JeffCo Fire Investigators 2014 Spring Seminar

Disasters in the Process Industries

presented by Mike Schmidt

BLUEFIELD
PROCESS SAFETY

Mike Schmidt bio

- **Principal of Bluefield Process Safety since 2008**
- **Joined Union Carbide in 1977**
- **Began work in process safety, following tragedy in Bhopal in 1984**
- **Joined faculty at Missouri S&T in Rolla in 2009, teaching on safety and risk**
- **Work includes**
  - **Facilitating PHAs, LOPAs, RTC establishment**
  - **SIS conceptual design, SIL verification calcs**
  - **PSM compliance and audits**
  - **Incident investigations**

What we will cover

- **Process Hazards**
- **Process Fires**
- **Process Explosions**
- **Layers of Protection Analysis**
- **Independent Layers of Protection**
- **When emergency response makes it worse**

Disasters in the Process Industries

Process Hazards

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The Regulation

29 CFR 1910.119

- **The Process Safety Management Standard**
- **Promulgated in 1992**
- **Sometimes known as "OSHA 1910" or "OSHA PSM"**

Purpose of PSM

"…preventing or minimizing the consequences of catastrophic releases of toxic, reactive, flammable, or explosive chemicals. These releases may result in toxic, fire, or explosion hazards."

Types of releases

- Toxic
- Reactive
- Flammable
- Explosive

Types of hazards

- Toxic
- Fire
- Explosion

Application of PSM Standard

"the covered processes"

- **29 CFR 1910.119(a)**
- **When the standard applies**
- **Exceptions**

...preventing or minimizing consequences of...

Releases of

- **Toxic**
- **Reactive**
- **Flammable**
- **Explosive chemicals**

These types of chemicals determine coverage by the PSM standard

Threshold Quantities

- A process is covered only if it exceeds TQ
- A process that can stay below the TQ is not covered

Threshold Quantities

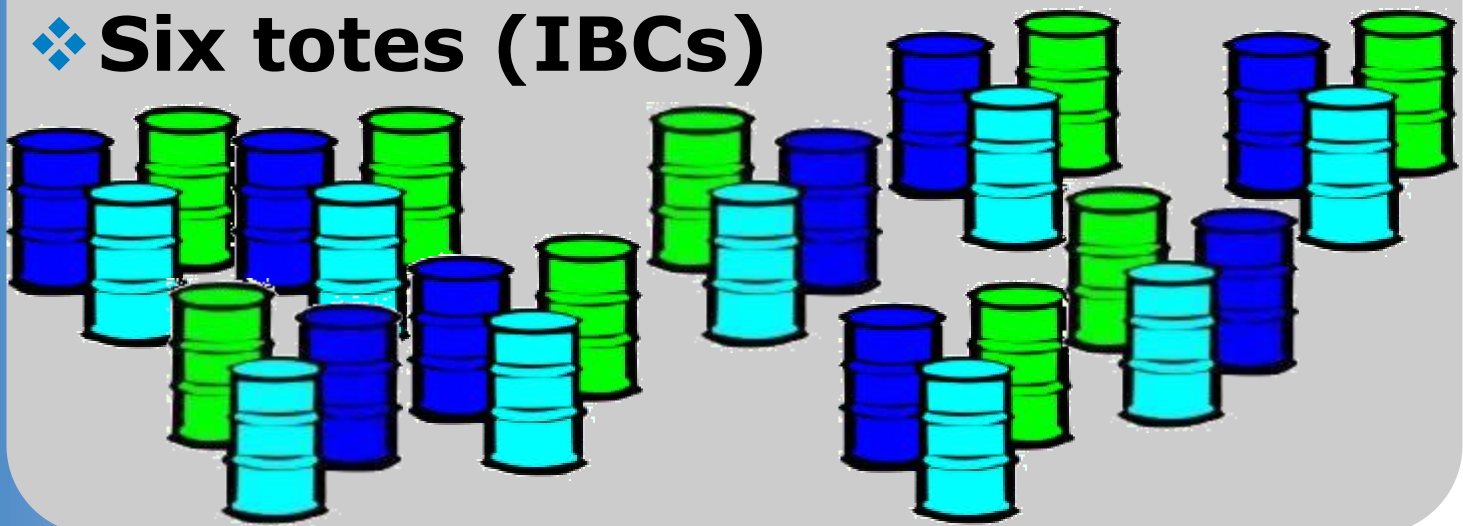
- **Flammable Liquids and Gases**
  - **10,000 lbs**
- **Toxic or Reactive Chemicals**
  - **Depends on chemical, ranges from 100 to 15,000 lbs**

A Flammable Liquid or Gas?

- Defined in 29 CFR 1910.1200(c)
- Flammable Liquid – Any liquid with flashpoint at or below 100°F
  - Except any mixture having 99% or more of components with flashpoints above 100°F
- Flammable Gas – Any gas at ambient temperature/pressure
  - LEL ≤ 13%
  - UEL – LEL ≥ 12%

How much is 10,000 lbs?

- **Typically, around 1,500 gallons (s.g. = 0.8)**
- **Around ¼ of tank truck**
- **A little over two dozen drums**
- **Six totes (IBCs)**



A Toxic or Reactive Chemical?

- **One of 137 chemicals listed in Appendix A**
- **Hazard determined by**
  - **Toxicity or reactivity**
  - **Volume of use in commerce**
- **Some chemicals with greater toxicity are not listed**
- **Those that are listed have different threshold quantities, based on toxicity or reactivity**

Some Toxic TQs

- 100 lb – Sarin nerve gas
- 150 lb – Nickel carbonyl
- 250 lb – Nitrogen oxides
- 500 lb – Furan
- 1000 lb – Hydrogen cyanide
- 1500 lb – Chlorine
- 2500 lb – Methyl bromide
- 5000 lb – Anhydrous hydrochloric acid
- 7500 lb – Hydrogen peroxide (≥ 52%)
- 10000 lb – Anhydrous ammonia
- 15000 lb – Methyl chloride

Exceptions

- **Flammable materials exceptions**
  - **Fuel exception**
  - **Atmospheric storage exception**
- **Facility exemptions**

Fuel Exception

- **Hydrocarbons**
- **Used solely as fuels**
- **Not connected to process that uses other chemical covered by PSM standard**

For example

- **Propane tank, used for heating**
- **Gasoline tank, used to fuel vehicles**
- **Acetylene, used for torch welding**

Atmospheric Storage Exception

- **Flammable liquids stored in atmospheric tanks or transferred**
- **Kept below their normal boiling point without chilling or refrigeration**
- ***Atmospheric tank* – a storage tank designed to operate between 0 and 0.5 psig.**
- **Meer decision of 1997.**

Facility Exemptions

- **Retail facilities**
- **Oil or gas well drilling or servicing operations**
- **Normally unoccupied remote facilities**

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Process Fires

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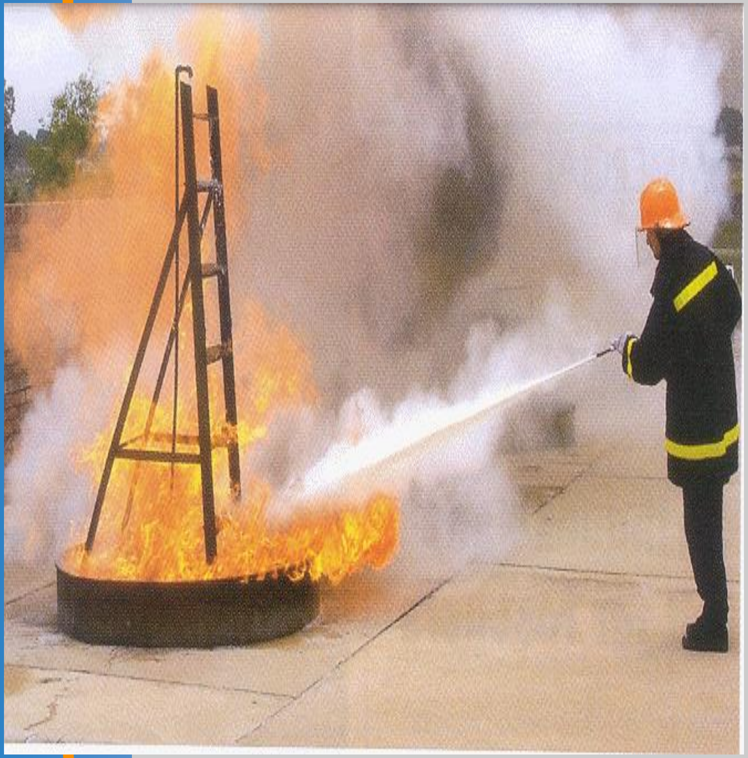
Process Fires

- **Combustion reaction that releases light, heat, and combustion products**
  - **Conflagrations**
  - **Pool fires**
  - **Jet fires**
  - **Vapor cloud fires**

Photo by Rick Martin, 2005, CC-SA-3.0

Pool Fire



- Fire occurs on surface of a flammable liquid
- Major harm of pool fire is caused by thermal radiation of sooty fire
- Localized effects; major concern is to prevent fire from spreading

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Jet Fire

- Pressures above 30 psig—choked flow, sonic velocity
- Significant erosive force
- Flashing liquid (2-phase) are worst—they have high velocity and highly radiant, sooty flames

CSB Safety Video: Wastewater Plant Explosion

Source: flashovertv.firerescue1.com/videos/2485490721001-csb-safety-video-public-worker-safety-wastewater-plant-explosion/

Vapor Cloud Fire (Fireballs)

- Cloud must form first
- Cloud must be between LFL and UFL
- Flame front moves through flammable cloud
- No
  - Shrapnel
  - Shock wave
  - Overpressure

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Process Explosions

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Process Explosions

- Rapid increase in volume and release of energy, resulting in shrapnel, overpressure, and shock wave
  - VCE
  - BLEVE
  - Dust Explosion
  - Physical Explosion
  - Decomposition

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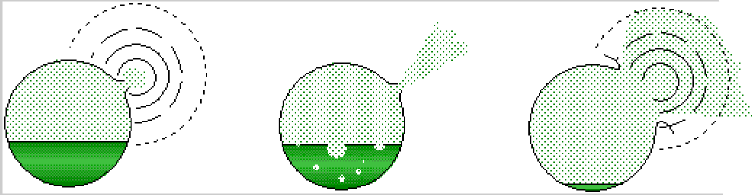
Vapor Cloud Explosions

- **Normally requires**
  - **Large release of flammable material above normal boiling point**
  - **Formation of cloud within flammable limits of sufficient size**
  - **Conditions to provide sufficient confinement**
- **An ignition source ignites the cloud; typically a deflagration rather than a detonation**

BLEVE



- **Boiling Liquid Expanding Vapor Explosion**
- **Release of pressure on liquid above its normal b.pt. results in boiling into an expanding vapor, causing explosion**
- **Combustion is not part of BLEVE, but if a flammable liquid forms a vapor cloud and finds an ignition source, a vapor cloud fire or VCE could also occur.**

BLEVE Explosion

Source: http://flashovertv.firerescue1.com/videos/2542082434001-bleve-explosion/

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Dust Explosions

- Any solid that can burn can explode if reduced to a fine enough particle size
- Relatively minor event disturbs accumulated dust, creating dust cloud, which then explodes
- Preventative measures
  - Dust collection
  - Housekeeping

Imperial Sugar Dust Explosion

Source: www.youtube.com/watch?v=Jg7mLSG-Yws

Physical Explosions

- **Pressurized gas from ruptured vessel rapidly expands**
  - **Shrapnel**
  - **Shock wave**
- **Caused by vessel overpressure**
  - **External heating**
  - **Runaway reaction**
- **Energy released into**
  - **Vessel fragmentation**
  - **Velocity of fragments**
  - **Force of shock wave**

Decomposition

- Single molecule breaks down into several molecules
- Decomposition products are gases
- Exothermic
- Examples
  - Ethylene oxide
  - Propylene oxide
  - Ammonium nitrate

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Layers of Protection Analysis

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Layer of Protection Analysis

Likelihood analysis linking:

- **Frequency of initiating event (cause)**

  TO

- **Frequency of resulting fault (consequence)**
- **Through chain of enabling conditions and layers of protection, each with their own probability**

LOPA Scenarios

- **Scenario description**
  “Deviation” leads to “Event”
- **Cause**
  “Failure”   “Frequency”
- **Consequence**
  “Safety impact”   “Tolerable freq.”
  “Social impact”   “Tolerable freq.”
  “Envir. impact”   “Tolerable freq.”
  “Asset impact”   “Tolerable freq.”

Causes

- “Cause” *aka* “Initiating event” *aka* “Basic Event”
- Refers to “Failure”
  - Equipment failures
  - Human failures (commission and omission)
  - External events

Some Typical Failure Rates

Initiating Cause	Frequency (1/yr)
Pump trip/failure	1
Seal or flange leak	1
Unit trip/failure	1
BPCS control failure	0.1
Heat tracing failure	0.1
Tube leak-corrosive service	0.1
Control valve-opposite of design	0.01
Relief valve-spurious operation	0.01
Total packing failure	0.01
Lightning strike	0.001
Rupture of rotating equipment	0.001
Tube failure-mild service	0.001

Frequency of Human Failure

- **What is the error?**
- **What is the frequency of the opportunity to make the error?**
- **What is the probability that the error will be made during the opportunity?**

Stochastic Human Reliability

Probability of human error:

- **Error executing high-stress, non-routine task: P = 1**
- **Error executing routine, or low stress, non-routine task: P = 0.1**
- **Failure to properly execute routine written procedure: P = 0.01**
- **Failure to execute multiple step checklist with review: P = 0.001**

Consequences

- **Risk is discussed in terms of consequences**
- **"Consequence" aka "Resulting Fault" aka "Hazardous Outcome"**
- **Two parts: Events → Impacts**
- **One event, many impacts:**
  - **Safety**
  - **Community (Social)**
  - **Environmental**
  - **Asset (Commercial, Financial)**

Events

- **Fire**
- **Explosion**
- **Toxic Release**
- **Vessel Rupture**
- **Structural Collapse**
- **Cave-in**

- **Invites the question, "Yes, and...?"**

Impact Severity

- **Probable intensity of harm to specific type of receptor**
- **How bad is it?**
- **Expressed in "____ per event"**
- **Answers the question, "Yes, and…?"**

Examples of Impacts

- **Safety—3 workers killed**
- **Community—19 residents hospitalized**
- **Environment—53 miles of shoreline contaminated**
- **Asset—$170 million in damages and lost production**

Frequency Modifiers

- **Must occur or be present before initiating event can lead to hazardous outcome**
- **May be either an ongoing state or a specific event**
  - **Ongoing states are always called enabling conditions**
  - **Specific events are sometimes called enabling events**

Standard Frequency Modifiers

- **Time at Risk**
- **Occupancy Factor**
- **Ignition Probability**
- **Vulnerability Factor**

Time at Risk

- Standard failure rates are based on continuous operation
- Many components are only vulnerable to failure part of the time
- "Time at risk" takes this into account

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Time at Risk – Examples

- **Unit is down for turnaround 15 days each year:**
  350/365 = 0.959 → 0.96
- **Weather is cold enough to freeze line 3½ months a year:**
  3.5/12 = 0.2917 → 0.3
- **Batch with 8.3 hour average cycle time is in raw material charge phase for 1.6 hours**
  1.6/8.3 = 0.1927 → 0.2

Time at Risk and Opportunity

- **"Time at Risk" does not apply to opportunity based scenarios**
- **The number of opportunities is determined without regard to time at risk**

Occupancy Factor

- **Safety impacts based on personnel being there to become victims during an event**
- **In many operations, personnel are not always present**
- **"Occupancy factor" takes this into account**

Occupancy Factor and Impact

- **"Occupancy Factor" only applies to safety risks**
- **Based on probability of being there during event**
  - **What is "there"?**
  - **What is occupancy <u>during event</u>**
- **Environment, community, and assets are always there**

Ignition Probability

- Conservative assumption:
  Given fuel and oxidizer, there is always ignition
- Less conservative:
  Ignition has probability
  Based on
  - Type of release
  - Size of release
  - Release environment

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Ignition Probabilities

- **Immediate Ignition**
  - **Release caused by or near high energy source 0.3**
  - **Other cause of immediate ignition 0.1**
  - **Average probability of immediate ignition 0.2**
- **Delayed ignition**
  - **Local cloud, not high energy 0.1**
  - **Local cloud, some high energy 0.3**
  - **Cloud over large on-site area 0.5**
  - **Cloud over large off-site area 0.9**

Vulnerability Factor

- **Not everyone exposed to an event will suffer the worst impact**
- **Vulnerability Factor is a way to address this**
- **Not applicable if vulnerability has already been taken into consideration when defining impact or occupancy factor**

Other Frequency Modifiers

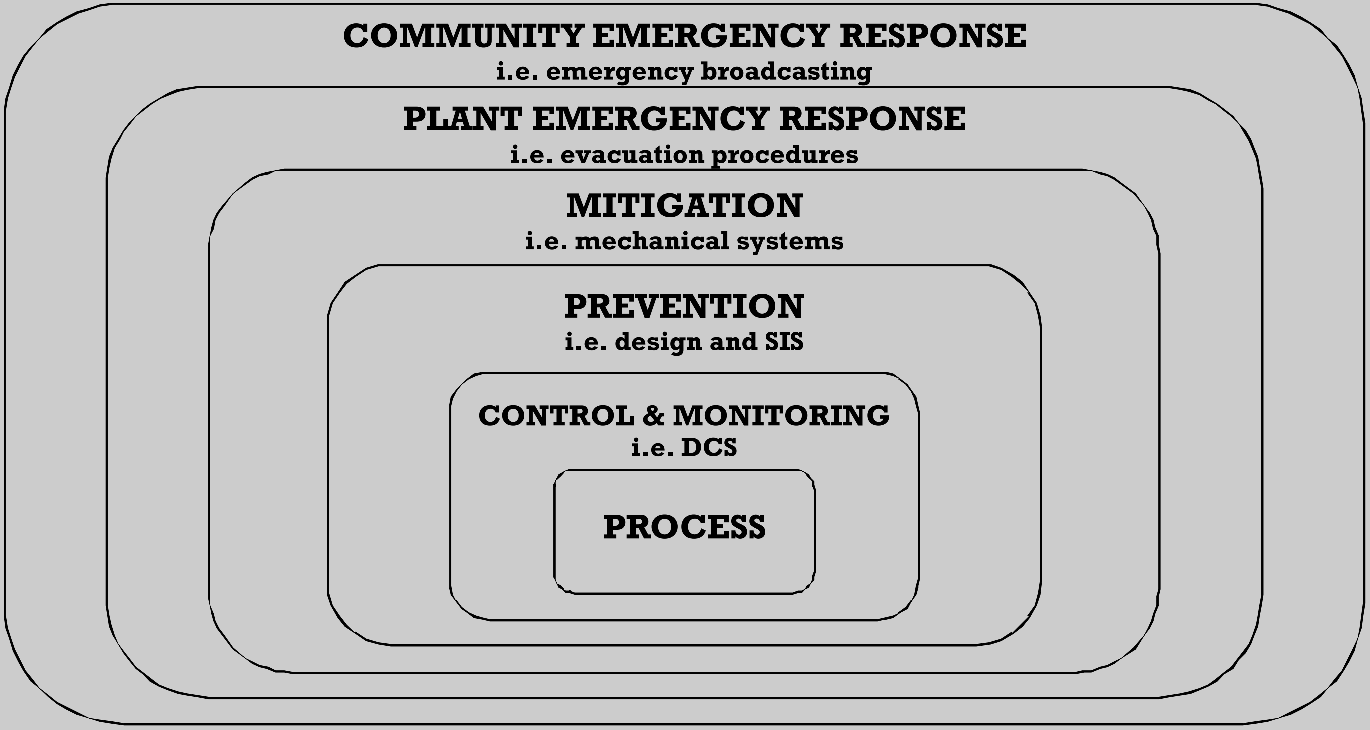
- **Other frequency modifiers can be applied as appropriate**

Examples:

- **Fraction of time a storage tank is full enough that receiving a load could result in a spill**
- **Fraction of time that sensitizing contaminant is present**

Layers of Protection

- **Each Layer is Independent**
- **Failure of one does not affect the next**

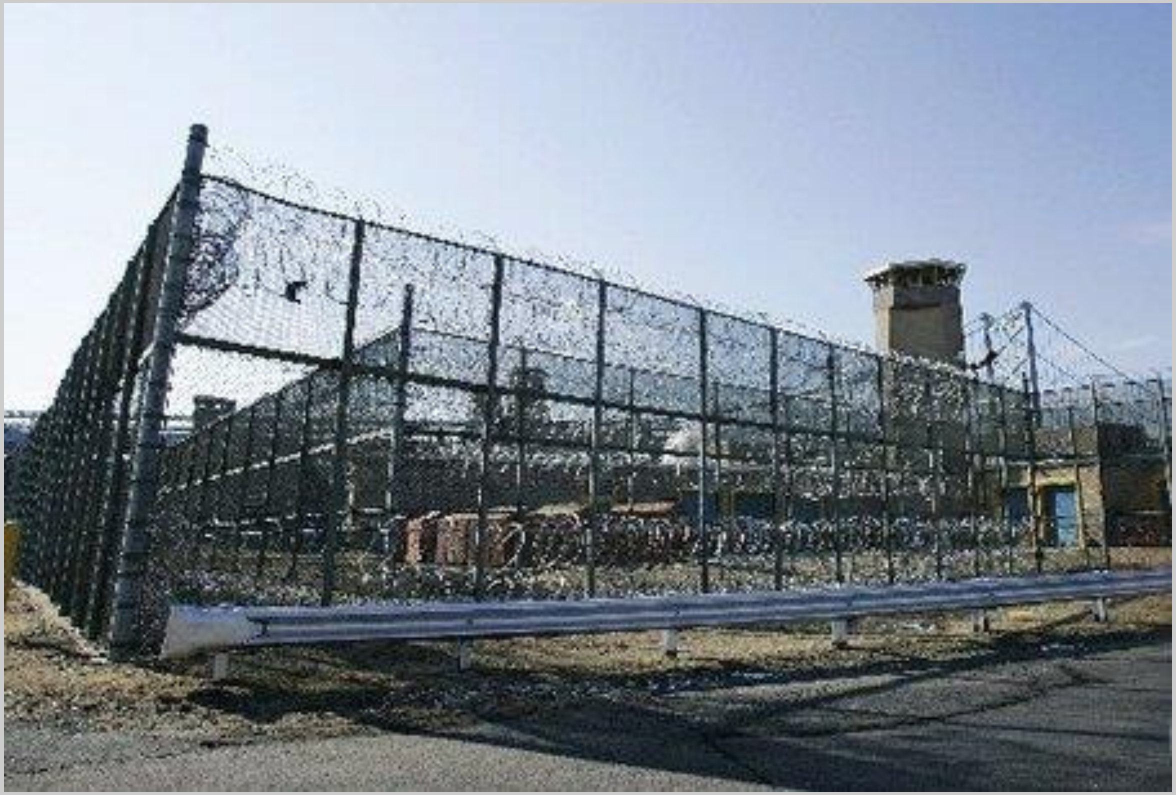


Layers of Protection

- **Less like an onion…**

Layers of Protection

…and more like a prison



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Independent Layers of Protection

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Administrative control

- **PFD_{AVG} = 0.1**
- **Comments: Any procedural safety measure, relying on human action, that is routinely done to prevent a hazard. Not done in response to a hazardous condition. Examples include valve car sealing programs, and checklists to double check execution.**

Atmospheric vent

- PFD_{AVG} = 0.001
- Comments: Protects against overpressure and excessive vacuum, if atmospheric vent is properly sized and directed to safe location. Low PFD_{AVG} depends on having no intervening valves or obstruction. Presence of valve increases PFD_{AVG} to 0.1.

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Auto fire suppression (aqueous)

- **PFD_{AVG} = 0.1**
- **Comments: Includes water and foam suppression. No credit if fire is event, but credit if fire is cause of further event, like BLEVE, runaway, equipment failure.**

Auto fire suppression (dry)

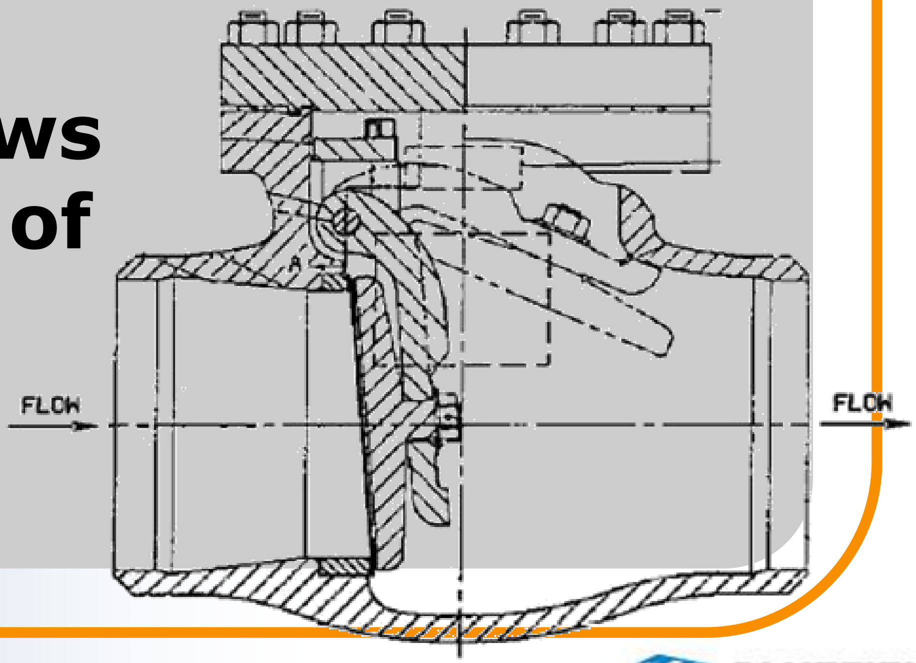
- $PFD_{AVG} = 0.01$
- **Comments: Includes Halon and dry chemical system. Credit if fire is within enclosure.**

Blast wall/bunker

- **PFD_{AVG} = 0.001**
- **Comments: Protects against explosion overpressure, flying shrapnel, thermal exposure.**

Check valve (w/MI program)

- **PFD_{AVG} = 0.1**
- **Comments: Do not take credit for more than two. Good for bulk flow, not leak-by. Only credit if MI program allows performance of check valve to be audited**



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Conservation vent

- PFD_{AVG} = 0.01
- Comments: Protects against overpressure, or excessive vacuum, or both, if properly sized. Must consider discharge location.

Detonation arrestor

- **PFD_{AVG} = 0.01**
- **Comments: Properly sized and installed, with liquid drain, and periodic inspection of device internals.**

Dike/bund

- **PFD_{AVG} = 0.01**
- **Comments: No penetrations. Includes periodic inspections for cracks or failed joints. Protects against environmental releases and minimizes size of pool fire.**

Flame arrestor

- $PFD_{AVG} = 0.1$
- **Comments:**
  Properly sized and installed, with liquid drain, and periodic inspection of device internals

Isolation valve

- PFD_{AVG} = 0.1
- **Comments: Mechanically operated valve that responds to hazardous condition without logic solver, e.g. fusible link**

Overpressure vent panels

- PFD_{AVG} = 0.01
- **Comments: Protects against overpressure from dust, gas, or vapor explosion in equipment or rooms. Must consider discharge location.**

Relief valve

- PFD_{AVG} = 0.01
- Comments: Do not take credit for more than two. Reclose after pressure is relieved. Must consider discharge location.

Rupture disk

- **PFD_{AVG} = 0.001**
- **Comments: Relieves more reliably than a relief valve, but does not reclose once pressure is below set point. Must consider discharge location.**

Disasters in the Process Industries

When Emergency Response Makes it Worse

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Two big issues

- **Occupancy**
- **Water**

Occupancy

Worksheet: **LOPA**

Bluefield Process Safety Proj. No.: **100XX**
ABC Chemical Corporation
Location: **Anytown, Anystate, USA**
Unit: **Reactor 3**

LOPA Rev.: **A**
LOPA Rev. Date: **17-Sep-2010**
Facilitator: **Mike Schmidt**

Hazard Identification

LOPA Scenario No.:	000
Ref. HazOp Node:	2011-03; Reactor 3
Ref. P&ID:	D-4233-201-1, Rev B
Hazard Description:	Loss of cooling to R-003 during exotherm, leading to overpressure, explosion

Initiating Cause (complete separate LOPAs for each cause of a consequence, then evaluate SIL)

Type of Cause	*Description of Initiating Cause*	*Annual Frequency*
Ongoing	Pump trip	1

Consequences

Type of Consequence	*Description of consequence per event*	*Severity Level*	*Tolerable Frequency*
Safety	≥ 1 fatality per event	B	0.0001
Environmental	≥ 1 reportable release	D	0.01
Community	≥ 1 hospitalization	C	0.001

Frequency Modifiers and Independent Layers of Protection

Description	*Details*	*FM or PFD*
Time at Risk	Exotherm during middle 4 hours of 13 hour batch	0.308
Occupancy Factor	24/7 occupation by multiple operators	2.5
Ignition Probability*	Not used	1
Vulnerability Factor*	Not used	1
Other FM 1	Not used	1
Other FM 2	Not used	1
IPL 1	Relief valve	0.01
IPL 2	BPCS control loop	0.1
IPL 3	Not used	1
IPL 4	Not used	1
IPL 5	Not used	1

Initiating frequency reduction factors: E/C = 0.000308 S = 0.000769

Integrity Level Requirements

	Envir or Oper	Safety
Likelihood of consequence (events per year) =	0.000307692	0.000769231

Type of Consequence	*Maximum PFD of SIF*[1]	*Required SIL*
Safety	0.13	Not rated
Environmental	1	No function required
Community	1	No function required

Notes

Cause: Cooling loop pump trip
BPCS Loop: Stop all feeds on high temperature

Consider additional cooling pump with auto-start for R-003

[1]Suggested SIF:

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Occupancy factor

- **“Evacuation during external fire”**
  → Occupancy factor = 0.01

  Replaced with

- **“First responders present during external fire”**
  → Occupancy factor > 1

Water

- Structural failures
- Water reactives
- Pool fires
- Boilover

Structural failures

- **Very hot steel, when suddenly cooled, becomes hard and brittle, subject to catastrophic failure**

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Water reactives - examples

- **Alkali metals**
  Reacts violently, generates H_2
- **Alkali metal hydrides**
  Reacts explosively, generates H_2
- **Alkyl aluminum**
  Reacts explosively
- **Chlorosilanes**
  Reacts violently, generates HCl
- **Metal trichlorides, tetrachlorides**
  Reacts violently, generates HCl

Pool fires

- Most flammable liquids are
  - Immiscible with water
  - Less dense than water
- They float to the top and spread over the surface
- Water spreads the fire

Boilover

- **Water, sitting at the bottom of a tank with external fire, flashes through combustible liquid above**

Crude Oil Boilover Explosion

Source: flashovertv.firerescue1.com/videos/2487202643001-crude-oil-boilover-explosion/

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Summary

- **OSHA PSM addresses some facilities with potential for fires, explosions, toxic releases—but not all**
- **Explosions can result from dust, pressure vessels, and confined spaces**
- **IPLs reduce risk, but are not perfect**
- **Emergency response—can makes things worse, especially in terms of occupancy and water**

Questions?

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