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Best practices in incident investigation in the chemical process industries with examples from the industry sector and specifically from Nova Chemicals

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Abstract

This paper will summarize best practices in incident investigation in the chemical process industries and will provide examples from both the industry sector and specifically from NOVA Chemicals. As a sponsor of the Center for Chemical Process Safety (CCPS), an industry technology alliance of the American Institute of Chemical Engineers, NOVA Chemicals participates in a number of working groups to help develop best practices and tools for the chemical process and associated industries in order to advance chemical process safety. A recent project was to develop an update on guidelines for investigating chemical process incidents.

A successful incident investigation management system must ensure that all incidents and near misses are reported, that root causes are identified, that recommendations from incident investigations identify appropriate preventive measures, and that these recommendations are resolved in a timely manner. The key elements of an effective management system for incident investigation will be described. Accepted definitions of such terms as near miss, incident, and root cause will be reviewed. An explanation of the types of incident classification systems in use, along with expected levels of follow-up, will be provided.

There are several incident investigation methodologies in use today by members of the CCPS; most of these methodologies incorporate the use of several tools. These tools include: timelines, sequence diagrams, causal factor identification, brainstorming, checklists, pre-defined trees, and team-defined logic trees.

Developing appropriate recommendations and then ensuring their resolution is the key to prevention of similar events from recurring, along with the sharing of lessons learned from incidents. There are several sources of information on previous incidents and lessons learned available to companies. In addition, many companies in the chemical process industries use their own internal databases to track recommendations from incidents and to share learnings internally.

Keywords: NOVA Chemicals; Chemical process; Process safety; Incident investigation

1. Introduction

As a sponsor of the Center for Chemical Process Safety (CCPS), an industry technology alliance of the American Institute of Chemical Engineers, NOVA Chemicals participates in a number of working groups to help develop best practices and tools for the chemical process and associated industries in order to advance chemical process safety. A project to develop an update on guidelines for investigating chemical process incidents was recently completed.

The update of the book, *Guidelines for Investigating Chemical Process Incidents* [1] involved representatives from 12 chemical process industry companies who authored the second edition along with process safety consultants and a member of the United States Chemical Safety Board (CSB). This edition illustrates best practices developed over the last 10 years in the chemical process industries.

This paper draws from the best practices illustrated in the *Guidelines* to contribute to a forum for discussion at the European Safety, Reliability and Data Association (ESReDA) 24th Seminar, Safety Investigation of Accidents.

2. Categorization/classification of incidents

To begin a discussion of best practices in incident investigation, it is important to understand some of the different terms used in categorizing incidents. The following terms

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are typical for the chemical process industries and will be used throughout this paper.

Incident—an unusual or unexpected event, which either resulted in, or had the potential to result in:

- serious injury to personnel,
- significant damage to property,
- adverse environmental impact, or
- a major interruption of process operations [1].

Incidents include accidents, near misses, and operational interruptions. An accident is an event in which property damage, detrimental environmental impact, or human loss (either injury or death) occurs. A near miss is an event in which property loss, human loss, or operational difficulties could have plausibly resulted if circumstances had been slightly different. And an operational interruption is an event in which production rates or product quality is seriously impacted [1].

Further classification of incidents is necessary in order to properly follow-up on them and to identify trends. There are several classification schemes in use by the chemical process industries; Table 1 shows some of the ways an incident could be categorized using classification by system complexity, type of incident, severity, and applicable regulation.

At NOVA Chemicals, a classification system based on incident severity is used. The four categories used are incident, serious incident, major incident, and critical incident. The types of safety, environmental, risk, and security events that define each category are shown below (these categories also contain financial, quality, and logistics issues not mentioned here).

Incident: near miss, unverified community complaint, hazardous condition, first aid case, non-compliance with laws/regulations resulting in fines <US$ 500, non-process fire <US$ 25,000, failure or activation of safety protection equipment, spill or release, internal report only, <US$ 25,000, security breach—no damage or safety implications, theft/vandalism/fraud <US$ 5000.

Serious incident: verified community complaint with safety or environmental implications, restricted work case, medical treatment case, non-process fire, damage US$ 25,000–100,000, controlled process fire with no damage, administrative penalty, issuance of regulatory order, spill or release of product reportable to authorities, security breach with damage and no safety implications, theft/vandalism/fraud US$ 5000–10,000, threatened workplace violence.

Major incident: fine or legal proceedings resulting from prosecution by authorities, event investigated by authorities, event that *could* result in significant and immediate adverse impact to the health of people, away from work case, unplanned contact with pressurized pipeline, overhead or underground electrical cable, non-process fire, damage US$ 100,000–500,000, uncontrolled process fire, damage <US$ 500,000, vehicle accident where third party suffers serious injury, event that results in long term adverse impact to fish, wildlife, or the environment, spill or release with impact beyond facility boundaries, security breach with safety implications and no damage, theft/vandalism/fraud US$ 50,000–500,000, workplace violence, media coverage that has the potential to create negative impact on the company image.

Table 1
Common classification schemes (adapted from [1])

System complexity	Type of incident	Severity	Applicable regulation (US)
High	Accident	Multiple fatalities/serious injuries	OSHA process safety MGMT
Nuclear materials	Major releases	Fatality	EPA risk MGMT program
High pressure (>3.5 bar g)	Minor releases	Injury	OSHA general duty clause
High temperature (>93 °C)	Explosion	Hospitalization	
Exothermic reactions	Fire	Lost work day	
Explosive environment	Personnel harm	Recordable	
Several relief devices	Near MISS	First aid	
Highly automated	Small release	Evacuation	EPA general duty clause
Several operators	Safety permit violation	Shelter-in-place	Coast guard
Moderate	Failure of critical safeguard	Reportable (to the authorities)	Department of energy
0.7–3.5 bar g	Challenge last line of defense	Levels of business interruption/product losses	Department of defense
38–93 °C	Serious process excursion	Levels of equipment damage	Department of transportation
Minor reactivity	Other		Nuclear regulatory commission
Low probability of explosions	Process upset		Permit violation
Single relief device	Quality variation		None
1–3 operators	Downtime		
Simple			
Ambient conditions			
Little/no reaction(s)			
Non-explosive environment			
Single/no relief valve			
1–2 operators			

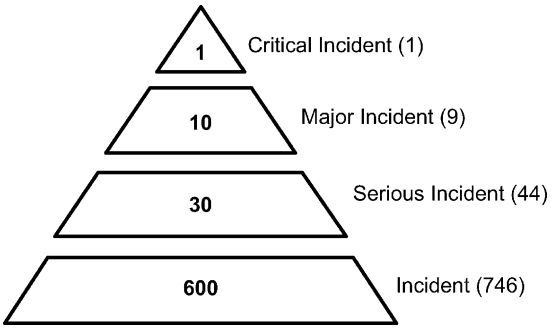

Fig. 1. Relationship between near miss incidents and more serious occurrences.

Critical incident: event that results in extraordinary investigation by authorities, fatality, life-threatening injury/illness, event that results in significant and immediate adverse impact to the health of people, pipeline rupture, fire/explosion, damage >US$ 500,000, evacuation, event that results in charges or shutdown by authorities, event that results in significant and immediate impact to fish, wildlife, or the environment which could lead to health impacts to people, security breach with safety implications and damage, theft/vandalism/fraud >US$ 500,000, armed robbery, workplace violence with police involvement, bomb threat, civil unrest, extortion/blackmail/terrorism, media coverage creating immediate negative impact on the company image.

2.1. Reducing number and severity of incidents through near miss reporting/evaluation

NOVA Chemicals believes that in achieving high reporting and follow-up of near misses (classified as incidents), the number of serious, major, and critical incidents that actually occurs will be minimized. Fig. 1 depicts our focus on the base of the "triangle" and on using the learnings to reduce the severity of future incidents and the level of risk in our businesses. In addition to targets for reduction of specific types of incidents (total recordable cases, uncontrolled process fires, etc.) the company has established a target of the ratio of the total of serious, major, and critical incidents to the number of total incidents. This ratio has averaged 2.4% over the last 3 years, indicating a very good reporting rate of near misses. Over the last 5 years, the relationship between incidents, serious incidents, major incidents, and critical incidents is depicted to the right in Fig. 1.

3. Incident type, frequency, and follow-up

A comparison with the terms from the ISO/IEC Guide 51 on Safety Aspects [2] to the terms used by NOVA Chemicals is shown below.

The Type 1 Harmful Event, an event which results in internal follow-up only, such as statistical data processing, generation of lessons learned, etc., would be equivalent to most incidents that occur within NOVA Chemicals. Most events classified as incidents, serious incidents, major incidents, and critical incidents in NOVA Chemicals have not triggered external independent investigation. The internal requirements for investigation and follow-up of these incidents are shown in Table 2.

A Type 2 Harmful Event, which is an event that results in external follow-up of "limited extent", such as independent investigation, would be equivalent to a small subset of major and critical incidents at NOVA Chemicals. There have been only two incidents at NOVA Chemicals in the last 5 years that triggered an independent, external investigation, both classified as critical incidents.

The most serious incident type, the Type 3 Harmful Event (an event that results in external follow-up of "larger extent", such as a public inquiry), would be classified as a critical incident at NOVA Chemicals. There have been no incidents at NOVA Chemicals meeting the Type 3 Harmful Event criteria.

Average annual numbers for NOVA Chemicals of the three types of events are illustrated in Fig. 2.

4. Initiation, planning, and execution of incident investigation

4.1. Regulatory requirements

In the United States, the regulation that provides specific requirements for incident investigation is the Occupational

Table 2
Internal requirements of incident types at NOVA Chemicals

Incident	Serious incident	Major incident	Critical incident
Communication to Site Leadership and externally if required	Communication to Site Leadership and externally if required	Communication to Site Leadership, Vice President, Corporate, and externally if required	Immediate communication to Site Leadership, Vice President, Corporate, and externally if required
Initial report required within 10 working days	Initial report required within 10 working days	Initial report required by next business day	Initial report required immediately
Investigate with individuals involved	Investigate with individuals involved, technical experts, team leader, Health and Safety Committee member	Investigate with individuals involved, technical experts, team leader, Health and Safety Committee member, Site Leader	Investigate with individuals involved, technical experts, team leader, Health and Safety Committee member, Site Leader, and Business Leader

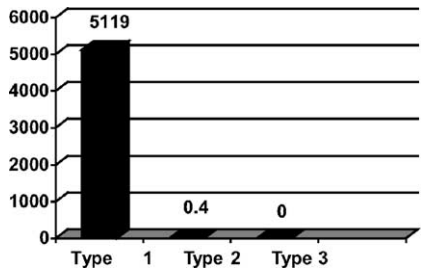

Fig. 2. Average annual type 1/2/3 events at NOVA Chemicals.

Health and Safety Administration's (OSHA) Process Safety Management (PSM) Standard [3]. Incident investigation requirements from this standard are:

- The employer shall investigate each incident that resulted in, or could reasonably have resulted in a catastrophic release of highly hazardous chemical in the workplace.
- An incident investigation shall be initiated as promptly as possible, but not later than 48 h following the incident.
- An incident investigation team shall be established and consist of at least one person knowledgeable in the process involved, including a contract employee if the incident involved work of the contractor, and other persons with appropriate knowledge and experience to thoroughly investigate and analyze the incident.
- A report shall be prepared at the conclusion of the investigation which includes at a minimum:
  - Date of incident.
  - Date investigation began.
  - A description of the incident.
  - The factors that contributed to the incident.
  - Any recommendations resulting from the investigation.
- The employer shall establish a system to promptly address and resolve the incident report findings and recommendations. Resolutions and corrective actions shall be documented.
- The report shall be reviewed with all affected personnel whose job tasks are relevant to the incident findings including contract employees where applicable.
- Incident investigation reports shall be retained for 5 years [3].

There are very similar requirements in the Environmental Protection Agency's (EPA) Risk Management Program Regulation [4]. These requirements are applied equally across all NOVA Chemicals Styrenics sites.

4.2. Incident learning process program and requirements

In NOVA Chemicals, the process for handling incidents is called the Incident Learning Process (ILP). The centerpiece of the system is a company-wide database of all incidents. All employees, from front-line operators and maintenance personnel to the highest levels of management, are encouraged to use the system to record all incidents, and especially near misses. This database is periodically reviewed and "data-mined" to understand the issues and trends in the company.

As mentioned earlier, an incident at NOVA Chemicals is what many other companies might call a near miss. All employees have been trained in the use of the ILP database so that they can input the incident, select a number of basic causes, and input recommendations into the system that are tracked to completion. The system automatically emails the persons that are assigned recommendations and progress on action item closure is reviewed at regular staff meetings. At the incident (near miss) level, the incident only has to be investigated with the persons involved so that front-line personnel can input these types of incidents directly without any other approval.

4.3. Third party investigations

In addition to the internal requirements for who must be involved in incident investigations in NOVA Chemicals described in Table 2, there are several external parties that may become involved depending on the nature and severity of the incident. In the United States these organizations include OSHA, EPA, CSB, and possibly state and provincial agencies with jurisdiction. There could be three separate federal investigations of the same incident going on at the same time at the site. If civil or criminal litigation is possible, the investigating bodies of civil litigators, state-prosecuting agencies, district attorneys or state attorneys general could also be involved [1].

4.4. External investigation assistance

To assist in an incident investigation of a complex or seemingly unexplainable incident, there are a number of external consultants available. Consultants that have been used by members of the chemical process industries to assist with incident investigations include: ABS Group; AcuTech Consulting Group; AKZO Nobel Safety Research Laboratories; Battelle; Chilworth Technology; DNV; DuPont SHE Excellence Center; EQE International; FM Global Research; ioMosaic Corporation; Primatech, Inc.; Risk, Reliability and Safety Engineering; System Improvements, Inc.; TNO; US Department of Energy; Baker Engineering and Risk Consultants (adapted from [1]).

4.5. Incident investigation methodologies, tools, and costs

CCPS conducted a survey of its members to determine the types of incident investigation methodologies currently in use. Table 3 illustrates several methodologies currently in use and also lists the tools that make up these methodologies. These tools range from the relatively unstructured, such as the timeline, to the very structured logic tree. As shown in the table all of the methodologies combine the use of at

Table 3
Types of incident investigation methodologies/tools used by the chemical process industries [1]

Methodology	Tools						
	Timeline	Sequence diagram	Brain-storming	Causal factor identification	Checklists	Pre-defined tree	Logic tree
Apollo	X		X	X			X
Causal Tree Method (CTM)				X			X
Cause Effect Logic Diagram (CELD)				X			X
Comprehensive List of Causes (CLC)	X			X		X	
Management Oversight Risk Tree (MORT)/mini-MORT				X		X	
Multilinear Event Sequencing (MES)/Events and Causal Factors Charting (E&CF)	X	X					
Multiple-Cause, Systems-Oriented Incident Investigation (MCSOII)	X		X				X
Sequentially Timed Events Plot (STEP)	X	X					
Seeking out the Underlying Root Causes of Events (SOURCE^{TM})/Root Cause Map		X		X		X	
Systematic Cause Analysis Technique (SCAT)	X				X		
TapRoot^{TM}		X		X		X	

least two tools. A short description of each tool used by an investigation team is given below:

- Timelines—a chronological listing of events using a variety of formats.
- Sequence diagram—a graphical depiction of a timeline with related events and conditions shown in parallel branches.
- Brainstorming—judgment and experience are used to find credible causes.
- Causal factor identification—identification of negative events, conditions, and actions that contributed to the incident.
- Checklists—review of causal factors against investigative checklists to determine why that factor existed at the time of the incident.
- Pre-defined trees—application of causal factors to the branches of a ready-made tree tool, discarding branches that are not relevant to the specific incident.
- Logic trees—root causes integrated with the process safety management program are determined through the use of a multiple-cause, system-oriented approach [1].

NOVA Chemicals uses all of these tools in different combination depending on the complexity and severity level of the incident.

Based on a review of 5 years of incident-related costs, for NOVA Chemicals the ratio of the costs of the harmful effects of incidents to the costs of investigation is 35–1.

5. Path forward—institutionalizing lessons learned from incidents

"Organizations have no memory. Only people have memory. A proactive and sustained effort is needed so that lessons learned once will not have to be relearned" [5]. The reason we conduct incident investigations, develop recommendations, and implement them is to prevent recurrence of the same or similar incidents. Sharing lessons learned from incidents broadly across a company will help retain corporate memory and is another requirement to prevent incidents. There are many resources available to companies that want to use lessons learned from incidents to leave a lasting impression on management and workers to bring about change. The most readily available source of incidents is from your own organization. Other sources of lessons learned include: incident case histories available in publications and conference symposia from the American Institute of Chemical Engineers (AIChE), specific lessons learned booklets from the American Petroleum Institute (API), the Loss Prevention Bulletin published by the Institution of Chemical Engineers, case studies and incident investigation reports published by the CSB, incident case studies and causal data from databases including CCPS' Process Safety Incident Database, and the one-page process safety messages for manufacturing personnel in the Process Safety Beacon, also published by CCPS [1].

Sharing lessons from internal incidents should be a formal part of the incident investigation management system. The recommendations coming from internal incidents should be tailored to the underlying cause and promote improvements; they should be shared across the organization, both across business units boundaries and personnel levels. In order to do this effectively it is sometimes necessary to prepare different information releases:

- A detailed communication of what happened, why, and what direct specific changes are to be made should be developed for the personnel who work directly in the unit where the incident occurred and other similar facilities in the company.
- A somewhat more generic communication should be prepared for personnel in adjacent units who may not be exposed to the same specific hazards as in the unit where the incident occurred.

In addition to the internal communication of lessons learned from incidents that have occurred in a company, there are many other ways to communicate and learn from previous external and internal incidents:

- A search and review of internal and external incidents should be conducted as part of any periodic hazard analysis.
- In the early design phase of a new project a search of databases should be conducted.
- Periodic publication of incident abstracts from both internal and external sources should be considered.
- The use of pertinent messages from incidents should be used in regular safety or "toolbox" meetings [1].

At NOVA Chemicals all of these methods are used to varying degrees throughout the organization. In addition, built into the ILP system is a requirement that all Site Leaders throughout the company review the incident investigation reports inside the ILP database for all major and critical incidents—the ILP system automatically emails them to initiate the review.

6. Conclusions

During the last 10 years, companies have greatly improved the practices and tools available in the area of incident investigation. Increasing the level of near miss reporting reduces the number and severity of harmful events as the number of incident pre-cursor events can be reduced. It is important to make it as easy as possible for employees to report near miss events and it is also critical that the information be used. Sharing lessons learned from both internal and external incidents helps retain corporate memory so that history will not be repeated. Companies should make use of the various incident investigation methodologies available and use appropriately structured tools based on the severity/complexity of the incident. As the chemical process sector continues to reduce the number of incidents with negative consequences, it will become even more important to increase near miss reporting and evaluation.

References

[1] Guidelines for Investigating Chemical Process Incidents, Center for Chemical Process Safety, 2003.
[2] ISO/IEC Guide 51, Safety Aspects—Guidelines for their Inclusion in Standards, 2nd ed., 1999.
[3] OSHA, Process Safety Management of Highly Hazardous Chemicals, 29 CFR 1910.119, 1992.
[4] EPA, Accidental Release Prevention Requirements: Risk Management Programs, Clean Air Act Section 112(r)(7), 40 CFR Part 68, 1996.
[5] T. Kletz, Organizations have no memory, in: Proceedings of the AIChE Loss Prevention Symposium, 1979.