9th Chemical Process Safety Sharing (CPSS)

Consequence based Solutions for Process Safety Engineering Design



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- Conventional Process Safety Design
- Problems and Limitations
- Consequence based Approach – Way of Solutions
- Applications of Consequence based Solutions

Conventional Process Safety Design

Design on context based references in accordance with the following order of precedence;

I. Country Laws and Regulations

II. International Codes and Standards

III. Company Standards

IV. General Best Practices/Guidelines

V. Internal/External Lessen Learns

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ประกาศกระทรวงอุตสาหกรรม
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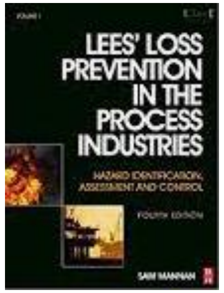
NFPA®

API American Petroleum Institute

GE GAP Guidelines

An AIChE Technology Alliance CCPS Center for Chemical Process Safety



CSB

Conduct PHA study to assist the design

Problems and Limitations

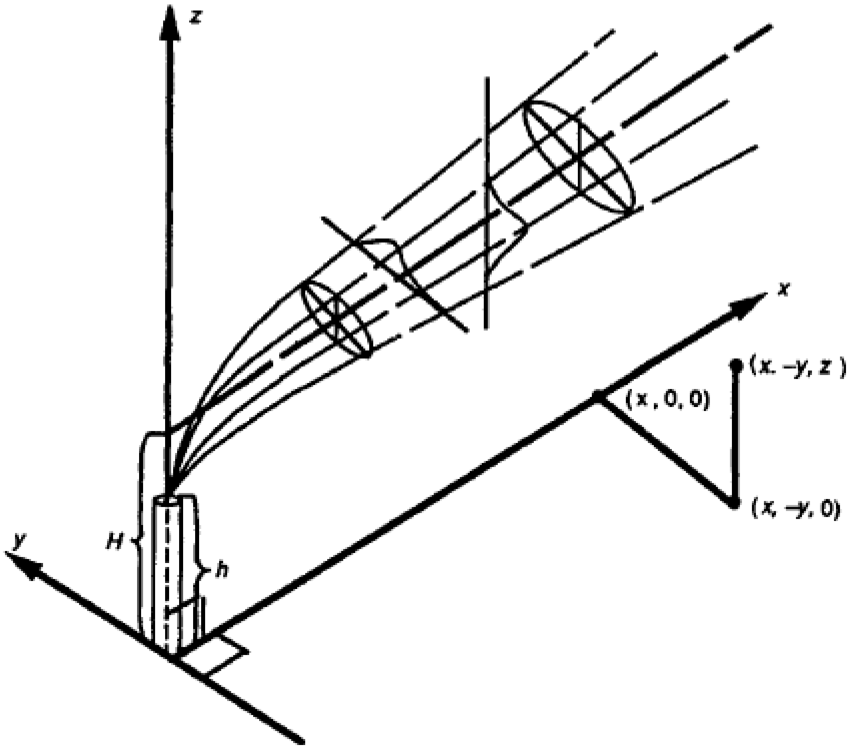
There are pain points facing when we design under context references based;

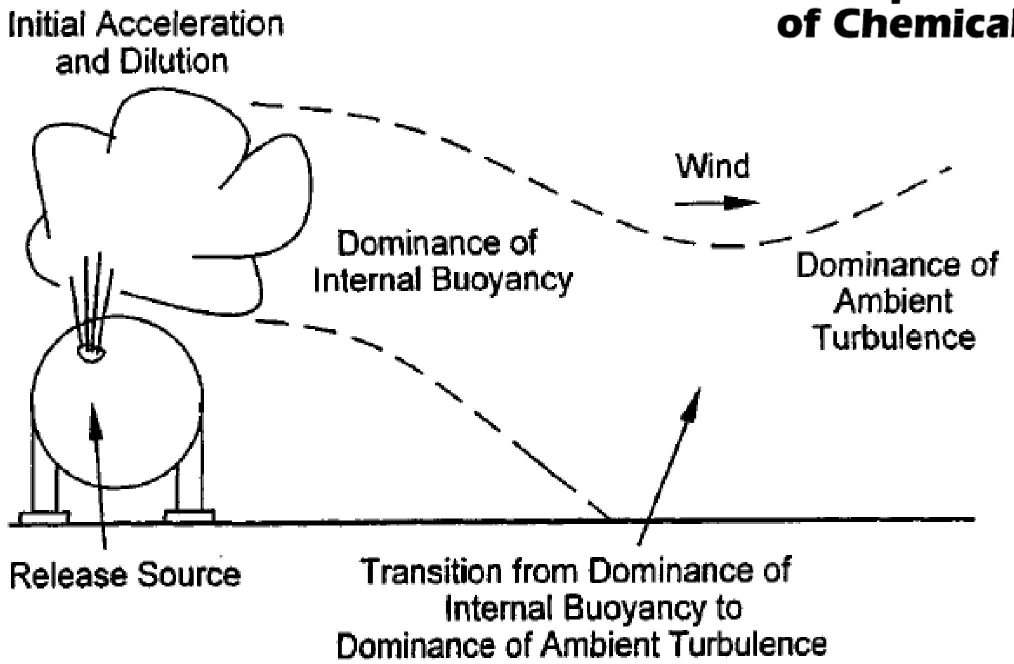
- Unable to implement
- Over design (over budget)
- Under design (ensure safe?)
- Unclear
- Too general
- Not define/Not relate

Consequence based Approach – Way of Solutions

Apply the physical effect model by consequence modeling tool(s) to quantify the hazard impact i.e. dispersion, fire and explosion to solve engineering design problems

GUIDELINES FOR
Consequence Analysis of Chemical Releases

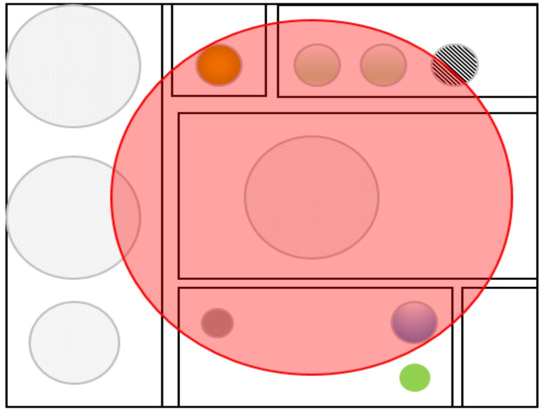




Consequence based Approach – Benefits

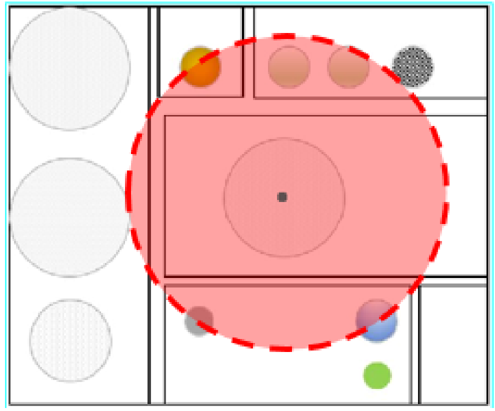
Offer effective solutions and optimum safety design

e.g. Limit firefighting resource for spray cooling



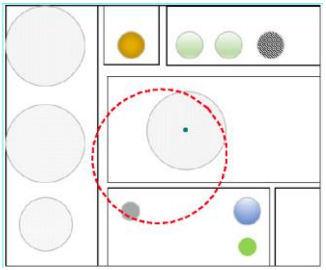
1-dia of burning tank (NFPA30) needs exposure protection.

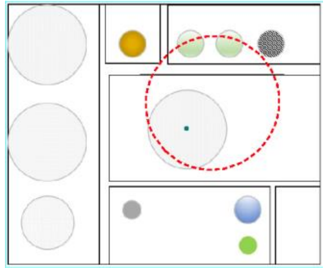
Code based

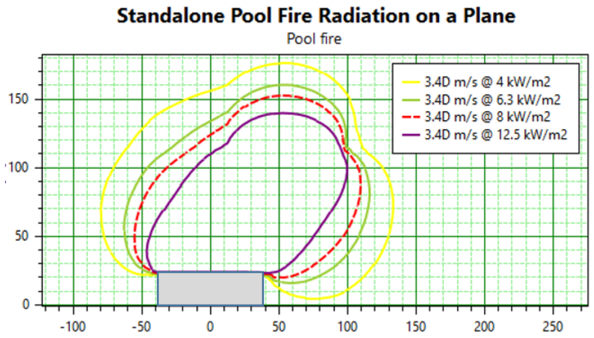


Ambient wind, radius is 91% of 1-dia burning tank

Consequence based







→ Person pain after 20 s (world bank)
→ Max heat limit for fire responder (IP19)
→ Fire escalation if long exposure & no protection (IP19)
→ Safe operating maximum for steel structure & process equipment with no protection (API2218)

Consequence based Approach – Suggestions

Select the right consequence modeling tool(s)

- Validated and technically proved math model for the hazard scenario studied
- Known features and appropriate use of each model for the hazard scenario
- Known limitations of those consequence modeling tool(s)

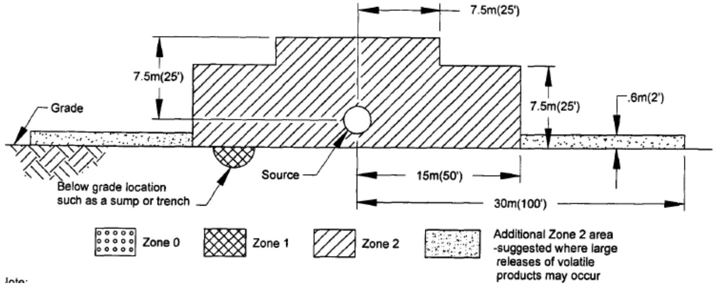
Select the reliable impact criteria source(s)

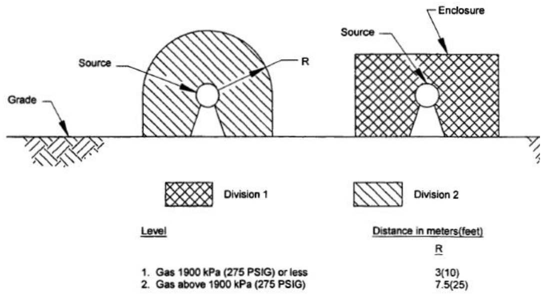
- Dispersion (flammable/toxic) impact
- Fire (Thermal) impact
- Explosion (Overpressure) impact

Applications of Consequence based Solutions

Hazardous Area Classification

Code based → API500/505, NFPA 497, IE(IP) 15





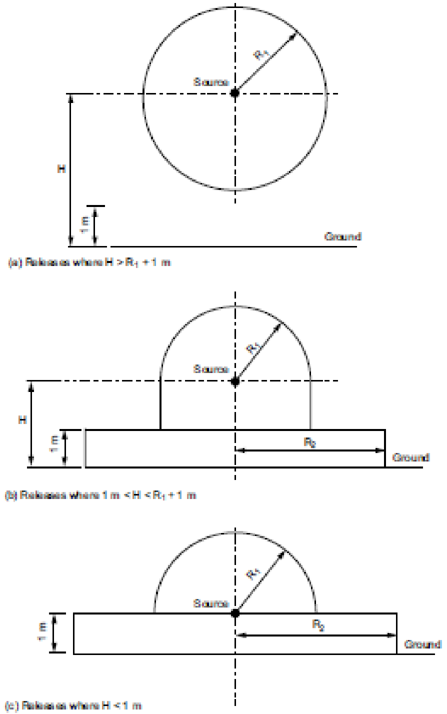
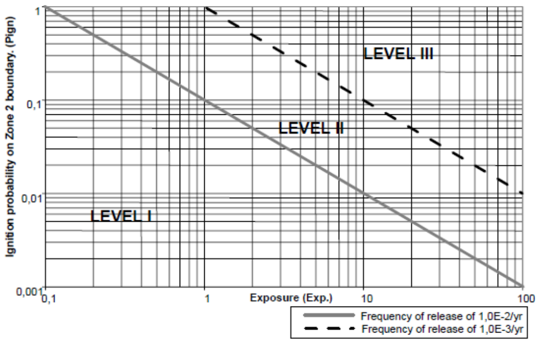


Table 5.3 Example calculation for compressors – leak hole size and hazard radius (R_1)

Release frequency	Seal type	Release hole diameter (mm)	Hazard radius R_1 (m) G(i)	Hazard radius R_1 (m) G(ii)
LEVEL I	Floating ring	5	4	6
	Purged labyrinth	12	10	13
LEVEL II	N/A	22	†	†
LEVEL III	N/A	70	†	†

N/A Not applicable since hole size is independent of seal type.
† These hole sizes are considered greater than should be used for hazardous area classification purposes. This Code does not therefore give hazard radii for these hole sizes. The user may determine the hazard radii by calculation.



Individual Risk (/yr) from a number of ignited secondary grade release sources is defined as:

$IR_{ignited\ release}$ (/yr) = F_{flam}(/release source-yr)*P_{ign}*P_{occ}* V *N_{range}

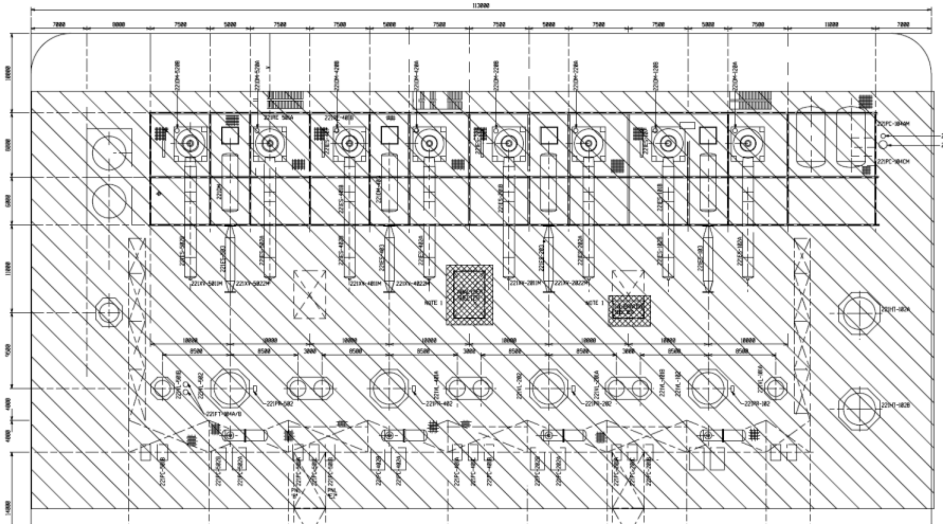
Direct example **Point source/Risk-based**

Applications of Consequence based Solutions

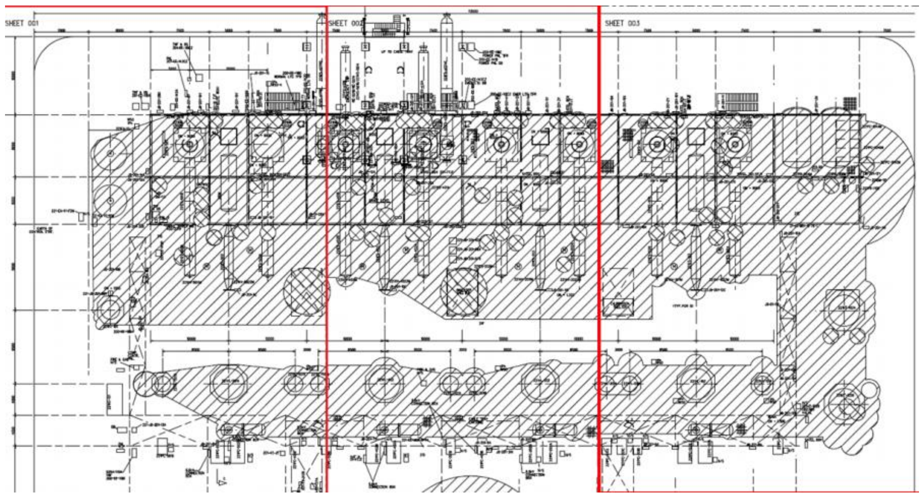
Hazardous Area Classification

Code based → API500/505, NFPA 497, IE(IP) 15

Scientific and lower budget !!!



Direct example



Point source/Risk-based

Applications of Consequence based Solutions

Hazardous Area Classification

Code based → Point source/risk based

Conduct dispersion modeling

Not applicable for chemical plants !!!

Stream component (mol %)	Fluid category					LFL (vol %)	Molecular weight (g/mol)	Boiling point (°C)
	A	B	C	G(i)	G(ii)			
N_2 Nitrogen	0,00	0,00	0,00	2,00	2,00	-	28,01	-196
C_1 Methane	0,00	4,00	0,00	88,45	10,00	5,00	16,04	-161
C_2 Ethane	0,00	0,00	0,00	4,50	3,00	3,00	30,07	-87
C_3 Propane	70,00	6,00	1,00	3,00	3,00	2,10	44,09	-42
C_4 Butane	30,00	7,00	1,00	100	1,00	1,80	58,12	-1
C_5 Pentane	0,00	9,00	2,00	1,00	0,00	1,40	72,15	36
C_6 Hexane	0,00	11,00	3,00	0,00	0,00	1,20	86,17	69
C_7 Heptane	0,00	16,00	3,00	0,00	0,00	1,05	100,20	98
C_8 Octane	0,00	22,00	27,00	0,00	0,00	0,95	114,23	126
C_9 Nonane	0,00	0,00	25,00	0,00	0,00	0,85	128,26	151
C_{10} Decane	0,00	25,00	38,00	0,00	0,00	0,75	142,28	173
H_2O Water	0,00	0,00	0,00	0,05	0,00	-	18,02	100
Carbon dioxide	0,00	0,00	0,00	0,00	1,00	-	44,01	-78
Hydrogen	0,00	0,00	0,00	0,00	80,00	4,00	2,02	-253
Average MW (g/mol)	48,30	100,06	125,03	18,74	7,03			
LFL (vol %)	2,00	1,05	0,86	4,6	4,00			
LFL (kg/m³)	0,039	0,042	0,043	0,034	0,011			

Reference may not reflect to real conditions !!!

Table C2: Physical parameters used in dispersion modelling

Parameter	Value used in EI15
Ambient temperature	30 °C
Storage/process temperature	20 °C
Relative humidity	70 %
Wind speed	2 m/s
Stability class	D
Surface roughness length	0,03 m
Release direction	Horizontal
Release height	For R_1: 5 m For R_2: 1 m
Release angle	For R_1: horizontal For R_2: unknown
Sample time	18,75 s
Reference height	10 m
Hazard distances	To LFL

The dispersion modelling contained in EI *Research Report: Dispersion modelling and calculations in support of EI Model code of safe practice – Part 15: Area classification code for installations handling flammable fluids* was carried out using DNV *PHAST*. The results were sufficiently consistent with those in the previous edition of this Model Code[2] to support using DNV *PHAST* without modifying the standard approach to modelling these releases.

Applications of Consequence based Solutions

Plant layout and sitting

How to solve when unable to comply ?

	Service Buildings	Motor Control Centers And Electrical Substations	Utilities Areas	Cooling Towers	Control Rooms	Compressor Buildings	Large Pump Houses	Process Units Moderate Hazard	Process Units Intermediate Hazard	Process Units High Hazard	Atmospheric Storage Tanks	Pressure Storage Tanks	Refrigerated Storage Tanks Dome Roof	Flares	Unloading And Loading Racks	Fire Water Pumps	Fire Stations
Service Buildings	/																
Motor Control Centers And Electrical Substations	/	/															
Utilities Areas	50	50	/														
Cooling Towers	50	50	100	50 (1)													
Control Rooms	/	/	100	100	/												
Compressor Buildings	100	100	100	100	100	30											
Large Pump Houses	100	100	100	100	100	30	30										
Process Units Moderate Hazard	100	100	100	100	100	30	30	50									
Process Units Intermediate Hazard	200	100	100	100	200	50	50	100	100								
Process Units High Hazard	400	200	200	200	300	100	100	200	200	200							
Atmospheric Storage Tanks	250	250	250	250	250	250	250	250	300	350	*						
Pressure Storage Tanks	350	350	350	350	350	350	350	350	350	350	*	*					
Refrigerated Storage Tanks Dome Roof	350	350	350	350	350	350	350	350	350	350	*	*	*				
Flares	300 (2)	300	300	300	300	300	300	300	300	300	300	400	400	/			
Unloading And Loading Racks	200	200	200	200	200	200	200	200	200	300	250	350	350	300	50		
Fire Water Pumps	50	50	50	50	50	200	200	200	300	300	350	350	350	300	200	/	
Fire Stations	50	50	50	50	50	200	200	200	300	300	350	350	350	300	200	/	/

1 ft = 0.305 m
/ = no spacing requirements
* = spacing given in Table 3

GE GAP Guidelines

Table A (metric)
TYPICAL SPACING FOR PLANT EQUIPMENT FOR FIRE CONSEQUENCES
Explosion and toxic concerns may require greater spacing
Horizontal Distance (m)

CCPS — An AIChE Technology Alliance — Center for Chemical Process Safety

	Text References	Boundaries	Process Unit Battery Limits	Property	Emergency	ESD Valves—Manual	Fire Pumps	Hydrants, Monitors	Water Spray and ESD Activation Switches	Process Vessels	Equipment handling nonflammables, noncombustibles, nontoxics	Reactors and Desalters	Towers, Drums, Knock Out Pots, On-site Storage Tanks
Boundaries													
Process Unit Battery Limits	5.7.3 6.8.1		30										
Property	5.2.5		61	NM									
Emergency													
ESD Valves—Manual	6.8.15		15	NM		NM							
Fire Pumps	5.8.2		61	NM		NM	NM						
Hydrants, Monitors	6.8.18		NM	NM		NM	NM	NM					
Water Spray and ESD Activation Switches	6.8.14		15	NM		NM	NM	NM	NM				
Process Vessels													
Equipment handling nonflammables, noncombustibles, nontoxics	6.8.2		NA	NM		NM	NM	NM	NM		NM		
Reactors and Desalters	6.8.4		NA	61		15	61	15	15		NM	NM	
Towers, Drums, Knock Out Pots, On-site Storage Tanks	6.8.3 6.8.5		NA	61		15	61	15	15		NM	5	5
Heat Transfer Equipment													
Air cooled heat exchangers—process	6.8.7		NA	61		15	61	15	15		NM	5	5
Boilers, Air Compressors, Power Generation (Utility Area)	5.5		30	30		15	61	15	15		NM	30	30

Applications of Consequence based Solutions

Plant layout and sitting

Topic	Impact Criteria for design parameter	
	Unit	Description
Thermal Radiation Level impact on equipment unit	12.5 kW/m2	Glazed building impairment
	37.5 kW/m2	Complete failure of the structure or significant damage to wall or roof
	250 kW/m2	Structural steel and reinforced concrete framed building initiated failure and up to 30 minute impingement lead to total failure
	35 kW/m2	Failure on building with combustible materials i.e. wood paneling
	25 kW/m2	Failure on building with soft paneling i.e. porta cabin
Thermal Radiation Level impact on manned occupancy	4 kW/m2	working area (personnel starting pain/injury)
Explosion Overpressure Level impact on building	<0.02 barg	No damage: Potential damage to window glass but no structural damage
	0.02-0.07 barg	For glazing and lightweight structures building ; • Large windows shatter at 0.03-0.069 bar, • At 0.069 bar corrugated asbestos shatters/fastenings on corrugated steel or aluminum panels fail, • Minor damage to house structure at 0.048 bar

Topic	Impact Criteria for design parameter	
	Unit	Description
Location for non-rated (no-ex-proof) electrical equipment	100%LFL	Located away from this contour coverage plus xxx m margin.
Location for equipment creating source of ignition (i.e. hot surface, open flame)	100%LFL	Located away from this contour coverage plus xxx m margin.

Quantify the possible hazard impacts of facilities

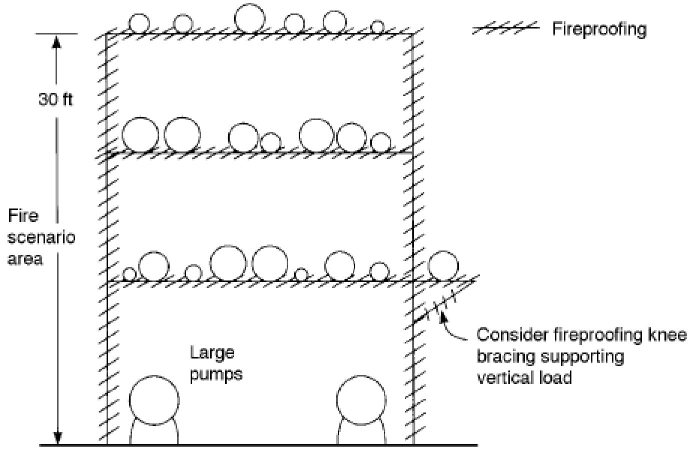
Conduct dispersion, fire & explosion modeling

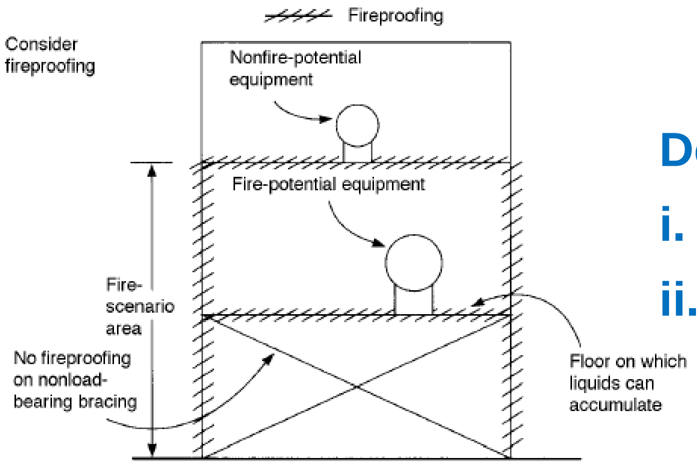
Applications of Consequence based Solutions

Fire proof design for building structure

Equipment	Protection Level[a]	Section in API 2218 or Other Reference
LPG vessels if not protected by fixed water spray systems.	Fireproofed equivalent to 1 ½ hours in UL 1709 (or functional equivalent).	API 2510 (1995) Section 8.7 Section 6.2.2
Pipe supports within 50 ft or in spill containment area of LPG vessels, whichever is greater.	Fireproofed equivalent to 1 ½ hours in UL 1709 (or functional equivalent).	Sections 6.2.2 and 6.2.3 API 2510 (1995) Section 8.8.5
Critical wiring and control systems.	15-to-30-minute protection in UL 1709 (or functional equivalent) temperature conditions.	Section 6.1.8.1 API 2510 (1995) Section 8.11

Note: [a]Some company standards require protection greater than that shown in column 2.





Over-design or Under-design ?

Conduct fire modeling

Determine

i. The contour of thermal impact

ii. How long does the burning last ?

Applications of Consequence based Solutions

Firewater supply duration

- **NFPA 15**

A.4.4.8 It is desirable to contain runoff for the anticipated duration of any fire. However, in large chemical or petrochemical facilities, a major fire can last for 8 hours or more, resulting in extremely large holding basins or retention ponds. Where the anticipated incident duration results in retention basins that are of impractical size, methods to limit the duration of runoff might be required.

When an extended duration is anticipated, a duration of 4 hours is usually considered the practical maximum. During that time, it is often possible to isolate equipment and reduce the flow rate of water and other materials so that the continuous discharge flow rate is less than the initial flow rate. If a significant amount of flammable materials can be removed from the protected area, it could be possible to shut down water spray systems and manually fight the fire, greatly reducing the amount of material that needs to be contained.

- **CCPS (AIChE)**

7.4.1.2. Tanks and Reservoirs

Limited capacity sources such as tanks and reservoirs can be provided as a source of water. The designs of tanks and reservoirs should be for the minimum judged necessary for fighting fire within the facility. This may be as little as a two hour supply for a relatively low risk plant, but a minimum of 4 hours is typical, based on the largest fire water demand. Within a facility, there may be certain units that require more than a four hour supply, i.e. due to a larger inventory of flammable materials. In such cases, additional sources of fire water will be required. This may mean temporary hook-up of a neighbor's system, use of cooling water, storm impoundment ponds, or reliance on municipal systems. A larger capacity may be warranted for larger and more complex facilities. Fire water pump suction tanks should be on ground level. Freeze protection should

Too general ?

Applications of Consequence based Solutions

Firewater supply duration

ประกาศกระทรวงอุตสาหกรรม

เรื่อง การป้องกันและระงับอัคคีภัยในโรงงาน

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หมวด ๔

ระบบน้ำดับเพลิง

ข้อ ๑๐ ผู้ประกอบกิจการโรงงานต้องจัดเตรียมน้ำสำหรับดับเพลิงในปริมาณที่เพียงพอที่จะส่งจ่ายน้ำให้กับอุปกรณ์ฉีดน้ำดับเพลิงได้อย่างต่อเนื่องเป็นเวลาไม่น้อยกว่าสามสิบนาที

Not specific !!!

- **API 2030**

areas can be based on the potential fire exposure, the expected fire duration and drainage capacity. If process equipment cannot be isolated and de-inventoried quickly a fire can have a duration longer than the 1 to 4 hours protection that passive fireproofing can reasonably provide. Application of cooling water from spray systems (or firewater monitors or hand lines) should be given consideration in such cases since this can provide continuing protection for as long as the water supply lasts.

Conduct fire modeling

Assist to determine;

How long does the fire burning possibly last ?

Applications of Consequence based Solutions

Fire/Smoke & Gas Detectors mapping study

ประกาศกระทรวงอุตสาหกรรม

เรื่อง การป้องกันและระงับอัคคีภัยในโรงงาน

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หมวด ๒

ระบบสัญญาณแจ้งเหตุเพลิงไหม้

ข้อ ๘ อาคารโรงงานต้องจัดให้มีอุปกรณ์ตรวจจับและแจ้งเหตุเพลิงไหม้ครอบคลุมทั่วทั้งอาคารตามความเหมาะสมกับสภาพพื้นที่ โดยเฉพาะในพื้นที่ที่ไม่มีคนงานปฏิบัติงานประจำและมีการติดตั้งหรือใช้งานอุปกรณ์ไฟฟ้า หรือจัดเก็บวัตถุไวไฟหรือวัสดุติดไฟได้ง่ายจะต้องติดตั้งอุปกรณ์ตรวจจับและแจ้งเหตุเพลิงไหม้อัตโนมัติ

Not define !!!

Conduct dispersion & fire/smoke(CFD) modeling

17.8.3.2 Spacing Considerations for Flame Detectors.

17.8.3.2.1* The location and spacing of detectors shall be the result of an engineering evaluation that includes the following:

(1) Size of the fire that is to be detected
(2) Fuel involved
(3) Sensitivity of the detector
(4) Field of view of the detector
(5) Distance between the fire and the detector
(6) Radiant energy absorption of the atmosphere
(7) Presence of extraneous sources of radiant emissions
(8) Purpose of the detection system
(9) Response time required

- **NFPA 72**

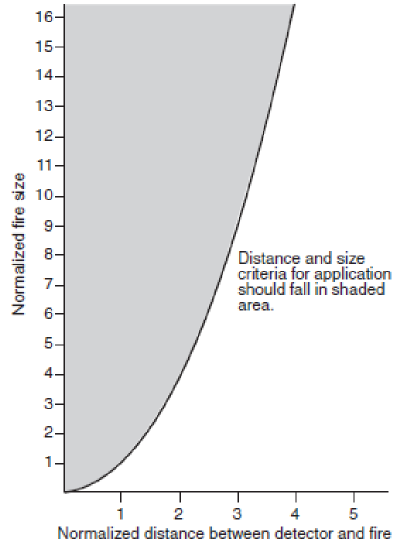

FIGURE A.17.8.3.1.1 Normalized Fire Size vs. Distance.

Q & A

Chemical Process Safety Sharing

Thank you for your attention