence should begin as soon as practical immediately after securing the site and continues throughout the early part of the investigation. Collecting of other evidence not within the restricted area, like interviewing of eye witnesses, can also begin immediately. The investigation team should begin a preliminary sequence of events timeline and sketch of the equipment or system involved to help the team understand what happened, what was involved, and the scope of the investigation.

The investigation team should survey the scene and identify people, equipment, and materials involved in the incident. The investigation leader should then prioritize the information to be gathered and assign responsibilities to the team members to conduct interviews and gather evidence. The coordination of the effort is to assure data is gathered systematically and purposefully.

One way to start determining what evidence to gather is to have a collection of generic lists for each type of evidence. These generic lists can be used by the team as a starting point and can be customized for the specific incident. An example of generic lists for each type of evidence is provided in Annex D. Depending on the type of incident being investigated, not all the evidence mentioned will be applicable or necessary to collect. If the incident did not have a defined consequence, like a loss of containment that happened suddenly, there may not be any eye-witnesses or process data at the time the incident occurred.
PEI personnel that are not on the investigation team can assist the investigation team by providing any all the information that they have about the equipment or system that was involved in the incident. They should also be very open and honest with any information they have, including historical information from memory, correspondence like email and any notes in personal log books. All information should be freely provided to the team by the PEI personnel without any filtering or bias. In some cases individuals may believe that they have made some sort of mistake or in some other way had a vital role in why the incident occurred. If that is the case, such individuals should not be on the investigation team. The investigation team should convey that they are not looking to blame any individuals, but rather are just seeking the truth, so that appropriate corrective actions can be applied to those management systems that are not as robust as they should be.

PEI and maintenance/repair personnel should not do anything with the equipment or system involved in the incident until the site has been released by the investigation team or team leader.

Consideration should be given to protecting the integrity of the evidence. Have two people collect and handle the evidence to minimize the chance that evidence will be mishandled unintentionally or tampered with intentionally. Evidence, such as physical evidence, that cannot be replaced should be kept in a secure location such as a locked room or storage area and under the control of the investigation leader.

7.3.3.1 Collecting People Evidence

The people evidence is one form of very perishable evidence. Immediately after an incident people’s recollection of the events begin to change, especially as they talk to others. It is important to initially interview the eye witnesses and people directly involved in the incident as soon as possible. Ideally, they are asked not to talk to each other until they have been interviewed.

Interviewing people constitutes a major element in the initial stages of a PEI incident investigation. Some general guidelines for the interview process are as follows:

- Write questions to ask ahead of time to make the interview and note taking go smoothly. It is a good idea to have a template for interviewing that all investigators use. An example of generic questions to ask eye witnesses is included in Annex E but it should be modified to suit the site-specific incident.

- Begin by interviewing the people directly involved in the incident and eye witnesses first. They know the details of what happened and are most likely to forget them if not interviewed promptly.

- Interview individually to help keep the interview private and prevent individuals from influencing each other's memories. This also minimizes the intimidation factor associated with interviews. The site investigation procedure should address
how to interview union represented employees and fulfill the requirements of the local labor contract.

• Interview at the scene if practical/safe to help the person being interviewed remember details.

• Explain that the intent of the investigation is to identify causes, not to place blame. Tell the interviewee that although their information may be used in the investigation, they, as a source will be kept confidential or anonymous; no names will be attached to specific statements.

• Avoid speculating, trying to solve the reason why, or identifying causes. You are just gathering information without judgment and should be careful not to influence their statements in any way.

• Ask open-ended questions versus those answered by "yes" or "no". For example, ask story telling questions such as "Tell me what you saw?", and "What happened next?". Start the interview with open-ended questions that cannot be answered with a one word answer. For example, ask story telling questions such as "Tell me what you saw?", and "What happened next?". Later in the interview, use closed-end questions to get more specific detail.

• Do not "lead" the interviewee; start the interview with broad questions (i.e., "Would you please tell me what you saw, heard, smelled?"). Leading questions indicate the answer as part of the question, and may be useful in confirming what was said, but not in gathering overall information. For example, "You had recently inspected the piping and found xyz thickness?" is a leading question, but may be useful in clarifying information after the interviewee tells you information. Leading questions are good for confirming understanding, but not for pulling out the facts initially.

• Ask questions for clarification as necessary like "What do you mean when you say....?"

• Progress to more detailed questions (i.e., "Can you explain the procedure for....").

• Treat the interviewee with respect and compassion to assure they understand that their answers and information are critical to the investigation process.

• At the end, paraphrase what you heard to improve and confirm your understanding and provide the individual a chance to add more detail or make clarifications.

• Thank the interviewee for their time and cooperation and provide them information such as your name and phone number or email, to contact you if they think of anything else.
Information collected from interviewing people needs to be collaborated compared with information from other sources before stating as fact. Collaboration might include supporting interview statements with physical or records evidence or by multiple people independently making the same statements.

7.3.3.2 Collecting Physical Evidence

An initial site visit should occur as soon as the area where the incident occurred is determined to be safe for entry by investigation personnel. The investigation team or at least the investigation team leader should survey the site to look for physical evidence. They should look at the entire surrounding area and not just the point of the incident. They should look for signs of evidence and also look for what should be there but is not. They should also look for what is correct and document that, this will be helpful later in confirming or disproving theories. The investigation team should not disturb anything at this point and should not be focused on fixing the problem or determining the cause. They should only be looking at recording, collecting and documenting physical evidence.

The initial activities of the site survey might include the following and should typically be performed in the stated order:

- Take a large number of photographs of the scene from various angles and distances to help orient people to the incident. Consider the need and value of videotaping to add additional orientation and perspective to the scene. Take photographs of the surrounding areas and equipment. Placing a recognizable object or ruler next to the object being photographed may add perspective, particularly for close in photos of small objects. Using index cards to write what the object is and place in the photo helps with documenting the photographs.

- Write observations or make sketches for things that may not show up on a photograph (e.g., warped, discolored, cracked, etc.)

- Incidents that involved an explosion may require special mapping of the location of fragments and debris. It is important to map the exact location of any fragments and their condition. The size of the parts and the distance they are from the source are good information to determine the energy released.

- Collect any failed parts that do not require disassembly. Be very careful in handling damaged parts to preserve evidence that may be present on a macro or microscopic level. Label where the part came from and its orientation. Any equipment that requires disassembly should be done later under the direct observation of an investigation team member or failure analysis laboratory.

- Samples of process fluids or solids that may be involved should be collected.
• Incidents that involved fires should have the damage of the material in the area recorded for determining the heat pattern. API 579 as well as NFPA 921M provide guidelines for assessing fire damage.

• It is important to record what equipment was not damaged in the area or system involved.

Equipment damaged in an incident should be carefully preserved. Fracture surfaces should not be disturbed to prevent incidental damage and hinder the failure evaluation of the part. Similarly, cleaning of the part should not be done unless absolutely necessary to enable chemical analysis of the part.

When handling failed parts and fracture surfaces, care must be taken to preserve specimens in the original condition to provide as much information as possible for determination of the cause of the failure. For any failure the following guidelines for preparation of samples for analysis should be followed, as appropriate:

• Do not mechanically clean, sandblast, wire-brush, or acid clean any failed parts prior to proper analysis. Deposits on the failed part might be helpful in determining the cause(s) of the failure.

• If a part is fractured into two or more separate pieces, do not try to fit the fracture surfaces back together. Certain metallurgical features on the fracture face can help determine the cause of the failure and can be easily damaged by improper handling.

• Only apply preservatives (e.g. lubricating oil) to fracture surfaces when directed to do so. The lubricating oil can be removed prior to fractographic analysis; however, the integrity of surface deposits and corrosion products could be compromised by applying oil to fracture surfaces.

• Wrap the failed section in plastic e.g. bubble wrap in the "as-is condition” without removal of surface deposits beforehand.

• Do not store failed items outside

If at all possible, a good practice is for the team to conduct an initial site survey and collect initial evidence, then take a break and come back later in the day or even the next day to survey the site again before clean up or demolition begins. This provides the team the opportunity to see things that might have been missed on the first survey.

Generally, after this second site survey, the site is released from evidence gathering so that clean up and repair activities can begin. During repair and restoration activities if any PEI personnel discover anything they think is unusual or they think might be relevant to the investigation, they should notify the investigation team leader immediately.
7.3.3.3 Collecting Record Evidence

The first day or two after the PEI incident it is important for the investigation team to concentrate on collecting the most perishable evidence as soon as practical as described above. After that is complete, the investigation team should then brainstorm on what other evidence should be collected. They should make a list of that evidence and the investigation team leader might assign responsibilities to the team members to gather the additional evidence. This additional evidence might include the following, depending on the type of PEI incident:

- Operating information showing process control data several days before the incident and at the time of the incident. (Process control information should be collected/archived as soon as possible. This should be an initial step backed up by further collection of information once the investigation is underway.)

- Related operating and maintenance procedures, including date last updated/reviewed.

- Copies of the appropriate design standards (Engineering Practices, Design Practices, etc.).

- Copies of management system documents related to the activities surrounding the incident, such as management of change documents.

- Copies of engineering drawings, P&IDs, JSAs

- Operator log books and shift turnover documentation.

- Relevant maintenance and inspection records.

- Equipment design and construction records.

- Materials information

- Applicable personnel training records.

7.3.4 Analyzing Evidence and Determining Causes for PEI Incidents
The collection of evidence and the analysis of evidence should be two distinct and separate activities. While collecting evidence the team should not try to analyze it and determine causes too early. This can lead to bias and not exploring all possible causes.

Once the investigation team leader believes that the team has collected all (or most of) the evidence, the team should begin analyzing the evidence. The investigation team should carefully review all the evidence and make sure they fully understand what it is revealing. If this is a large investigation and there is a lot of evidence, it can be beneficial to divide up the different types of evidence among the team. Have one or two members of the team review each type of evidence: records, people, physical, and summarize it. They would then present the summarized evidence to the rest of the team. Team members should draw conclusions from their reviewed evidence about the immediate, direct, contributing and root causes of the incident. Members would then present their conclusions to the team. The team should then determine if each form of evidence is pointing to basically the same conclusions about causes. That would be further confirmation that the correct causes are being identified.

Once the team begins analyzing the evidence, some gaps in evidence may be revealed which will require collecting of more evidence. The team should then gather that additional evidence. Also, when the analysis of evidence begins this will reveal any expertise that is needed to help analyze data and determine causes, such as metallurgical expertise to examine failed components, or process expertise to analyze process samples or process data.

Analyzing the evidence to determine the causes should define all the issues associated with the incident. The analysis should identify such things as: 1) Type of failure or damage mechanism, 2) Details of the components involved; material, service conditions, environment, stresses and loadings, 3) Prior service history, 4) Manufacturing history, 5) Design conditions. Tests needed to analyze failed components and determine the causes should be specified by the proper expertise. Annex F is an example of a form that can be used to send physical parts off for failure analysis and section 7.5 gives guidance on failure analysis of components.

An important part of the analysis would include determination if industry PEI codes and standards such as those listed in 1.4 and company PEI related procedures, standards and work practices were followed or not. The analysis might also determine if they were followed, why were they not effective in preventing the incident.

A structured analysis method should be used to analyze the evidence and explain the failure, such as, logic tree, cause and effect diagrams, or sequence diagrams. Whichever method is used, the results should be consistent with the evidence and facts. The determined causes (immediate, contributing and root) of the PEI incident should result from this analysis. Use a structured analysis method to analyze the evidence and explain the failure, such as, logic tree, cause and effect diagrams, or sequence diagrams. There
are many structured processes that can be found in the literature or offered by commercial vendors.

7.3.5 Developing Recommendations and Action Items

Once the investigation team has conducted a structured analysis and determined the immediate, direct, contributing and root causes of the PEI incident it is important to develop recommendations and action items to address the cause(s). Once action items are satisfactorily completed and a management system created or reinforced to sustain the corrective actions, the likelihood of reoccurrence of the incident and other similar incidents should be reduced.

Recommendations resulting from the incident investigation should be developed to prevent reoccurrence of the condition or activity. The investigation team should not attempt to analyze the cost or engineering required to implement a recommendation, unless directed to do so by their sponsor. Generally such efforts are part of the next phase to develop action items and typically involve different individuals.

For PEI incidents, consideration should be given to what changes are required to improve the PEI program in order to prevent similar incidents.

EXAMPLE: The inspection plan for the equipment involved and other similar equipment should be reviewed to determine if it should be changed or modified in any way to prevent another such incident. Consideration should also be given to determination of whether any procedures, documented work practices and other management systems need to be reviewed for improvement.

Each recommendation that the investigation team develops should be clearly written and state which cause(s) it is designed to address and Recommendations should be clear and concise requiring no interpretation. A suitable implementation plan would then be developed to resolve the recommendations. Where management rejects a team’s recommendation, the reason for rejection should be documented. All investigation team recommendations resulting from a level 2 investigation may not end up being implemented. The level of risk reduction, effectiveness of the implementation, and cost of implementing recommendations will need evaluation by management and SME’s.

The investigation team will develop recommendations to address the causes identified as a result of the investigation. The investigation team may suggest action items to address their recommendations but they do not typically define the action items and responsibility. This is more appropriately done by the management of the group or area that owns the issue or the group that has to commit resources or funding to solve the issue. It is management’s responsibility to define appropriate action items to address the recommendations and assign the appropriate owner of the action item.
Action items assigned to address the investigation team’s recommendations would typically be clearly written and state which recommendation it addresses. Alternative actions may be substituted by the responsible manager or action items may be modified as corrective action work progresses, so long as the recommendation is adequately addressed and the proper approval is received. All action items are typically assigned a responsible owner with a reasonable completion date assigned, considering the risk associated with continued operation which may influence the specified completion dates.

The owner of the action item is then responsible for understanding and managing the follow-up and completion of it.

7.3.6 Final Report and Documentation

A final report is written by the investigation team that documents the PEI incident investigation effort, the findings, analyses, causes, and recommendations. It is important that the final report is laid out in an efficient and logical format so that it is easy for the reader to understand. There will be many audiences for each report, so the various readers should be considered when writing the report. The report should be written without a need for technical interpretation. The report may contain or reference the technical information used as part of the analysis.

All reports, as a minimum, should include the following information:

- Description of the incident, how and what happened
- A clear statement defining the problem that was investigated Describe the incident, where and what happened
- Estimation of the total cost of the incident.
- Costs may include: the equipment damage, repair costs, lost profit due to unit down time, personnel lost time, medical costs and the cost of the investigation
- Presentation of the findings of how and why the incident happened
- Presentation of the conclusions on what were the immediate, direct, contributing and root causes
- Indicate what management systems that may be related to the root causes
- Include all the recommendations to prevent a repeat incident and/or lower the risk

A standard template or consistent format for final reports assists those writing and reviewing reports and will help ensure that all required information is documented. An example template for a level 2 final report is included in Annex G.

The final report is only a portion of the overall record of the investigation. All of the documentation that was generated or collected as part of the investigation effort should be maintained for future reference as part of the investigation record. These documents should be cataloged so that a subsequent reviewer could review the team’s analysis and
decision making. All of the documents associated with the investigation The final report and other documentation deemed necessary for record keeping per the company’s record retention policy should be stored per the company’s records retention policy.

The final report should be reviewed and approved by the investigation sponsor.

### 7.3.7 Tracking of Action Items

There should be a system in place to track progress and ultimate completion of all action items assigned. The problems and issues discovered during a PEI incident investigation remain unchanged until the action items assigned to address them have been completed and a system is put in place to sustain the changes.

The owner/user should have a process whereby action items are periodically reviewed and progress monitored. All action items should be completed by the assigned target date. Action item target dates should not be changed without proper risk assessment consideration to the risk associated and management review and approval. In some cases, there may also be regulatory requirements on the time allowed to implement certain actions. If an action item is changed or deleted, it should be clearly documented as to why and how this decision was made and what alternative actions were taken. All action items should have an clear auditable trail.

The appropriate level of manager should be assigned to monitor the progress of all action items.

### 7.3.8 Determining effectiveness of Action Items

For a select number of level 2 PEI investigations, it may be important to review the effectiveness of the actions taken to resolve recommendations. A post implementation audit should be conducted to review the recommendations and associated completed action items and determine if they were effective as intended for the desired systemic improvement. A follow up audit should be conducted after a longer specified time to make sure the completed actions are still in place and are still effective.

### 7.4 Level 3 PEI Investigation

Most of the information in section 7.3 for conducting a level 2 investigation of a PEI incident also applies to level 3 investigations of PEI incidents. It is assumed that most level 3 PEI incident investigations would rise to the level of a process safety-PSM investigation. As such, the description herein of a level 3 PEI incident investigation would need to be in conjunction with and in support of the site’s process safety-PSM investigation procedure. A level 3 type investigation could also rise to the level of an Attorney Work Product (AWP) investigation if legal matters are involved. Where failure events give rise to potential legal liabilities, it may be desirable to conduct failure investigations in a manner that is privileged from discovery in litigation. An
investigation may be privileged to the extent its purpose is to assist attorneys in providing legal advice or preparing for litigation, and where privileged communications are not disclosed to third parties outside the privileged relationship. Whether — and to what extent — a particular investigation is privileged will depend on the circumstances and the applicable law. As a result, in order to maximize the potential for successful assertion of privilege claims, it is essential to consult legal counsel at the outset of the investigation. No attempt is made in this section to describe a PSM or AWP investigation. However, the description herein pertains to how PEI personnel can contribute to a PSM or AWP investigation when a PEI issue may be involved in the incident.

A level 3 PEI incident investigation would likely be led and/or overseen by other parts of the organization (such as site managers, the site safety or process safety group), but would be supported by PEI personnel when loss of containment was an issue. Additional breadth and depth of investigation and root cause understanding is warranted for the PEI aspects of incidents with level 3 actual or potential consequences. The following guidelines supplement those provided above for level 2 PEI incident investigations.

Level 3 investigations are performed on the PEI incidents with the highest actual or potential consequence and require a multi-disciplined team to fully analyze the deepest level of cause (root causes), as well as contributing causes and probable causes. Typically, only a very small percentage of PEI incidents would be investigated at this level of detail. This level of investigation is generally selected for incidents that had actual or potential to result in significant Safety, Health or Environmental consequences, fires, explosions, large economic impacts, and other issues that involved or could have involved serious injuries, fatalities or major environmental damage.

In reality, Typically, there is almost always there is more than one cause in a level 3 PEI incidents. Some of the causes may be latent (or hidden), or a cause cannot be verified to a high degree of certainty (referred to as a probable cause). In the refining and chemical processing industry, hazardous processes are protected by multiple layers of protection or barriers, commonly referred to as layers of protection or LOP. Typically, more than one barrier or protection layer or LOP has to fail to have a catastrophic incident. For an incident that warrants a level 3 investigation, the all of majority of the LOP layers of protection would have failed or been weakened in some way. Some of the barriers might have latent or hidden weaknesses in them, but these had not been revealed or known before because the other LOP barriers were preventing any incidents. It is important when conducting a level 3 PEI incident investigation to determine the contributing weaknesses of the multiple LOP layers of protection.

A structured root cause analysis method should be used to analyze the evidence and explain the failure and the incident, including those methods such as logic trees, cause and effect diagrams, sequence diagrams, etc. Whichever method is used, the investigation results should be based on the evidence and facts and every effort made to eliminate bias. Development of these types of trees or diagrams will also reveal any additional evidence or data analysis to assure that the conclusions are thoroughly supported by the evidence.
The PEI incident investigation team leader/member should be a trained and experienced person in the specific RCA investigation methodology used. For level 3 incidents the PEI incident investigation leader should be someone from another area of the company or plant than where the incident occurred or even a contract principal investigator. It may also be beneficial for the team leader to have their primary area of technical expertise outside of the PEI functional discipline. This will reduce the potential for bias and over looking some potential causes. The team leader should make sure that all evidence is gathered and considered to avoid predetermining causes and consequently the bias of gathering evidence to confirm these predetermined causes.

The team members might be a cross functional group of individuals with knowledge and technical expertise in different functional disciplines. Team members who were not involved with or associated with the equipment being investigated are preferred to minimize introducing bias or conflicts of interest. PEI personnel from another area of the facility could serve as team members for pressure equipment failures to lend their knowledge and expertise to the investigation. If personnel from outside the area are not available, then special attention by the investigation leader and investigation sponsor is needed to be sure bias is not skewing the investigation conclusions. If contractors are involved in the incident, then consideration should be given to including someone from the contractor’s company on the team, but not someone that was directly involved in the incident.

Once a level 3 investigation is determined to be caused by a PEI failure, then PEI personnel can lend their knowledge and expertise to the investigation team to improve evidence gathering and determination of causes. Under strict guidance by the investigation team leader the following are areas of expertise that may assist PEI personnel may assist can help with the investigation with include with:

- Knowledge of the PEI codes and standards (see 1.4) that apply and if any had not been followed or adhered too or were not effective.
- Knowledge of the company PEI procedures and work practices and if any had not been followed or adhered too or were not effective.
- Guidance in determining the specific damage mechanism that caused the failure and the type of failure analysis that should be done on specific physical evidence.
- Guidance in specifying non-destructive examinations (NDE) to identify other damage in the remaining equipment and also specifically where to look. E.g. if the failure was caused by an elbow thinning and rupturing due to naphthenic acid corrosion, the PEI personnel can determine other all associated systems that are susceptible to naphthenic acid and the specific areas to inspect for damage, like on elbows or other change in flow direction.
- Help in reviewing past inspection records to determine if the damage should have been predicted and reasons it wasn’t.

Level 3 investigations should be sponsored by the highest level of site management who is responsible for Safety, Health and Environment personnel and may include other senior management sponsor team members. For example, if the incident happened in a refinery...
or chemical plant, the plant manager might should be the sponsor. The sponsor’s role is to ensure that the team has the time, resources and cooperation to conduct the investigation in a very professional manner, but not to manage the activities of the investigation.

The level 3 investigation should identify the all-immediate, direct, contributing and root causes, with the investigation depth and scope supported by the investigation sponsor and fully utilizing the RCA methodology selected. The investigation should be extensive enough to fully understand the immediate and direct causes (the specific equipment damage mechanisms that resulted in the failure), and also identify the contributing and root cause factors and systemic reasons (management systems and work culture) that caused or allowed the physical causes to exist and to progress to failure. Management system, work process, safety systems, and/or work culture root cause factors will be identified as defined by the specific RCA investigation methodology selected at the facility or company.

7.5 Component Failure Analysis (FA)

Laboratory failure analysis of the component that led to the loss of containment is vital to many most PEI investigation PEI incident investigations. Formal laboratory analysis Level 2 and 3 investigations should be completed for most failed components to determine failure mechanisms and appropriate components have a formal laboratory analysis. Depending upon the complexity and type of Level 1 investigation, failure analysis can be an appropriate step in those as well. Failure analysis will typically involve some form of metallurgical failure analysis of the failed component, but could also be a failure analysis on non-metallurgical components and entail chemical analysis of deposits that might be helpful in identifying corrosion deposits, corrosive fluids or fouling materials. As mentioned previously, it will be vital to protect the integrity of those components and samples to be analyzed.

Depending upon the level of investigation, an agreed upon protocol for selecting, shipping, examining, testing and recording the failed specimens will be needed and should be agreed upon in the investigation team and with any other parties that may be involved e.g. regulatory bodies and/or legal. The protocol should cover at least five stages of handling the physical evidence that will be analyzed, namely:

1. Selection of the samples
2. Packaging, handling and shipping the samples,
3. Documenting the various stages of analysis and handling,
4. Examination and testing, and
5. Reporting.

Annex F shows an example of a simple form for requesting a failure analysis from an in-house company or contract failure analysis firm, as shown in Annex F.
Sometimes it will be obvious from the outset which component failed and caused the loss of containment. Other times because of the ensuing destruction and multiple equipment and piping failures due to the fire and explosion, it will not be so obvious which component failed first and which components may have failed due to the incident and consequence of the release (knock-on effects). In the later case, multiple samples may need to be shipped from the site to the laboratory for analysis, not only to determine the physical cause of the loss of containment, but also to determine which pieces of equipment may have failed as a result of the consequences that followed the original failure.

Preparing the samples for shipment, handling the samples and shipping them needs to be sufficiently detailed with appropriate QA/QC to ensure that they arrive at the laboratory in the same condition that they were found at the site. Care to avoid potential handling and shipping damage will help to avoid erroneous or lack of conclusions during the failure analysis due to damage that was not actually incurred during the incident. Shipping and handling protocol may need to specify type of packaging, type of crating, protection from the environment, need for desiccant, etc.

But even before investigators begin to define the protocol for failure analysis work, they must decide where to send the samples for analysis. Failure analysis for PEI incident investigation should be performed by organizations competent, qualified and experienced in refinery and chemical plant failure mechanisms. Some large companies have their own in-house failure analysis laboratories with competent, experienced personnel who they can trust to provide them with quality failure analysis results. Companies that do not have that resource should define contract engineering/metallurgical firms with appropriate skills, equipment and experience in refinery and chemical plant failure analysis that they can rely upon, preferably before they actually need that service. There are many failure analysis firms in business that do not have much experience with API RP 571 type degradation mechanisms and therefore cannot be relied upon to do a credible failure analysis for refining and chemical plants. A best practice is to identify and evaluate firms and establish a business relationship prior to an incident.

The next major step in the failure analysis part of a PEI incident investigation is to assemble, document and agree upon the various required steps in the laboratory failure analysis that is needed to support the PEI incident investigation analysis. The objective of this FA protocol is to perform metallurgical/material inspection, examination and testing of the selected physical evidence items in an effort to identify failure modes and contributing damage mechanism that caused the PEI incident, i.e. determine the immediate physical cause for the loss of containment.

The investigation team should create a FA protocol with the input of the selected FA laboratory. Decisions will need to be made about the kinds and amount of testing and examination that will be required, including such things as:

- Visual examination,
- Sample preservation,
• Physical measurements,
• Nondestructive examination,
• Cleaning methods and techniques,
• Sample cutting, extraction and marking,
• Macro and micro metallographic examination,
• X-Ray diffraction,
• Scanning electron microscope (SEM) examination,
• Chemical analysis,
• Energy dispersive x-ray spectroscopy (EDS) examination,
• Macro and/or micro hardness testing,
• Fracture surface examination,
• Deposit/residue collection and analysis, and
• Mechanical testing.

The amount and type of documentation at every step should be agreed upon and included in the FA protocol, including such things as:
• When, where and how much photographic and/or video documentation is needed,
• How much and what laboratory documentation is needed,
• The amount and type of sample marking/tagging,
• The need for hold points and witnessing of selected steps by members of the investigation team,
• At what point and when verbal reports of FA progress are needed, and
• Details of what needs to be contained in the final report.

8 Training and Qualifications

When an incident occurs it is important to have the right people who are already trained to immediately respond and begin the investigation. Facility management should plan for team composition requirements and have trained and qualified people ready and available. All front-line supervisors of the organization need to know who to call and when, before an incident occurs. Everyone in the organization needs to know how to recognize incidents and how to report them.

8.1 PEI-incident Investigation Team Leaders

The organization should define a pool of potential investigation team leaders. Example of training for team leaders includes:
• An overview of the company incident investigation management system and the PEI-incident investigation program
• Investigation concepts
• Specific investigation techniques used by the organization
• Proper interviewing techniques
• Proper gathering of evidence
• Concepts of laboratory failure analysis techniques
• How to analyze evidence for immediate, direct and contributing causes using the methodology selected by the company
• How to determine root causes
• How to write effective recommendations
• How to avoid bias in investigation analysis
• Documentation and report requirements

Most PEI personnel should be trained on how to do an effective level 1 investigation. whereas, only select PEI and other personnel might be trained on how to lead a level 2 investigation. Once trained, it is important that these potential team leaders practice the skills learned in the training to develop and maintain proficiency. Ideally they should conduct a level 1 investigation within a couple months and/or be a team leader or team member on a level 2 investigation within 6 months of their training.

The organization should also have a plan for periodic refresher training and retraining that would also include new or improved investigating concepts and methodologies.

8.2 PEI-Incident Investigation Team Members

The organization may want to define a larger pool of potential investigation team members. Example of training material for team members include:

• An overview of the company incident investigation management system and the PEI incident investigation program
• Investigation concepts
• The specific investigation techniques used by the organization
• Proper interviewing techniques
• Proper gathering of evidence
• Documentation and report requirements

Once trained this pool of personnel are ready to respond when needed. Once members of this pool have been a team member on several investigations, they may be considered for additional training to become a PEI incident investigation team leader.

Periodic refresher training should also be planned for this group.

8.3 Site Management Personnel

Site management personnel needs to provide the proper support for the PEI incident investigation program to be successful. It is important that they are knowledgeable in the following so they can know how to properly support the process:
8.4 Training for Others in the Organization

Others in the organization need training so they can properly support the investigation process, especially those who are associated with pressure equipment. PEI incidents happen regularly, so people need to know how to respond immediately to aid in the reporting and investigation requirements. Operators, maintenance workers, engineers in the organization should be trained on the following:

- An overview of the PEI incident investigation program
- Company policies related to PEI investigation investigations
- Basic PEI incident investigation concepts
- How to recognize PEI incidents
- The site’s PEI incident reporting procedure

9 Continuous Improvement for PEI Investigation Investigations

9.1 Information sharing
The final investigation reports will document the entire investigative effort, findings, and recommendations. This information may be made available to shared with all-site personnel who were affected by the PEI incident or are affected by the action items. The investigation team, working with the investigation sponsor should determine information to be shared with others at the site and in the broader organization. Owner/users may consider sharing details of the incident within the industry if nothing proprietary in the report. The format of the communication should highlight learnings, how it applies to the operation, and what is recommended to prevent similar or other incidents.

A communication bulletin may be beneficial for review within the facility at the conclusion of every investigation. A communication bulletin would be a summary of the key learning’s from the PEI incident investigation. It would typically contain a brief explanation of the incident and then explain the causes with particular emphasis on what others should do differently to reduce the risk of other adverse incidents. An example might be that one contributing cause of a PEI incident was adhering to IOWs for corrosion was not viewed as important as maintaining product quality process parameters, since most IOW were long term developing issues. This is a mindset or cultural change that needs to be communicated and acted on through out the organization.

Some example formats of PEI incident communication are:
- One page bulletins distributed to supervisors for review with work groups.
- Lessons learned documented and stored on an intracompany website.
- Safety type bulletins posted around the areas and distributed electronically.

9.2 Monitoring Auditing of the PEI Investigation Program

The effectiveness of the PEI investigation program should be audited to determine if it is performing as intended and to look for opportunities to improve. PEI incident investigations should be periodically reviewed to identify areas for improvement. Following each level 2 and level 3 investigation, a post investigation critique should be conducted with all the team members to understand areas where improvements to the investigation process can be made, from the initiation of the investigation through to the final report. Level 1 PEI investigations should have a similar critique conducted on a random sample. Any identified improvements should be incorporated into the PEI investigation program.

In addition to audits, companies could also establish key performance indicators that reflect the effectiveness of the PEI incident investigation program. For example, tracking the frequency and consequences of PEI incidents will provide an indication of improvements in reducing them.
### Annex A

**Example Reporting Form for PEI Incidents:**

<table>
<thead>
<tr>
<th>General Incident Information</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Completed by:</td>
<td>Company/Site:</td>
</tr>
<tr>
<td>Incident Date:</td>
<td>Incident Time:</td>
</tr>
<tr>
<td>Area/Unit:</td>
<td>Equipment Involved:</td>
</tr>
</tbody>
</table>

**Incident Description:** Describe what happened and what you know about the incident.

**Consequence:** Describe actual or potential

<table>
<thead>
<tr>
<th>Incident Classification</th>
<th>Equipment Type: and Observations:</th>
<th>Observations:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Level 1: Low consequence incident</td>
<td>Pressure Vessel</td>
<td>Corrosion</td>
</tr>
<tr>
<td>Level 2: Medium consequence incident</td>
<td>Piping</td>
<td>Cracking</td>
</tr>
<tr>
<td>Level 3: High consequence incident</td>
<td>Storage Tank</td>
<td>Dripping</td>
</tr>
<tr>
<td>Record incident data for compiling and analysis later, no investigation.</td>
<td>Rotating Equipment</td>
<td>Hazardous Release</td>
</tr>
<tr>
<td></td>
<td>Boilers, Heaters</td>
<td>Fire</td>
</tr>
<tr>
<td></td>
<td>Heat Exchangers</td>
<td>Smoking</td>
</tr>
<tr>
<td></td>
<td>Pressure Relief Device</td>
<td>Spray</td>
</tr>
<tr>
<td></td>
<td>Structural System</td>
<td>Staining</td>
</tr>
<tr>
<td></td>
<td>Flange Joint</td>
<td>Incorrect Spec</td>
</tr>
<tr>
<td></td>
<td>Other (describe)</td>
<td>QA/QC Problem</td>
</tr>
</tbody>
</table>
Annex B

Example Application of the “5-Whys” Investigation Methodology

**Description:** The “5-Whys” tool is a simple process to follow to determine the causes of incidents. This method adds some structure to brainstorming on causes and does utilize a logic tree approach without actually drawing the logic tree diagram. This method is dependent on the judgment and experience of the person or group that is asking why. The method is typically best used for simple problems with out multiple causal factors.

It is important to begin the process with a clear problem statement that defines the incident that is being investigated. Once the problem statement is determined, you begin asking why to the problem statement and then ask why again to that, typically after asking why five (5) times you have reached the contributing and root cause. If you have not, then you continue to ask why until you reach the root cause. In some cases the root cause is reached in less than five (5) whys, so five (5) whys is just a guideline and a name for the process.

**Example:** This example demonstrates the basic method of the 5-Whys.

*During a plant’s maintenance turnaround, an exchanger bundle was pulled, cleaned and inspected. The tubes were discovered to have corrosion damage and numerous leaks, the number of tubes needing plugging would exceed 20 percent of the tubes and therefore would be too many. It was determined the best course of action was to have a new bundle built and sent to the plant. The unit mechanical engineer pulled the heat exchanger drawings from the main records center and sent those to the fabricator. The new bundle was built and shipped to the plant only a few days before the turnaround was scheduled to end. When the maintenance crews went to install the new bundle in the existing shell, it was discovered it would not fit. The heat exchanger had been modified sometime in the past. At this point the plant had to plug the old exchanger bundle leaking tubes and put it back in service. The unit rates were reduced to accommodate the large number of plugged tubes. Block valves were also installed around this exchanger so that it could be taken out of service online, and the correct tube bundle built and installed later.*

*The unit mechanical engineer decided to conduct a level 1 investigation on this incident, since it did cost additional maintenance dollars to have another bundle built, install the isolation block valves and then install the new second bundle. There were also associated production losses due to having to run at reduced rates for 2 weeks.*

*Because since this unit mechanical engineer had only been assigned to this unit for about 2 years, he did not have knowledge of the change made to this exchanger. As part of his investigation, he talked with unit operators who had been on the unit for a long time. The operators remembered some issues with that exchanger about 10 years ago. He also...*
talked with the unit process engineer about why the change was made. The unit mechanical engineer, then reviewed all of the inspection records for this exchanger, he could see that the ultrasonic thickness data showed that the exchanger was renewed about 10 years before, but there was no explanation of why. There was also a file cabinet in his office of files that he inherited from the previous unit engineers. He looked through that file cabinet and found the correct drawings for the existing exchanger bundle.

After looking at all the data collected and also using his knowledge of the records system at the plant, he began his 5-Why analysis. The following is the 5-Why form he filled out.

Note: A separate level 1 investigation might need to be conducted on why the tube bundle had so many tubes needing plugging and why the bundle corrosion was so severe that it was not anticipated or planned for.

<table>
<thead>
<tr>
<th>5-Why’s Worksheet</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Name of Investigator:</strong> John Smith</td>
</tr>
<tr>
<td><strong>Equipment Involved:</strong> E-101</td>
</tr>
<tr>
<td><strong>What happened that should not have:</strong> E-101 replacement exchanger bundle was fabricated incorrectly.</td>
</tr>
<tr>
<td><strong>1. Why?</strong> The wrong drawings were used to fabricate the replacement bundle.</td>
</tr>
<tr>
<td><strong>2. Why?</strong> The drawings of the exchanger bundle were not updated in the main equipment files.</td>
</tr>
<tr>
<td><strong>3. Why?</strong> A previous unit engineer did not update the equipment file when the exchanger was redesigned.</td>
</tr>
<tr>
<td><strong>4. Why?</strong> The previous unit engineer did not trust the records room equipment files and so he kept his own files.</td>
</tr>
<tr>
<td><strong>5. Why?</strong> The records room does not have controlled access and documents have been lost or misplaced in the past.</td>
</tr>
<tr>
<td><strong>6. Why?</strong> Keeping up to date equipment files is not given a high priority by management.</td>
</tr>
</tbody>
</table>

You have gotten to the end of asking why when you have identified the system related issues that can be corrected to prevent this incident from happening again.

**Identified Root Cause:** The equipment files record room is not secured and there is not a defined and auditable process for updating records.

**Corrective actions to prevent reoccurrence:** Actions would be identified on how to improve the security of the equipment records room and to develop an auditable process for updating equipment records, with identified roles and responsibilities. This would be assigned to the plant technical manager.
### Annex C

**Example: Level 1 PEI Investigation Results Form:**

<table>
<thead>
<tr>
<th>Incident: What should be investigated?</th>
<th>Date of Incident:</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Investigation Method:</strong></td>
<td></td>
</tr>
<tr>
<td>Analysis Method:</td>
<td>Investigation Leader:</td>
</tr>
<tr>
<td>Team Members: name, job and area if any</td>
<td></td>
</tr>
<tr>
<td>Sponsor: name and title</td>
<td>Date Investigation Initiated:</td>
</tr>
<tr>
<td>Date Investigation Completed:</td>
<td>Report Completed:</td>
</tr>
<tr>
<td><strong>Investigation Results:</strong></td>
<td></td>
</tr>
<tr>
<td>Evidence: Summarize the evidence gathered.</td>
<td></td>
</tr>
<tr>
<td>Sequence of Events or Timeline:</td>
<td>Provide a brief timeline leading up to and including the incident.</td>
</tr>
<tr>
<td>Immediate or Physical and Direct Causes: Explain the PHYSICS of the incident, define the causes that directly related to the incident.</td>
<td></td>
</tr>
<tr>
<td>---</td>
<td></td>
</tr>
<tr>
<td>Contributing Causes: What were the causes that contributed to this incident or the severity of it.</td>
<td></td>
</tr>
<tr>
<td>Root Causes: What were the underlying system related reason the incident occurred.</td>
<td></td>
</tr>
<tr>
<td>Incident Costs: Include the total costs, equipment repair costs, lost profit costs, personnel lost time, medical costs and investigation costs.</td>
<td></td>
</tr>
<tr>
<td>Follow-up Action Items:</td>
<td></td>
</tr>
</tbody>
</table>
Annex D

Example Lists of Generic Evidence to be Gathered:

People Data:
- All Eye-Witness reports
- First Responders/Emergency responders reports
- Process Operators- on-shift and off-shift
- Maintenance personnel associated with the equipment
- Inspection personnel associated with the equipment
- Metallurgist or Corrosion Engineer
- Process Engineers
- Reliability or Maintenance Engineers
- Project/Design Engineers
- Manufacturer’s representatives
- Chemistry and other laboratory personnel

Physical Data:
- Pressure boundary equipment such as gaskets and flanges
- Damaged equipment components
- Process samples from relevant equipment
- Metallurgical samples
- Explosion fragments and Pieces of process equipment
- Direction of glass pieces
- Location and position of fragments
- Process volumes and levels
- Blast and fire damage
- Location of burn and scorch marks
- As found position of valves, controls and switches
- Position of relief valves
- Location of witnesses
- Location of other personnel involved in the process
- Smoke traces
- Melting patterns
- Impact marks
- Location of chemicals in the process
- Video recordings of the area if available

Record Data:
- Process operating records and conditions, electronic and manual
- Process operating procedures
• Shift logs
• Work permits
• Maintenance records
• Inspection records
• Records of process sample analyses
• Repair records
• Process and Instrument Diagram (P&ID) drawings
• Equipment drawings and specification sheets
• Repair and rerating records
• Material balances
• Corrosion data
• Management of change records
• Prior incident investigation reports or near miss reports
• Training manuals and records
• Inspection Plans
Annex E

Examples of questions to ask eyewitnesses:

- What do you do here, what is your job?
- How long have you been doing that job?
- How long have you been at this facility/plant?
- Where were you at the time of the incident?
- What were you doing at the time of the incident?
- Would you describe the incident?
- What did you see, hear, feel or smell?
- What did you do in reaction to the incident?
- How did you know what to do when the incident occurred?
- Who else was around you at the time of the incident?
- What were the others doing right before the incident?
- What were you doing right before the incident happened?
- Did you have any indications before the incident that something was about to happen?
- What were the weather conditions when the incident occurred?
- Was there anything different right before the incident?
- In your opinion why do you think this incident occurred? (note this information as opinion, not fact)
- Was this incident very unexpected, or were you expecting something like this might happen and why?
- Has this incident or a very similar event occurred previously and if so, when and what happened?
Annex F

Request for Failure Analysis Form

<table>
<thead>
<tr>
<th>From:</th>
<th>Date:</th>
</tr>
</thead>
<tbody>
<tr>
<td>To:</td>
<td></td>
</tr>
</tbody>
</table>

**ANALYSIS REQUIREMENTS:**

**Prioritization Category:**
- A – Urgent Request – if work requires overtime or work after hours
- B – Standard Request – if work will be conducted during regular business hours

**Requested Due Dates:**
- Verbal Report: [Blank]
- Final Report: [Blank]

**How Shipped:**
- Carrier: [Blank]
- Expected Date of Arrival: [Blank]
- Tracking #: [Blank]
- Shipped To: [Blank]

**BACKGROUND:**

<table>
<thead>
<tr>
<th>Type of Component: i.e. shell, head, nozzle, pipe, flange, valve, etc.</th>
<th>Material Type:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Equipment No:</td>
<td>ASTM/ASME spec no:</td>
</tr>
<tr>
<td>Unit:</td>
<td>Wall Thickness:</td>
</tr>
<tr>
<td>Operating Dept:</td>
<td>Year built:</td>
</tr>
</tbody>
</table>

**PROCESS/DESIGN CONDITIONS:**

<table>
<thead>
<tr>
<th>Process Design Temperature: °F</th>
<th>Process Operating Temperature: °F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Process Design Pressure: _____ psig</td>
<td>Process Operating Pressure: _____ psig</td>
</tr>
</tbody>
</table>

Internal Environment: (including major/minor fluids and contaminent)

External Environment: (including major/minor fluids and contaminent)
HOW WAS PROBLEM DISCOVERED?

DEFINITION OF PROBLEM?

TYPE OF INVESTIGATION NEEDED
(Please include drawings and data sheets as applicable):

SPECIAL REQUESTS: i.e. chemical analysis, special testing, PMI, mechanical testing, etc.

IMPACT OF INVESTIGATION ON BUSINESS AND FUTURE UTILIZATION OF EQUIPMENT:

CONTACTS:
Recipient of Verbal Failure Analysis Results/Conclusions by Phone:
Annex G

Example Template for Level 2 or Level 3 PEI Investigation Report:

The following sections are suggested as a template for an investigation final report.

Incident Description:
Provide a summary of the incident that occurred and that was investigated.

Summary of Consequences:
Provide a summary of the consequences of the incident. This would include a summary of the injuries if there were any, environmental damage, a summary of the equipment damage, the production loss and downtime and associated costs.

Investigation Process:
Describe in general how the incident was investigated. This would include the make up of the team, when the investigation started after the incident, how long it took, an overview of all that was done to investigate the incident.

Summary Sequence of Events:
brief summary of the major events leading up to and immediately after the incident in chronological order.

Evidence
an overview of what evidence was gathered and how it was

People Evidence:
Provide a summary of the people evidence that was gathered, including who was interviewed, job titles.

Key Findings from People Evidence:
a summary of the key findings from the people evidence that was gathered.

Physical Evidence:
a summary of the physical evidence that was examined and the key findings from it.

Paper Evidence:
a summary of the paper evidence and the key findings from it.

Incident Sequence:
describe how the incident occurred, the events leading up to it.

Immediate and Direct Causes:
define the immediate physical causes that allowed the incident to occur based on all of the evidence gathered and the investigation team’s analysis of that evidence.
**Contributing Causes:**
define the contributing causes of this incident based on the evidence gathered and investigation team’s analysis of that evidence

**Root Causes:**
define the root causes of this incident based on the evidence gathered and investigation team’s analysis of that evidence

**Recommendations:**
define the recommendations to mitigate the contributing and root causes in order to reduce the likelihood that they will contribute to another incident.

**Appendix:**
The appendices would include more detail about the investigation team’s findings. They might include further detail on key physical evidence, such as photos of failed parts and how the analysis was completed and what the analysis discovered. A more detailed timeline could be provided in the appendix, if one was developed. If a logic tree or sequence diagram is drawn for the investigation conclusions, those should be included in an appendix.
Bibliography

API 510, *Pressure Vessel Inspection Code: Maintenance Inspection, Rating, Repair, and Alteration*

API 570, *Piping Inspection Code: Inspection, Repair, Alteration, and Rerating of In-service Piping Systems*

API Recommended Practice 572, *Inspection of Pressure Vessels*

API Recommended Practice 573, *Inspection of Fired Heaters and Boilers*

API Recommended Practice 574, *Inspection of Piping System Components*

API Recommended Practice 575, *Guidelines and Methods for Inspection of Existing Atmospheric and Low-Pressure Storage Tanks*

API Recommended Practice 576, *Inspection of Pressure-relieving Devices*

API Recommended Practice 577, *Welding Inspection and Metallurgy*

API Recommended Practice 578, *Material Verification Program for New and Existing Piping Systems*

API Standard 653, *Tank Inspection, Repair, Alteration, and Reconstruction*

API Recommended Practice 580, *Risk-Based Inspection*


