Pressure Equipment Integrity Incident Investigation

API ~~RECOMMENDED PRACTICE~~BULLETIN 585

~~SECOND~~ THIRD EDITION, ~~MARCH 2021~~TBD

1 Scope

1.1 General

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

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

1.2 Industry Scope

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

1.3 Flexibility in Application

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

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

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

1.4 Pressure Equipment Integrity (PEI) Focused

Investigation is a vital element for learning from unexpected discoveries or incidents. (~~e.g.~~For example, finding significantly more corrosion damage or other forms of deterioration than expected.~~)~~ ~~and~~ This information can be used in a continuous improvement process. Investigating and determining the causes of unexpected leaks, equipment degradation, or near misses associated with pressure equipment may be used to improve mechanical integrity programs and management systems for maintaining PEI, such as design and construction procedures, maintenance and inspection practices, and operating practices. ~~including~~ These programs/systems include, but are not ~~limite~~limited to: corrosion control documents (CCD) per API 970, Integrity Operating Windows (IOWs) per API 584, and Risk-Based Inspection (RBI) ~~planning~~ per API 580. In addition, the~~The~~ API Committee on Refinery Equipment (CRE) Subcommittees have produced a variety of codes and standards referenced in Table 1 to guide owners/users in maintaining PEI and reliability.

1.5 Types of Pressure Equipment Covered

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

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

Type of Equipment	Components	API CRE Subcommittee	Example API Reference Documents
Pressure Vessels	all pressure-containing components	SCIMI	API 510, *Pressure Vessel Inspection Code*, RP 572, *Inspection Practices for Pressure Vessels*
Piping	pipe and piping components (valves, expansion joints, sight glasses)	SCOPV SCIMI	API 570, *Piping Inspection Code*, RP 574, *Inspection Practices for Piping System Components*
Storage Tanks	atmospheric, low pressure, and pressurized	SCAST SCIMI	Std 620, *Design and Construction of Large, Welded, Low-Pressure Storage Tanks* Std 650, *Welded Tanks for Oil Storage* Std 653, *Tank Inspection, Repair, Alteration and Reconstruction* RP 575, *Inspection of Atmospheric and Low Pressure Storage Tanks*
Rotating Equipment	pump and compressor cases and associated pressure-containing piping and pressure vessels, excluding seals.	SOME	Std 610, *Centrifugal Pumps for Petroleum, Petrochemical, and Natural Gas Industries* Std 617, *Axial and Centrifugal Compressors and Expander-compressors for Petroleum, Chemical, and Gas Industry Services* Std 618, *Reciprocating Compressors for Petroleum, Chemical, and Gas Industry Services*
Boilers and Heaters	pressurized components	SCHTE SCIMI	Std 538, *Industrial Fired Boilers* Std 560, *Fired Heaters for General Refinery Services* RP 573, *Inspection of Fired Boilers and Heaters*
Heat Exchangers	shells, heads, channels, and pressure-containing components and tube bundles.	SCHTE SCIMI	Std 660, *Shell-and-tube Heat Exchangers* Std 661, *Petroleum, Petrochemical, and Natural Gas Industries—Air-cooled Heat Exchangers* Std 663, *Hairpin-type Heat Exchangers* Std 664, *Spiral Plate Heat Exchangers* API 510, *Pressure Vessel Inspection Code* RP 572, *Inspection Practices for Pressure Vessels*
Pressure-relief Devices		SCPRS SCIMI	Std 520, *Sizing, Selection, and Installation of Pressure-relieving Devices* Std 521, *Pressure-relieving and Depressuring Systems* Std 526, *Flanged Steel Pressure-relief Valves* Std 527, *Seat Tightness of Pressure Relief Valves* Std 2000, *Venting Atmospheric and Low-Pressure Storage Tanks (Nonrefrigerated and Refrigerated)* RP 576, *Inspection of Pressure-Relieving Devices*
~~Cooling Water Towers~~			~~Refer to OEM practices~~
Structural Systems	integral to supporting pressure-containing systems	SCIMI	API 510, *Pressure Vessel Inspection Code* RP 572, *Inspection Practices for Pressure Vessels* API 570, *Piping Inspection Code* RP 574, *Inspection Practices for Piping System Components*

Stacks and Flares		SCHTE SCIMI	Std 537, *Flare Details for General Refinery and Petrochemical Service* RP 573, *Inspection of Fired Boilers and Heaters*

1.6 Types of Equipment Excluded

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

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.

Documents may exist that are managed and/or sponsored by other API CRE Subcommittees to address these equipment areas ~~(~~[e.g., ~~SOME =~~ Subcommittee on Mechanical Equipment (SOME)].

1.7 Target Audience

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

1.8 Organizational Responsibilities

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

2 Normative References

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

3 Terms, Definitions, Acronyms, and Abbreviations

3.1 Terms and Definitions

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

3.1.1
bias
When people or groups use their experience or judgment to direct the evidence gathering and development of causes toward potentially incorrect conclusions or when investigators predetermine the cause of an incident and then look for confirming evidence and disregard disputing evidence.

3.1.2
chronic incidents
Frequent occurrences, especially when each occurrence alone typically has a low or minor consequence and is routine to fix.

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

3.1.3
consequence
An undesirable outcome from an incident. There may be one or more consequences from an incident for different categories, such as safety, environmental, and/or economic. Consequences are always negative for integrity incident investigations.

3.1.4
contributing cause
A cause that increases the likelihood or consequence, or both, of an incident but is not the immediate or root cause. Eliminating the contributing causes ~~will not~~ by ~~itself~~ themselves may not prevent reoccurrence but ~~will~~ can likely reduce the frequency or consequence, or both, of any reoccurrence.

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

3.1.5
immediate cause
The most direct or primary contributor to the incident that if eliminated or avoided would have prevented the incident. Also known as the physical cause or direct cause.

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

3.1.6
integrity operating window (IOW)
Established limits for process variables (parameters) that can affect the integrity of the equipment if the process operation deviates from the established limits for a predetermined amount of time. Reference API 584 for more information regarding IOWs.

3.1.7
investigation
The process of identifying the immediate, contributing, and root causes of incidents (failures, near misses or discoveries) and developing recommendations to prevent similar occurrences in the future.

3.1.8
investigator
The person or group that conducts the investigation by collecting the evidence, analyzing the evidence, determining the causes, and making recommendations.

3.1.9
owner-operator
An owner or user of pressure equipment who exercises control over the operation, engineering, maintenance, inspection, repair, and testing of the pressure equipment.

3.1.10
pressure equipment integrity
PEI
fixed equipment mechanical integrity
The state of pressure equipment when it has been and continues to be designed, fabricated, installed, operated, and maintained in a way to prevent loss of containment or loss of structural stability.

3.1.11
pressure equipment integrity failure PEI failure
fixed equipment failure
The termination of the ability of a pressure equipment system, structure, or component to perform its function of containment of the process fluid (i.e. a leak or loss of containment). Loss of containment due to misoperation of equipment and not involving material damage mechanisms is not considered PEI failure for the purpose of this ~~RP~~bulletin. Within this document, the term "failure" is intended to refer to a PEI failure.

3.1.12
pressure equipment integrity incident

PEI incident
fixed equipment mechanical integrity incident
Refers to a PEI failure, a PEI near miss, or a PEI discovery. Within this document, the use of the term "incident" is intended to refer to a PEI incident.

3.1.13
pressure equipment integrity near miss
PEI near miss
fixed equipment mechanical integrity near miss
The discovery of equipment degradation or process operating conditions outside of acceptable limits that requires immediate or other unplanned action to shut down the equipment and/or perform repairs to avoid a loss of containment, usually the result of some form of damage mechanism such as those covered in API 571 but did not result in a loss of containment or structural stability. Within this document, the term "near miss" is intended to refer to a PEI near miss.

3.1.14
pressure equipment integrity discovery
PEI discovery
fixed equipment mechanical integrity discovery
The discovery of unexpected conditions, damage, or deterioration that was not anticipated in the inspection planning process that causes some form of follow-up or unscheduled TA or maintenance work scope adjustment, but does not cause equipment shutdown or slowdown to make immediate repairs i.e. not a near-miss.

3.1.15
pressure equipment integrity personnel
PEI personnel
fixed equipment mechanical integrity personnel
Personnel in an organization assigned to maintaining, developing, improving, and implementing the organization's PEI program.

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

3.1.16
probable cause
If, after thorough analysis of the evidence and facts, a cause cannot be fully proven but is determined to be very likely (more likely than not), then it is called a probable cause. A probable cause can be identified in any of the different causes (immediate, contributing, or root).

3.1.17
process safety incident
An incident that resulted in, or could reasonably have resulted in, a catastrophic release of highly hazardous chemicals in the workplace as defined by the Occupational Safety and Health Administration's process safety management (PSM) regulation.

3.1.18
risk
Combination of the frequency of an incident and its consequence. In some situations, risk is used to describe a deviation from the expected. When frequency and consequence are expressed numerically, risk is the product.

3.1.19
root cause
A fundamental, underlying system or culture related reason why an incident occurred or allowed the immediate or contributing cause(s) to exist. There is often more than one root cause for every incident.

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

3.1.20
sporadic incident
An infrequent or very infrequent occurrence. These incidents tend to have an unusual combination of causes and could have a high consequence.

3.2 Acronyms and Abbreviations

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

CCD corrosion control document
CUI corrosion under insulation

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

4 PEI Incidents

4.1 PEI Incident Types

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

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

a) PEI Failures:

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

b) PEI Near misses:

- corrosion or other damage/degradation that does not pass a Fitness-for-Service assessment and requires immediate repair or other corrective actions (e.g., preventative mechanical clamp, non-metallic wrap, lower operating conditions), but did not result in a leak;
- a damaged bolt or gasket that requires immediate repair/replacement, but before any failure or leak occurred;
- structural deterioration that is deemed not fit for continuing service (e.g., for static load support or during potential wind loading), but before a structural failure occurred;
- inspection or testing failure of a pressure-relieving device indicating that it would not have protected the equipment during an overpressure incident, but there was no incident that resulted in an overpressure or equipment failure;

c) PEI Discoveries:

— discovery of process chemistry or other operating condition that is found to be outside of an acceptable process or integrity operating window (IOW) for corrosion or other material degradation mechanism that was put in place to prevent leaks and failures.

— discovery of a compromised overpressure protection device (such as a closed block valve in the relief path or the wrong relief valve installed with a higher cold differential test pressure setting), but there was no incident that resulted in overpressure or equipment failure.

— discovery of corrosion or other damage/degradation that was beyond that expected in the inspection or maintenance planning process and thereby required unscheduled repairs/replacement during routine maintenance or turnarounds.

— discovery of the wrong gaskets or bolting being installed (e.g., B7 bolting installed where B7M was specified), but before being put in service or before there was a leak.

— discovery of the incorrect metallurgical component installed (e.g., CS fitting installed in a 5Cr-1/2Mo piping system), but before any significant damage or failure occurred;

— discovery of the incorrect specification piping or fitting installed but before any failure occurred (e.g., wrong schedule pipe or nipples installed or low Si pipe pup installed in an A106 piping system subject to sulfidation).

4.2 Other Determinates for Failures

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

4.2.1 Announced or Unannounced Failures

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

4.2.2 Chronic or Sporadic Incidents

PEI incidents differ in the typical frequency of occurrence (chronic or sporadic) and the severity or consequence of the outcome. A chronic incident typically has ongoing common cause(s) that result in recurrence of the same or similar type of outcome over time. Examples of chronic incidents include reoccurring flange leaks, continuing discovery of CUI damage throughout a plant, multiple instances of finding the incorrect specification material or bolting during final inspection, and multiple cases of finding the incorrect schedule piping installed as nipples. Sporadic incidents tend to have an unusual combination of causes that result in an outcome of a certain type very infrequently or possibly only once in the life cycle of the pressure equipment. Any of the PEI failure examples listed in 4.1 Item a) could be considered a sporadic incident. Valuable lessons can be learned from investigating both chronic and sporadic incidents, regardless of the outcomes.

4.3 Documenting PEI Incidents

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

The reporting of PEI incidents ~~should be done~~ needs to be completed in a consistent manner ~~and tracked~~ so that the data can be more easily reviewed and analyzed. Annex A ~~is~~ provides an example of an incident reporting form that may be useful for such purpose. An incident report ~~should~~ needs to be documented within a short period of time after the incident is recognized~~.~~

~~The incident document should be~~and reviewed to determine if an investigation is warranted. If trends are identified or suspected, then that grouping of PEI incidents can be investigated further to determine underlying common systemic causes. For example, it may be appropriate to investigate a grouping of chronic incidents (e.g., several instances of the wrong gasket being installed or several instances of a minor flange leak on a feed/effluent exchanger during start-up). PEI incidents also need to be tracked in order to provide timely actions, review of progress, and closure of recommendations. Reporting could be computerized to facilitate analysis for systemic causes and to improve the ability to steward follow-up items to closure.

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

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

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

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

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

— A process parameter deviation that exceeds a safe operating limit (SOL). For PEI purposes those exceedances would include Critical IOWs, as defined in API 584. The owner-operator may also choose to include other exceedances which involve passing beyond an established barrier for reliable or potentially safe operation.

— An inspection or test finding that indicates that primary containment equipment has been operated outside acceptable limits. These findings typically trigger an action such as: replacement in kind, repairs to restore fitness for service, replacement with other materials, increased inspection or testing, or derating of process equipment. That definition could include all of the examples above of PEI failures, near-misses, and discoveries.

— A demand of a safety system designed to prevent a LOPC. For PEI purposes, that could include activation of a PRD not counted as a Tier 1 or 2 event. That means any challenge to a PRD including the rupture of a protective RD under a PRV would be counted as a Tier 3 event.

5 PEI Incident Causes

5.1 Types of Causes

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

a) ~~1)~~ immediate causes,

b) ~~2)~~ contributing causes,

c) ~~3)~~ root causes.

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

1) identifying and correcting the immediate causes of an incident ~~will~~ may 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~~ typically result in improved PEI management systems and work culture and ~~should~~ can prevent or reduce the likelihood of many other PEI incidents from occurring throughout the facility or company.

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

5.2 Determining Causes

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

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

All three levels of investigation are designed and intended to identify the immediate and contributing causes, but Level 2 or Level 3 investigations may be ~~required~~ necessary to uncover the root causes of the incident.

Each investigation, at any level, ~~should~~ needs to determine the exact immediate cause of the incident, based on evidence. If the immediate cause cannot be determined, then the team or investigator ~~should~~ may look for more evidence or consult with additional expertise or request a metallurgical failure analysis (FA). Typically, when the immediate 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 cause can~~ still ~~not be determined, then the most probable immediate cause of the incident ~~should~~ can be defined and clearly documented using ~~, with both~~ the known facts and assumptions that have been 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, work processes and systems is used to identify the probable causes. For a Level 1 investigation, the identified causes may not be true root causes based on detailed analysis of evidence; they could be people's opinion based on their knowledge and experiences of the cultural and systemic issues within the organization. It is important to document these causes, even if they are not 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 can most likely identify real systemic or cultural issues that could then be addressed to determine corrective actions.

The Level 2 investigations should be able tocan determine the immediate causes, contributing causes, and probable root causes of the incident based on analysis of the evidence and agreement between the team members and the investigation sponsor. The Level 2 investigation may not determine all the root causes because of 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 can 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 may be given to making recommendations based on the probable causes to best mitigate the potential for additional incidents.

The Level 3 investigations are typically led by trained and experienced RCA personnel and are thorough enough to identify all of the causes of the incident, including the root causes. Level 3 investigations will may normally typically be driven by others outside of the PEI organization (e.g., the PSM group) and include members from either within and/or outside the site organization.

5.3 Probable Causes

Any of the three types of causes (immediate, contributing, and root) can also include a probable cause. If, after thorough analysis, some causes cannot 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 may 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.

5.4 Example PEI Investigation Layout

An example to illustrate the three types of causes from a fictitious PEI incident investigation is shown in Figure 1.

Incident: A carbon steel pipe in a sulfuric acid alkylation unit leaked and released alkylate.
Investigation Results
Immediate causes: *Explain the PHYSICS of the incident, Define the causes that directly related to the incident.* The loss of containment occurred because sulfuric acid came in contact with the carbon steel pipe, which was not the correct material for corrosion resistance to sulfuric acid and rapidly corroded it to the point of failure.
Contributing causes: *What were the causes that increased the likelihood and consequence of the incident?* a) There are inadequate operating controls to prevent acid carryover in the process. b) Operators did not recognize and properly react to abnormal operating conditions that caused acid to carry over. c) There was no IOW identified/implemented to monitor the potential for acid carryover. d) The process unit CCD did not address the issue of acid carryover in this piping system. e) The piping design and material specifications did not address the likelihood of acid carryover.
Root causes: *What were the underlying system/work process-related reasons the incident occurred?* a) Leadership did not adequately address the lack of controls on process operations. b) Rigorous training and retraining of operators are not considered important to site management. c) An IOW work process had not yet been implemented at the site.

Figure 1—Example Incident Investigation Illustrating the Three Types of Causes

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 of investigation needed. Every PEI incident could 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~~ can 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~~ need to be clearly documented and agreed upon with the investigation sponsor.

EXAMPLE 1 — If a leak occurs and releases gasoline that 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.

EXAMPLE 2 — If a leak releases diesel and a small pool fire results that is contained by the emergency response, it might not be reasonable to say that the potential consequence would have been major equipment damage if the fire monitors were not working and the emergency shutdown valves had not been activated.

The three levels of investigation described in this ~~RP~~ bulletin differ in scope and depth of investigation and the amount and type of personnel involved. Owner-operators may provide guidelines defining the different levels of investigations and the circumstances under which they are used. Table 2 is an example of defining the guidelines for PEI incident investigations. 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 Incident Investigation Levels

For the purpose of this ~~RP~~bulletin, 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.

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 or specifics, might have a Level 1, Level 2, or Level 3 investigation conducted. The starting point for near misses or discoveries is usually a Level 1 or Level 2 investigation.

The following are some **examples** of PEI incidents that might warrant a Level 1, Level 2, or Level 3 investigation. Owners/Users typically provide criteria or designate a position for assigning the level of investigation ~~required~~necessary.

a) Level 1

- incorrect gasket installed and leaked without causing a fire;
- short-term corrosion or other damage rate discovered to have significantly increased over long-term rate or expected 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 °F hot spot on radiant tube;
- a relief valve fails to open during pre-pop testing before servicing;
- a relief valves opens on demand more than three times in one year;
- unexpected weld corrosion discovered during profile radiography that does not require immediate attention;
- inspector discovers a new damage mechanism in equipment that was not described or predicted in the process unit corrosion control document (CCD) or inspection planning process (e.g., RBI);
- small underground leak discovered in class 2 buried piping.

b) Level 2

- high-pressure boiler tube rupture;
- storage tank bottom leak;
- inspection finds a process pipe in operation below minimum required thickness that necessitates an immediate shutdown or temporary repair;
- a feed/effluent heat exchanger flange regularly 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 offline;
- a heat exchanger tube failure causes heat exchanger to be blocked in and taken offline for inspection and repairs;
- CUI leak causes side-stripper column to be blocked in and taken offline for repair;
- unexpected damage is discovered during a TA inspection that causes unplanned repairs or replacement;
- unexpected weld corrosion discovered during profile radiography that requires immediate mitigation e.g., mechanical clamping;
  - high corrosion rates found downstream of an alloy spec break indicating that the spec break is no longer in the right position;
- a gasket blows out on a blocked-in product line releasing a few hundred gallons of hazardous fluid;
- pinhole leak develops on a hydrocarbon process line and ignites, but an operator is able to extinguish it and block it in before major damage.

c) Level 3

- a pipe segment on a high-temperature hydrocarbon line ruptures releasing a hydrocarbon which auto-ignites resulting in a fire producing significant damage to process equipment;
- a process drum catastrophically ruptures while being taken out of service to perform maintenance work resulting in equipment damage and injuries to nearby maintenance personnel;
- an elbow ruptured on the outlet of a high-pressure reactor causing a significant blast which damaged nearby homes in the community;
- the cooling water return feed riser to the cooling tower severed at the soil to air interface resulting in the emergency shutdown of five unit;
- pre-insulated instrumentation tubing failed releasing hot hydrocarbon vapor resulting in a significant fire with damage to nearby structures and equipment;
- a deadleg that collected water and contaminants ruptures in-service and causes a fire and equipment damage;
- a mixing point where a heat exchanger by-pass line reconnects with the fluid coming through the exchanger causes highly localized erosion-corrosion from water flashing at the mixing tee which ruptures the line and causes burn injuries during the ensuing fire;
- severe HTHA of a heat exchanger causes the shell to rupture, resulting in a fire and several fatalities;
- high-temperature sulfidation of a piping system causes pipe rupture and large fire that attracts significant media and community attention.

6.3 PEI Incident Investigation Guidelines

Owners/users may develop investigation guidelines that define what consequences and what types of failures or near misses trigger what level of PEI incident investigation. The guidelines typically include the combinations of actual and potential consequences and frequency of occurrence for the different levels of investigation.

The investigation guidelines ~~should~~ may include the following:

a) examples of incident types and consequences for each;

b) team leadership, team size, and composition;

c) timing for investigation initiation;

d) management level of sponsorship.

Table 2 is an example of an investigation guideline for PEI type incidents and specifically does not define investigation characteristics, team makeup, or timing ~~requirements~~ for any particular regulatory requirement.

6.4 Initial Response to a PEI Incident

The owner-operator may 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, which is outside the scope of this ~~RP~~bulletin.

As previously noted, the facility or company may have a written process that defines how information from PEI incidents could 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 cleanup activities. The most serious or highest consequence PEI incidents ~~should~~ may have evidence gathering started as soon as it is practical and safe (after ~~it~~ the incident occurs). It is important that accurate data on PEI incidents be collected so that those incidents can be properly tracked and reviewed to determine the causes and corrective action.

The facility may 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).

a) For PEI incidents that require emergency response:

- ~~, t~~The lead investigator might 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 may begin the evidence gathering, or at least taking steps to preserve the evidence.

b) For PEI incidents that *do not require* emergency response:

- ~~, t~~The supervisor or PEI personnel closest to the equipment could 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 could be reviewed by the appropriate manager or supervisor to determine if an investigation is warranted and the appropriate level of investigation.

Table 2—Example PEI Incident Investigation Guidelines

	Level 1 Investigations	Level 2 Investigations	Level 3 Investigations
Incident Characteristics	— Unexpected condition or damage found that if it had been allowed to progress would have led to loss of containment before the next scheduled outage or inspection interval. — Discovered PEI damage significantly beyond expectation but with no loss of containment or unit shutdown. — Small leaks (other than environmental fugitive emissions) from pressure equipment or joints that were easily contained. — Typically, no fire, significant toxic release, injuries, or environmental damage would occur in a Level 1 incident.	— Leak from pressure equipment that resulted in or could have resulted in localized equipment damage, small to medium size release quantity, or small safety or environmental damage. — Unexpected pressure equipment failure from damage mechanisms or structural deterioration. — Unexpected pressure equipment damage or associated structural damage discovered that required equipment or unit shut down or immediate mitigation. — Repetitive Level 1 type characteristics in the same process or system.	Leak or rupture from pressure equipment that resulted in or could have resulted in significant process safety incident or environmental damage, equipment damage, large release quantity, or production loss.
Investigation Characteristics	Investigate using less structured analysis tools such as “What If” or “5-Whys.” Uses evidence, judgment, and experience to identify causes.	Investigate using company or department causal factor identification or logic trees, seeking probable contributing and root causes.	Investigate using company structured root cause analysis (RCA) seeking to determine the deepest management system and cultural causes.
Team Makeup ~~Recommended~~	Investigated by the PEI personnel from the affected area and trained in simple investigation techniques. Can be investigated by one person, possibly two. Involve subject-matter experts (SMEs) as needed.	Leader would be someone from the affected area trained in investigation techniques. Team members would include one to three others of different disciplines from the area; include at least one PEI person on the team. Involve other SMEs as needed.	Leader would be someone trained in structured RCA and from another area of the plant or another business unit. There would be at least three team members and possibly from different disciplines or groups, such as inspection, operations, process engineering, maintenance, or process safety. Appropriate SMEs ~~should~~ may be included on the team.
Initiation	Within a few days.	Begin investigation as soon as practical (e.g., 1 to 2 days).	Begin freezing and collecting evidence as soon as practical (e.g., within a few hours).
Sponsorship	Supervisor of investigator (First Line Supervisor).	Department Head level (Second Line Supervisor).	Management with overall responsibility for Safety Health Environment for the site.

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 those who 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~~ needs to be immediately preserved.

7 Conducting PEI Incident Investigations

7.1 General

This section provides general guidelines on how to perform the Level 1, Level 2, and Level 3 PEI incident investigations. For the purposes of these guidelines, the levels are as described in Table 2. Any PEI related incidents that are also process safety incidents may be governed by national regulations, jurisdictions, or both, having authority and ~~should~~ need to be handled by the appropriate group responsible for 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's *Guidelines for Investigating Chemical Process Incidents* [1], 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 Incident Investigations

7.2.1 General

Level 1 investigations are ~~recommended~~ typically completed for incidents with minor actual or potential consequences, near misses, or unexpected discoveries concerning PEI. These investigations involve a review of the facts and identification of appropriate corrective action items. Level 1 investigations are less resource intensive than Level 2 and Level 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, engineer). 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 may be~~often used for Level 1 PEI incident investigations and is described further with an example in Annex B.

A Level 1 investigation ~~might~~ starts 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~~bulletin, developing a form or guidelines for gathering and recording the information ~~will~~can be useful when reviewing these investigations for trends and further improvements.

7.2.2 PEI Level 1 Investigation Personnel

The Level 1 PEI incident investigation ~~would be~~is normally performed by one or two persons, typically the PEI personnel responsible for the equipment involved in the incident (e.g., inspector or engineer, or both 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~~has the training and knowledge to carry out the responsibilities for this level of investigation. At times, ~~T~~this person ~~may be~~ is 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, 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 would be dictated by the type of PEI incident that occurred and the need for assistance of the investigation leader. Others ~~may be~~are involved as needed to assist on an ad hoc basis by providing data/evidence, providing SME input, or being interview witnesses regarding the incident.

3) Sponsor—These investigations ~~might be~~are often 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 helps 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.~~

7.2.3 Collecting/Examining Evidence

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

The investigator ~~would~~ considers interviewing eyewitnesses (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 ~~would~~ collects and/or examines any physical evidence or parts involved or damaged in the incident. The investigator ~~would~~ also examines 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 ~~could~~ asks for expert help in the examination of some evidence or determining what additional evidence to examine.

7.2.4 Analyzing Evidence and Determining Causes

The investigator ~~would~~ analyzes the evidence gathered and 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, 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 ~~may be~~is 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 causes from the evidence gathered, ~~they may need to gather~~ more evidence gathering or asking for additional SME expertise to help determine the immediate cause(s) is useful.

Level 1 investigations ~~should~~ identify the immediate causes of the incident. The investigation leader ~~would also~~ makes 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.

7.2.5 Action Items

The Level 1 investigation ~~should include~~includes an understanding of the immediate cause to identify what actions need to be taken to address the immediate cause to prevent a similar incident. The investigator ~~would also try~~ tries 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~~ recommends what action items are assigned and to whom.

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 used in specifying on-stream nondestructive examination (NDE), or the investigation might reveal that additional process parameters ~~should~~ need to be monitored for IOWs.

7.2.6 Reports

Level 1 investigation results ~~may~~ can be documented on a simple form or template such as that shown in Annex C. The report ~~may~~ documents what happened, the immediate 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.

7.2.7 Determining Effectiveness of Action Items

The identified contributing causes from many Level 1 investigations ~~may be~~are reviewed over time to look for common or systemic causes and to determine if they are being reduced 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 is often~~may be~~ conducted to determine how to address the reoccurring contributing causes more effectively or to identify additional contributing and/or root causes that ~~should~~ need to be addressed. This ~~might~~ can involve a Level 2 investigation on a grouping of similar Level 1 incidents.

7.3 Performing Level 2 PEI Incident Investigations

7.3.1 General

Level 2 investigations are conducted on medium actual or potential consequence incidents (i.e. all that fall between Level 1 and Level 3). As previously discussed, the Level 2 processes are ~~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 multidisciplined team to analyze the evidence and identify contributing causes and probable root causes. Some level 2 PEI incident investigations ~~may~~ rise to the level of a process safety incident investigation. If that is the case, the description herein of a Level 2 PEI incident investigation ~~would need to be~~is in conjunction with and in support of the site's process safety incident investigation procedure.

7.3.2 Beginning the Level 2 PEI Incident Investigation

Similar to the Level 1 investigation, the Level 2 investigation ~~would~~ starts 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~~ can be useful when reviewing these investigations for trends and further improvements. See Annex A for a simple example form. It is 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; t~~The PEI incident investigation ~~should~~ addresses why the loss of containment occurred for different causes.

The owner-operator investigation program ~~should~~ defines how a PEI incident investigation team leader is assigned and how a team is formed for a Level 2 investigation. The team composition ~~should~~ considers the type, size, consequences, and nature of the incident.

It is important to collect the 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 member 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. A person can begin collecting eyewitness statements if the eyewitnesses are not involved in the emergency response and downloading DCS data. ~~For Level 2 investigations that did not involve loss of containment, the program might 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~~is not normally involved in the repair work that may be required because of the incident. This ~~will~~ allows the person to concentrate on evidence/data gathering and not miss an opportunity to collect data, such as while a piece of equipment is shut down, before a patch is installed over a corroded area, or before corrosion or fouling products are lost or disposed. More details about evidence gathering are contained in 7.3.4.

7.3.3 PEI Level 2 Investigation Personnel

Defining the team composition requirements associated with a Level 2 investigation ~~may be~~is 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.

a) PEI Incident Investigation Team Leader—The investigation leader ~~should be~~is usually 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:

   1) conducting the investigation by the specific company methodology,

   2) defining the required resources or team members to help conduct the investigation,

   3) leading the team in collecting the evidence and analyzing the evidence in an unbiased way to determine the causes based on the evidence and facts,

   4) presenting to appropriate management the conclusions and recommendations,

   5) writing the final report.

b) Team Members—The size and complexity of the incident ~~will~~ determines the number of team members that are needed. The team ~~may be~~is typically comprised of a diverse mix of backgrounds from either the area where the incident occurred or another area within the facility to facilitate the thinking process from different perspectives. Team members ~~should~~ include someone to represent the PEI aspects. The PEI team representative(s) ~~may be chosen from~~have knowledge and background in PEI such as: an inspector, pressure equipment engineer, inspection engineer, corrosion specialist, reliability engineer, or similar person with the appropriate knowledge and skills. Any of these can also serve as the team leader. The PEI team members ~~should consist of~~are knowledgeable but impartial people who were not directly involved in the incident. If the team leader sees indications that a person believes they have made a mistake and ~~will~~ be held culpable for the incident, then that person ~~should not be~~is not a good selection ~~selected~~ as a team member.

   The investigation team members assist in the investigation by collecting evidence and helping to analyze the evidence to determine the causes. Team members ~~may also be needed to~~also assist the team leader in writing the final report.

c) Sponsor—The sponsor ~~would~~ is 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 is not to manage the activities of the investigation. The sponsor ~~should~~ conveys to all those who ~~will be~~ assisting in the investigation team the importance of their cooperative participation in the investigation. Additionally, the sponsor ~~would be~~is 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.

7.3.4 Level 2 Evidence Collection

7.3.4.1 General

The determination of immediate, contributing and root causes is 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 be lost, such as DCS data being overwritten, damaged components being thrown away, or fracture surfaces improperly handled. The priority for collecting data ~~should be~~id based on how perishable the data can be. The more perishable or changeable data ~~should~~ needs to be collected first. The team ~~should~~ begins collecting data without trying to solve why the incident occurred or determining the immediate, contributing, or root causes.

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 ~~may be~~are used by the team as a starting point and ~~can be~~are 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~~ may 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 eyewitnesses or process data at the time the incident occurred is not normally available.

7.3.4.2 Securing the Incident Site/Data

In PEI incidents that involve fires or toxic releases, once the area has been secured and it is safe for personnel to enter, evidence gathering ~~should~~ begins. The investigation lead ~~will~~ needs ~~need to~~ work with operations to control the scene until they determine that initial evidence gathering is complete. ~~The area might be designated for no unauthorized entry.~~ Collection of physical evidence ~~would~~ begins as soon as practical after securing the site and continues throughout the early part of the investigation. Collecting of other evidence not within the restricted area, such as interviewing of eyewitnesses, can begin immediately. The investigation team might 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 ~~could~~ surveys the scene and identify people, equipment, and materials involved in the incident. The investigation leader ~~could~~ then prioritizes 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 that data are gathered systematically and purposefully.

PEI and maintenance/repair personnel ~~should not do anything~~take no action 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~~is given to protecting the integrity of the evidence. Evidence, such as physical evidence, that cannot be replaced ~~should~~ needs to be kept in a secure location such as a locked room or storage area and under the control of the investigation leader.

7.3.4.3 Collecting Evidence from People

~~The people e~~Evidence form people is one form of very perishable evidence. Immediately after an incident, people's recollection of the events begin to change/fade, especially as they talk to others. It is important to initially interview the eyewitnesses 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 good to have a~~Having template for interviewing that investigators use is helpful. An example of generic questions to ask eyewitnesses 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 eyewitnesses first. People's recollection regarding details of what happened can change quickly, so timely interviews could be important.
- Interview people 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.

— 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, ~~no~~ names ~~will~~are not be attached to specific statements.

— Avoid speculation. Do not try to solve the reason why or identify the causes of the incident. Gather information without judgment and be careful not to influence a person's statement in any way. Start the interview with open-ended questions that cannot be answered with a one-word answer. For example, ask storytelling 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 (e.g., "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 (e.g., "What do you mean when you say…?").

— Progress to more detailed questions (e.g., "Can you explain the procedure for...?").

— When the interview has ended, paraphrase what you heard to improve and confirm your understanding and provide the individual a chance to add more detail or make clarifications.

Information collected from interviewing people needs to be compared with information from other sources before stating as fact. ~~Collaboration might include~~Corroboration of supporting interview statements with physical or records evidence or by multiple people independently making the same statements provides more reliable information.~~.~~

In addition, other data ~~could be~~is often obtained from PEI personnel who are not on the investigation team. They can assist the investigation by providing any information/data that they have about the equipment or system that was involved in the incident. ~~They should be candid~~Being candid with any information they have, including historical information from memory, correspondence like email, and any notes in personal logbooks is helpful to the investigation. ~~Information should be freely provided to the team by the PEI personnel without any filtering or bias.~~ In some cases, individuals may feel that they have made some sort of mistake or in some other way had a vital role in why the incident occurred due to the nature of a PEI incident. In this case, ~~T~~the investigation team ~~should~~ conveys that they are not looking to blame any individuals but rather are just seeking the facts so that appropriate corrective actions can be applied to those management systems that are not as robust as they ~~should~~ need to be.

7.3.4.4 Collecting Physical Evidence

An initial site visit ~~would~~ occurs 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 ~~would~~ surveys the site to look for physical evidence. They ~~would~~ look at the entire surrounding area and not just the point of the incident. They ~~would~~ look for signs of evidence and also look for what ~~should~~ needs to be there but is not. They ~~would~~ also look for what is correct and document that as ~~;~~ this ~~will~~ can be helpful later in confirming or disproving theories. The investigation team does ~~should~~ not disturb anything at this point and ~~should not~~i ~~be~~ is not focused on fixing the problem or determining the cause. They ~~should only be~~are only looking at recording, collecting, and documenting physical evidence.

The initial activities of the site survey ~~might~~ include the following and ~~would~~ are typically be performed in the stated order.

— Take 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 up close photos of small objects. Use index cards to write what the object is and place in the photo to help with documenting the photographs.

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

- 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~~ needs to be done later under the direct observation of an investigation team member or FA laboratory.
- Samples of process fluids or solids ~~that may be~~ involved ~~should~~ needs to be collected, when possible.
- Incidents that involved fires ~~should have~~record the damage of the material in the area recorded for determining the heat pattern. API 579-1/ASME-FFS-1 as well as NFPA 921 [4] provide guidelines for assessing fire damage.
- It is important to record what equipment was not damaged in the area or system involved.

Carefully preservation of ~~Equipment~~equipment damaged in an incident is necessary~~should be carefully preserved~~. Care is taken to not to disturb ~~F~~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~~is only done if ~~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~~is provided, as appropriate.

- ~~Do not m~~Mechanically cleaning, sandblasting, wire brushing, or acid cleaning of any failed parts prior to proper analysis makes analysis difficult. Deposits on the failed part ~~might be~~are often 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 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 cleanup or demolition begins. This provides the team the opportunity to see things that might have been missed on the first survey.

Generally, after the second site survey, the site is released from evidence gathering so that cleanup and repair activities can begin. If PEI personnel discover something that is unusual or relevant to the investigation during repair and restoration activities, ~~they should notify~~ the investigation team leader is notified immediately.

7.3.4.5 Collecting Record Evidence for a Level 2 Investigation

It is important for the Level 2 investigation team to concentrate on collecting the most perishable evidence as soon as practical. After that is complete, the investigation team would then brainstorm on what other evidence to collect. ~~They could~~A list is made ~~make a list~~ of ~~that~~additional evidence and the investigation team leader ~~might~~ often assigns responsibilities to the team members to gather the additional evidence. This additional evidence ~~might~~ includes 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~~is collected or archived as soon as possible because the granularity in data could be lost. Some data systems take discrete data and after a short time may archive the data to long-term storage, and in the move compress the data set thus losing some details. The granularity of the data may be important in pinpointing change events. This ~~should be an~~ initial step is 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, piping and instrument diagrams (P&IDs), and job safety analyses.

— Operator logbooks and shift turnover documentation.

— Relevant maintenance and inspection records.

— Equipment design and construction records.

— Materials information.

— Applicable personnel training records.

7.3.5 Analyzing Evidence and Determining Causes for PEI Incidents

The collection of evidence and the analysis of evidence ~~should be~~is two distinct and separate activities. While collecting evidence, the team ~~should~~ does 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 then ~~should~~ begins analyzing the evidence. The investigation team ~~should~~ carefully reviews the evidence and makes sure they fully understand what it is revealing. If this is a large investigation and there is a lot of evidence, it ~~can be~~is 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, and 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, contributing, and root causes of the incident. Members ~~would~~ then present their conclusions to the team. The team ~~could~~ then determines if each form of evidence is pointing to basically the same conclusions about causes. That ~~would be~~is further confirmation that the correct causes are being identified.

Once the team begins analyzing the evidence, some gaps in evidence may be revealed that ~~will~~ require collecting of more evidence. The team ~~should~~ then gathers that additional evidence. Also, when the analysis of evidence begins this ~~will~~may 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 usually defines the issues associated with the incident such 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 ~~would be~~are specified by the proper expertise. Annex F is an example of a form that can be used to send physical parts off for FA and 7.5 gives guidance on FA of components.

One important part of the analysis ~~would~~ includes determination of whether 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. If they were followed, the analysis ~~might~~ focuses on ~~determine~~ why they were not effective in preventing the incident.

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.

7.3.6 Developing Recommendations and Action Items

Once the investigation team has conducted a structured analysis and determined the immediate, 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~~ is considered~~be reduced~~.

Recommendations resulting from the incident investigation ~~should be~~are developed to prevent reoccurrence of the condition or activity. The investigation team ~~should~~ is not expected to~~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 ~~might be~~is often given to what changes are required to improve the PEI program to prevent similar incidents.

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

~~Each~~ Clearly written recommendations from ~~that~~ the investigation team ~~develops should be clearly written, should~~ state which cause(s) it is designed to address, and ~~should be~~are clear and concise.~~, requiring no interpretation~~. A suitable implementation plan ~~would~~ is then be developed to resolve the recommendations.

The investigation team ~~will~~ may develop recommendations to address the causes identified as a result of the investigation. The investigation team ~~may~~ suggests 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~~are clearly written and state which recommendation it addresses. Alternative actions can~~may~~ be substituted by the responsible manager, or action items ~~may~~ can be modified as corrective action work progresses provided the recommendation is adequately addressed and the proper approval received. Action items are typically assigned a responsible owner with a reasonable completion date assigned; considering the risk associated with continued operation may influence the specified completion dates.

7.3.7 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. The report ~~may~~ contains or reference the technical information used as part of the analysis.

Reports ~~might~~ often include the following information:

- describe the incident—where and what happened;
- presentation of the findings of how and why the incident happened;
- presentation of the conclusions on what were the immediate, contributing, and root causes;
- indicate what management systems that may be related to the root causes;
- include the recommendations to prevent a repeat incident or lower the risk.

A standard template or consistent format for final reports assists those writing and reviewing reports and ~~will~~ can help with documenting required information. 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. The final report and other documentation deemed necessary for recordkeeping per the company's record retention policy ~~should be~~ are stored.

7.3.8 Tracking of Action Items

~~There should be a~~A system in place to track progress and ultimate completion of action items assigned is helpful to ensure item closure. 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 o~~Owner-operator ~~should~~ normally have a process whereby action items are periodically reviewed, and progress monitored. ~~Action items should be completed by the assigned target date.~~ Action item target dates ~~should not~~are only changes ~~be changed~~ with~~out~~ consideration of the risk associated and management review and approval. In some cases, there ~~may~~are also ~~be~~ regulatory requirements on the time allowed to implement certain actions. If an action item is changed or deleted, ~~it should be~~ document~~ed~~ation as to why and how this decision was made and what alternative actions were taken is needed. Action items ~~should have an~~ are included in an auditable trail.

The appropriate level of manager ~~should be~~is often assigned to monitor the progress of action items.

7.3.9 Determining Effectiveness of Action Items

For a select number of PEI investigations, it ~~may be~~ is important to review the effectiveness of the actions taken to resolve recommendations.

7.4 Level 3 PEI Incident Investigations

Most of the information in 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 incident investigation. As such, the description herein of a Level 3 PEI incident investigation ~~would need to be~~is in conjunction with and in support of the site's process safety incident investigation procedure.

A Level 3 PEI incident investigation ~~would~~ is 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~~ is 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 multidisciplined 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~~ are 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.

Typically, there is more than one cause in a Level 3 PEI incident. Some of the causes ~~may be~~are 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. Typically, more than one barrier or protection layer has to fail to have a catastrophic incident. For an incident that warrants a Level 3 investigation, the majority of the 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 barriers were preventing any incidents. It is important when conducting a Level 3 PEI incident investigation to determine the contributing weaknesses of the multiple layers of protection.

A structured RCA method ~~should be~~is often 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~~are based on the evidence and facts and every effort made to eliminate bias. Development of these types of trees or diagrams ~~will~~ can~~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~~is ~~typcially~~typically a trained and experienced person in the specific RCA investigation methodology used. For Level 3 incidents, the PEI incident investigation leader might 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~~ can reduce the potential for bias and overlooking some potential causes. The team leader ~~should~~ makes 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~~are normally 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~~ often serve as team members for pressure equipment failures to lend their knowledge and expertise to the investigation. If contractors are involved in the incident, then consideration ~~should be~~is given to including someone from the contractor's company on the team, but not normally ~~to~~ someone that was directly involved in the incident.

Once a Level 3 incident 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. The following areas of expertise that PEI personnel ~~may~~ assist the investigation with include:

- 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;
- guidance in determining the specific damage mechanism that caused the failure and the type of FA that ~~should~~ can be ~~done~~ completed on specific physical evidence;
- guidance in specifying NDEs to identify other damage in the remaining equipment. Help in reviewing past inspection records to determine if the damage ~~should~~ may have been ~~predicted~~ predictable and reasons it was not.

Level 3 investigations ~~should be~~are sponsored by site management who is responsible for safety, health, and environment. The sponsor's role is to ensure that the team has the time, resources, and cooperation to conduct the investigation.

The Level 3 investigation ~~should~~ identifies~~y~~ the immediate, contributing, and root causes, with the investigation depth and scope supported by the investigation sponsor and fully using the RCA methodology selected. The investigation ~~should be~~is extensive enough to fully understand the immediate 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~~ can be identified as defined by the specific RCA investigation methodology selected at the facility or company.

7.5 Component Failure Analysis

Laboratory FA of the component that led to the loss of containment is vital to many PEI incident investigations. Formal laboratory analysis ~~should be~~is completed for most failed components to determine failure mechanism. FA ~~will~~ typically involves some form of metallurgical FA of the failed component but ~~could~~ may also be a FA 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 is ~~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~~is ~~needed~~ necessary and ~~should~~ needs to be agreed upon ~~in~~ by the investigation team and with any other parties that may be involved (e.g., regulatory bodies). The protocol ~~should~~ covers at least five stages of handling the physical evidence that ~~will~~ need to 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 FA from an in-house company or contract FA firm.

Sometimes it ~~will~~ becomes 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~~ may not be so obvious which component failed first and which components may have failed because of the incident and consequence of the release (knock-on effects). In the latter 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, handling, and shipping the samples needs to be sufficiently detailed with appropriate quality assurance/quality control (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~~ helps to avoid erroneous or lack of conclusions during the FA due to damage that was not actually incurred during the incident. Shipping and handling protocol ~~may need to~~ normally specify type of packaging, type of crating, protection from the environment, need for desiccant, etc.

~~But even b~~Before investigators begin to define the protocol for FA work, they must decide where to send the samples for analysis. FA for PEI incident investigations ~~should be~~are best performed by organizations competent, qualified, and experienced in refinery and chemical plant failure mechanisms. A best practice is to identify and evaluate firms and establish a business relationship prior to an incident.

The next major step in the FA part of a PEI incident investigation is to assemble, document, and agree upon the various required steps in the laboratory FA 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~~ creates a FA protocol with the input of the selected FA laboratory. Decisions ~~will need to be~~~~are~~needs to be made about the kinds and amount of the required testing and examination ~~that will be required~~, including but not limited to the following:

- visual examination;
- sample preservation;
- physical measurements;
- NDE;
- cleaning methods and techniques;
- sample cutting, extraction, and marking;
- macro and micro metallographic examination;
- X-ray diffraction;
- scanning electron microscope examination;
- chemical analysis;
- energy dispersive X-ray spectroscopy 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~~is agreed upon and included in the FA protocol, including the following:

- when, where, and how much photographic or video documentation, or both, 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

8.1 General

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~~Having trained and qualified people ready and available is important for prompt investigations. Frontline supervisors of the organization need to know who to call and when an incident occurs. Everyone in the organization needs to know how to recognize incidents and how to report them.

8.2 Incident Investigation Team Leaders

The organization ~~could~~ defines a pool of potential investigation team leaders. Example of training for team leads includes the following:

— an overview of the company incident investigation management system;

— investigation concepts;

— specific investigation techniques used by the organization;

— proper interviewing techniques;

— proper gathering of evidence;

— concepts of laboratory FA;

— how to analyze evidence for immediate 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.

PEI personnel ~~should be~~ are typically trained on how to do an effective Level 1 investigation, while only select PEI and other personnel ~~might be~~are 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. ~~The organization could also have a plan for p~~Periodic refresher training for investigation leaders is also beneficial.

8.3 Incident Investigation Team Members

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

— an overview of the company incident investigation management system,

— investigation concepts,

— the specific investigation techniques used by the organization,

— proper interviewing techniques,

— proper gathering of evidence,

— documentation and report requirements.

8.4 Site Management Personnel

Site management ~~should be~~is trained to be knowledgeable in the following so they can support the process:

— incident investigation program and how it relates to the site/company PSM incident investigation management system,

— basic investigation concepts.

9 Continuous Improvement for PEI Incident Investigations

9.1 Information Sharing

Information sharing provides an important method for all stakeholders to improve processes, materials of construction, monitoring, inspection, and/or other key parameters. This information sharing is also known as conveying “lessons learned”. Lessons learned ~~should be~~are shared with all stakeholders that could benefit by knowing the incident causes and subsequent mitigation to avoid future incidents at the site, at other company sites or within industry, or both.

For events that represent a high learning value or convey a key preventative topic, communication externally through appropriate Industry channels ~~should be made~~is beneficial. A primary method for sharing this data, is through the American Fuels and Petrochemical Manufacturers Event Sharing Safety Portal Database. This database provides a mechanism for industry to share causal factors and lessons learned from API RP 754 Tier 1 and 2 Process Safety Events, as well as key findings and near misses. API RP 754 identifies leading and lagging process safety indicators useful for driving performance improvement. As a framework for measuring activity, status or performance, this document classifies process safety indicators into four tiers of leading and lagging indicators. Tiers 1 and 2 are suitable for nationwide public reporting and Tiers 3 and 4 are intended for internal use at individual facilities. In 2019, additional data fields were added to the event sharing database to better capture mechanical integrity data, identifying the specific damage mechanisms and other relevant data. The “API Guide to Reporting Process Safety Events” provides additional information on classifying and reporting these events.

An internal communication bulletin summarizing key learnings may be beneficial for review within the facility at the conclusion of PEI incident investigations. It would typically contain a brief explanation of the incident and then explain the causes with particular emphasis on what others could 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 throughout 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 of the PEI Incident Investigation Program

The effectiveness of the PEI Incident Investigation Program ~~should be~~is periodically reviewed to identify areas for improvement.

9.3 Updating Site PEI Documents/Procedures as a Result of Investigations

Following each investigation, site PEI program documentation (CCD, RBI, inspection plans, IOW) may require update or adjustment to reduce the likelihood of future equipment damage and PEI incidents. Action items resulting from investigations of PEI incidents ~~should be~~are managed in an action item tracking system and stewarded accordingly.

Annex A
(informative)
Example Reporting Form for PEI Incidents [1]

General Incident Information	
Completed by:	Company/Site:
Incident Date:	Incident Time:
Area/Unit:	Equipment Involved:
Incident Description: *Describe what happened and what you know about the incident.*	
Consequence: *Describe actual or potential.*	

Type of Incident/Equipment Involved		
Incident Classification:	Equipment Type:	Observations:
❒ Level 1—Low-consequence incident	❒ Pressure vessel	❒ Corrosion
❒ Level 2—Medium-consequence incident	❒ Piping	❒ Cracking
❒ Level 3—High-consequence incident	❒ Storage tank	❒ Dripping
❒ Record incident data for compiling and analysis later, no investigation	❒ Rotating equipment	❒ Hazardous release
	❒ Boilers, heaters	❒ Fire
	❒ Heat exchangers	❒ Smoking
	❒ Pressure-relief device	❒ Spray
	❒ Structural system	❒ Staining
	❒ Flange joint	❒ Incorrect spec
	❒ Other (describe)	❒ QA/QC problem

[1] The following examples are merely examples for illustration purposes only. ~~[Each company should develop its own approach.]~~ They are not to be considered exclusive or exhaustive in nature. API makes no warranties, express or implied for reliance on or any omissions from the information contained in this document.

Annex B

(informative)
Example Application of the "5-Whys" Investigation Methodology [2]

B.1 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 without 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 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 whys, so 5-Whys is just a guideline and a name for the process.

B.2 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, and the number of tubes needing plugging would exceed 20 % of the tubes and, therefore, would be too many to reuse the bundle. 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 two weeks.

Because this unit mechanical engineer had only been assigned to this unit for about two 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 the inspection records for this exchanger, and he could see that the ultrasonic thickness data showed that 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 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.

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[2] The following examples are merely examples for illustration purposes only. ~~[Each company should develop its own approach.]~~ They are not to be considered exclusive or exhaustive in nature. API makes no warranties, express or implied for reliance on or any omissions from the information contained in this document.

5-Whys Worksheet	
Name of Investigator: John Smith	**Date:** January 15, 2010
Equipment Involved: E-101	**Persons Involved:**
What Happened That Should Not Have: E-101 replacement exchanger bundle was fabricated incorrectly.	
1. Why? The wrong drawings were used to fabricate the replacement bundle.	
2. Why? The drawings of the exchanger bundle were not updated in the main equipment files.	
3. Why? A previous unit engineer did not update the equipment file when the exchanger was redesigned.	
4. Why? The previous unit engineer did not trust the records room equipment files and so he kept his own files.	
5. Why? The records room does not have controlled access and documents have been lost or misplaced in the past.	
6. Why? Keeping up-to-date equipment files is not given a high priority by management.	
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

(informative)
Example: Level 1 PEI Incident Investigation Results Form [3]

Incident: *What should be investigated?*	Date of Incident:
Investigation Method:	
Analysis Method:	Investigation Leader:
Team Members: *Name, job, and area, if any*	
Sponsor: *Name and title*	Date Investigation Initiated:
Date Investigation Completed:	Report Completed:
Investigation Results	
Evidence: *Summarize the evidence gathered.*	
Sequence of Events or Timeline: *Provide a brief timeline leading up to and including the incident.*	
Immediate Causes: *Explain the PHYSICS of the incident, define the causes that directly related to the incident.*	
Contributing Causes: *What were the causes that contributed to this incident or the severity of it?*	
Root Causes: *What were the underlying system-related reasons the incident occurred?*	
Follow-up Action Items:	

[3] The following examples are merely examples for illustration purposes only. ~~[Each company should develop its own approach.]~~ They are not to be considered exclusive or exhaustive in nature. API makes no warranties, express or implied for reliance on or any omissions from the information contained in this document.

Annex D

(informative)
Example Lists of Generic Evidence to be Gathered [4]

People data:

- — eyewitness 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;
- — 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;

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- 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;
- P&IDs;
- 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

(informative)
Examples of Questions to Ask Eyewitnesses [5]

— What is your job title, and what do you do here?
— 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?
— How 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 other people doing right before the incident occurred?
— What were you doing right before the incident happened?
— Did you have any indications before the incident that something was about the happen?
— What were the weather conditions when the incident occurred?
— Was there anything different right before the incident occurred?
— In your opinion why do you think this incident occurred? (Note this information as opinion, not fact.)
— Was this incident unexpected, or did you expect something like this might happen and why?
— Has this incident or a very similar event occurred previously and if so, when and what happened?

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Annex F

(informative)
Request for Failure Analysis Form [6]

From:	**Date:**
To:	
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: Final Report:	
How Shipped: Carrier: Expected Date of Arrival: Tracking No.:	
Shipped To:	

BACKGROUND	
Type of Component: *shell, head, nozzle, pipe, flange, valve, etc.*	Material Type:
Equipment No.:	ASTM/ASME Spec No.:
Unit:	Wall Thickness:
Operating Dept:	Year Built:

PROCESS/DESIGN CONDITIONS	
Process Design Temperature: ______ °F	Process Operating Temperature:_______ °F
Process Design Pressure: ______ psig	Process Operating Pressure: ______ psig
Internal Environment (including major/minor fluids and contaminant):	
External Environment (including major/minor fluids and contaminant):	

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How Was the Problem Discovered?
Definition of Problem?
Type of Investigation Needed (please include drawings and datasheets as applicable):
Special Requests: *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

(informative)

Example Template for Level 2 or Level 3 PEI Incident Investigation Report [7]

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 down time, and associated costs.*
Investigation Process: *Describe in general how the incident was investigated. This would include the makeup of the team, when the investigation started after the incident, how long it took, and 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.*
Evidence from People: *Provide a summary of the evidence that was gathered from people, including who was interviewed and job titles.*
Key Findings from Evidence Gathered from People: *A summary of the key findings from the evidence that was gathered from people.*
Physical Evidence: *A summary of the physical evidence that was examined and the key findings from it.*
Record Evidence: *A summary of the record evidence and the key findings from it.*
Incident Sequence: *Describe how the incident occurred and the events leading up to it.*
Immediate Causes: *Define the immediate physical causes that allowed the incident to occur based on 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.*

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[10] API 510, *Pressure Vessel Inspection Code*

[11] API 570, *Piping Inspection Code*

[12] API Recommended Practice 571, *Damage Mechanisms Affecting Fixed Equipment in the Refining Industry*

[13] API Recommended Practice 572, *Inspection Practices for Pressure Vessels*

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

[15] API Recommended Practice 574, *Inspection Practices for Piping System Components*

[16] API Recommended Practice 575, *Inspection of Atmospheric and Low Pressure Storage Tanks*

[17] API Recommended Practice 576, *Inspection of Pressure-Relieving Devices*

[18] API Recommended Practice 577, *Welding Inspection and Metallurgy*

[19] API Recommended Practice 578, *Material Verification Program for New and Existing Alloy Piping Systems*

[20] API Recommended Practice 579, *Fitness-For-Service*

[21] API Recommended Practice 580, *Risk-Based Inspection*

[22] API Recommended Practice 581, *Risk-Based Inspection Methodology*

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[9] National Fire Protection Association, 1 Batterymarch Park, Quincy, Massachusetts 02169-7471, www.nfpa.org.

[23] API Recommended Practice 582, *Welding Guidelines for the Chemical, Oil and Gas Industries*

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