Excerpts from Process Safety Lessons Learned and Re-Learned the Last 50+ Years and Industry Best Practices

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VISION 20/20
AIChE CCPS Has Been a Global Advocate and Leader for Chemical Process Safety for > 30 Years

Creating Industry-wide Programs and Data Bases
Creating Guidelines Books
Sharing Best Practices

Training and Professional Development at Global Conferences and Workshops
http://www.aiche.org/ccps
Lessons Learned from Chemical Process Incidents Last 50+ Years—Things NOT in COMMON

Incidents occurred at facilities globally in organizations:

– **of all sizes** (from very small to very large)

– **in many different industry sectors**
  - petroleum and natural gas production / processing / storage and distribution,
  - petrochemicals and other commodity organic chemicals and polymers,
  - inorganic chemicals, metals and minerals processing including fertilizers,
  - specialty chemicals and materials including for electronic device manufacturing
  - explosives / propellants/ pyrotechnics manufacturing,
  - pulp and paper manufacturing,
  - agricultural commodity / food processing and food cold storage/distribution,
  - pharmaceuticals and other consumer products,
  - utilities(electric power plants, water and wastewater treatment plants)

– **with varying levels of technical sophistication / competencies in chemical process safety**

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Lessons Learned from Chemical Process Incidents--Things IN COMMON

• Inherent chemical hazard(s) were generally well known in the technical community but not managed

• Management of many organizations often thought they had good safety programs (based on a “regulatory compliance focus” and using “occupational safety metrics”)

• In fact, many deficiencies existed in identifying, evaluating, and appropriately managing the risks

• They were preventable

• There were warning signs before the incidents
Occupational Safety and Process Safety—are they different?

• YES

• How they differ is described in the following slides
Occupational Safety Typically Addresses both Physical and Chemical Hazards and is Focused on Preventing Occupational Injuries

• Under occupational safety, the focus for chemical hazards in the workplace is typically on mitigating potential exposures by use of personal protective apparel (fire retardant clothing, chemically resistant aprons, coveralls, gloves, boots) and equipment (splash shields and safety glasses, etc.)
The Focus for Chemical Process Safety is different from that for occupational safety!

Chemical Process Safety is a technical and management systems discipline that focuses primarily on prevention of loss of containment or control of hazardous materials and stored energy. KEEP IT IN THE VESSELS AND PIPES

It also addresses the mitigation of possible consequences (to people on site and offsite, to the environment, and to property) of accidental chemical releases, fires, and explosions.
Key Issues with Process Safety Incidents over the Last 50+ Years

(in design / operation / maintenance / emergency preparedness)

- **Human Errors** (influenced by issues below)
- **Complacency** (Lacking a Sense of Vulnerability)
- **Not Fully Understanding Hazards & Risks** (the potential for major accidents)
- **Design Deficiencies** (not adopting standards or inherently safer designs, inadequate barriers)
- **Inadequate Operating & Maintenance Procedures / Practices & Training**
- **Not following Procedures** (Normalization of Deviance / Lack of Operating Discipline)
- **Deficiencies with Management of Change**
- **Inadequate Maintenance / Reliability**
- **Insufficient Emergency Preparedness** (by those onsite and offsite stakeholders)
- **Insufficient Program Metrics/Oversight**
<table>
<thead>
<tr>
<th>Step 1: Few Mgt. System Processes</th>
<th>Reactive to Losses and Violations (poor compliance record but realize that mgt. system needed)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Step 2: Compliance Based</td>
<td>Mgt. System Practices &amp; Processes (typically segregated by organizational function)</td>
</tr>
<tr>
<td>Step 3: Proactive/Risk Based</td>
<td>Mgt. System Processes &amp; Programs for Some Functions within Organization (some resources allocated based on risk)</td>
</tr>
<tr>
<td>Step 4: An Enterprise Risk Mgt. Framework</td>
<td>Integrated with Key Business Processes Across All Functions (resources allocated based on risk)</td>
</tr>
<tr>
<td>Step 5: Operational Excellence</td>
<td>Focus on Continually Improving Risk Mgt. Culture, Competencies and Conduct of Operations</td>
</tr>
</tbody>
</table>

Steps or Stages in the Development of Management System Processes
# Consensus standards with risk based core elements

<table>
<thead>
<tr>
<th>Category</th>
<th>Standard</th>
</tr>
</thead>
<tbody>
<tr>
<td>Asset Mgt. Systems</td>
<td>ISO 55000:2014 Asset management -- provides a risk based approach to management of physical assets of the enterprise</td>
</tr>
<tr>
<td>Environmental Mgt.</td>
<td>ISO 14001: 2015 Environmental Management -- this newest version for the first time uses the work risk in a new section on organizational risks and opportunities.</td>
</tr>
<tr>
<td>Quality Mgt. Systems</td>
<td>ISO 9001:2015 Quality Management Systems -- this newest version explicitly expects organizations to identify and address risks affecting product and service compliancy</td>
</tr>
<tr>
<td>Quality Mgt. Systems -- Food Safety Mgt.</td>
<td>ISO 22000:2005 Follows the risk management principles outlined in ISO 31000 and is the food industry implementation of ISO 9000 quality management principles in food safety</td>
</tr>
<tr>
<td>Quality Mgt. Systems -- Medical Devices</td>
<td>ISO 14971:2007 Medical Devices - Application of risk management to medical devices</td>
</tr>
</tbody>
</table>
### Professional society guidelines with risk based core elements

|----------------------------|-------------------------------------------------------------------------------------------------------------------------------------|
Is there evidence that risk management systems reduce losses?

Figure below is typical of experience of many companies in reducing incident of all kinds, not just IIR, but also loss of containment events, fires, etc.

The better the risk management system...

the lower the losses for protecting, people, the environment, property and production capabilities!

Key Issues with Process Safety Incidents and a Possible Solution

Key Issues with Process Safety Incidents:
- **Human Errors** (influenced by issues below)
- **Complacency** (Lacking Sense of Vulnerability)
- **Not Fully Understanding Hazards & Risks** (the potential for major accidents)
- **Design Deficiencies** (not adopting stds. or inherently safer designs, inadequate barriers)
- **Inadequate Operating & Maintenance Procedures / Practices & Training**
- **Not following Procedures** (Normalization of Deviance / Lack of Operating Discipline)
- **Deficiencies with Mgt. of Change**
- **Inadequate Maintenance / Reliability**
- **Insufficient Emergency Preparedness** (by those onsite and offsite stakeholders)
- **Insufficient Program Metrics/Oversight**

Risk Based Process Safety Management System with Six More Elements Added (not in OSHA PSM) to Address the Issues:
- **Process Safety Culture**
- **Process Safety Competency**
- **Stakeholder Outreach**
- **Conduct of Operations**
- **Measures and Metrics**
- **Mgt. Review Continual Improvement**
AIChE CCPS Risk Based PSM System Elements

20 Elements

• Commit to Process Safety
  – Process Safety Culture
  – Compliance with Standards
  – Process Safety Competency
  – Workforce Involvement
  – Stakeholder Outreach

• Understanding Hazards & Risks
  – Process Knowledge Management
  – Hazard Identification & Risk Management

• Manage Risk
  – Operating Procedures
  – Safe Work Practices
  – Asset Integrity & Reliability
  – Contractor Management
  – Training & Performance Assurance
  – Management of Change
  – Operational Readiness
  – Conduct of Operations
  – Emergency Management

• Learn from Experience
  – Incident Investigation
  – Measures & Metrics
  – Auditing
  – Management Review & continuous Improvement
Warning Signs--Leadership and Culture

1. Lack of appropriate *sense of vulnerability* to hazards and appreciation of level of risk from top to bottom of company

2. Conflict between production and safety goals

3. Confusion between *process safety (PS)* & *occupational safety* and lack of communication about process risks

4. Poorly defined chain of command and roles & responsibilities (including for PS)

5. Overdue PS action items/priorities not set based on risk

6. Strained communications with management or a perception that management does not listen

7. Slow management response to PS concerns
Warning Signs-- Leadership and Culture

8. Not consulting and listening to technical experts
9. A lack of trust in mgt. including field supervision and not visible on units and involved with PS discussions
10. High absenteeism among workers or high staff turnover
11. Workers complain of “bullying” by colleagues that results in deviating from standards and procedures
12. Management and workers either not aware or not committed to safety standards and lack of enforcement of applicable standards and rules
13. Poor housekeeping in production areas and support areas
14. Operating outside safe operating limits accepted
15. Varying shift operating practices tolerated

Normalization of Deviance or Drift
1. No PS competency registry of requirements for staff across functions and verification of competencies
2. No training on possible catastrophic events and barriers
3. Informal or ineffective training on many topics
4. Frequent process upsets or performance errors
5. Signs of chaos during plant upset conditions
6. Workers appear unfamiliar with plant equipment and procedures (operating and/or maintenance)
7. Training sessions often cancelled or postponed
8. Training records incomplete or not current
9. Long-term workers have not attended recent training
10. Training materials not suitable, instructors not competent, or overuse and dependence on only CBT
Stakeholders in Chemical Process Safety

Focused on managing risks to prevent loss of containment incidents and being prepared to effectively respond to emergencies to mitigate consequences of releases should they occur.

Neighbors & Government
- Individuals near chemicals / fuels production, use or storage sites & pipelines
- Emergency Response Agencies
- Public Interest Groups
- Regulatory Agencies
- US Chemical Safety Board
- Legislative Bodies

Govt. Supported Training
- US Fire Administration
- FEMA – National Fire Academy
- OSHA Training Institute

Industry
- Chemicals / Fuels Production, Use or Storage Facilities and their onsite employees and contractors
- Industry Associations (e.g. API, AFPM, ACC, SOCMA, Chlorine Institute, CGA, TFI)
- Engineering Designers and Other Technical Consultants
- Manufacturing Technology / Equipment Suppliers
- Insurers

The organizations below, government agencies, industry associations and consortiums, provide competency training and certifications to scientists, engineers, operators, technicians, emergency responders and those in the construction trades, share lessons learned, and develop consensus standards and guidelines.

Academic Institutions, Professional / Technical Organizations & Unions
- Colleges & Universities
- Professional Societies
- Labor Unions (e.g. USW, IAFF)
- Technical Associations and others that provide:
  - standards (e.g. NFPA, ASME, IEEE, API, CGA, IIAR),
  - guidelines (e.g. AIChE CCPS & DIERS)
  - training (e.g. NFPA, AIChE, ASME, IEEE, IRC, RETA, TFI, ASTI, TRANSCAER, USW, IAFF, OSHA, USFA, FEMA)
Barriers Can Stop Progression from Initiating Cause to Loss of Containment and Mitigate Consequences
A Key Principle of Risk Based Process Safety—Multiple Layers of Protection

Multiple layers of protection (barriers or safeguards) are typically required to effectively manage risks to tolerable levels because of the vulnerability (reliability) of the barriers.

The holes in the barriers and their root causes are “warning signs” we are trying to identify before a loss of containment event!

Source: “Swiss cheese” model discussed by James Reason, Managing the Risks of Organizational Accidents (1997)
Bow-Tie Model to Illustrate Preventive and Mitigative Safeguards

Basic Risk Concepts

HAZARD* and RISK are NOT the same.

• One Definition of a Hazard: An inherent chemical or physical characteristic or condition that has the potential for causing damage to people, property, or the environment.

* A HAZARD is also often referred to as a THREAT, DANGER, or PERIL
Risk Analysis and Assessment Scenarios (“initiating cause—consequence pairs) are developed for often involving estimating a Risk Score:

Risk Score = Severity Factor \times \text{Likelihood Factor}
## RISK ASSESSMENT--EXAMPLE OF GUIDELINES FOR RATING THE SEVERITY OF CONSEQUENCES (HARM OR LOSS)

(Identify dominant / plausible losses in each category that applies.)

### Types of Potential Consequences

<table>
<thead>
<tr>
<th>Severity</th>
<th>Physical Harm to People (Injury / Illness)</th>
<th>Environmental Harm</th>
<th>Legal Non-Compliance Consequences</th>
<th>Business Interruption</th>
<th>Product Quality</th>
<th>Total Financial Loss (Including Legal Costs)</th>
<th>Damage to Reputation (Loss of Credibility &amp; Goodwill)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Very High Consequences</strong> (Catastrophic or Disastrous)</td>
<td>Multiple Fatalities</td>
<td>Extreme Widespread Contamination / Ecosystem Impacts Far Beyond Immediate Area of Release. Cleanup / Recovery Requires Months to Years.</td>
<td>Possible Criminal / Civil Prosecution</td>
<td>Business Operations Cease for Extended Time and Extreme Loss</td>
<td>Recalls, Hold on Shipments and/or Severe Customer Impacts</td>
<td>More Than $10 Million</td>
<td>Adverse International and/or Continuing National News Coverage</td>
</tr>
<tr>
<td><strong>High Consequences</strong> (Very Serious)</td>
<td>Fatality and/or Permanent Disability</td>
<td>Very Severe Contamination / Ecosystem Impacts Beyond Immediate Area of Release. Cleanup / Recovery Requires Months.</td>
<td>Possible Criminal / Civil Prosecution</td>
<td>Business Operations Severely Impacted</td>
<td>Recall or Hold on Shipments and/or Serious Customer Impacts</td>
<td>More Than $1 Million</td>
<td>Adverse National and/or Continuing Local News Coverage</td>
</tr>
<tr>
<td><strong>Moderate Consequences</strong> (Serious)</td>
<td>Temporary Disability from Weeks to Months</td>
<td>Serious Contamination / Ecosystem Impacts in the Immediate Area of Release. Cleanup/Recovery Requires Days to Weeks.</td>
<td>Serious Violations with Very Substantial Fines</td>
<td>Portions of Business Operations Severely Impacted</td>
<td>Product Discrepancy and/or Numerous Customer Impacts</td>
<td>More Than $100,000</td>
<td>Adverse Local News Coverage</td>
</tr>
<tr>
<td><strong>Low Consequences</strong> (Significant)</td>
<td>Medical Treatment / Short Term Temporary Disability</td>
<td>Contamination / Ecosystem Impacts Limited to Immediate Area of Release. Cleanup/Recovery Requires at Most Days.</td>
<td>Possibly a Violation with Fines</td>
<td>Non-Critical Loss of Capacity Schedule Impacted</td>
<td>Product Discrepancy with Internal Investigation--Few Customer Impacts</td>
<td>More Than $10,000</td>
<td>Complaints to Regulatory Agencies</td>
</tr>
<tr>
<td><strong>Very Low Consequences</strong> (Minor to No Harm)</td>
<td>First Aid or No Symptoms</td>
<td>Small Release or Spill Well Contained with No Significant Environmental Impacts</td>
<td>Warning To No Impact</td>
<td>Little to No Schedule or Delivery Impact</td>
<td>Quality Procedure Deviation--Minor Impacts</td>
<td>Less Than $10,000</td>
<td>External Complaints to Organization</td>
</tr>
</tbody>
</table>

**Impact Considered Serious Above This Line**

- More than $10,000
- Adverse International and/or Continuing National News Coverage
- Adverse National and/or Continuing Local News Coverage
- Adverse Local News Coverage
- Complaints to Regulatory Agencies
- External Complaints to Organization
# RISK ASSESSMENT--EXAMPLE OF GUIDELINES FOR ESTIMATING THE LIKELIHOOD OF LOSS

<table>
<thead>
<tr>
<th>Likelihood of Loss Event</th>
<th>Guidelines</th>
<th>Likelihood of Loss Factor</th>
</tr>
</thead>
</table>
| EXTREMELY HIGH           | Expect event to occur at least several times every year. 
  (>10^0 event/yr = >1 event/yr) 
  Commonly reported event. | 6 |
| VERY HIGH (Expected)     | Expect event to occur once per year. 
  (10^0 event/yr = 1 event/yr) 
  Many reported incidents. | 5 |
| HIGH (Very likely)       | Expect event to occur once per decade. 
  (10^{-1} event/yr = 0.1/yr or 1/decade) 
  Numerous reported incidents. | 4 |
| MEDIUM ( Likely)         | Expect event to occur during a 100 year period. 
  (10^{-2} event/yr = 0.01 event/yr or 1 event/century) 
  Unusual but reported somewhere. | 3 |
| LOW (Unlikely but possible) | Expect event to occur less than once per century. 
  (10^{-3} event/yr = 0.001 event/yr or 1 /1,000 years). 
  A rare event. | 2 |
| VERY LOW (Very unlikely) | Expect event to occur less than once during 1,000 years. 
  (<10^{-3} event/yr = <0.001 event/yr or <1 /1,000 years) 
  A very rare event. | 1 |
<table>
<thead>
<tr>
<th>RISK MATRIX</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>VERY LOW</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LOW</td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MEDIUM</td>
<td></td>
<td></td>
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<td></td>
<td></td>
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<tr>
<td>HIGH</td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>VERY HIGH</td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>EXTREMELY HIGH</td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>

Risk Score = Severity Factor x Likelihood Factor

<table>
<thead>
<tr>
<th>SEVERITY of EVENT CONSEQUENCE FACTOR</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>VERY HIGH CONSEQUENCES (catastrophic loss)</td>
<td>5</td>
<td>10</td>
<td>15</td>
<td>20</td>
<td>25</td>
<td>30</td>
</tr>
<tr>
<td>HIGH CONSEQUENCES (Very serious loss)</td>
<td>4</td>
<td>8</td>
<td>12</td>
<td>16</td>
<td>20</td>
<td>24</td>
</tr>
<tr>
<td>MEDIUM CONSEQUENCES (Serious loss)</td>
<td>3</td>
<td>6</td>
<td>9</td>
<td>12</td>
<td>15</td>
<td>18</td>
</tr>
<tr>
<td>LOW CONSEQUENCES (Significant loss)</td>
<td>2</td>
<td>4</td>
<td>6</td>
<td>8</td>
<td>10</td>
<td>12</td>
</tr>
<tr>
<td>VERY LOW CONSEQUENCES (Minor or no loss)</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>6</td>
</tr>
</tbody>
</table>

Very High Risk Region (Often 3-4 Independent Protection Layers)

Moderate to High Risk Region (Often 1-2 Independent Protection Layers)

Lower Risk Region (Often ≤ 1 Independent Protection Layers)
Risk Reduction Example – Reduce Frequency for a given consequence

Initial Risk = frequency \times \text{consequence}

\text{PFD}_1^* \quad \text{PFD}_2 \quad \text{PFD}_3

\text{Reduced Risk} = \text{reduced frequency} \times \text{same consequence}

*PFD = \text{Probability of Failure on Demand} for an Independent Protection Layer (IPL) or barrier

Note: Thickness of arrow represents frequency of the consequence if later IPLs are not successful
AIChe CCPS 7-Minute Process Safety Video Series

• Free online videos on process safety topics available for online viewing free of charge at link below:

http://www.aiche.org/academy/series/ccps-7-minute-video-series

See Spinning Disc Model

Discusses random nature of initiating events and vulnerability of barriers or controls and the differences between preventive and mitigative barriers.
Root Cause Analysis--Consider Each Step in Anatomy of Incident During an Investigation

**Hazard**

- **Initiating Cause**
  - Was the hazard identified and understood? If not, why?
  - Why did the initiating cause occur? Was it anticipated? If not, why?

- **Deviation**
  - Why was the deviation not stopped? Was it anticipated? If not, why?

- **Consequence**
  - Was this magnitude of release anticipated? Why was the loss event not mitigated? Were inadequate mitigation measures in place or did they fail? Why?

**Impact**
Root Cause Analysis Exercise

Using the worksheet handout with the 20 management system elements for Risk Based Process Safety, each breakout group should discuss an ammonia release event and identify the root causes for the event.

Video Link
Safety and Risk

• Risks are typically managed within manufacturing organizations under a variety of safety and quality assurance management systems/programs.

• As shown on the following slide, there are various definitions for the term safety and one relates directly to the concept of risk.
SAFETY is defined various ways

- The expectation that a system does not, under defined conditions, lead to a state in which human life, economics or environment are endangered.
  

- The state of not being dangerous or harmful.
  

- Being “in compliance” with applicable government regulations
  
  Source: a default definition used by many companies

- The management of risk to a tolerable level.
  
  Source: a definition used widely by leading industrial companies for decades
A PRUDENT and PREFERRED DEFINITION of “SAFETY”

Many leading companies consider compliance with applicable codes and standards as a minimum requirement. These companies often go beyond regulatory compliance and incorporate the concepts of risk and risk tolerance criteria and adopt the last definition on the previous slide:

Safety is the management of risk to a tolerable level.
A Risk-Based Process Safety Management System

Goal: To design, implement, correct, and improve process safety management activities based on consideration of the risk exposures.

• A risk-based process safety management system allocates resources for specific business processes, implementation tactics and activities commensurate with the process safety risk exposures.

• Risk-based analysis and decision making need to be core competencies.
A Risk Management Business Process

4 Steps in the Process

Step 1: Identify Hazards or Threats

Step 2: Analyze Hazards and Risks
(Estimate severity of consequences and likelihood of event with that severity of loss)

Step 3a: Assess Risks and Make Risk-Based Decisions
(Specify risk controls)

Step 3b: Ensure Specified Controls Implemented

Step 4: Monitor Risk Controls / Learn from Experience
(Inspect/test/maintain, investigate incidents, audit, report metrics, and review effectiveness)

5 Risk Decision Options (5Ts)

- Terminate risk? (Avoid)
- Transfer risk? (Share)
- Treat risk? (Reduce)
- Is the risk tolerable?
- YES

Tolerate Residual Risk

Tell (ALWAYS inform those at risk - decide how to do so)
Risk Acceptance Criteria: ALARP
Concept Adopted in the UK

Magnitude of Risk Exposure

Higher Risk Region

Medium Risk Region

Lower Risk Region

Generally Unacceptable Risk Exposure Region

Possibly Tolerated Risk Exposure Region

Generally Accepted Risk Exposure Region

ALARP stands for “As Low As Reasonably Practicable”

Risks might be tolerated if significant additional risk reduction is impractical from a technical perspective or costs are very high in comparison to the amount of risk reduction achievable.
Review the FREE CCPS Vision 20/20 Tools at: http://www.aiche.org/ccps/resources/vision-2020

Discuss the **Assessment Tool** (in MS Excel spreadsheet) with your area and/or site management team and use the tool to conduct self-assessments to help drive continual improvement at your site for the **Five Industry Tenets** under CCPS’s Vision 20/20:

1. Committed Culture
2. Vibrant Management Systems
3. Disciplined Adherence to Standards
4. Intentional Competency Development
5. Enhanced Application & Sharing of Lessons Learned