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INTRODUCTION

Warning signs are indicators that something is wrong or about to go wrong. When we recognize and act on these indicators, a loss may be prevented. Of course, this will only happen when we know what to look for and are willing to take the initiative to do something about it. A review of significant incidents in the process industries suggests that most if not all incidents were preceded by warning signs. Some of these signs were clearly visible but not acted upon because their significance was not understood. Other warning signs were less obvious, but observant personnel may have detected them.

This book is about warning signs that have preceded or contributed to past incidents. There is one common characteristic shared by the incident warning signs presented here:

The organization does not perceive or recognize them.

An incident warning sign is a subtle indicator of a problem that could lead to an incident. Some minor incidents might have the potential to escalate to a catastrophic level. There are warning signs of a physical or tangible nature, and there are warning signs related to the management practices of an organization. Some warning signs may be problems in themselves while others may be symptoms of potential problems or incidents. Every sign provides a clue that may be an early warning of catastrophe. These clues give us an opportunity to do things differently to reduce the risk of a catastrophe.

It is common for an organization that experiences a major catastrophic incident to respond initially with shock and surprise. Somehow, facility workers and their supervisors may have developed the impression that catastrophic incidents only happen elsewhere and are the result of gross misconduct or total system breakdown. As the organization or local facility may have sustained itself without a catastrophic incident for many years, managers, technical staff, and facility workers often hold the sentiment... *We must be doing things right.* In many cases, this is a misguided perception. Consider taking a closer look at possible warning signs at your facility to avoid this experience.

The following quote from Professor Andrew Hopkins, an author on safety and professor of sociology at Australian National University, emphasizes the importance of addressing these indicators.

Prior to any major accident there are always warning signs which, had they been responded to, would have averted the incident. But they weren't. They were ignored. Very often there is a whole culture of denial operating to suppress these warning signs.

The early warning signs we discuss either are unknown to the organization due to their lack of visibility or because the associated risk was unrecognized, downplayed, or ignored.

There are many types of warning signs, including the following:

- Early indicators of failure that provide opportunities to take appropriate action. Process equipment that is not functioning properly may be prone to failure. Organizations sometimes ignore these on the basis that they will address the issues later (or if the problem escalates).
- Suggestions that a major incident may be imminent. An example might include a piece of process equipment reaching its end-of-cycle or retirement limit.
- Indicators of other issues that are less obvious and require detailed analysis. For this reason, a practical follow-up option is to conduct an audit to help ensure that programs and systems are managed effectively.
- Seemingly insignificant issues that, when combined with other warning signs, suggest a breakdown of management systems.
- Actual incidents with measurable consequences. If we ignore these, they can increase in frequency or magnitude and contribute to a catastrophic incident.

Some of the warning signs discussed in this book are commonplace across the process industries. They may exist within your own operation or facility. Other significant warning signs may have been missed in our analysis and you may need to augment the list to make it more suitable to your organization's needs. It would be rare to find a facility that does not have a warning sign present. When any warning sign becomes widespread or becomes the norm within an organization or when multiple warning signs are present, there is reason for concern. However, some warning signs might be inherent in your type of operation, and total elimination may be impossible or impractical.

Although some warning sign discussions do offer suggested approaches, the goal of this book is not to explain *how to do it* or *how to fix the problem*. We hope this book is a trigger for initiating self-assessment and follow-up action. It should help to alert responsible leaders that trouble may be on the way and, unless these

warning signs are recognized and addressed, the probability of experiencing a major incident could increase.

1.1 PROCESS SAFETY MANAGEMENT

Process safety management (PSM) is a systematic framework of activities used to manage the integrity of hazardous operations and processes. Specifically, it deals with the prevention of *loss of containment* incidents that are commonly associated with the process industries. When hazardous materials are released outside their primary containment, especially to the atmosphere, the effects can be widespread and difficult to predict. Prevention is of paramount importance. Initiating proactive and systematic response to incident warning signs is a powerful tool to augment the standard elements of process safety. Determine your organization's process safety philosophy. Ask the following question of your organization.

Do our actions related to process safety reflect that process safety is an integral part of our organizational culture?

Organizations that understand the importance of process safety will want to reflect that awareness in their actions. To be most effective, embrace rigorous process safety as a value throughout the organization and show it in the organization's actions. Priorities change with the working environment or business climate. Values do not. They are something that a group internalizes and characterizes in its behavior to help define a framework for its actions.

1.1.1 Identifying process safety management system deficiencies

Less serious incidents precede most catastrophic incidents. Many of these less-than-catastrophic incidents can reveal early warning signs that could have prevented the catastrophic incident from occurring if leaders had recognized and acted upon them. Management system deficiencies are a root cause in all effective incident investigation methodologies. Our goal should be to identify common management system deficiencies and their associated early warning signs. We use case studies to illustrate these warning signs, and we hope to help you make a connection from these examples to your facilities. The case studies chosen are landmark events supported by thorough investigations. These catastrophes influenced how companies manage process safety activities worldwide.

Industry generally understands the central concept of designing and implementing management systems to maintain and improve performance. Process safety management embodies the following principles, although you may not recognize these as elements in your company's program:

- Know your processes—both physically and in terms of information about them.
- Communicate process hazards effectively to all affected employees and contractors.

- Analyze the processes as necessary to understand them and their associated hazards.
- Operate the processes within their safe operating envelopes.
- Maintain the equipment properly in accordance with a documented asset integrity program.
- Manage and communicate all process changes over time.
- Train your employees and contractors on the processes and the associated hazards.
- Evaluate the operation regularly to see how you are doing.
- Get out into your facility so you can observe the visible warning signs and encourage site leadership to do the same.
- Develop the competencies and resources required by your business processes and process safety management system.
- Modify your business processes and management system as needed to meet changing requirements.
- Communicate the status of the facility's activities and findings from any periodic reviews to the site senior management and others as appropriate.
- Develop action plans to address and close all findings.

When all workers see that the organization values and supports these types of systems, it encourages the employee's individual commitment to safety and environmental excellence. The Center for Chemical Process Safety (CCPS) publication *The Business Case for Process Safety* demonstrates that a rigorous process safety framework also improves the bottom line.

Many of these management systems may already be in place in a high-hazard facility or operation. It is wise to consider extending these to all parts of an operation, regardless of the process hazards.

1.2 NORMALIZATION OF DEVIANCE

Normalization of deviance is a long-term phenomenon in which individuals or work teams gradually accept a lower standard of performance until the lower standard becomes the norm. It is typically the result of conditions slowly changing and eroding over time.

Normalization of deviance often begins in the form of a shortcut or poorly documented temporary change in a standard work practice or procedure. If there are no apparent negative consequences, the new practice becomes accepted and displaces the original practice. Over time, this process repeats. When the changes are small and seemingly insignificant, they are easy to miss. One subset of normalized deviance is organizational creep. This is a common term for this type of incremental change away from set work practices in an operating organization. In the midst of such change, it is sometimes difficult to recognize or appreciate the value of the original practice or procedure. Even when discussing this situation with local management, the news may be met with opposition in the form of comments like—*it works just fine*—or—*it has not caused us any problems yet*.

Normalization of deviance represents a serious breach in the management of change system. It is also a major contributor to many serious incidents.

1.3 A STRATEGY FOR RESPONSE

The response upon recognition of incident warning signs at your facility should not be a knee-jerk reaction but rather a disciplined approach to collecting all the facts and moving forward in a planned and organized manner. Figure 1-1 illustrates an approach to responding to an incident warning sign.

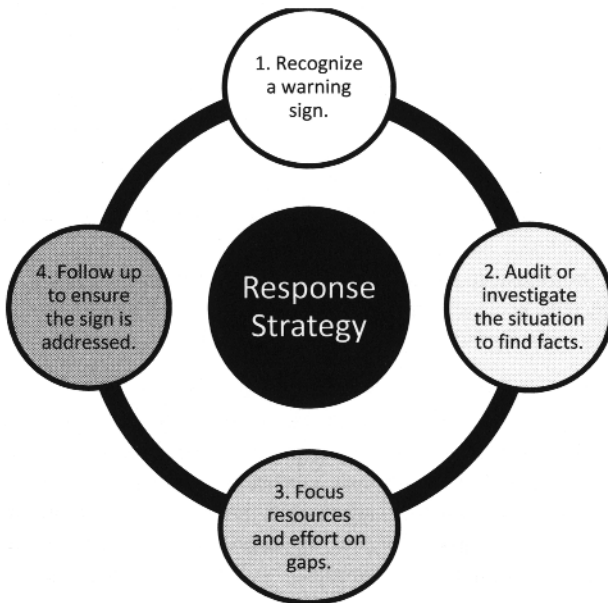


Figure 1-1 A Strategy for Response

There may be a tendency in some organizations to deny the importance or significance of certain warning signs. This may be the case when these warning signs have existed for a considerable period without consequence. Some facilities may not consider a warning sign important if the entire staff has a high level of seniority and experience, and they have become complacent about plant operations. This indicates a false sense of security. Both new and senior workers may need training on the correct methods for doing things so that they develop a heightened sense of awareness regarding the importance of warning signs.

Professor Andrew Hopkins further states, “Organizational culture is one of the key factors why companies fail to recognize the warning signs prior to workplace accidents.”

An analysis of actual incidents may suggest that certain early warning signs correlate with specific types or categories of incidents. This assumption may not

be valid. Managers need to take time to examine the local trends. They should stay close to day-to-day operations and not be lulled into complacency by short-term successes.

Finding multiple warning signs within your organization provides a more compelling reason to be concerned and to take action. Carefully screen the operation to determine system gaps or weaknesses. If these exist, are they universal or localized in one part of the operation? For example, procedural weaknesses can result in poor training. Likewise, inadequate training can result in inadequate written procedures. Analyze each detected sign carefully to ensure that you are fixing the right problem.

- Some of the warning signs may appear similar in context. While it is tempting to combine these, each might have a unique explanation or cause.
- Incident warning signs are unlikely to exist in isolation. Where a significant warning sign exists, chances are that other warning signs are present as well.
- It may be possible to rationalize a system weakness, but it is difficult to explain why so many things have gone wrong. This is why it is advisable to investigate further before initiating action.

Ultimately, all employees and contractors at a facility play a role in ensuring that the organization follows its programs rigorously and addresses all gaps. Addressing incident warning signs is a practice that should accompany other established initiatives within a company's process safety framework. Recognizing and understanding these warning signs will better prepare you and your co-workers to take on that task. Success in achieving this goal depends on the combination of well-understood process safety guidelines and operational discipline.

The questions in Table 1-1 support the recognition and follow-up for these early incident warning signs. Ask these questions whenever a warning sign is detected.

TABLE 1-1 Key Questions for Warning Sign Incident Investigations

Has this warning sign been observed previously?
If so, was it acted upon with satisfactory results?
Is this warning sign evident in all operating areas or particular parts of the operation?
Is there a rational explanation for this warning sign that would suggest that the operation is not really at risk?
Are there other coexisting incident warning signs?
Are the coexisting warning signs related?
If so, how are they related?
Is there a common theme linking the warning signs? (For example, a particular staff person or team, a corporate policy reinforcing the existence of warning signs, or funding cuts.)
Is there any action or activity that might alleviate or eliminate the warning signs noted?

1.4 MAINTAINING ORGANIZATIONAL MEMORY AND A HEALTHY SENSE OF VULNERABILITY

A process safety management system that is well documented and maintained will augment an organization's memory. Up-to-date piping and instrument diagrams (P&IDs), accurate procedures, hazardous area classification drawings, and a thoroughly documented and implemented management of change and pre-startup safety review system are prime examples of how the system creates memories. Maintenance of organizational memory should be reinforced continuously throughout the life cycle of a processing facility.

Maintaining accurate configuration data in real time and regular emergency drills are common practice in the commercial nuclear power industry. This promotes the concept of a healthy sense of vulnerability. Management encourages

everyone to maintain the calm sense of awareness that—*the worst-case scenario can happen right now...we need to be ready to follow our response procedures.* Extensive training, strict document control for all critical procedure performance, configuration management, and other good practices keep this in the front of each employee's mind. A healthy sense of vulnerability is an attitude to consider developing for your organization. Do not rely on an organization's history of no catastrophic incidents as a sign of good performance. That history may be a function of good luck.

1.5 RISK BASED PROCESS SAFETY

Since the initial introduction of formal regulations in many countries, process safety appears to have stagnated in some companies. Citing perceptions that—*we experience lower than normal industry risk—or—we have a clean record regarding catastrophic incidents*—as possible excuses, some companies have chosen to scale down or compromise the scope of their process safety activities. To address this issue, CCPS has adopted a 20-element risk-based framework for process safety that better addresses the needs of all industry sectors, including those with and without high risks. CCPS member companies developed this framework based on a causal analysis of several major incidents that have occurred since the early 1990s.

Risk based process safety is not a way to circumvent the basic tasks or regulatory elements of process safety as they apply to your facility. Adopting risk based process safety means that your organization must meet the applicable regulations for all of your processes and then look longer, deeper, and in more detail at those processes or parts of processes that present the greatest risk of catastrophic incident. It also involves looking harder at seemingly innocuous utilities such as steam supply, electrical distribution, cooling water, or nitrogen that, in some processes, are critical to bringing a unit back to a safe mode after an excursion. The CCPS risk-based framework helps organizations set up and administer a more effective process safety management system. Through risk based process safety, organizations can focus resources more effectively. This reduces the potential for warning signs to exist. When warning signs do appear, risk based process safety can provide more effective response and correction.

The elements of risk based process safety are shown in Table 1-2.

TABLE 1-2 Risk Based Process Safety's (RBPS) Four Pillars and Twenty Elements

RBPS PILLARS AND ELEMENTS
RBPS PILLAR 1—COMMIT TO PROCESS SAFETY
<p>PROCESS SAFETY CULTURE COMPLIANCE WITH STANDARDS PROCESS SAFETY COMPETENCY WORKFORCE INVOLVEMENT STAKEHOLDER OUTREACH</p>
RBPS PILLAR 2—UNDERSTAND HAZARDS AND RISK
<p>PROCESS KNOWLEDGE MANAGEMENT HAZARD IDENTIFICATION AND RISK ANALYSIS</p>
RBPS PILLAR 3—MANAGE RISK
<p>OPERATING PROCEDURES SAFE WORK PRACTICES ASSET INTEGRITY AND RELIABILITY CONTRACTOR MANAGEMENT TRAINING AND PERFORMANCE ASSURANCE MANAGEMENT OF CHANGE OPERATIONAL READINESS CONDUCT OF OPERATIONS EMERGENCY MANAGEMENT</p>
RBPS PILLAR 4—LEARN FROM EXPERIENCE
<p>INCIDENT INVESTIGATION MEASUREMENT AND METRICS AUDITING MANAGEMENT REVIEW AND CONTINUOUS IMPROVEMENT</p>

A more detailed description of each of the elements can be found in the CCPS guideline series book *Guidelines for Risk Based Process Safety*.

A process safety management system involves a wide range of activities. A performance gap or void in any one of these can increase the likelihood of an incident. When voids exist in several elements, the chance of a major incident is higher. To illustrate this point, Table 1-3 lists several noteworthy incidents that have occurred throughout industry over the past three decades along with the management system deficiencies that contributed to the event. Very few incidents, if any, have resulted from just one cause.

TABLE 1-3 Catastrophic Incident by Element Analysis

Incident	Year	Contributing Process Safety Element Deficiencies									
		Leadership and Culture	Process Safety Information	Hazard ID & Risk Analysis	Management of Change	Operating Procedures	Training	Incident Investigation	Contractor Management	Emergency Preparedness	Pre-startup Safety Review
Phillips 66 Explosion	1989	X	X	X	X	X	X		X	X	
NASA Challenger	1986	X		X	X				X		X
Piper Alpha Platform	1988	X		X	X	X	X		X	X	X
Chernobyl Explosion	1986	X	X	X	X	X	X			X	X
Longford Explosion	1998	X	X	X	X	X	X	X		X	
Jilin, China Explosion	2005	X		X	X	X	X			X	
Bhopal Toxic Gas Release	1984	X	X	X	X	X	X	X		X	
Hickson-Welch Jet Fire	1992	X	X	X	X	X	X		X	X	

Process safety audits measure compliance to process safety management (PSM) goals and standards and pinpoint deficiencies. Audits can be very effective in revealing these deficiencies. However, they are time consuming and require considerable planning. Considering the time and effort required to conduct a formal process safety audit, a facility may be vulnerable during the span between

audits. The practical question to answer is—*how does a front line supervisor or manager quickly pinpoint problems or gaps and take appropriate action?* Incident warning signs provide such an opportunity. They are subtle indicators that suggest a need to look further and possibly tighten up or alter process safety practices. Incident warning signs are not to be confused with the components or sub-elements of process safety.

1.6 OUR TARGET AUDIENCE

Our goal is to appeal to a wide range of readers. We especially hope to reach the team leaders, front line supervisors, and production leaders in all process industries. A partial list of these industries is provided below.

- Chemical processing
- Oil and gas production
- Oil refining
- Petrochemical production and processing
- Fossil power generation
- Nuclear power generation
- Pulp and paper
- Pharmaceutical
- Food processing
- Biofuels and bioprocessing
- Cryogenic separation
- Bulk terminals
- Oil and gas pipeline
- Transportation and bulk shipping
- Weapons manufacture
- Water treatment
- Waste treatment

Often, supervisory roles are in the best position to drive change both up and down in the organizational hierarchy. Such change will require strong support from the organization's senior leaders. We want to help you understand the concepts in order to influence players at all levels of the organization. The last chapter of the book, Chapter 12, *A Call to Action*, provides some guidance in achieving this goal through risk communication and individual empowerment. A person detecting a warning sign and failing to present a credible case to management for how to address it leaves an organization vulnerable to failure. Future efforts to communicate after a failed attempt may not go well. If the need for action and improvement is not universally recognized, nothing will change.

Anyone interested in understanding, identifying, and taking action related to catastrophic incident warning signs can benefit from this book. The following list suggests personnel who may reap an advantage from this book.

- Operations, maintenance, and other manufacturing personnel who may be critical in implementing parts of a facility's process safety management system
- Safety professionals at the facility and corporate levels
- Process safety and risk management program managers and coordinators at manufacturing facilities
- Corporate process safety management staff
- Project managers and project team members whose projects have process safety implications
- Engineers or other staff members initiating changes under the management of change protocol
- Facility managers and other members of manufacturing plant management teams responsible for the overall safety of chemical processing facilities
- Regulatory agency staff involved in the initial permitting and ongoing compliance of processing facilities with relevant process safety standards

The concepts in this book are helpful to all who strive to develop a culture where safety is exhibited in everyday actions.

1.7 HOW TO USE THIS BOOK

Each of the chapters on warning signs provides a brief overview of the related management systems, associated warning signs, and a relevant case study. This book provides you with an opportunity to evaluate the warning signs, their associated process safety elements, and the case studies of incidents in which the warning signs may have been present as precursors.

If you find that several warning signs exist within a single element category at your facility, thoroughly check all the associated warning signs. If you cannot readily correct the ones you find, you may want to conduct a thorough audit. This can help identify appropriate follow-up actions. Formal audit findings can address some of the prevalent warning signs. This book can also help you strengthen an organization's audit protocol and provide a cross-check against a process safety audit report.

Finding numerous warning signs across multiple categories may signal the need for significant improvements in the facility's process safety culture. The Baker Panel Report issued in January 2007 as part of the follow-up to the 2005 BP Texas City explosion provides guidance for safety culture improvement.

Finally, this book is useful for safety meeting topics. The leader can refer to examples of past events and ask the questions—*What if*—and—*Could this happen here?* A reference to past incidents is particularly valuable in today's operating environment. Many of the workers and leaders who were involved in your site's process safety management system's initial implementation are leaving the industry. The rate of experience loss in the process industries is expected to

increase over the next several years. Without some guidance, today's staff may not realize that they are on a path toward repeating past incidents.

1.8 CASE STUDY – TOXIC GAS RELEASE IN INDIA

The 1984 Bhopal, India, incident ranks as the worst chemical facility disaster in history. It claimed the lives of 3000 to 10,000 people and injured 100,000 others. An analysis of the Bhopal incident reveals failures in each element of process safety. For this reason, we have used the Bhopal case study to support our introductory chapter. It occurred on an average night when work practices and habits were typical of day-to-day management.

The incident took place in an intermediate storage area of the facility where liquid methyl isocyanate (MIC) was stored in three separate tanks embedded in a berm. MIC is a feedstock used in the production of carbamate, a common insecticide. MIC liquid is highly reactive in the presence of water and iron oxide, and it generates heat. In sufficient quantities, this heat may generate highly toxic vapor. The process design included a refrigeration coil to ensure that the temperature could not exceed 5°C and a vent gas scrubber to prevent vapor escape. In addition, despite a low process operating pressure, a closed relief and blowdown subsystem was installed to further decrease the risk.

For several months before the catastrophic incident, conditions at the facility had been deteriorating. For example, workers did not follow procedures carefully and several mechanical features were either shut down or compromised. Examples include the refrigeration circuit, which was low on coolant, and the vent gas scrubber and flare system, which was out-of-service. The temperature indicator on one tank was defective and the temperature in another of the tanks exceeded the maximum limit by as much as 15°C with no corrective action.

On the night of the catastrophic incident, operators heard a screeching noise from the relief valve on one of the tanks. Unfortunately, the closed blowdown system was out of service for maintenance. At the time, workers were cleaning out a clogged pipe with water about 400 feet from the tank. It was later thought that while operators were on their shift change or on a break, someone could have intentionally disconnected a pressure gauge from the cover plate on one of the tanks and attached a water hose. A significant quantity of water entered one of the tanks and triggered a runaway reaction and subsequent release of MIC vapor into the community. Another theory suggested that due to ineffective maintenance and leaking valves, water may have leaked into the tank.

Principal factors leading to the magnitude of the gas leak include the following items.

- Storing MIC in large tanks and filling beyond recommended levels
- Poor maintenance
- Failure of several safety systems (due to poor maintenance)

- Safety systems being switched off to save money—including the MIC tank refrigeration system, which could have mitigated the disaster severity

Other physical contributors to the incident included the following items.

- The MIC tank alarms had not worked for at least four years.
- There was only one manual backup system, compared to a four-stage system used at facilities operated by the parent company.
- The flare tower and the vent gas scrubber had been out of service for five months before the disaster. The gas scrubber, therefore, did not treat escaping gases with sodium hydroxide (caustic soda), which might have brought the concentration down to a safe level, although the scrubber and flare system design was inadequate for the flow rate of MIC involved in the incident.
- To reduce energy costs, the refrigeration system, designed to inhibit the escape of MIC vapor, had been left idle; the MIC was stored at a hotter temperature than recommended. It was determined that the refrigerant was being used to cool the management offices.
- The steam boiler, intended to clean the pipes, was out of service for unknown reasons.
- Pipe blinds that would have prevented water from pipes being cleaned from leaking into the MIC tanks through faulty valves were not installed.
- The water pressure was too low to spray the escaping gases from the stack. They could not spray high enough to reduce the concentration of escaping gas.
- According to facility operators, the pressure gauge on the MIC tank had been malfunctioning for one week prior to the incident.
- Carbon steel valves were widely used at the facility, even though they corrode when exposed to acid.

The technical details provided above were not made available to the investigators for a period of one year. A lockout by the Indian government prevented technical experts from the parent company from entering the site. An analysis of chemical residue in various pieces of process equipment was used to support the development of incident logic.

The incident at Bhopal was not really an accident. There was no real element of surprise. Conditions had deteriorated for many months while no one stepped forward to intervene. Physical and paper evidence suggesting huge gaps in the safety culture were very visible and should have been apparent to any responsible worker on the facility site. However, the definition of responsible worker has little meaning if management has not defined a safety culture and declared a clear set of operating priorities. Process safety culture is a state of excellence that starts with strong leadership and demands discipline and accountability at all levels.

Several additional questions need to be asked.

- Why did the parent company not enforce its own policies and procedures?
- Why did workers not complain about conditions in the facility?
- Why was defective equipment not properly maintained and repaired?
- Why were emergency plans and procedures not developed?
- Why was there no dialogue between facility management and the local community that might have led to a timely evacuation?
- Why was there little cooperation between the company and the government in accessing evidence and reaching timely conclusions?

This catastrophic incident led to the financial ruin of the parent company and resulted in the development of process safety protocols and regulations worldwide.

Exercise: Some of the warning signs that may have been noticed prior to this incident are listed below.

- Operating outside the safe operating envelope is accepted.
- Operation continues when safeguards are known to be impaired.
- Critical safety systems are not functioning properly or are not tested.

Can you identify other warning signs that may have been present?

