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Presentation of a Graphical Model for Assessing Opportunities for Inherently Safer Industrial Systems

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Introduction

Inherent safety is a term that describes a system, technology or process that, through various design features, is able to operate in such a state that various failures modes do not present a risk to people, property or environment. The concept was initially introduced by Trevor Kletz of ICI in the 1980's. He applied the term to the study of chemical accident prevention, expressing it as, "Inherently safer plants are plants which can withstand deviations from normal operating conditions without having to rely on safety systems."[1] The term continues to be used in the context of the chemical processing industry (CPI), primarily in the context of acute events. It is a concept that has great value well beyond the CPI.

While many will acknowledge that inherently safe systems are ideal, we also realize that, in many systems, risk cannot be eliminated without also eliminating the utility of that system. As a result, the concept of *inherently safe* has evolved into *inherently safer*. This acknowledges that, while a comprehensive inherently safe system may not always be achievable; there is value in assessing any system for opportunities to make it inherently safer. At the same time, especially in organizations where there is substantial risk to people, property and the environment, there needs to be an innovation infrastructure in place so that opportunities for achieving inherently safe systems can be identified, promoted, analyzed and implemented.

This paper introduces a simple graphical model for assessing the extent to which various the risk management options create an inherently safer system. Drawing on the concepts of primary prevention, secondary prevention and mitigation, it has been used to represent various acute chemical release events, from the vapor cloud explosion in Flixborough, England to the methylisocyanate (MIC) release in Bhopal, India to the release of mecury-based pesticides into the Rhine River in Basel, Switzerland. It has also been used to demonstrate the gains achieved with inherently safer options, such as transitioning from batch to continuous processing to substantially reduce quantities of hazardous intermediate products.[2]

Core Concepts

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[1] Kletz, T., "Friendly Plants", *Chemical Engineering Progress*, July 1989, p18.

[2] Minzner, A, *Chemical Accident Prevention,* MIT Master's Thesis, 1990

To understand the effectiveness of a firm's safety efforts, it is worthwhile to subdivide measures which fall under an organization's definition of prevention. These measures can be classified as:

- primary prevention
- secondary prevention
- mitigation

Mitigation

Mitigation measures generally exist as stand-by systems which perform in response to an event. These measures are intended to minimize the amount of personal injury and property damage *given the occurrence of an accident* such as a chemical release. They are not intended to actually prevent the event from occurring. Many emergency response measures fall into this category. For adverse consequences to be minimized, it is important that response procedures be properly implemented by those involved. Especially for acute events, such as chemical releases, that have low frequencies of occurrence and great variability in how they manifest themselves, there can be numerous factors that impact whether or not emergency response actions are appropriate and effective.

Secondary Prevention:

Secondary prevention systems are more integrated into the overall process design than mitigation measures. They are often being applied continually to prevent an initiating event but they do not eliminate the probability of event. Systems which monitor in-process characteristics, such as pressure and temperature, for critical deviations and introduce safety measures in response to these deviations are forms of secondary prevention. Components such as seals and check valves designed to contain hazardous substances within process chambers are also forms of secondary prevention.

Other forms of secondary prevention include add-on mechanical systems which are designed to decrease the rate or duration of a release, or interfere with the transport of a release or reduce the concentration of a release. Examples of such devices include emergency vent-gas scrubbers and water sprays.

In order for many secondary prevention systems to operate effectively, they must be appropriately designed and maintained, demanding time and resources from the organization. Failures of secondary prevention systems are reported repeatedly in accounts of chemical process accidents. Many of the accidents that have occurred in the CPI have occurred despite the presence of "safety systems" that would be considered secondary prevention.

Both mitigation and secondary prevention are considered forms of extrinsic safety, meaning they operate outside of the scope of a core technological system, perhaps even to the extent where they are being provided by the community, such as emergency response personnel.

Relying on secondary prevention and mitigation systems for process safety is the dominant practice in many organizations.

Primary Prevention

The most effective type of accident prevention is primary prevention. In this case, the hazard is eliminated through such measures as redesigning the process, choosing different process technology, selecting more benign inputs, and/or reformulating the final product. Another means for achieving inherently safer systems involves altering the scope of the production process.

Concepts common to a dialogue on inherent safety include minimization, substitution, moderation and simplification. *Minimization* includes reducing the quantities of hazardous materials and / or reducing the scale of equipment and systems operating under hazardous conditions. *Substitution* involves the use of less hazardous materials, processes and conditions. *Moderation* involves altering processes to reduce the hazards presented by various operating conditions, such as temperature and pressure. *Simplification* involves the elimination of unnecessary complexity to enhance safety.[3] Some of the greatest successes in inherent safety have arisen from instances where the objectives of minimization, substitution, moderation and simplification are realized as an opportunity to create a strategic advantage for an organization. In the product safety field, goals to simplify a machine by producing a more robust product with fewer maintenance requirements will lead to an inherently safer system, since this will reduce the need for worker intervention with the system and possibly unintended exposure to high speed moving parts, cutting surfaces, high temperatures, etc.

Why Inherent Safety?

Inherent safety is a concept that, in a theoretical sense, can be easy to accept. However, because accidents are seldom expected, and because in some instances, the goal of inherent safety can seem so revolutionary, it can be difficult to get companies to embrace it in a practical sense.

In many ways, inherent safety is analogous to pollution prevention. One of the primary distinctions, however, is that pollution prevention generally addresses daily operations. Baseline data can be established and impacts can be quantified. Because companies do not intend to experience an accident, the need for, and the benefits of an inherently safer system can be more difficult to establish and quantify. In Ashford's work with European companies, his greatest success (from idea generation through to implementation and measured positive economic impact) was with companies that had experienced regular safety and operational problems in existing installations, so there was a tangible incentive for pursuing a range of solutions. In most cases, for each of the companies Ashford worked with, the proposed solutions not only created inherently safer operating systems, but provided pay-back periods of less than two years. This includes solutions for existing installations.[4]

Inherently safer systems often offer greater flexibility and require less regulatory oversight. In contrast, to rely on extrinsic systems for achieving safety goals makes an organization susceptible to the vulnerabilities of add-on safety technologies. Such vulnerabilities include:

- resource requirements
- added complexity
- maintenance requirements

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[3] Hendershot, Dennis C. Inherently Safer Design. Washington, DC: American Chemical Society, 2002.

[4] Ashford, Nicholas, and Garard Zwetsloot. "Encouraging Inherently Safer Production in European Firms: A Report from the Field." Journal of Hazardous Materials: Special Issue on Risk Assessment and Environmental Decision Making (1999): 123-144.

- safety technologies may need to be upgraded with production systems
- safety technologies may be adversely affected by the event itself.

At one chemical processing plant, the “safety measure” on a particular unit consisted of monitoring the contents of a line to determine whether recycled materials contained contaminants at a sufficient concentration to initiate a violent exothermic reaction. Mitigation measures would be taken if such concerns were noted. After several years and a change of unit management, the monitoring was arbitrarily terminated. A few months later, a violent exothermic reaction did occur due to contaminant build up.[5]

In the field of fire protection, it is often the case that a manufacturer changes his operations or warehousing configuration without considering whether or not the automatic sprinkler system’s design density is appropriate for such changes. An appropriate design density is crucial to water discharge being sufficient to absorb enough heat to control fire spread. Failure to upgrade the fire protection system consistent with changes in operations makes the facility extremely vulnerable to a fire.

A relatively small hydrocarbon explosion at a Torrance, CA refinery resulted in failure of a hydrogen fluoride (HF) storage vessel and destroyed the water spray system specifically intended to keep a HF release from migrating off site. Three thousand residents had to be evacuated from their homes.[6]

The Model

Since the initial introduction of this concept of inherent safety, numerous models and methods have been introduced to assist organizations in measuring degrees of inherent safety and in identifying opportunities. Some of these have been advocated by standards and regulations, while others have been promoted by specific organizations. These models and methods vary greatly in their complexity. They include Technology Options Analysis (Ashford), Inherent Safety Index (Heikkila), Inherent Safety Opportunity Audit (Ashford), Inherent Safety Potential Index (ISPI), Integrated Inherent Safety Index (Khan), and the Inherently Safer Design Index.

The model presented in this paper enables comparison of various prevention and mitigation measures currently being employed or being considered by the firm as regards their ability to actually eliminate hazards as opposed to decreasing the probability of hazards becoming an accident. For example, evacuation procedures would intervene between the *release of materials* and *consequences*; an emergency vent gas scrubber would intervene between *the initiating event* and the *release of material*; a temperature control system would intervene between the *production system* and the *initiating event*; and substituting a more benign input will directly impact the *production system* itself.

Succeeding with Inherently Safer Systems

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[5] Knowlton, R.E., “Dealing with the Process Safety Management Gap”, *Plant / Operations Progress,* Vol. 9, No. 2, p 74, April 1990.

[6] *Chemical Week,* “California Mulls HFR Storage Ban”, Vol. 164, No. 19

Opportunities for inherently safer systems that have been successfully employed in chemical processing facilities throughout the world include:

- Using just-in-time deliveries to substantially reduce the amount of highly hazardous materials at a facility at any given point in time.
- Moving from batch to continuous processing to eliminate storage of highly hazardous intermediate products
- Substituting aqueous ammonia at atmospheric pressure for pressurized anhydrous ammonia to reduce the effects of volatility in the event of a spill
- Switching from ammonia to urea-based pollution control systems
- Replacing large quantities of elemental chlorine with sodium hypochlorite at waste water treatment plants.

Increased communication of such successes will hopefully encourage others to pursue similar opportunities for their own organizations.

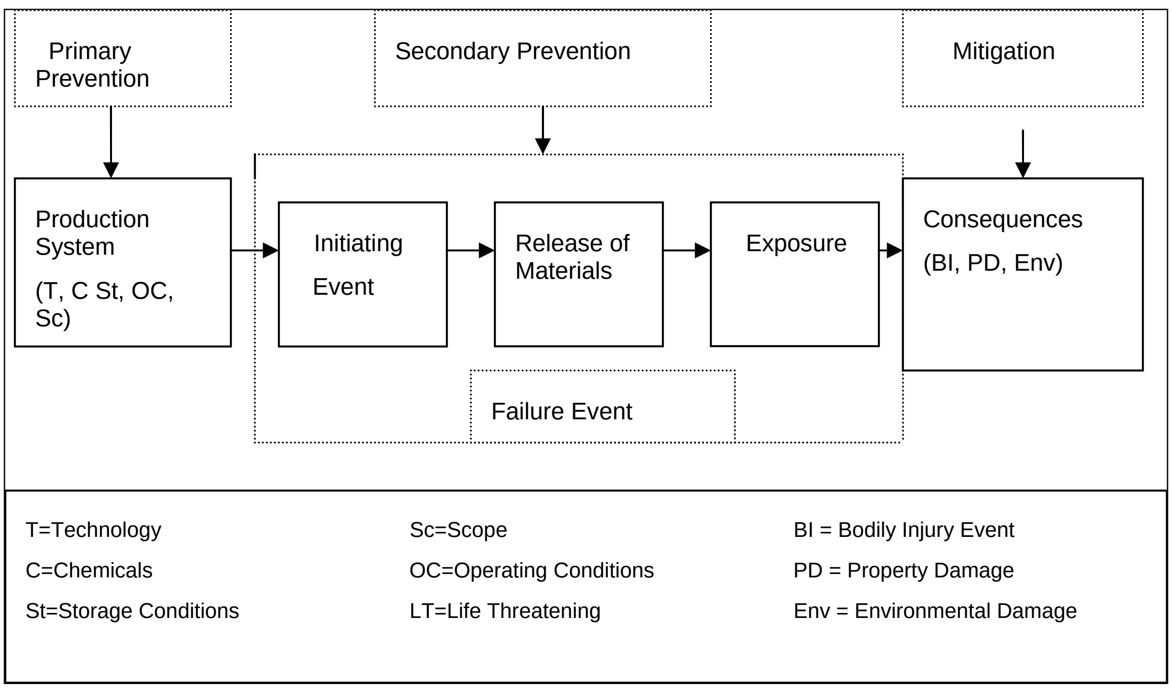

Figure 1. Combined Model of Acute Hazardous Release Event[7]

Conclusion

Since the severe events of Flixborough, Bhopal and others, notable achievements have been made in the area of inherent safety for the chemical processing industry. According to US Chemical

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[7] Minzner, A, *Chemical Accident Prevention,* MIT Masters Thesis, 1990

Safety Board Member Irv Rosenthal, "The EPA Risk Management Program's five-year accident data, which only cover a limited sphere of industries, show there are hundreds of casualties each year from fixed-facility chemical accidents."[8] This need is further emphasized by recent significant chemical release events including the Bethune Point Wastewater Treatment Plant explosion, the Valero McKee Refinery fire, and the Formosa Plastics explosion.[9] Each of these operations had secondary prevention and mitigation systems in place, yet the events still occurred.

We should be encouraged by the successes, both large and small, that have been achieved in the field of inherent safety. Drawing on these successes, both technological and economical, and our awareness of the risks that continue to exist, we should turn to methodologies and models like the one presented here to facilitate further efforts aimed at creating inherently safer technological systems.

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[8] http://www.mapcruzin.com/news/rtk_csb_withdraws_600k.htm, CSB Restructures Accident Data Program, Withdraws '600K' Study,

[9] US Chemical Safety and Hazard Investigation Board, CSB News, http://www.chemsafety.gov/, March 2007

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