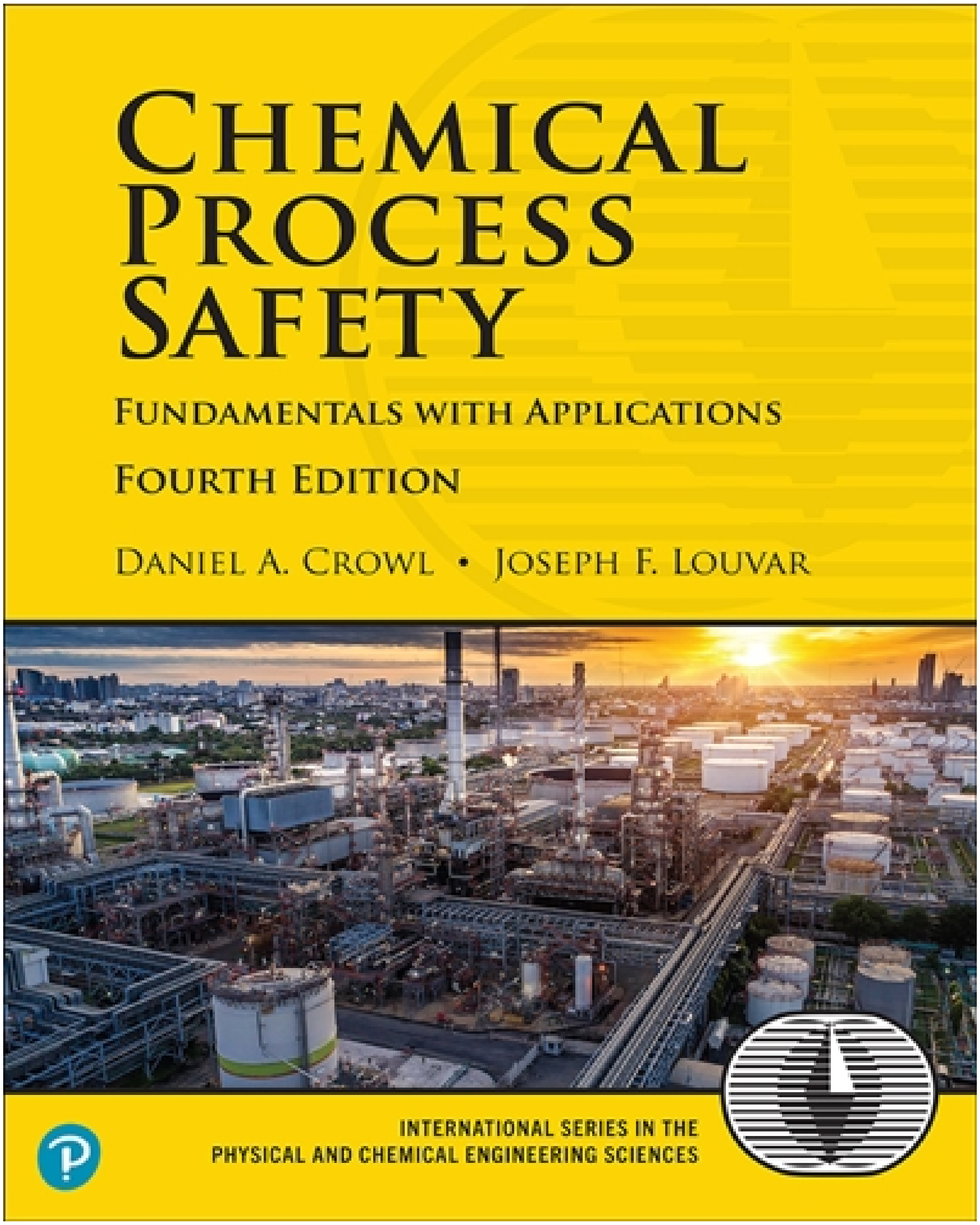
Solutions for Chemical Process Safety 4th Edition by Crowl



Solutions

Chapter 1 Legacy Homework Problems – From 3rd edition of Crowl and Louvar

1-1. An employee works in a plant with a FAR of 4. If this employee works a 4-hr shift, 200 days per year, what is the expected deaths per person per year?

$$\text{FAR} = \frac{\text{Number of fatalities} \times 10^{8}}{\text{Total hours worked by all employees during period covered}}$$

1-2. Three process units are in a plant. The units have FARs of 0.5, 0.3, and 1.0, respectively.

a. What is the overall FAR for the plant, assuming worker exposure to all three units simultaneously?
b. Assume now that the units are far enough apart that an accident in one would not affect the workers in another. If a worker spends 20% of his time in process area 1, 40% in process area 2, and 40% in process area 3, what is his overall FAR?

1-3. Assuming that a car travels at an average speed of 50 miles per hour, how many miles must be driven before a fatality is expected? The FAR for traveling by car is 57.

1-4. A worker is told her chances of being killed by a particular process are 1 in every 500 years. Should the worker be satisfied or alarmed? What is the FAR (assuming normal working hours) and the deaths per person per year? What should her chances be, assuming an average chemical plant? The FAR for a chemical plant is 4.

1-5. A plant employs 1,500 full-time workers in a process with a FAR of 5. How many industrial-related deaths are expected each year?

1-6. How many hours must be traveled by car for each hour of rock climbing to make the risk of fatality by car equal to the risk of fatality by rock climbing? The FAR for rock climbing is 4,000 and the FAR for travelling by car is 57.

1-7. Identify the initiation, propagation, and termination steps for the following accident reports. Suggest ways to prevent and contain the accidents.

a. A contractor accidentally cut into a 10-in propane line operating at 800 psi at a natural gas liquids terminal. The large vapor cloud estimated to cover an area of 44 acres was ignited about 4–5 min later by an unknown source. Liquid products from 5 of 26 salt dome caverns fed the fire with an estimated 18,000–30,000 gal of LPGs for almost 6 hr before being blocked in and the fires extinguished. Both engine-driven fire pumps failed, one because intense radiated heat damaged its ignition wires and the other because the explosion broke a sight glass fuel gauge, spilling diesel fuel, which ignited, destroying the fire pump engine.
b. An alkylation unit was being started up after shutdown because of an electrical outage. When adequate circulation could not be maintained in a deisobutanizer heater circuit, it was decided to clean the strainer. Workers had depressurized the pipe and removed all but three of the flange bolts when a pressure release blew a black material from the flange, followed by butane vapors. These vapors were carried to a furnace 100 ft away, where they ignited, flashing back to the flange. The ensuing fire

exposed a fractionation tower and horizontal receiver drums. These drums exploded, rupturing pipelines, which added more fuel. The explosions and heat caused loss of insulation from the 8-ft × 122-ft fractionator tower, causing it to weaken and fall across two major pipe-lines, breaking piping — which added more fuel to the fire. Extinguishment, achieved basically by isolating the fuel sources, took 21⁄2 hours.

The fault was traced to a 10-in valve that had been prevented from closing the last 3⁄4-inch by a fine powder of carbon and iron oxide. When the flange was opened, this powder blew out, allowing liquid butane to be released.

1-8. The airline industry claims commercial airline transport has fewer deaths per mile than any other means of transportation. Do the accident statistics support this claim? In 1984 the airline industry posted 4 deaths per 10,000,000 passenger miles. What additional information is required to compute a FAR? a fatality rate?

1-9. A university has 1,200 full-time employees. In a particular year this university had 38 reportable lost-time injuries with a resulting 274 lost workdays. Compute the OSHA incidence rate based on injuries and lost workdays.

$$\text{OSHA incidence rate (based on lost workdays)} = \frac{\text{Number of lost workdays} \times 200{,}000}{\text{Total hours worked by all employees during period covered.}}$$

1-10. Based on workplace fatalities (Figure 1-4, Crowl and Louvar, 3rd edition) and assuming you are responsible for a safety program of an organization, what would you emphasize?

1-11. Based on the causes of the largest losses (Figure 1-7, Crowl and Louvar, 3rd edition), what would you emphasize in a safety program?

1-12. After reviewing the answers to Problems 1-10 and 1-11, can inherent safety help?

1-13. What conclusions can you derive from Figure 1-9, Crowl and Louvar, 3rd edition?

1-14. What is the worst thing that could happen to you as a chemical engineer in industry?

1-15. An explosion has occurred in your plant and an employee has been killed. An investigation shows that the accident was the fault of the dead employee, who manually charged the wrong ingredient to a reactor vessel. What is the appropriate response from the following groups?

a. The other employees who work in the process area affected.
b. The other employees elsewhere in the plant site.
c. Middle management.
d. Upper management.
e. The president of the company.
f. The union.

1-16. You have just begun work at a chemical plant. After several weeks on the job you determine that the plant manager runs the plant with an iron fist. He is a few years away from retirement after working his way up from the very bottom. Also, a number of unsafe practices are performed at the plant, including some that could lead to catastrophic results. You bring up these problems to your immediate supervisor, but he decides to do nothing for fear that the plant manager will be upset. After all, he says, "We've operated this plant for 40 years without an accident." What would you do in this situation?

1-17. Answer the questions below and then comment on the similarities of parts a and b below.

a. You walk into a store and after a short while you decide to leave, preferring not to do any business there. What did you observe to make you leave? What conclusions might you reach about the attitudes of the people who manage and operate this store?
b. You walk into a chemical plant and after a short while you decide to leave, fearing that the plant might explode at any moment. What did you observe to make you leave? What conclusions might you reach about the attitudes of the people who manage and operate this chemical plant?

1-18. A large storage tank is filled manually by an operator. The operator first opens a valve on a supply line and carefully watches the level on a level indicator until the tank is filled (a long time later). Once the filling is complete, the operator closes the valve to stop the filling. Once a year the operator is distracted and the tank is overfilled. To prevent this, an alarm was installed on the level gauge to alert the operator to a high-level condition. With the installation of the alarm, the tank now overfills twice per year. Can you explain?

1-19. Careful numbering of process equipment is important to avoid confusion. On one unit the equipment was numbered J1001 upward. When the original allocation of numbers ran out the new equipment was numbered JA1001 upward. An operator was verbally told to prepare pump JA1001 for repairs. Unfortunately, he prepared pump J1001 instead, causing an upset in the plant. What happened?

1-20. A cover plate on a pump housing is held in place by eight bolts. A pipefitter is instructed to repair the pump. The fitter removes all eight bolts only to find the cover plate stuck on the housing. A screwdriver is used to pry off the cover. The cover flies off suddenly, and toxic liquid sprays throughout the work area. Clearly the pump unit should have been isolated, drained, and cleaned before repair. There is, however, a better procedure for removing the cover plate. What is this procedure?

1-21. The liquid level in a tank 10 m in height is determined by measuring the pressure at the bottom of the tank. The level gauge was calibrated to work with a liquid having a specific gravity of 0.9. If the usual liquid is replaced with a new liquid with a specific gravity of 0.8, will the tank be overfilled or underfilled? If the actual liquid level is 8 m, what is the reading on the level gauge? Is it possible that the tank will overflow without the level gauge indicating the situation?

1-22. One of the categories of inherent safety is simplification/error tolerance. What instrumentation could you add to the tank described in Problem 1-21 to eliminate problems?

1-23. Pumps can be shut-in by closing the valves on the inlet and outlet sides of the pump. This can lead to pump damage and/or a rapid increase in the temperature of the liquid shut inside the pump. A particular pump contains 4 kg of water. If the pump is rated at 1 HP, what is the maximum temperature increase expected in the water in °C/hr? Assume a constant water heat capacity of 1 kcal/kg/°C. What will happen if the pump continues to operate?

1-24. Water will flash into vapor almost explosively if heated under certain conditions.

a. What is the ratio in volume between water vapor at 300 K and liquid water at 300 K at saturated conditions?
b. Hot oil is accidentally pumped into a storage vessel. Unfortunately, the tank contains residual water, which flashes into vapor and ruptures the tank. If the tank is 10 m in diameter and 5 m high, how many kilograms of water at 300 K are required to produce enough water vapor to pressurize the tank to 8 in of water gauge pressure, the burst pressure of the tank?

1-25. Another way of measuring accident performance is by the LTIR, or lost-time injury rate. This is identical to the OSHA incidence rate based on incidents in which the employee is unable to continue their normal duties. A plant site has 1,200 full-time employees working 40 hr/week and 50 weeks/yr. If the plant had 2 lost-time incidents last year, what is the LTIR?

1-26. A car leaves New York City and travels the 2800-mi distance to Los Angeles at an average speed of 50 mph. An alternative travel plan is to fly on a commercial airline for 4½ hr. What are the FARs for the two methods of transportation? Which travel method is saf-er, based on the FAR? See Table 1-4 in Crowl and Louvar, 3rd edition.

1-27. A column was used to strip low-volatile materials from a high-temperature heat transfer fluid. During a maintenance procedure, water was trapped between two valves. During normal operation, one valve was opened and the hot oil came in contact with the coldwater. The result was almost sudden vaporization of the water, followed by considerable damage to the column. Consider liquid water at 25°C and 1 atm. How many times does the volume increase if the water is vaporized at 100°C and 1 atm?

1-28. Large storage tanks are designed to withstand low pressures and vacuums. Typically they are constructed to withstand no more than 8 in of water gauge pressure and 2.5 in of water gauge vacuum. A particular tank is 30 ft in diameter.

a. If a 200-lb person stands in the middle of the tank roof, what is the resulting pressure (in inches of water gauge) if the person's weight is distributed across the entire roof?
b. If the roof was flooded with 8 in of water (equivalent to the maximum pressure), what is the total weight (in pounds) of the water?

c. A large storage tank was sucked in when the vent to the outside became plugged and the operator turned on the pump to empty the tank. How did this happen?

Note: A person can easily blow to a pressure of greater than 20 in of water gauge.

1-29. A 50-gal drum with bulged ends is found in the storage yard of your plant. You are unable to identify the contents of the drum. Develop a procedure to handle this hazard. There are many ways to solve this problem. Please describe just one approach.

1-30. The plant has been down for extensive maintenance and repair. You are in charge of bringing the plant up and on-line. There is considerable pressure from the sales department to deliver product. At about 4 AM a problem develops. A slip plate or blind has accidentally been left in one of the process lines. An experienced maintenance person suggests that she can remove the slip plate without depressurizing the line. She said that she routinely performed this operation years ago. Since you are in charge, what would you do?

1-31. Gasoline tank trucks are load restricted in that the tank must never be between 20% and 80% full when traveling. Or it must be below 20% and above 80%. Why?

1-32. In 1891 the copper industry in Michigan employed 7,702 workers. In that year there were 28 fatalities in the mines. Estimate the FAR for this year, assuming that the workers worked 40-hour weeks and 50 weeks per year. Compare the result to the published FAR for the chemical industry.

1-33. The Weather Channel reports that, on average, about 42 Americans are killed by lightning each year. The current population of the U.S. is about 300 million people. Which accident index is suitable for this information: FAR, OSHA incident rate, or deaths per person per year? Why? Calculate the value of the selected index and compare it to published values.

1-34. The CSB video "Preventing Harm from Sodium Hydrosulfide" presents an incident involving sodium hydrosulfide (NaSH) and hydrogen sulfide (H2S). Go on-line and find at least two material safety data sheets (MSDS) for both of these chemicals. Tabulate the following physical properties for these chemicals at room temperature and pressure, if available: physical state density, PEL, TLV, and vapor pressure. List any other concerns that might be apparent from the MSDS. Which of these properties are of major concern in using these chemicals?

Chapter 1

1-1. Essays will vary. Of course, process safety is an important part of an engineering ethics statement.

1-2.

a. This is a bit difficult to classify since it doesn't fit explicitly into the hierarchy. However, it does appear that safety is a core value for this company so it is likely a 5.
b. This is clearly reactive to accidents. It is at level 1.
c. This is a level 3 since it contains the JSA management system.
d. This is likely a level 0 since the faculty member does not participate in the safety program.
e. This is also likely a level 0. Even though the faculty member has made a verbal commitment to the safety program, the faculty member does not do anything.
f. This is at level 4 since the metrics are performance monitoring.
g. This is at level 2 since it is just complying to rules and regulations.
h. This is probably at level 0 since this is disdain for safety.
i. A messy lab or even plant area is a sure indicator of safety problems. If they are unable to keep the lab clean, how can they manage a safety program? This is likely an indication of a 0 on the hierarchy.

1-3.

a. This sends a strong message to the participants at the meeting that safety is NOT the most important thing. This greatly weakens safety culture.
b. If this policy is enacted, it is very likely that eventually no one will wear safety glasses in the lab. Why? Initially, the workers will wear the safety glasses, but over time a number of marginal situations will occur where they really should have worn them and no one alerted them to wear them. As time goes by this marginal boundary will move until eventually no one is wearing safety glasses. This will weaken safety culture over time. This is called normalization of deviations and occurs when people slowly move the acceptable boundary over time without consequence. Eventually the boundary moves far enough that a major incident occurs with major consequences.
c. A safety program and cleanliness go hand in hand. If the workers are not able to keep the laboratory clean, how can they manage a safety program? The faculty member is effectively stating that "No work is ever done in a safe lab!" This weakens the safety culture.
d. Responsibility for safety must be shared at all levels of administration, including the students, faculty member in charge and the university administration. This weakens the safety culture.
e. This strengthens the safety culture, since the plant manager is participating actively in the safety program.
f. Delay in reviewing and implementing safety suggestions sends the hidden message that "your opinions are not valued – we have other important things to do!" Eventually there will be no safety suggestions. This weakens the safety culture.
g. Safety equipment must be provided free of charge to the workers – this is actually an OSHA requirement! This also sends the message to the workers that safety is not important since the lab is not willing to pay the small price for the safety glasses. This weakens the safety culture.

h. The workers must have easy access to the safety equipment – if you make it difficult then the workers will not be inclined to use the safety equipment. This weakens the safety culture.
i. This weakens the safety culture - it sends the message that safety is not important since the lab safety manual is not important.
j. This strengthens the safety culture. The students are the ones that are directly exposed to the hazards in the lab – not the faculty member. So the students should have primary responsibility. The faculty member must insure that the safety program will work by providing the training, resources and management tools to make it work. The faculty member must also continuously audit the students to insure that it is working.

1-4.

a. The worker is the primary person at risk. This is individual risk and voluntary.
b. The primary risk population are the plant workers and the community adjacent to the storage facility. If the workers or the people immediately adjacent to the plant were aware of the plant hazards then the risk would be voluntary. Otherwise it is involuntary. It is likely that the plant workers are more voluntary and the community more involuntary. In both cases this is societal risk.
c. The primary risk population is the driver. For the driver this is individual risk and voluntary. The other drivers on the road are also a primary risk population. This is societal risk and involuntary.
d. In this case the driver is increasing his / her risk since they are not wearing their seat belt – the probability of an accident has not been changed for the driver or the other drivers on the road. The risk to the other drivers has not been changed. The increased risk by the driver is voluntary.
e. The primary risk population is the driver. For the driver this is individual risk and voluntary. The other drivers on the road are also a primary risk population. This is societal risk and involuntary.
f. The primary risk populations are the plane passengers and people injured or killed on the ground. This risk is societal and involuntary.
g. The primary risk populations are the driver, other drivers on the road, potentially people living near the highway, the workers / people at the gas station, and the workers at the refinery. The driver, refinery workers and gas station workers are voluntary risk. The other drivers on the road and the people living near the highway are societal risk and involuntary.
h. The people living near the pipeline are the primary risk community. This is societal and involuntary.
i. The person climbing is the primary risk community. The risk is individual and voluntary.

1-5.

The key to this problem is determining whether an accident has occurred or not. If an accident has occurred it is a lagging indicator. If an accident has not occurred it is leading.

a. This is leading since an accident has not occurred.
b. This is leading since an accident has not occurred.
c. This is lagging, since an insurance claim implies that an accident has already occurred.
d. This is lagging, since visits to a first aid facility implies that an accident has occurred.
e. This is leading since an accident has not occurred.
f. This is leading since an accident has not occurred.

1-6.

a. From Equation 1-2:

$$\text{Worker based fatal injury rate} = \frac{\text{Total number of fatalites during period}}{\text{Total number of employees}} \times 100{,}000 \text{ workers}$$

$$= \frac{1}{1{,}000 \text{ workers}} \times 100{,}000 \text{ workers}$$

$$= 100$$

b. From Equation 1-4:

$$\text{Hours based fatal injury rate} = \frac{\text{Total number of fatalites during period}}{\text{Total hours worked by all employees}} \times 200{,}000{,}000 \text{ hours}$$

$$= \frac{1 \text{ fatality}}{(1 \text{ yr})(1{,}000 \text{ employees})(50 \text{ weeks/yr})(40 \text{ hours/wk})} \times 200{,}000{,}000 \text{ hour}$$

$$= \frac{200{,}000{,}000 \text{ hours}}{(1 \text{ yr})(2{,}000{,}000 \text{ hours})}$$

$$= 100$$

c. From Equation 1-5 :

$$\text{Recordable incidence rate} = \frac{\text{Number of incidents during period}}{\text{Total hours worked by all employees}} \times 200{,}000 \text{ hours}$$

$$= \frac{1 \text{ recordable incident}}{(1 \text{ yr})(2{,}000{,}000 \text{ hours})} \times 200{,}000 \text{ hours}$$

$$= 0.1$$

d. The part b answer compares to a chemical manufacturing value of 2.0 and the answer for part c compares to a chemical manufacturing value of 2.1. The hours based fatal injury rate is very high and the recordable injury rate very low compared to chemical industry statistics.

e. Return to the equation used for part b. Substitute in the value or 2.0 for the hours based fatal injury rate and calculate the number of years.

$$2.0 = \frac{1 \text{ fatality}}{(1 \text{ yr})(1{,}000 \text{ employees})(50 \text{ weeks/yr})(40 \text{ hours/wk})} \times 200{,}000{,}000 \text{ hours}$$

$$2.0 = \frac{200{,}000{,}000 \text{ hours}}{(x \text{ yrs})(2{,}000{,}000 \text{ hours})}$$

$$x = 50 \text{ years}$$

f. Return to the equation used for part c. Substitute in the value or 2.1 for the total recordable incidence rate and calculate the number of years.

$$2.1 = \frac{1 \text{ recordable incident}}{(x \text{ yrs})(2,000,000 \text{ hours})} \times 200,000 \text{ hours}$$

$$x = 0.048 \text{ years}$$

This is about 17.5 days.

1-7. The deaths per 100,000 people is given by the following equation provided in class:

$$\text{Deaths per 100,000 people} = \frac{\text{Total number of deaths}}{\text{Total people in exposed population}} \times 100,000 \text{ people}$$

Substituting the numbers,

$$\text{Deaths per 100,000 people} = \frac{25 \text{ deaths}}{325,000,000 \text{ people}} \times 100,000 \text{ people}$$

$$= 0.0077$$

1-8. For the suggested consequence / severity level:

For human health impact, there were multiple fatalities, so this is "catastrophic."
For fire explosion direct cost, there was no explosion or fire, so this is not considered.
For chemical impact, the threshold quantity for MIC from Table 1-15 is 5 kg = 11 lb_m.
We do not know the exact amount of MIC released, but it is certainly greater than 20 times the TQ. Thus, this is "catastrophic."

From Table 1-14, the severity level is "catastrophic" and the safety severity level is 4..

For the likelihood, this is a bit more difficult. Considering that the safeguards were not functioning, the likelihood is somewhere between "likely" and "unlikely."

This results in a risk level of "A." This risk is "unacceptable" and additional safeguards must be implemented immediately. In this case, the existing safeguards should all be brought on-line immediately.

1-9. a. Anhydrous ammonia: 10,000 lb_m
b. Chlorine: 1,500 lb_m
c. Hydrogen fluoride: 1,000 lb_m
d. Propylene oxide: not listed under this regulation – the regulation does not apply.

1-10. The key is to decide if the incident or consequences have already occurred. If it has, the safeguard is mitigative.

a. Mitigative – the incident has already occurred and the consequence is the loss of production.
b. Mitigative since the hydrocarbon has leaked.
c. Mitigative since the dike contains the spill.

d. Preventive – this prevents the reaction from running away.
e. Mitigative – the leak has already occurred.
f. Mitigative since the liquid has already escaped.
g. Mitigative – the consequence is that the reactor has lost contents.
h. Mitigative – the relief has already opened and discharged material.
i. Preventive – it controls the process within normal operating limits.
j. Mitigative – an incident has already occurred since it is an emergency.
k. Preventive – no consequence or incident has occurred yet.
l. Preventive – this provides more information to the operator to operate the process safely.
m. Mitigative – since the training is designed to mitigate incidents.

1-11. Will accept any one of the following answers:

a. Stakeholder outreach
b. Emergency management
c. Training and performance assurance, process knowledge management, process safety culture, process safety competency.
d. Process safety culture
e. Contractor management
f. Workforce involvement, process safety culture.
g. Incident investigation.
h. Safe work practices
i. Asset integrity and reliability
j. Auditing
k. Operating procedures
l. Management of change
m. Compliance with standards
n. Hazard identification and risk analysis.
o. Process knowledge management
p. Operational readiness
q. Process safety competency
r. Measurement and metrics
s. Management review and continuous improvement
t. Conduct of operations

1-12.

a. Substitute
b. Simplify
c. Moderate
d. Minimize
e. Substitute
f. Moderate or simplify