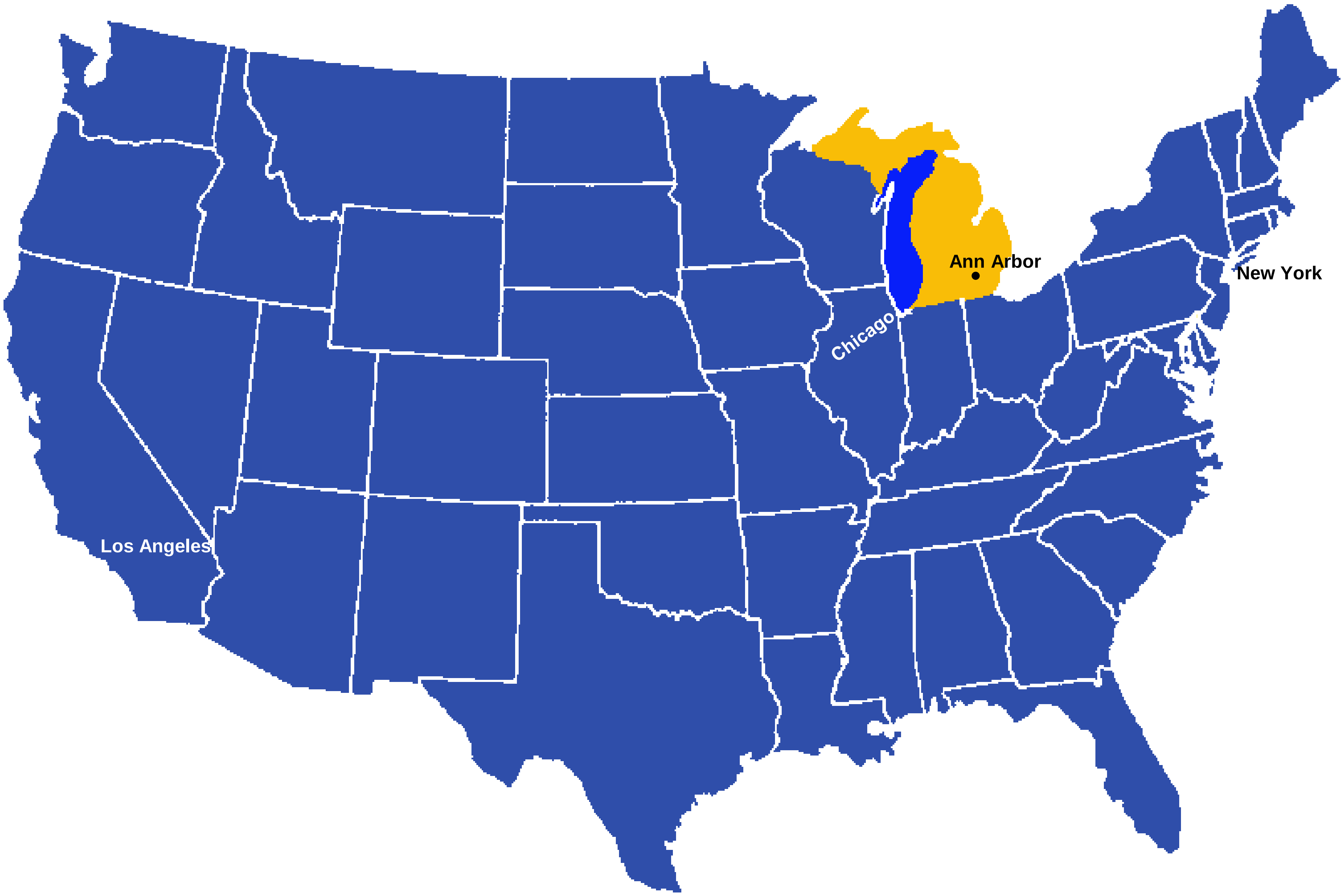


9/16/19

An Initiative on Safety Across the Chemical Engineering Curriculum

The 12th European Congress of Chemical Engineering
September 15 - 19

H. Scott Fogler
University of Michigan
Department of Chemical Engineering
Ann Arbor, Michigan

MichiganEngineering

About

What is Chemical Process Safety?

A critical aspect of process safety is “anticipating” what could go wrong in a chemical process and ensuring it won’t go wrong.

Chemical Process Safety is a blend of engineering and management practices focused on ***preventing accidents****, particularly explosions, fires, and toxic releases which result in loss of life and property.*

Dr. Trevor Kletz is considered by most as the *Father of Chemical Process Safety*.

About

What is Chemical Process Safety and Why Do We Study It ?

What surprises most students is that virtually **all previous chemical engineering accidents were preventable**.

- Most disasters are the result of **poor engineering decisions**, **made by a handful of people who lacked fundamental understanding** of of the consequences of their actions and a basic chemical engineering concepts and chemical engineering safety.

Image of Bhopal disaster by Simone Kaiser and Der Spiegel

- One of the best ways to prevent future industrial disasters is to **understand how to effectively and safely design, operate, and troubleshoot chemical processes**.

Process Safety Undergraduate Education

Sometimes chemical process safety is taught in a **separate safety course** within the chemical engineering curriculum, and sometimes it is taught only in the senior year as a part of the process design course.

Chemical Engineering Curriculum

	Fall	Winter
1st Year		
	Engineering 100	--
2nd Year		
	230 Introduction to Materials and Energy Balance	330 Chemical and Engineering Thermodynamics
		341 Fluid Mechanics
3rd Year		
	342 Mass and Heat Transfer	344 Chemical Reaction Engineering and Design
	343 Separation Processes	360 Chemical Engineering Laboratory I
4th Year		
	460 Chemical Engineering Laboratory II	487 Process Simulation and Design
	466 Process Dynamics and Control	488 Chemical Product Design I
		4XX Elective

U or MICHIGAN **ChE 407 Course Outline**

Elements of an Effective Process Safety Program

Sept 3 Overview of ChE 407

Introduction to Process Safety - *Ken First*

Homework – OSHA Academy 736 Introduction to Process Safety Management (9 modules, 2.5 hours)

Sept 10 Regulatory Requirements (OHSA-PSM, EPA-RMP) – *Jeff Fox (Dow Corning retired)*

Overview of Process Risk Management - *Ken First*

Homework – SAChE ELA 951 Hazard Recognition (3 Units, 2 hours)

Identification of Chemical and Process Hazards

Sept 17 Identifying Process Hazards – *Ken First*

Identifying Flammability and Toxicity Hazards – *Ken First*

Homework – SAChE ELA 970 Units 1 and 2 - What Can Go Wrong? (2 Units, 1.5 hours)

Sept 24 Identifying Reaction Hazards – *Ken First*

Reactive Chemicals Testing – *Steve Horsch (Dow)*

Homework – SAChE ELA 970 Units 3 and 4 - What Can Go Wrong? (2 Units, 2.5 hours)

Hazard Evaluation and Scenario Development

Oct 1 Process Hazard Evaluation (types of studies and when used) – *Ken First*

Hazard and Operability Studies – *Paul Keptner (Dow)*

Homework – SAChE ELA 984 Inherently Safer Design (3 Units, 3 hours)

Oct 8 Inherently Safer Design – *Ken First*

Overview of Consequence Analysis – Ken First

Homework – CCPS Chemical Hazard Engineering Fundamentals pgs 76-111 with Examples

Oct 15 FALL STUDY BREAK – NO CLASS

Consequence and Risk Analysis

Oct 22 Source Models (estimation of leak rate, evaporation rate, etc.) – *Ken First*

Vapor Dispersions (evaluation of concentration versus distance) – *Ken First*

Homework – CCPS Chemical Hazard Engineering Fundamentals pgs 112-133 with Examples

Oct 29 Explosion Modeling (evaluation of damage from fires and explosions) – *Ken First*

Consequence and Frequency Analysis – *Ken First*

Homework – SAChE ELA 980 Risk Review Using LOPA (3 Units, 2.5 hours)

Nov 5 Overview of Risk Analysis – *Ken First*

Layers of Protection Analysis (identifying barriers and safeguards) – *Ken First*

Homework – Example Problems

Effective Safeguards, Barriers and Protective Layers

Nov 12 Procedures and Human Reliability – *Ken First*

Fire Pressure Relief Systems – *Jeremy Morris (Dow)*

Homework – Term Project

Nov 19 Pressure Relief Systems – *Ken First*

Safety Instrumented Systems – *John Palmer (Shell retired)*

Homework – Term Project

Process Risk Management Systems

Nov 26 Management of Change – *Ken First*

Emergency Response - *Mike Snyder (DEKRA)*

Homework – Term Project

Dec 3 Term Project Oral Presentations – *All*

Class Feedback– All

Safety Courses

- University of Michigan
  - 120-130 Seniors ….yet…
  - Only 12-14 students take the 2 credit hour Safety Course
- Other Schools
  - Safety assignments in Senior Design
  - Get SACHE Certification

However, usually it is only a small fraction (10-15 %) of the graduating class that gets a satisfactory training in safety

What is the goal of the Process Safety Website?

The purpose of this website is to provide professors and students with real case studies and resources so that **process safety can be more effectively and easily learned <u>throughout</u> the curriculum** and become an integral part of chemical engineering culture.

Safety Module in Every Core ChE

	Fall	Winter
2nd Year	230 Introduction to Materials and Energy Balance	330 Chemical and Engineering Thermodynamics 341 Fluid Mechanics
3rd Year	342 Mass and Heat Transfer 343 Separation Processes	344 Chemical Reaction Engineering and Design 360 Chemical Engineering Laboratory I
4th Year	460 Chemical Engineering Laboratory II 466 Process Dynamics and Control	487 Process Simulation and Design 488 Chemical Product Design I 4XX Elective

Homepage of Safety Website

UNIVERSITY OF MICHIGAN

Process Safety Across the Chemical Engineering Curriculum

Initiative Led by Professor H. Scott Fogler

Home | Courses | Tutorials | Resources | About

"If you think safety is expensive, try an accident"

Dr. Trevor Kletz, 1922-2013 Father of Industrial Process Safety
More from Dr. Kletz

Course Specific Safety Modules

- Components of a Safety Module
- Material and Energy Balances
- Thermodynamics
- Fluid Mechanics
- Heat and Mass Transfer
- Separations
- Chemical Reaction Engineering
- Process Control
- Laboratory and Personal Safety

Tutorials

- NFPA and GHS
- Swiss Cheese Model
- BowTie Diagram
- Process Safety Triangle
- Fire Triangle
- Safety Analysis of Incident
- Critical Thinking Applied to Safety
- Safety Acronyms

Course Specific Short Exercises

- CCPS Safety Beacons
- CEP Spotlight on Safety

Other Resources

- Complete Safety Module with Solutions
- Assessment of a Safety Module
- AIChE and SACHE Resources
- Chemical Safety Board Video List

Module

- Video

- Safety Analysis

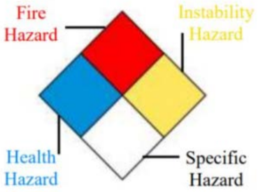
Safety Analysis of the Incident

Activity: ____________________

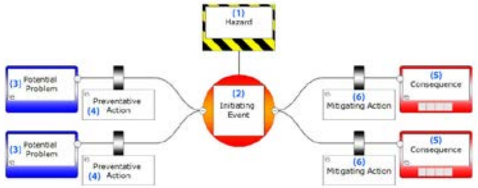
Hazard: ____________________

Incident: ____________________

- NFPA Diamond



- BowTie Diagram



- Calculation

(1) The Clausius-Clapeyron equation

$$\ln\left(\frac{P}{P_{sat}}\right) = \frac{-H_{vap}}{R}\left(\frac{1}{T} - \frac{1}{T_{sat}}\right)$$

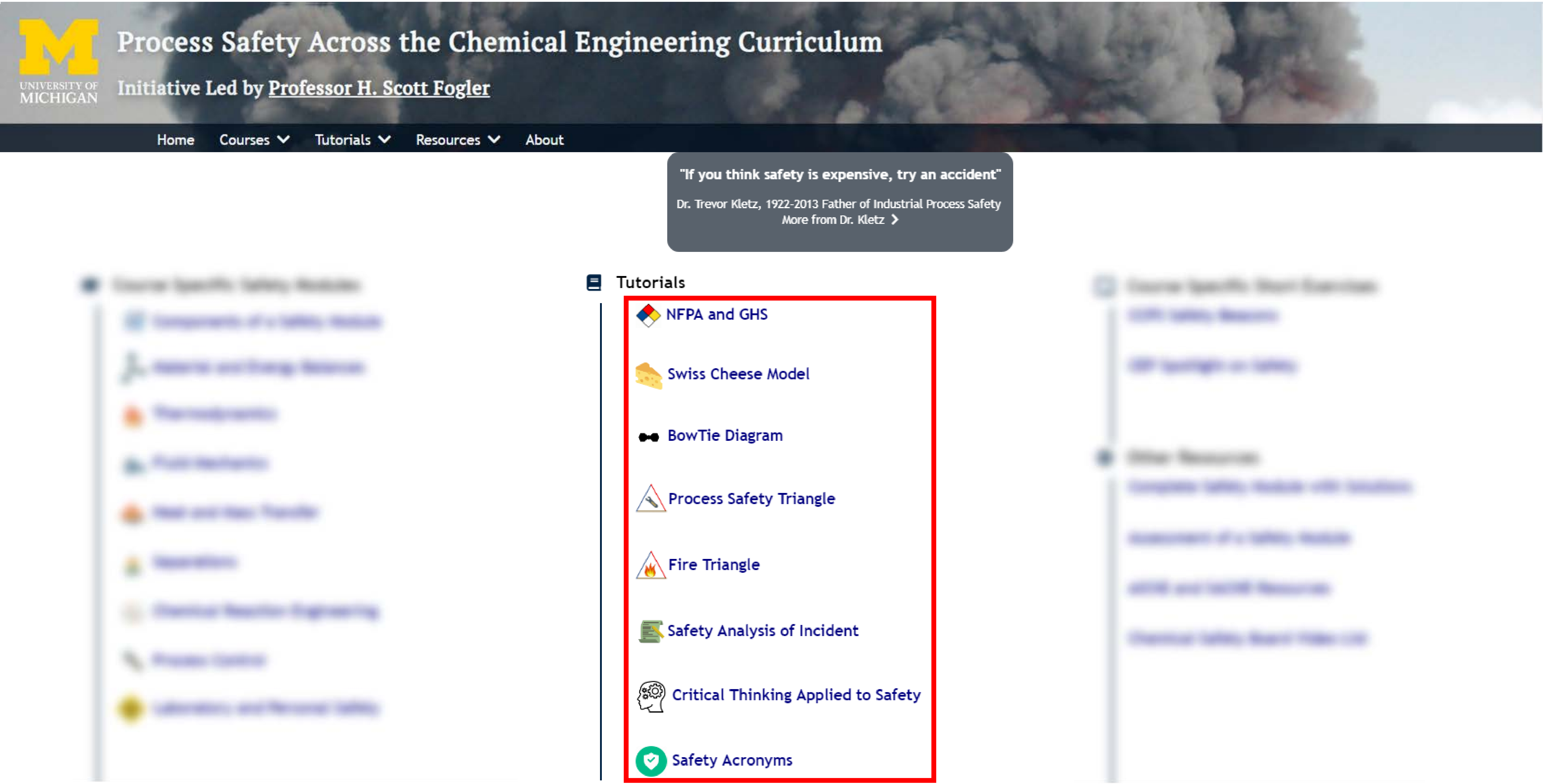
$$\ln\left(\frac{P}{0.101\,MPa}\right) = \frac{-18400\ ^{J}/_{mol\cdot K}}{8.314\ ^{J}/_{mol\cdot K}}\left(\frac{1}{298\,K} - \frac{1}{225.6\,K}\right)$$

$$\boxed{P(25\,°C) = 1.09\,MPa}$$

$$\ln\left(\frac{P}{0.101\,MPa}\right) = \frac{-18400\ ^{J}/_{mol\cdot K}}{8.314\ ^{J}/_{mol\cdot K}}\left(\frac{1}{330\,K} - \frac{1}{225.6\,K}\right)$$

$$\boxed{P(57\,°C) = 2.25\,MPa}$$

Tutorials on analysing hazards



Safety Analysis of the T2 Incident

Problem Statement

Plot and analyze the reactor temperature and head space pressure as a function of time along with the reactant concentrations for the scenario where the reactor cooling fails to work ($UA = 0$). In Problem P13-2(f) you will be asked to redo the problem when the cooling water comes as expected whenever the reactor temperature exceeds 455 K.

Safety Analysis of the Incident

Activity: ____________________

Hazard: ____________________

Incident: ____________________

Initiating Event: ____________________

Preventative Actions and Safeguards: ____________________

Contingency Plan/ Mitigating Actions: ____________________

Lessons Learned: ____________________

Safety Analysis

Process Safety Across the Chemical Engineering Curriculum

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Definitions

Activity: The process, situation or activity for which risk to people, property or the environment is being evaluated.

Hazard: A chemical or physical characteristic that has the potential to cause damage to people, property or the environment.

Incident: What happened? Description of the event or sum of the events along with the steps that lead to one or more undesirable consequences, such as harm to people, damage to the property, to the environment, or asset/business.

Initiating Event: The event that triggers the incident may be at the intersection of two or more failures, (e.g. failure of equipment, instrumentation and controller malfunction, human actions, flammable release, etc.). It could also include precursor events that precede the initiating event (e.g., no flow from pump, valve closed, inadvertent human action, ignition). The root cause of the sum events in causing the incident.

Preventative Actions and Safeguards: Steps that can be taken to prevent the initiating event from occurring and becoming an incident that causes damage to people, property or the environment. Brainstorm all potential problems and hazards that could go wrong. Next, brainstorm and list for each potential problem or hazard all the things that could cause that particular problem to occur (note there my be more than one cause for each potential problem). Finally, for each and every cause, list a preventative action that could be taken to prevent the cause from occurring.

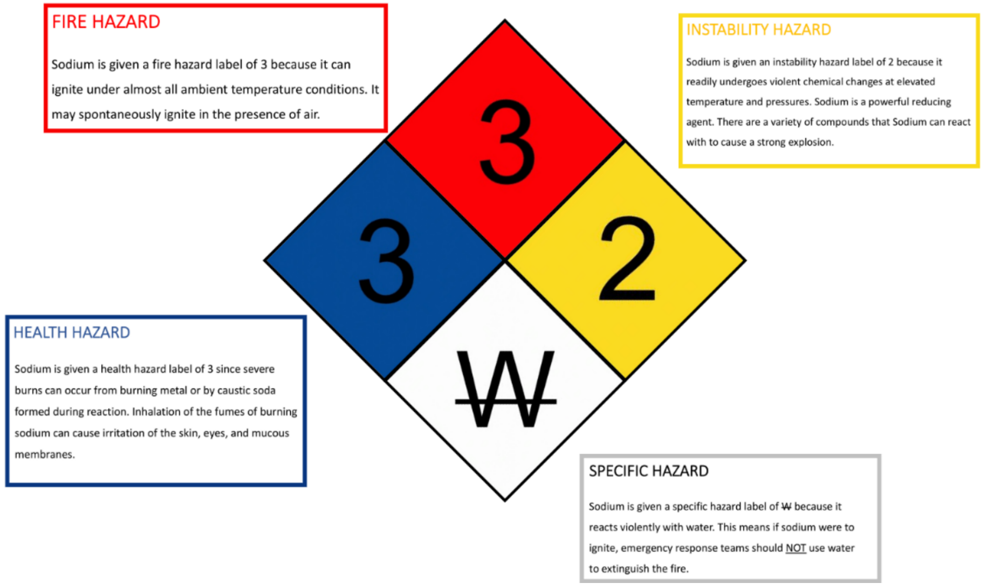
Contingency Plan/ Mitigating Actions: Brainstorm and list all the steps that reduce or mitigate the incident after the preventative action fails and the initiating event occurred.

Lessons Learned: What we have learned and can pass on to others that can prevent similar incidents from occurring

Tutorials explaining identification systems – NFPA Diamond

NFPA Diamond

The NFPA Diamond is used by emergency personnel, like firefighters, to quickly identify any risks of hazardous materials involved in the emergency they are responding to. The diamond identifies any precautions or special measures emergency responders should take when dealing with the emergency situations. They are usually seen on trucks transporting chemicals, chemical storage containers, cylinders, or drums, and outside of laboratories.



Globally Harmonized System (GHS)

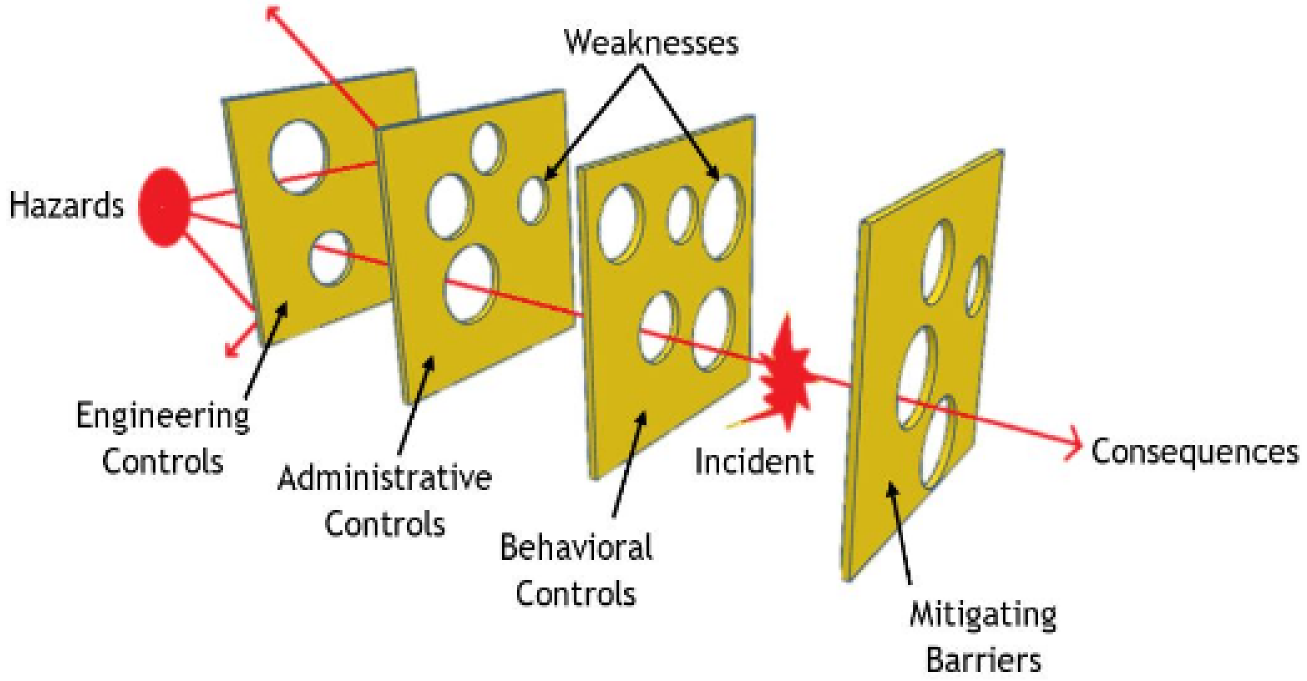
Globally Harmonized System (GHS)

The three different categories are flammables, health hazards, and environmental hazards, which have a variety of sub categories. GHS uses 9 different pictograms, as seen below, that are placed on containers to identify the hazard of the chemical being stored in the container.

Swiss Cheese Model

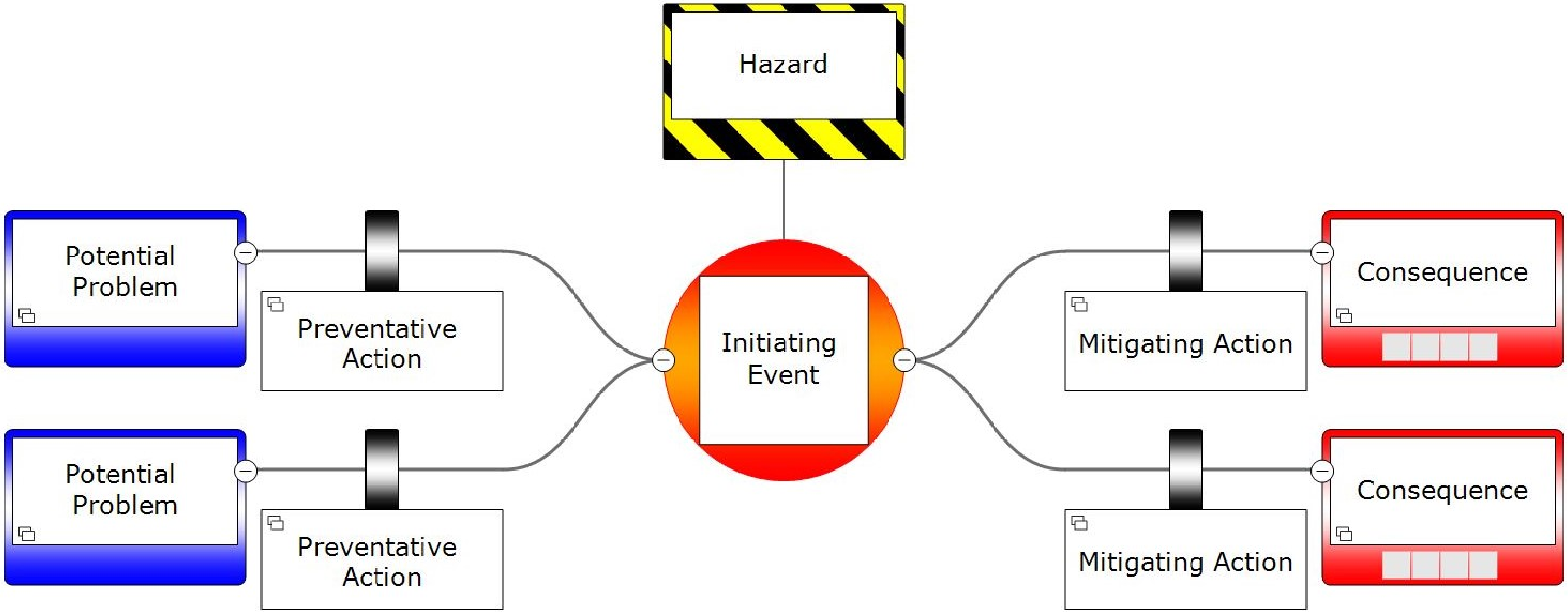
Swiss Cheese Model

The Swiss cheese model is another risk assessment tool, one that offers a deeper understanding into the layers of protection for chemical processes. A layer of protection is either a *preventative action* that reduces the chance of an incident will occur, or a *mitigating action* that lessens the severity of an accident. These layers of protection can include using inherently safer designs, following proper lab procedures, wearing adequate personal protective equipment (PPE), or having an emergency response plan.



Components of a Safety Module

5. Construct a BowTie diagram for the incident in the video.
In each Safety Module, students are asked to construct a BowTie diagram for the incident. Information about the different elements of the BowTie diagram are provided as to a link to the BowTie Diagram Tutorial found on our website.

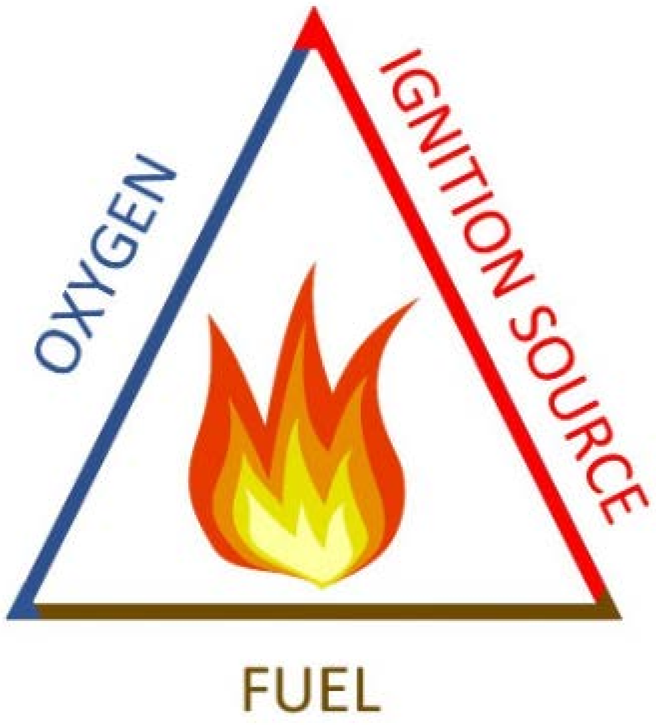


Process Safety Triangle

Process Safety Triangles are used to illustrate the different indicators that can lead to an accident. The process safety triangle illustrates the different actions that can lead to an accident. This tool highlights how the smallest unsafe act can lead to a major accident. It is applied from the bottom up, where each layer can be thought of as a preventative measure to the layer above it. The purpose is to show how an unsafe mindset can grow and produce tragic consequences.

Fire Triangle

The fire triangle, also referred to as the combustion triangle, is a visual representation of the three essential components needed for the ignition of a fire. Each side of the triangle represents a different component.



Safety Analysis

Safety Analysis of the Incident

The Chemical Safety Board (CSB) has documented and made videos of a number of accidents that have occurred over the last 40 years. These videos and associated modules can be found on the safety website (http://umich.edu/~safeche/).

Use *Safety Analysis of the Incident* in analyzing the accident after viewing the video.

Course Specific Safety Modules

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Course Specific Safety Modules

- Components of a Safety Module
- Material and Energy Balances
- Thermodynamics
- Fluid Mechanics
- Heat and Mass Transfer
- Separations
- Chemical Reaction Engineering
- Process Control
- Laboratory and Personal Safety

Thermodynamics Safety Modules

The U.S. Chemical Safety Board referred to in the safety modules is an independent federal agency that is tasked with investigating the major causes of chemical accidents. They provide recommendations on safety improvements and provide lessons learned in hope to protect the community and environment from future incidents.

Module 1: Praxair Cylinder Fire and Explosion

Class Tested by UM Thermodynamics Course in Spring 2018

- Description: Vapor pressure increases with temperature and escapes from cylinder and ignites
- Location: St. Louis, Missouri, US
- Date: June 24, 2005

Safety Module

Module 2: Williams Owens Olefin Plant Explosion

- Description: Liquid heats up causing he vapor pressure to increase causing an explosion
- Location: Geismar, Louisiana, US
- Date: June 13, 2013

Safety Module

Thermodynamics Module

Chemical and Engineering Thermodynamics

[i]**Safety Module 1:** *Praxair Flammable Gas Cylinder Explosion, June 24, 2005 in St. Louis, MO*

Problem Statement: It was a hot day in St. Louis, 96°F (35.9°C), where Praxair had set cylinders with flammable gases on hot black asphalt pavement. Direct sunlight and radiant heat from the asphalt pavement[†] heated the propylene cylinders.

The vapor pressure in a liquid propylene cylinder exceeded a faulty set pressure on the cylinder's relief valve that was too low and propylene escaped into the yard. The resulting vapor plume found an ignition source and a fire started. The fire heated nearby acetylene and liquefied petroleum gas (LPG) cylinders and they in turn released more flammable gases, which enlarged the fire.

Pressure relief valve – cut away

Watch the Video: (*https://www.youtube.com/watch?v=-_ZLQkn7X-k*)

Incident Report Available At: (*https://www.csb.gov/file.aspx?DocumentId=5642*)

Thermodynamics Module

(a) It is important that chemical engineers have an understanding of what the accident was, why it happened and how it could have been prevented in order ensure similar accidents may be prevented. Applying a safety algorithm to the accident will help achieve this goal. In order to become familiar with a strategy for accident awareness and prevention, view the Chemical Safety Board video on the Praxair flammable gas fires and explosion and fill out the following algorithm. See definitions on the last page. If necessary, view pages 1-10 of the incident report.

Safety Analysis of the Incident

Activity: ______________________________

Hazard: ______________________________

Incident: ______________________________

Initiating Event: ______________________________

Preventative Actions and Safeguards: ______________________________

Contingency Plan/ Mitigating Actions: ______________________________

Lessons Learned: ______________________________

Thermodynamics Module

The air temperature reached 96°F (36.9°C) at 2 p.m. and the asphalt surface was approximately 140°F (333 K) causing the cylinder temperature to be at least 135°F (330 K).

Additional information

Propylene boils at 225.6K at 1 atm (101.3 kPa). The heat of vaporization is 18.4 kJ/mol R = 8.314 J/mol•K, the critical pressure and temperature are P_C = 4.0 MPa and T_C = 364.9 K respectively, and the vapor molar volume of propylene is $2.13 \cdot 10^{-3}\, m^3/_{mol}$

(b) Use the ideal gas law to estimate the pressure, P, inside the cylinder at 25°C and at 57°C (330 K) when there is only propylene gas.

(c) Assuming vapor liquid equilibrium estimate the pressure, P, in the cylinder at 25°C and at 57°C using

(1) The Clausius-Clapeyron equation

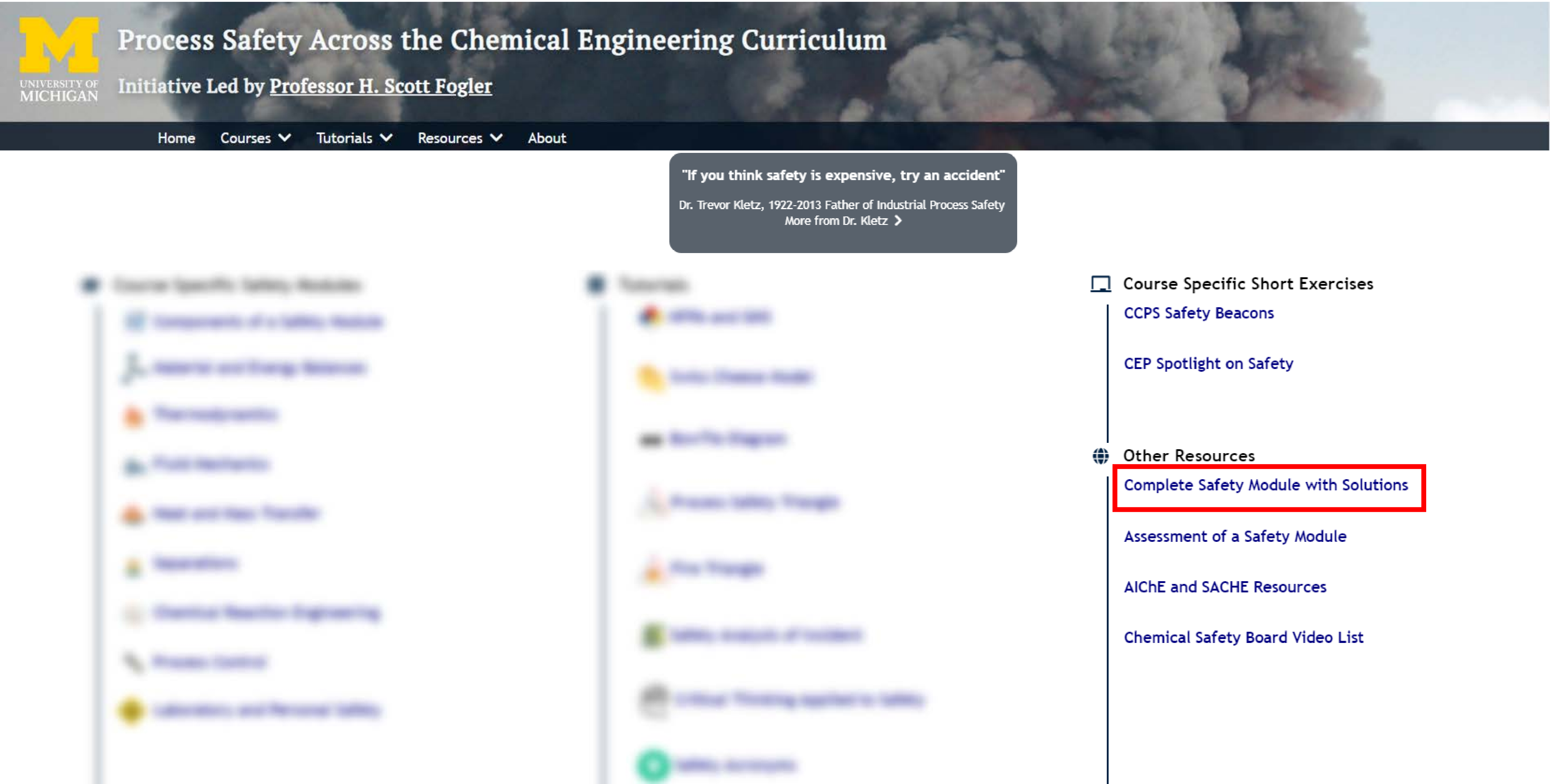
$$P_2 = P_1 \exp\left[\frac{-\Delta H_{vap}}{RT}\left(\frac{1}{T_2} - \frac{1}{T}\right)\right]$$

(2) The short cut equation

$$\log_{10}\left(\frac{P}{P_C}\right) = \frac{7}{3}(w+1)\left(1 - \frac{T_C}{T}\right)$$

where ω is the acentric factor[1,2] with ω = 0.142 for propylene.[3]

Complete Safety Module with Solutions



Safety Analysis of the Incident

Safety Analysis of the Incident

Activity: The activity in this incident is the storage of propylene cylinders outdoors in the sun during high heat weather.

Hazard: The hazard in this incident is the flammability of propylene.

Incident: The incident was the pressure in the storage tanks reaching the set point, which vented the propylene gas out to relieve the pressure. This release of the flammable gas then led to the explosion at the Praxair facility. This explosion resulted in fire and other damage to the surrounding community.

Initiating Event: The initiating event in this scenario was the release of propylene due to the increase of pressure in the storage cylinders.

Preventative Actions and Safeguards: Some preventative actions or safeguard include the revision of safety standards for relief valves, routine inspection/maintenance of set points on the relief valves, provide shade for the cylinders stored outside, place the cylinders farther apart from one another in storage yard, inspect the cylinders to determine if there is any liquid propylene within, and provide a cooling system to the storage area.

Contingency Plan/Mitigating Actions: Some mitigating actions include installation of fire protection systems and gas release detectors to notify when gas has been released, place cylinders farther apart from one another and barriers to contain exploding cylinders.

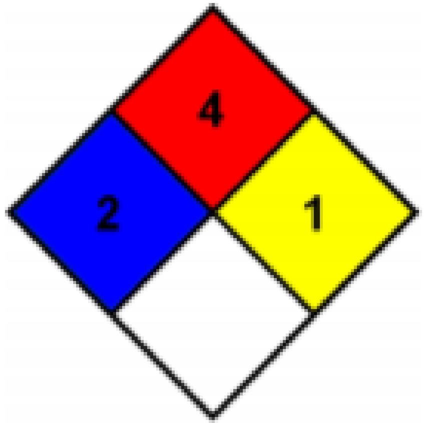
Lessons Learned: The lesson learned from this incident was that many pressure relief valves are susceptible to mechanical failure that results in lowered set pressures that can be reached during hot summer days.

NFPA Diamond on Propylene

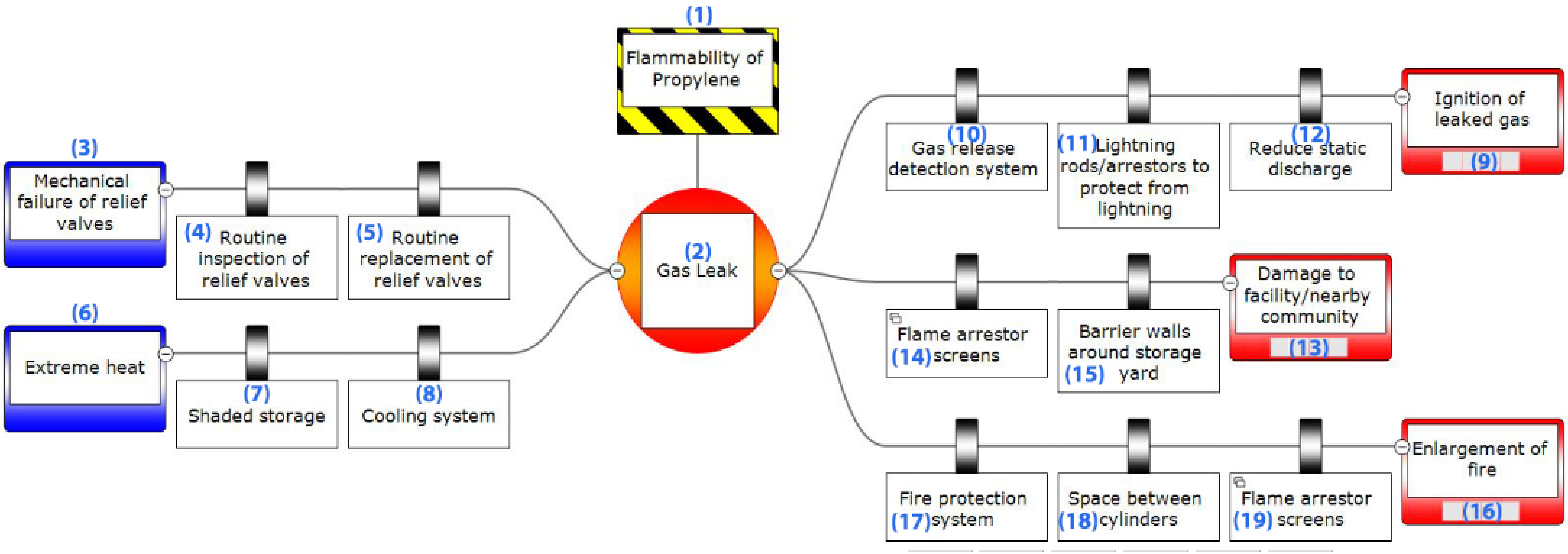
2 - Materials that, under emergency conditions, can cause temporary incapacitation or residual injury.

4 - Materials that rapidly or completely vaporize at atmospheric pressure and normal ambient temperature or that are readily dispersed in air and burn readily.

1 - Materials that in themselves are normally stable but can become unstable at elevated temperatures and pressures.



Praxair BowTie Diagram



Calculated Solutions

(1) The Clausius-Clapeyron equation

$$\ln\left(\frac{P}{P_{sat}}\right) = \frac{-H_{vap}}{R}\left(\frac{1}{T} - \frac{1}{T_{sat}}\right)$$

$$\ln\left(\frac{P}{0.101\ MPa}\right) = \frac{-18400\ {}^{J}/_{mol\ \cdot K}}{8.314\ {}^{J}/_{mol\ \cdot K}}\left(\frac{1}{298\ K} - \frac{1}{225.6\ K}\right)$$

$$\boxed{P(25\ ℃) = 1.09\ MPa}$$

$$\ln\left(\frac{P}{0.101\ MPa}\right) = \frac{-18400\ {}^{J}/_{mol\ \cdot K}}{8.314\ {}^{J}/_{mol\ \cdot K}}\left(\frac{1}{330\ K} - \frac{1}{225.6\ K}\right)$$

$$\boxed{P(57\ ℃) = 2.25\ MPa}$$

(2) The short cut equation where Z is the acentric factor, with Z = 0.142 for propylene

$$log_{10}\left(\frac{P}{P_C}\right) = \frac{7}{3}(\omega + 1)\left(1 - \frac{T_C}{T}\right)$$

$$log_{10}\left(\frac{P}{P_C}\right) = \frac{7}{3}(0.142 + 1)\left(1 - \frac{364.9\ K}{298\ K}\right)$$

$${}^{P}/_{P_C} = 0.253$$

$$P(25\ ℃) = P_r \cdot P_C = 0.253 \cdot 4.6\ MPa = \boxed{1.164\ MPa}$$

$$log_{10}\left(\frac{P}{P_C}\right) = \frac{7}{3}(0.142 + 1)\left(1 - \frac{364.9\ K}{330\ K}\right)$$

$${}^{P}/_{P_C} = 0.523$$

$$P(57\ ℃) = P_r \cdot P_C = 0.523 \cdot 4.6\ MPa = \boxed{2.41\ MPa}$$

Materials and Energy Balance Modules

Process Safety Across the Chemical Engineering Curriculum

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Material and Energy Balances Safety Modules

The U.S. Chemical Safety Board referred to in the safety modules is an independent federal agency that is tasked with investigating the major causes of chemical accidents. They provide recommendations on safety improvements and provide lessons learned in hope to protect the community and environment from future incidents.

Module 1: CAPECO Explosion

Class Tested by UM Material and Energy Balances Course in Fall 2018

- Description: Overfilling of storage tank with a flammable liquid
- Location: Bayamón, Puerto Rico
- Date: October 23, 2009

Safety Module

Module 2: Acetone Drum Explosion

Class Tested by UM Material and Energy Balances Course in Fall 2018

- Description: Calculate the flammability limits of one teaspoon of acetone in an inverted drum
- Location: N/A
- Date: N/A

Safety Module

Materials and Energy Balance Modules

Introduction to Material and Energy Balances

[i]**Safety Module 1:** *Explosion at Caribbean Petroleum Company (CAPECO), October 23, 2009 in Bayamón, Puerto Rico*

Problem Statement: This incident occurred while gasoline was being unloaded from a tanker vessel. The main storage tank was full, so the flow was diverted to one of two smaller storage tanks. The use of a faulty manual level monitoring system on a storage tank resulted in the overflow, ignition, and explosion of 200,000 gallons of gasoline, culminating in a fire which continued for 2 days. Over 300 homes and businesses were damaged and nearby soil, waterways, and wetlands were contaminated.

csb.gov

Watch the Video: (https://www.youtube.com/watch?v=41QMaJqxqIo)

Incident Report Available At: (https://www.csb.gov/file.aspx?DocumentId=5965)

Materials and Energy Balance Modules

(a) It is important that chemical engineers have an understanding of what the accident was, why it happened and how it could have been prevented to ensure similar accidents may be prevented. Applying a safety algorithm to the accident will help achieve this goal. In order to become familiar with a strategy for accident awareness and prevention, view the Chemical Safety Board video on the explosion at the Caribbean Petroleum Company and fill out the following algorithm. See definitions on the last page. If necessary, view pages 9-13 and 25-28 of the incident report.

Safety Analysis of the Incident

Activity: ____________________

Hazard: ____________________

Incident: ____________________

Initiating Event: ____________________

Preventative Actions and Safeguards: ____________________

Contingency Plan/ Mitigating Actions: ____________________

Lessons Learned: ____________________

Safety Analysis of the Incident

Activity: The activity in this incident is the above ground storage of oil that is not well regulated by the EPA.

Hazard: The hazard in this incident was CAPECO's use of the unreliable floating tape measurement system for monitoring the level of gasoline in their storage tanks.

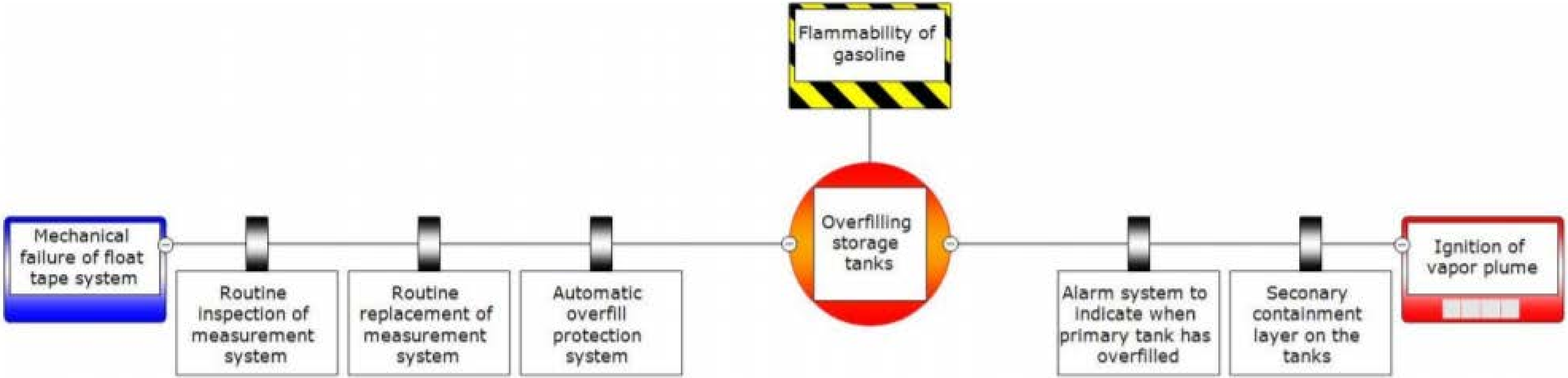
Incident: The incident in this scenario was that the tank being monitored by employees had been thought to be almost empty and the engineers calculated it would be full within a certain number of hours. Once the tank was filled, the employee would have to manually switch the valve to keep the tank from overflowing. When an employee went to check on the tank an hour before the calculated time, he noticed a strong odor of gasoline. It was then within 23 minutes of the tank overflowing that the explosion occurred.

Initiating Event: The initiating event in this scenario was the manual measurement of when the storage tanks would be full and the measuring system being unreliable since it was prone to mechanical failure. The inaccurate readings were used to calculate the time that the tank would fill, but since the measurement was inaccurate the tank overfilled and gasoline poured onto the ground and formed a flammable vapor plume.

Preventative Actions and Safeguards: Preventative actions would have been installing an automatic overfill protection system that would have stopped the flow as soon as it detected overfill or diverted the flow to another tank, instead of having to manually calculate when the tanks are full and manually diverge the flow to a different tank.

Contingency Plan/Mitigating Actions: Having at least two additional layers on the storage tank in case of overflow to mitigate leakage would have given additional time to stop the flow before it leaked outside of the tank. Having a secondary independent alarm system that alerts when the tank is nearing overflow in case the primary alarm fails.

Lessons Learned: Having preventative safety measures would have kept employees and nearby residents safe from this risk. Additionally, safety is good business practice, as preventative measures would have saved CAPECO enormous amounts of money due to the destruction of the tank farm and associated equipment, as well as from lawsuits, lost business, and bad publicity.



Flammability of gasoline
Mechanical failure of float tape system
Routine inspection of measurement system
Routine replacement of measurement system
Automatic overfill protection system
Overfilling storage tanks
Alarm system to indicate when primary tank has overfilled
Seconary containment layer on the tanks
Ignition of vapor plume

(1) Calculate the vapor pressure of octane using Antoine's equation.

$$log_{10}\left(P^{sat}(27°C)\right) = 6.91874 - \frac{1351.756}{27 + 209.1}$$

$$P^{sat}\ (27°C) = 15.6088\ mmHg$$

Note: used Antoine coefficients from Felder, measured for 52.9 – 126.6 °C range.

(2) Calculate the mole fraction of octane using Raoult's Law.

$$P^{sat} = y_{sat}P$$

$$y_{sat} = \frac{P^{sat}}{P} = \frac{15.6088\ mmHg}{760\ mmHg} = 0.0205$$

$$y_{sat} = \boxed{2.05\ mole\%}$$

(3) Calculate the volume of the plume.

$$107\ acres = 4.661 \cdot 10^6 ft^2$$

$$V_{total} = 4.661 \cdot 10^6 ft^2 \cdot 1\ ft = 4.661 \cdot 10^6 ft^3 = 131984.822\ m^3$$

(4) Calculate the total moles in the plume using the Ideal Gas Law.

$$PV = nRT$$

$$n = \frac{PV}{RT} = \frac{101325\ Pa \cdot 131984.822\ m^3}{8.314\ {m^3 \cdot Pa}/{mol \cdot K} \cdot 300K} = 5361.78\ kmol\ vapor\ total$$

(5) Calculate the number of moles of octane in the plume.

$$n_{octane} = y_{sat} \cdot n = 0.0205 \cdot 5361.78\ kmol$$

$$n_{octane} = \boxed{110.12\ kmol\ octane}$$

Heat and Mass Transfer Modules

UNIVERSITY OF MICHIGAN

Process Safety Across the Chemical Engineering Curriculum

Initiative Led by Professor H. Scott Fogler

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Heat and Mass Transfer Safety Modules

The U.S. Chemical Safety Board referred to in the safety modules is an independent federal agency that is tasked with investigating the major causes of chemical accidents. They provide recommendations on safety improvements and provide lessons learned in hope to protect the community and environment from future incidents.

Module 1: Williams Owens Olefin Plant Explosion

Class Tested by UM Heat and Mass Transfer Course in Fall 2018

- Description: Tar build up on heat exchanger containing propylene that explodes
- Location: Geismar, Louisiana, US
- Date: June 13, 2013

Safety Module | Wolfram Code

Module 2: West Fertilizer Explosion and Fire

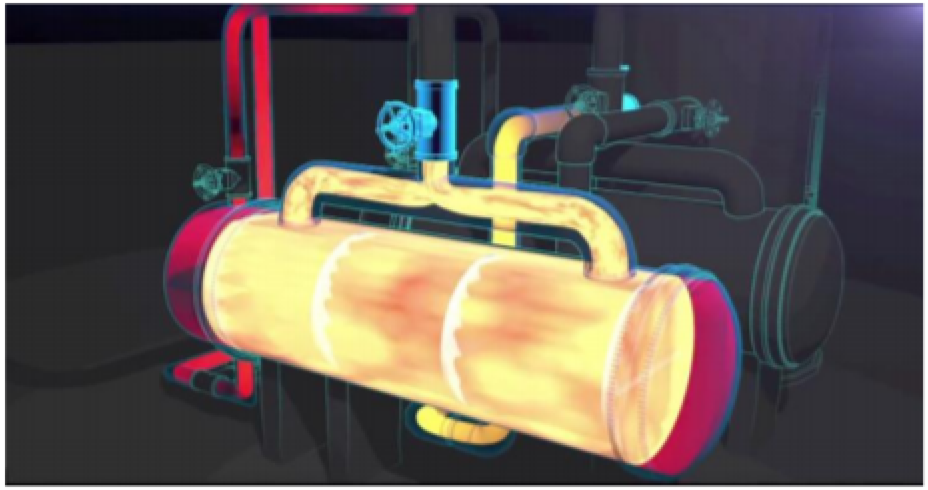
- Description: Radiant and convective heat exchange to an NH3NO3 pile
- Location: West, Texas, US
- Date: April 17, 2013

Safety Module

Heat and Mass Transfer

[i]**Safety Module 1:** Williams Owens Olefin Plant Explosion, Geismer, LA, June 13, 2013

Problem Statement: The Williams Owens Plant in Geismar, LA produces ethylene and propylene. A shell and tube reboiler on a fractionator column heats shell side propane and propylene using tube side hot water. Workers understood that oily tar had a tendency to build up on the inside of the reboiler tubes, requiring periodic shut down for cleaning. The plant manager observed a significant decrease in hot water flow rate over the past day and attributed it to tar build up on the inside of the tube walls. Workers decided to switch to the stand-by exchanger, which had not been in use for 16 months. Unknown to workers, this stand-by heat exchanger was detached from its pressure relief valve and contained liquid propane. When hot water was introduced into this heat exchanger, it violently ruptured and exploded within three minutes. The incident killed two workers and injured 167.



Watch the Video: (*https://www.youtube.com/watch?v=Z1KaykPaF8M*)

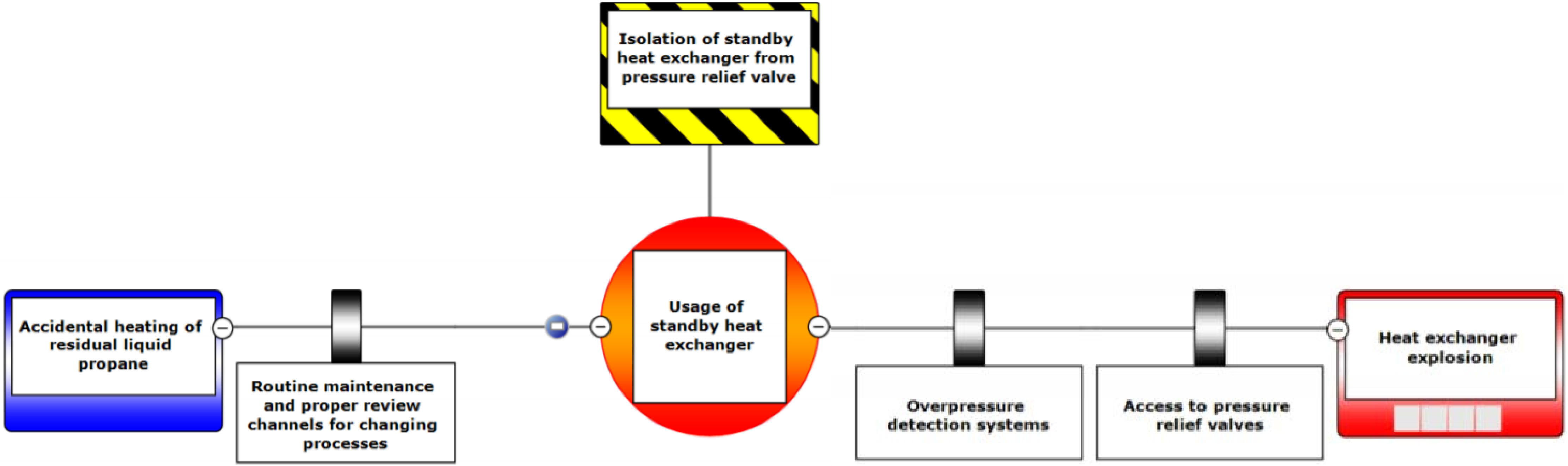
Incident Report Available At: (*https://www.csb.gov/file.aspx?DocumentId=6004*)
(Pages 5, 9, 11-15, 56)

Safety Analysis of the Incident

Activity: The activity in this incident is turning on the heat exchanger without checking for remaining substances in it first since it had not been in use. Also, the changing a process unit without going through the proper management of change procedures to determine potential hazards, specifically not allowing proper heat exchanger flow through or pressure relief of the unit can be considered the activity.

Hazard: The hazard was the trapped flammable liquid propane in the shell side of a heat exchanger being heated with hot water.

Incident: The incident was the explosion of one of the two heat exchangers. Heat exchangers provided heat to the propylene fractionator needed to separate propane and propylene. When an employee went to switch to the standby heat exchanger from the currently running heat exchanger, so it could undergo maintenance, the employee unknowingly heated liquid propane that had leaked into the heat exchanger. The pressure built up and could not be relieved by the pressure relief valves because they were blocked off. This build up led to the heat exchanger exploding and igniting the propane, killing and injuring many employees.

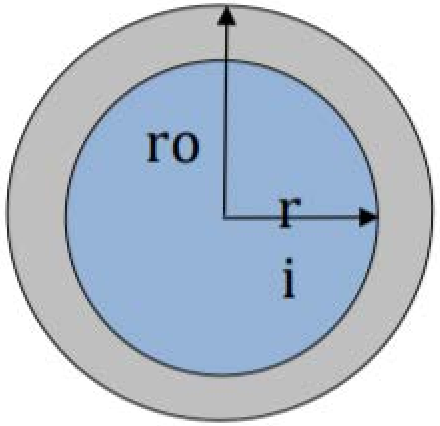

Isolation of standby heat exchanger from pressure relief valve
Accidental heating of residual liquid propane
Routine maintenance and proper review channels for changing processes
Usage of standby heat exchanger
Overpressure detection systems
Access to pressure relief valves
Heat exchanger explosion

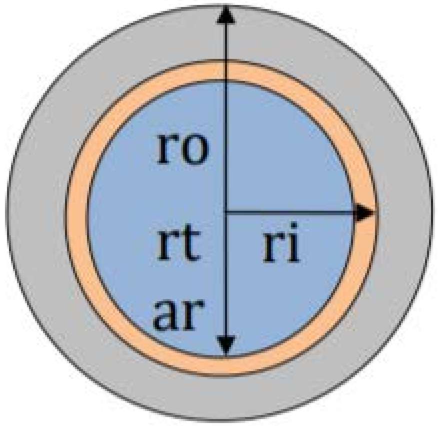
(b) Using a shell balance approach, prove that $r_q(r)$ = constant.

(c) In the Fluids Mechanic module, we found r_{tar} to be approximatey $\sqrt{0.2}r_i$, where r_i is the inner radius of the tube before fouling. Using this estimate for the incident, calculate the following when there is no fowling:

1. The temperature difference Tw - T_p from the water flowing inside the tubes (T_w) to the propylene flowing in the shell (T_p)
2. The overall heat transfer coefficient, U at $r = r_i$
3. The energy flux, q_1 at $r = r_i$

(d) Find an expression for the energy flux q_2 at $r = r_{tar}$ when fouling occurs. What is the percent reduction in heat flux when fouling occurs? [% reduction = $(q_1-q_2)/q_1$]





(1) Calculate the vapor pressure of propane at 298˚K using Antoine's equation.

$$log_{10}(P) = A - \frac{B}{T + C}$$

$$log_{10}\left(P^{sat}(25°C)\right) = 4.53678 - \frac{1149.36}{298 + 24.906}$$

$$P^{sat}(25°C) = 9.49\ bar$$

(2) Calculate the pressure in the heat exchanger at 373˚K (100˚C) using Clausius-Clapeyron.

$$\ln\left(\frac{P}{P^{sat}(25°C)}\right) = \frac{-H_{vap}}{R}\left(\frac{1}{T} - \frac{1}{T_{sat}}\right)$$

$$\ln\left(\frac{P}{9.49\ bar}\right) = \frac{-16250\ {}^{J}/_{mol}}{8.314\ {}^{J}/_{mol \cdot K}}\left(\frac{1}{373\ K} - \frac{1}{298\ K}\right)$$

$$\boxed{P = 35.48\ bar}$$

Chemical Reaction Engineering Modules

Chemical Reaction Engineering Safety Modules

The U.S. Chemical Safety Board referred to in the safety modules is an independent federal agency that is tasked with investigating the major causes of chemical accidents. They provide recommendations on safety improvements and provide lessons learned in hope to protect the community and environment from future incidents.

Module 1: T2 Laboratories Explosion

Class Tested by UM Chemical Reaction Engineering Course in Fall 2018

- Description: Explosion of batch chemical reactor after heat exchanger fails for 10 minutes
- Location: Jacksonville, Florida, US
- Date: December 19, 2007

Safety Module

Module 2: Runaway Reaction at Monsanto and Synthron

- Description: Explosion of a batch reactor after heat exchanger fails
- Location: Sauget, Illinois (Monsanto) and Morganton, North Carolina (Synthron)
- Date: August 8, 1969 (Monsanto) and January 31, 2006 (Synthron)

Safety Module

Differential equations

1 d(CA)/d(t) = SW1*r1A

change in concentration of methylcyclopentadiene (mol/dm3/hr)

2 d(CB)/d(t) = SW1*r1A

change in concentration of sodium (mol/dm3/hr)

3 d(CS)/d(t) = SW1*r2S

change in concentration of diglyme (mol/dm3/hr)

4 d(P)/d(t) = SW1*((FD-Fvent)*0.082*T/VH)

5 d(T)/d(t) = SW1*((V0*(r1A*DHRx1A+r2S*DHRx2S)

-SW1*UA*(T-373.15))/SumNCp)

Explicit equations

1 V0 = 4000

dm3

2 VH = 5000

dm3

3 DHRx1A = -45400

J/mol Na

4 DHRx2S = -3.2E5

J/mol of Diglyme

5 SumNCp = 1.26E7

J/K

6 A1A = 4E14

per hour

7 E1A = 128000

J/kmol/K

8 k1A = A1A*exp(-E1A/(8.31*T))

rate constant reaction 1

9 A2S = 1E84

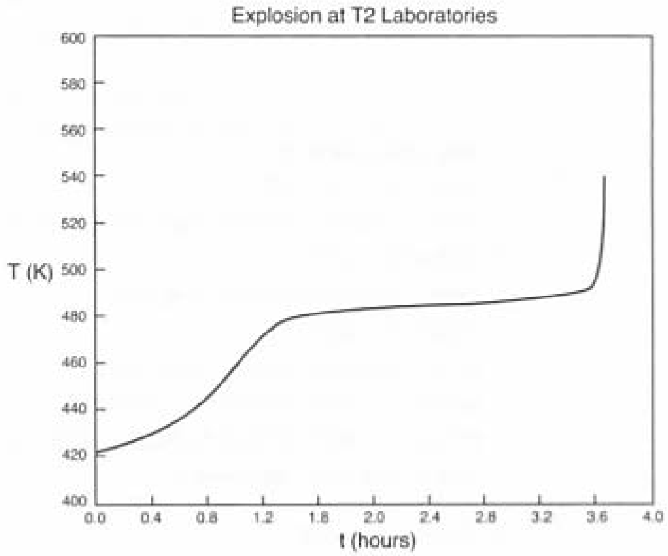
per hour

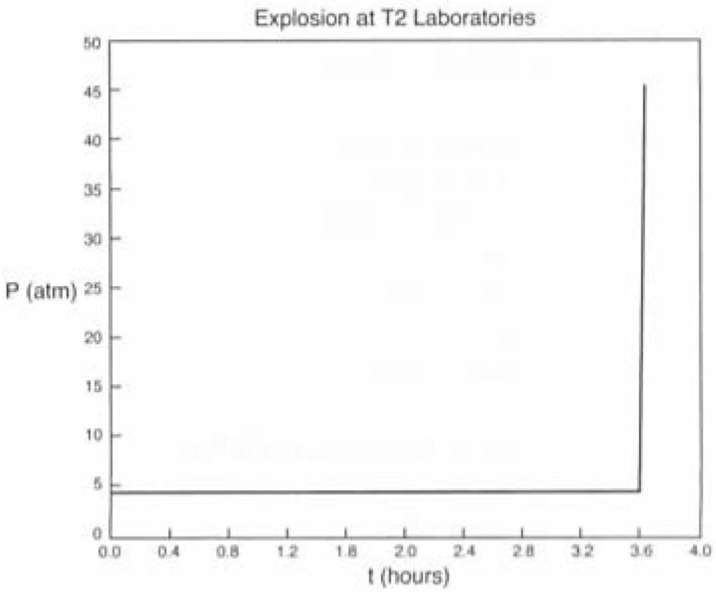
POLYMATH Report

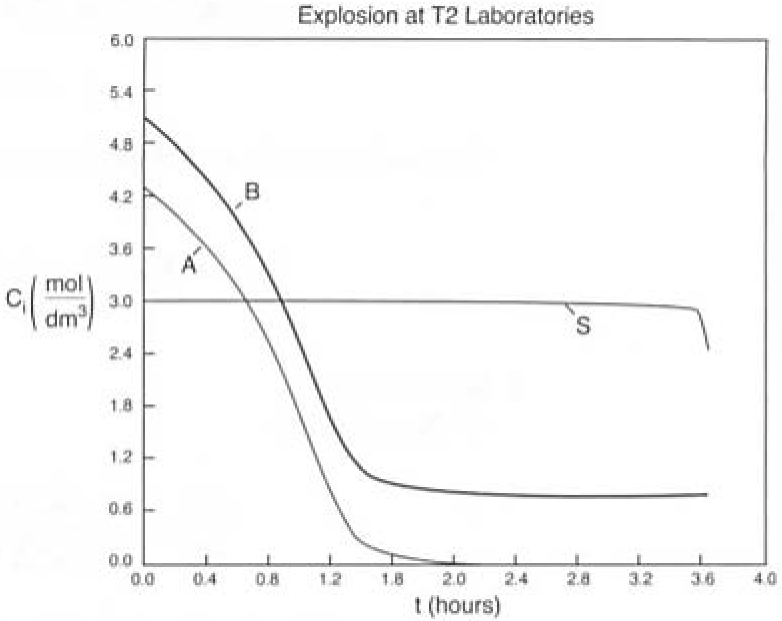
Ordinary Differential Equations

Calculated values of DEQ variables

	Variable	Initial value	Final value
1	A1A	4.0E+14	4.0E+14
2	A2S	1.0E+84	1.0E+84
3	CA	4.3	9.919E-07
4	CB	5.1	0.800001
5	CS	3.	2.460265
6	Cv1	3360.	3360.
7	Cv2	5.36E+04	5.36E+04
8	DHRx1A	-4.54E+04	-4.54E+04
9	DHRx2S	-3.2E+05	-3.2E+05
10	E1A	1.28E+05	1.28E+05
11	E2S	8.0E+05	8.0E+05
12	FD	2467.445	7.477E+10
13	Fvent	2467.445	2.507E+06
14	k1A	0.0562573	153.6843
15	k2S	8.428E-16	2.533E+06
16	P	4.4	45.01004
17	r1A	-1.233723	-0.000122
18	r2S	-2.529E-15	-6.231E+06
19	SumNCp	1.26E+07	1.26E+07
20	SW1	1.	0
21	t	0	4.
22	T	422.	538.8048
23	UA	0	0
24	V0	4000.	4000.
25	VH	5000.	5000.

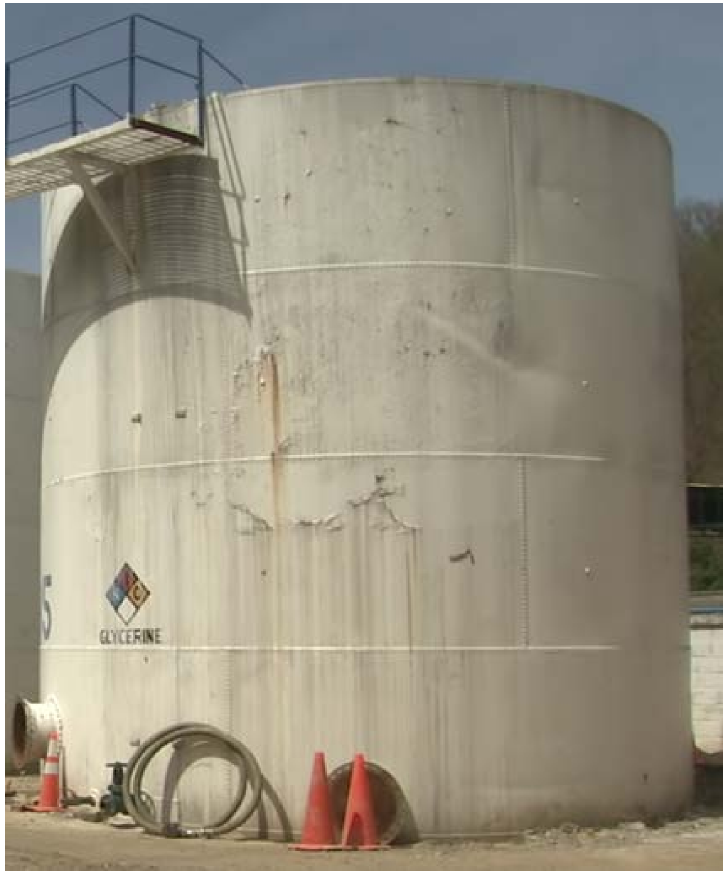






Application of Critical Thinking in Safety

Actual Case History: A large tank containing ethylene oxide has been insulated and is out in the plant. There is uncertainty as to whether or not corrosion has taken place under the insulation. To strip of the insulation and check for corrosion would require shutting the plant down for 3 weeks. Because such a shutdown would affect the supply chain and many customers, the shutdown would be very costly, ca. 5 million dollars. Let's apply R. W. Paul's Six Types of Critical Thinking questions to this situation to help us decide whether or not to strip the insulation.



What is Critical Thinking?

Critical thinking is the process we use to recognize underlying assumptions, scrutinize arguments, question problem statements and solutions, and interpret and assess the accuracy of information.

Socratic Questioning is at the Heart of Critical Thinking

R.W. Paul’s Six Types of Critical Thinking Questions

1) Questions about the Question
2) Questions for Clarification
3) Questions that Probe Assumptions
4) Questions that Probe Reasons and Evidence
5) Questions about Viewpoints and Perspectives
6) Questions that Probe Implications and Consequences

Application of Critical Thinking in Safety

Type of CTQ	Example Phrases of CTQ	CTQ Safety Examples
1. **Questions about the question or problem statement:** *The purpose of this question is to determine why the question was asked, who asked it, and why the question or problem needs to be solved.*	• What is the main question you want to answer? • What is the point of this question? • Why do you think I ask this question? • Why is it important you learn the answer to that question? • How does this question relate to our discussion?	Why do you think I questioned you about corrosion under the insulation, considering the storage tank is only 10 years old?

Application of Critical Thinking in Safety

Type of CTQ	Example Phrases of CTQ	CTQ Safety Examples
1. **Questions about the question or problem statement:** *The purpose of this question is to determine why the question was asked, who asked it, and why the question or problem needs to be solved.*	• What is the main question you want to answer? • What is the point of this question? • Why do you think I ask this question? • Why is it important you learn the answer to that question? • How does this question relate to our discussion?	Why do you think I questioned you about corrosion under the insulation, considering the storage tank is only 10 years old?
2. **Questions for clarification:** *The purpose of this question is to identify missing or unclear information in the problem statement question.*	• What do you mean by that? • What information do we need to answer this question? • How does that relate to our discussion? • What do we already know about that?	Are there industry identified case histories about corrosion occurring under insulation?

Application of Critical Thinking in Safety

Type of CTQ	Example Phrases of CTQ	CTQ Safety Examples
1. **Questions about the question or problem statement:** *The purpose of this question is to determine why the question was asked, who asked it, and why the question or problem needs to be solved.*	• What is the main question you want to answer? • What is the point of this question? • Why do you think I ask this question? • Why is it important you learn the answer to that question? • How does this question relate to our discussion?	Why do you think I questioned you about corrosion under the insulation, considering the storage tank is only 10 years old?
2. **Questions for clarification:** *The purpose of this question is to identify missing or unclear information in the problem statement question.*	• What do you mean by that? • What information do we need to answer this question? • How does that relate to our discussion? • What do we already know about that?	Are there industry identified case histories about corrosion occurring under insulation?
3. **Questions that probe assumptions:** *The purpose of this question is to identify any misleading or false assumptions.*	• What could we assume instead? • How does one verify or disapprove that assumption? • Explain why. . . (Explain how. . .) • What would happen if. . . ? • What is the basis of this assumption?	How did you assume stripping the insulation is the only method to check for corrosion?

Application of Critical Thinking in Safety

4. Questions that probe reasons and evidence: *The purpose of this question is to explore whether facts and observations support an assertion.*	• What would be an example? • Why is . . . happening? • What is analogous to. . . ? • What do you think causes. . . ? Why? • What evidence is there to support your answer?	What evidence do you have that corrosion may have occurred in this tank in the last 10 years?

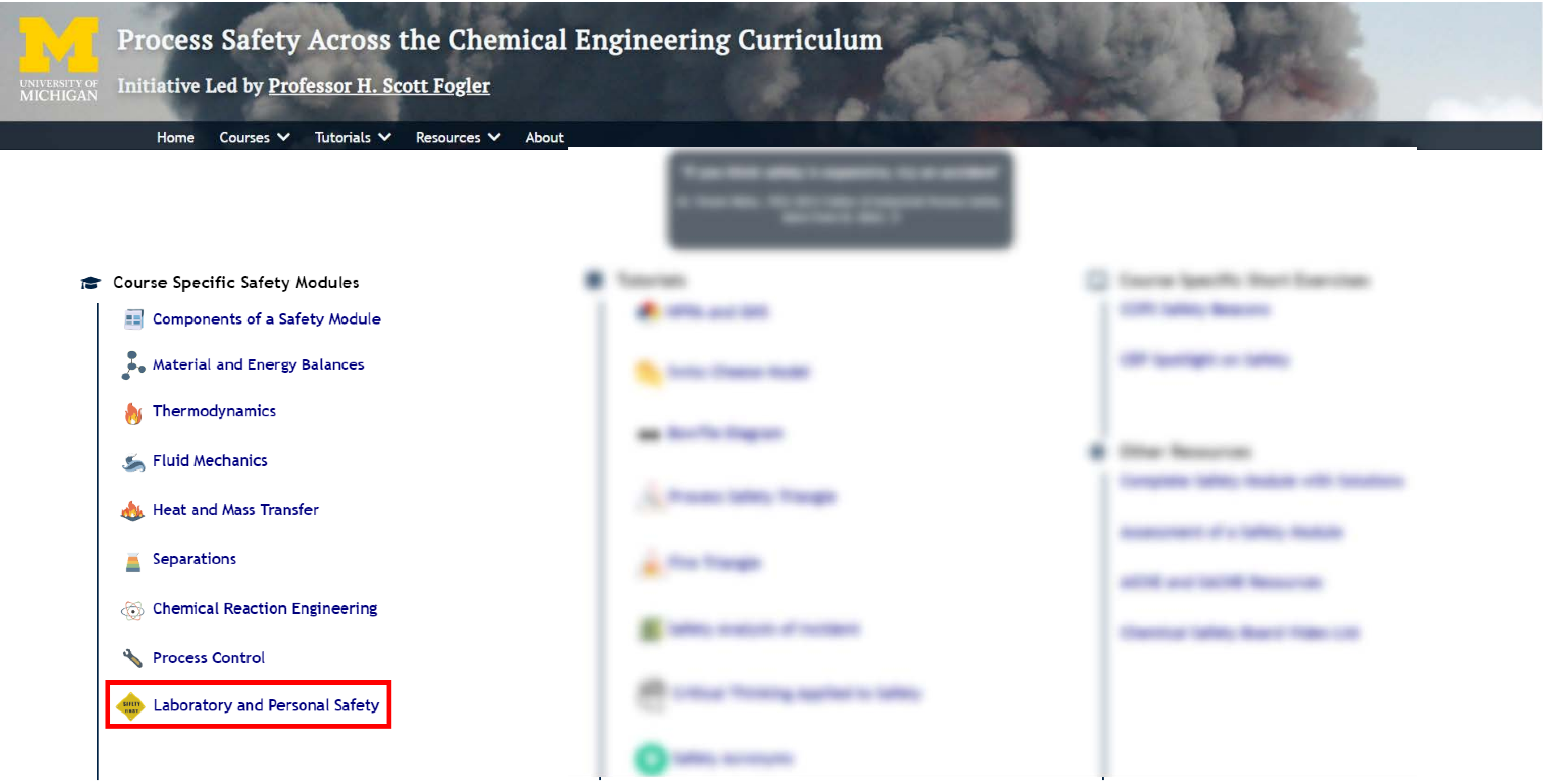
Application of Critical Thinking in Safety

4. Questions that probe reasons and evidence: *The purpose of this question is to explore whether facts and observations support an assertion.*	• What would be an example? • Why is . . . happening? • What is analogous to. . . ? • What do you think causes. . . ? Why? • What evidence is there to support your answer?	What evidence do you have that corrosion may have occurred in this tank in the last 10 years?
5. Questions that probe viewpoints and perspectives: *The purpose of this question is to learn how things are viewed or judged and consider things not only in a relative perspective but also as a whole.*	• What is a counterargument for ____? • What are the strengths and weaknesses of that viewpoint? • What are the similarities and differences between your point of view and compare the other person's point of view? • Compare ______ and ______ with regard to _________. • What is your perspective on why it happened?	What are counter arguments for taking all the insulation off and inspecting the tank?

Application of Critical Thinking in Safety

4. Questions that probe reasons and evidence: *The purpose of this question is to explore whether facts and observations support an assertion.*	• What would be an example? • Why is . . . happening? • What is analogous to. . . ? • What do you think causes. . . ? Why? • What evidence is there to support your answer?	What evidence do you have that corrosion may have occurred in this tank in the last 10 years?
5. Questions that probe viewpoints and perspectives: *The purpose of this question is to learn how things are viewed or judged and consider things not only in a relative perspective but also as a whole.*	• What is a counterargument for ____? • What are the strengths and weaknesses of that viewpoint? • What are the similarities and differences between your point of view and compare the other person's point of view? • Compare ______ and ______ with regard to _________. • What is your perspective on why it happened?	What are counter arguments for taking all the insulation off and inspecting the tank?
6. Questions that probe implications and consequences: *The purpose of this question is to help understand the inferences or deductions and the end result if the inferred action is carried out.*	• What are the consequences if that assumption turns out to be false? • What will happen if the trend continues? • Is there a more logical inference we might make in this situation? • Could you explain how you reached that conclusion? • Given all the facts, is that really the best possible conclusion?	What are consequences of ethylene oxide leaking into the atmosphere on people, equipment and the environment?

Laboratory and Personal Safety



Laboratory and Personal Safety

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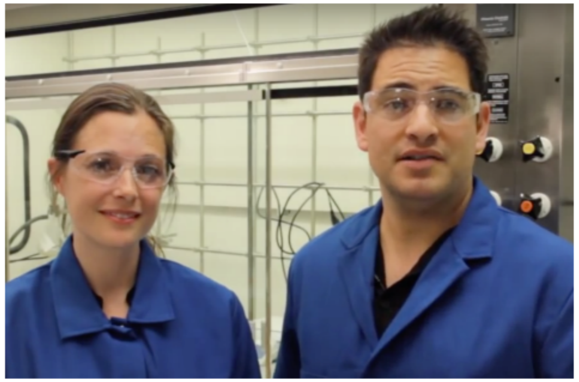
Laboratory Safety

Safety Snippet Videos

Assignment: After viewing each safety snippet, write down 1 to 3 key takeaways for each video.

Outfit for Safety



Play video (5 minutes)

Description:

A video created by the University of California, San Diego that comprehensively discusses the appropriate pieces of personal protective equipment for different laboratory environments.

Safety Gear

Play video (1 minute)

Description:

This video, developed by the EECS Department at the University of Michigan, highlights the importance of wearing the proper safety gear in the lab.

The Sloppy Lab

Play video (2 minutes)

Description:

The EECS Department at the University of Michigan created this video to demonstrate the hazards that a sloppy lab poses.

Evacuate

Play video (2 minutes)

Description:

The EECS Department at the University of Michigan stresses the importance of evacuating the building at the sound of any alarm, even if it may just be a drill in this video.

Food in the Lab

Play video (2 minutes)

Description:

This video emphasizes the potential consequences of bringing food into the lab and was produced by the EECS Department at the University of Michigan.

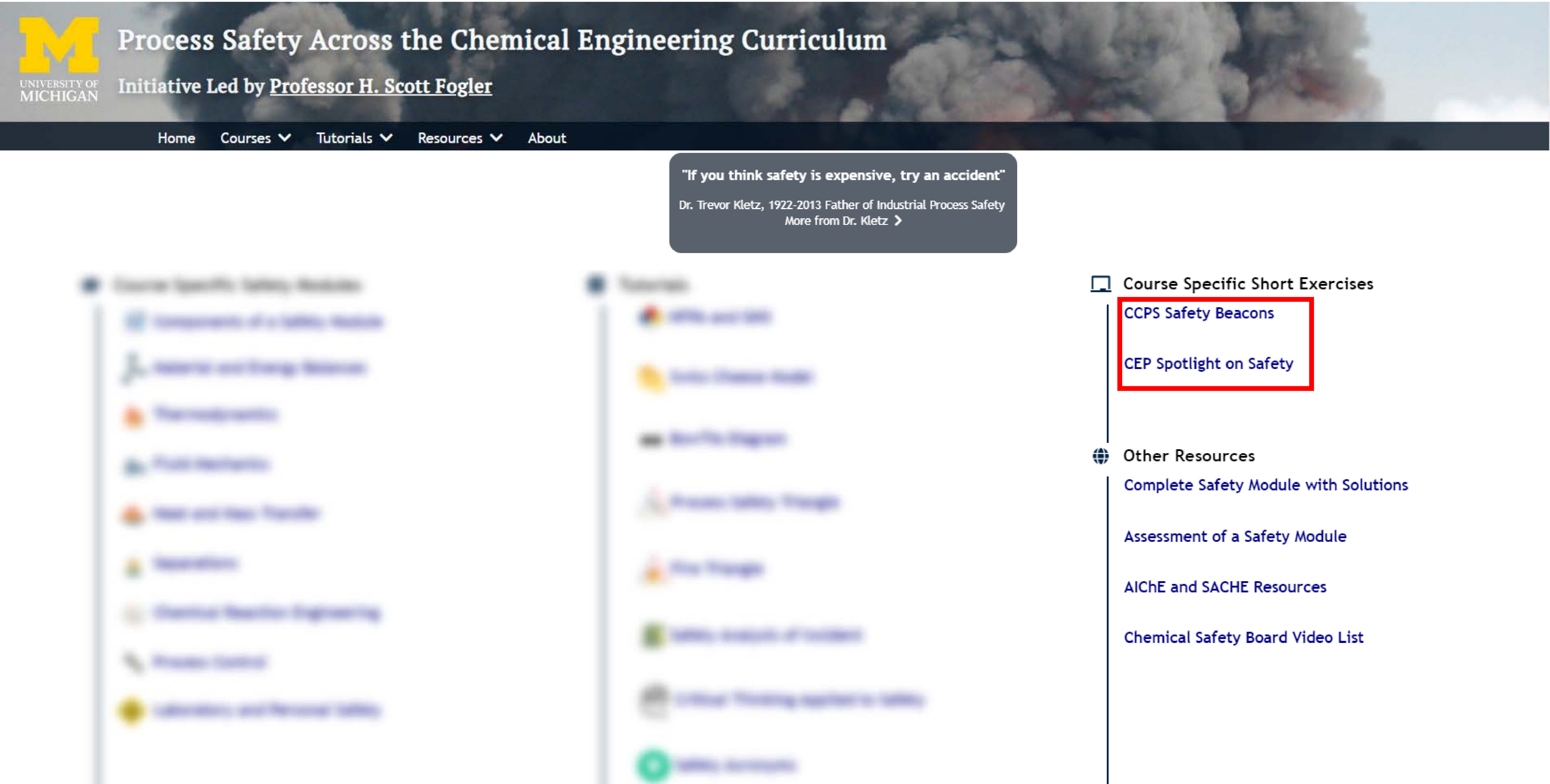
How to Use an Emergency Safety Shower

Play video (2 minutes)

Description:

This video, produced by EHS at Iowa State University, reviews the proper use of an emergency safety shower.

CCPS Safety Beacons



CCPS Safety Beacons

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Abbreviated CCPS Safety Beacon Archive

Material and Energy Balances

Hazards of High Oxygen Concentration

- Date: January 2017

Link

Mixing Incompatible Materials in Storage Tanks

- Date: February 2017

Link

Liquefied Gases

- Date: December 2017

Link

CCPS
An AIChE Technology Alliance
Center for Chemical Process Safety
www.aiche.org/ccps

Process Safety Beacon

http://www.aiche.org/CCPS/Publications/Beacon/index.aspx
Messages for Manufacturing Personnel

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Liquefied Gases

December 2017

1

2

In July 1948 a tank car filled with dimethyl ether (DME) arrived at a factory in Ludwigshafen, Germany. It stood in sunlight for about 10 hours when it is believed that a weld seam failed. About 200 people were killed, nearly all by the explosion of the flammable DME vapor cloud created by the leak. Nearly 4000 people were injured, the majority by exposure to toxic substances escaping from installations damaged by the blast (Picture 1).

In July 1978, a tank truck carrying propylene ruptured, and the released gas ignited. This occurred in a vacation area near Tarragona, Spain. The explosion killed 217 people, including the driver. 200 other people were severely burned (Picture 2).

A common cause of these accidents was a tank overfilled with liquefied gas. In the first incident, the tank identification plate incorrectly showed a higher capacity than the tank car could actually hold. In the second incident the cause may have been human error when filling the tank.

Did you know?

- Gases such as nitrogen, oxygen, and argon are shipped or stored as liquids at extremely low temperature, or as compressed gas at ambient temperature and thousands of psig (hundreds of bars) pressure.
- Other gases such as ammonia, chlorine, sulfur dioxide, vinyl chloride, propane, LPG, and dimethyl ether (DME) condense to a liquid at room temperature under moderate pressure, and are usually shipped or stored as liquefied gas.
- A vessel filled with condensed liquid contains more material than the same size vessel filled with compressed gas – liquid has a higher density. For example, a cylinder of argon gas at 2900 psig (200 bar) holds about the same amount of material as a cylinder of the same size containing liquefied propane at only 116 psig (8 bar).
- Liquefied gases, like most other liquids, expand when heated. As the liquid expands, the vapor space in a closed container shrinks. If the container becomes completely liquid filled and continues to be heated, it can rupture from the pressure of liquid expansion. Thermal expansion of a liquid can generate very large pressures with a relatively small temperature increase. The result of the container rupture is a boiling liquid expanding vapor explosion – BLEVE (November 2009 and August 2013 *Beacons*).

What can you do?

- Energy in a pressurized container depends on its size, temperature, pressure, and the state of the contents – condensed liquid or compressed gas. Avoid adding to this energy by exposing containers to heat from their surroundings.
- Read the safety information about gas containers you handle, and follow recommended procedures.
- If you fill containers with a liquefied gas, ensure that you do not overfill them.
- Read the October and December 2006 *Beacons* which discuss gas cylinder safety.
- You may have liquefied gases at home – for example, as fuel for a grill, a home heater, or a stove. Liquefied flammable gas may also be present in lighters or aerosol cans. Handle these with the same care as you would at work, and make sure that your family understands the hazards.

Do not underestimate the hazards of liquefied gases!

Questions:

1. **(10 min)** Considering that tanker trucks often must be driven and parked in the sun, discuss in 3-4 sentences the errors which seemed the most avoidable.

2. **(5 min)** List two hazards of working with DME.

3. **(5 min)** *What did you learn?*
   What kinds of serious consequences are likely to occur when a tanker truck vessel explodes and what kinds of federal or state regulation could have prevented this from occurring?

Questions:

1. **(10 min)** Considering that tanker trucks often must be driven and parked in the sun, discuss in 3-4 sentences the errors which seemed the most avoidable.

    - Incorrect/Non-existent listing of the storage tank capacity.
    - Tanker truck vessels not regularly pressure and leak tested and visually inspected for cracks.
    - Tanker truck liner not used or inspected.

2. **(5 min)** List two hazards of working with DME.

    - Inhalation toxicity.
    - Extreme combustibility and flammability in the liquid and gaseous states.

3. **(5 min)** *What did you learn?*
    What kinds of serious consequences are likely to occur when a tanker truck vessel explodes and what kinds of federal or state regulation could have prevented this from occurring?

    Lack of mandatory inspections of large transport vehicles resulted in 417 people dead and 4200 injured between these two incidents. In the U.S., the Department of Transportation mandates that all chemical transport vehicles be externally and internally inspected, pressure and leak tested, thickness tested, and have the proper load capacity listed. These inspections are performed on a routine and regular basis. Also vessel liners are required whenever corrosive materials are being transported. These regulations could have saved the lives of hundreds of people.

CEP Spotlights

Process Safety Across the Chemical Engineering Curriculum

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CEP Spotlight on Safety Archive

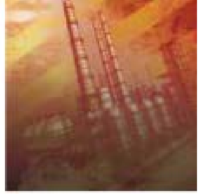
Introduction: Below is a compilation of Spotlight on Safety articles from CEP. They have been listed in a suggested to order you might consider reading but can be read in any order.

Why am I Passionate about Process Safety?, Feburary 2012
Article

The Importance of Considering the Highly Improbable, Feburary 2013
Article

Hazard Awareness and Operational Discipline, May 2013
Article

Process Safety Starts in the School Laboratory, Feburary 2016
Article



Louisa A. Nara
CCPS

What is Safety Worth?

The U.S. Chemical Safety and Hazard Investigation Board (CSB) has issued more than 130 investigative reports during its almost two decades of operation. These valuable documents detail investigations of incidents at industrial facilities involving fatalities, injuries, and environmental impacts. The insights and recommendations they provide have helped prevent reoccurrences. I have heard first-hand testimonials at chemical facilities in the U.S. and around the world of the usefulness of CSB investigations and reports in evaluating hazards and risks.

The president's recent budget request, however, seeks to eliminate the CSB entirely. While the tiny agency requires a budget of only about $12 million, the "America First: Budget Blueprint to Make America Great Again" overlooks the value of that small financial investment. The CSB helps to maintain the safety and security of U.S. businesses and citizens, helping to save both money and lives.

The CSB began operation in 1998 as an independent, nonregulatory, federal agency with a mission to conduct investigations of chemical accidents, identify root causes and potential contributing factors, and communicate findings to the American people. Reports of these investigations are distributed for free and are used by industry, emergency responders, and communities to prevent future catastrophic incidents. Many of the CSB's recommendations have been directed at the U.S. Occupational Safety and Health Administration (OSHA), the U.S. Environmental Protection Agency (EPA), and industry trade organizations to improve existing regulations, standards, guidelines, and outreach programs.

What is the value of the CSB?

To people. According to a 2017 Strata report, the EPA set the value of a statistical human life at $6.3 million; the U.S. Food and Drug Administration (FDA) at $6.5 million; and the U.S. Dept. of Transportation (DOT) at around $9.1 million. If recommendations from the CSB save just two lives a year, the CSB would pay for itself.

Asphyxiation in industrial settings is one hazard to human life that the CSB has highlighted. Nitrogen is safe to breathe when mixed with an appropriate level of oxygen, but disrupting the balance in air (78% nitrogen, 21% oxygen, 1% other) can cause nitrogen asphyxiation. Decreases in oxygen concentration can cause impaired judgment, and concentrations below 10% can be fatal. From 1992 to 2002, the CSB investigated 85 incidents of nitrogen asphyxiation that caused 80 deaths and 50 injuries. To share this information with industry and the public, the CSB created a training presentation on the hazards of nitrogen (www.csb.gov/assets/1/19/Nitrogen_Asphyxiation_Bulletin_Training_Presentation.pdf).

To property and the environment. Many of the incidents that the CSB investigates have profound consequences that extend beyond the borders of the facility and affect the surrounding community. Such was the case in West, TX, at the West Fertilizer Co. storage and distribution facility (www.csb.gov/west-fertilizer-explosion-and-fire-). An ammonium nitrate explosion at the facility killed 15, injured 260, and caused widespread damage to the surrounding community. Lack of zoning regulations to restrict buildings near hazardous industrial facilities allowed the town of West to encroach on and overtake a safety buffer zone around the plant.

CSB recommendations based on its investigations of the incident include training and certification programs, hazardous response operating procedures for emergency responders, and updates to regulations and codes that aim to make facilities, personnel, communities, emergency responders, and citizens safer.

In addition to impacting facilities and communities, incidents can have an environmental footprint as well. A toxic release of allyl alcohol vapor at the MFG Chemical, Inc., facility in Dalton, GA, sent 154 people to the hospital and forced the evacuation of nearby residents (www.csb.gov/mfg-chemical-inc-toxic-gas-release). The release also contaminated water at the facility that made its way into two nearby creeks, killing fish and other aquatic life.

Priceless

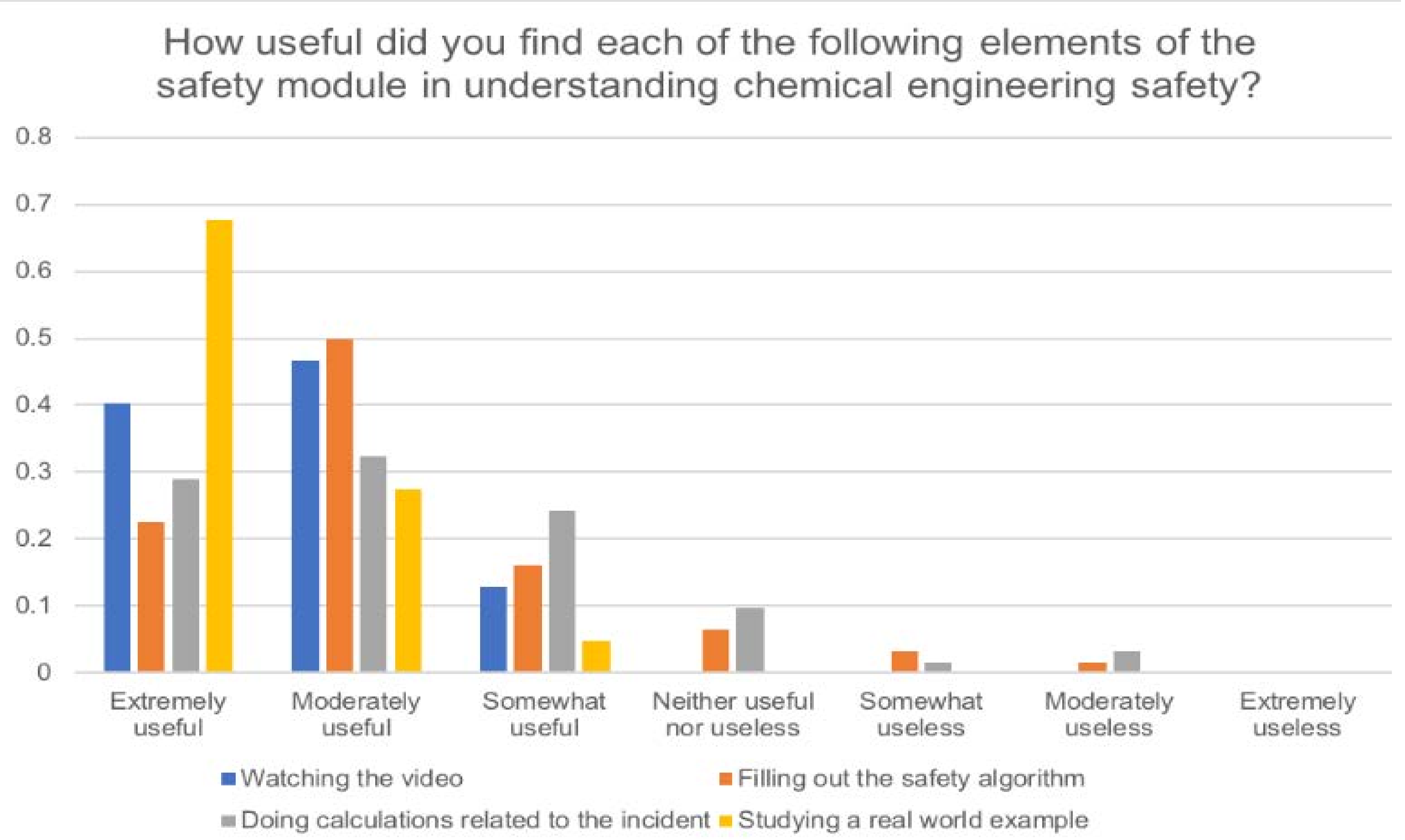
Bruce K. Vaughen, a well-regarded process safety professional and coauthor of *Process Safety: Key Concepts and Practical Approaches,* says, "Incidents with fatalities, injuries, environmental harm, and property damage, described in detail in the publicly available CSB reports and videos, provide yet another set of eyes to help us better understand what happened, and additional guidance on how we can prevent the incident from recurring."

Preventing an industrial incident means preventing fatalities, injuries, damage, and environmental impacts. Prevention can be difficult to quantify, especially when there are injuries and fatalities involved. Although I attempted to detail the financial cost, the moral and ethical value is more nebulous. For this reason, when considering the value of the CSB, I would conclude that it is priceless. CEP

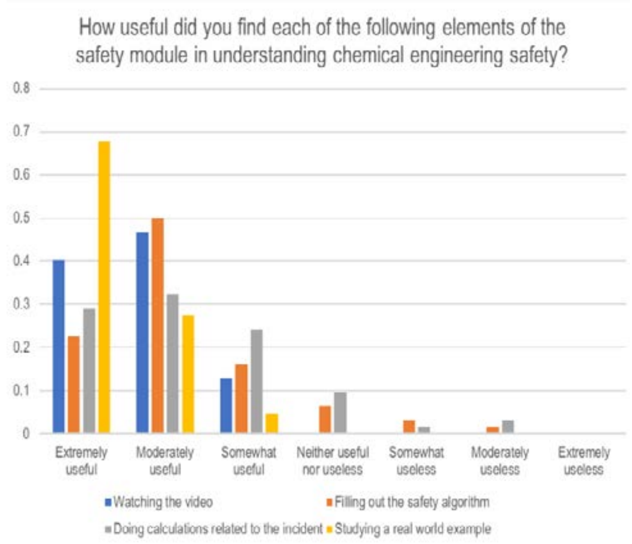
CEP Spotlight Solutions

What is Safety Worth? **Course:** General Interest, Process Economics	In two or three sentences, explain the role of the U.S. Chemical Safety and Hazard Investigations Board (CSB). Ex: The CSB investigates process safety incidents in the chemical engineering industry. Their investigations serve to ascertain the root causes and contributing factors of these incidents, and to determine measures for preventing incidents from recurring. The agency communicates findings to the industry and the public in the form of incident reports and training presentations, in order to raise awareness of process safety hazards and risk mitigation and/or elimination procedures. Explain, in 3-4 sentences, the author's view on the value of process safety. Ex: The author believes that safety is priceless. It is possible—albeit very difficult—to estimate the value of preventing incidents and their consequences. However, evaluating the moral and ethical ramifications of process safety is prohibitively difficult, leading to the author's conclusion. Explain three risks of process safety incidents involving explosions and/or flammable substances for people and the value of CSB incident reporting and communication programs to prevention and/or mitigation of these incidents. Ex: Improper handling of explosive and flammable substances may lead to severely injurious or even lethal incidents. The overpressure caused by explosions may yield critical injuries or deaths. Explosions which originate within ruptured equipment may shoot heavy debris over large distances; anyone struck by this debris will likely be severely injured or killed. Additionally, explosions may lead to the release of flammable substances from ruptured chemical engineering equipment, the ignition of which may lead to large fires, which may cause burns to operators and/or emergency responders during containment operations. The findings of a CSB investigation on incidents involving explosions may prove to be informative to chemical engineering facilities and the public. All parties will be further aware of the hazards of explosives and/or flammables and recommendations for risk mitigation or elimination. The incident analysis may prove to be a learning opportunity for improving process safety programs across the chemical engineering industry.

Feedback from the Students

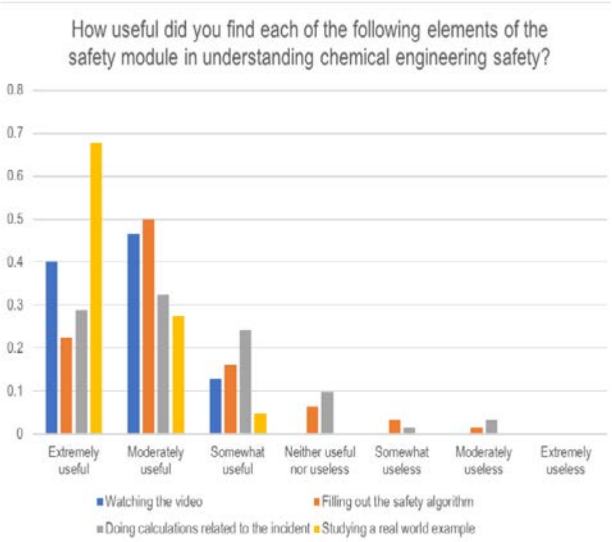


Feedback from the Students



At the end of the survey, students were asked to provide additional feedback. The responses below were selected to reflect students' positive impressions of the use of the safety module in their course. Students reported:

Feedback from the Students



Students reported:

•"It was insightful to learn and see the consequences when safety factors are not properly considered."

•"This was a helpful experience and helped me begin my study of safety in the context of chemical engineering."

•"The safety module was very interesting. It was cool to see how what we learn in class has an immediate impact in the real world."

•"I thought it was an interesting way to apply what we are learning in class to a real-world example and especially safety, which we don't get a lot of directly in class."

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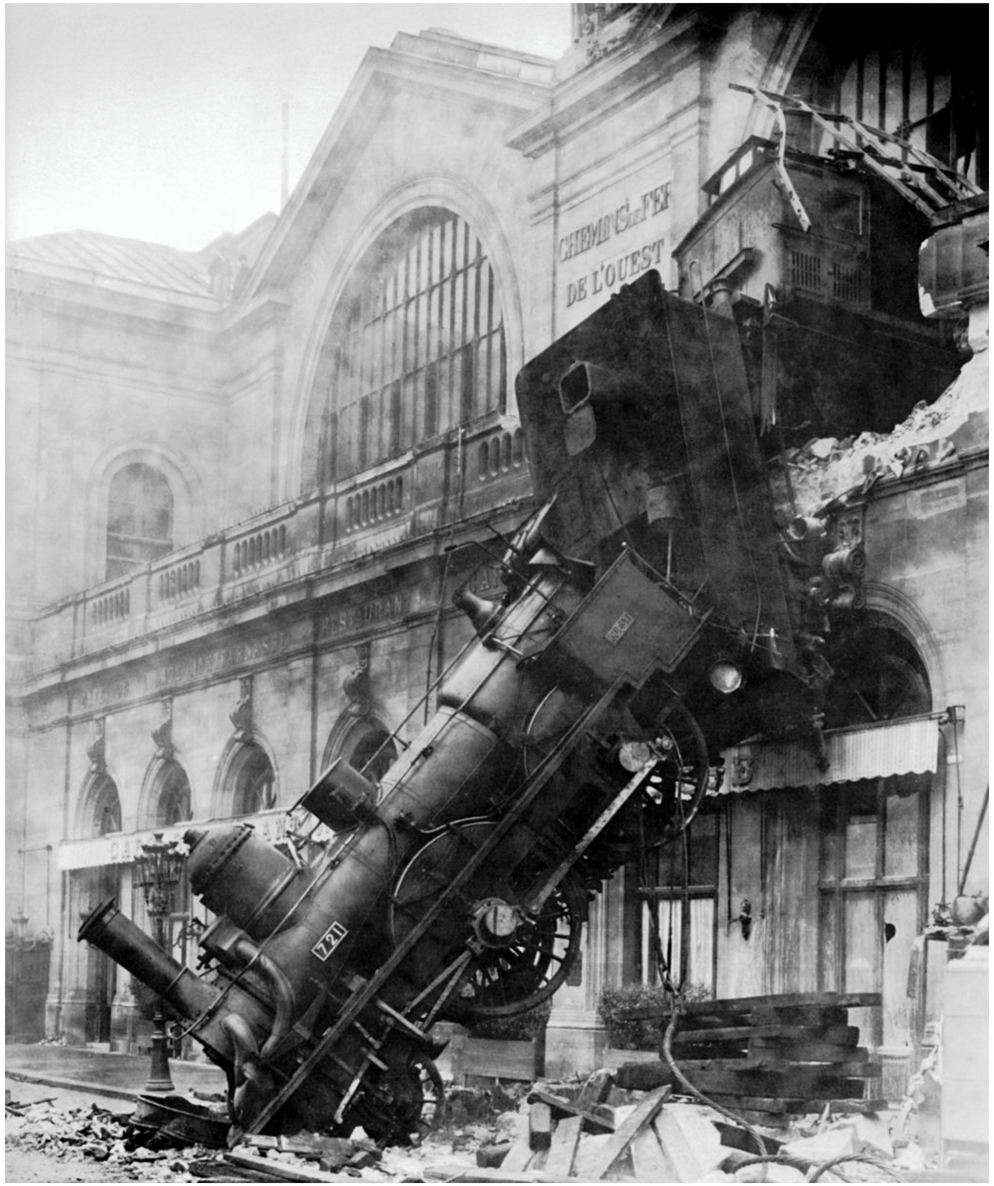
Chemical Engineering Curriculum

Fall		Winter
	1st Year	
Engineering 100		--
	2nd Year	
230 Introduction to Materials and Energy Balance		**330 Chemical and Engineering Thermodynamics**
	3rd Year	
342 Mass and Heat Transfer		**344 Chemical Reaction Engineering and Design**
343 Separation Processes		**360 Chemical Engineering Laboratory I**
	4th Year	
460 Chemical Engineering Laboratory II		**487 Process Simulation and Design**
466 Process Dynamics and Control		**488 Chemical Product Design I**
		4XX Elective

Conclusions

1. The students view a number of case history videos and analyze them.
2. The reoccurring safety algorithms and NFPA diamond and Bow Tie diagrams *instill a mindset* about safety.
3. Every student has safety training rather than a small faction of the graduating class.
4. The student sees the disastrous consequences when safety conditions are violated and an accident occurs.
5. These Modules received a very positive response when they were class tested and followed by an evaluation of the students in the class.

… and if you don’t stop on time.



Any questions?