API RP 585 Pressure Equipment Integrity Incident Investigation

AFPM Maintenance and Reliability Conference

Trace Silfies
Equity Engineering

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Overview

- What is a Pressure Equipment Incident (PEI)?
- Equipment Included/Excluded
- PEI Incident Types
- Consequences to Incidences
- Level of Incidences
- Gathering Data
- Investigation Methods
- Causes of Incidences
- Reports and Action Items
What is a Pressure Equipment Integrity Incident?

- The termination of the ability of a pressure equipment system, structure, or component to perform its function of containment of the process fluid. Loss of containment due to miss operation of equipment and not involving material damage mechanisms is not considered PEI failure.
Types of Pressure Equipment Covered

- Pressure Vessels and Piping
- Storage Tanks (atmospheric, pressurized)
- Rotating Equipment (pumps, excluding seals)
- Boilers and Heaters (pressurized components)
- Heat Exchanger Components
- Pressure Relief Devices
- Structural Systems (integral to supporting pressure-containing systems, skirts)
- Cooling Water Towers
- Stacks and Flares
## Equipment Excluded

- Instruments and Control Systems
- Electrical Systems
- Machinery Components (except casing)
- Structural Equipment (not pressure supporting)
- Movable Pressure Systems (barges, trucks, skids)
# Purpose of Incident Investigation

- Rarely the result of one, isolated issue  
  - Almost always less severe precursors to a major failure  
  - Precursors are frequently near misses
- Value of recognizing precursors to identify causes
- If near miss causes can be resolved, then major catastrophic failures of pressure equipment could be minimized or prevented
- Continuous improvement process
PEI Incident Types

- **Near Misses**
  - Damage not passing FFS (non leak)
  - Operating outside of IOW
  - Failure of a pressure-relief device (closed valve in path)
    Wrong alloy in circuit (PMI errors)
  - Incorrect fitting or piping (Sch. 40 instead Sch. XS)
  - Wrong gasket or bolting for piping class
PEI Incident Types

- Failures
  - Flange leak (not fugitive emissions leak)
  - Corrosion thinning to a leak
  - Through wall cracking
  - Rupture
  - Leak to atmosphere
  - Structural failure that causes derate or alters operation (e.g., support rings)
Documenting 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... The tracking of PEI incident data provides opportunity to identify trends and improve PEI.”
PEI Investigation Levels

- It is impractical/unnecessary to investigate every PEI to a high level or detail.
- Levels of investigation exist for different consequences.
- The more serious or potentially serious an incident, the greater the scope and depth of investigation.
Determining Consequence

- Consider both actual and potential consequences to determine the level of the investigation.
- Potential consequences should be only the most likely scenarios that might have occurred if one or possibly two other events had happened. Not more than two.
- Consequences should be clearly documented and agreed upon with the investigation sponsor.
Examples of Consequence

“If a leak occurs and releases gasoline that forms a vapor cloud but does not cause a fire...because an operator immediately saw the leak and turned on fire monitors, then it is reasonable to consider fire...as a potential consequence and investigate based on that.”

“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.”
# Level 1 - Low Consequence Events

- Incorrect gasket installed – leak without fire
- Short term corrosion rate doubled over long term
- Incorrect alloy discovered in valve before it was installed
- Schedule 40 nipple installed where Schedule 80 required in piping specification
- Inspector discovers wrong weld rod being used by welder for Cr-Mo piping replacement
- Inspector discovers utility hose being used for process drain hose

- **Goal is to document data and look at trends to prevent a larger incident or promote a larger investigation or repeat “level 1” events**
- **Serves as a leading indicator**
Level 2 - Medium Consequence Events

- Grouping/repeat of Level 1 events
- Boiler tube rupture
- Tank bottom leak
- UT findings below T min
- Flange leak on start up (small fire)
- Relief valve opens prematurely
- Relief valve found plugged
- Heat exchanger tube rupture
- Gasket blows on blocked in line
Level 3 - High Consequence Events

- Repeat events not solved by Level 1 or 2 investigation
- Anything above “medium” consequence
- Events causing fire with damage to equipment
- Production Loss
- Significant safety incident
- Large release (regulator involvement)

- All levels are built on actual or potential consequences
- Investigations started on a lower level can be extended if repeat/trend occurs
Levels of Investigation

- Besides consequences, levels differ in resources (timing and personnel included)
  - Level 1 (Low Consequence)
    - One or two person investigation – 5 Whys technique
    - Experience to determine cause (not 100% certain)
    - Starting point - may not determine root cause
  - Level 2 (Medium Consequence)
    - Small team
    - Casual factor or logic tree decision
  - Level 3 (High Consequence)
    - Team led by trained root cause investigator
    - Substantial evidence gathering
    - Structured RCA methodology, several weeks
<table>
<thead>
<tr>
<th>Incident Characteristics</th>
<th>Level 1 Investigations</th>
<th>Level 2 Investigations</th>
<th>Level 3 Investigations</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>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.</td>
<td>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.</td>
<td>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.</td>
</tr>
<tr>
<td></td>
<td>Discovered PEI damage significantly beyond expectation but with no loss of containment or unit shutdown.</td>
<td>Unexpected pressure equipment failure from damage mechanisms or structural deterioration.</td>
<td>Repetitive Level 1 type characteristics in the same process or system.</td>
</tr>
<tr>
<td></td>
<td>Small leaks (other than environmental fugitive emissions) from pressure equipment or joints that were easily contained.</td>
<td>Unexpected pressure equipment damage or associated structural damage discovered that required equipment or unit shut down or immediate mitigation.</td>
<td>Investigate using company structured root cause analysis (RCA) seeking to determine the deepest management system and cultural causes.</td>
</tr>
<tr>
<td></td>
<td>Typically no fire, significant toxic release, injuries, or environmental damage would occur in a Level 1 incident.</td>
<td>Repetitive Level 1 type characteristics in the same process or system.</td>
<td>Investigate using company structured root cause analysis (RCA) seeking to determine the deepest management system and cultural causes.</td>
</tr>
<tr>
<td>Investigation Characteristics</td>
<td>Investigate using less structured analysis tools such as “What If” or “5-Why’s.” Uses evidence, judgment, and experience to identify causes.</td>
<td>Investigate using company or department causal factor identification or logic trees, seeking probable contributing and root causes.</td>
<td>Investigate using company structured root cause analysis (RCA) seeking to determine the deepest management system and cultural causes.</td>
</tr>
<tr>
<td>Team Makeup Recommended</td>
<td>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.</td>
<td>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, including at least one PEI person on the team. Involve SMEs as needed.</td>
<td>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.</td>
</tr>
<tr>
<td>Initiation</td>
<td>Within a few days.</td>
<td>Begin investigation as soon as practical (e.g. 1 to 2 days).</td>
<td>Begin freezing and collecting evidence as soon as practical (e.g. within a few hours).</td>
</tr>
<tr>
<td>Sponsorship</td>
<td>Supervisor of investigator (First Line Supervisor).</td>
<td>Department Head level (Second Line Supervisor).</td>
<td>Management with overall responsibility for Safety Health Environment for the site.</td>
</tr>
</tbody>
</table>
API Disclaimer

- “Owners/users may provide guidelines defining the different levels of investigations and the circumstances under which they are used.”
- API 585 does not directly call out consequence levels, a brief review of API 754 will be included at the end.
- API 585 is an RP, no Shall statements included.
Investigation Method

- Gather Evidence – Conduct Analysis – Determine Cause
**Gathering Evidence**

- Begin collecting evidence as soon as safely possible. May occur before repair activity.
- **People** – interview eyewitnesses, operators, process or design engineers
- **Physical** – photograph as-found condition, chemical samples, secondary damage, valve positions
- **Records** – operating logs, inspection records, recorded operating trends, maintenance records, emails
- Collect perishable evidence first (memories)
People Data

- Eyewitness reports
- First Responders (incident reports)
- Operators – on shift and off shift
- Inspection & Maintenance Personnel
- Metallurgist/Process/Reliability/Design Engineers
- Manufacturer’s representatives
- Laboratory personnel
Eyewitness Questions (Examples)

- Let them tell the story. Do not lead a response with a yes/no question.
- Ensure them this is not to place blame but to learn from experiences.
- Start simple and work up, ask for clarification (what do you mean when you say...?)

Where were you at the time of the incident?
Would you describe the incident?
What did you see, hear, feel, or smell?
Did you have any indications before the incident that something was about to happen?
Was there anything different right before the incident?
Has this incident or a very similar event occurred previously? If so, when and what happened?
Physical Evidence

- Photograph as-found (scale)
- Secondary damage caused
- Sketches of the scene (location of fragments)
- Take notes on deformation/color/smell
- Collect deposits
- **Handle fractures with care**
- Plastic bags/Store indoors
- Avoid cleaning (grit blasting)
- Label everything!
Analyzing Evidence

- Collect all evidence first/analyze after
  - Keep separate focus and don’t become biased
- PEI team members – knowledgeable but unbiased
- Review each piece of evidence and summarize what was learned from each
- Stay focused on why the loss of containment occurred
  - Not events caused by incident (improper drainage or fire monitor coverage)
- Multiple separate field visits may be necessary
Types of Causes

- **Immediate Causes**
  - Un-neutralized acid came in contact with CS and rapidly corroded to point of failure

- **Contributing Causes**
  - Inadequate operating conditions allowing carry over
  - Operators did not recognize or react to carry over

- **Root Causes**
  - Lack of retraining of operators
  - Leadership did not address lack of process controls
Determining Causes

- Level 1 may only determine Immediate Cause
- If Immediate Cause is not determined by evidence (Level 1 or 2), Metallurgical Failure Analysis may provide more insight
- Level 3 is typically needed for identifying Root Cause
- “Root causes are typically related to management systems or organizational cultural issues that need to be corrected to prevent other incidents from occurring.”
Probable Cause

- Causes that cannot be verified to a high degree of certainty
- Typically contributing or immediate causes
- Level 1 may conclude based on probable cause
- Level 2 or 3 may have multiple causes; however, some contributing causes are theorized or probable causes.
**Action Items**

- Opportunities for future improvement
- Items may be related to immediate, root, or contributing cause
- Clearly written (no interpretation), address which cause it is linked to and implementation plan
- Important to follow-up on implementation

- *Implement on-stream NDE*
- *Add more process variables to IOW*
Effectiveness of Action Items

- Continued review of PEI incidents
- Are common and systematic incidents reduced or eliminated?
- This may lead to a higher level investigation if action item did not create progress
- Continues improvement cycle

https://inspectioneering.com/journal/2012-07-01/3073/the-role-of-continuous-improve
Final Report and Documentation

- Summary of the incident (where and what)
- Investigation effort
- Presentation of the findings (how and why)
- Conclusions on findings (immediate, contributing, root causes)
- Indicate what management systems that may be related to the root cause
- Recommendations to prevent repeat incident (action items)
- Highlight assumptions made along the way
Level 3 Additions

- Component Failure Analysis Techniques
  - Visual Examination
  - Physical Measurements
  - Cutting and Extraction
  - Macro and Micro Examination
  - SEM and EDS examination
  - Macro and Micro Hardness Testing
  - Fracture Surface Examination
  - Deposit Analysis
  - Mechanical Testing (fracture toughness/tension)
Training and Information Sharing

- Training personnel to lead PEI investigation
  - To understand multiple facets, mainly highlighted in this presentation

- Sharing Experiences with different site and the whole industry

https://inspectioneering.com/journal/2012-07-01/3073/the-role-of-continuous-improve
Annex (Informative)

- A – Example Reporting Form for PEI Incidents
- B – Example Application of the “5 Whys” Investigation Methodology
- C – Example Level 1 PEI Incident Investigation Results Form
- D – Example Lists of Generic Evidence to be Gathered
- E – Examples of Questions to Ask Eyewitnesses
- F – Request for Failure Analysis Form
- G – Example Template for Level 2 or Level 3 PEI Incident Investigation Report
“5 Whys” Case

- HE bundle was pulled and cleaned, excessive damage lead to need for replacement (>20% plugged)
- New engineer pulled drawing from main records and sent to the fabricator
- Bundle made it to plant a before end of TA
- Bundle would not fit into shell
- Shell had been modified in the past
- Old bundle was replaced in service and block valves were installed for future bundle
- Unit load was reduced due to plugged tubes
"5 Whys" Example

- What Happened that should not have: bundle fabricated incorrectly
- 1 Why - Wrong drawings were used to fabricate
- 2 Why - Drawings were not updated in main equipment file
- 3 Why - Previous engineer did not update the files
- 4 Why - Previous engineer did not trust security, kept his own files instead
- 5 Why - Equipment file room does not have controlled access, documents have been lost in the past
- 6 Why - Keeping up-to-date equipment files is not given a high priority by management
Consequence Guidance from API 754

- Incidents are rarely caused by a single catastrophic failure (Multiple that coincide)
- Swiss Cheese and Spinning Disk (dynamic)
- “Barriers” can be active, passive, or procedural
- “Holes” can be latent, incipient, or actively opened by people

Image From: API RP 754 Process Safety Performance Indicators for the Refining and Petrochemical Industries
Consequence Guidance from API 754

Image From: API RP 754 Process Safety Performance Indicators for the Refining and Petrochemical Industries
Lagging vs. Leading

- Lagging tends to be outcome-oriented and retrospective
- Hindsight is always 20:20

- Leading tends to be forward-looking and indicates the performance of the key work processes, operating discipline, or protective barriers
- Key in on early enough so that corrective actions may be taken
- In this context, the Level 1 PEI near misses can be used as a leading indicator

- Capture information that can be acted upon to correct a situation, identify lessons learned, and communicate knowledge
Tiers in API 754

- **1** – most lagging, greater consequences from **actual loss of containment** due to weakness in barriers
- **2** – Loss of Primary Containment (LOPC) that are contained in a secondary system, or release of non-toxic non-flammable process
- **3** – Challenge to barriers but stopped short of Tier 1 or 2 consequence (safety system utilized or IOW limit exceeded)
- **4** – Thought process behind facility specific barriers, operating discipline and management system performance
Comparison of API 754, API 585, Two Example Companies’ Incident Levels

<table>
<thead>
<tr>
<th></th>
<th>API 754</th>
<th>API 585</th>
<th>Company A</th>
<th>Company B</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tier 1</td>
<td>Level 3</td>
<td>Level 3</td>
<td>Level 5</td>
<td>Level 4</td>
</tr>
<tr>
<td>Tier 1</td>
<td>Level 3</td>
<td></td>
<td>Level 4</td>
<td>Level 3</td>
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<tr>
<td>Tier 2</td>
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<td>Level 1</td>
<td></td>
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<td></td>
</tr>
</tbody>
</table>

Company A approximates a large Fortune 100 company, Company B is a fictitious small refinery.
## Tier 1 Thresholds

### Table 1—Tier 1 Material Release Threshold Quantities

<table>
<thead>
<tr>
<th>Threshold Release Category</th>
<th>Material Hazard Classification</th>
<th>Threshold Quantity (outdoor release)</th>
<th>Threshold Quantity (indoor release)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>TIH Zone A Materials</td>
<td>30 kg (11 lb)</td>
<td>2.5 kg (5.5 lb)</td>
</tr>
<tr>
<td>2</td>
<td>TIH Zone B Materials</td>
<td>25 kg (55 lb)</td>
<td>12.5 kg (27.5 lb)</td>
</tr>
<tr>
<td>3</td>
<td>TIH Zone C Materials</td>
<td>100 kg (220 lb)</td>
<td>50 kg (110 lb)</td>
</tr>
<tr>
<td>4</td>
<td>TIH Zone D Materials</td>
<td>200 kg (440 lb)</td>
<td>100 kg (220 lb)</td>
</tr>
<tr>
<td>5</td>
<td>Flammable Gases or</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Liquids with Initial Boiling Point ≤ 35 °C (95 °F) and Flash Point &lt; 25 °C (73 °F) or Other Packing Group I Materials excluding strong acids/bases</td>
<td>500 kg (1100 lb)</td>
<td>250 kg (550 lb)</td>
</tr>
<tr>
<td>6</td>
<td>Liquids with Initial Boiling Point &gt; 35 °C (95 °F) and Flash Point &lt; 25 °C (73 °F) or Other Packing Group II Materials excluding moderate acids/bases</td>
<td>1000 kg (2200 lb) or 7 bbl</td>
<td>500 kg (1100 lb) or 3.6 bbl</td>
</tr>
<tr>
<td>7</td>
<td>Liquids with Flash Point ≥ 23 °C (73 °F) and ≤ 80 °C (140 °F) or Liquids with Flash Point &gt; 80 °C (140 °F) released at a temperature at or above Flash Point or strong acids/bases or Other Packing Group III Materials</td>
<td>2000 kg (4400 lb) or 14 bbl</td>
<td>1000 kg (2200 lb) or 7 bbl</td>
</tr>
</tbody>
</table>

Image From: API RP 754 Process Safety Performance Indicators for the Refining and Petrochemical Industries
## Tier 2 Thresholds

### Table 2—Tier 2 Material Release Threshold Quantities

<table>
<thead>
<tr>
<th>Threshold Release Category</th>
<th>Material Hazard Classification</th>
<th>Threshold Quantity (outdoor release)</th>
<th>Threshold Quantity (indoor release)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>TIH Zone A Materials</td>
<td>0.5 kg (1.1 lb)</td>
<td>0.25 kg (0.55 lb)</td>
</tr>
<tr>
<td>2</td>
<td>TIH Zone B Materials</td>
<td>2.5 kg (5.5 lb)</td>
<td>1.2 kg (2.6 lb)</td>
</tr>
<tr>
<td>3</td>
<td>TIH Zone C Materials</td>
<td>10 kg (22 lb)</td>
<td>6 kg (11 lb)</td>
</tr>
<tr>
<td>4</td>
<td>TIH Zone D Materials</td>
<td>20 kg (44 lb)</td>
<td>10 kg (22 lb)</td>
</tr>
<tr>
<td>5</td>
<td>Flammable Gases or Liquids with Initial Boiling Point ≤ 35 °C (95 °F) and Flash Point &lt; 23 °C (73 °F) or Other Packing Group II Materials excluding strong acids and bases</td>
<td>50 kg (110 lb)</td>
<td>25 kg (55 lb)</td>
</tr>
<tr>
<td>6</td>
<td>Liquids with a Initial Boiling Point &gt; 35 °C (95 °F) and Flash Point ≥ 50 °C (122 °F) or Liquids with Flash Point &gt; 80 °C (140 °F) released at or above Flash Point, or Other Packing Group II and III Materials excluding moderate acids and bases</td>
<td>100 kg (220 lb) or 1 bbl</td>
<td>50 kg (110 lb) or 0.5 bbl</td>
</tr>
<tr>
<td></td>
<td>Liquid with Flash Point &gt; 80 °C (140 °F) released at a temperature below Flash Point or Moderate acids and bases</td>
<td>1000 kg (2200 lb) or 10 bbl</td>
<td>500 kg (1100 lb) or 5 bbl</td>
</tr>
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Image From: API RP 754 Process Safety Performance Indicators for the Refining and Petrochemical Industries
QUESTIONS?

Shaker Heights, OH  •  Houston, TX  •  Victoria, TX
Alberta, Canada  •  Abu Dhabi, UAE

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