

SoCalGas-135

**American Petroleum Institute Recommended Practice 585 (April
2014).**

I.19-06-016

ALJs: Hecht/Poirier

Date Served: March 16, 2021

Pressure Equipment Integrity Incident Investigation

API RECOMMENDED PRACTICE 585
FIRST EDITION, APRIL 2014



AMERICAN PETROLEUM INSTITUTE

Special Notes

API publications necessarily address problems of a general nature. With respect to particular circumstances, local, state, and federal laws and regulations should be reviewed.

Neither API nor any of API's employees, subcontractors, consultants, committees, or other assignees make any warranty or representation, either express or implied, with respect to the accuracy, completeness, or usefulness of the information contained herein, or assume any liability or responsibility for any use, or the results of such use, of any information or process disclosed in this publication. Neither API nor any of API's employees, subcontractors, consultants, or other assignees represent that use of this publication would not infringe upon privately owned rights.

Users of this recommended practice should not rely exclusively on the information contained in this document. Sound business, scientific, engineering, and safety judgment should be used in employing the information contained herein.

Work sites and equipment operations may differ. Users are solely responsible for assessing their specific equipment and premises in determining the appropriateness of applying the recommended practice. At all times users should employ sound business, scientific, engineering, and judgment safety when using this recommended practice.

API publications may be used by anyone desiring to do so. Every effort has been made by the Institute to assure the accuracy and reliability of the data contained in them; however, the Institute makes no representation, warranty, or guarantee in connection with this publication and hereby expressly disclaims any liability or responsibility for loss or damage resulting from its use or for the violation of any authorities having jurisdiction with which this publication may conflict.

API publications are published to facilitate the broad availability of proven, sound engineering and operating practices. These publications are not intended to obviate the need for applying sound engineering judgment regarding when and where these publications should be utilized. The formulation and publication of API publications is not intended in any way to inhibit anyone from using any other practices.

Any manufacturer marking equipment or materials in conformance with the marking requirements of an API standard is solely responsible for complying with all the applicable requirements of that standard. API does not represent, warrant, or guarantee that such products do in fact conform to the applicable API standard.

All rights reserved. No part of this work may be reproduced, translated, stored in a retrieval system, or transmitted by any means, electronic, mechanical, photocopying, recording, or otherwise, without prior written permission from the publisher. Contact the Publisher, API Publishing Services, 1220 L Street, NW, Washington, DC 20005.

Copyright © 2014 American Petroleum Institute

Foreword

Nothing contained in any API publication is to be construed as granting any right, by implication or otherwise, for the manufacture, sale, or use of any method, apparatus, or product covered by letters patent. Neither should anything contained in the publication be construed as insuring anyone against liability for infringement of letters patent.

Shall: As used in a standard, "shall" denotes a minimum requirement in order to conform to the specification.

Should: As used in a standard, "should" denotes a recommendation or that which is advised but not required in order to conform to the specification.

This document was produced under API standardization procedures that ensure appropriate notification and participation in the developmental process and is designated as an API standard. Questions concerning the interpretation of the content of this publication or comments and questions concerning the procedures under which this publication was developed should be directed in writing to the Director of Standards, American Petroleum Institute, 1220 L Street, NW, Washington, DC 20005. Requests for permission to reproduce or translate all or any part of the material published herein should also be addressed to the director.

Generally, API standards are reviewed and revised, reaffirmed, or withdrawn at least every five years. A one-time extension of up to two years may be added to this review cycle. Status of the publication can be ascertained from the API Standards Department, telephone (202) 682-8000. A catalog of API publications and materials is published annually by API, 1220 L Street, NW, Washington, DC 20005.

Suggested revisions are invited and should be submitted to the Standards Department, API, 1220 L Street, NW, Washington, DC 20005, standards@api.org.

Contents

	Page
1 Scope	1
1.1 General	1
1.2 Industry Scope	1
1.3 Flexibility in Application	1
1.4 Pressure Equipment Integrity (PEI) Focused	1
1.5 Types of Pressure Equipment Covered	2
1.6 Types of Equipment Excluded	2
1.7 Target Audience	2
1.8 Organizational Responsibilities	3
2 Normative References	3
3 Terms, Definitions, Acronyms, and Abbreviations	3
3.1 Terms and Definitions	3
3.2 Acronyms and Abbreviations	5
4 PEI Incident Tracking	6
4.1 PEI Incident Types	6
4.2 Documenting PEI Incidents	7
5 PEI Incident Causes	8
5.1 Types of Causes	8
5.2 Determining Causes	9
6 PEI Incident Investigations	10
6.1 General	10
6.2 PEI Incident Investigation Levels	10
6.3 PEI Incident Investigation Guidelines	12
6.4 Initial Response to a PEI Incident	12
6.5 Types of Evidence	13
7 Conducting PEI Incident Investigations	14
7.1 General	14
7.2 Performing Level 1 PEI Incident Investigations	14
7.3 Performing Level 2 PEI Incident Investigations	16
7.4 Level 3 PEI Incident Investigations	24
7.5 Component Failure Analysis	25
8 Training and Qualifications	27
8.1 General	27
8.2 Incident Investigation Team Leaders	27
8.3 Incident Investigation Team Members	28
8.4 Site Management Personnel	28
9 Continuous Improvement for PEI Incident Investigations	28
9.1 Information Sharing	28
9.2 Monitoring of the PEI Incident Investigation Program	29

Contents

	Page
Annex A (informative) Example Reporting Form for PEI Incidents	30
Annex B (informative) Example Application of the “5-Whys” Investigation Methodology	31
Annex C (informative) Example: Level 1 PEI Incident Investigation Results Form	33
Annex D (informative) Example Lists of Generic Evidence to be Gathered	34
Annex E (informative) Examples of Questions to Ask Eyewitnesses	36
Annex F (informative) Request for Failure Analysis Form	37
Annex G (informative) Example Template for Level 2 or Level 3 PEI Incident Investigation Report	39
Bibliography	40
Table	
1 Example PEI Incident Investigation Guidelines	13

Pressure Equipment Integrity Incident Investigation

1 Scope

1.1 General

The purpose of this document is to provide owners/users with practices for developing, implementing, sustaining, and enhancing an investigation program for pressure equipment integrity (PEI) incidents. This recommended practice (RP) describes characteristics of how an effective investigation could be structured so organizations can learn from PEI incidents. This RP is not intended to define or supplement criteria for compliance with regulatory requirements for which companies already have defined investigation processes in place. Rather, API 585 provides a specific focus on investigating PEI failures that are precursors to potential incidents that could have significant impact on safety, health, and environment.

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

1.2 Industry Scope

The investigation principles and concepts that are presented in this RP are specifically targeted for application to process pressure equipment in the refining and petrochemical industry but could be applied to other equipment at the discretion of the owner/user.

1.3 Flexibility in Application

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

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

1.4 Pressure Equipment Integrity (PEI) Focused

Investigation is a vital element for learning from unexpected discoveries or incidents (e.g. finding significantly more corrosion damage or other forms of deterioration than expected) and can be used in a continuous improvement process. Investigating and determining the causes of unexpected leaks, equipment degradation, or near misses associated with pressure equipment may be used to improve mechanical integrity programs and management systems for maintaining PEI, such as design and construction procedures, maintenance and inspection practices, and operating practices.

The Inspection, Corrosion/Materials, and Storage Tank Subcommittees of the API Committee on Refinery Equipment have produced a variety of codes and standards to guide owners/users in maintaining pressure equipment integrity and reliability, a listing is included in the Bibliography for reference.

1.5 Types of Pressure Equipment Covered

The following examples are the types of equipment considered to be within the scope of this document.

- a) Pressure vessels—all pressure-containing components.
- b) Piping—pipe and piping components (valves, expansion joints, sight glasses).
- c) Storage tanks—atmospheric, low pressure, and pressurized.
- d) Rotating equipment—pump and compressor cases and associated pressure-containing piping and pressure vessels, excluding seals.
- e) Boilers and heaters—pressurized components.
- f) Heat exchangers—shells, heads, channels, and pressure-containing components and tube bundles.
- g) Pressure-relief devices.
- h) Structural systems—integral to supporting pressure-containing systems.
- i) Cooling water towers.
- j) Stacks and flares.

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

1.6 Types of Equipment Excluded

The following nonpressurized equipment is not intended to be covered by this RP but could be included at the discretion of the owner/user.

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

1.7 Target Audience

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

1.8 Organizational Responsibilities

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

2 Normative References

The following referenced document is indispensable for the application of this document. The latest edition of the referenced document (including any amendments) applies.

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

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 past experience or judgment to direct the evidence gathering and development of causes towards 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 and/or consequence of an incident but is not the immediate or root cause. Eliminating the contributing cause will not by itself prevent reoccurrence but will likely reduce the frequency and/or consequence of any reoccurrence.

EXAMPLE An example of a contributing cause for a failure caused by corrosion under insulation (CUI) might be: the plant has poor 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 (pending publication) for more information regarding IOWs.

3.1.7

investigation

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

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/user

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

3.1.10

pressure equipment integrity

PEI

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

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

3.1.12

pressure equipment integrity incident

PEI incident

A PEI failure or a PEI near miss. 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

The discovery of equipment degradation or process operating conditions outside of acceptable limits that requires immediate action to shut down the equipment and/or perform repairs to avoid a loss of containment, usually the result of some form of damage mechanism such as those covered in API 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 personnel****PEI 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.

3.1.15**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).

3.1.16**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.

3.1.17**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.

3.1.18**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.

3.1.19**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

For the purposes of this document, the following acronyms and abbreviations apply.

CUI	corrosion under insulation
DCS	distributed control system
FA	failure analysis
IOW	integrity operating window
NDE	nondestructive examination
PEI	pressure equipment integrity
P&ID	piping and instrument diagram

QA	quality assurance
QC	quality control
PSM	process safety management
RCA	root cause analysis
SME	subject-matter expert

4 PEI Incident Tracking

4.1 PEI Incident Types

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

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

a) Failures:

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

b) Near misses:

- discovery of corrosion or other damage/degradation that does not pass a Fitness-For-Service assessment and requires immediate repair, but did not result in a leak;
- discovery of a damaged bolt or gasket that requires immediate repair, but before any failure or leak occurred;
- structural deterioration that is found and deemed not fit for service (e.g. during potential wind loading), but before a structural failure occurred;
- process chemistry or other operating condition that is found to be outside of an acceptable process integrity operating window (IOW) for corrosion or other material degradation mechanism and requires immediate inspection or repair, but before failure or leak 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;
- 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 significantly more damage than expected upon a routine inspection;
- discovery of the wrong metallurgical component installed, but before any significant damage or failure occurred;
- discovery of the wrong specification piping or fitting installed, but before any failure occurred (e.g. wrong schedule nipples installed);
- discovery of the wrong gaskets or bolting being installed, but before being put in service or before there was a leak.

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

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

4.2 Documenting PEI Incidents

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

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

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

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

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:

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

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

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

An effective investigation will determine not only the immediate cause of the incident but also the contributing causes and root causes. Root causes are typically related to management systems or organizational cultural issues that need to be corrected to prevent other incidents from occurring.

Conducting investigations and utilizing a structured root cause analysis (RCA) methodology to determine the systems related causes will often reveal that there are multiple underlying causes. Most investigations can determine many of the contributing causes. Determination of the true root causes of an incident takes a thorough investigation conducted by trained and experienced personnel and is generally best accomplished with a Level 3 investigation, described in 5.2.

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 review these probable causes to assure they are based on sound reasoning and some evidence and not personal bias. Bias can be the result of intentional or unintentional predetermination of causes.

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

- a) Immediate cause: the loss of containment occurred because sulfuric acid came in contact with the carbon steel pipe and rapidly corroded it to the point of failure.
- b) Contributing causes:
 - there are inadequate operating controls to prevent acid carryover in the process,
 - operators did not recognize and properly react to the abnormal operating condition that caused the acid carryover.
- c) Probable root causes:
 - leadership did not adequately address the lack of controls on process operations,
 - rigorous training of operators and retraining is not considered important to site management.

5.2 Determining Causes

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

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

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 to uncover the root causes of the incident.

Each investigation, at any level, should determine the exact immediate cause of the incident, based on evidence. If the immediate cause cannot be determined, then the team or investigator should look for more evidence or consult with additional expertise or request a metallurgical failure analysis (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 be defined and clearly documented, with both the known facts and assumptions identified.

Two of the main differences between the investigation levels are in the depth of the investigation and the precision used in determining the contributing and root causes. For the Level 1 investigation, the investigator's best knowledge of the organization and systems is used to identify the probable causes. For a Level 1 investigation, the identified

causes may not be true root causes based on detailed analysis of evidence but are people's opinion based on their experiences of the cultural and systemic issues within the organization. It is important to document these 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 most likely identify real systemic or cultural issues that could then be addressed to determine corrective actions.

The Level 2 investigations should be able to determine the immediate causes, contributing causes, and probable root causes of the incident based on analysis of the evidence and agreement between the team and the investigation sponsor. The Level 2 investigation may not determine all the root causes 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 help to prevent future incidents from occurring.

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

The Level 3 investigations are typically 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 often be driven by others outside of the PEI organization and either within or outside the site organization.

6 PEI Incident Investigations

6.1 General

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

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 differ in scope and depth of investigation and the amount and type of personnel involved. Owners/users may provide guidelines defining the different levels of investigations and the circumstances under which they are used. Table 1 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, 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 and/or specifics, might have a Level 1, Level 2, or Level 3 investigation conducted. The starting point for near misses is usually a Level 1 or Level 2 investigation.

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

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

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

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

- a gasket blows out on a blocked-in product line releasing a few hundred gallons of hazardous fluid;
- pinhole leak develops on a hydrocarbon process line and ignites, but an operator is able to extinguish it and block it in, before major damage.

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 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 1 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/user 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.

This RP is not intended to detail the emergency response or internal and external notifications. (For example purposes, the company should designate who should be notified immediately to determine the need to notify regulatory and insurance representatives, if necessary.)

As previously noted, the facility or company 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 have evidence gathering started soon as practical after it occurs. It is important that accurate data on PEI incidents is 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). For PEI incidents that require emergency response, 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.

For PEI incidents that do not require emergency response, 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 1—Example PEI Incident Investigation Guidelines

	Level 1 Investigations	Level 2 Investigations	Level 3 Investigations
Incident Characteristics	<ul style="list-style-type: none"> — 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. 	<ul style="list-style-type: none"> — 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 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 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 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 1. Any PEI related incidents that are also process safety incidents may be governed by national regulations and/or jurisdictions having authority and should 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*, 2003 ^[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 for failures 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). 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 used for Level 1 PEI incident investigations and is described further with an example in Annex B.

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

7.2.2 PEI Level 1 Investigation Personnel

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

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

The investigation leader should have the training and knowledge to carry out the responsibilities for this level of investigation. This person may be the only one conducting the investigation and is responsible for collecting the evidence and analyzing the evidence in an unbiased way to determine the immediate, 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 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 sponsored by the investigation leader's immediate supervisor or a supervisor/manager of the unit or department involved with the equipment where the incident occurred. The role of the sponsor is to ensure the investigator has the time and skills to complete and document the investigation and to set a date by which it needs to be complete. The sponsor would also help guide the investigator to ensure they are conducting an appropriate level of investigation and analysis. The sponsor would also have the responsibility to assure that follow-up corrective actions from the investigation were completed in a timely manner.

7.2.3 Collecting/Examining Evidence

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

The investigator would consider 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 collect and/or examine any physical evidence or parts involved or damaged in the incident. The investigator would examine any relevant documentation for the equipment or system, such as past inspection records, process operating history, design records, purchasing records, and maintenance or repair records.

If needed, the investigator could ask 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 analyze 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 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 or ask for additional SME expertise to help determine the immediate cause(s).

Level 1 investigations should identify the immediate causes of the incident. The investigation leader would also make a best effort at identifying contributing and possible root causes, based on the investigator's knowledge of the component failure mode or damage mechanism in conjunction with some specific information gathered about the

particular incident, and the investigator's knowledge of the facility's systems and work processes. Level 1 investigations are usually not rigorous enough to identify all of the contributing and root causes.

7.2.5 Action Items

The Level 1 investigation should include 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 to understand the contributing and possible root causes, with special emphasis on issues that represent opportunities for improvement that are within the control of the investigator or the control of the investigation sponsor. The investigator with approval from the investigation sponsor would recommend what action items are assigned and to whom.

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

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

7.2.6 Reports

Level 1 investigation results may be documented on a simple form or template such as that shown in Annex C. The report may document 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 reviewed over time to look for common or systemic causes and to determine if they are being reduced and/or eliminated. If no improvement is shown, then this may be an indication that the follow-up actions were not effective. In such a case, a review may be conducted to determine how to more effectively address the reoccurring contributing causes or to identify additional contributing and/or root causes that should be addressed. This might involve a Level 2 investigation on a grouping of similar Level 1 incidents.

7.3 Performing Level 2 PEI 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 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.

7.3.2 Beginning the Level 2 PEI Incident Investigation

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

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

It is 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. This person(s) can begin collecting eyewitness statements, if the eyewitnesses are not involved in the emergency response, and also 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 involved in the repair work that may be required because of the incident. This will allow the person to concentrate on evidence/data gathering and not miss an opportunity to collect data, such as while a piece of equipment is shut down, before a patch is installed over a corroded area, or before corrosion or fouling products are lost or disposed of. More details about evidence gathering are 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 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 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 determine the number of team members that are needed. The team may be comprised of a diverse mix of backgrounds from either the area where the incident occurred or another area within the facility in order to facilitate the thinking process from different perspectives. Either one team member or the team leader could be a PEI person; this could be an inspector, pressure equipment engineer, inspection engineer, metallurgical/corrosion engineer, or reliability engineer. The PEI team members should consist of 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 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 assist the team leader in writing the final report.

- c) *Sponsor*—The sponsor would typically be the process unit's area manager or could be the engineering manager or project manager, depending upon the type of incident.

The sponsor's role is to ensure that the team has the time, resources, and cooperation to conduct the investigation but is not to manage the activities of the investigation. The sponsor should convey to all those who will be assisting the investigation team the importance of their cooperative participation in the investigation. Additionally, the sponsor would be responsible for assuring that identified and approved corrective actions were implemented on a timely basis and that the lessons learned were communicated to affected individuals.

7.3.4 Collecting Evidence

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 based on how perishable the data is. The more perishable or changeable data should be collected first. The team should begin collecting data without trying to solve why the incident occurred or determining the immediate, contributing, or root causes.

In PEI incidents that involve fires or toxic releases, once the area has been secured and it is safe for personnel to enter, evidence gathering should begin. The investigation lead will 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 begin 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 survey the scene and identify people, equipment, and materials involved in the incident. The investigation leader could then prioritize the information to be gathered and assign responsibilities to the team members to conduct interviews and gather evidence. The coordination of the effort is to assure data is gathered systematically and purposefully.

One way to start determining what evidence to gather is to have a collection of generic lists for each type of evidence. These generic lists may be used by the team as a starting point and can be customized for the specific incident. An example of generic lists for each type of evidence is provided in Annex D. Depending on the type of incident being investigated, not all the evidence mentioned will be applicable or necessary to collect. If the incident did not have a defined consequence, like a loss of containment that happened suddenly, there may not be any eyewitnesses or process data at the time the incident occurred.

PEI personnel that are not on the investigation team can assist the investigation team by providing any information that they have about the equipment or system that was involved in the incident. They should be candid with any information they have, including historical information from memory, correspondence like email, and any notes in personal log books. Information should be freely provided to the team by the PEI personnel without any filtering or bias. In some cases, individuals may believe that they have made some sort of mistake or in some other way had a vital role in why the incident occurred. The investigation team should convey 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 be.

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

Consideration should be given to protecting the integrity of the evidence. Evidence, such as physical evidence, that cannot be replaced should be kept in a secure location such as a locked room or storage area and under the control of the investigation leader.

7.3.4.2 Collecting Evidence from People

The people evidence is one form of very perishable evidence. Immediately after an incident, people's recollection of the events begin to change, especially as they talk to others. It is important to initially interview the 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 template for interviewing that investigators use. 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 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 be attached to specific statements.
- Avoid speculating, trying to solve the reason why, or identifying causes. You are just gathering information without judgment and should be careful not to influence their statements in any way. 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...?").
- At the end, paraphrase what you heard to improve and confirm your understanding and provide the individual a chance to add more detail or make clarifications.

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

7.3.4.3 Collecting Physical Evidence

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

The initial activities of the site survey might include the following and would 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 close in photos of small objects. Using index cards to write what the object is and place in the photo helps with documenting the photographs.
- Write observations or make sketches for things that may not show up on a photograph (e.g. warped, discolored, cracked).
- Incidents that involved an explosion may require special mapping of the location of fragments and debris. It is important to map the exact location of any fragments and their condition. The size of the parts and the distance they are from the source are good information to determine the energy released.
- Collect any failed parts that do not require disassembly. Be very careful in handling damaged parts to preserve evidence that may be present on a macro or microscopic level. Label where the part came from and its orientation. Any equipment that requires disassembly should be done later under the direct observation of an investigation team member or FA laboratory.
- Samples of process fluids or solids that may be involved should be collected.
- Incidents that involved fires should have the damage of the material in the area recorded for determining the heat pattern. API 579 as well as NFPA 921 ^[4] provide guidelines for assessing fire damage.
- It is important to record what equipment was not damaged in the area or system involved.

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

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

- Do not mechanically clean, sandblast, wire brush, or acid clean any failed parts prior to proper analysis. Deposits on the failed part might be helpful in determining the cause(s) of the failure.
- If a part is fractured into two or more separate pieces, do not try to fit the fracture surfaces back together. Certain metallurgical features on the fracture face can help determine the cause of the failure and can be easily damaged by improper handling.
- Only apply preservatives (e.g. lubricating oil) to fracture surfaces when directed to do so. The lubricating oil can be removed prior to fractographic analysis; however, the integrity of surface deposits and corrosion products could be compromised by applying oil to fracture surfaces.
- Wrap the failed section in plastic (e.g. bubble wrap) in the “as-is condition” without removal of surface deposits beforehand.
- Do not store failed items outside.

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

7.3.4.4 Collecting Record Evidence

It is important for the 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 make a list of that evidence and the investigation team leader might assign responsibilities to the team members to gather the additional evidence. This additional evidence might include the following, depending on the type of PEI incident:

- Operating information showing process control data several days before the incident and at the time of the incident. (Process control information should be collected or archived as soon as possible. This should be an initial step backed up by further collection of information once the investigation is underway.)
- Related operating and maintenance procedures, including date last updated/reviewed.
- Copies of the appropriate design standards (engineering practices, design practices, etc.).
- Copies of management system documents related to the activities surrounding the incident, such as management of change documents.
- Copies of engineering drawings, piping and instrument diagrams (P&IDs), and job safety analyses.
- Operator log books and shift turnover documentation.
- Relevant maintenance and inspection records.
- Equipment design and construction records.
- Materials information.
- Applicable personnel training records.

7.3.5 Analyzing Evidence and Determining Causes for PEI Incidents

The collection of evidence and the analysis of evidence should be two distinct and separate activities. While collecting evidence, the team should not try to analyze it and determine causes too early. This can lead to bias and not exploring possible causes.

Once the investigation team leader believes that the team has collected all (or most of) the evidence, the team should begin analyzing the evidence. The investigation team should carefully review the evidence and make sure they fully understand what it is revealing. If this is a large investigation and there is a lot of evidence, it can be beneficial to divide up the different types of evidence among the team. Have one or two members of the team review each type of evidence—records, people, 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 determine if each form of evidence is pointing to basically the same conclusions about causes. That would be further confirmation that the correct causes are being identified.

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

Analyzing the evidence to determine the causes 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 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 include 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 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 be reduced.

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

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

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

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

The investigation team will develop recommendations to address the causes identified as a result of the investigation. The investigation team may suggest action items to address their recommendations, but they do not typically define the action items and responsibility. This is more appropriately done by the management of the group or area that owns the issue or the group that has to commit resources or funding to solve the issue. It is management's responsibility to define appropriate action items to address the recommendations and assign the appropriate owner of the action item.

Action items assigned to address the investigation team's recommendations would typically be clearly written and state which recommendation it addresses. Alternative actions may be substituted by the responsible manager, or action items may be modified as corrective action work progresses, so long as the recommendation is adequately addressed and the proper approval is received. 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 contain or reference the technical information used as part of the analysis.

Reports might 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 and/or lower the risk.

A standard template or consistent format for final reports assists those writing and reviewing reports and will 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 stored.

7.3.8 Tracking of Action Items

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

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

The appropriate level of manager should be 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 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 investigation. As such, the description herein of a Level 3 PEI incident investigation would need to be in conjunction with and in support of the site's process safety investigation procedure.

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

Level 3 investigations are performed on the PEI incidents with the highest actual or potential consequence and require a multidisciplinary team to fully analyze the deepest level of cause (root causes), as well as contributing causes and probable causes. Typically, only a very small percentage of PEI incidents would be investigated at this level of detail. This level of investigation is generally selected for incidents that had actual or potential to result in significant safety, health, or environmental consequences.

Typically, there is more than one cause in a Level 3 PEI incidents. Some of the causes may be latent (or hidden), or a cause cannot be verified to a high degree of certainty (referred to as a probable cause). In the refining and chemical processing industry, hazardous processes are protected by multiple layers of protection or barriers. 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 used to analyze the evidence and explain the failure and the incident, including those methods such as logic trees, cause and effect diagrams, sequence diagrams, etc. Whichever method is used, the investigation results should be based on the evidence and facts and every effort made to eliminate bias. Development of these types of trees or diagrams will also reveal any additional evidence or data analysis to assure that the conclusions are thoroughly supported by the evidence.

The PEI incident investigation team leader/member should be a trained and experienced person in the specific RCA investigation methodology used. For Level 3 incidents, the PEI incident investigation leader 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 reduce the potential for bias and overlooking some potential causes. The team leader should make sure that all evidence is gathered and considered to avoid predetermining causes and consequently the bias of gathering evidence to confirm these predetermined causes.

The team members might be a cross-functional group of individuals with knowledge and technical expertise in different functional disciplines. Team members who were not involved with or associated with the equipment being investigated are preferred to minimize introducing bias or conflicts of interest. PEI personnel from another area of the facility could serve as team members for pressure equipment failures to lend their knowledge and expertise to the investigation. If contractors are involved in the incident, then consideration should be given to including someone from the contractor's company on the team but not 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 be done 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 have been predicted and reasons it was not.

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

7.5 Component Failure Analysis

Laboratory FA of the component that led to the loss of containment is vital to many PEI incident investigations. Formal laboratory analysis should be completed for most failed components to determine failure mechanism. FA will typically involve some form of metallurgical FA of the failed component but could also be a FA on nonmetallurgical components and entail chemical analysis of deposits that might be helpful in identifying corrosion deposits, corrosive fluids, or fouling materials. As mentioned previously, it will be vital to protect the integrity of those components and samples to be analyzed.

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

- 1) selection of the samples;
- 2) packaging, handling, and shipping the samples;
- 3) documenting the various stages of analysis and handling;
- 4) examination and testing; and
- 5) reporting.

Annex F shows an example of a simple form for requesting a FA from an in-house company or contract FA firm.

Sometimes it will be obvious from the outset which component failed and caused the loss of containment. Other times because of the ensuing destruction and multiple equipment and piping failures due to the fire and explosion, it will not be so obvious which component failed first and which components may have failed 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 help 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 specify type of packaging, type of crating, protection from the environment, need for desiccant, etc.

But even before investigators begin to define the protocol for FA work, they must decide where to send the samples for analysis. FA for PEI incident investigations should be 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 create a FA protocol with the input of the selected FA laboratory. Decisions will need to be made about the kinds and amount of testing and examination that will be required, including such things as:

- visual examination;
- sample preservation;
- physical measurements;
- 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 agreed upon and included in the FA protocol, including such things as:

- When, where, and how much photographic and/or video documentation is needed;
- how much and what laboratory documentation is needed;
- the amount and type of sample marking/tagging;
- the need for hold points and witnessing of selected steps by members of the investigation team;
- at what point and when verbal reports of FA progress are needed; and
- details of what needs to be contained in the final report.

8 Training and Qualifications

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 trained and qualified people ready and available. Frontline supervisors of the organization need to know who to call and when, before an incident occurs. Everyone in the organization needs to know how to recognize incidents and how to report them.

8.2 Incident Investigation Team Leaders

The organization could define 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 trained on how to do an effective Level 1 investigation, while only select PEI and other personnel might be trained on how to lead a Level 2 investigation. Once trained, it is important that these potential team leaders practice the skills learned in the training to develop and maintain proficiency. The organization could also have a plan for periodic refresher training.

8.3 Incident Investigation Team Members

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

Investigation reports may be made available to site personnel. Owners/users may consider sharing details of the incident within the industry to communicate learnings.

A 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 periodically reviewed to identify areas for improvement

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: <i>Describe what happened and what you know about the incident.</i>		
Consequence: <i>Describe actual or potential.</i>		
Type of Incident/Equipment Involved		
Incident Classification:	Equipment Type:	Observations:
<input type="checkbox"/> Level 1—Low-consequence Incident <input type="checkbox"/> Level 2—Medium-consequence Incident <input type="checkbox"/> Level 3—High-consequence Incident <input type="checkbox"/> Record incident data for compiling and analysis later, no investigation	<input type="checkbox"/> Pressure Vessel <input type="checkbox"/> Piping <input type="checkbox"/> Storage Tank <input type="checkbox"/> Rotating Equipment <input type="checkbox"/> Boilers, Heaters <input type="checkbox"/> Heat Exchangers <input type="checkbox"/> Pressure-relief Device <input type="checkbox"/> Structural System <input type="checkbox"/> Flange Joint <input type="checkbox"/> Other (describe)	<input type="checkbox"/> Corrosion <input type="checkbox"/> Cracking <input type="checkbox"/> Dripping <input type="checkbox"/> Hazardous Release <input type="checkbox"/> Fire <input type="checkbox"/> Smoking <input type="checkbox"/> Spray <input type="checkbox"/> Staining <input type="checkbox"/> Incorrect Spec <input type="checkbox"/> 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 five 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. 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 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.

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.

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.

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.	
<i>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.</i>	
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: <i>What should be investigated?</i>	Date of Incident:
Investigation Method:	
Analysis Method:	Investigation Leader:
Team Members: <i>Name, job, and area, if any</i>	
Sponsor: <i>Name and title</i>	Date Investigation Initiated:
Date Investigation Completed:	Report Completed:
Investigation Results	
Evidence: <i>Summarize the evidence gathered.</i>	
Sequence of Events or Timeline: <i>Provide a brief timeline leading up to and including the incident.</i>	
Immediate Causes: <i>Explain the PHYSICS of the incident, define the causes that directly related to the incident.</i>	
Contributing Causes: <i>What were the causes that contributed to this incident or the severity of it?</i>	
Root Causes: <i>What were the underlying system related reason the incident occurred.</i>	
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;
- as-found position of valves, controls, and switches;

⁴ 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.

-
- position of relief valves;
 - location of witnesses;
 - location of other personnel involved in the process;
 - smoke traces;
 - melting patterns;
 - impact marks;
 - location of chemicals in the process;
 - video recordings of the area, if available.

Record data:

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

⁵ 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 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: <i>shell, head, nozzle, pipe, flange, valve, etc.</i>	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):	

⁶ 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.

How Was the Problem Discovered?
Definition of Problem?
Type of Investigation Needed (please include drawings and datasheets as applicable):
Special Requests: <i>chemical analysis, special testing, PMI, mechanical testing, etc.</i>
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: <i>Provide a summary of the incident that occurred and that was investigated.</i>
Summary of Consequences: <i>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.</i>
Investigation Process: <i>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.</i>
Summary Sequence of Events: <i>Brief summary of the major events leading up to and immediately after the incident in chronological order.</i>
Evidence: <i>An overview of what evidence was gathered and how it was.</i>
Evidence from People: <i>Provide a summary of the evidence that was gathered from people, including who was interviewed and job titles.</i>
Key Findings from Evidence Gathered from People: <i>A summary of the key findings from the evidence that was gathered from people.</i>
Physical Evidence: <i>A summary of the physical evidence that was examined and the key findings from it.</i>
Record Evidence: <i>A summary of the record evidence and the key findings from it.</i>
Incident Sequence: <i>Describe how the incident occurred and the events leading up to it.</i>
Immediate Causes: <i>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.</i>
Contributing Causes: <i>Define the contributing causes of this incident based on the evidence gathered and investigation team's analysis of that evidence.</i>
Root Causes: <i>Define the root causes of this incident based on the evidence gathered and investigation team's analysis of that evidence.</i>
Recommendations: <i>Define the recommendations to mitigate the contributing and root causes in order to reduce the likelihood that they will contribute to another incident.</i>
Appendix: <i>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.</i>

⁷ 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.

Bibliography

- [1] CCPS⁸, *Guidelines for Investigating Chemical Process Incidents*, 2003
- [2] CCPS, *Guidelines for Design Solutions for Process Equipment Failures*, 1998
- [3] CCPS, *Guidelines for Risk Based Process Safety*, 2007
- [4] NFPA 921⁹, *Guide for Fire and Explosion Investigations*, 2011
- [5] ABS Consulting, *Root Cause Analysis Handbook: A Guide to Efficient and Effective Incident Investigation*, Third Edition, Rothstein Associates Inc., July 2008
- [6] Kletz, Trevor, *What Went Wrong? Case Histories of Process Plant Disasters*, Fourth Edition, Gulf Publishing Company, 1999
- [7] Latino, Robert J., and Latino, Kenneth C., *Root Cause Analysis: Improving Performance for Bottom-Line Results*, CRC Press LLC, 2002
- [8] Nelms, C. Robert, *What You Can Learn from Things That Go Wrong*, C. Robert Nelms Publisher, 1996
- [9] Lees, F. P., *Loss Prevention in the Process Industries*, Elsevier, 1996
- [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*;

⁸ American Institute of Chemical Engineers, Center for Chemical Process Safety, 3 Park Avenue, 19th Floor, New York, New York 10016, www.aiche.org/ccps.

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*;
 - [24] API Recommended Practice 583, *Corrosion Under Insulation and Fireproofing* (pending publication);
 - [25] API Recommended Practice 584, *Integrity Operating Windows* (pending publication);
 - [26] API Standard 653, *Tank Inspection, Repair, Alteration and Reconstruction*;
 - [27] API Publication 932-A, *The Study of Corrosion in Hydroprocess Reactor Effluent Air Cooler Systems*;
 - [28] API Publication 932-B, *Design, Materials, Fabrication, Operation, and Inspection Guidelines for Corrosion Control in Hydroprocessing Reactor Effluent Air Cooler (REAC) Systems*;
 - [29] API Recommended Practice 939-C, *Guidelines for Avoiding Sulfidation (Sulfidic) Corrosion Failures in Oil Refineries*;
 - [30] API Recommended Practice 941, *Steels for Hydrogen Service at Elevated Temperatures and Pressures in Petroleum Refineries and Petrochemical Plants*;
 - [31] API Recommended Practice 945, *Avoiding Environmental Cracking in Amine Units*.



1220 L Street, NW
Washington, DC 20005-4070
USA

202.682.8000

Additional copies are available through Techstreet

Phone Orders: 1-800-699-9277 (Toll-free in the U.S. and Canada)
734-780-8000 (Local and International)

Fax Orders: 734-780-2046

Online Orders: www.techstreet.com

Information about API Publications, Programs and Services
is available on the web at www.api.org

Product No. C58501

SoCalGas-135.0047