Preparing For Large Atmospheric Storage Tank Fires

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FIRE & RISK ALLIANCE

About Me

- B.S. & M.S. in Fire Protection Engineering from UMD
- MBA R.H. Smith School
- PhD Candidate University of Waterloo
- Licensed FPE

- Subject Matter Expert (SME) for Saudi Aramco
  - Loss Prevention
  - Fire Protection
  - Hazard and Risk Assessment

- Adjunct Professor & Visiting Researcher UMD
  - Industrial Fire Protection
  - Fire & Explosion Investigation

- Principal Fire & Risk Alliance www.fireriskalliance.com
- Principal Custom Spray Solutions www.customspraysolutions.com

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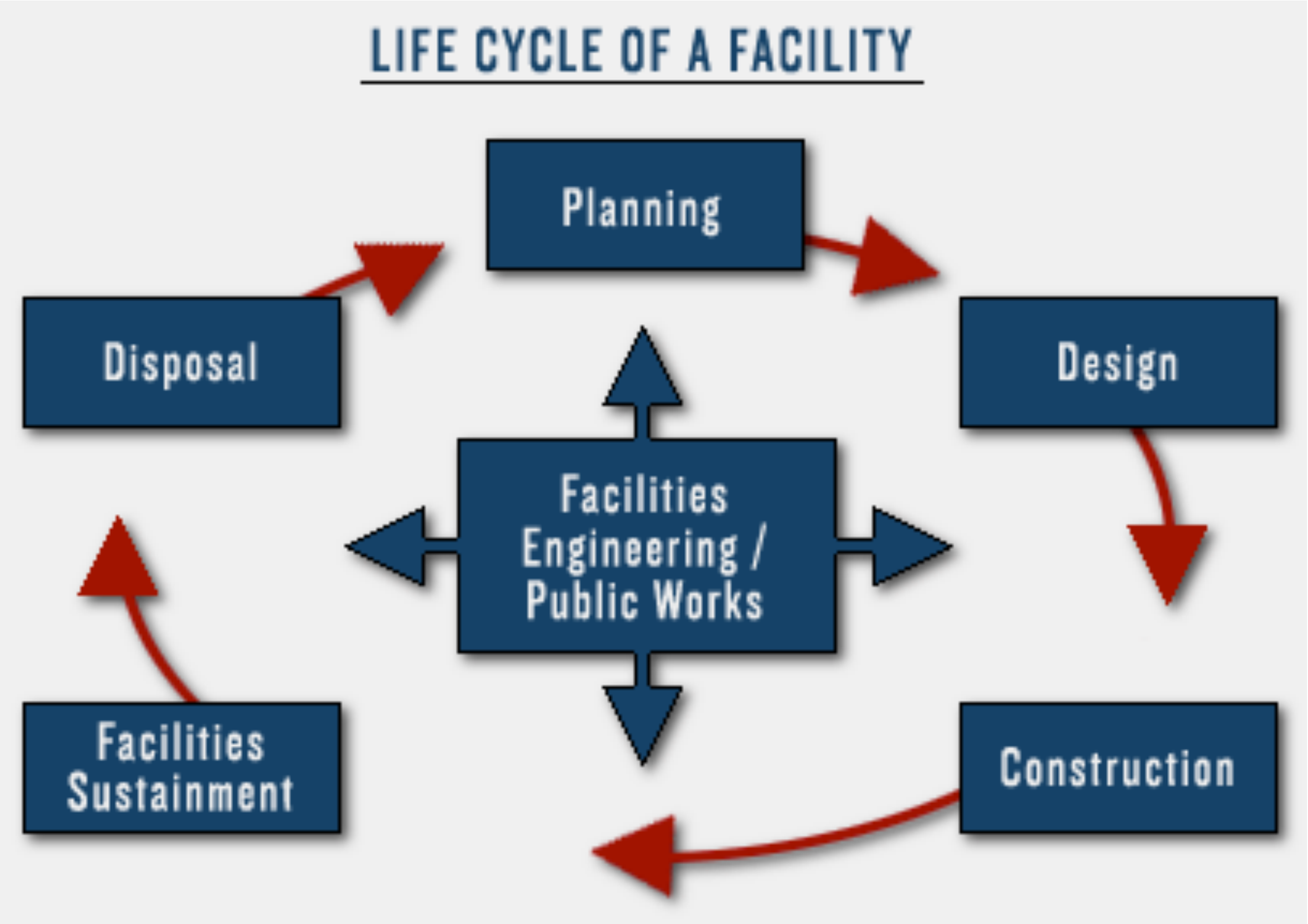
Presentation Overview

- Optimal Time to Prepare Strategy
- Tank Fire Scenarios
- Defining Acceptable Loss (Risk) & Assessment Methods
  - Lives
  - Monetary (Business interruption, loss of market, public image)
  - Prescriptive vs. Performance
  - Qualitative vs. Quantitative
- Optimizing Protection
  - Fixed
  - Semi-fixed
  - Manual emergency response

Protection Strategy Definition

- When is the best time to prepare your protection strategy?
- What can you do at various stages of the facility life cycle to prevent/mitigate incidents?
- How can a well thought out plan affect the outcome of events?

Life Cycle of a Facility



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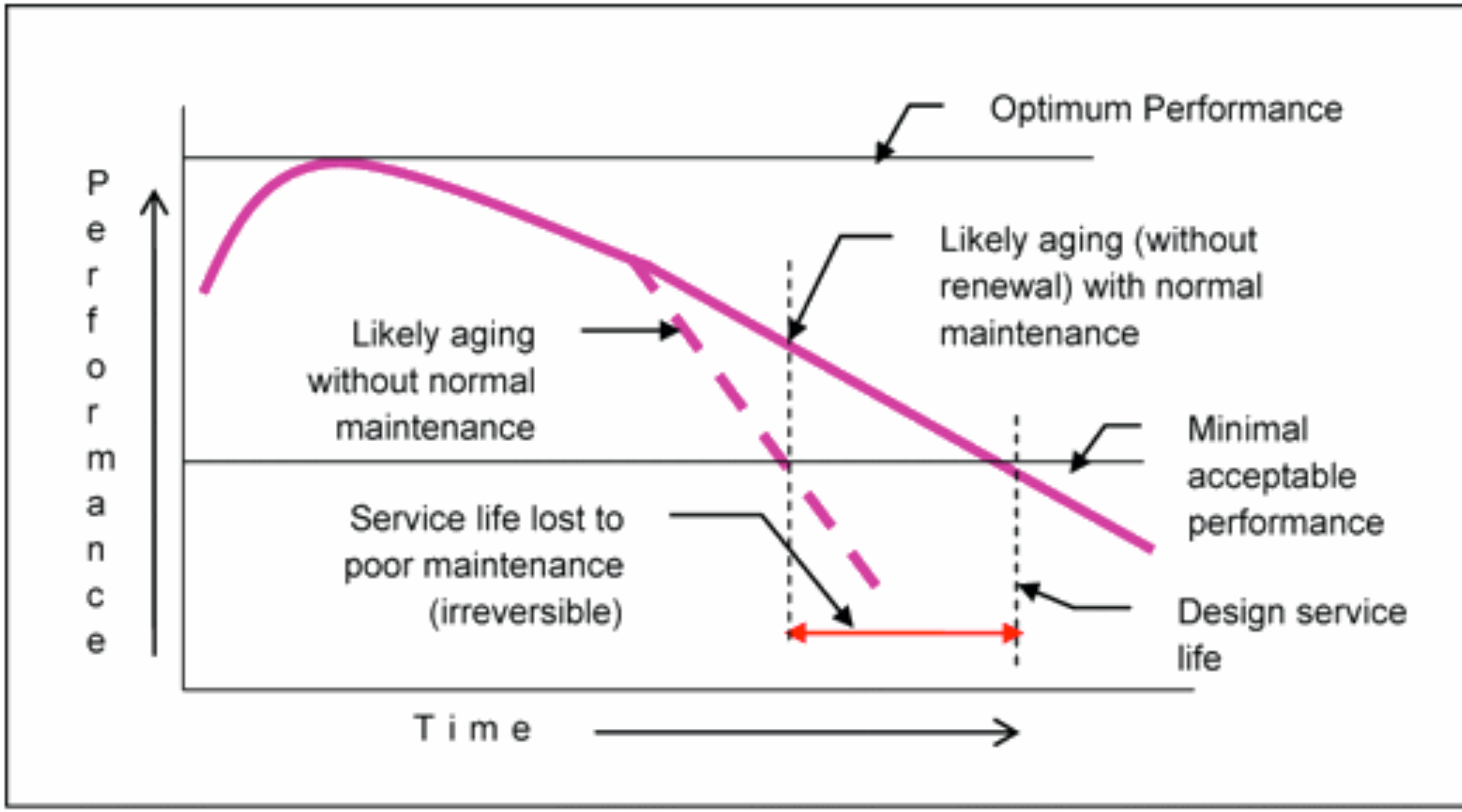
Life Cycle of a Facility



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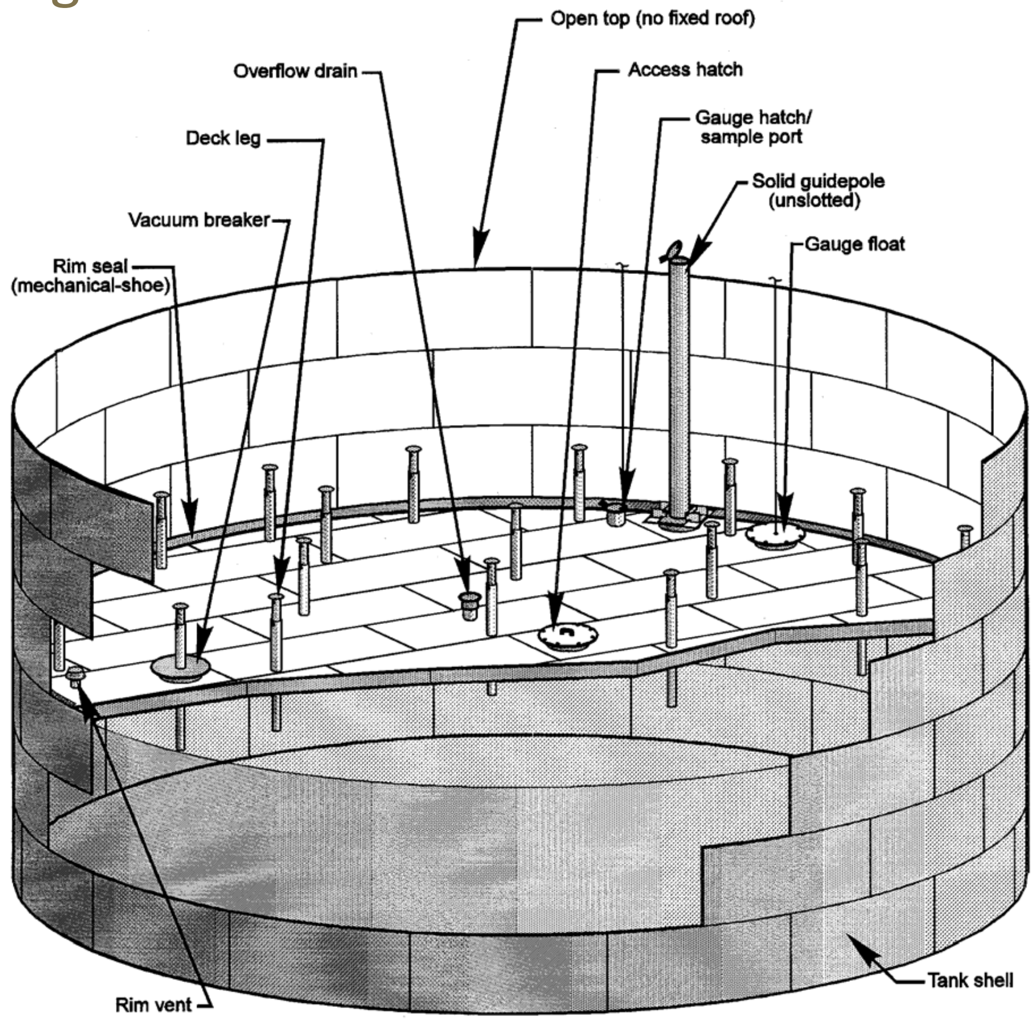
Typical Tank Construction

- Floating Roof Tank



Wikicommons: http://upload.wikimedia.org/wikipedia/commons/c/c0/External_floating_roof_tank_(double_deck).png

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Primary Causes of Tank Failure

1. Operational errors	**4. Static electricity**	**7. Piping rupture/leak**
Tank overfilling	Rubber seal cutting	Valve leaking
Drain valves left open accidentally	Poor grounding	Flammable liquid leak from a gasket
Vent closed during loading/unloading	Fluid transfer	Piping failure
Oil leaks due to operators errors	Improper sampling procedures	Pump leak
High inlet temperature		Cut accidentally
Drainage ducts to retention basin obstructed		Failure owing to liquid expansion
2. Equipment/instrument failure	**5. Maintenance errors**	**8. Miscellaneous**
Floating roof sunk	Welding/cutting	Earthquake
Level indicator	Non explosion-proof motor and tools used	Extreme weather
Discharge valve rupture	Circuit shortcut	Vehicle impact on piping
Rusted vent valve does not open	Transformer spark	Open flames/smoking flame
	Poor grounding of soldering equipment	Escalation from another unit (domino)
	Poor maintenance of equipment both normal and blast proof	Accident caused by energy/fuel transportation lines
		Arson (intentional damage)
3. Lightning	**6. Tank crack/rupture**	**9. Safety supporting systems**
Poor grounding	Poor soldering	Electric power loss
Rim seal leaks	Shell distortion/buckling	Insufficient tank cooling
Flammable liquid leak from seal rim	Corrosion	Firefighting water loss
Direct hit		Firefighting water in piping freezing

C.D. Argyropoulos et al. / Journal of Loss Prevention in the Process Industries 25 (2012)

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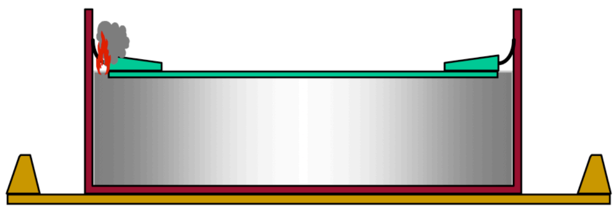
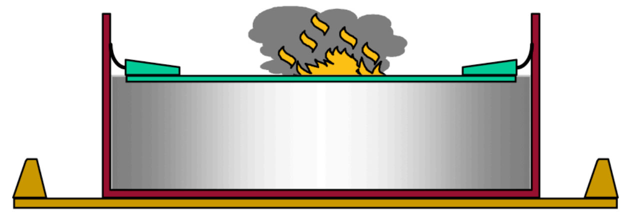
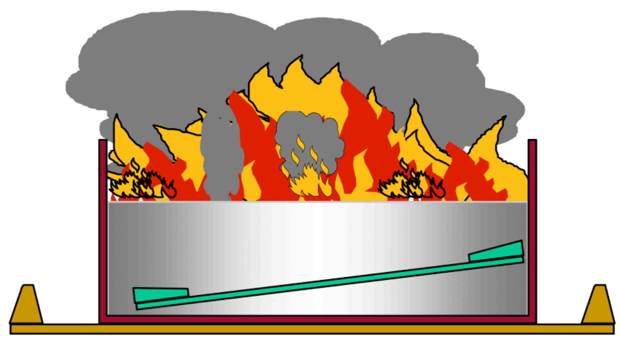
Typical Tank Fire Scenarios



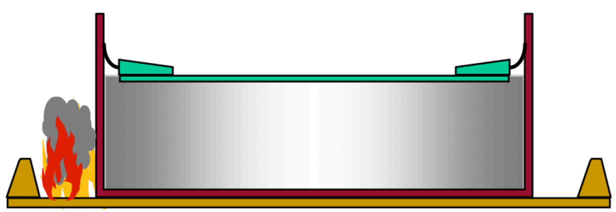
Rimseal Fire



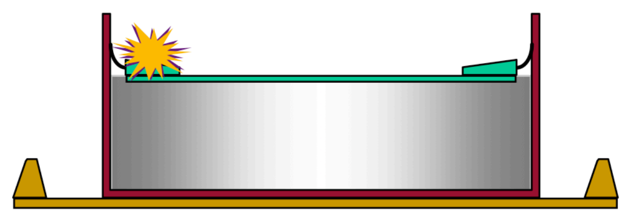
Spill on Roof Fire



Full Surface Fire



Bund Fire



Pontoon Explosion

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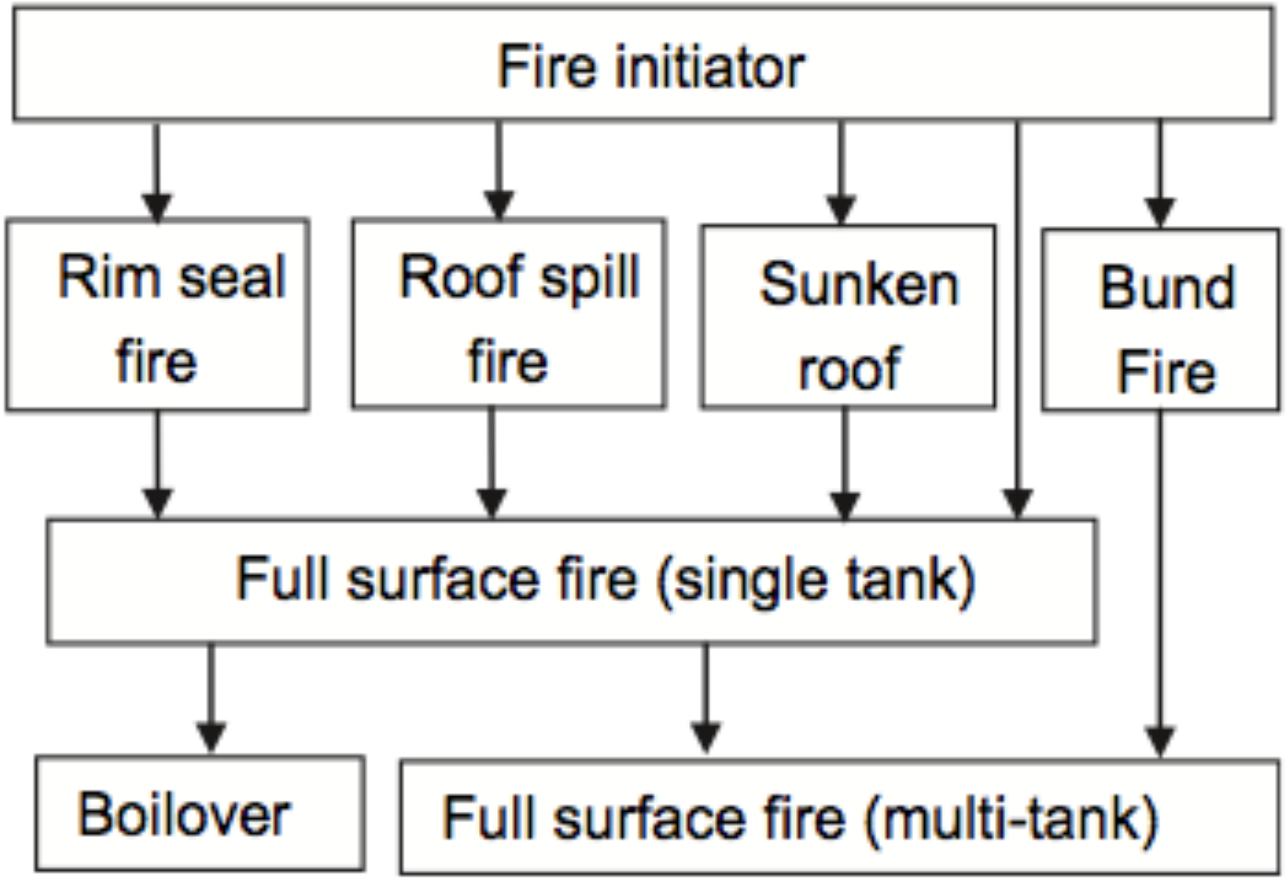
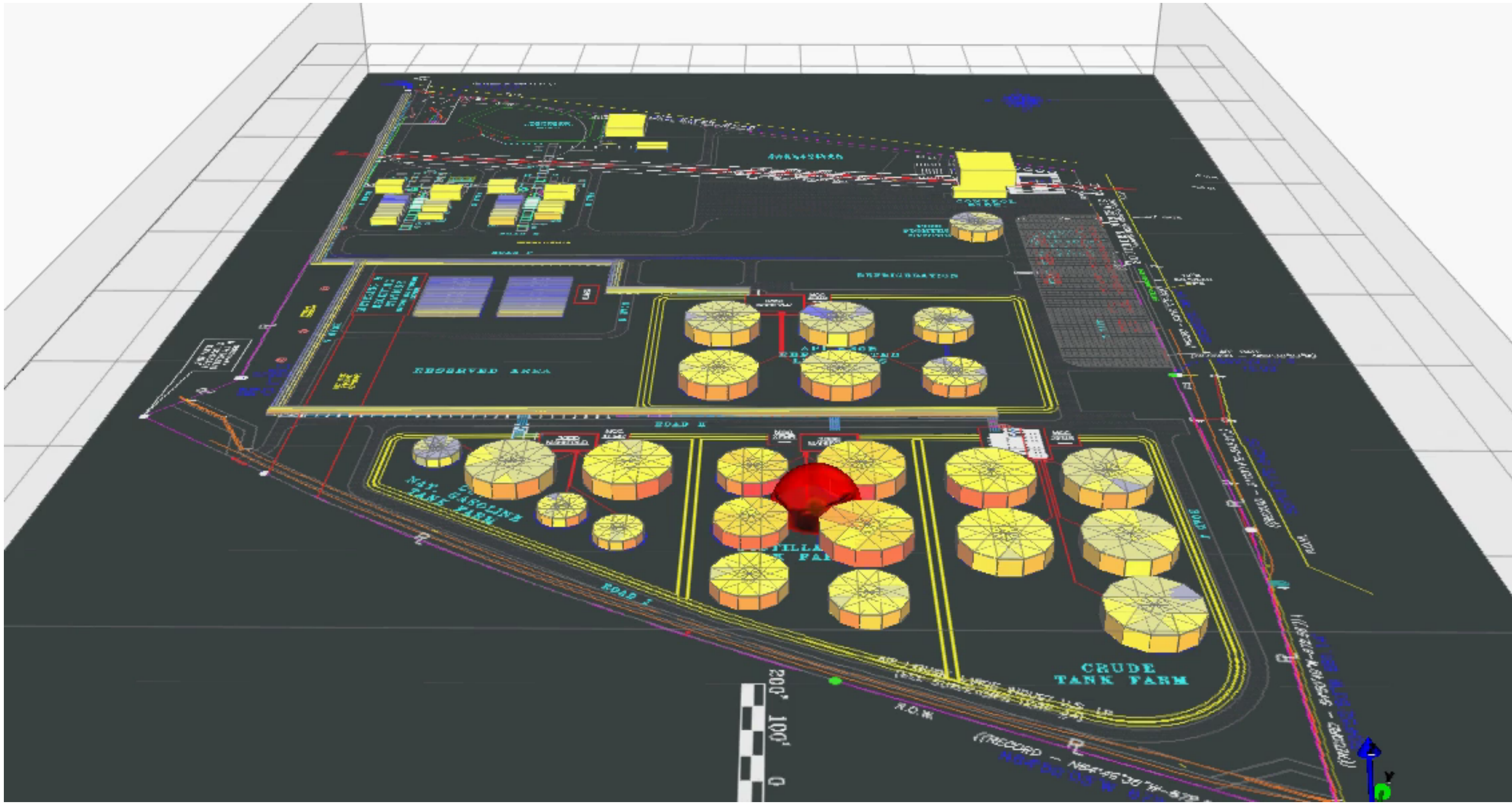
Fire Progression



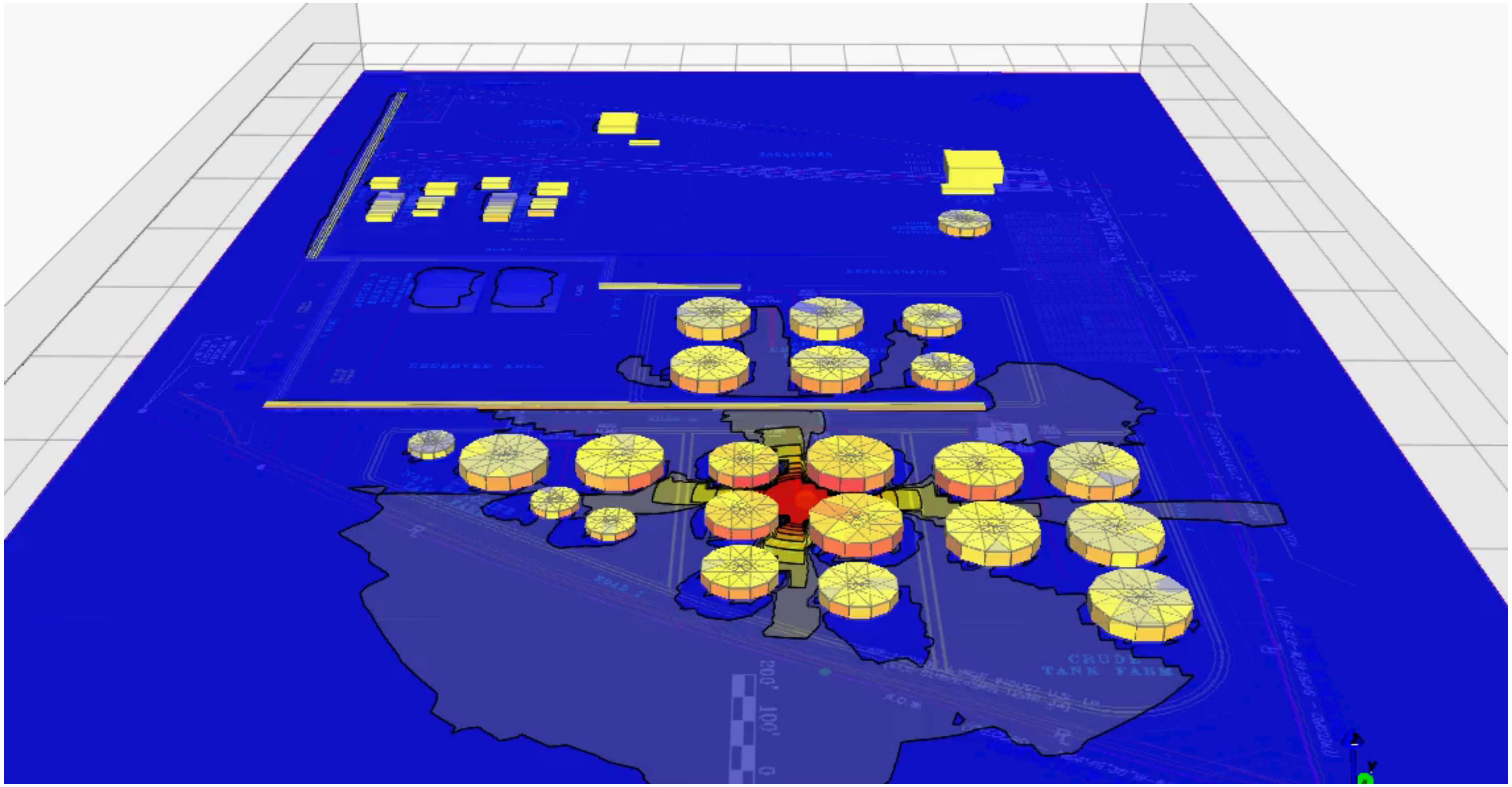
Explosions

- If a flammable liquid release occurs and ignition is not immediate an explosion (fireball with associated pressure wave) may occur
- Explosions have the ability to escalate an incident quickly and often are the initiating event in incidents involving multiple tanks
- Quickly escalate incident from a single tank to other tanks or equipment

Example: Explosion Overpressure



Example: Explosion Overpressure



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Need For Protection & Prior Incidents

- Estimated 15-20 tank fires per year worldwide
- Average frequency of fire 0.362 x 10^{-3}/tank yr
- Implies 1 fire per ~2700 tanks
- Rate and magnitude of incidents is not decreasing
- Tank sizes and storage capacity is increasing
- Most guidance only “good” up to 200’ in diameter

“None of the losses listed in this document should be considered “black swan” events”

Marsh, The 100 Largest Losses, 1974-2014

Prior Incidents

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Prior Incidents

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Prior Incidents

- Many studies provide information on incidents
  - LASTFire
  - Mansour 2012
  - Chang et. al. 2004
  - Persson, Lonnermark 2004

What is Risk?

- Risk=Consequences x Probability

- Risk deals with the realization of a hazard, that is the consequences of a hazard * the probability that the hazard will come to fruition

- We encounter risk all the time in all our daily actions.
  - Driving a car
  - Walking across the street
  - Etc.

–**Risk is unavoidable! However we can minimize it**

Acceptable Loss

- Most often put in terms of
- "Accepted Risk" or "Approved Risk"

- Accepted Risk: is a risk that is knowingly accepted by the persons that are exposed, regardless of the level of risk.

- Approved Risk: a risk that has been approved by the appropriate authority or regulator on behalf of workers or the general community. This risk may or may not be accepted by those exposed.

Acceptable Loss

- An "Acceptable Loss" is a loss that is deemed within reason for a business.

- Think of it as: "What are we willing to lose (risk) to achieve our goal?"

- Zero loss is not achievable, therefore everyone and every business has an explicit or implicit Acceptable Loss Criteria

How to Reduce Risk

- Systematic Risk Reduction
  - Reduce hazards in facilities
  - Implement safer process designs
  - Increase reliability of systems
  - Increase fire suppression capabilities
  - Transfer risk

–This all sounds "easy" but how do you actually do it?

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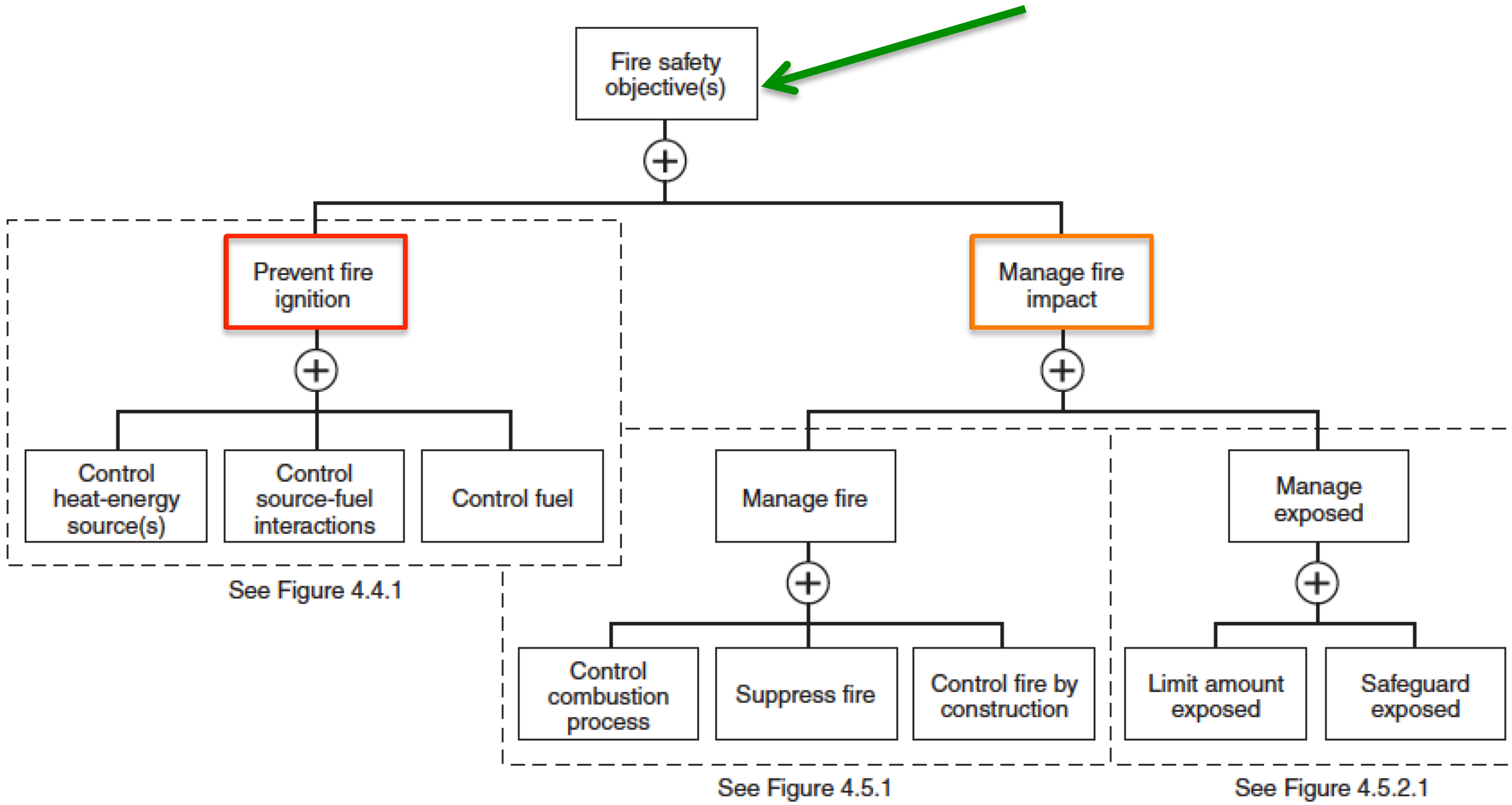
Risk & The NFPA 550 Fire Safety Concepts Tree



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Assessing Risk

- Qualitative
  - Relative risk indexes
  - Risk matrices
- Quantitative
  - Calculations of consequences
  - Link to probability of incident

Basic Process

1. Discuss risk position with stakeholders
2. Define and understand the hazards & risk that may be present
    a. Consequences & Probabilities
3. Agree on Accepted or Approved risk criteria
4. Evaluate existing or proposed mitigation
5. Identify gaps between Actual Risk & Protection
6. Choose how to handle "additional" risk
    a. Accept the Risk
    b. Reduce the Risk
    c. Transfer the Risk

Stakeholders

- There are numerous stakeholders that should be consulted
  - Treasury
  - Engineering
  - Maintenance
  - Fire Protection/Loss Prevention
  - Responsible agent for standards
  - Public/Government representatives

•Each stakeholder plays a key role and has a unique perspective

Qualitative vs. Quantitative

- Qualitative
  - Often quicker
  - May be less expensive initially
  - Provides a means of ranking, but is limited to framework in which information is presented (i.e. cannot compare risk between different methods)
  - Can be viewed as an "average" risk in many cases, you may not capture the true risk

Qualitative: Classifying Risk

- Use a Hazard Risk Matrix to classify the the risk

Frequency of occurrence of a hazardous event	Risk Levels			
Frequent	Undesirable	Intolerable	Intolerable	Intolerable
Probable	Tolerable	Undesirable	Intolerable	Intolerable
Occasional	Negligible	Undesirable	Undesirable	Intolerable
Remote	Negligible	Tolerable	Undesirable	Undesirable
Improbable	Negligible	Negligible	Tolerable	Tolerable
Incredible	Negligible	Negligible	Negligible	Negligible
	Insignificant	Marginal	Critical	Catastrophic
	Severity Level of Hazard Consequence			

Qualitative vs. Quantitative

- Quantitative
  - May take longer in some cases
  - Provides quantitative physical results that can be compared with other risks and across facilities
  - Allows for a detailed analysis of consequences
  - Provides data that can result in truly optimized performance based solutions

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Prescriptive vs. Performance

- Quantitative vs. Qualitative, assumption is that guidelines and standards that specify protection are linked to performance.
- Stated requirement inherently has minimum performance associated with it.
  - Is the performance acceptable?
- Performance requires understanding of consequences
  - Design to meet stated goals, not to a specific standard
  - In some cases this may be more or less than standard requires

Saudi Arabian Chapter SFPE 2005

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Risk & Tanks

- Already established that the observed incidents are not "Black Swan" incidents
- Desire to reduce probability of tank fires
- Some residual probability exists and this is the reason for fire protection systems; assumption is the layers of protection have failed and that the consequences for an unmitigated event are too high

- Therefore key component is fire size and tank-to-tank radiation potential

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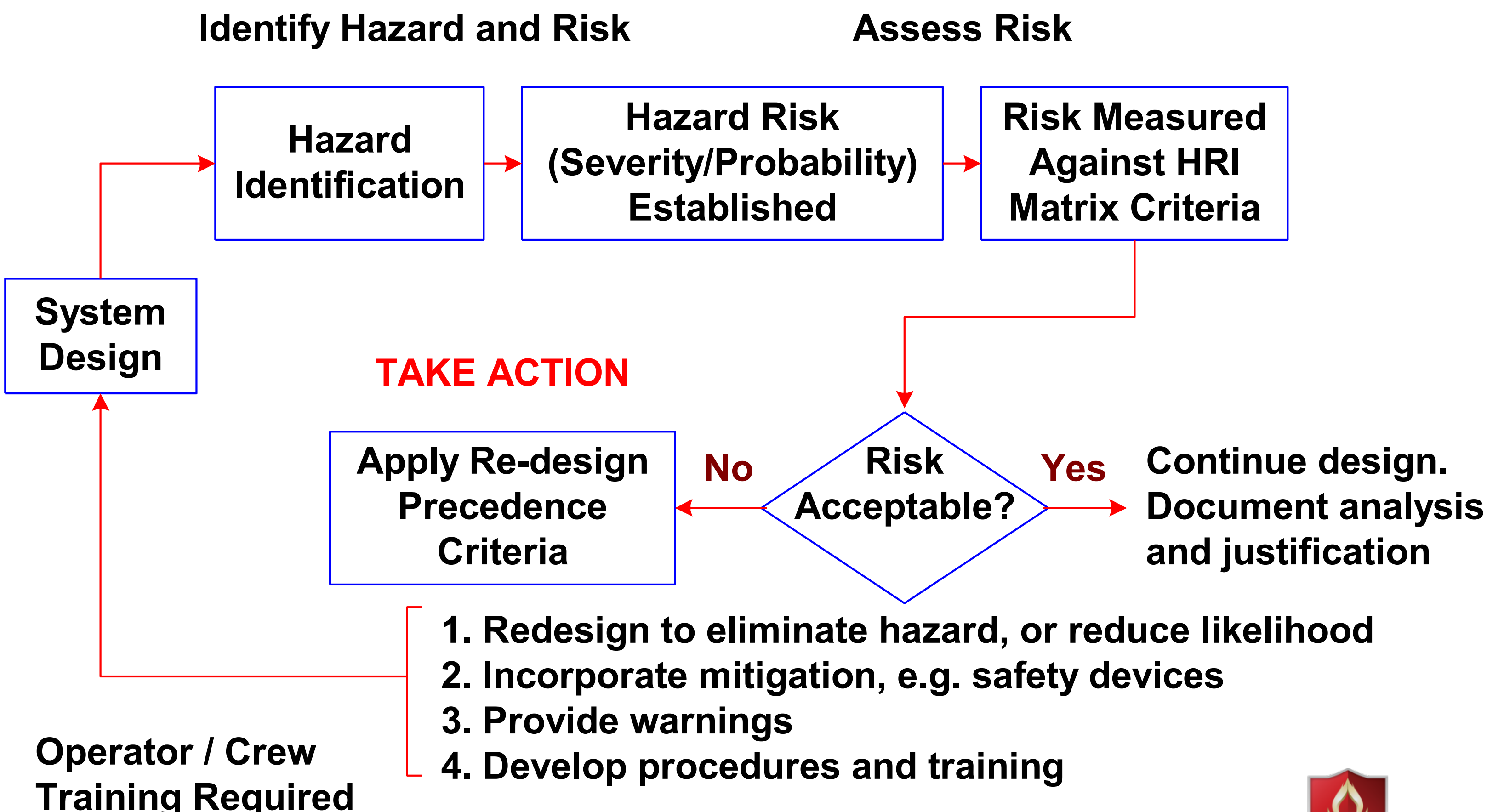
Risk Reduction Flowchart



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Methods of Evaluating Radiation

- Hand calculations/Spreadsheets
- Experimental data
- Simple computer models
  - Phast
  - Breeze Incident Analysis
- Computational Fluid Dynamics (CFD) Models

Effects of Radiant Heat Flux

Incident Heat Flux	Effect	Estimated Surface T (C)
1.4	Harmless for person without any special protection for short exposure	150
2.1	Minimum required to casue pain after 60s	185
4.7	Causes pain in 15-20s and burns after 30s	275
6.3	Tolerance limit for firefighters completely protected by turnout gear	330
10.0	Certain polymers (EFR clothing) may ignite	380
11.7	Partly or non-insulated steel may lose integrity	405
12.6	Wood will ignite after prolonged exposure, 100% lethality	420
25.0	Fully insulated steel may lose integrity	545
37.5	Damage to process equipment and collapse of structures	630

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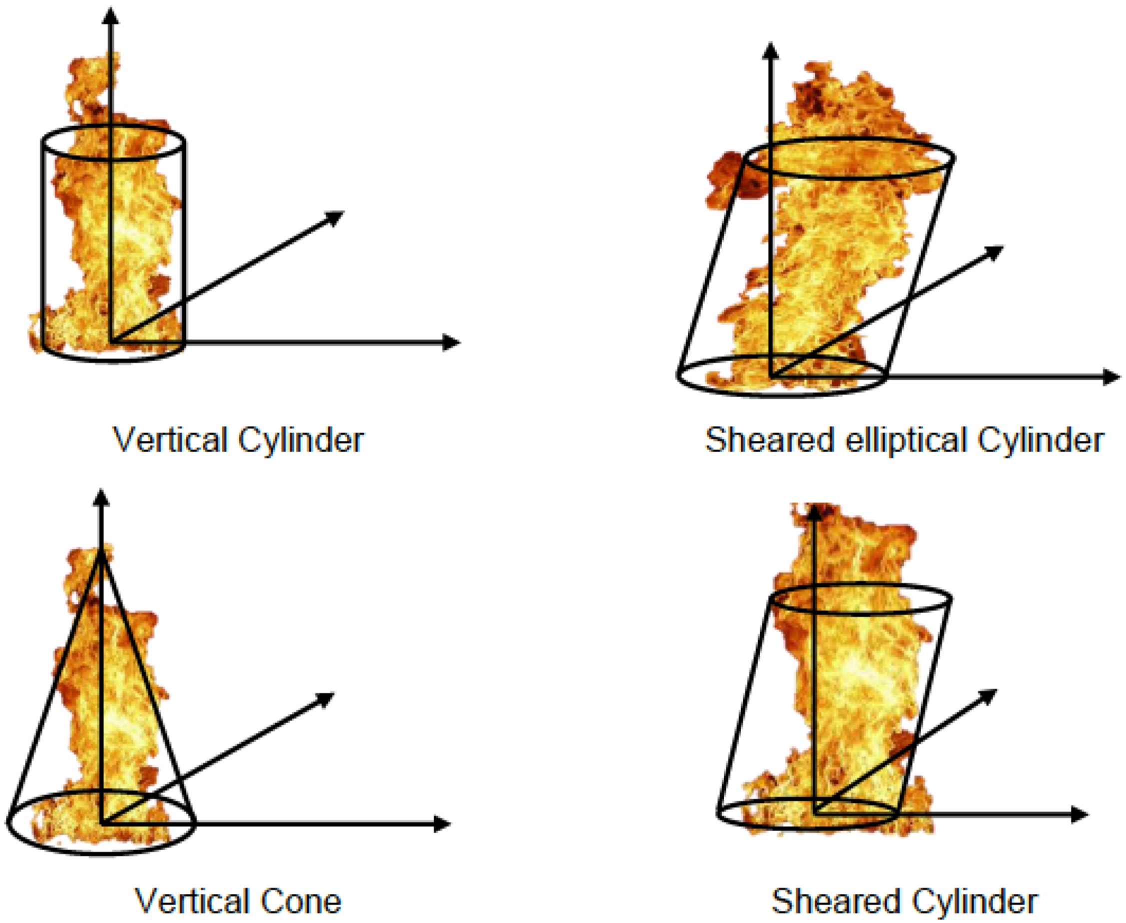
Typical Radiation Flame Shapes



Mansour, 2012

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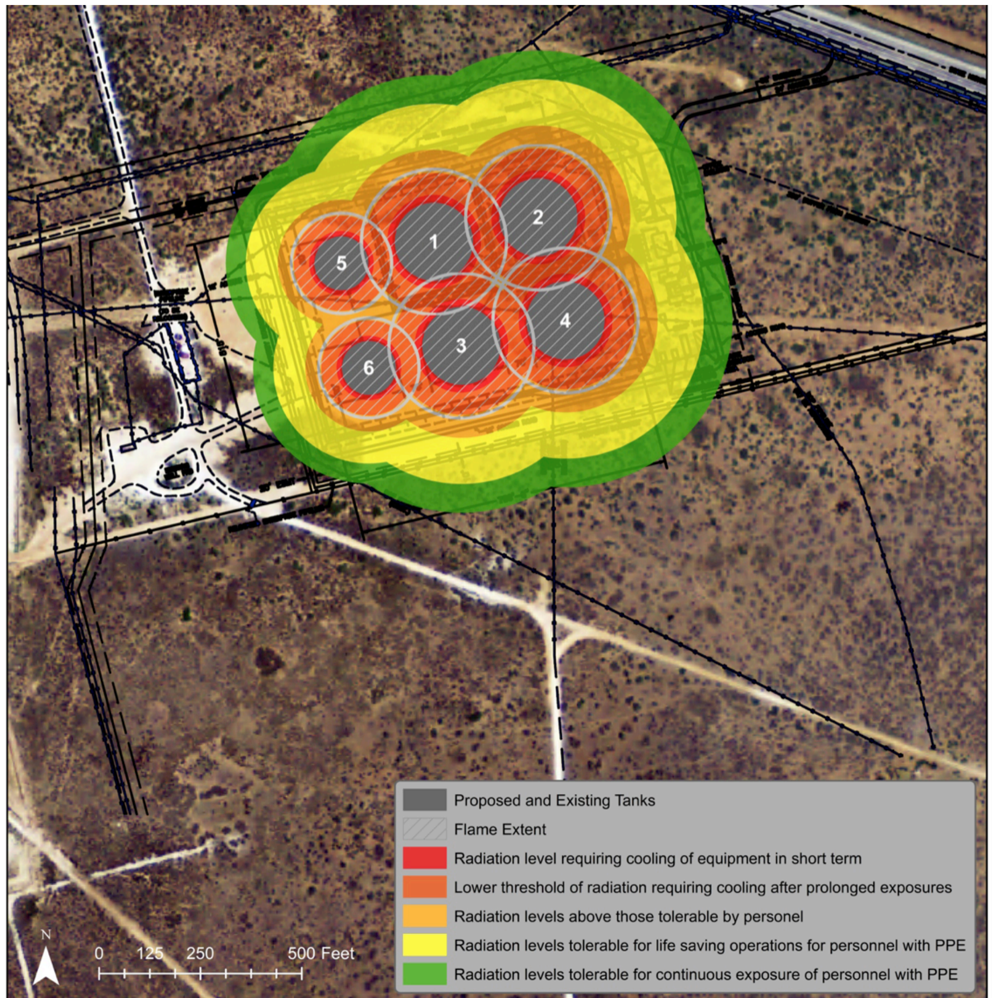
Example Tank Terminal: Phase 1



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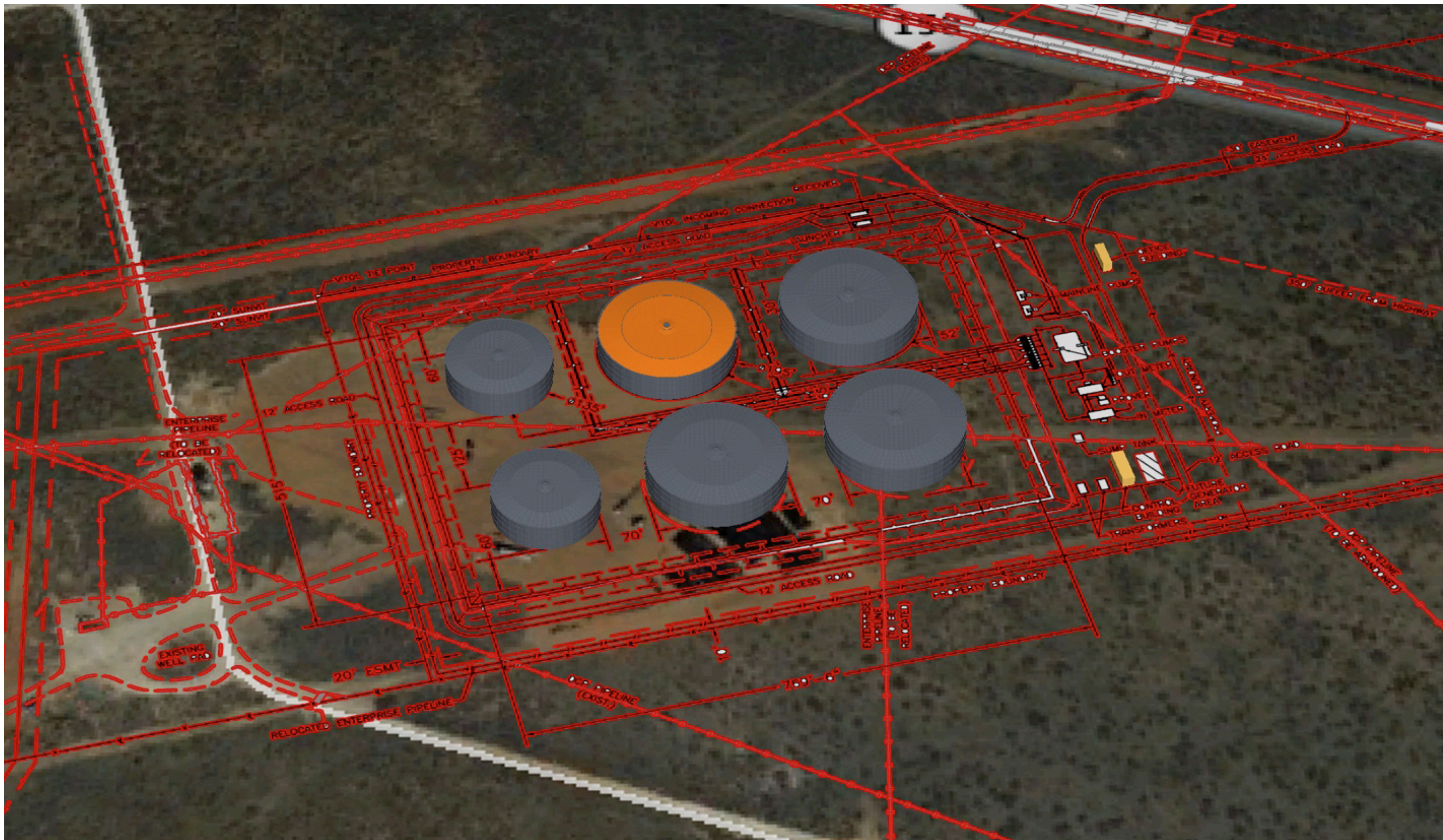
Empirical Radiation to Target

Distance (m) / Diameter (m)	10	20	30	49	50	57	67	75	86	100	115	125	135	145	150	165	200	250	300
10	15.4	5.115	2.68	1.23	1.19	0.97	0.75	0.63	0.5	0.4	0.3	0.3	0.2	0.2	0.2	0.2	0.1	0.1	0.07
15	29.34	9.747	5.12	2.34	2.27	1.84	1.43	1.19	0.96	0.8	0.6	0.5	0.5	0.4	0.4	0.3	0.3	0.2	0.13
20	46.36	15.4	8.08	3.7	3.59	2.91	2.25	1.88	1.51	1.2	1	0.8	0.7	0.7	0.6	0.5	0.4	0.3	0.21
30	88.34	29.34	15.4	7.06	6.84	5.55	4.29	3.59	2.89	2.3	1.8	1.6	1.4	1.3	1.2	1	0.8	0.5	0.4
34.1	108.3	35.97	18.9	8.65	8.38	6.8	5.26	4.4	3.54	2.8	2.2	2	1.7	1.5	1.5	1.3	0.9	0.6	0.49
37.5	126	41.84	22	10.1	9.75	7.91	6.12	5.12	4.12	3.2	2.6	2.3	2	1.8	1.7	1.5	1.1	0.8	0.56
40	139.6	46.36	24.3	11.2	10.8	8.77	6.78	5.67	4.56	3.6	2.9	2.5	2.2	2	1.9	1.6	1.2	0.8	0.63
48.2	187.7	62.36	32.7	15	14.5	11.8	9.12	7.62	6.13	4.8	3.9	3.4	3	2.7	2.5	2.2	1.6	1.1	0.84
50	199	66.11	34.7	15.9	15.4	12.5	9.67	8.08	6.5	5.1	4.1	3.6	3.2	2.8	2.7	2.3	1.7	1.2	0.89
59.4	261.7	86.94	45.6	20.9	20.3	16.4	12.7	10.6	8.55	6.7	5.4	4.7	4.2	3.7	3.5	3	2.2	1.6	1.17
60	265.9	88.34	46.4	21.3	20.6	16.7	12.9	10.8	8.69	6.8	5.5	4.8	4.2	3.8	3.6	3.1	2.3	1.6	1.19
65.8	308	102.3	53.7	24.6	23.8	19.3	15	12.5	10.1	7.9	6.3	5.6	4.9	4.4	4.2	3.6	2.6	1.8	1.38
75	379.2	126	66.1	30.3	29.3	23.8	18.4	15.4	12.4	9.7	7.8	6.8	6	5.4	5.1	4.4	3.2	2.3	1.7
100	599.1	199	104	47.9	46.4	37.6	29.1	24.3	19.6	15	12	11	9.6	8.5	8.1	6.9	5.1	3.6	2.68
125	854.3	283.8	149	68.3	66.1	53.7	41.5	34.7	27.9	22	18	15	14	12	12	9.9	7.3	5.1	3.83

Example Tank Terminal: Phase 1



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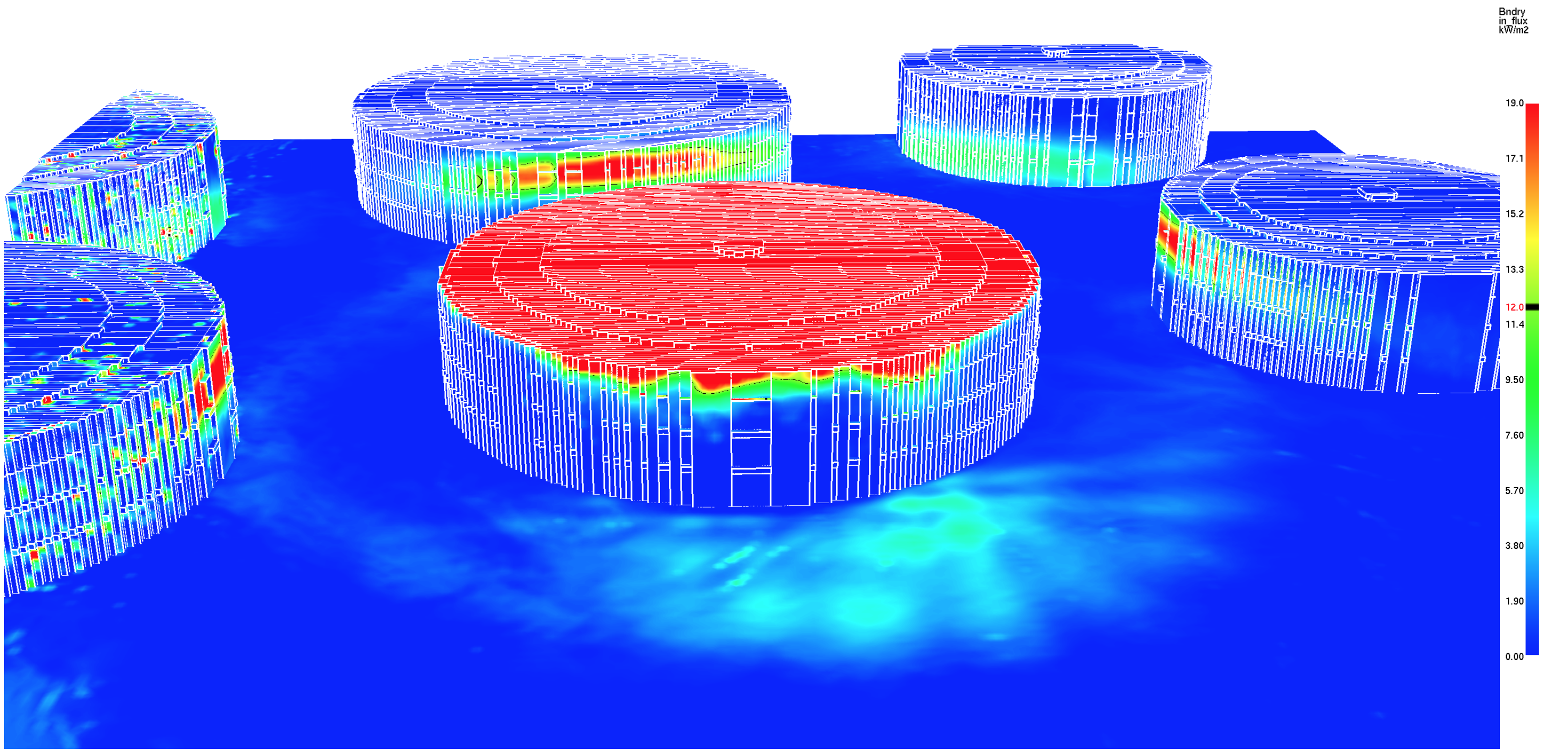
Example: Radiation & Cooling



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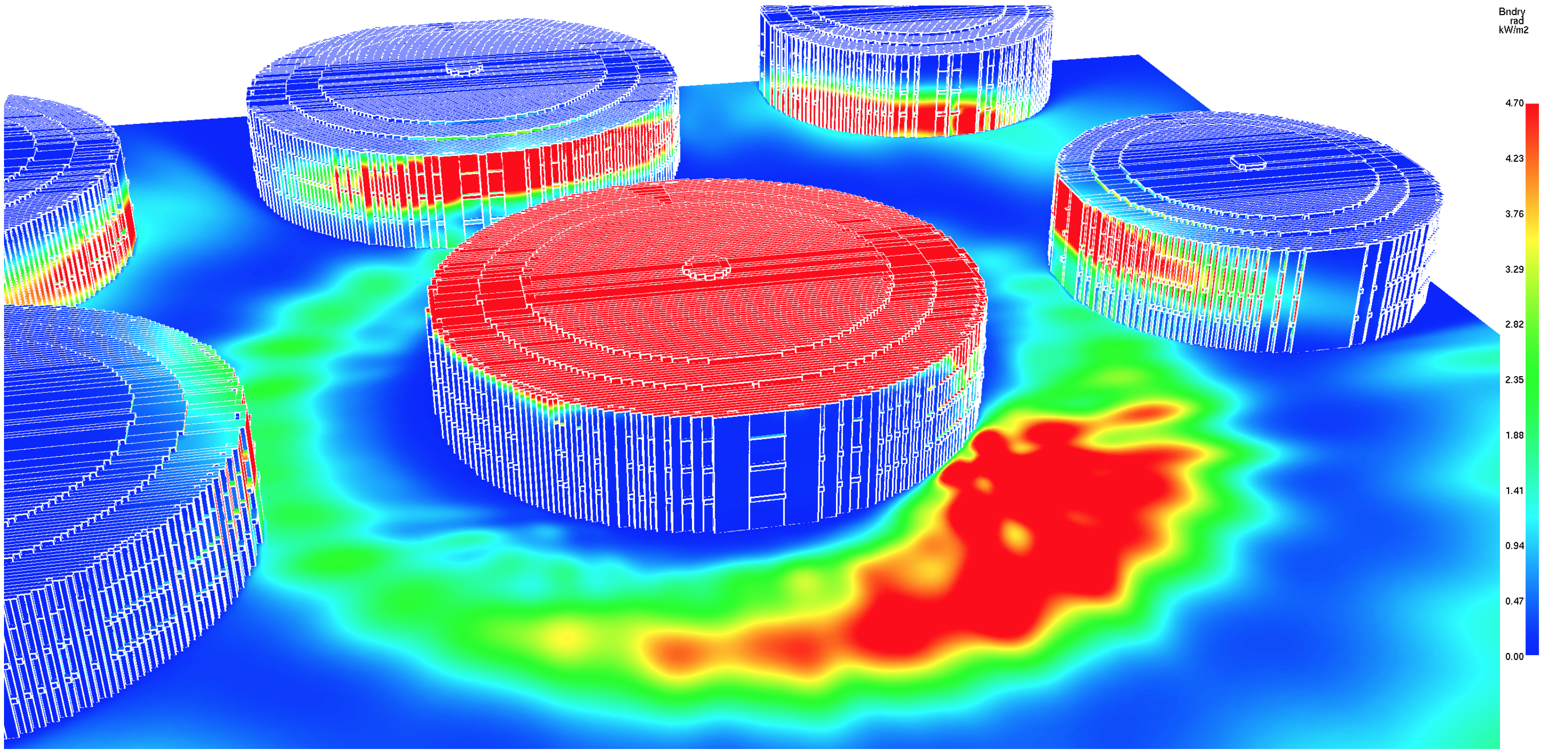
Example: Radiation & Personnel



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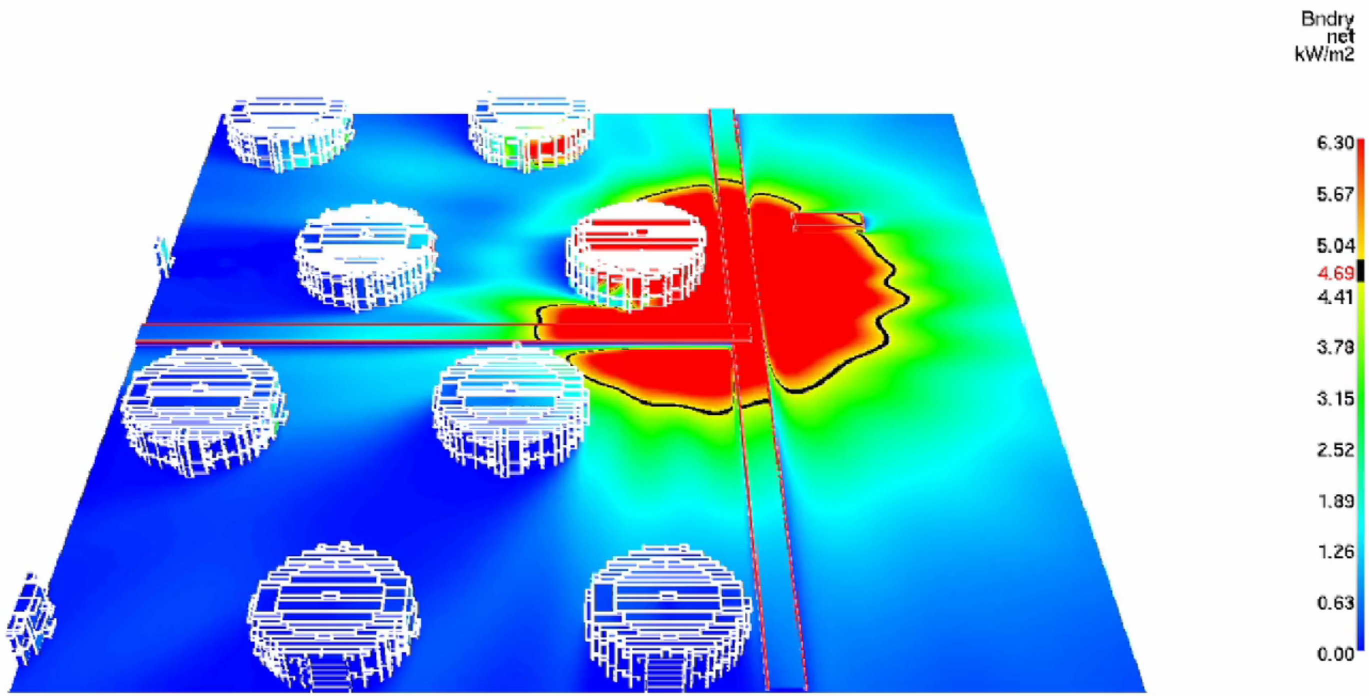
Radiation



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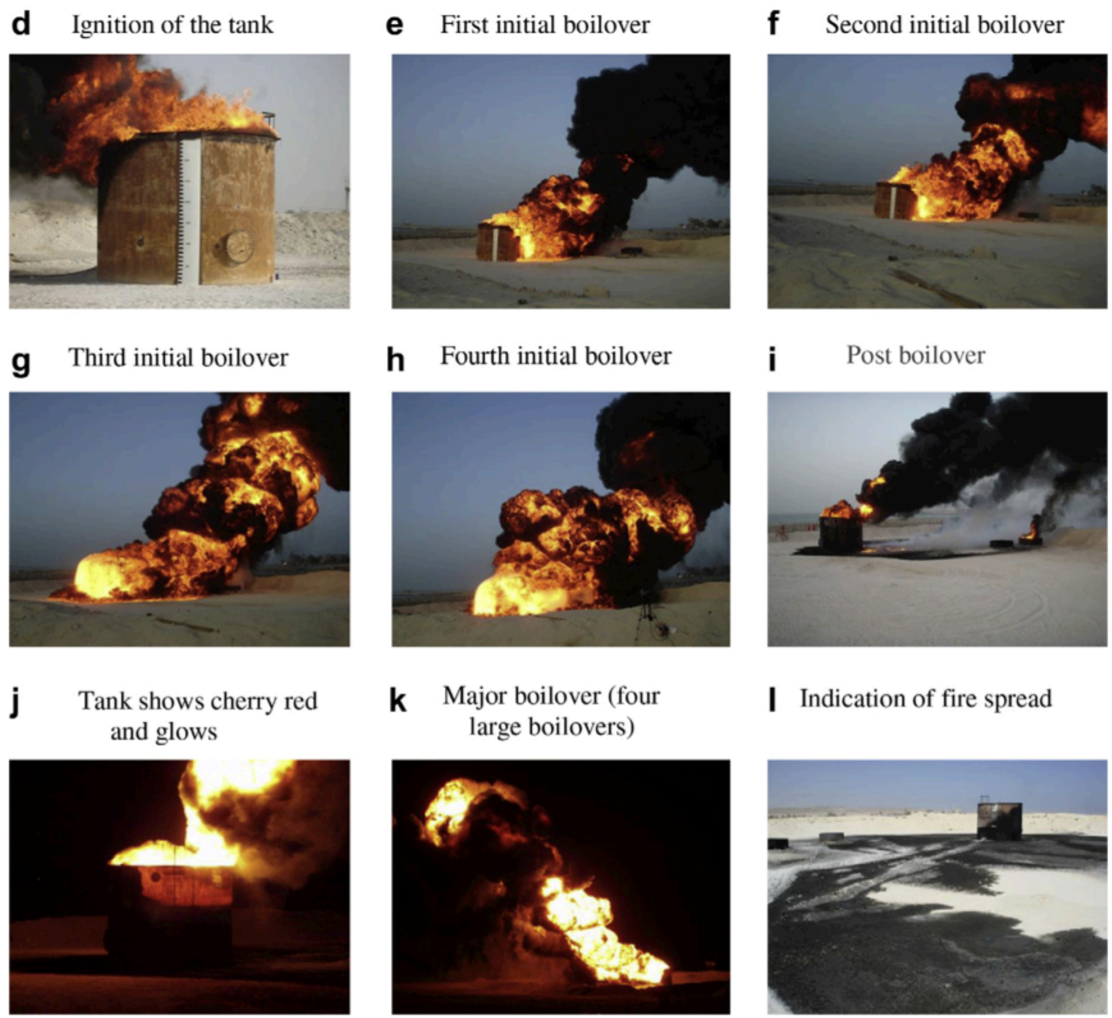
Boilover



Shaluf & Abdullah, 2011

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Boilover

A.1. Tank Boilover Calculations

Tank Information							
	Tank Number	Tank Diamter (ft)	Tank Height (ft)	Tank Roof Type	Contained Product	Estimated time to Boilover (Gravity Pump)[A]	Estimated time to Boilover (Mechanical Pump)[B]
1	A2	36.66	40	Fixed	Crude	4.75	3.45
2	B2	9	24	Fixed	Fuel Oil	2.75	2.00
3	F1	137	48	Fixed	Fuel Oil	5.75	4.18
4	F2	137	48	Fixed	Fuel Oil	5.75	4.18
5	F3	106	48	Fixed	Fuel Oil	5.75	4.18
6	F4	62	48	Fixed	Fuel Oil	5.75	4.18
7	F5	62	48	Fixed	Fuel Oil	5.75	4.18
8	F6	48	48	Fixed	Fuel Oil	5.75	4.18
9	F7	137	48	Fixed	Fuel Oil	5.75	4.18
10	F8	200	48	Fixed	Fuel Oil	5.75	4.18
11	G1	62.0	48	Fixed	C.P.P.	5.75	4.18
12	H2	10.5	31.25	Fixed	Diesel	3.66	2.66
13	3001	113	56	Floating Roof	Fuel Oil	6.75	4.91
14	3002	113	56	Floating Roof	Diesel	6.75	4.91
15	3006	55	48	Fixed	Fuel Oil	5.75	4.18
16	3009	31	32	Fixed	Crude	3.75	2.73
17	8001	253	56	Floating Roof	Fuel Oil	6.75	4.91
18	8002	253	56	Floating Roof	Fuel Oil	6.75	4.91
19	8003	253	56	Floating Roof	Crude	6.75	4.91
20	8004	253	56	Floating Roof	Crude	6.75	4.91
21	8005	253	56	Floating Roof	Fuel Oil	6.75	4.91

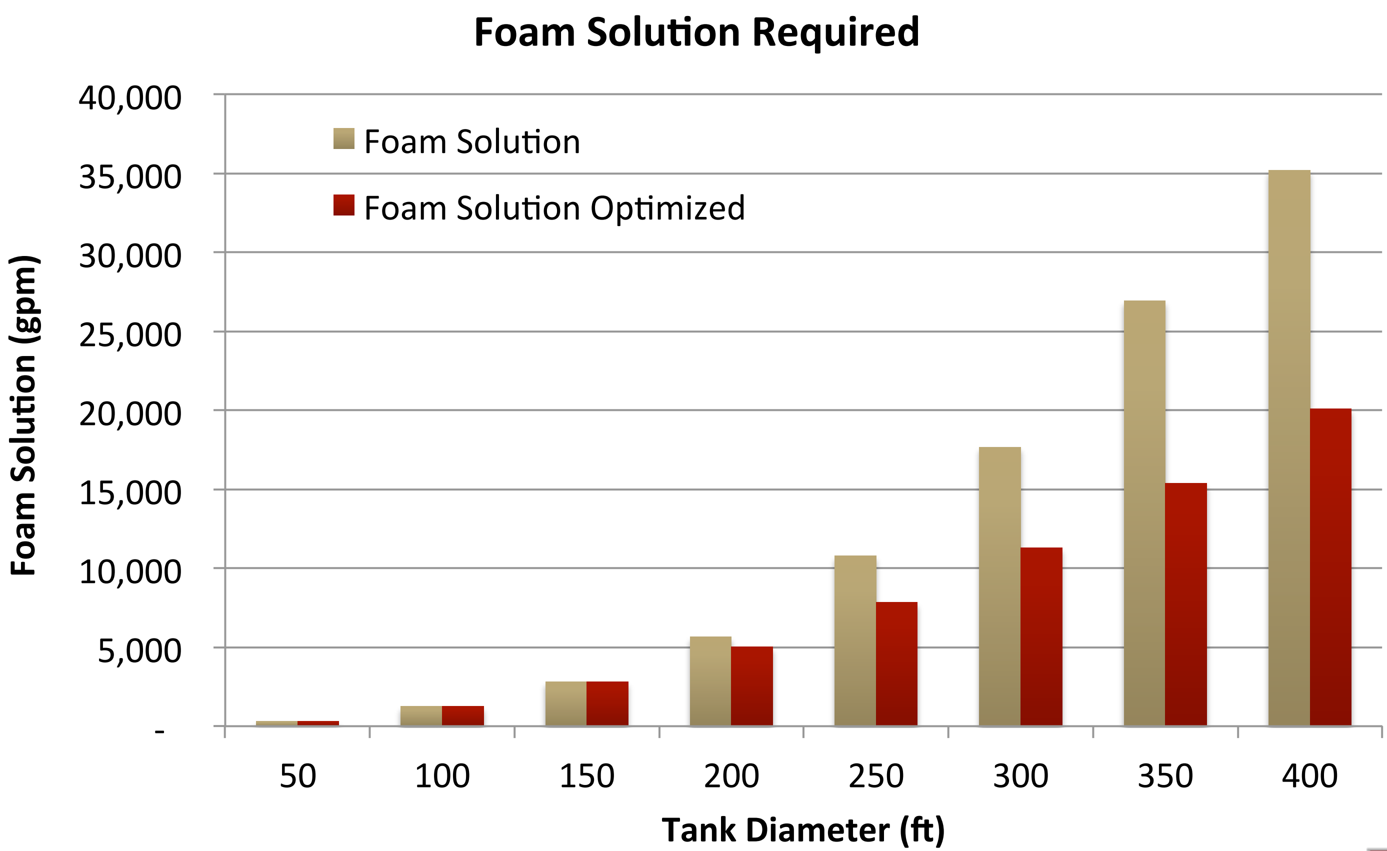
Tank Extinguishment vs. Cooling

- Desire to extinguish tanks requires water & foam sufficient for tank
  - This is "easy", well established guidelines for what is necessary
  - Challenge: as tanks get larger requirements are higher and physical performance of systems becomes limited
  - Infrastructure & logistics becomes complex
- Prevention of incident expansion requires cooling
  - This is "easy" as well
  - Are estimates reasonable for provision of cooling water

Manual Tank Suppression & Extinguishment

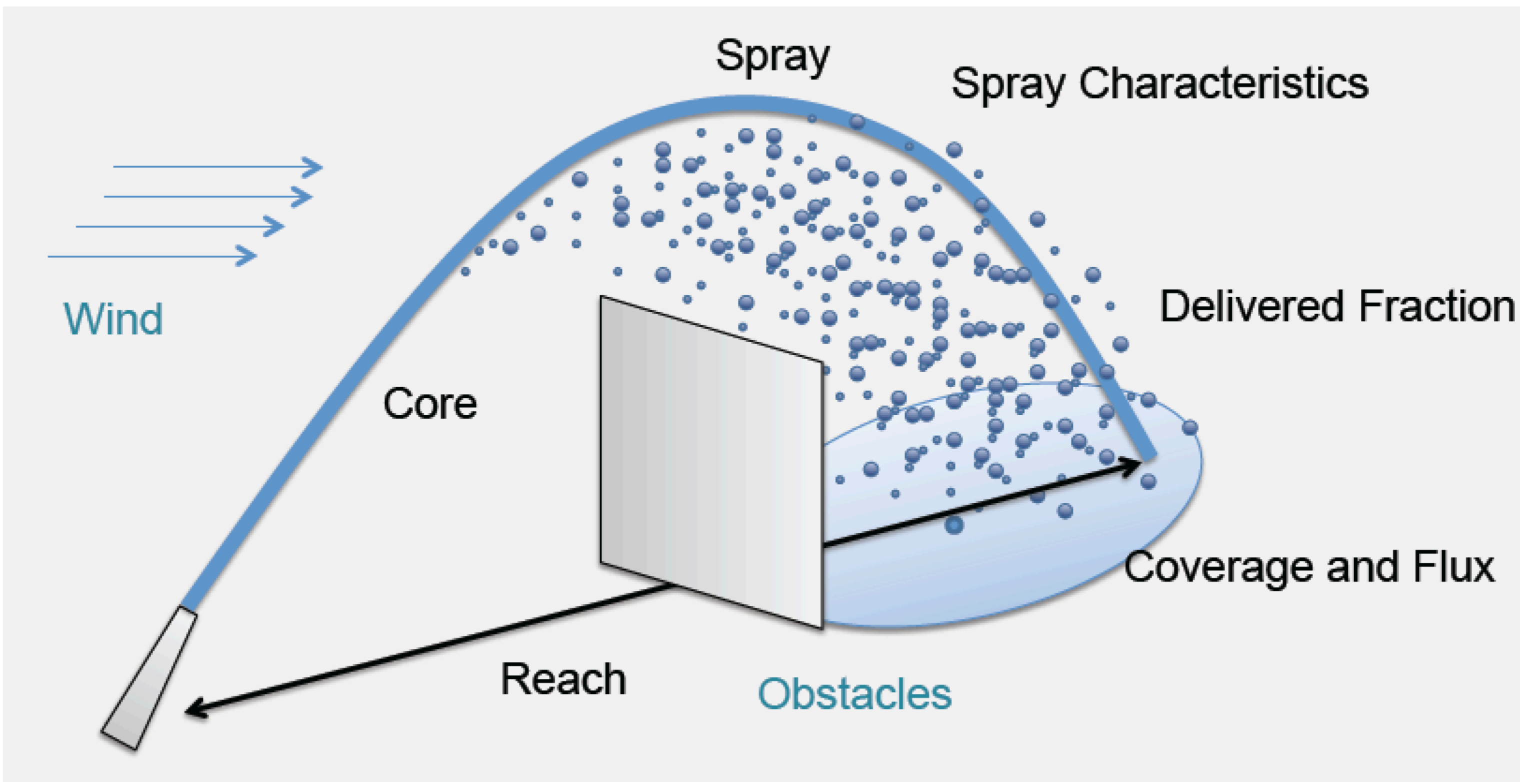
API 2001 Recommended Application Rates	
Tank Diameter (ft)	*Application Rate (gpm/ft^2)*
0-150	0.16
151-200	0.18
201-250	0.20
251-300	0.22
300+	0.25

Manual Tank Suppression & Extinguishment



Nozzle Spray: Fallout

Nozzle Spray



Nozzle Spray

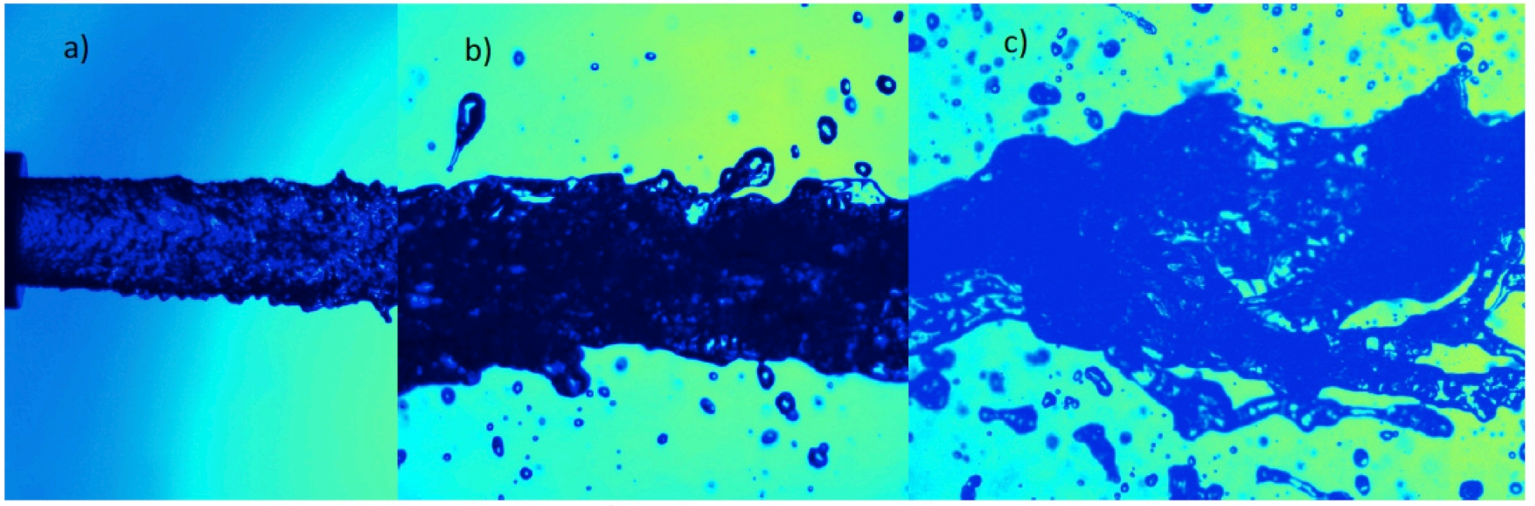
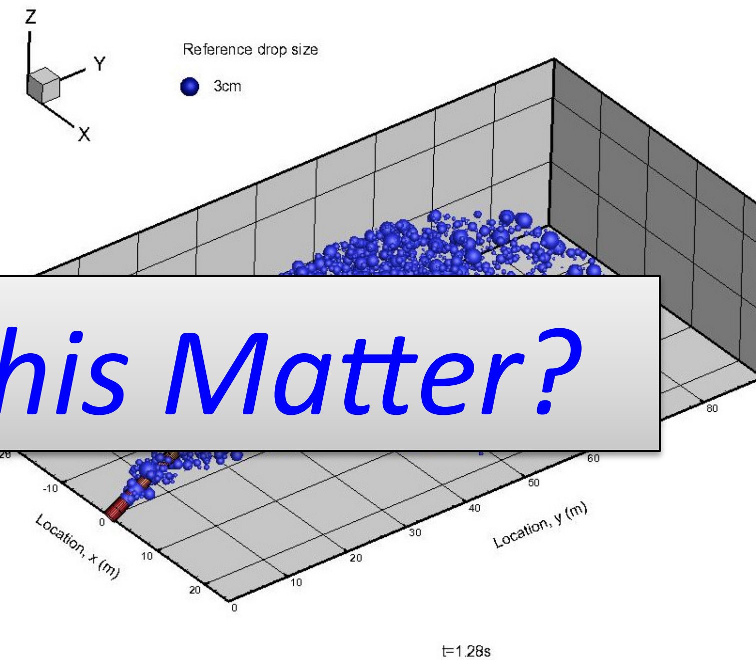
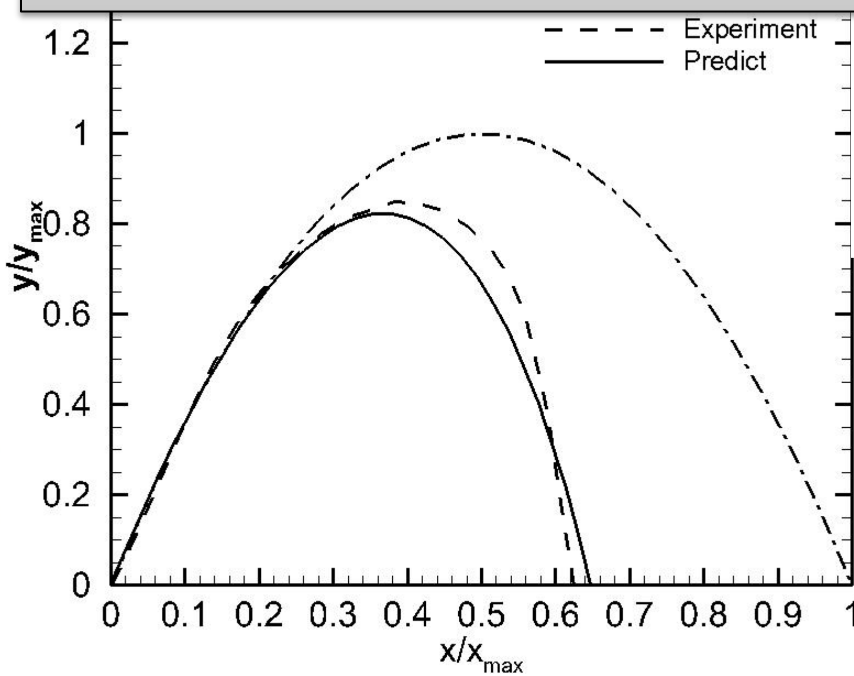


Fig. 2. Visualization of the hose stream, with nozzle diameter (D)
a) x/D=0 b) x/D= 76 c) x/D=317

Theory vs. Experiments vs. Predictions



So Why Does This Matter?



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FIRE & RISK ALLIANCE

Optimizing Protection: Options

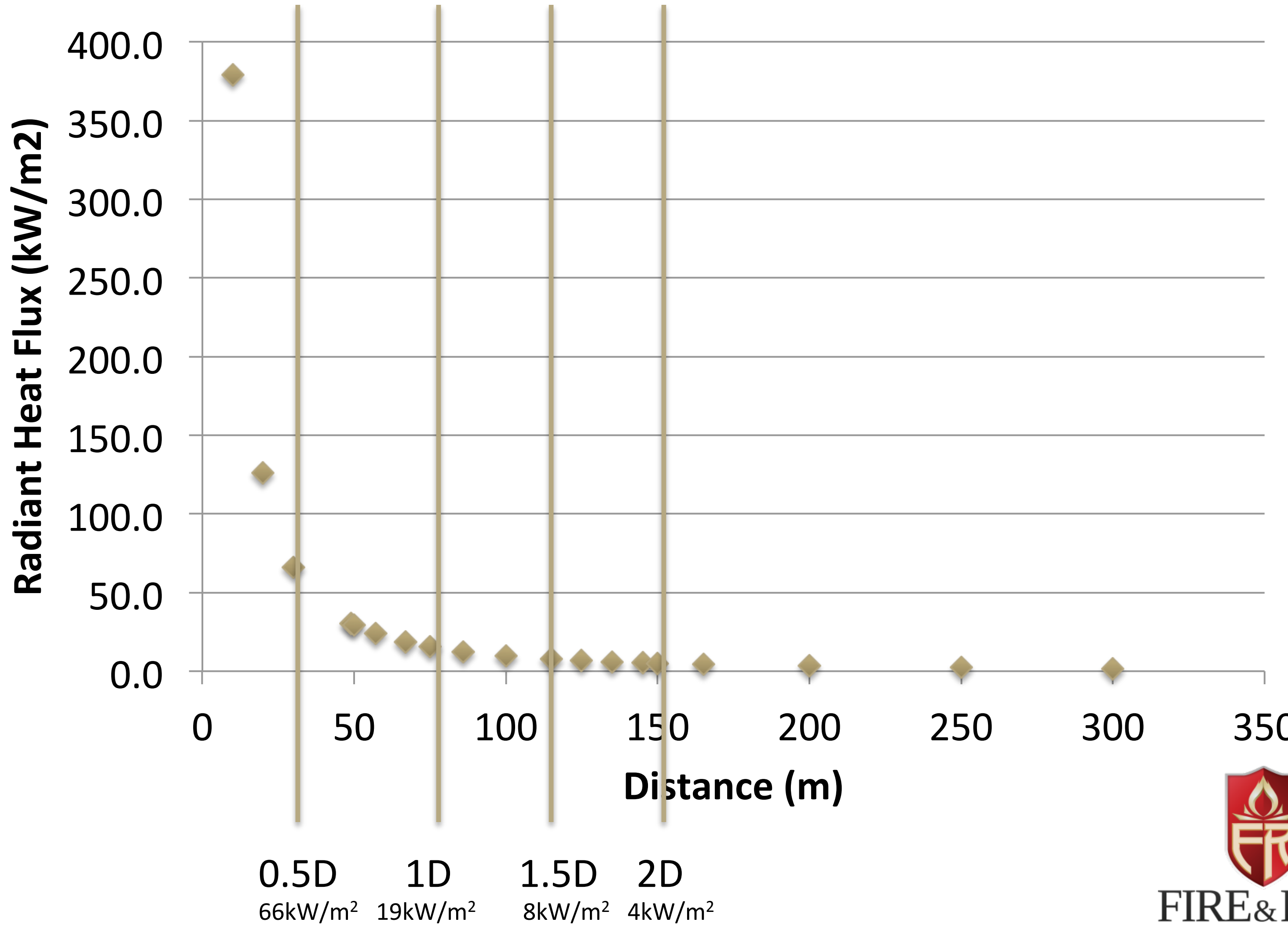
- Spacing: critical importance, radiation behaves according to the inverse square law ($1/R^2$), thus a doubling of the spacing produces a radiant heat flux ¼ as high
- Quality automatic suppression: well specified protection systems can quickly address fires in the early stages, reducing the need for full-surface fire-fighting.
- Detection: gauging of the system to prevent spills and gas monitoring to detect vagrant gasses
- Preplan: plan and rehearse for a variety of fire events and create a "playbook" for emergency responders

Design & Spacing

- Spread tanks
- Keep them in separate bunds
- Isolate tanks that have a greater potential for boilover
- Equipment that have higher probabilities of leakage (i.e. manifolds, pumps, etc.) should be located outside of bunds if possible
- Think about fire fighter access to equipment and staging
  - Road access, effects of maintenance, multiple routes

Location of Emergency Response Equipment

Radiation vs. Separation Distance (75m Diameter Tank)



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Suppression Options

- Fixed protection (dedicated supply)
  - Rim seal system
  - Deluge skid
  - Proportioning skids
  - Foam pourers
- Semi-fixed protection
  - Portable pumps
  - Fixed piping & nozzles
- Mobile/Manual suppression
  - Monitors
  - Water transport (pumps, hoses)
  - Water from remote location

Response Time

Increasing Capacity

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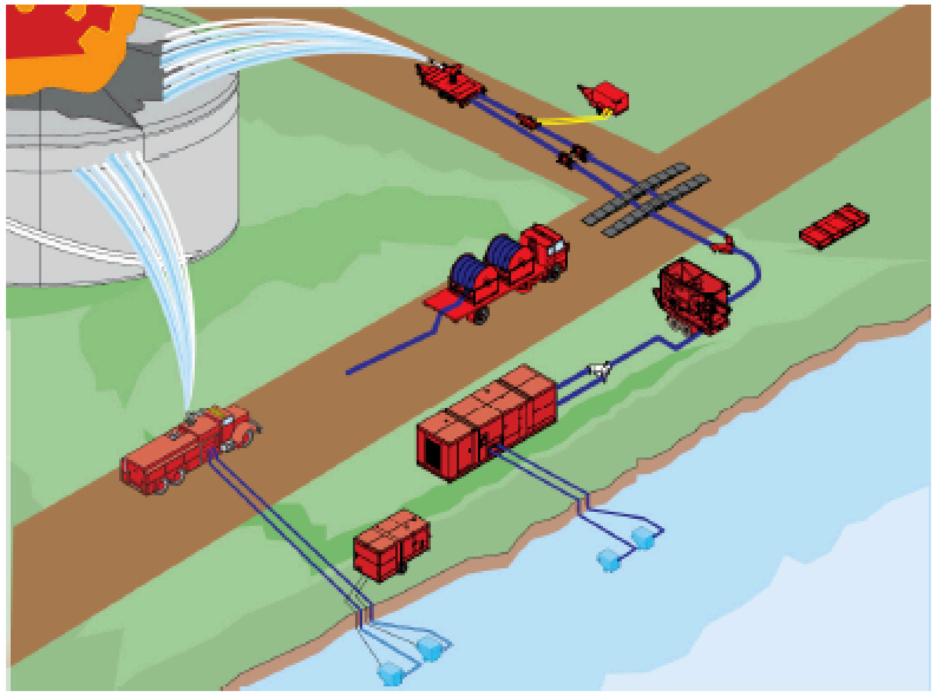
Large Capacity Mobile Response (MERS)



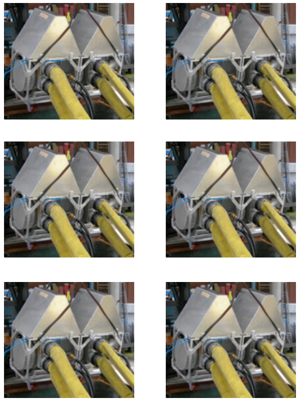
Flow volume: up to 13,000 gpm per monitor
Maximum throw: 500’ theoretically

Suppression (MERS)

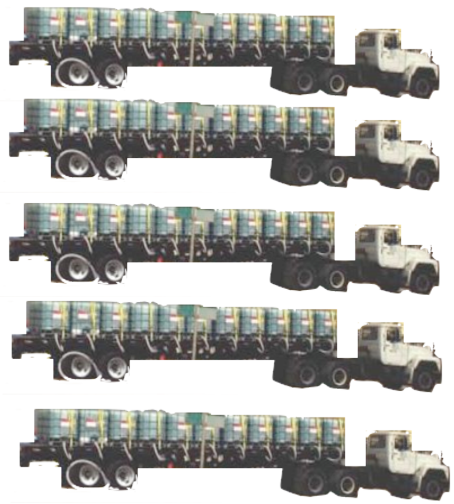
- 400’ tank would require ~35,000 gpm if applied manually
- API suggests 6 hours of water supply available
  - 2,100,000 gallons per hour
  - 12,600,000 gallons of water required for extinguishment
- Foam concentrate
  - 63,000 gallons/hr

Conventional Inventory

Sub-25

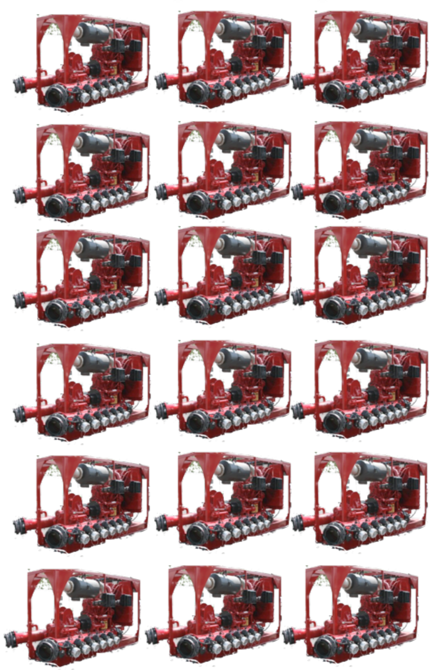


22-Tote Trailer



DCP Skid

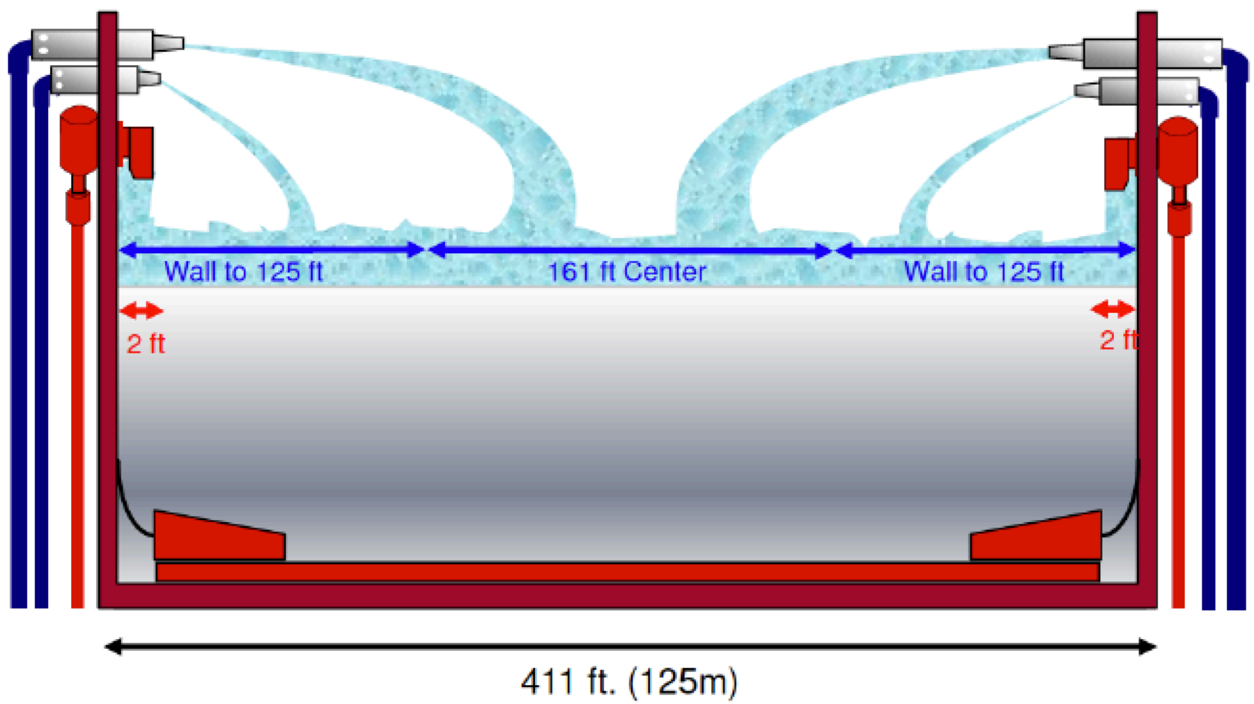
Super Pump



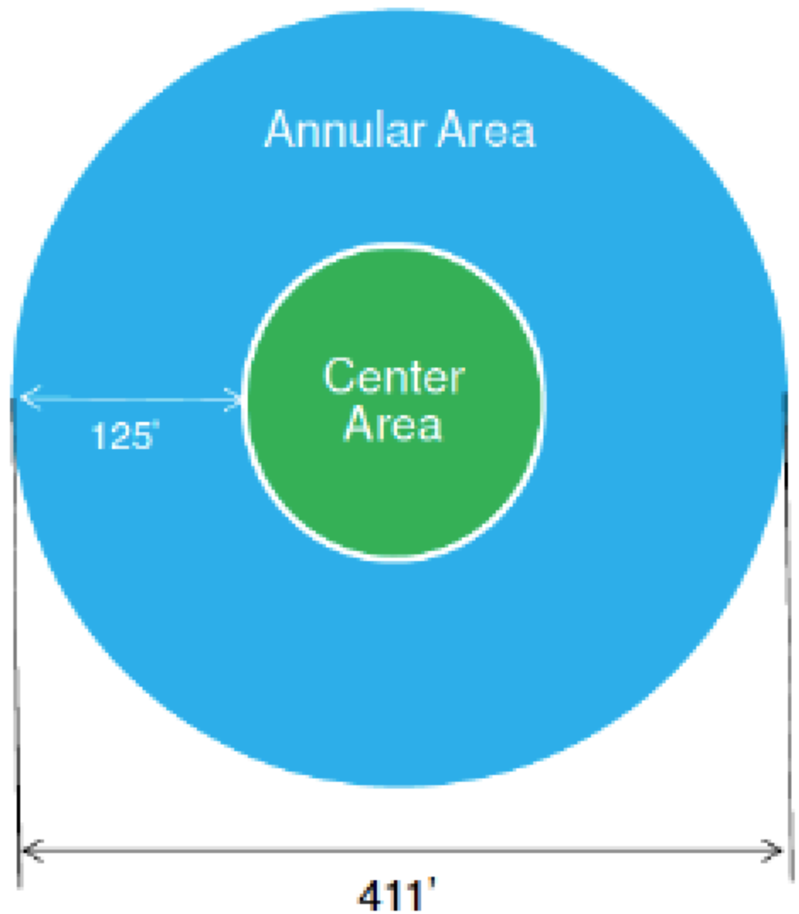
12" Hose Trailers (1,000 m x 12")

Suppression (Hybrid System)

- Relies on fixed nozzles and pourers
- Fixed piping to tank and to manifold
- Water and pumps provided from mobile response



Suppression (Hybrid System)



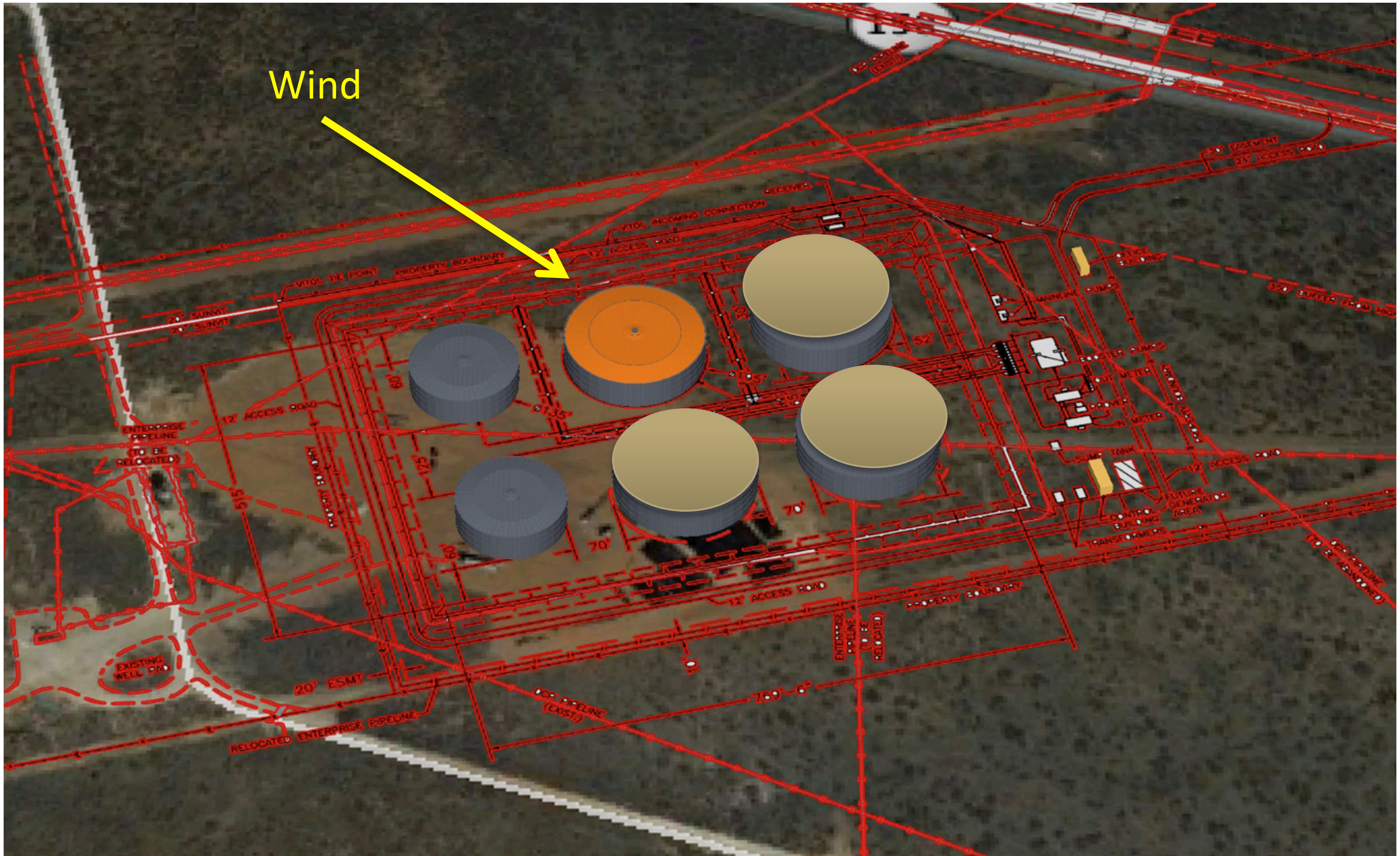
Cooling Water Requirements

- Typically calculated based on the anticipated exposure

$$H_2O = \left(0.10\,gpm/ft^2\right)*\left(\frac{1}{3}\right)(surface\ area\ of\ neighboring\ tanks)$$

- Need to determine what “neighboring” means from radiation analysis earlier

Cooling Example



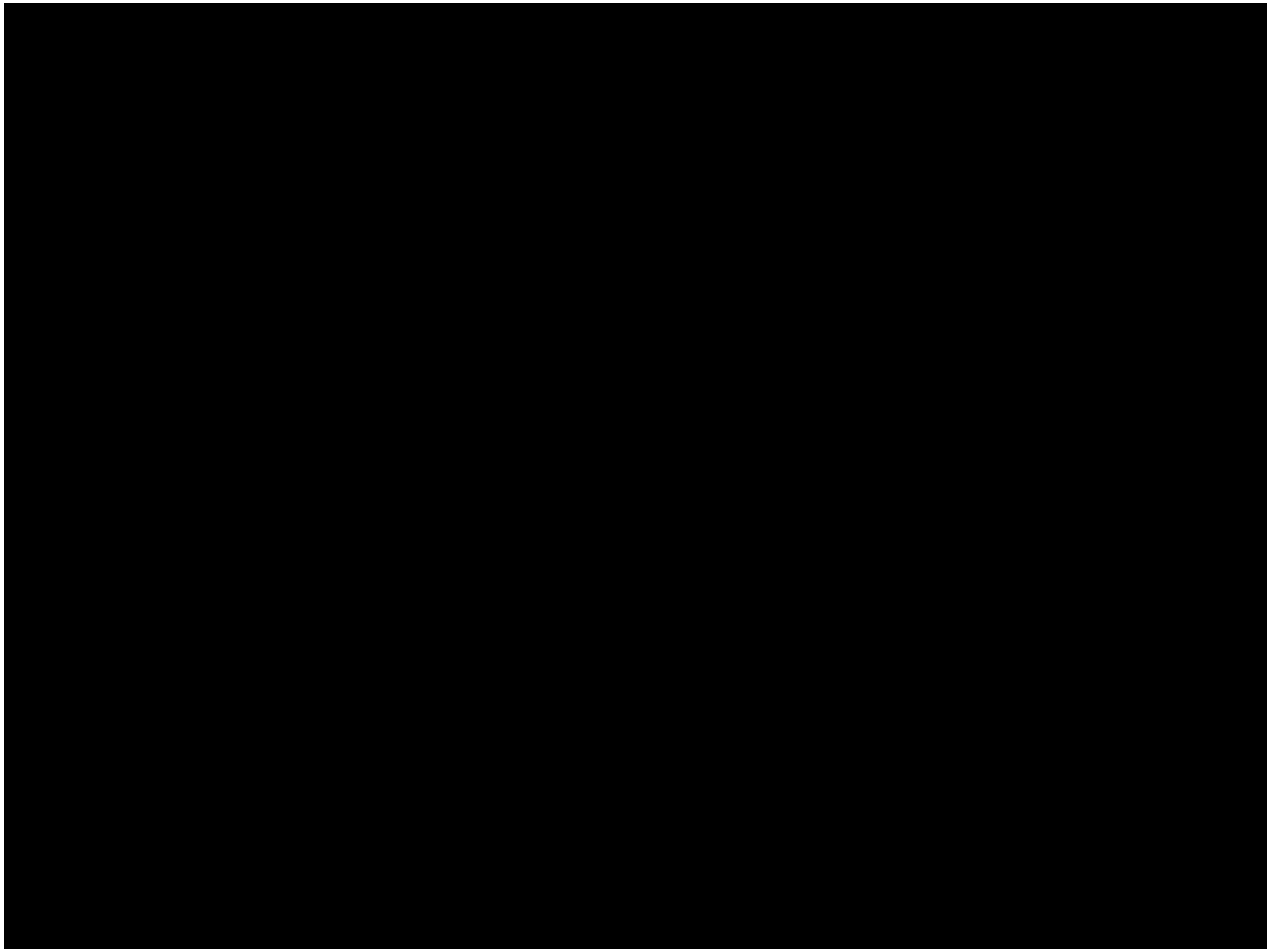
Cooling Example

$$H_2O = \Sigma\left[\left(0.10\,gpm/ft^2\right)*\left(\tfrac{1}{3}\right)(2\pi rh)\right]$$

$$= 3*\left[\left(0.10\,gpm/ft^2\right)*\left(\tfrac{1}{3}\right)(2\pi(125)(60)\right]$$

$$= 2355\,gpm$$

Why Cool



Performance & Cost Impact

- 55% reduction in cost
- 60% less water
- 60% less foam concentrate
- Significantly fewer man power resources required

Development of Response Plan

- Vital to develop detailed plan covering all relevant aspects of response
- Should cover all possible incidents and protection available

- Also should develop "playbook" for day of incident for quick access
  - Key contact information
  - Tabs for each tank/area
  - Approach routes
  - Water supply
  - Anticipated cooling requirements

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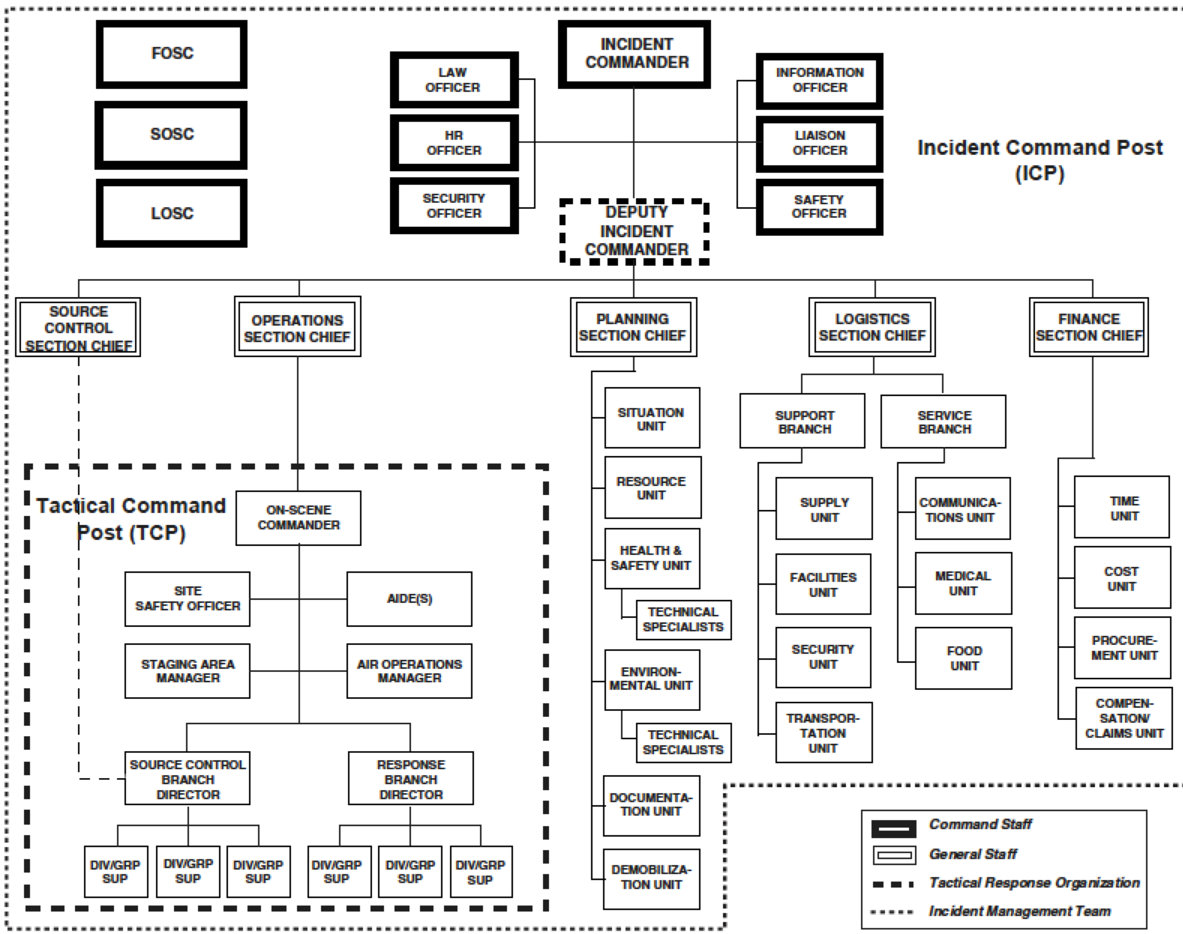
Fire Preplan: Incident Command Structure



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Fire Preplan: Reference Document

- Prepare full preplan including the following:
  - Site specific information
    - Site plan
    - Local resources available
    - Maps and photos from potential staging areas
  - Roles and responsibilities
    - ICS
    - First Responders
    - Commander
    - Internal/External responders
  - Tank Information Sheets
    - Size
    - Contents
    - Fixed/Semi-fixed protection
    - Application rates

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Example Tank Information Sheet

Tank Number: 1601 **Terminal:**

Specifications		
Diameter	134 ft	40.87 m
Height	41 ft	12.51 m
Fuel Surface Area	14,095 ft^2	1,309 m^2
Tank Contents ***	Crude Oil	
Tank Construction	Welded Steel	
Roof Type	Open Top Floater	
Mixers	1	
Number of Inlets/Outlets	2	
Foam Dam (Size/Surface Area)	24" / 829 ft^2	0.61 m / 77 m^2

Exposures (Tank)		
Adjacent Tanks/Exposures	Tanks 1602, 1603, 1604	
Risks	Medium – Low	
Cooling Water**	3 Portable Monitors	
Rate	500 GPM	1,890 L/min

Fire Water System		
Hydrant Supported	Yes	
Connections	No information	
Monitor(s)	No	
Flows/System Capacity	1,500 GPM	5,670 L/min

See Test Results

Fixed Foam System		
Number of Chambers	6 – Ansul FLR-90 Chambers	
Flow Each	50 GPM	190 L/min
Fixed/Semi Fixed	Semi-fixed	
Application Time	20 minutes	
Total Flow	300 GPM	1,135 L/min

Bermed Area		
Berm Dimensions	113 ft x 113 ft	34.46 m x 34.46 m
Potential Fuel Surface Area	12,769 ft^2	1,187 m^2
Foam Solution Application Rate	2,043 GPM	7,718 L/min
Minimum Concentrate Required	3,983 Gal	15,051 L
Minimum Water Required**	128,813 Gal	486,662 L

Exposures (Berm)		
Adjacent Tanks/Exposures	Tanks 1602, 1603, 1604, 1605	
Risks	High	
Cooling Water**	4 Portable Monitors	
Rate	1,000 GPM	3,780 L/min

Map/Drawing Number	D-1.2-10721-8-552

Minimum Extinguishment Requirements	Fully Involved		Seal Fire	
Application Rate Formula	0.16 GPM/ft^2	6.5 L/min·m^2	0.3 GPM/ft^2	12.2 L/min·m^2
Solution Application Rate	2,255 GPM	8,523 L/min	248 GPM	939 L/min
Application Time	65 minutes	65 minutes	20 minutes	20 minutes
Total Solution Required	146,588 Gal	554,102 L	4,974 Gal	18,780 L
Water Required **	142,190 Gal	537,479 L	4,824 Gal	18,216 L
Concentrate Required	4,397 Gal	16,620 L	149 Gal	563 L

Notes:
** Water supply may be required from a portable source
*** Tank contents may vary, consult with terminal Foreman/Supervisors for specifics, BS&W report and amount of water on roof.
- All foam calculations are based on National Fire Protection Association recommended standards.
- All foam calculations are made at the minimum amounts and flow required. Fire situations may dictate higher rates and amounts.

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Fire Preplan: Reference Document

- Fire situations
  - Vent fire
  - Bund fire
  - Seal fire
  - Full surface fire
  - Exposed adjacent tanks
  - BLEVE
  - Boilover
- Firewater system details
  - Capacity
  - Hydrant locations
  - Monitor locations

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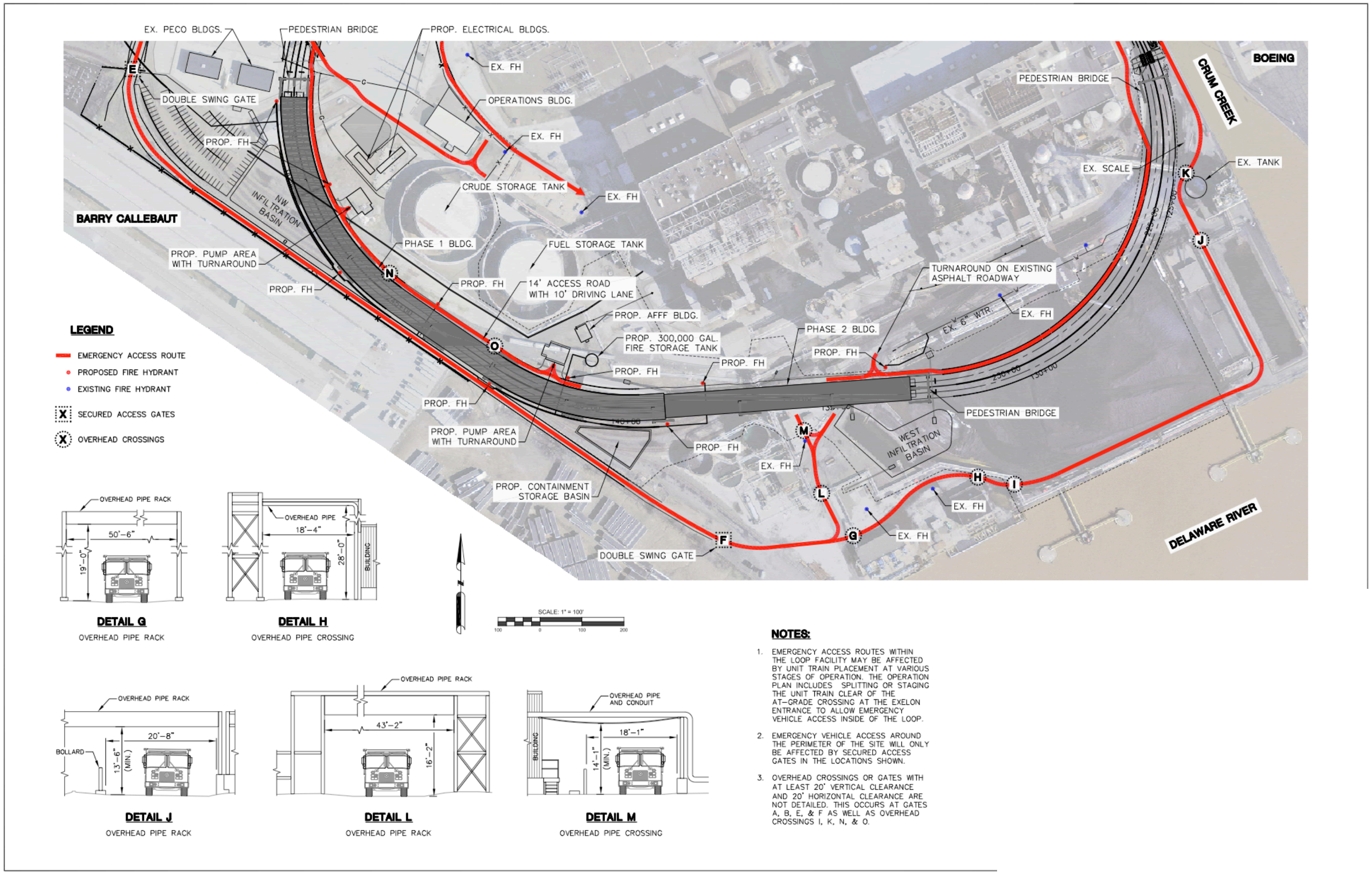
Emergency Access Routes



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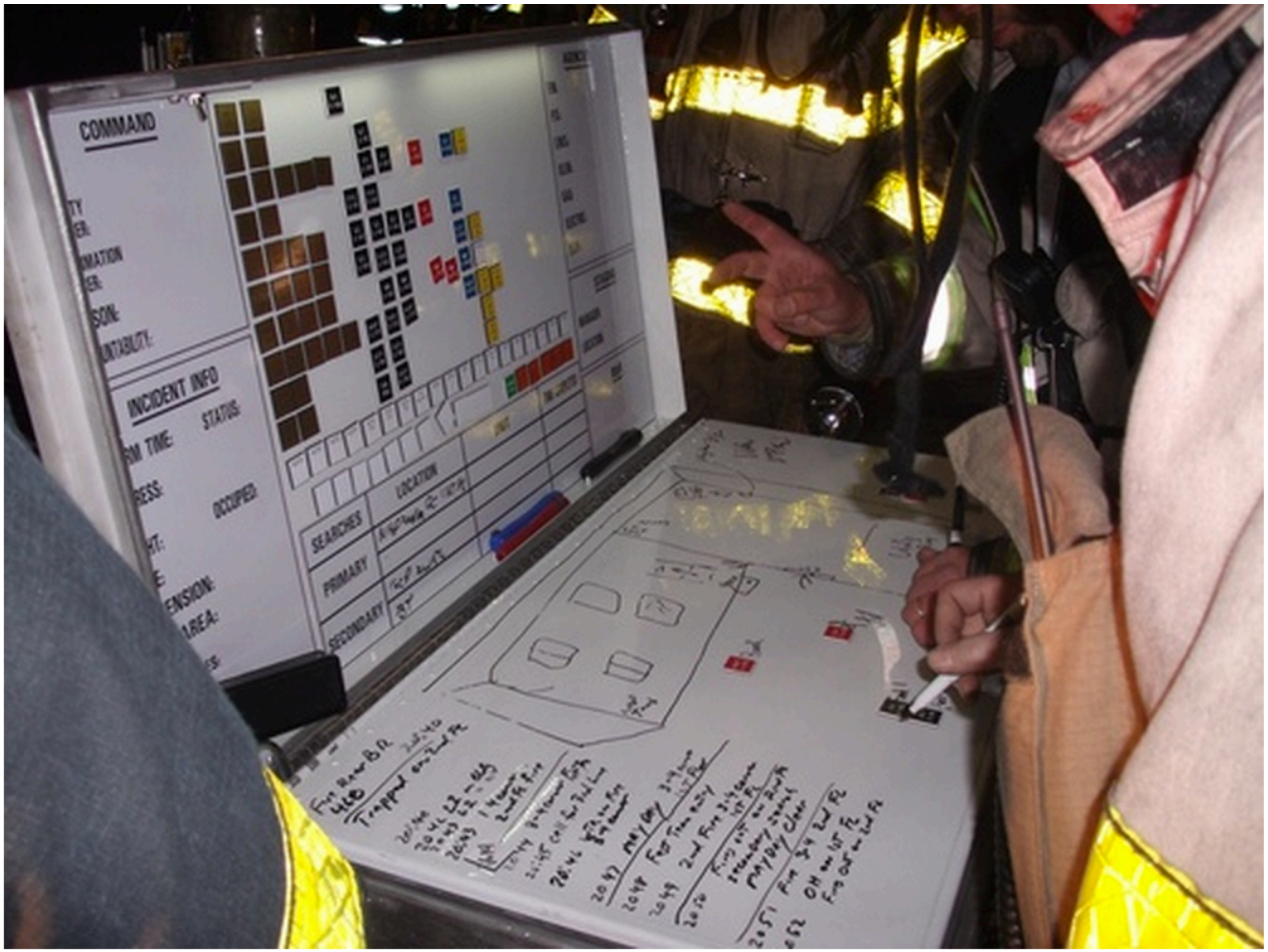
FIRE & RISK ALLIANCE

Practice & Maintain

- Once your system is in place it is vital to practice the emergency response plan routinely
- Critical that systems are maintained to ensure functionality when required
  - Preventative systems
  - Detection systems
  - Protection systems

Practice At the Scene



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Maintenance

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FIRE & RISK ALLIANCE

Summary

- Large tanks can pose a challenge to protect
- While low probability events the consequences can be catastrophic
- Well thought out planning and design can minimize complexities
- Number of protection options based on available resources
- Maintenance and Rehearsal of scenarios is essential

Additional Information

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