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Practicing chemical process safety: a look at the layers of protection

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Abstract

This presentation will review a few public perceptions of safety in chemical plants and refineries, and will compare these plant workplace risks to some of the more traditional occupations. The central theme of this paper is to provide a "within-the-fence" view of many of the process safety practices that world class plants perform to pro-actively protect people, property, profits as well as the environment. It behooves each chemical plant and refinery to have their story on an image-rich presentation to stress stewardship and process safety. Such a program can assure the company's employees and help convince the community that many layers of safety protection within our plants are effective, and protect all from harm.

Keywords: Chemical plants; Chemical plant safety; Dangerous jobs; Fire protection; Process safety; Petrochemical losses

1. Introduction

World-class chemical plants typically focus on a mission with at least four distinct elements. The focus of these elements: provide continuous customer satisfaction; strive to provide a safe work environment; strive to fully protect the environment; and be a low-cost producer. Over the past decade, numerous organizations accepted the challenges to incorporate all the requirements of the US occupational safety and health (OSHA) process safety management (PSM) standard and practice chemical process safety in a performance-based manner. The PSM standard required a quantum leap in well-developed procedures and readily available documented information. While increased protection of the worker was the focus of the PSM standard, enhanced preservation of the environment was a bonus.

Those corporations who accepted the challenge, by using these performance-based standards, are being rewarded. Good access to key information is paramount in any well-run organization. Many locations developed or improved extensive electronic data bases to cope with PSM requirements.

Today, a chemical plant's decision process can be enhanced by all the readily available information required by the OSHA PSM standard. Updated P&ID's, comprehensive process hazard analysis (PHA) details, and the well-documented operating procedures can help with training and many decisions. The substantial efforts to provide a stronger mechanical integrity program should reduce the risks of major leaks and extend the interval between shutdowns. An effective and rigorous use of management of change system should help keep information current.

This paper will review public perceptions of safety in the chemical plant workplace. By using Bureau of Labor statistics (BLS), comparisons will be made between the degree of safety experienced while working in a chemical plant to the degree of safety in some better understood occupations such as fishers, timber cutters, truck drivers, construction laborers, and others trying to make a living. Next, in the heart of this presentation, we will review many of the layers of process safety protection that world-class chemical plants utilize to be proactive in protecting people, property and profit.

Concluding sentences will suggest that an operation supported by multiple layers of effective protection can also provide increased security for the employees, the public, and increased profits. However, recent statistics of five-years summaries of property losses, provided by Marsh's property risk, which suggest that we still need lots more practice to reach the goal of making safety second nature.

Finally, there will be a few words to persuade key members of the audience to develop a program similar to the "heart" of this presentation to help convince each company's employees and their citizen neighbors that chemical process

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safety is "second nature". Industrial facilities should have ready-to-use presentations supported with action images of their operations to help the community understand the levels of safety that are incorporated in the design, operation, and maintenance of our facilities.

2. Perceptions of dangerous jobs

You might be surprised to know who has the most dangerous jobs. They are not the workers, who first come to mind. The US Bureau of Labor statistics provides an interesting insight to the safety of workers. The census of fatal occupational injuries administered by the Bureau of Labor Statistics, in conjunction with participating state agencies, compiles comprehensive and timely information on fatal work injuries occurring in the United States.

Guy Toscano, an economist in the Office of Safety, Health and Working, Bureau of Labor Statistics provided an easy-to-understand, thought-provoking article entitled 'Dangerous Jobs' [1]. His article is based upon 1995 statistics. Statistics, since 1995, show yearly variations, but Mr. Toscano's work is the most comprehensive to date.

Quoting from Mr. Toscano, "There are a number of ways to identify hazardous occupations. And depending on the method used, different occupations are identified as most hazardous. One method counts the number of job-related fatalities in a given occupation or other group of workers. This generates a fatality frequency count for the employment group, which safety and health professionals often use to indicate the magnitude of the safety and health problem. For example, truck drivers have the largest number of fatalities and accounted for about 12 percent of all the job-related fatalities in 1995. But this number is influenced not only by the risk workers face in that occupation, but also by the total number of workers in the occupation [1]."

"The second method, fatality rates, takes into account the differing total numbers among occupations. It is calculated by dividing the number of job-related fatalities for a group of workers during a given period by the average number of workers during that period. This rate depicts a worker's risk of incurring a fatal work injury within the employment group and is expressed as the number of fatalities per a standard measure. For example, the fatality rate for truck drivers is 26.2 deaths per 100,000 workers. When occupations are ranked by fatality rates, truck drivers become the ninth most dangerous occupation."

But, the easiest method to understand is Mr. Toscano's relative risk method. He states, "Another method of expressing risk is an index of relative risk. This measure is calculated for a group of workers as the ratio of the rate for that group to the rate for all workers. The index of relative risk compares the fatality risk of a group of workers with all workers." For example, the relative risk for truck drivers in Table 1 is 5.9, which means that they are roughly five times as likely to have a fatal work injury as the average worker.

Table 1
Guy Toscano's relative risks for fatal occupational injuries for 1995 (using Bureau of Labor statistics data)

Occupation	Leading fatal event (percentage)	Index
All occupations		1.0
Farm occupations	Vehicular (50)	5.1
Truck drivers	Highway crashes (68)	5.3
Electric power installers	Electrocutions (60)	5.7
Roofers	Falls (75)	5.9
Construction laborers	Vehicular (28), falls (27)	8.1
Taxicab drivers	Homicide (70)	9.5
Structural metal workers	Falls (66)	13.1
Airplane pilots	Airplane crashes (98)	19.9
Timber cutters	Struck by object (81)	20.6
Fishers	Drowning (81)	21.3

It turns out that occupations such as: fishers, timber cutters, small plane pilots, structural metal workers, and taxicab drivers for 1995 have the highest relative risks (see Table 1).

There can be significant variance in the worse occupations from year to year. The occupations with the higher rate of deaths in 2001 reported in Table 2 includes categories with 30 or more fatalities.

3. Just how dangerous is it to work in a US chemical plant?

Mr. Guy Toscano also provided some 1995 relative risk fatality statistics to help compare several industries relative risk with the occupations described above in his 'Dangerous Jobs' article. His article was specific to 1995, and only involved fatalities. His method was used with the latest Bureau of Labor Statistics data (2001). From the data, it can be seen that the rate of deaths (2001) in a chemical plant are about the same as working within a grocery store [2] (see Table 3).

Table 2
Twelve occupations with high fatality rates for 2001 (using Bureau of Labor statistics data)

Occupation	Number of fatalities	Rate
All occupations	5900	4.3
Fishers	62	151.2
Timber cutters	92	127.8
Mining machine operators	34	109.7
Airline pilots	87	64.0
Structural metal workers	45	57.7
Garbage collectors	31	55.4
Roofers	78	36.3
Construction laborers	349	33.5
Farm occupations	499	27.9
Electrical power installers	36	26.1
Truck drivers	799	25.3
Protective services (fire fighters, police, guards, etc.)	50	11.6

Selected occupations had a minimum of 30 fatalities in 2001. Excludes fatalities resulting from the September 11 terrorist attacks.

Table 3
2001 Relative risks of fatal accidents in the work place of selected occupations (using a relative risk index)

Fishers (as an occupation)	35.1
Timber cutters (as an occupation)	29.7
Airplane pilots (as an occupation)	14.9
Garbage collectors	12.9
Roofers	8.4
Taxi drivers	8.2
Farm occupations	6.5
Protective services (fire fighters, police guards, etc.)	2.7
"Average job"	1.0
Grocery store employees	0.91
Chemical and allied products	0.81
Finance, insurance and real estate	0.23

Excludes fatalities resulting from the September 11 terrorist attacks.

The typical man on the street in southwestern Louisiana (a region which is rich in fishing, shrimping, timber, rice farming and petroleum refineries and chemical plants, as well as anti-industry news reporters and attorneys) would be puzzled with the facts. Over the years the media has drawn attention to the blemishes of the industry in a way that the average person believes that the chemical industry is very dangerous. This is reinforced partially by a very few isolated disastrous world-wide incidents and the associated painful suffering.

There are, no doubt, many poor unfortunate individuals who perish in lower Louisiana harvesting shrimp, blue crabs, pogy fish, and edible fish. Their demise is not a top story and the only story may be a police report in the back section of the newspaper. In the case of the timber cutter, who is struck with a tree and dies, no one takes photos of the tree or the chain saw that was involved in a tragic incident. However, if there is an incident at a chemical complex with injuries it can be a media event, lasting several evenings with a follow-up story. Often during TV coverage the company logo or plant-scape is in the background.

Now, let us look at the "layers of protection" that are incorporated into the typical world-class chemical facility to make it such a safe operation.

4. Chemical plants layers of protection

Well-designed chemical plants, petro-chemical plants, and refineries have many interrelated layers of protection. Many of the seasoned chemical plant employees and perhaps most of the citizens in the surrounding communities are not aware of the extent of the proactive protective hardware and rigid procedures that good chemical plants have had in place for years.

The layers of protection are sort of like the layers on an onion. Each layer is important, but one thickness can entirely hide another. Not all the layers are distinct and not all the layers totally cover the entire potential risk, but together the sum total of layers offers a thick blanket of protection. It is arbitrary how an individual may chose to separate these overlays of security, but this paper chose design, backup protective designs, operations, and maintenance.

5. Design considerations focusing on layers of protection

All of a plant's technical staff understand that the chemical design teams rely on seasoned engineers. It is one of the fundamental layers of protection. Seasoned engineers depend on generally recognized good engineering practices, numerous consensus codes, standards, and regulations. The list of supporting codes is long. The top ten most referenced sets of standards and publications include those developed by the American Institute of Chemical Engineers, the American Society of Mechanical Engineers, the American Petroleum Institute, the Instrument Society of America, the National Association of Corrosion Engineers, National Electric Code, the National Fire Protection Association, the US Department of Transportation, the US Environmental Protection Agency, and the US Occupational Safety and Health Administration standards. Corporate engineering procedures or standards, corporate fire protection guidelines, property insurance organizations, various trade associations (i.e. the Chlorine Institute, the National Petroleum Refining Association, the Vibration Institute, and similar specialty groups) and state and local regulations provide other process safety reference resources.

During initial design ... location, location, and location ... are important and can be another fundamental layer of protection. The importance of proper location cannot be over-stressed. Insurance guidelines and fire code regulations often address the spatial arrangements including distances between flammable storage tanks, the distances between process and storage areas and to fence lines or control rooms. During this time, the design team must decide if the inherent hazards and the distances from a potential flammable vapor cloud justify the use of a more costly explosion-resistant control room. Included in the equipment design aspects are other considerations to withstand: internal and external pressure, temperatures, chemical exposures, forces of nature including earthquakes, hurricanes and so on.

It is not good enough to just provide proper equipment design information. The company must ensure the equipment meets the specification by providing inspections of critical equipment during fabrication, when it arrives at the plant site and during equipment installation.

Good plant facilities can only be constructed with the use of hard-working, skilled craftsmen, supervised by dedicated, technically-sound contractors and oversight reviews involving the owner/operator field engineering crews. Another essential layer of protection is achieved after the equipment and piping are in place and all of the prestart-up testing and inspection are successfully completed.

The design must include state-of-the-art process indication and control. References such as: the Instrument Society of America's ISA-S84, *Application of Safety Instrumented Systems for the Process Industries* should be consulted for designing the proper system of sensors, logic solvers, and final control elements in safety-instrumented systems. This reference takes in concerns for safety integrity levels and safety life cycles. ISA-S84 is in the process of incorporating the International Electrotechnical Commission's IEC 61511, "Functional safety: safety instrumented systems for the process sector" standards.

6. Additional design safeguards for avoiding catastrophic troubles

World-class plants have provided secondary containment (or diking) for selected flammable storage tank areas for years. Now, such organizations are going much further in providing secondary containment for tanks that handle environmentally unfriendly material. Double-wall piping is sometimes considered for highly-hazardous fluids.

In today's world, the engineering design teams spend a great deal of extra effort on the detail design and control systems for safety systems that provide upset tolerant emergency scrubbing, incineration, and standby flare capacity. There is also more design emphasis on the early detection systems that alert personnel of leaks of flammable, toxic, or carcinogen materials. More and more well-designed facilities engineer and locate vapor or gas detectors near pump seals and other potential accidental leak sources as well as on the fence lines at the boundaries of our facilities.

In chemical plants, that manufacture and store large inventories of flammable liquids and flammable gases, the active protective system of choice most often involves fire water. The tried-and-true fire water systems include deluge systems, water curtains or hydroshields and long-range water cannons. Fire water deluge systems are often engineered to provide more than 0.25 gal/min/ft^2, which is an engineering term that can be visualized in intensity as ferocious thundershowers of over 24 in. of rain an hour. Such fire protection systems must be designed and maintained to meet fire insurance requirements including reliable diesel pumps and a large volume of dedicated water supply. Important structural steel columns, beams, tank supports, and distillation column skirts should be evaluated for possible supplemental fire protection provided via fireproof coatings.

Strategically located, properly instrumented and well-maintained remote-operated emergency isolation valves can limit the consequences of unexpected failures of piping and equipment.

Before a project's costs are estimated the project should be reviewed by a group of process safety specialists, who may wish to recommend a process hazards analysis using the team approach.

7. Operational considerations focusing on layers of protection

Most major chemical manufacturing facilities operate around the clock, 365 days a year. Very often the evening, night, and week-end crews are mainly chemical process operators making product with support from shift supervisors, shift safety, and security employees.

The total security of a chemical plant now must be measured using security vulnerability analysis criteria. The scope of these important studies, facility characterization, threat assessments, and countermeasures identification are beyond the scope of this paper.

In addition to the physical security of keeping the wrong kind of people out of the plant, plants must be successful in the complex process of attracting, properly training, empowering, and keeping the right people in the organization. The importance of hiring of motivated workers and community-minded professional technical people, who can work as a team, cannot be over stated. But it also requires leadership in management to provide challenges to make the plant safer, more environmentally friendly, and competitive. In today's world, security also includes the periodically federally-required random drug testing.

Another distinct layer of protection is the security of providing effective training of employees in classroom settings and on the job. Good training is supported by effective procedures that reflect the unit needs. The training is more than the operation and maintenance of the unit , which also includes compliance with health and personnel safety rules. Some leaders in the industry have integrated the control displays and operating-emergency procedures. I have observed control systems in which a pump or furnace can be selected with a mouse click on an operating display and all of the critical procedures of that pump or furnace are immediately displayed.

The use of committees is another chemical plant cultural approach that may be hard to explain unless you work in industry. The concept of multi-disciplined committees is an effective method to encourage various safety interests and compliance. I am familiar with an umbrella-coverage structure of a Plant Responsible Care Leadership Team with a number of smaller committees whose focus is on specific areas of safety. There are smaller committees focused on distinct areas, such as: the Emergency Response Planning Committee, the Joint Union/Management Safety Committee, the Process Safety Management Review Board, the Electrical Safety Committee, the Off-the-Job Safety Committee, the Behavior-Based Accident Prevention Committee and similar committees. Team audits can also be effective in highlighting certain specific areas of safety.

The operation of a plant includes the professional services from the control laboratory. Such laboratory work includes the testing of the raw materials, intermediates, and finished products, as well as, special tests that may be on discharge water and ambient air to comply with permits or for personnel monitoring.

Another layer of protection is provided when operations is fully prepared for an emergency. There must be an effective plan and trained individuals to help with this plan. The plan must have the vital communications to warn surrounding areas of potential problems. Those individuals, who store large quantities of flammables and toxics, should have access to rough guidelines or real-time dispersion models to predict the dispersion and consequences of an accidental release.

Naturally, the responders must be well trained on a continuous basis and properly equipped to handle conceivable accidents. Often, the responders are sent to fire fighting schools to train on "live" fires. The emergency response planning coordinators must be periodically trained also, and refreshed in their training for an event they hope never occurs.

A good emergency plan requires excellent communication from the detection of the release to the projection and migration of the release. Good communications includes timely notification to local agencies to the news media.

8. Maintenance considerations focusing on layers of protection

Periodic and breakdown maintenance procedures and practices are another very important part of the process safety management package. Periodic inspections and tests are an essential layer of protection.

Rigorous programs are in effect to ensure that safety relief valves are tested with a frequency that provides reliable over-pressure protection. Other specialists routinely (often on a monthly basis) inspect rotating equipment to detect signs of wear or deterioration.

Some of the more universal standard equipment inspections are external vessel and piping inspections supported by thickness measurements taken at places where metal loss is anticipated. During periodic scheduled outages the pressure vessels and storage tanks are opened and inspected internally. No amount of external inspection can be as good as an internal inspection when pitting or localized corrosion is a possibility.

Cross-country underground pipelines are patrolled for signs of changes above ground and checked for proper cathodic protection systems. The cathodic protection inspections are not enough. Many companies rely on pipeline right-of-way pilot/inspectors, who survey the area from above in small planes to detect signs of mechanical threats from nearby construction activities or to spot leaks that may have developed from internal or external corrosion.

Infrared thermography is a non-invasive predictive/preventive maintenance inspection tool that is now beginning to be used extensively throughout industry. It is a proven technology and it is being regularly used on detecting hot spots on electrical distribution systems. By utilizing thermal imaging systems, it is possible to detect and display thermal temperature differences from infrared radiation (heat) emitted by an object. Creative individuals are finding other opportunities to use thermography, such as checking furnace tubes for signs of coking. Infrared technology and inspections of this type provide early warning and documentation of impending failures.

Maintenance program managers now understand the need for certified welders, welding procedures accepted by codes, and certified metal inspectors. Such managers are insisting on properly inspecting and periodically proof-testing instruments that detect leaks, out-of-range values, impending hazards, and provide emergency shutdown functions. These instruments must respond when required to warn and to safeguard the process.

9. Summary of employees providing layers of protection

World-class plants have placed the OSHA process safety management activities into the hands of the right people with the right motivation and the correct training. These include the intelligent, energetic supervisors, the enthusiastic, motivated chemical process operators, the hardworking, competent craftsmen, the well-trained specialists, and the other team players behind the scenes including the clerical and administrative employees.

10. Are we practicing enough?

Many professionals, who see a paper or presentation like this one, might say, we are doing most of those things. Isn't that good enough?

Despite all of the excellent efforts in the field of process safety, there are some serious questions challenging if we are doing enough. It is disappointing to note that property damage losses in US refineries and US chemical plants have not, dramatically, decreased in the past decade. Marsh's Risk consulting recently published '*The 100 Largest Losses 1972–2001*', documenting significant increases in losses in their last five-years interval. This publication is based upon 5,400 records, so there is depth to this study [3].

In the 20th edition of '*The 100 Largest Losses 1972–2001*' published in February 2003, the first page states, "Losses in the refinery industry have continued to increase over the last few years and the causes highlight the aging facilities is in this category. A significant number of larger losses (over $10,000,000) have been caused by piping failures or piping leaks. Several large losses due to piping failures were due to corrosion issues or using the wrong metallurgy" [3] (see Fig. 1).

The Marsh Risk pamphlet continues on page 23 with this comment on petrochemical plants, "As with losses in the refinery category, the number of losses in the petrochemical industry have also continued to increase over the last few

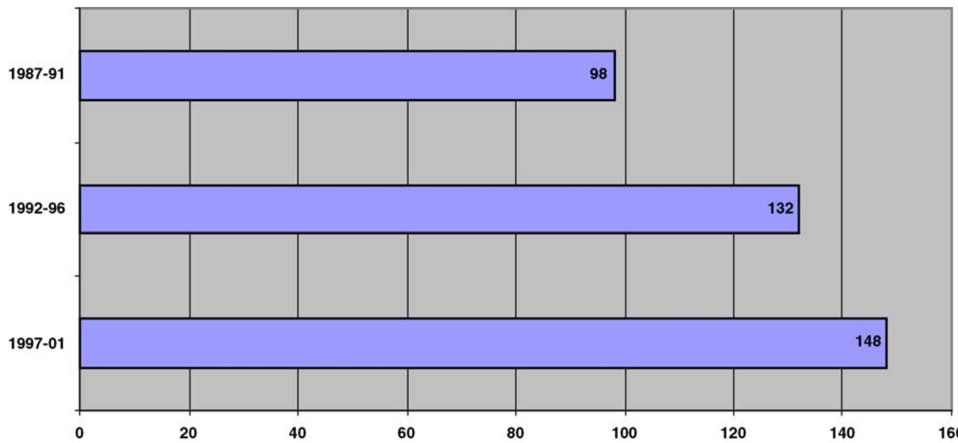

Fig. 1. Refinery losses in 5-year intervals in US.

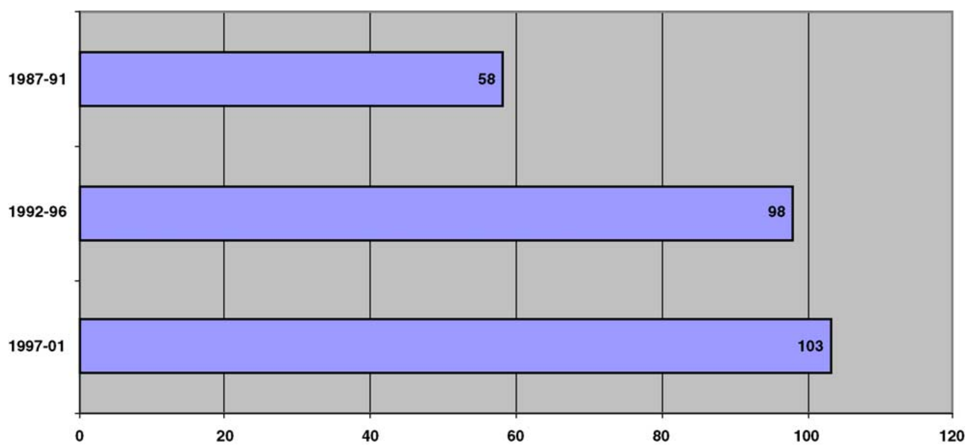

Fig. 2. Petrochemical losses in 5-year intervals in US.

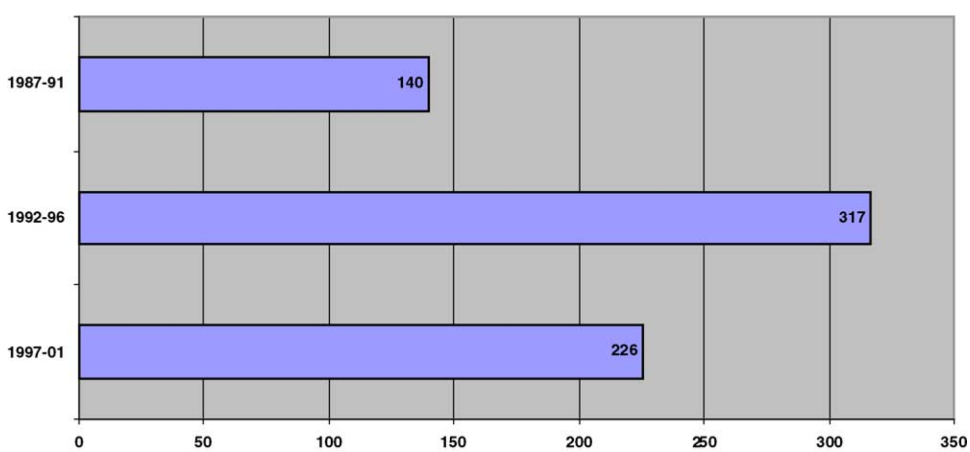

Fig. 3. Petrochemical losses in 5-year intervals outside US.

years, with the exception of facilities located outside the US. Outside the US, the number of losses in recent years has actually declined. Losses in recent years have been attributed to piping failures and management system failures."

A closer look at Figs. 2 and 3 shows signs that process safety principles are arresting the rate of increase in the US and providing a sharp decline in high-dollar value losses outside the US [3].

Recent loss history (from the graphs above) suggests that our work is far from done. In short, this says, we must continue to provide resources and increase our energies on effectively practicing chemical process safety.

11. Sharing a view of what we do

The public is often skeptical of what happens within the fence-line of a chemical plant. They just have no way of knowing about all of the layers of protection in design, operation, and maintenance. I believe each facility should develop an outreach program to discuss the degree of protection and the specific safeguards including supporting images (photos or videos) as I have just shown. This type of presentation takes considerable time to develop, but it will be of a high value. Such a program describing the "layers" should be used proactively to help convince each company's employees and their citizen neighbors that chemical process safety is "second nature" in their facility.

12. Suggested reading

This paper provides a practical look at "layers of protection" within many chemical plants and refineries. There is a new semi-quantitative tool for analyzing and assessing risk called layers of protection analysis. Please consider reading *Layer of protection analysis: simplified process risk assessment* (2001), by the Center of Chemical Process Safety of the American Institute of Chemical Engineers.

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