Introduction to Methods of Process Safety Hazard Assessment

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- 30+ years of industrial process safety experience
- 25 years experience in design and application of instrument systems to prevent accidents
- Author of over 30 technical papers
- Committee member or technical reviewer of approximately 20 CCPS guideline books
- Member ISA S84 Committee
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- Past Chairman of AIChE Safety and Health Division
- BS, MS, PhD Chemical Engineer - Univ of MO - Rolla
- Founder of S&PP Consulting

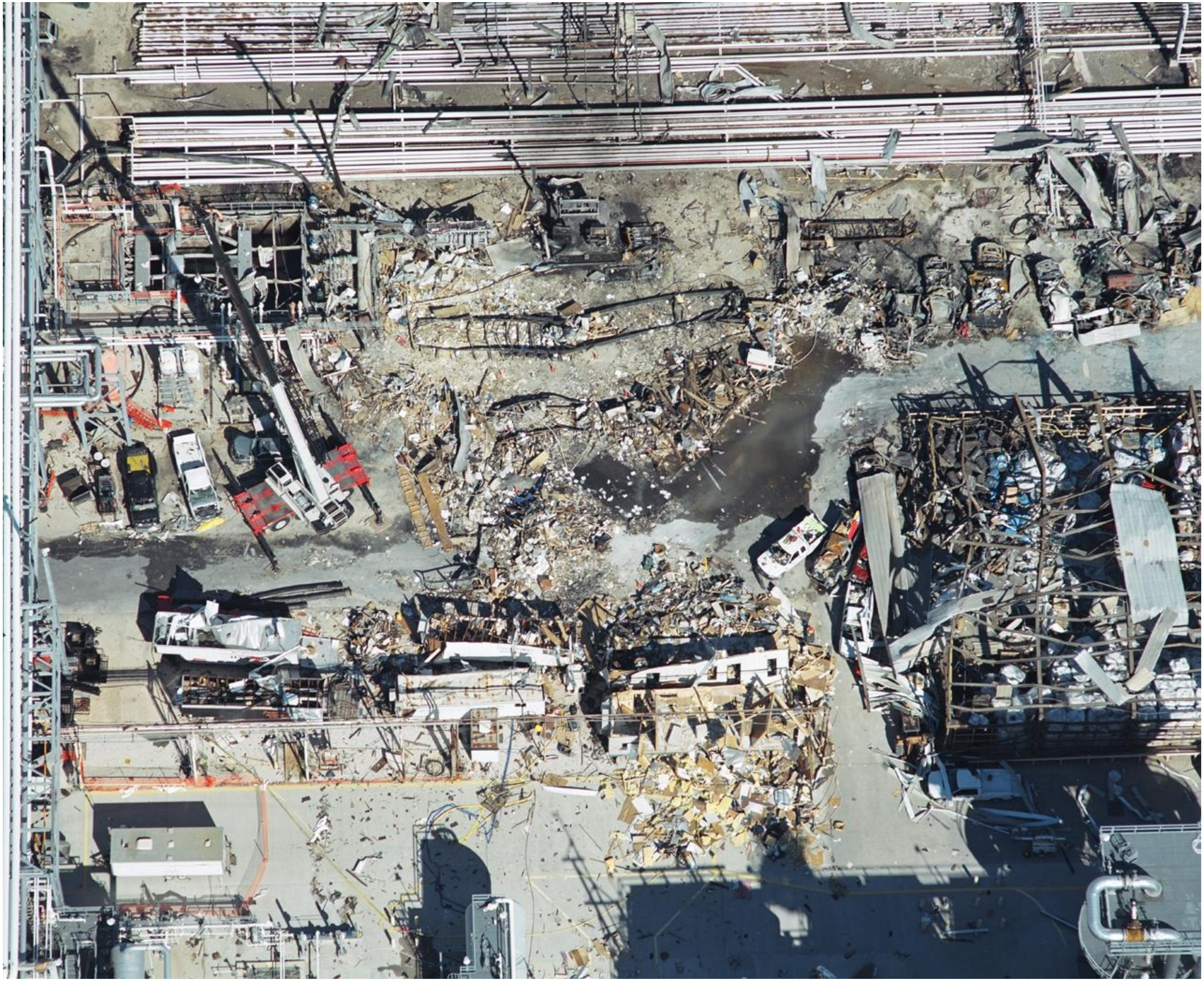
AGENDA

- Why Process Safety Reviews?
- Hazard Assessment Methods
  - HAZOP
  - What If
  - Checklists
- Advanced Techniques
  - LOPA
  - Consequence Analysis

A Few Examples

Photos from US Chemical Safety Board

1. Propane fire at Valero McKee Refinery
2. BP Texas City ISOM unit explosion kills 15 workers (2 photos)
3. Dust explosion in Kinston, NC
4. Solvent explosion at a Boston area ink blending plant damages local houses



Process Hazards Analysis

- A Process Hazards Analysis (PHA) is a systematic method for looking for potential process safety concerns before they become actual incidents
- A PHA is normally completed by a team

PHAs Per OSHA PSM Standard 29 CFR 1910.119

- A PHA is required for covered process systems
- Allowable PHA methods are:
  - What-If;
  - Checklist;
  - What-If/Checklist;
  - Hazard and Operability Study (HAZOP);
  - Failure Mode and Effects Analysis (FMEA);
  - Fault Tree Analysis; or
  - An appropriate equivalent methodology

Typical Events of Concern

- Fire
- Explosion
- Toxic material release
- Significant environment impact
- Release to a flare system
- Vessel Overpressure
- Runaway reaction

Typical PHA Team

Team Participant	**Function**
PHA Team Leader	Lead and document the PHA sessions. Primarily a facilitator of the team meetings
Process Engineer	Provides process chemistry knowledge to the PHA team
Control Systems Engineer	Provides control system knowledge to the PHA team
Production operator	Provides hands-on operations knowledge of how the system operates. For a new facility, the production operator may be chosen from a sister production unit or from a similar process system. A senior operator is normally assigned to this function.
Production supervision	Provides management and operating policy input to the team
Safety advisor	Provides knowledge of plant safety policies and risk toleration
Maintenance	Provides knowledge on how the system will be maintained

What If

- Creative Brainstorming Method
- Based on experience and knowledge of PHA Team
- Can be used to define emergency actions:
  - What if we have a fire in XYZ Department?
  - What if we spill a drum of 2, 3 DMD?
  - What if we overpressure TK-101?

Check Lists

- Used to evaluate a system with a predefined list of questions
- Easy to use
- Can be used where no accident scenario is known
- Often used to verify that a system complies with a design specification or practice
- “mother of all check lists” in CCPS Guideline Book HEP, 3rd Ed, pages 477-518

Check List Example

10. Are discharges from vents, relief valves, rupture disks, and flares located to avoid hazards to equipment and personnel? Could liquids be sprayed into the air? Are vents from relief devices (e.g., between rupture disks and relief valves, between balanced bellows, and between weep holes in discharge piping) also routed to a safe location? Are flame arresters installed?

11. Are relief devices located so that when they open, the process flow will continue cooling critical equipment (e.g., steam superheaters)?

12. What are the impacts of a flare, incinerator, or thermal oxidizer trip or flameout? What would happen if the flare gas recovery compressor tripped?

(Example from: CCPS, *Guideline for Hazard Evaluation Procedures*, 2rd Ed, page 406, 1992)

HAZOP

- Directed Creative Brainstorming Method
- Based on experience and knowledge of PHA Team
- Use Guide Words to Control the PHA Team Discussions
- Focuses on one small part of the system at a time
- Very Widely Used in Process, Chemical, Refining and Pharmaceutical Industries

HAZOP Guide Words

Guide Words	Meaning
NO / NOT	Complete negation of design intent
Less	Quantitative decrease
More	Quantitative increase
Part of	Only a portion of design intent achieved
As Well As	In addition to design intent
Reverse	Opposite to design intent
Other Than	Complete substitution

Typical Process Parameters

Flow	**pH**
Pressure	**Time**
Temperature	**Reaction**
Level	**Mixing**

Process Deviations

- Found by combinations of Guide Word and Process Parameters as Applied to Design Intent

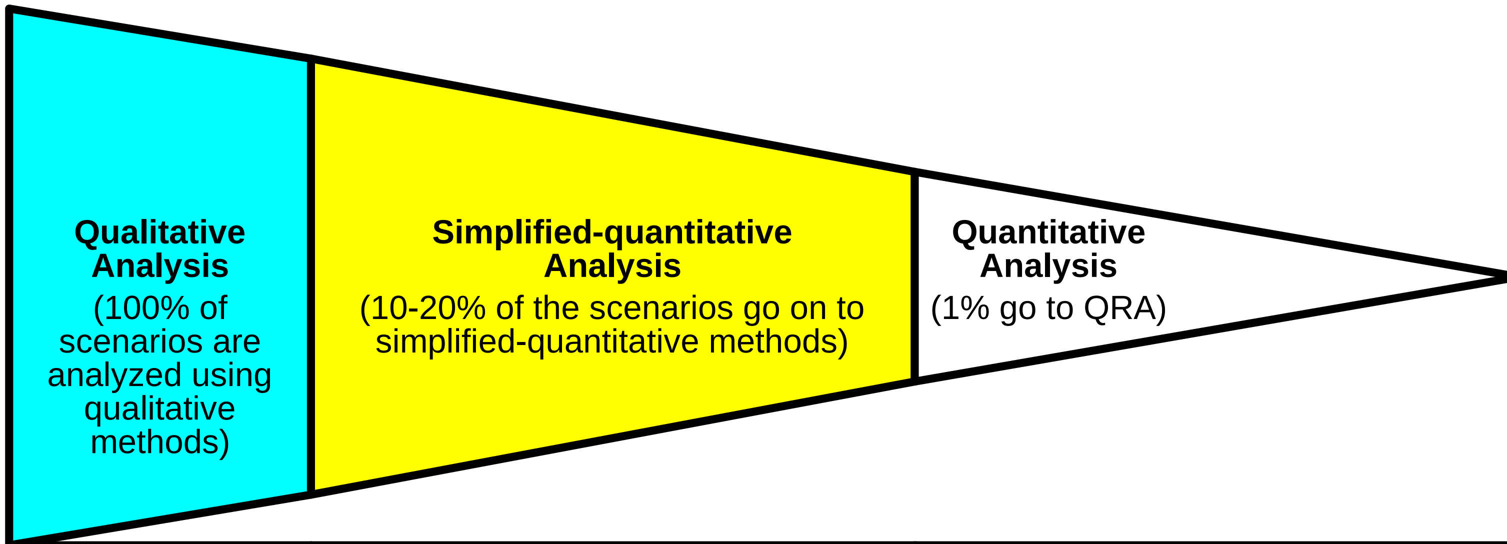
Design Intent	Transfer oil at 100 F from TK-101 to TK-102	
Guide Word	**Parameter**	**Process Deviation**
No	Flow	No Flow
More	Temperature	High Temperature
Other Than	TK-102	Misdirected Flow

Design Intent: Transfer Oil at 100 F from TK-101 to TK-102

Item	Deviation	Cause	Consequences	Safeguards	Action
1.3	More Level In TK-102	Failure of LT 102-1 on TK-102	Overflow TK-102 resulting in a release of 1000 barrels of oil to dike	None	Install a redundant level device on TK-102

Advanced PHA Techniques

Other methods of identification of accident scenarios

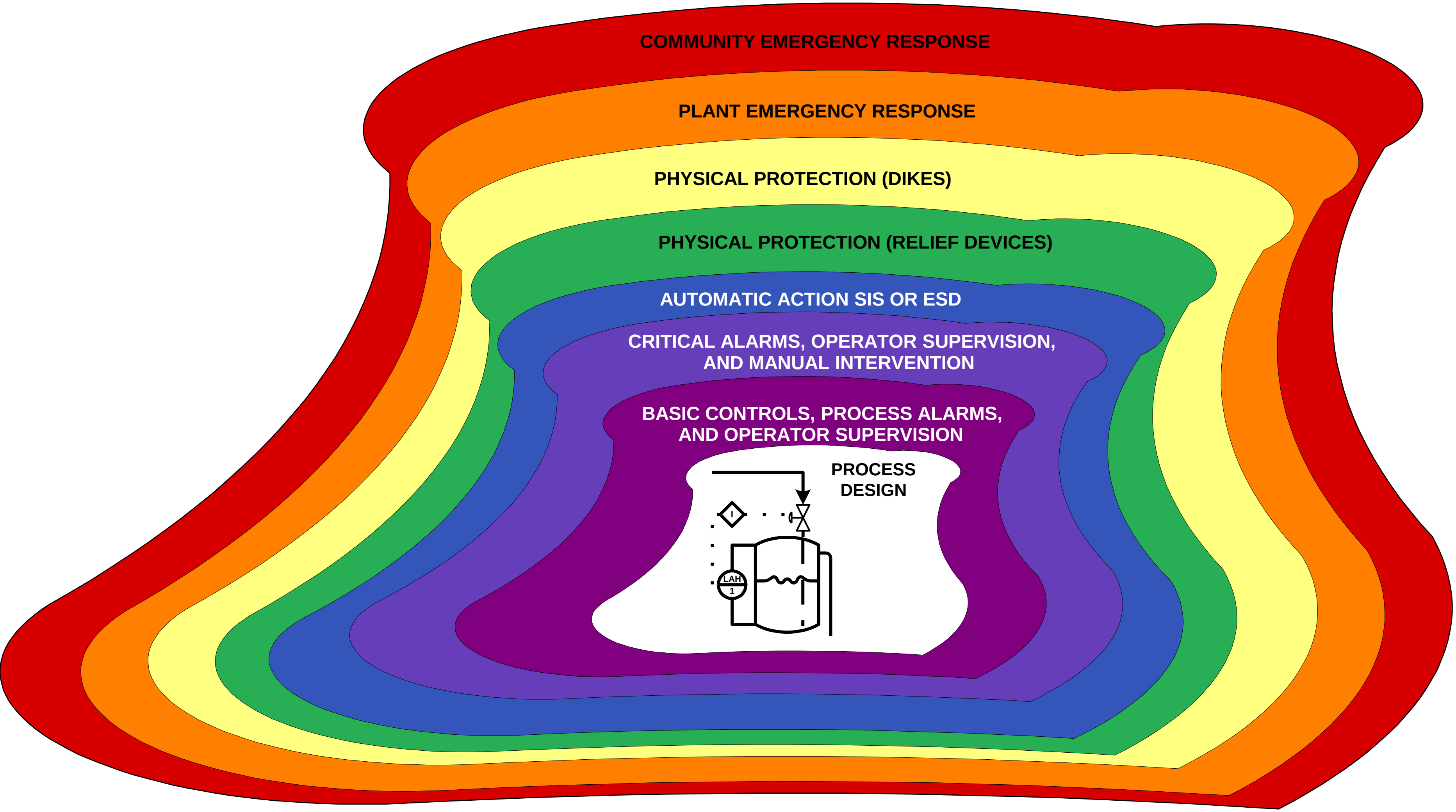


Techniques:	HAZOP What-if/Checklist FMEA	Quantified FMEA F&EI CEI	LOPA	Rough estimate with event tree	Event tree Fault tree HRA
Applicability to simple issues:	Good	Good	Good	Overkill	Gross overkill
Applicability to complex issues:	Poor	Poor	Usually good	Occasionally poor	Good

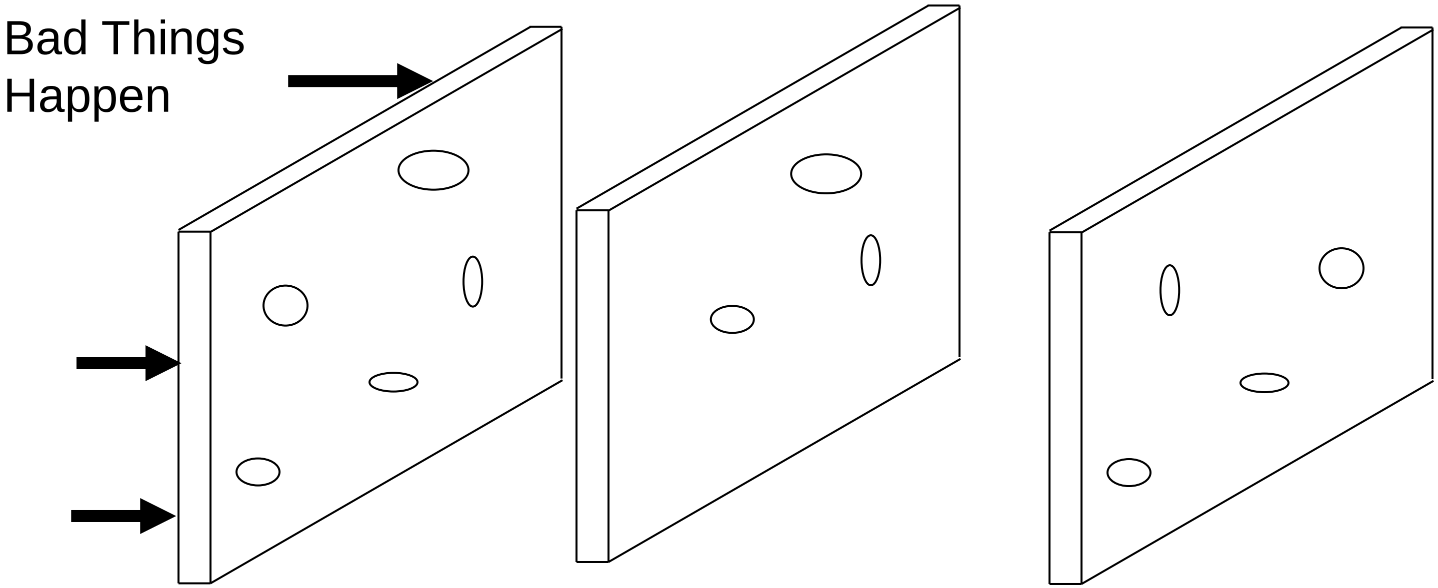
What is LOPA

- A systematic method for looking at the protective features of your plant
- Semi-quantitative method for evaluation of the risk of an incident
- Method for documenting the justification for risk reduction recommendations

Layers of Defense



Swiss Cheese View of Layers

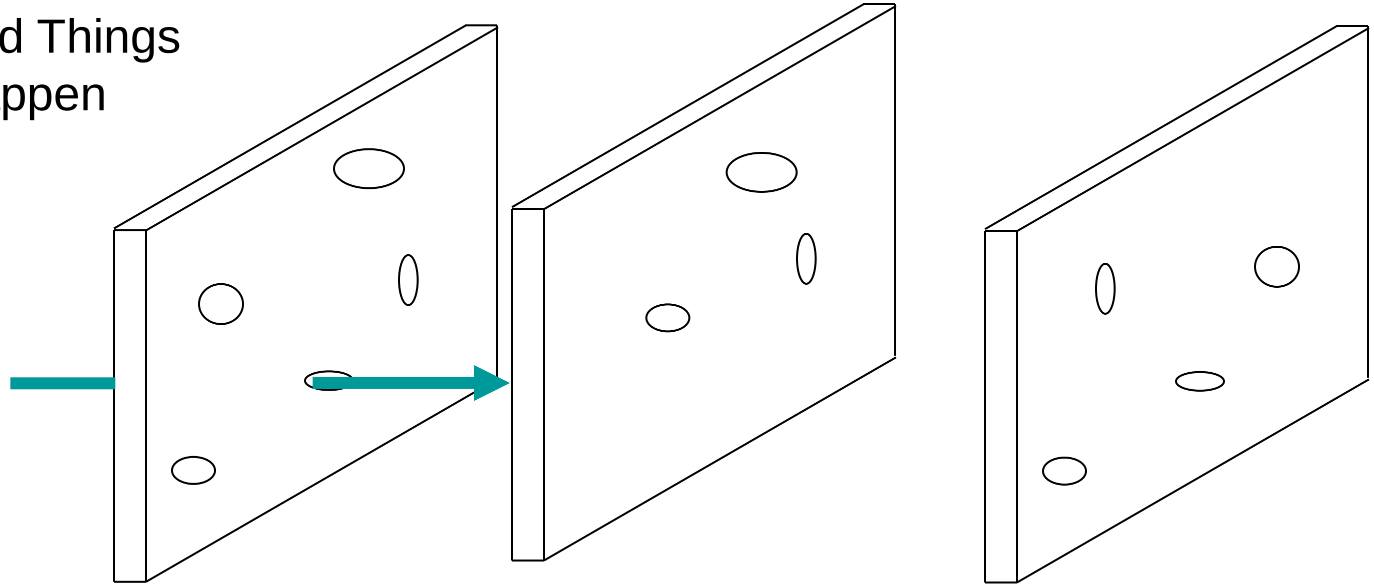


Protective Layers 1, 2, 3

Holes in Cheese are weaknesses in each layer
GOAL: Keep the holes from alignment

Swiss Cheese View of Layers

Bad Things
Happen



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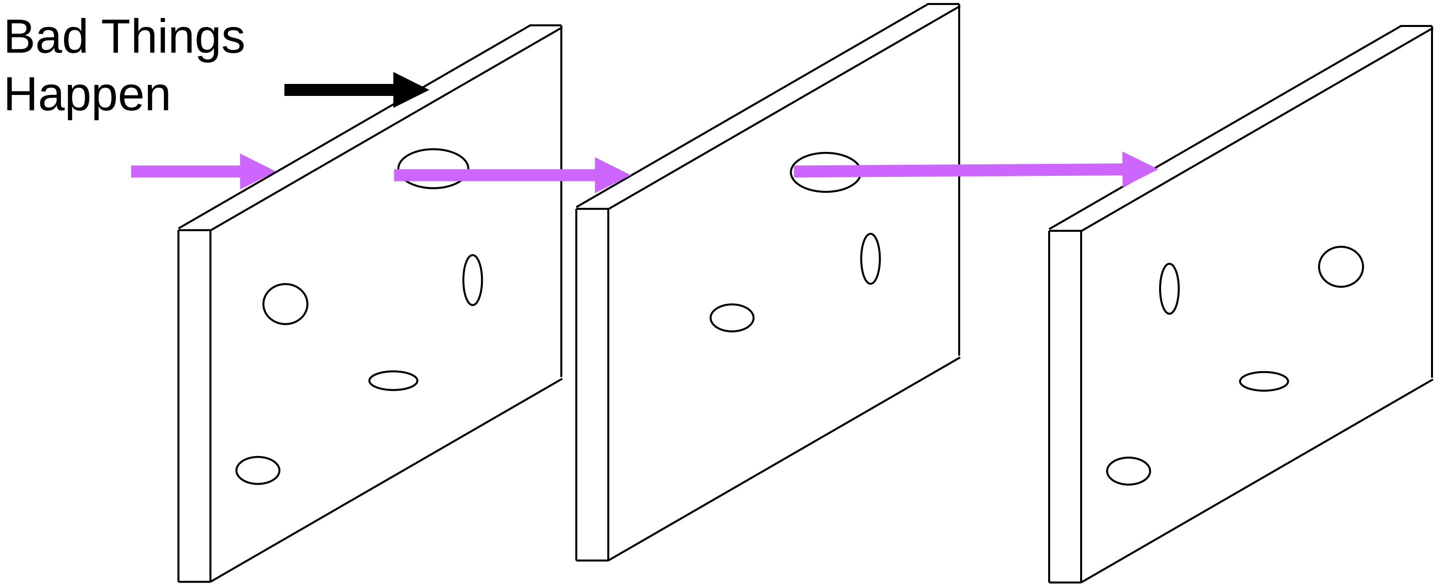

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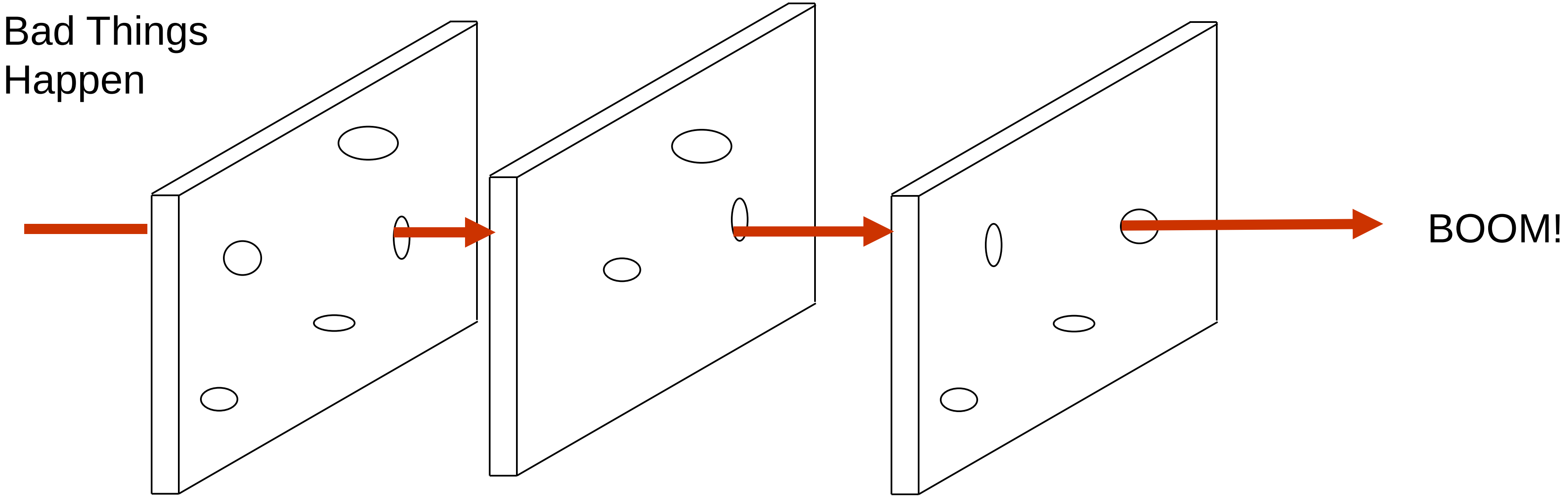

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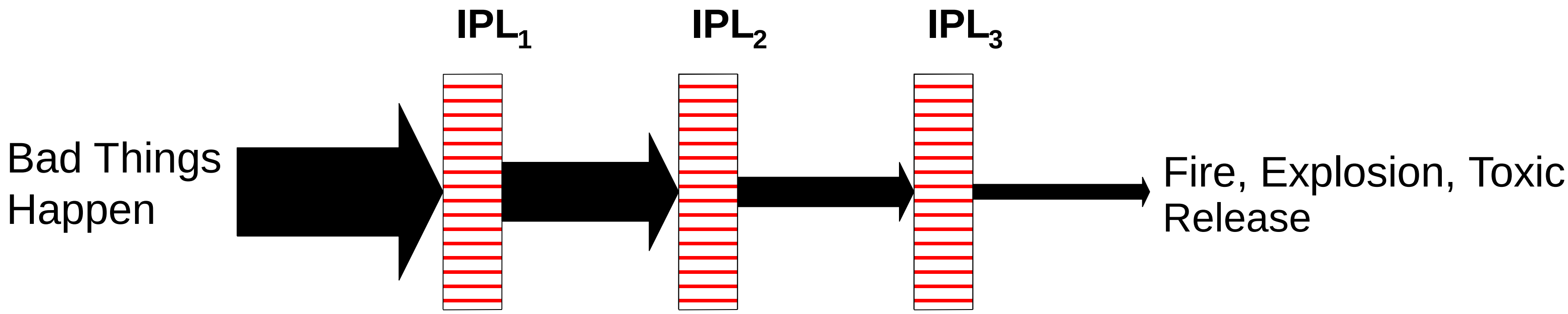
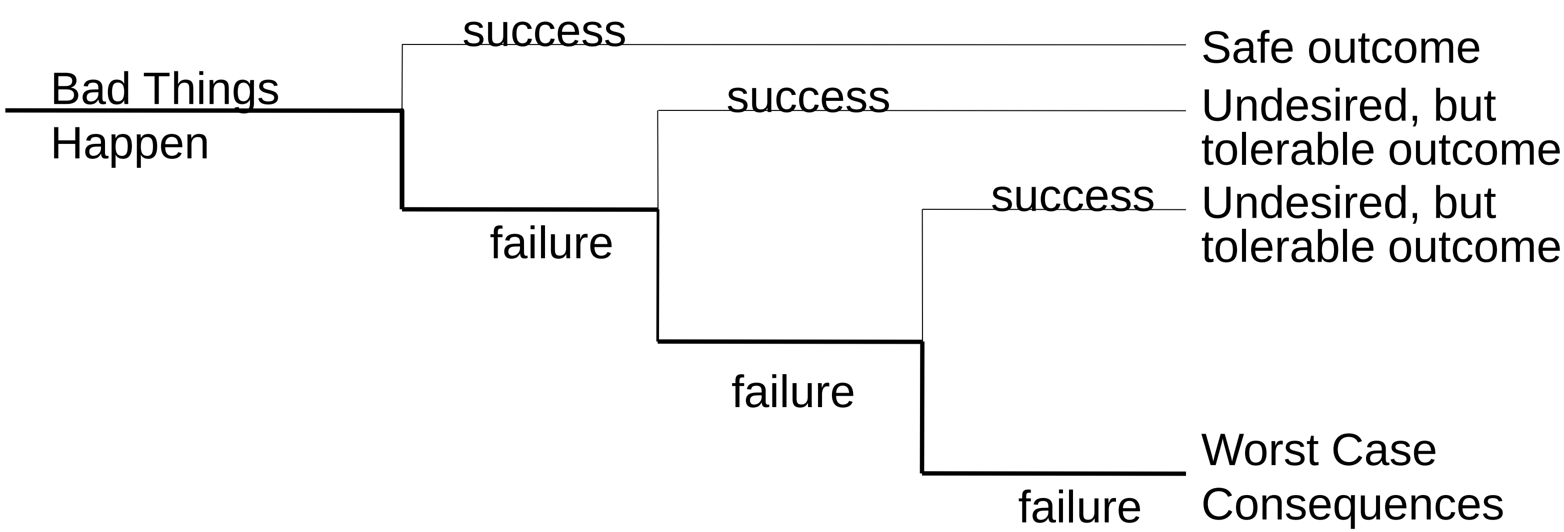
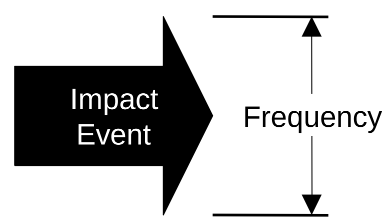




Key:
Thickness of arrow represents frequency of the consequence if later IPLs are not successful



Steps in a LOPA Study

1. Define the system to be studied (Scope)
2. Define the reason for the study (Why or what question are you trying to answer)
3. Organize the Team
4. Define Scenarios
5. Define Possible Protective Layers
6. Define Initiating Events
7. Determine Consequences
8. Evaluate Risk
9. Develop Recommendations for Improvement

Independent Protective Layers Must Be

- Capable of preventing the undesired event of concern
- Be independent of other safeguards to be counted as an IPL
- Be auditable

Generic Types of IPLs

- Procedural Control (With Qualifications)
- Passive Mechanical Device
- Active Mechanical Device
- Basic Process Control System
- Safety Interlock (With Qualifications)

Procedural Control IPLs

- Procedure must be capable of preventing consequence of concern
- Clear indication of event and need to complete procedure
- People must be trained
- Tools and equipment must be available
- Written procedure must exist
- People must have time to act (> 10 min)
- Must be able to complete procedure before event of concern occurs
- Only one procedural control normally allowed as an IPL (special considerations apply for more than one)

Initiating Event Frequencies

Event	**Frequency, Events/Yr**
Failure of BPCS	1×10^{-1}
Pump seal failure	1×10^{-1}
Pressure regulator failure	1×10^{-1}
Large fire of an entire process unit	1×10^{-3}
Small Fire in a process unit	1×10^{-1}
Pressure vessel rupture	1×10^{-6}
Human operator error – routine task performed frequently	1×10^{-1}
Spurious opening of a relief valve	1×10^{-2}

LOPA Risk Matrix

Severity -> Frequency (event/yr)	5	4	3	2	1
1.E+00	I	I	I	M	T
1.E-01	I	I	M	T	T
1.E-02	I	I	M	T	T
1.E-03	I	M	T	T	T
1.E-04	M	M	T	T	T
1.E-05	T	T	T	T	T
1.E-06	T	T	T	T	T

Consequence Scale

1. Very Low Consequence
   - So small that we don't care
2. Low Consequence Events
   - minor injuries in plant
3. Medium Consequence Events
   - Up to $1M damage to facility
4. High Consequence Events
   - Off site public injuries
5. Very High Consequence Events
   - Fatalities in plant, serious injuries (death) to public

Generic LOPA Credits

Protective Layer	LOPA Credit (Probability of Failure on Demand)
Basic Process Control System	1×10^{-1}
Procedural control with more than10 minutes to complete the task	1×10^{-1}
Procedural Control with more than 40 minutes to complete the task	1×10^{-2}
Active mechanical safeguard (relief valve, rupture disk, etc.)	1×10^{0} to 1×10^{-3} depending upon process conditions and history of the device
Passive mechanical safeguard (dike)	1×10^{-2}
Safety interlock (Safety Instrumented Function implemented in an Safety Instrumented System) at a Safety Integrity Level 1	1×10^{-1}
Safety interlock (Safety Instrumented Function implemented in an Safety Instrumented System) at a Safety Integrity Level 2	1×10^{-2}
Safety interlock (Safety Instrumented Function implemented in an Safety Instrumented System) at a Safety Integrity Level 3	1×10^{-3}

Communication of LOPA Results

- Identification data
- Reference Data
- Hazard Description
- Existing Safeguards
- Existing Hardware
- Desired Safety Function
- Additional Safeguards needed
- Use a standard format

Consequence Evaluation Techniques

How bad will the scenario be?

Consequence Evaluation Tools

- Simple hand calculations or spreadsheets (See CCPS Guidelines on Consequence Evaluation)
- Public Source Software (For example, NOAA ALOHA air dispersion model)
- Proprietary Software (For example, PHAST by DNV)

EXAMPLES

The following examples are a work of fiction. Equipment, locations and chemicals are either the product of the authors imagination or are used fictitiously. Any resemblance to an actual chemical plant or process is entirely coincidental.

Example - Chlorine Release

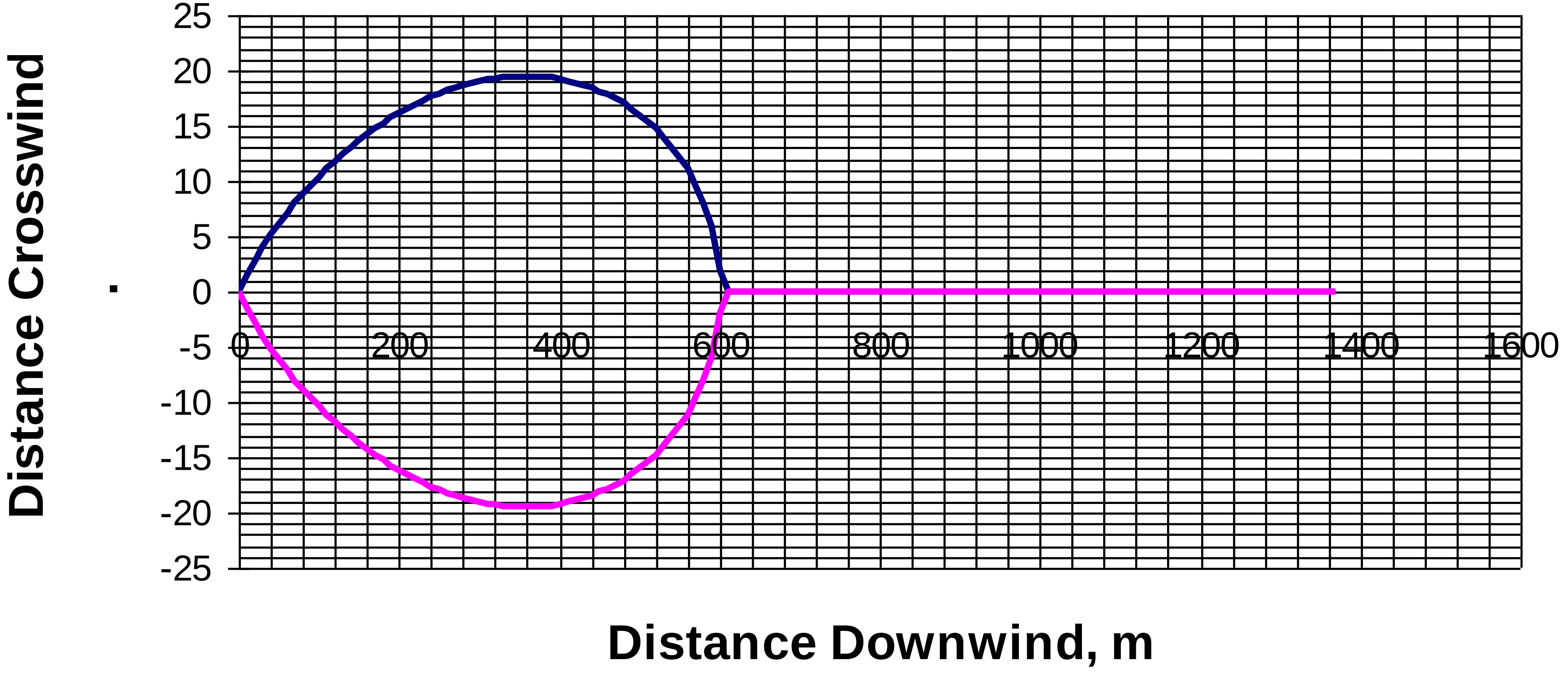
Accidental Release of Chlorine from a small storage cylinder. Release rate of 1 kg/s at 100 F. Compute downwind distance to concentration isopleth of 20 ppm (by volume in air)

Spreadsheet Calculation

Ref: Example 2.16 of CCPS CPQRA book

- Wind speed of 1.5 m/s
- Chlorine release rate of 1 kg/s
- Concentration of concern 20 ppm

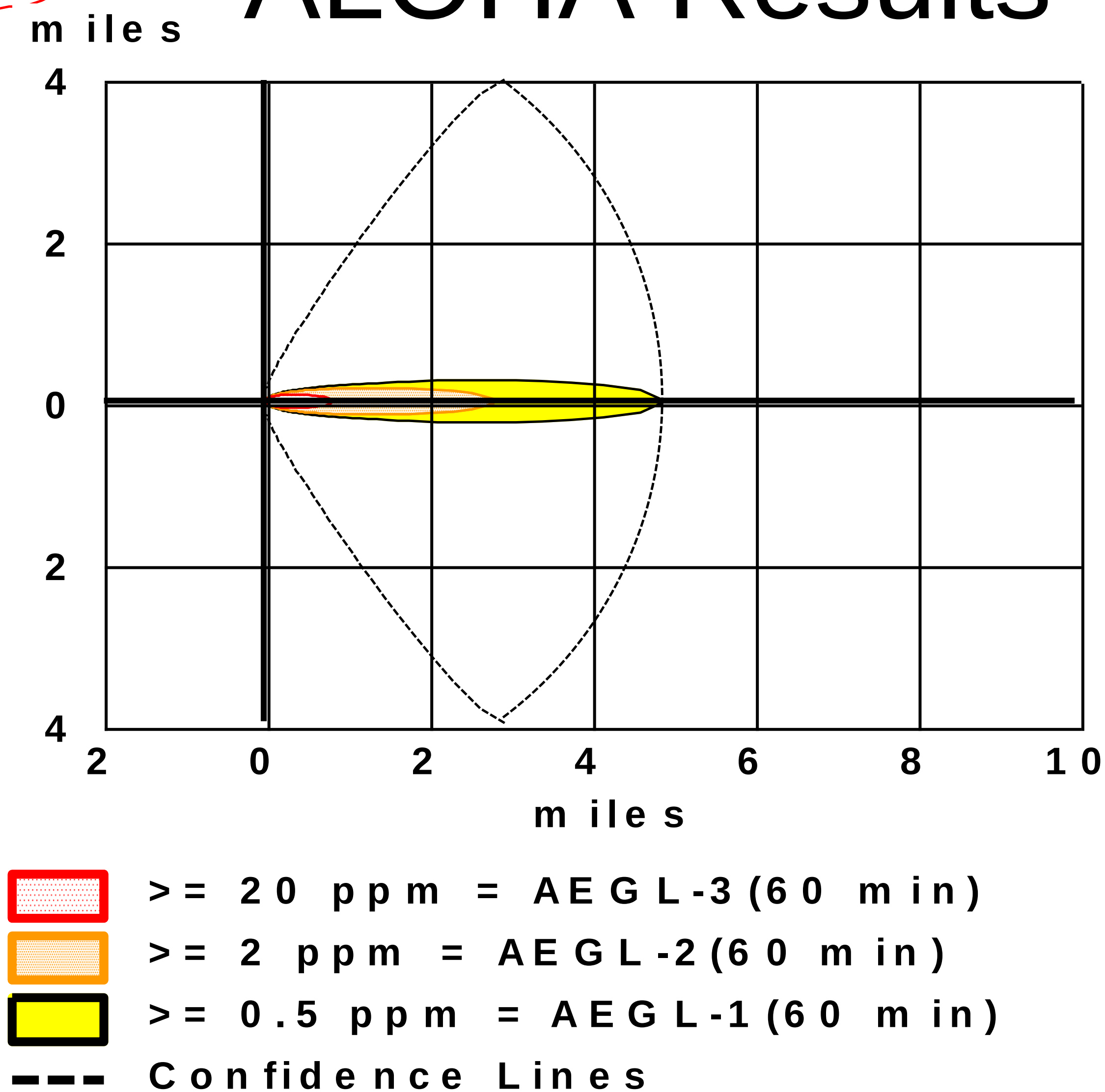
Spreadsheet Results



Calculation using ALOHA

- Pressurized cylinder (2000 lb) of chlorine at 100 F
- Hole size is ¼ inch diameter
- Wind speed is 1.5 meter/sec (mph)

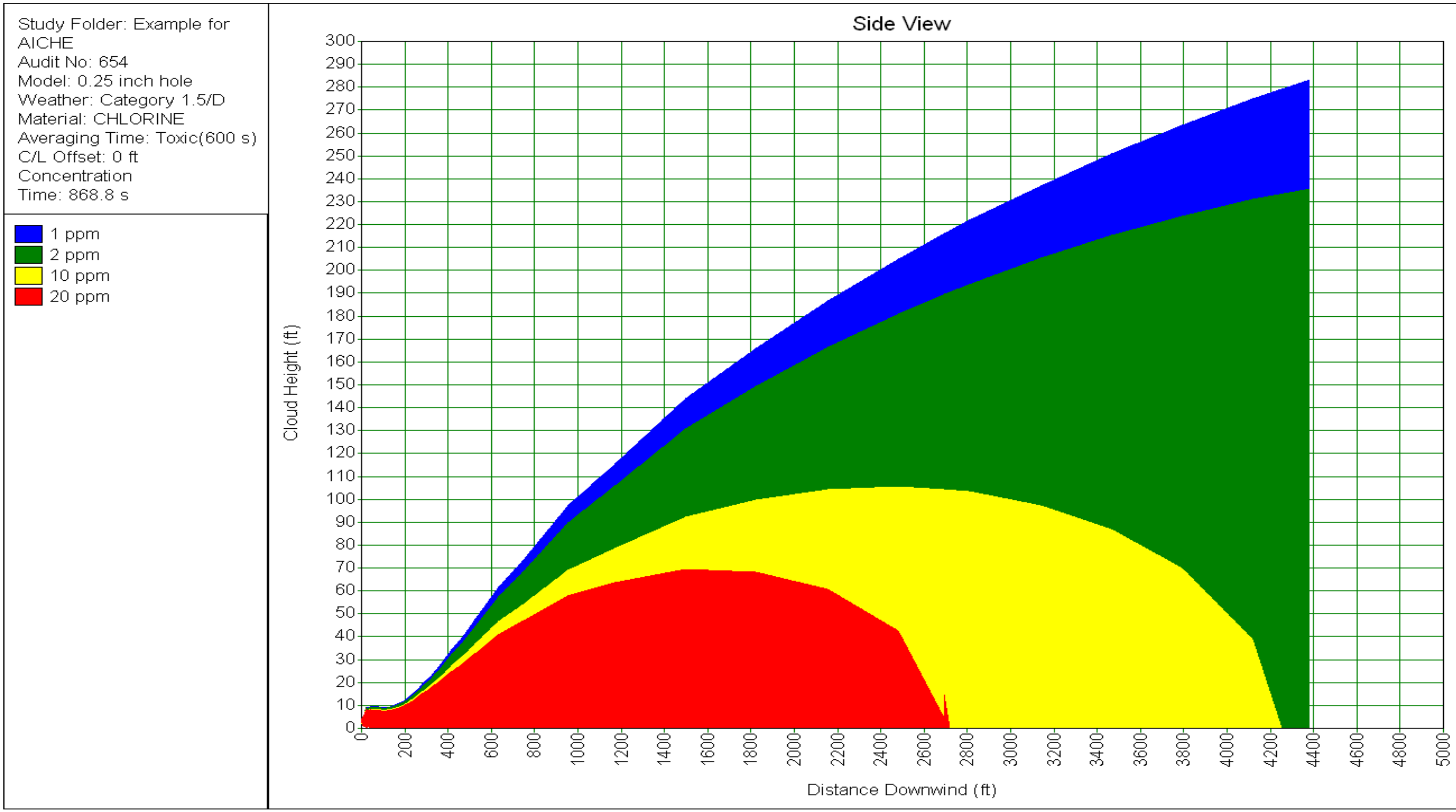
ALOHA Results



Calculation Using PHAST

- Pressurized cylinder (2000 lb) of chlorine at 100 F
- Hole size is ¼ inch diameter
- Wind speed is 1.5 meter/sec (mph)

PHAST Results



Center for Chemical Process Safety References

- CCPS, *Guidelines for Hazard Evaluation Procedures*, 3rd Edition, 2008
- CCPS, *Guidelines for Chemical Process Quantitative Risk Analysis*, 2nd Edition, 2000
- CCPS, *Guidelines for Consequence Analysis of Chemical Releases*, 1999
- CCPS, *Layer of Protection Analysis*, 2001

Consequence Analysis Software References

- DNV, PHAST Software Package, Version 6.53
- US EPA, Office of Emergency Management, ALOHA, Version 5.4.1.2

Government References

- US EPA, Risk Management Plan Rule, 40 CFR 68
  http://www.epa.gov/oem/content/rmp/
- US Department of Labor, OSHA, **Process Safety Management of Highly Hazardous Chemicals (PSM) Standard** , 29 CFR 1910.119
  http://www.osha.gov/pls/oshaweb/owadisp.show_document?p_table=STANDARDS&p_id=9760
- US Chemical Safety Board,
  http://www.chemsafety.gov/

QUESTIONS

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