KOCAELİ SANAYİ ODASI
KOCAELI CHAMBER OF INDUSTRY

Patlama Risk Analizleri ve Etkilerini Azaltma Çalışmalarında Yapılan Tipik Hatalar

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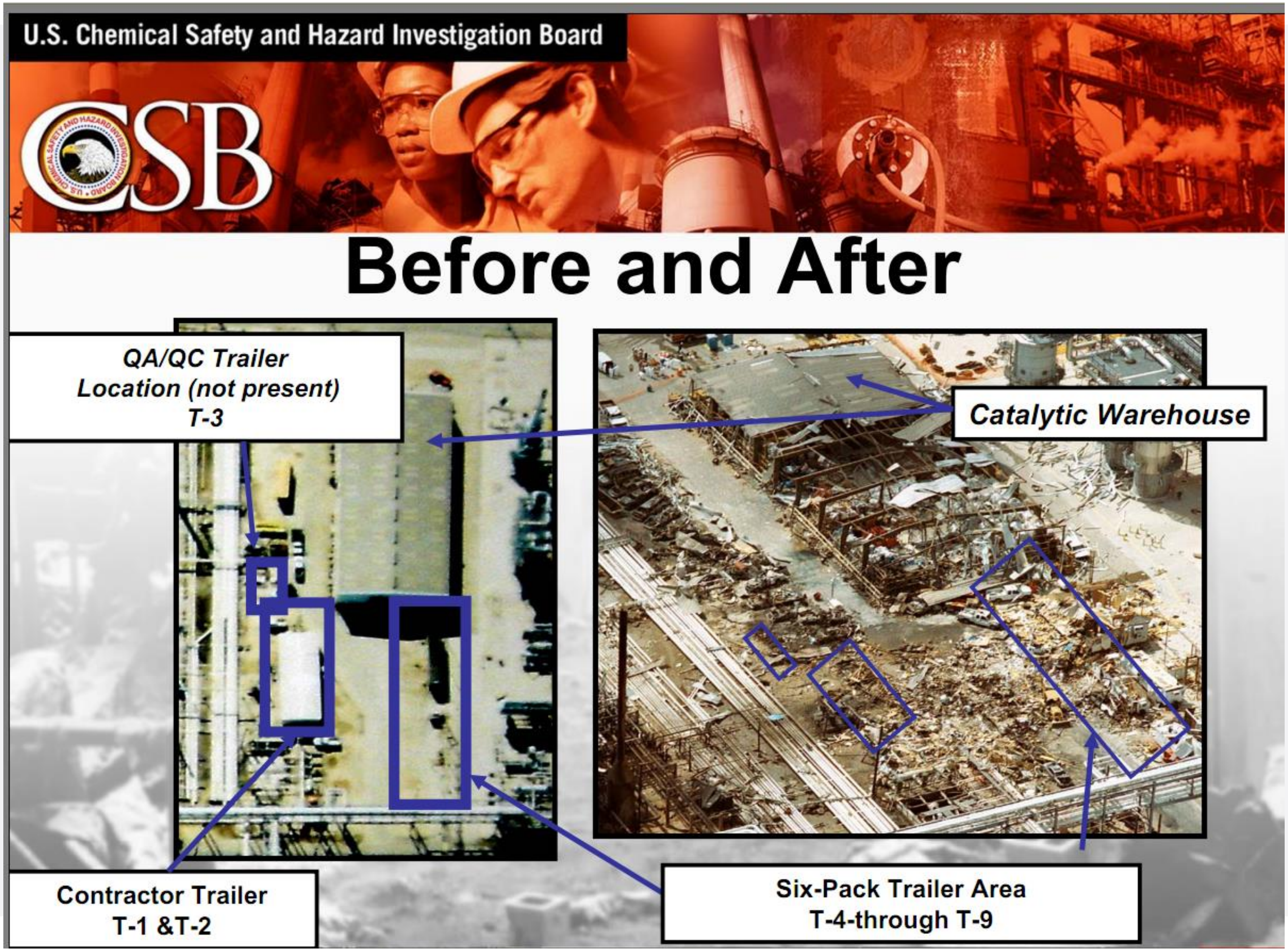
Sunumun İçeriği

KOCAELİ SANAYİ ODASI PROSES EMNİYETİ SEMPOZYUMU

- Giriş - Motivasyon
- Frekans Analizi için Tarihsel Veri Tabanlarının kullanılması
- Bina Patlama Yükü ve Yapı Hasarı
- Tasarım Patlama Yükü – Aşılma Basınç Aşılma Eğrisi (Exceedance Curve)
- Kişisel Risk - Yaralanabirlik (Vulnerability Analysis)
- Domino Etkisi ve Proses Harici Tehlikelerle Risk Analizi
- Patlama Etkisini Azaltma Çalışması (Mitigation Study)
- API 753 Zone Tanımı ve ATEX Zone

Giriş - Motivasyon



Giriş - Motivasyon

Giriş - Motivasyon

March 2005

April 2016

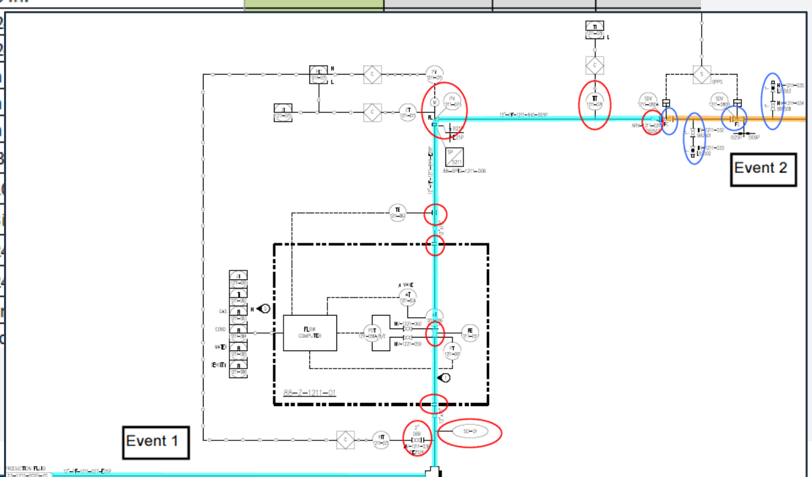
Kantitatif Risk Analizine Genel Bakış

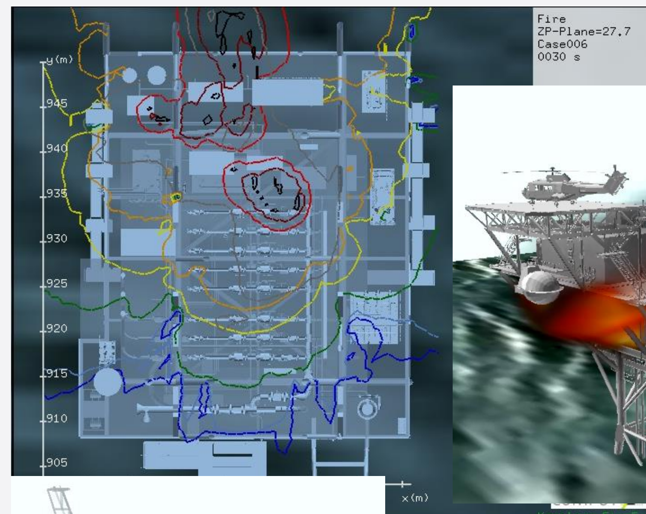
Risk = Frequency X Consequence

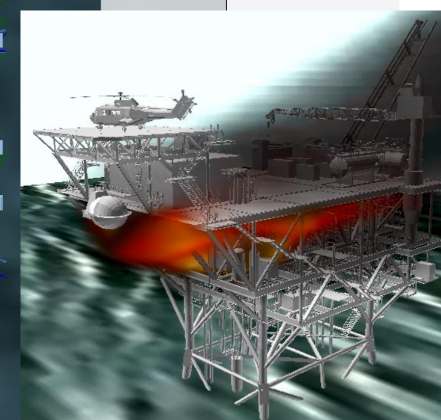
Frequency: Likelihood of hazardous scenario occurring

Consequence: Impact to Personnel, equipment, infrastructure

		Leak Frequency		
Type of Equipment	**# of equipment**	Small	Medium	Large
Air cooler (per section)				
Compressor (centrifugal-per stage)				
Compressor (reciprocating-per stage)				
Filter				
Fitting	10	1.37E-03	7.84E-04	8.08E-05
Flange < 3 in.				0.00E+00
Flange < 10 in.	8	1.84E-04	6.65E-05	3.86E-05
Flange > 3 in.				
Flange < 2				
Flange > 2				
Heat Exch				
Heat Exch				
Heat Exch				
Piping < 3				
Piping < 1				
Piping > 3				
Piping < 2				
Piping > 2				
Pump (ce				
Pump (re				

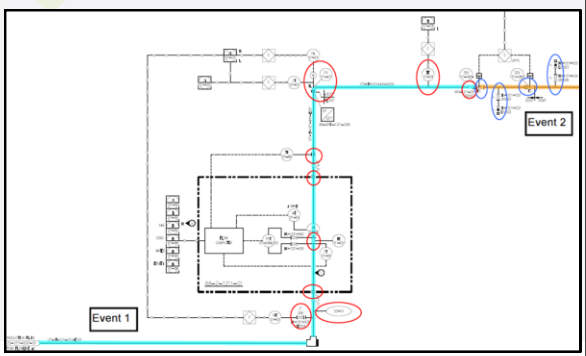






Frekans Analizi

- Define Isolatable Sections
- Conduct Parts Count
- Apply Failure Frequency Data to Parts Count
- Calculate Overall Ignition Probability
- Assign Immediate/Delayed Ignition Probability
- Apply Directional Probability

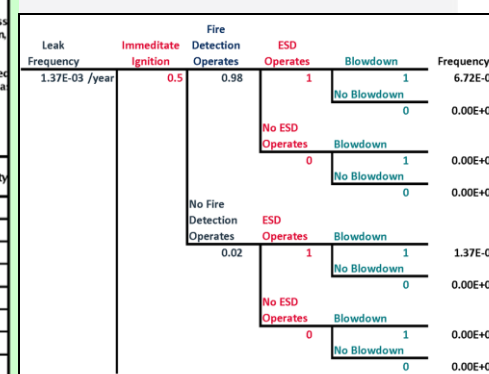


Type of Equipment	# of equipment		Small - 12mm	Medium - 50mm	Large - 100mm
Compressor (centrifugal-per stage)					
Compressor (reciprocating-per stage)					
Flange < 3 in. [<3]					0.00E+00
Flange < 10 in. [≥3 and <10]	8		1.84E-04	6.65E-05	3.86E-05
Flange > 3 in. [≥10 and <18]					
Flange < 24 in. [≥18 and <24]	2		1.01E-04	3.65E-05	6.45E-06
Flange > 24 in. [≥24]					
Heat Exch - shell					
Heat Exch - tube					
Piping < 3in. (per meter) [<3]					0.00E+00
Piping < 10 in. (per meter) [≥3 and <10]	10		1.84E-04	6.82E-05	3.87E-05
Piping > 3in. (per meter) [≥10 and <18]	20		2.94E-04	1.09E-04	1.98E-05
Piping < 24 in. (per meter) [≥18 and <24]					
Piping > 24 in. (per meter) [≥24]					
Pump (centrifugal)					
Pump (reciprocating)					
Tank - Refrig					
Valve - Block < 3 in. [<3]	5		1.21E-04	8.08E-05	0.00E+00
Valve - Block < 10 in. [≥3 and <10]	1		2.94E-05	1.40E-05	5.56E-06
Valve - Block > 3 in. [≥10 and <18]					
Valve - Block < 24 in. [≥18 and <24]					
Valve - Block > 24 in. [≥24]					
Valve - Check < 3 in. [<3]	4		9.67E-05	6.46E-05	0.00E+00
Valve - Check < 10 in. [≥3 and <10]					
Valve - Check > 3 in. [≥10 and <18]					
Valve - Check < 24 in. [≥18 and <24]					
Valve - Check > 24 in. [≥24]					
Valve - Control < 3 in. [<3]	8		1.42E-03	5.45E-04	0.00E+00
Valve - Control/MOV < 10 in. [≥3 and <10]	4		7.19E-04	2.19E-04	5.89E-05
Valve - Control > 3 in. [≥10 and <18]					
Valve - Control/MOV < 24 in. [≥18 and <24]					
Valve - Control/MOV > 24 in. [≥24]					
Vessel					
Pig launcher					

20 – Offshore Process Gas Typical

Releases of flammable gases, vapour or liquids significantly above their normal (NAP) boiling point from within offshore process modules or decks on integrated deck / conventional installations. Process modules include separation, compression, pumps, condensate handling, power generation, etc. If the module is mechanically ventilated or very congested – see curve No. 22 "Offshore Process Gas Congested or Mechanical Vented Module".

Release Rate (kg/s)	Ignition Probability
0.1	0.0010
0.2	0.0017
0.5	0.0036
1	0.0063
2	0.0109
5	0.0183
10	0.0240
20	0.0315
50	0.0400
100	0.0400
200	0.0400
500	0.0400
1000	0.0400



Frekans Analizi – Sızıntı Frekansı (Leak Frequency)

Issues with historical data

- No transparency of causes of the events (e.g. dropped object, corrosion, etc.)
- Single value is generated for the freq (uncertainty should be applied)
- Leak frequency is conducted as an isolated activity (doesn't rely on frequencies established during HAZOP or reliability assessments such as fault tree)
- Offshore databases are applied to onshore processes, when in reality there are differences in:
  - Types of equipment
  - Materials of construction
  - Hazards the equipment is exposed to
  - Safety management systems in place

http://www.energytransfer.com

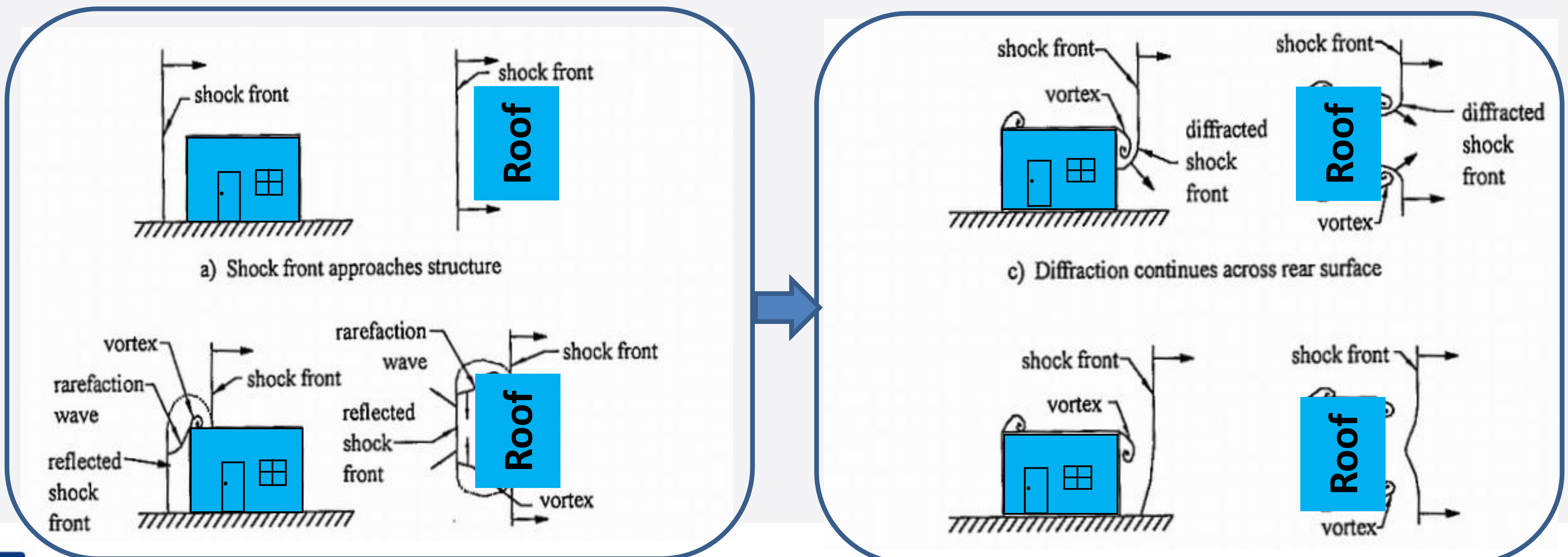
www.scotlandnow.dailyrecord.co.uk

Bina Patlama Yükü ve Yapı Hasarı

Blast Load Measured by

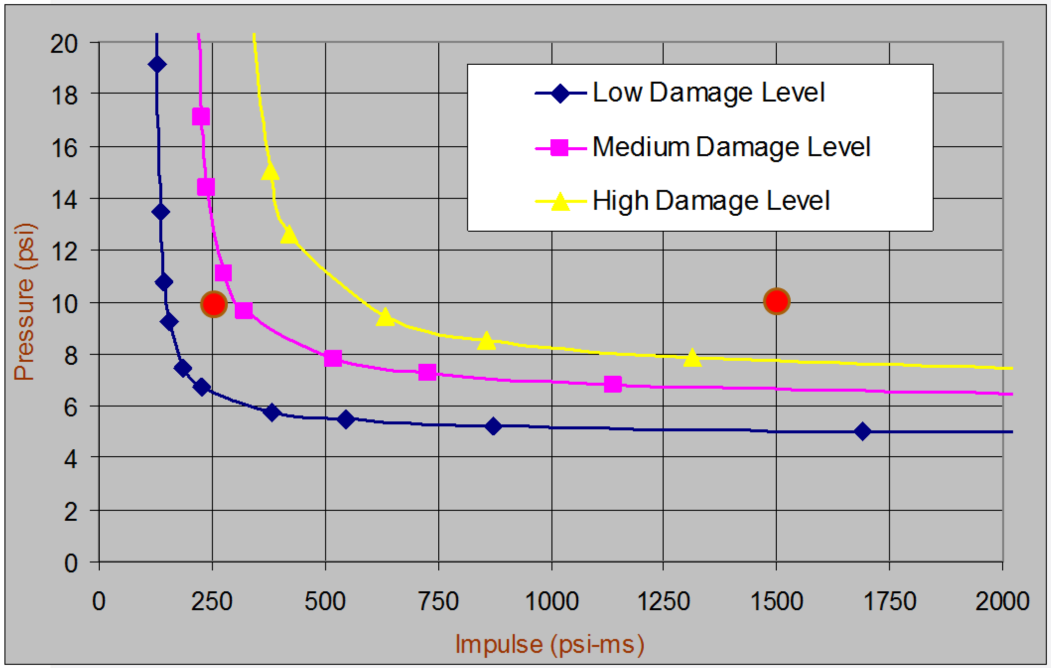
- Pressure
- Impulse/ Duration (assumes a shape)

- Reflected v Side-on
- Incident Angle
- Rise Time
- Negative Phase Pressure
- Clearing



Ref: Design of Blast Resistant Buildings in Petrochemical Facilities, ASCE

Bina Patlama Yükü ve Yapı Hasarı



Peak Overpressure (psi)	Level of Damage Expected
0.02	Annoying noise (137 dB), if of low frequency (1 – 15 Hz)
0.03	Occasional breaking of large glass windows already under strain
0.04	Loud noise (143 dB); Sonic boom glass failure
0.10	Breaking of small windows under strain
0.15	Typical pressure for glass failure
0.30	'Safe distance' (probability 0.95 no serious damage beyond this value) Missile limit Some damage to house ceilings; 10% window glass broken
0.40	Limited minor structural damage
0.50 - 1.0	Large and small windows usually shattered; occasional damage to window frames
0.70	Minor damage to house structures
1.0	Partial demolition of houses, made uninhabitable
1.0 – 2.0	Corrugated asbestos shattered Corrugated steel or aluminum panels, fastenings fail, followed by buckling Wood panels (standard housing) fastenings fail, panels blown in
1.3	Steel frame of clad building slightly distorted
2.0	Partial collapse of walls and roofs of houses
2.0 – 3.0	Concrete or cinder block walls, not reinforced, shattered
2.3	Lower limit of serious structural damage
2.4 – 12.2	Range for 1 – 90% eardrum rupture among exposed populations
2.5	50% destruction of brickwork of houses
3.0	Steel frame building distorted and pulled away from foundation
3.0 – 4.0	Frameless, self-framing steel panel building demolished
4.0	Cladding of light industrial buildings ruptured
5.0	Wooden utility poles snapped
5.0 – 7.0	Nearly complete destruction of houses
7.0	Loaded train wagons overturned
7.0 – 8.0	Brick panels, 8-12 in. thick, non-reinforced, fail by shearing or flexure
9.0	Loaded train boxcars demolished
10.0	Probable total building destruction
14.5 – 29.0	Range for 1 – 99% fatalities among exposed populations due to direct blast effects

Bina Patlama Yükü ve Yapı Hasarı

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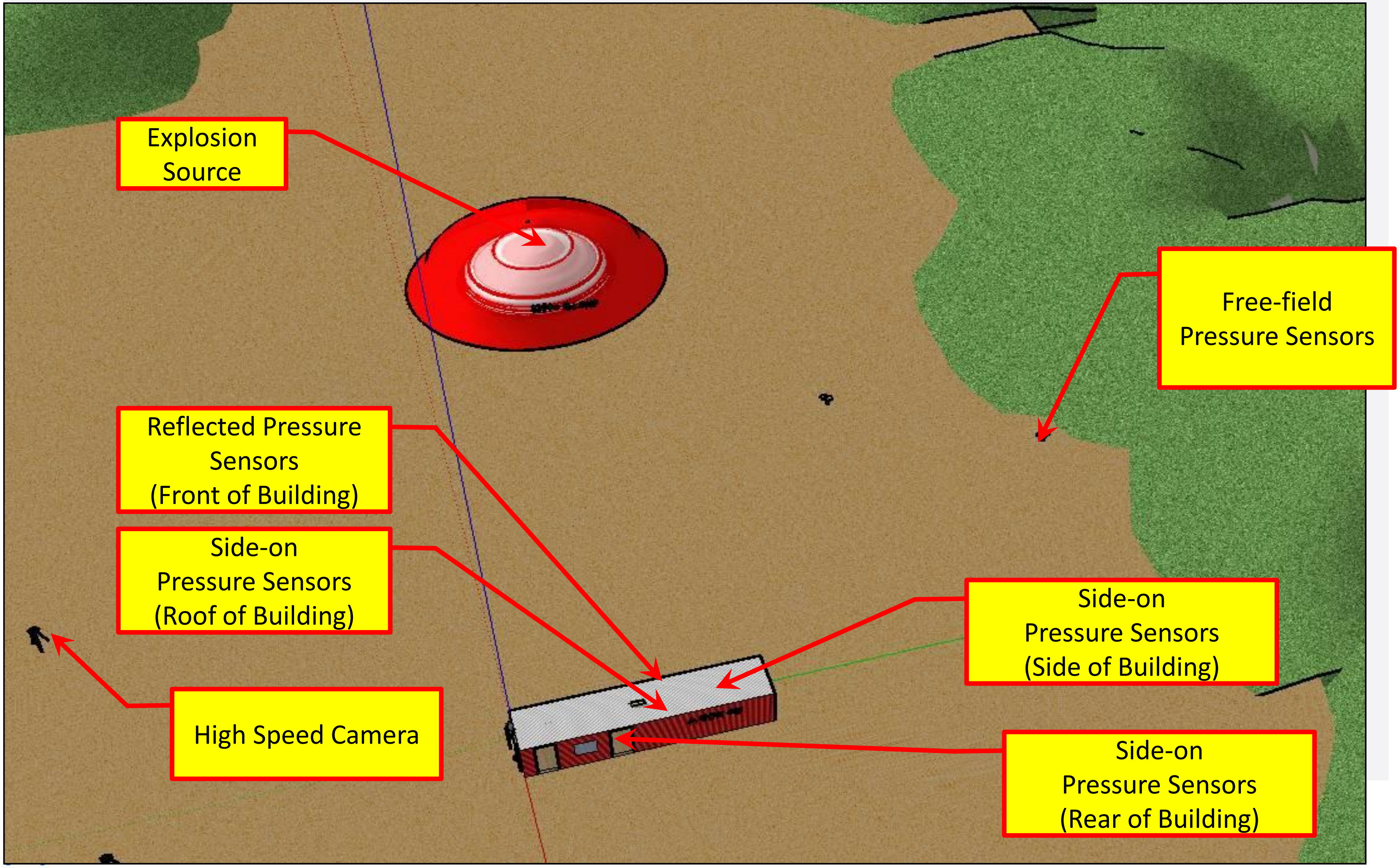
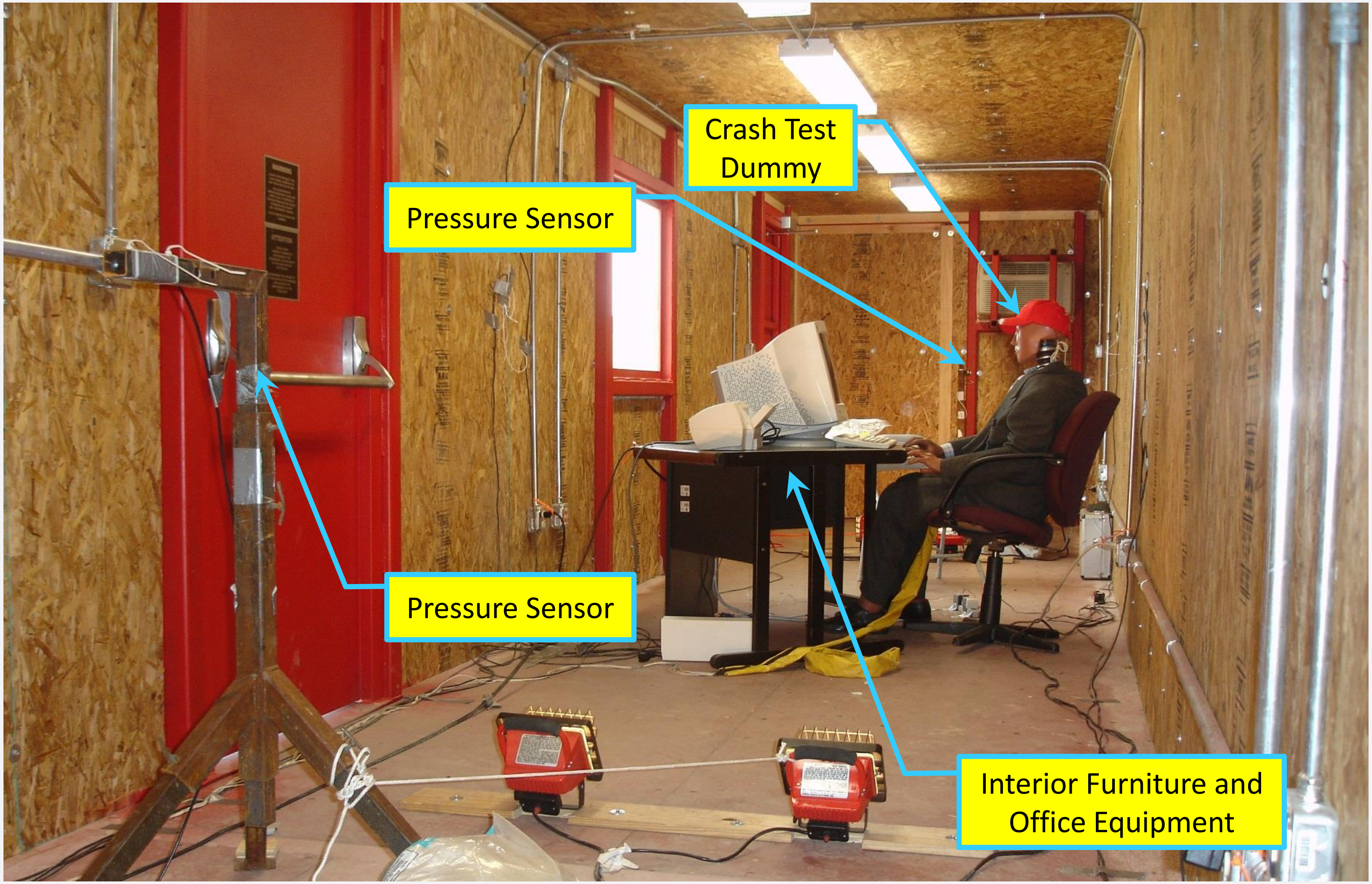
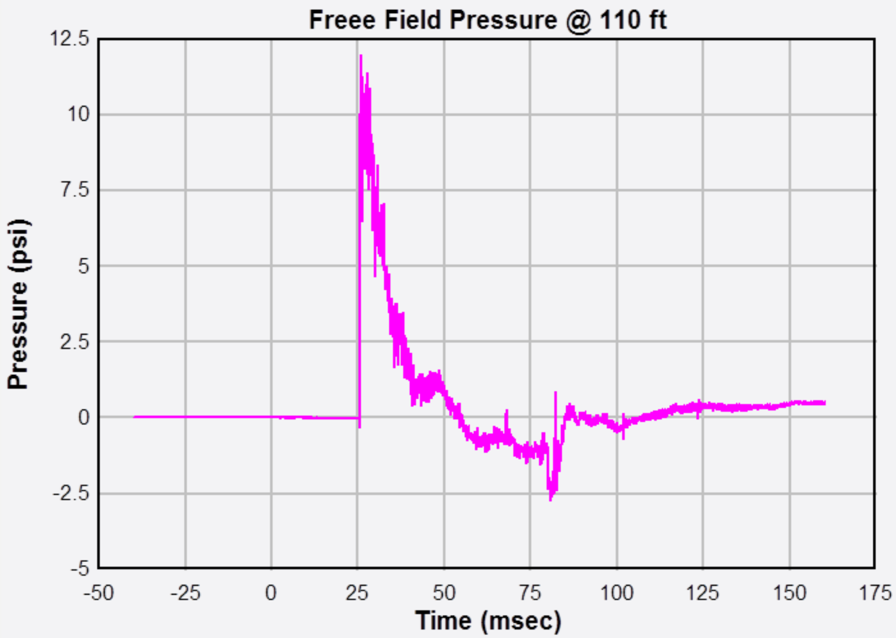
Bina Patlama Yükü ve Yapı Hasarı

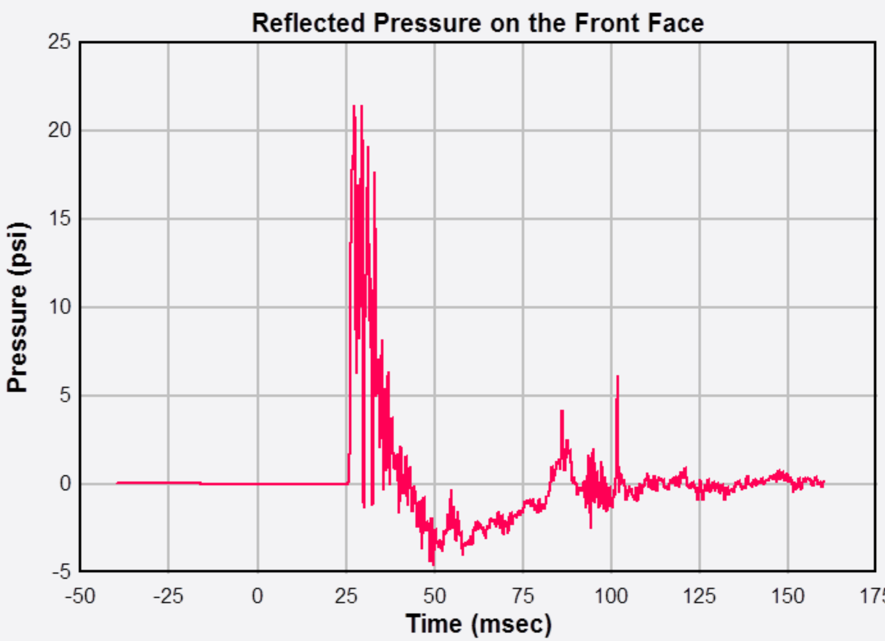


Bina Patlama Yükü ve Yapı Hasarı



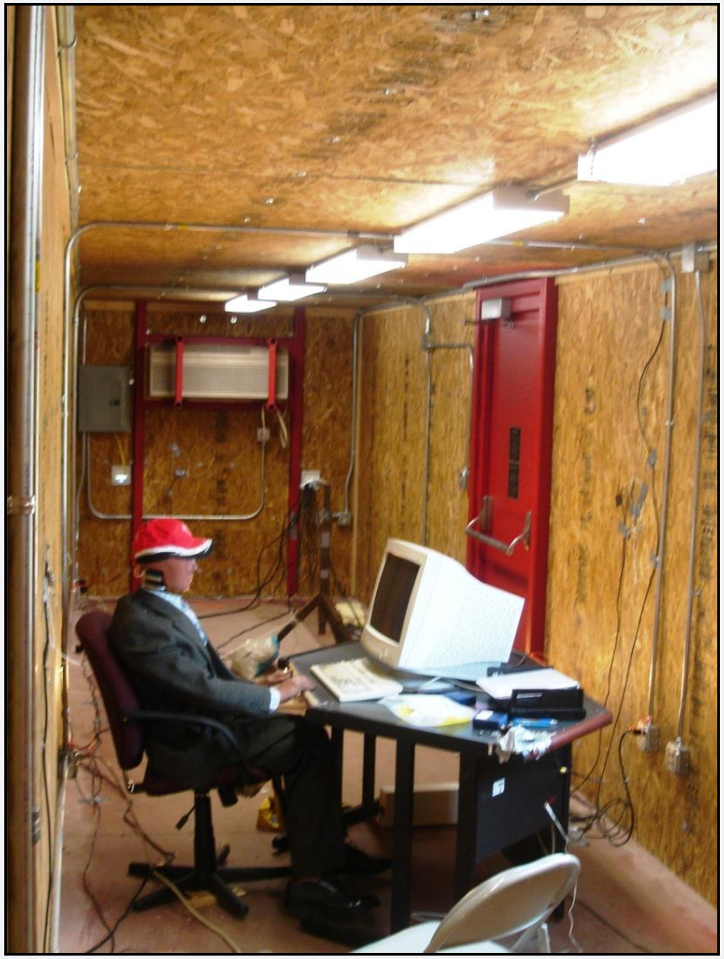
Bina Patlama Yükü ve Yapı Hasarı





1 psi = 6.9 kPa

Sunumun İçeriği



Before the test

After the test

Bina Patlama Yükü ve Yapı Hasarı

- Any design basis considers Non-Structural Members?

Bina Patlama Yükü ve Yapı Hasarı

Control Bldg

- Looking at the southwest corner of the control room.
- Notice the corner column still standing.
- The building was ~ 20 foot (6.1 mt) tall with reinforced
- Originally built to "so called" explosion proof requirements.

Bina Patlama Yükü ve Yapı Hasarı

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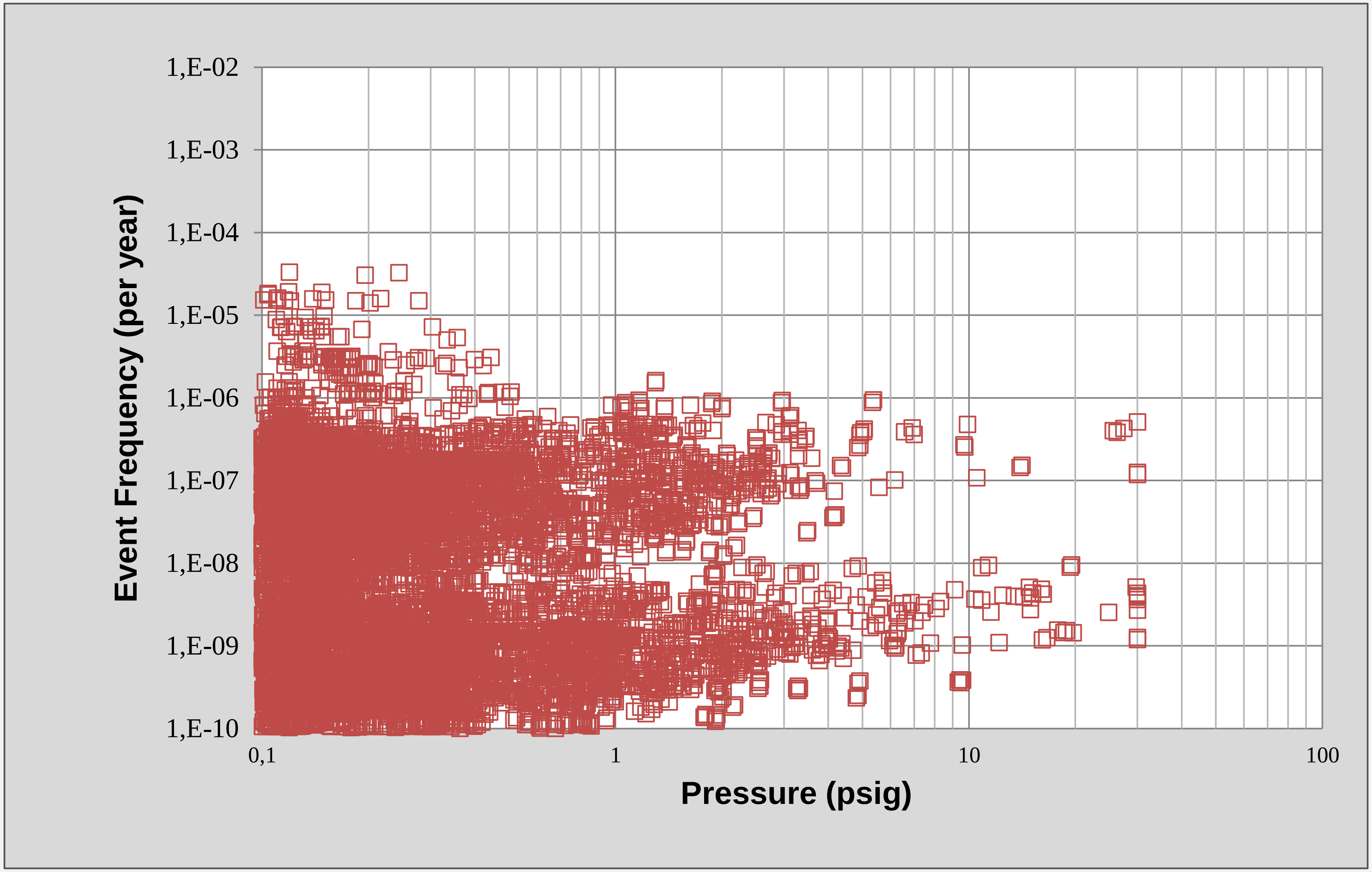
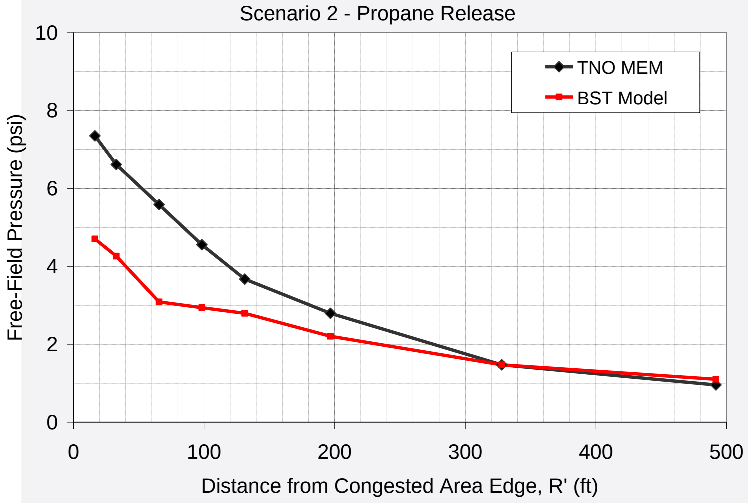
PROSES
EMNİYETİ SEMPOZYUMU

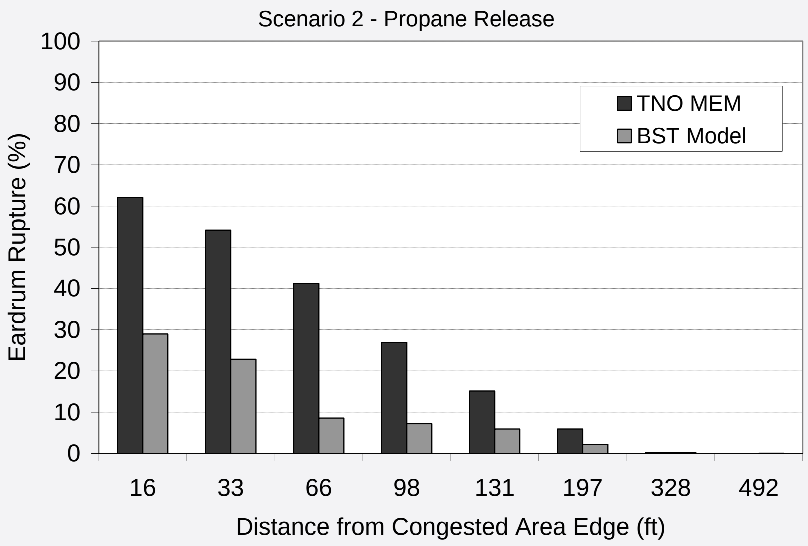
Tasarım Patlama Yükü – Aşılma Basınç Aşılma Eğrisi

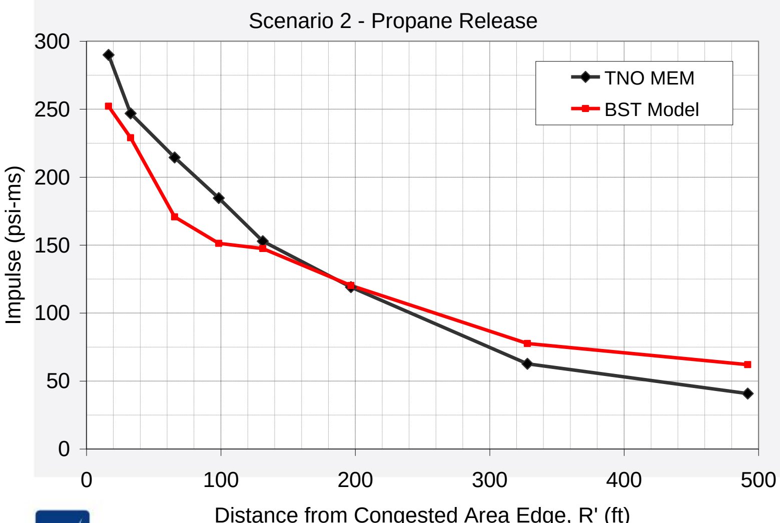


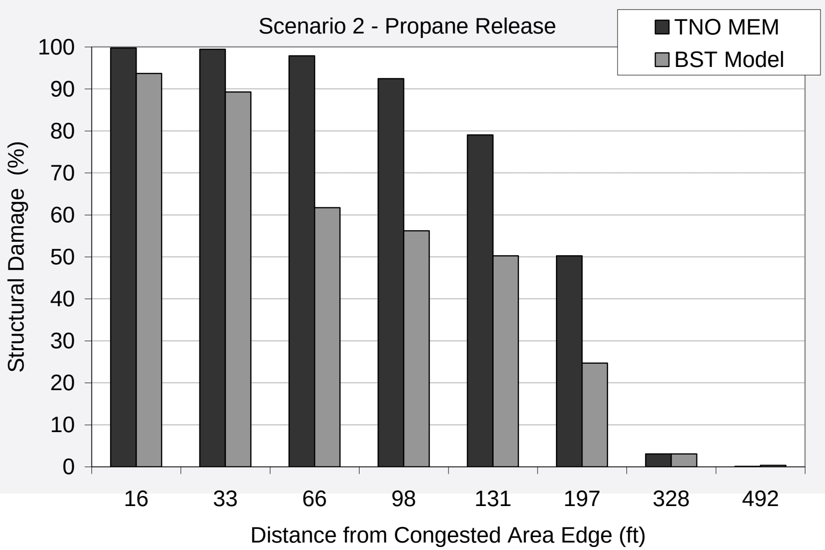
Many Scenarios! What is the design Load?

Kişisel Risk - Yaralanabirlik (Vulnerability Analysis)







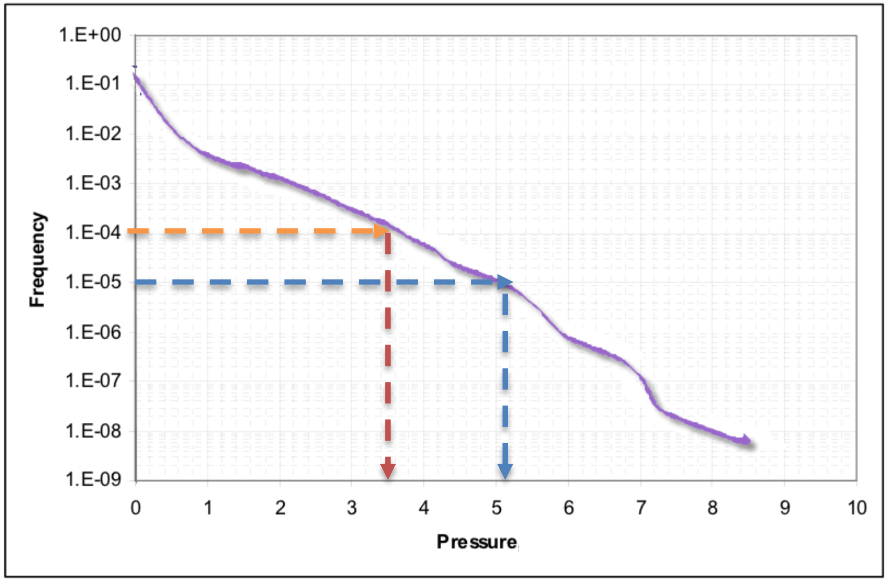


Tasarım Patlama Yükü – Aşılma Basınç Aşılma Eğrisi

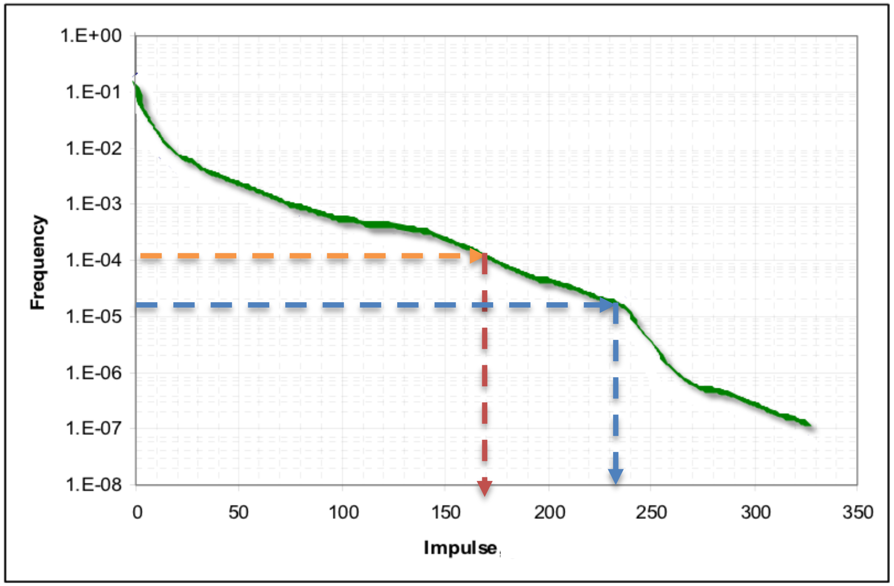
KOCAELİ SANAYİ ODASI PROSES EMNİYETİ SEMPOZYUMU

The graphical representation of the frequency of occurrence or exceedence and the representative overpressure or impulse derived for the relevant scenarios at a particular location.

- ***Location of leak source***
- ***direction of gas jet***
- ***flow rate of the leak***
- ***wind direction and speed***
- ***performance of barrier elements***

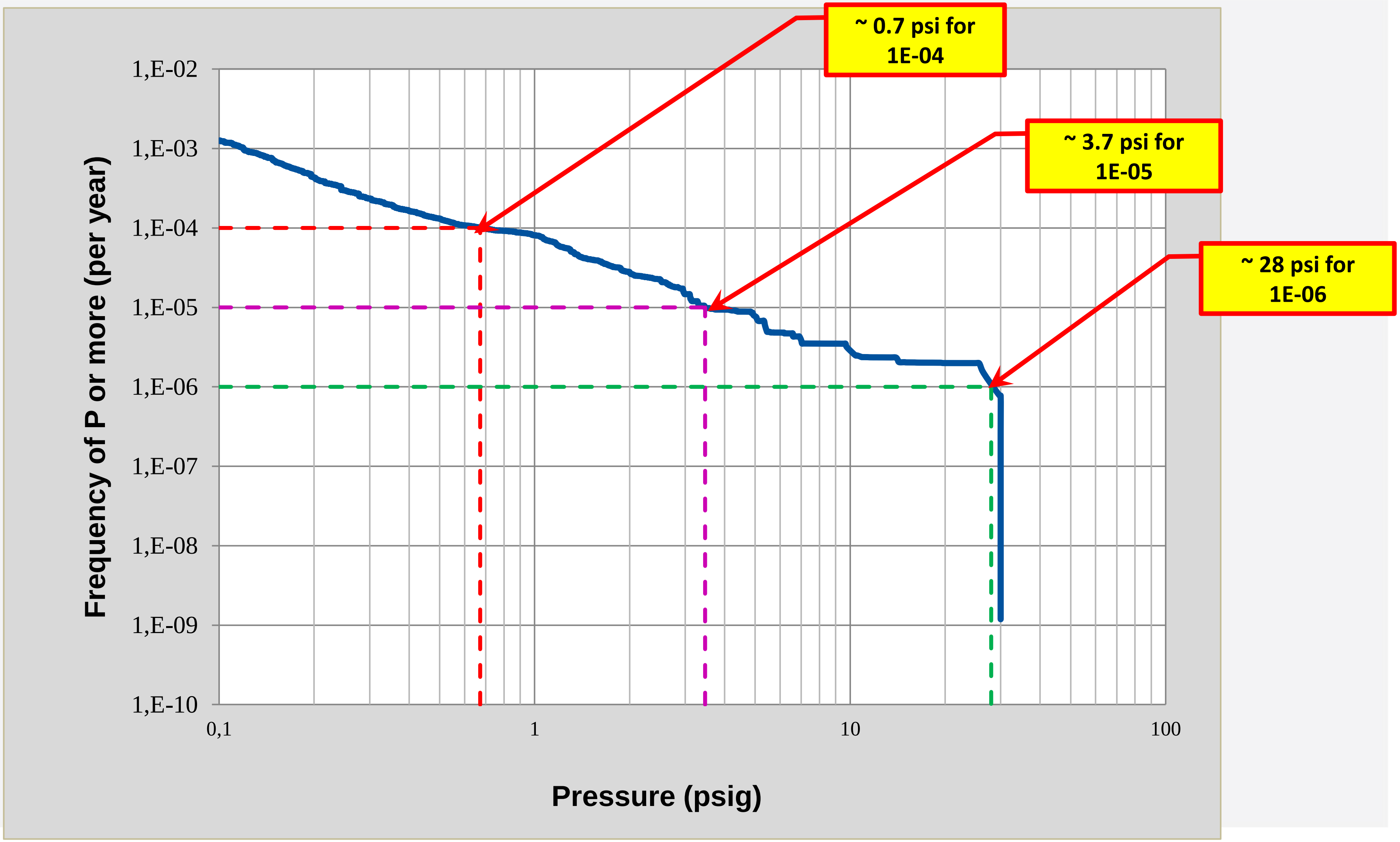


Pressure Exceedence Curve

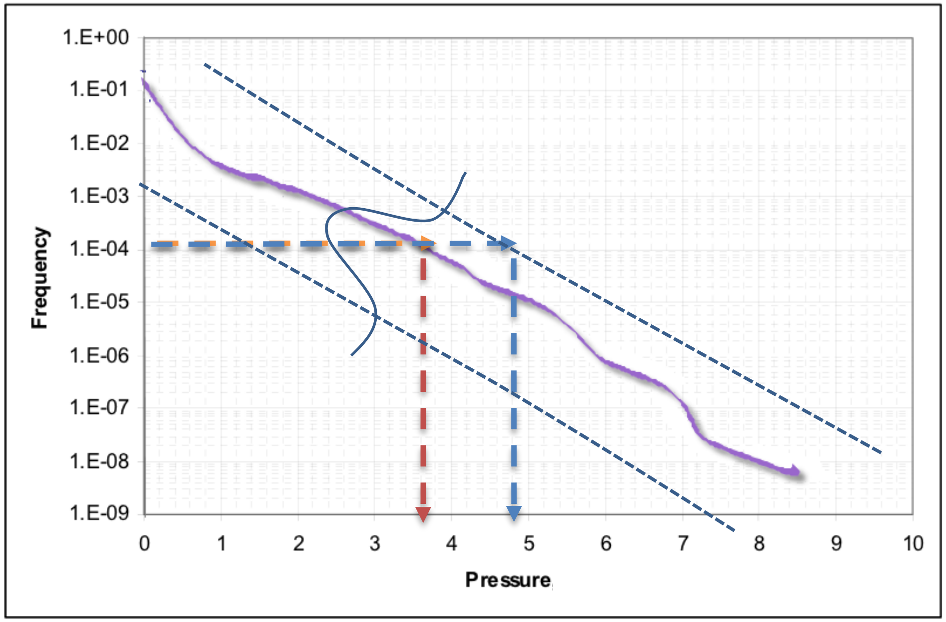


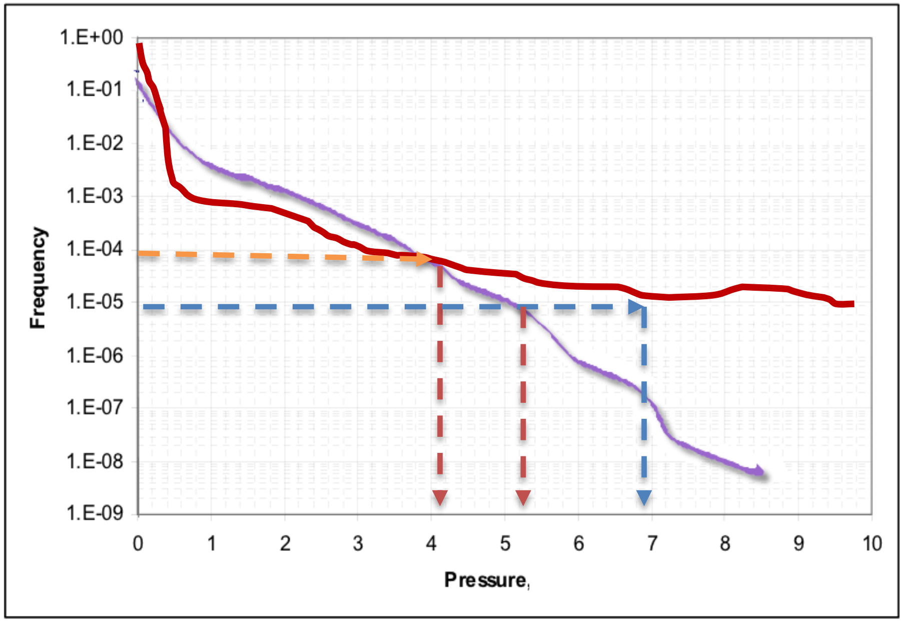
Impulse Exceedence Curve

Tasarım Patlama Yükü – Aşılma Basınç Aşılma Eğrisi



Tasarım Patlama Yükü – Aşılma Basınç Aşılma Eğrisi





Pressure Exceedence Curve

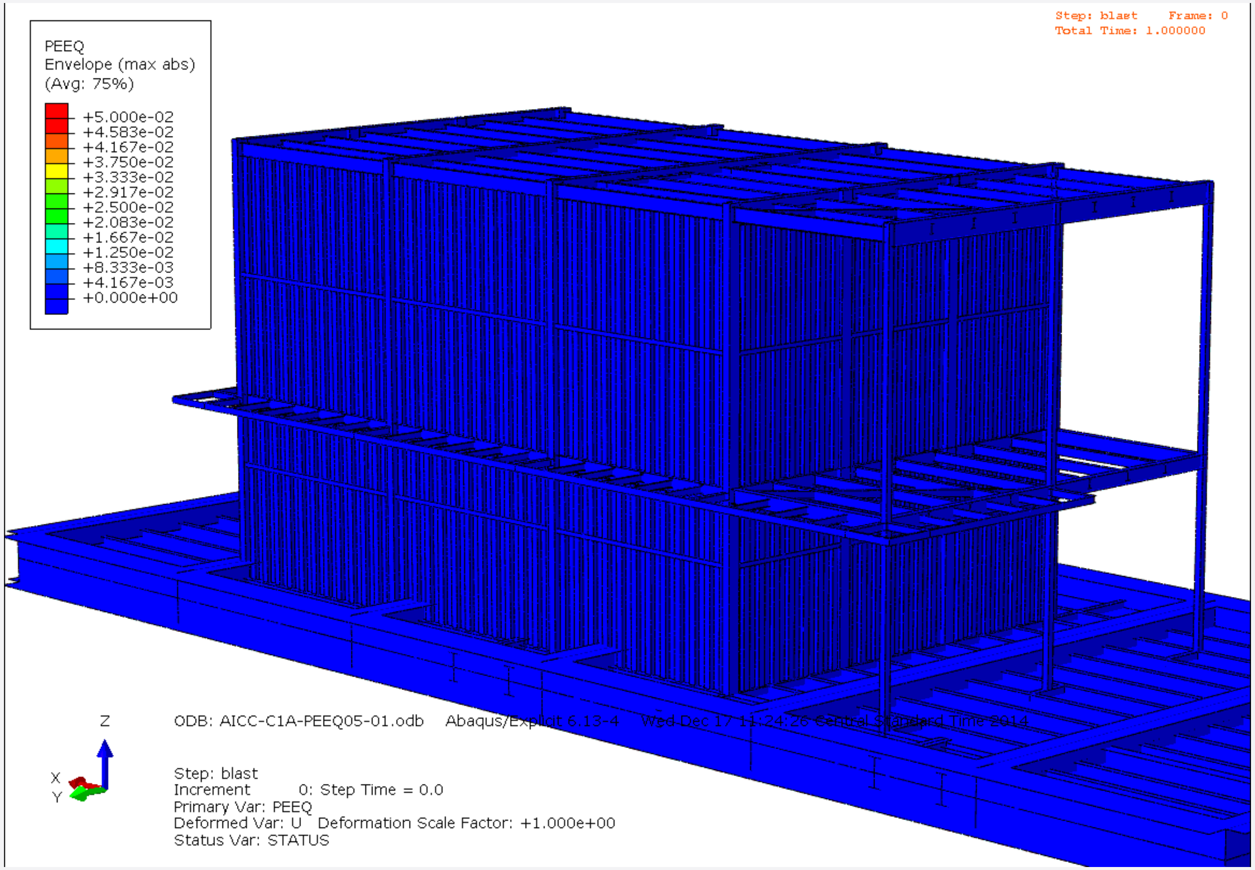
Pressure Exceedence Curve

Confidence level ?

Sensitivity of the design load to the

Frequency ?

Tasarım Patlama Yükü – Aşılma Basınç Aşılma Eğrisi



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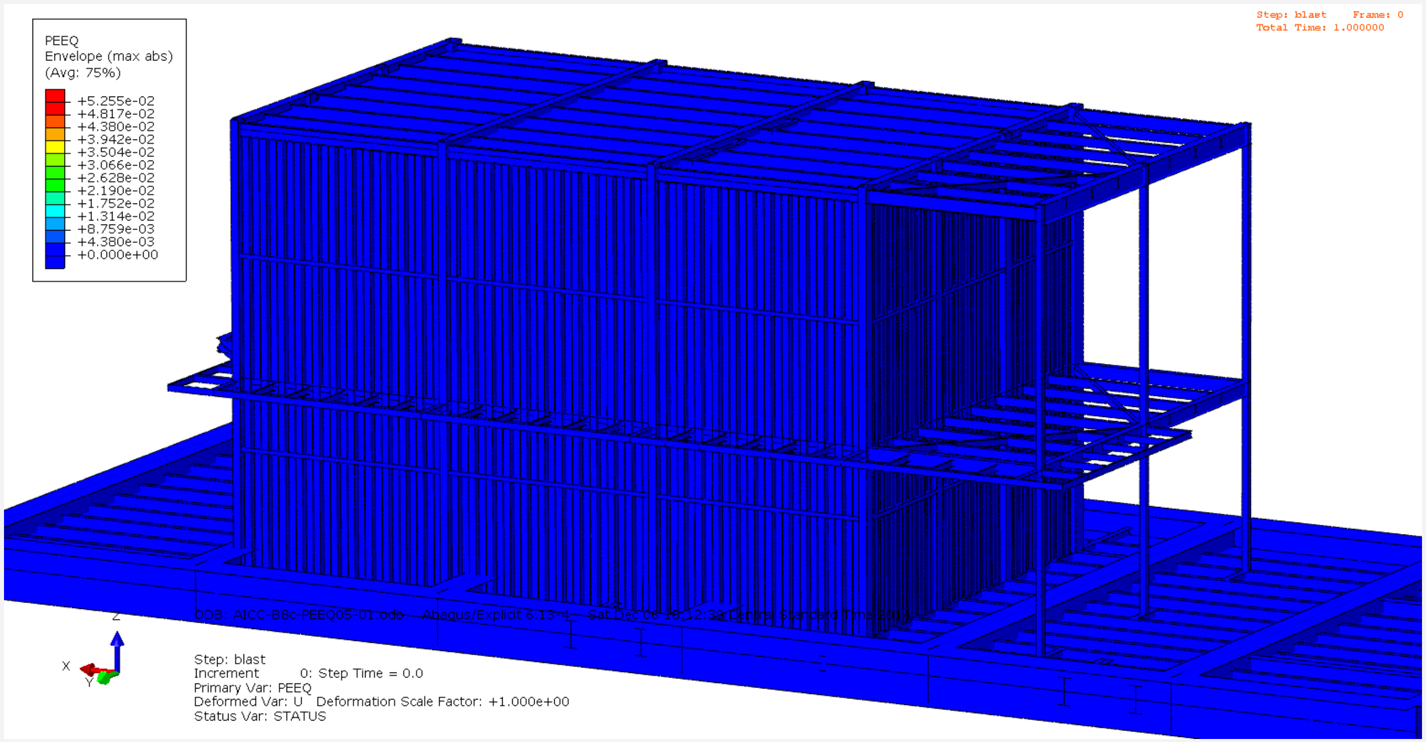

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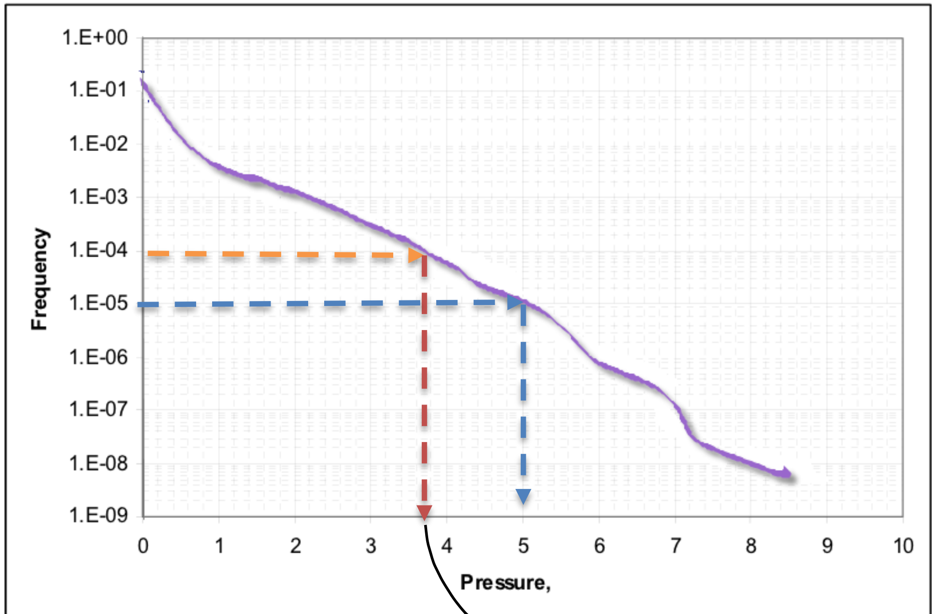


Pressure Exceedence Curve

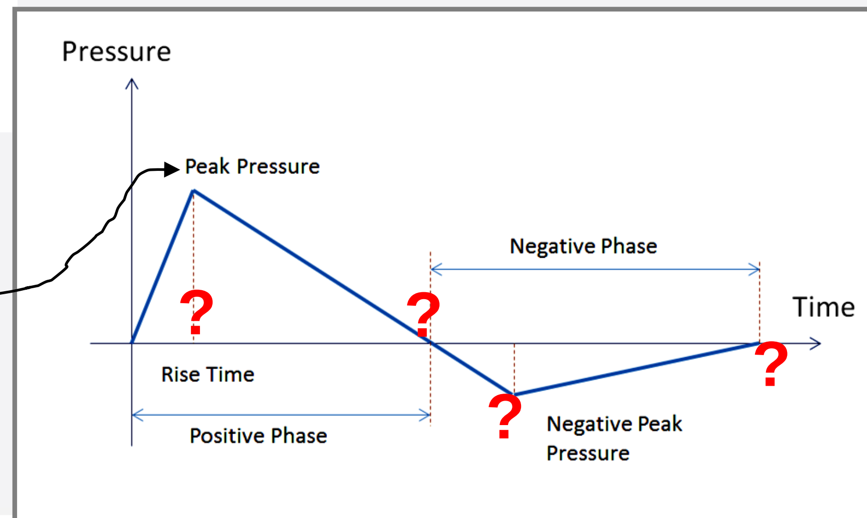
Rise Time?

Positive Duration?

Negative Phase Pressure?

Negative Phase Duration?

Will it be applied uniformly on the whole structure?

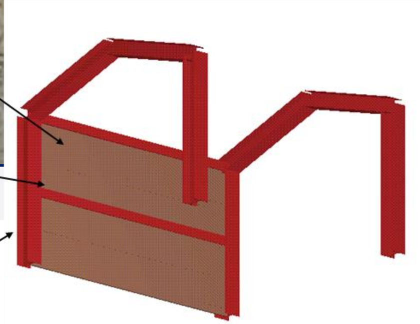


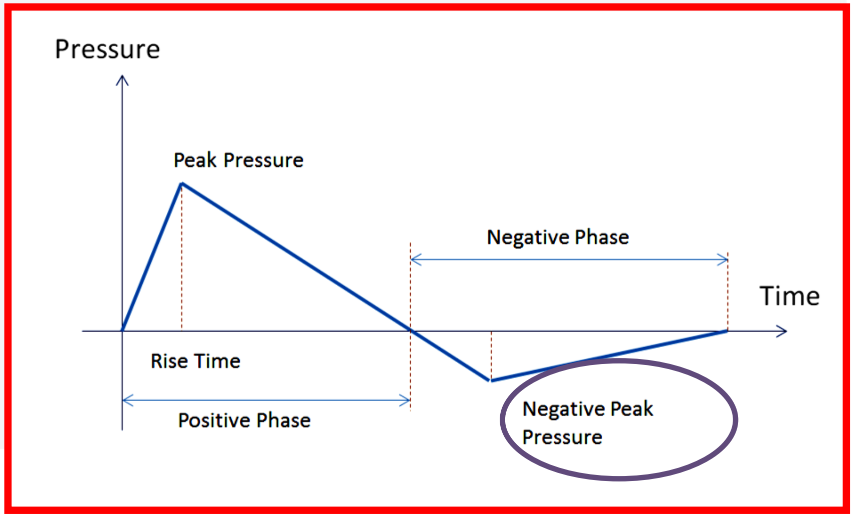
Tasarım Patlama Yükü – Aşılma Basınç Aşılma Eğrisi

Blast Wall Connections may deform plastically subject to the blast positive phase.

This will reduce the capacity of the connection and

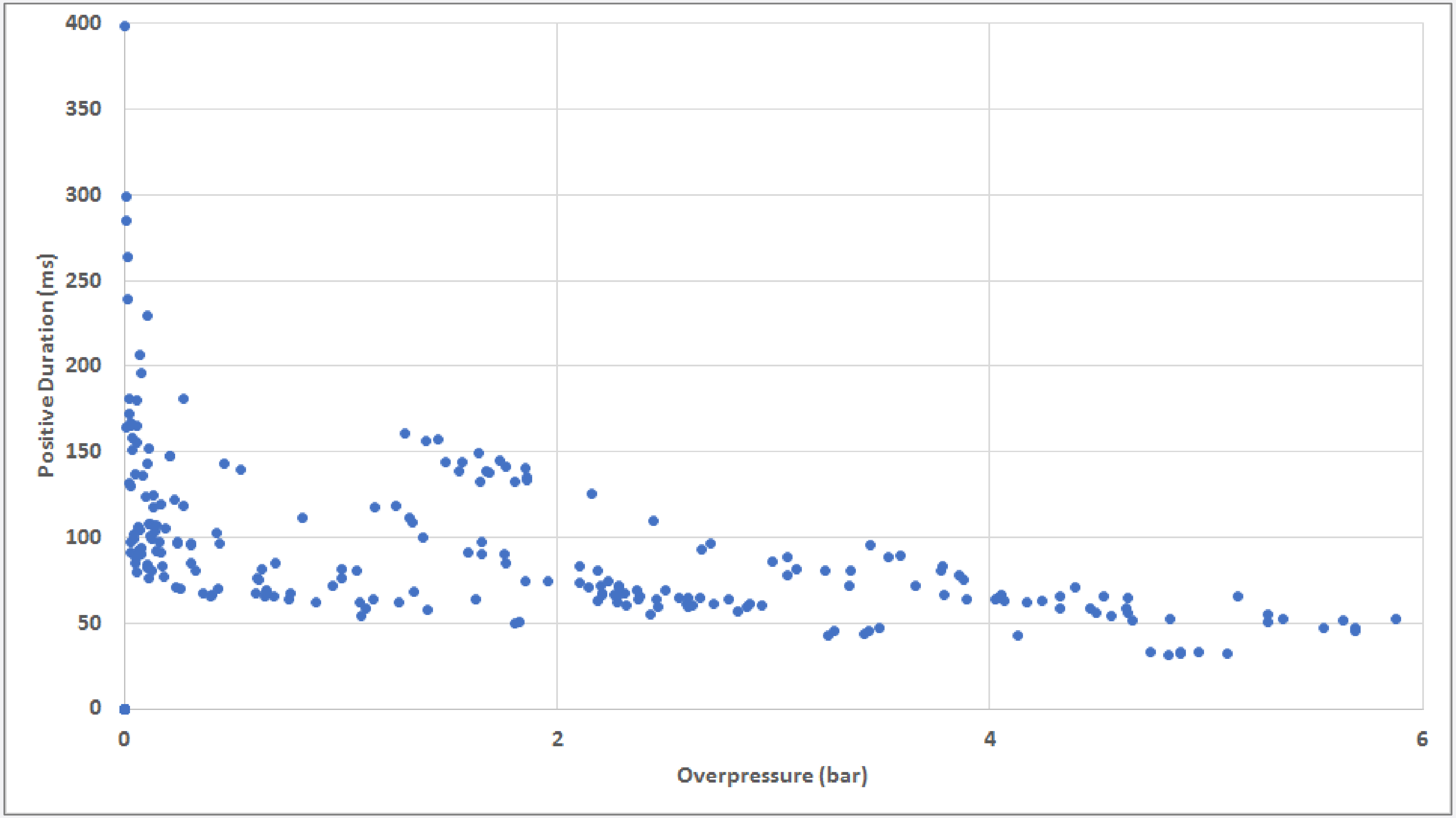
The connection may fail due to the negative peak pressure and rebounding of the wall





Tasarım Patlama Yükü – Aşılma Basınç Aşılma Eğrisi

KOCAELİ SANAYİ ODASI PROSES EMNİYETİ SEMPOZYUMU



Kişisel Risk - Yaralanabirlik (Vulnerability Analysis)

$$P\,(FII) = \sum_{i=1,n} P(FI\,|A_i) \times P(I\ at\ A_i) \times P(A_i)$$

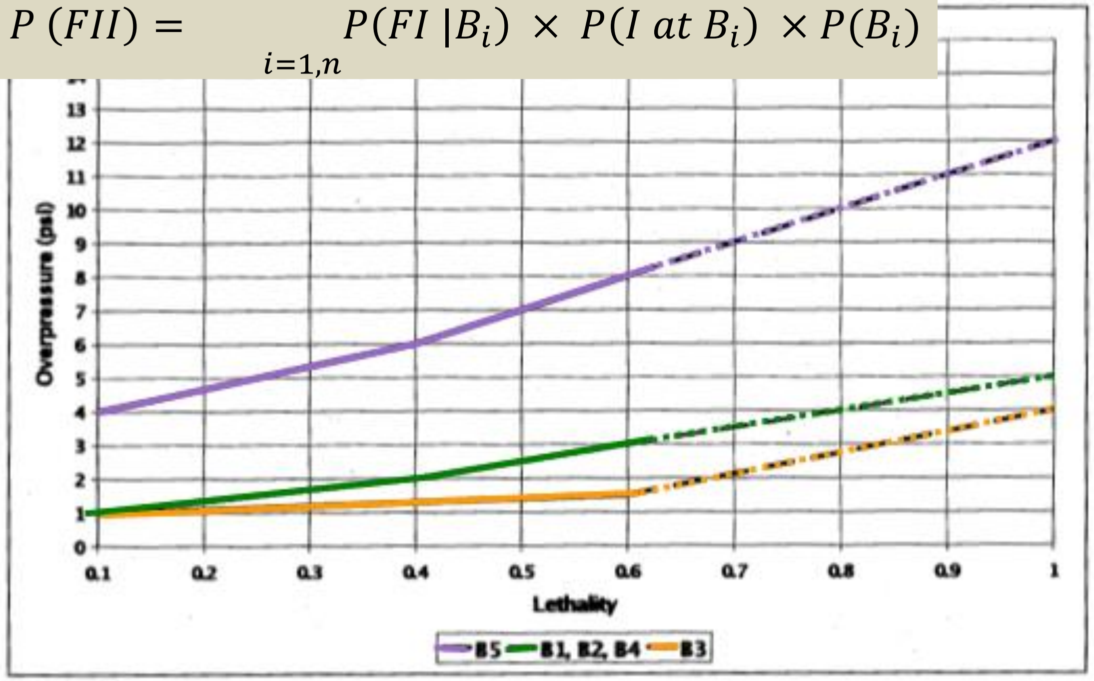
- $P\,(FII)$= the probability of an individual experiencing an Fatality or Significant Injury (FI) (individual risk)
- $P(A_i)$ = the probability that accident A_i occurs.
- $P(FI|A_i)$= the conditional probability that an FI occurs, given that event/accident A_i occurs.
- $P(I\ at\ A_i)$= the probability that an individual is present when accident A_i occurs.

❑ The vulnerability number (VN) is the fraction of occupants with serious, fatal injuries (FI) at a certain severity of structural damage.

Kişisel Risk - Yaralanabirlik (Vulnerability Analysis)

Reference: American Petroleum Institute (API), 2003. *Management of Hazards Associated with Location of Process Plant Buildings, 2nd ed.*, API RP 752, First Edition, May 1995.

$$P\,(FII) = \sum_{i=1,n} P(FI\,|B_i) \times P(I\ at\ B_i) \times P(B_i)$$



Building Types

B1: Wood-frame trailer or shack.

B2: Steel-frame/metal siding or pre-engineered building.

B3: Unreinforced masonry bearing wall building.

B4: Steel or concrete framed with reinforced masonry infill or cladding.

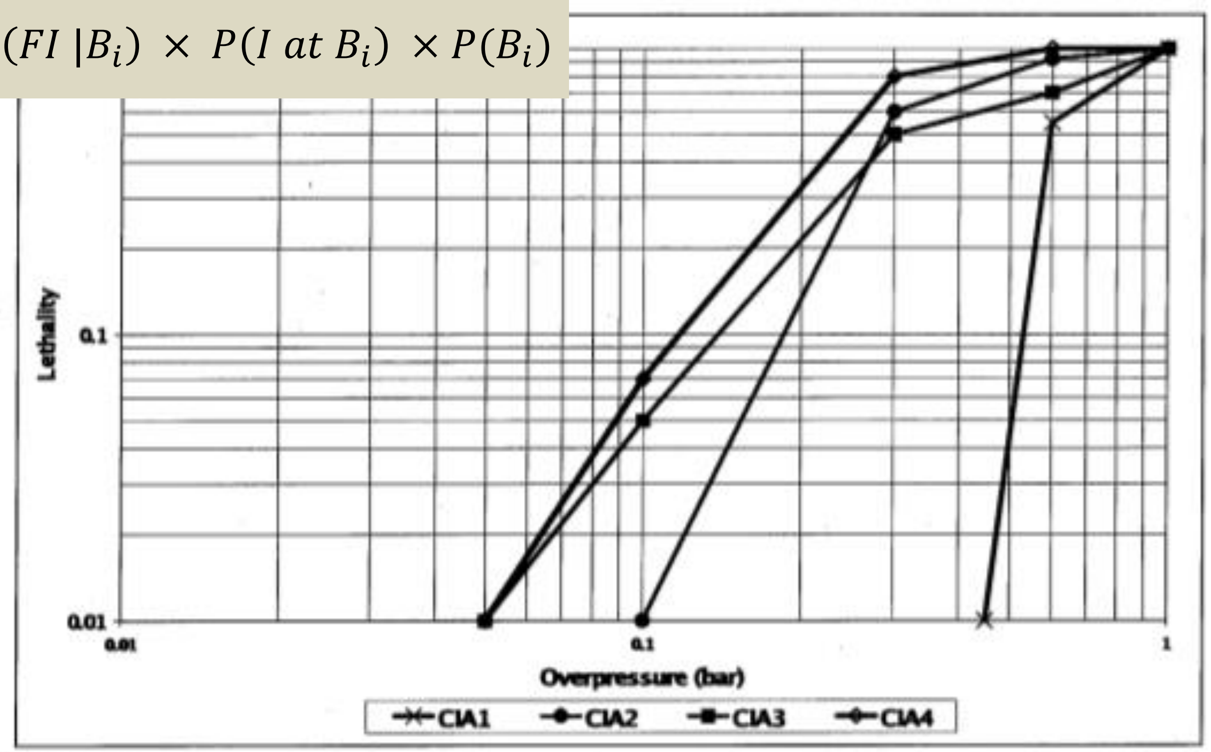
B5: Reinforced concrete or reinforced masonry shear wall building.

* Note that API RP 753 [5] has superseded API RP 752 [4] with regard to locating portable buildings (building type B1). However, it does not give any overpressure-lethality relationship for such buildings, for which API RP 753 [5] should be followed rather than using the curve on the above graph.

Kişisel Risk - Yaralanabirlik (Vulnerability Analysis)

Reference: Chemical Industries Association (CIA), 2003. *Guidance for the location and design of occupied buildings on chemical manufacturing sites,* 2nd ed., London: CIA, ISBN 1 85897 114 4.

$$P\,(FII) = \sum_{i=1,n} P(FI\,|B_i) \times P(I\;at\;B_i) \times P(B_i)$$



Building Types

CIA1: Hardened structure building: special construction, no windows

CIA2: Typical office block: four storey, concrete frame and roof, brick block wall panels

CIA3: Typical domestic building: two-storey, brick, walls, timber floors

CIA4: 'Portacabin' type timber construction, single storey

Kişisel Risk - Yaralanabirlik (Vulnerability Analysis)

$$P_{Fail}(i) = \quad {}_{j,k} \quad P(Fail|D) \times P\left(D \middle| A_{jk}^{(i)}\right) \times P(A_{jk}^{(i)})$$

For each type of accidental load

Probability of damaged system failure under relevant Accidental Load

Probability of accidental action at location (j) and intensity (k)

Probability of damage, D given $A_{jk}^{(i)}$

- $P(A_{jk}^{(i)})$is determined by risk analysis while the other probabilities are determined by structural reliability analysis.
- $P(Fail|D)$ is determined by due consideration of relevant action and their correlation with the hazard causing the damage

Kişisel Risk - Yaralanabirlik (Vulnerability Analysis)

$$IR = \sum_{i=1,n} VN|DL_i \times P(I|DL_i) \times P(DL_i)$$

$$IR = \sum_{i=1,n} VN|E_i \times P(I|E_i) \times P(E_i|DL_i) \times P(DL_i)$$

$$IR = VN \times OPP \times (Calculated\ Frequency_i - Calculated\ Frequency_{i-1})$$

$P(I|DL_i)$ = conditional probability that an I occurs given that damage level DL_i occurs.

$P(DL_i)$ = probability that damage level D_i occurs.

$VN|DL_i$ = vulnerability number at a certain structural damage level DL_i.

OPP= Occupant Presence Probability

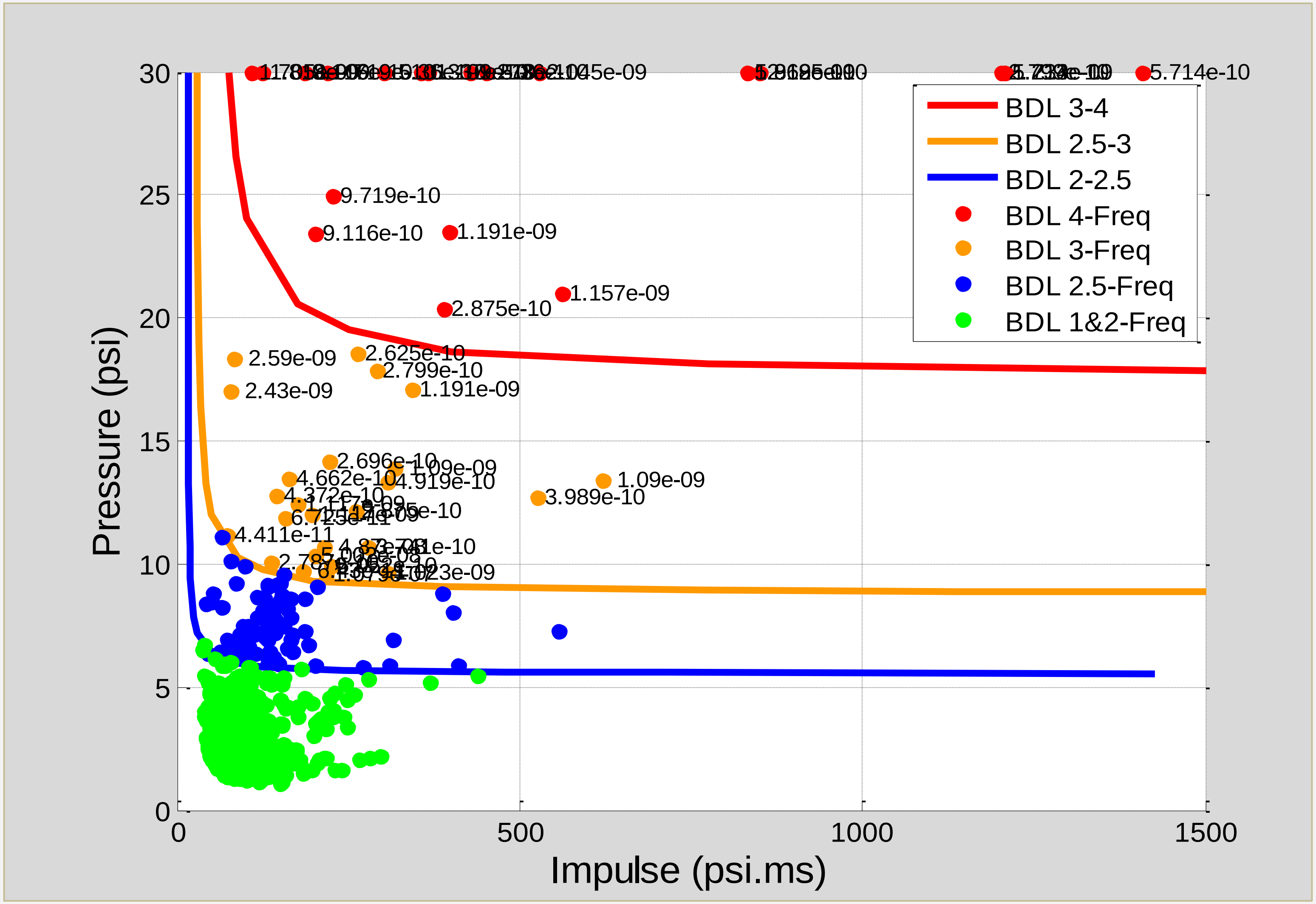
$P(I|E_i)$= conditional probability that an I occurs given that an escalation E_i occurs.

$P(E_i|DL_i)$= conditional probability that an escalation occurs given that damage level DL_i occurs.

$VN|E_i$ = vulnerability number at a certain escalation level E_i.

Kişisel Risk - Yaralanabirlik (Vulnerability Analysis)

KOCAELİ SANAYİ ODASI
PROSES
EMNİYETİ SEMPOZYUMU



Domino Etkisi ve Proses Harici Tehlikelerle Risk Analizi

Es Sider, Libya Tank Fire in 2014 (Cause: Terrorist Attack)

Response of a partially filled tank to blast within the shallow cloud (Buncefield explosion)

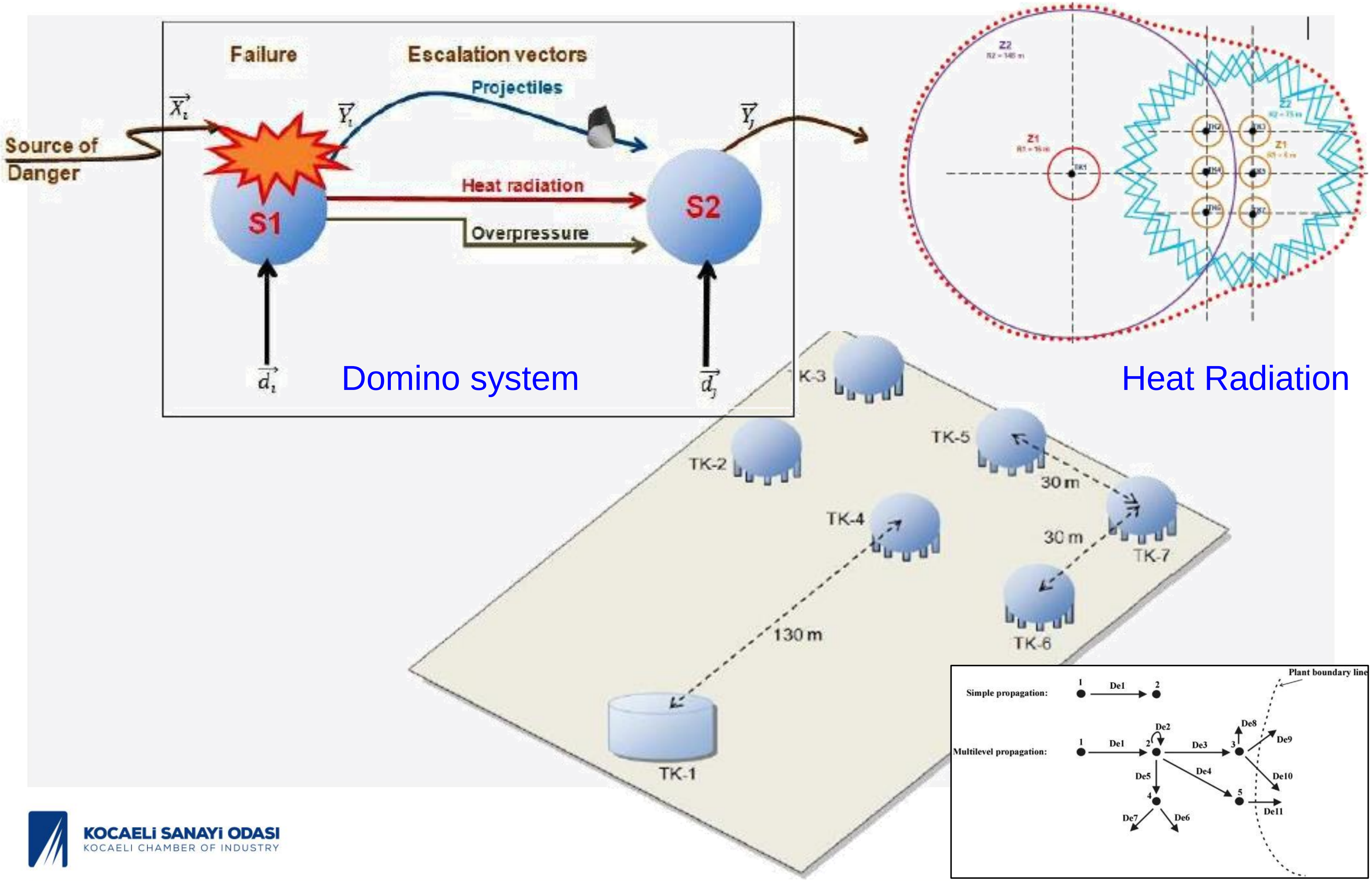
Domino Etkisi ve Proses Harici Tehlikelerle Risk Analizi

Tank farm fires after Kocaeli Earthquake in Turkey in 1999

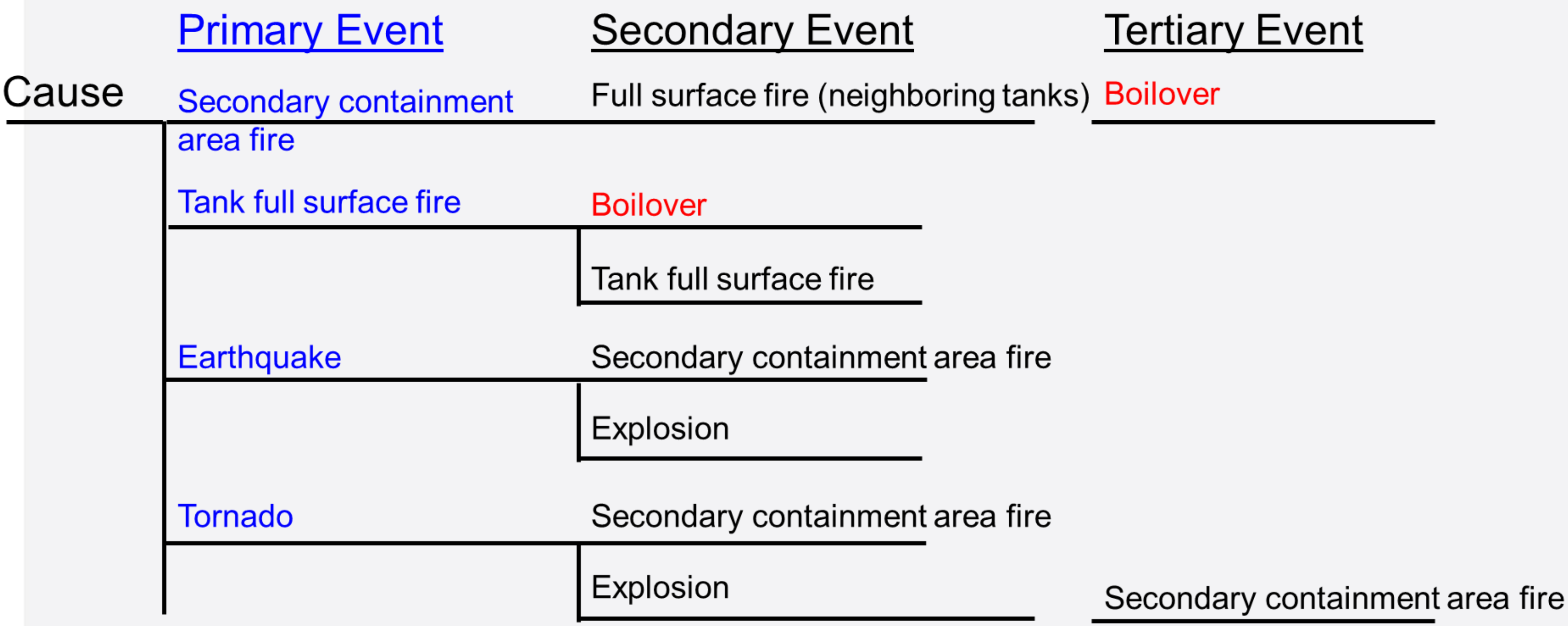
Collapsed tanks and piping system in tank farm due to fire after the Kocaeli Earthquake in Turkey in 1999

Explosions at Arkema Facility after flooded during Harvey Storm in Texas, 2017

Domino Etkisi ve Proses Harici Tehlikelerle Risk Analizi



Domino Etkisi ve Proses Harici Tehlikelerle Risk Analizi



Domino Etkisi ve Proses Harici Tehlikelerle Risk Analizi

KOCAELİ SANAYİ ODASI PROSES EMNİYETİ SEMPOZYUMU

(1) Secondary containment area fire:

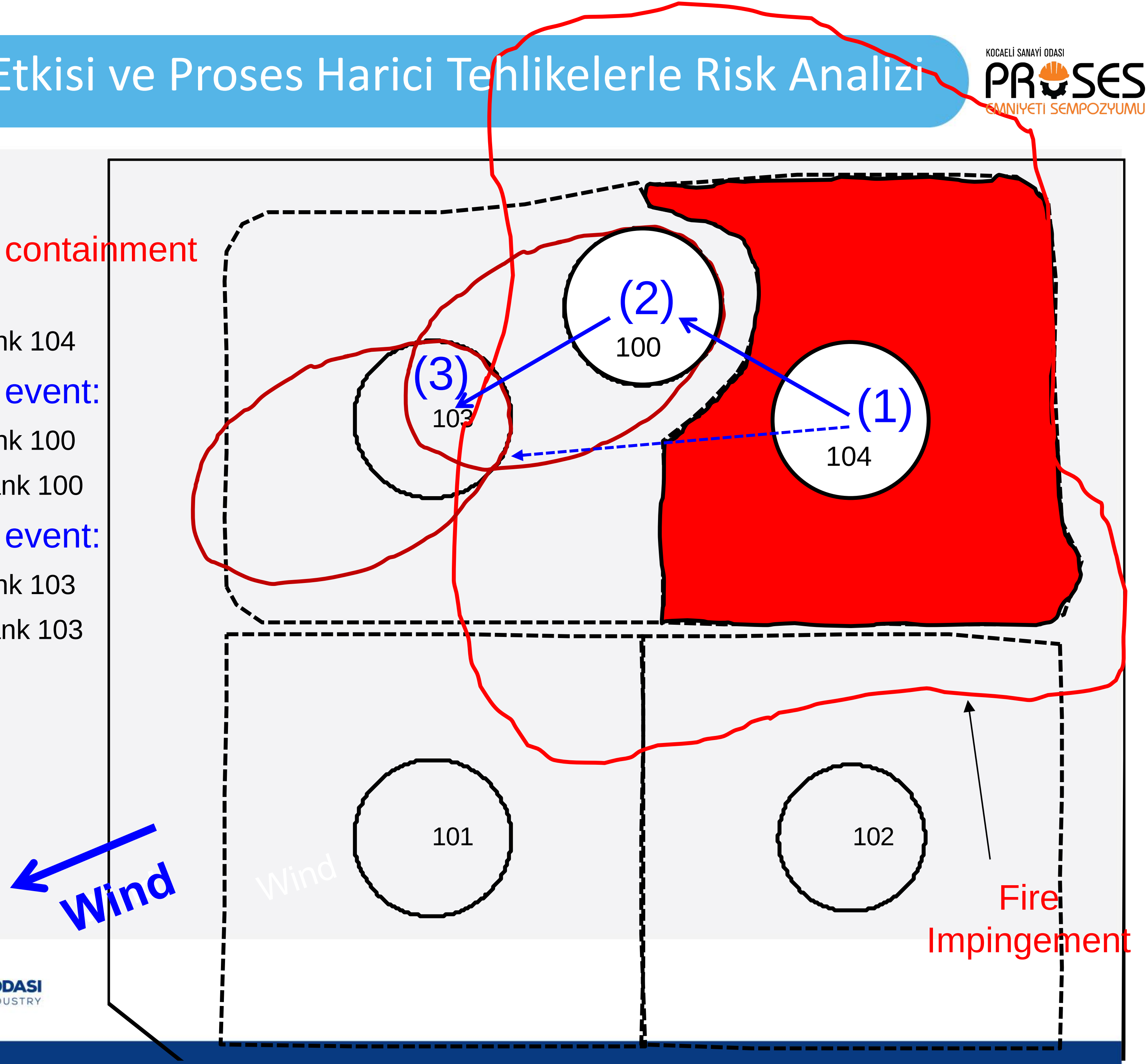
- Dike fire at Tank 104

(1) Secondary event:

- Pool fire at Tank 100
- Boil-over at Tank 100

(1) Secondary event:

- Pool fire at Tank 103
- Boil-over at Tank 103



KOCAELİ SANAYİ ODASI
KOCAELI CHAMBER OF INDUSTRY

(1) Primary event:

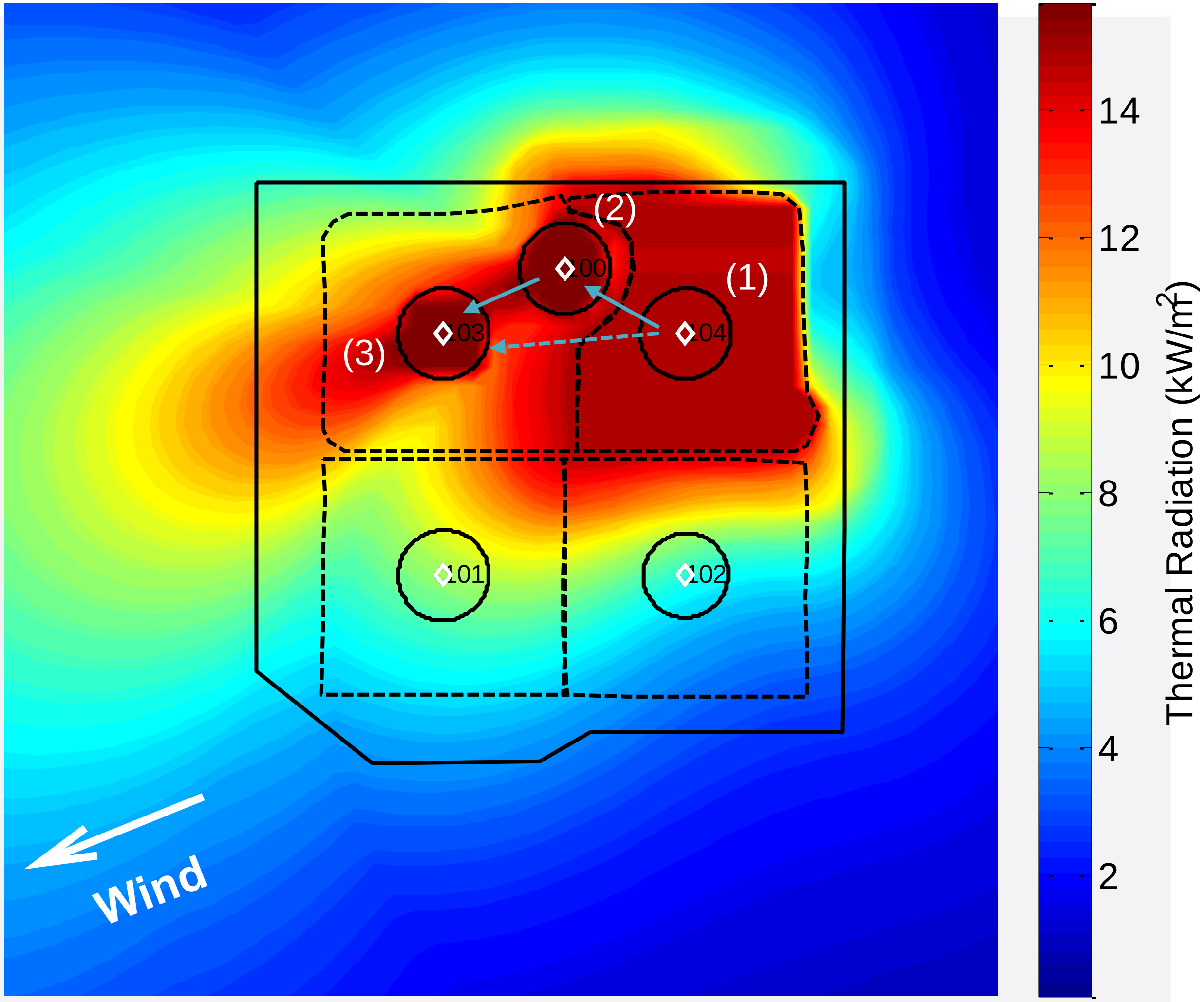
- Dike fire at Tank 104

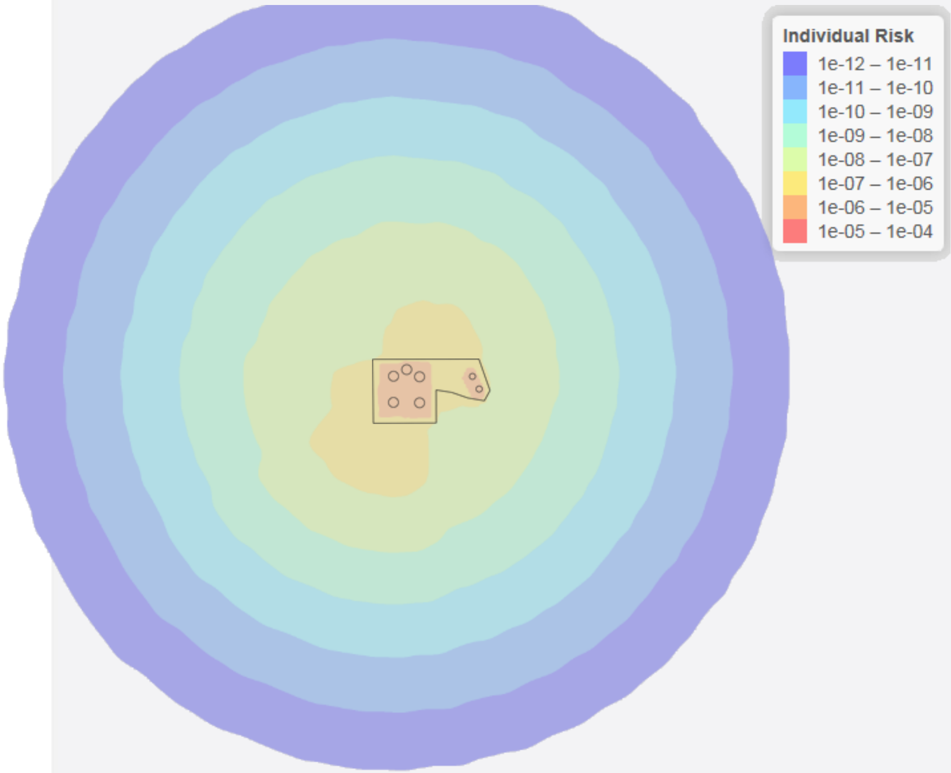
(2) Secondary event:

- Pool fire at Tank 100
- Boil-over at Tank 100

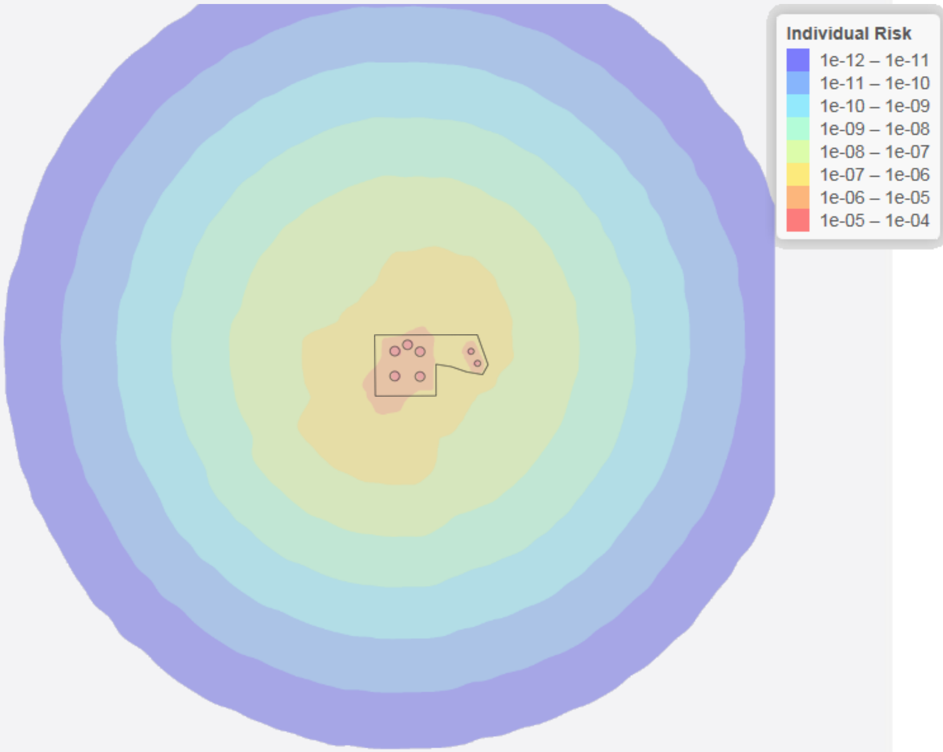
(3) Secondary event:

- Pool fire at Tank 103
- Boil-over at Tank 103





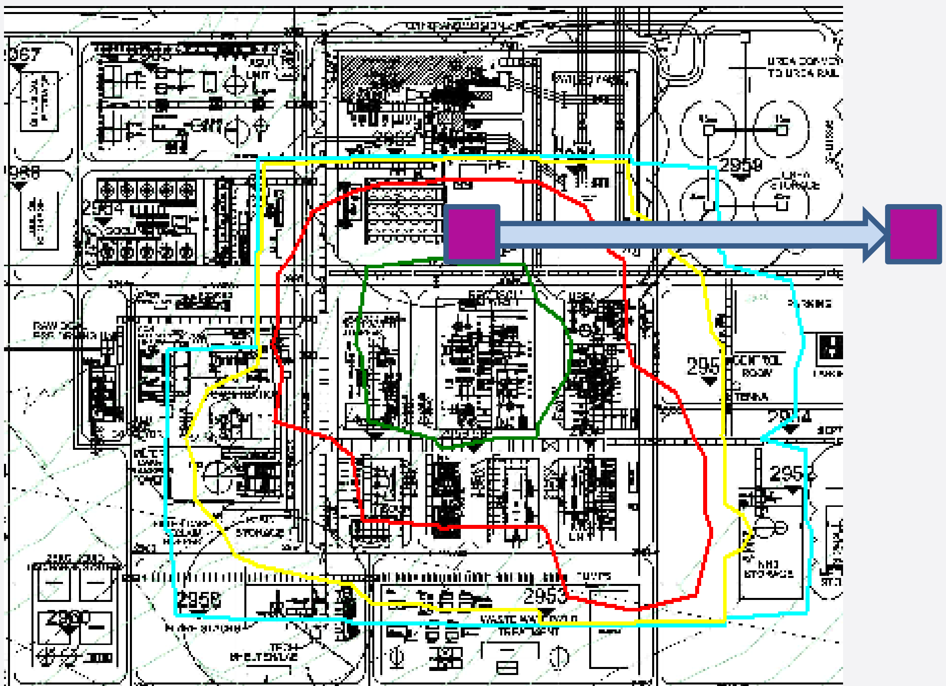
Without Domino Effect



With Domino Effect

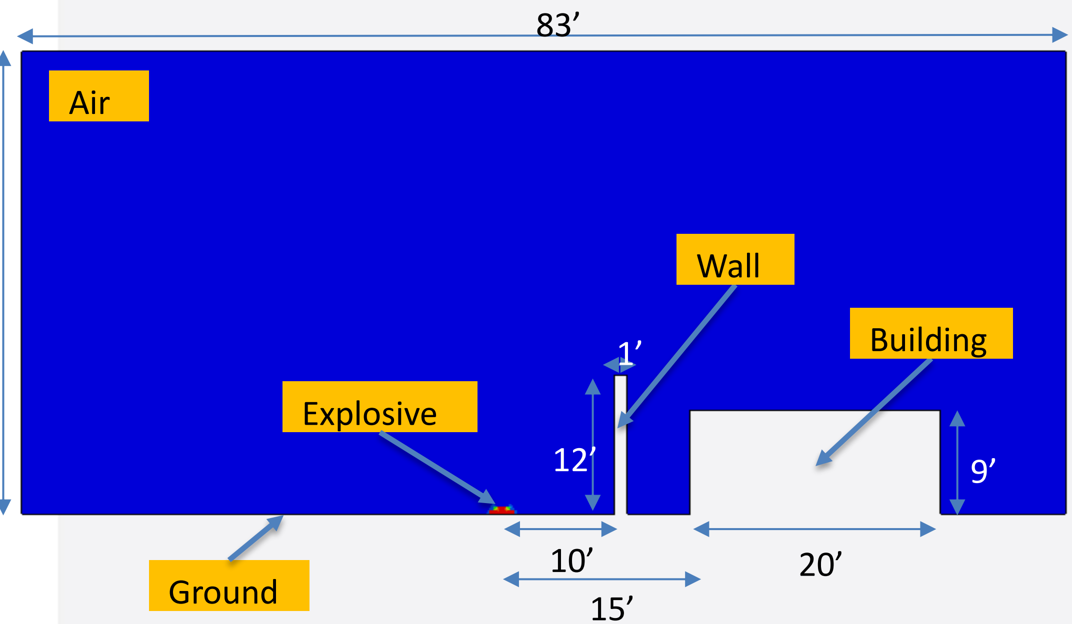
KOCAELİ SANAYİ ODASI PROSES EMNİYETİ SEMPOZYUMU

The Control Room Dilemma



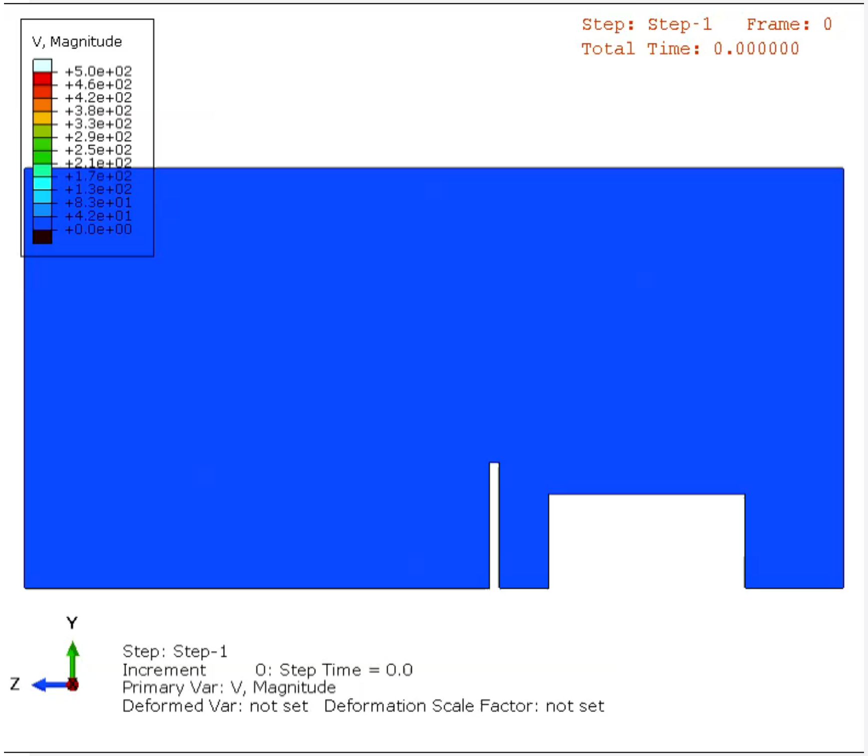
Free-field blast overpressure contours

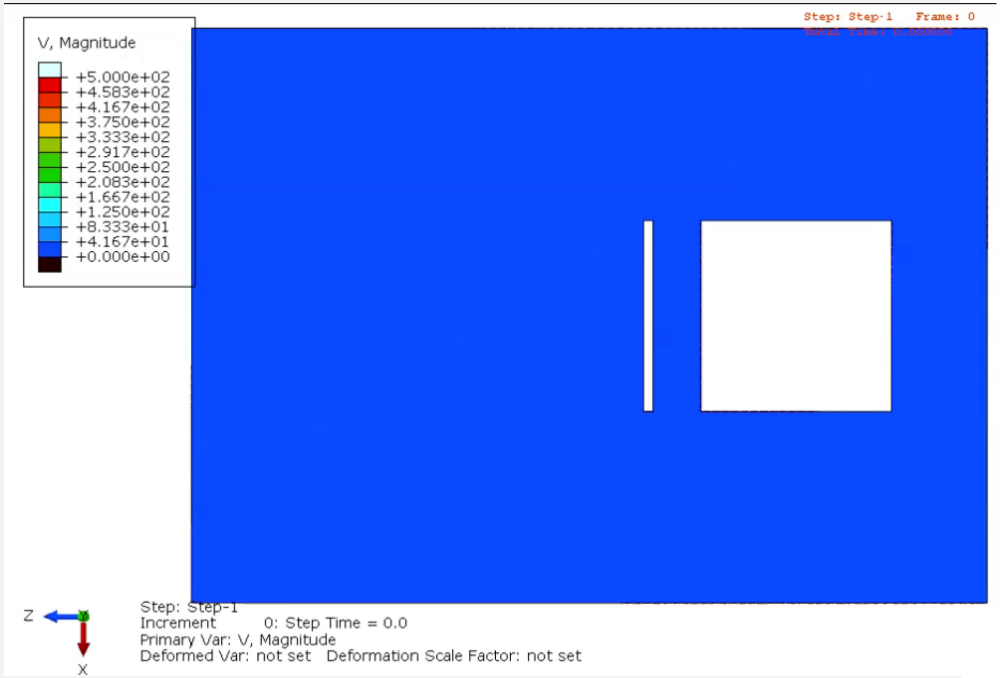
Blast Wall



This existing barricade was evaluated with CFD and found to offer only a 20% reduction in load on the building front wall. That wall and windows were still predicted to fail. Hence the barricade did not do its job.

Results: Animation of Velocity Contours in Mid-section





Masonry Shield Wall

Ref: Sari et al, ASCE Structures, 2009

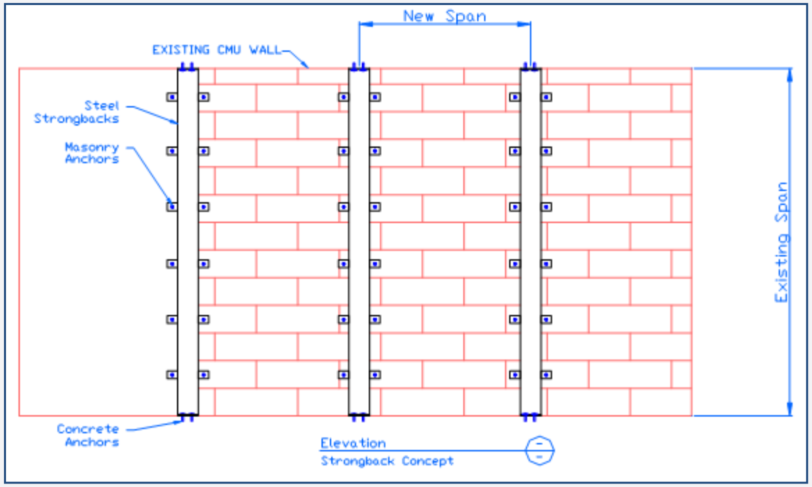
Patlama Etkisini Azaltma Çalışması (Mitigation Study)

Interior Catch System

Construction Photos

Ref: Sari et al, ASCE Structures, 2009

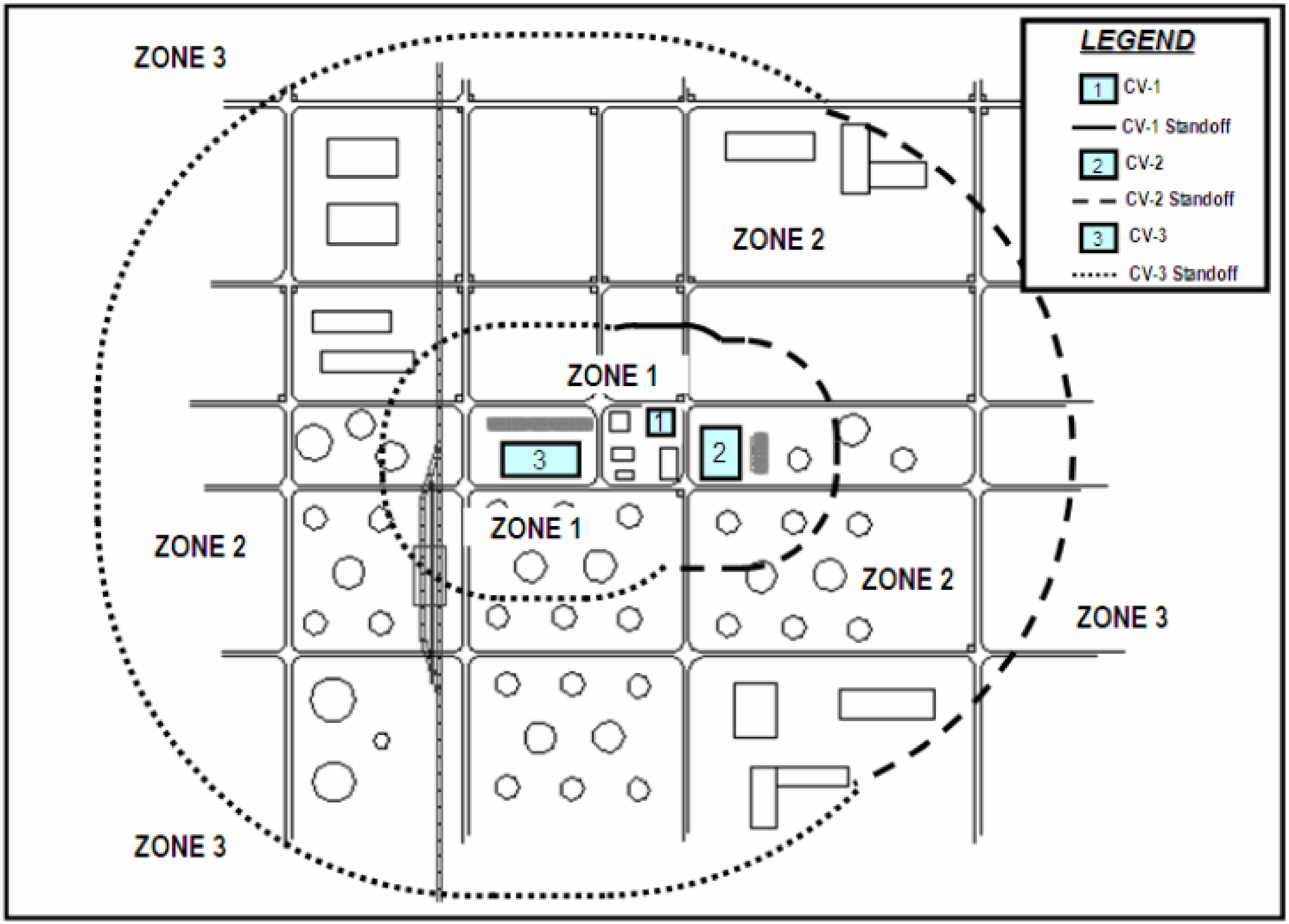
Strongback Masonry Retrofit



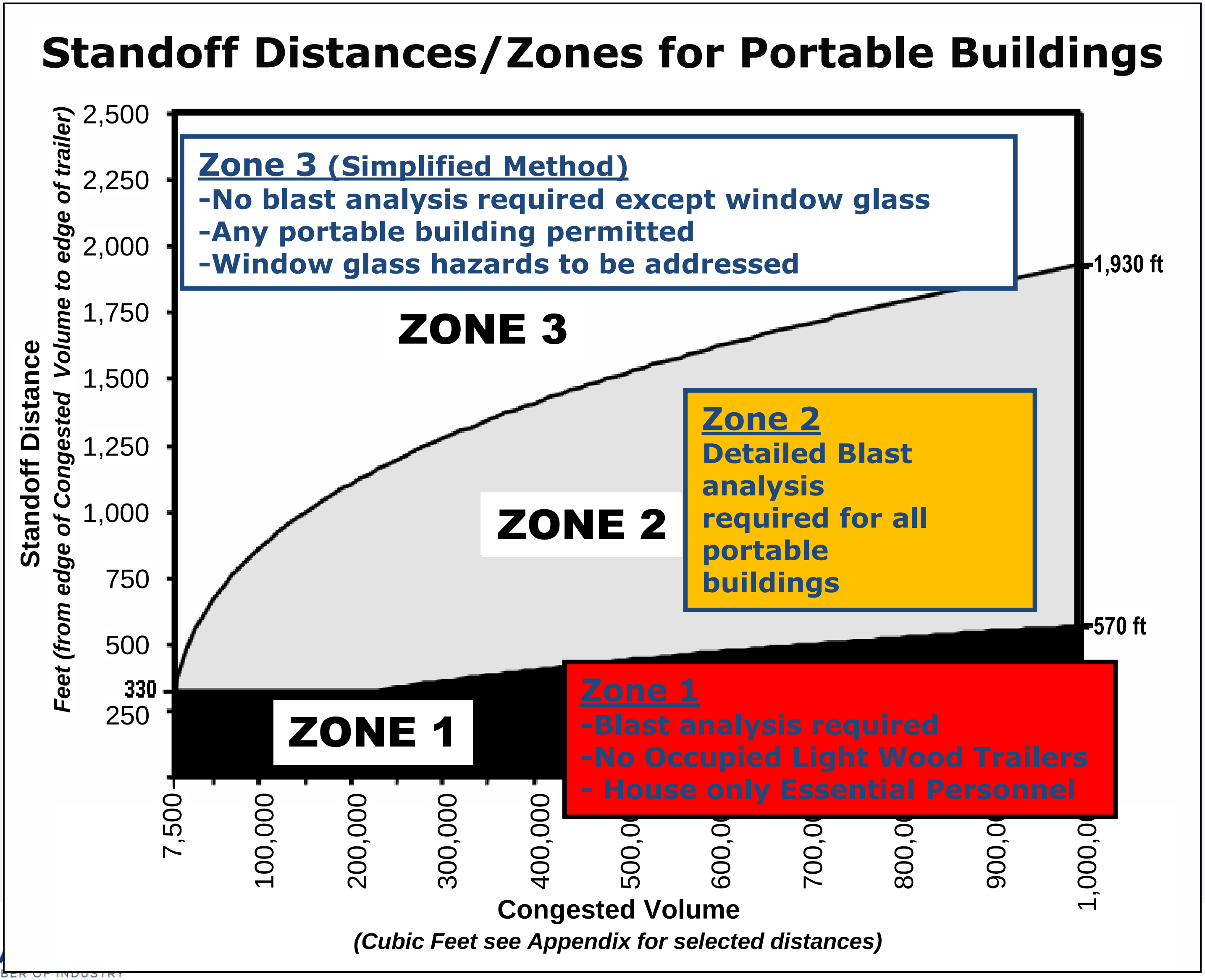
Masonry Wall –Strongback Retrofit

Ref: Sari et al, ASCE Structures, 2009

API 753 Zone Tanımı ve ATEX Zone



API 753 Zone Tanımı ve ATEX Zone



Ref: API 753

KOCAELİ SANAYİ ODASI
PROSES EMNİYETİ SEMPOZYUMU

Sorular?

Dinlediğiniz için Teşekkür Ederim.

Doç. Dr. Ali SARI

İTÜ

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KOCAELİ SANAYİ ODASI
KOCAELI CHAMBER OF INDUSTRY

KOCAELİ SANAYİ ODASI

PROSES EMNİYETİ SEMPOZYUMU

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KOCAELI CHAMBER OF INDUSTRY

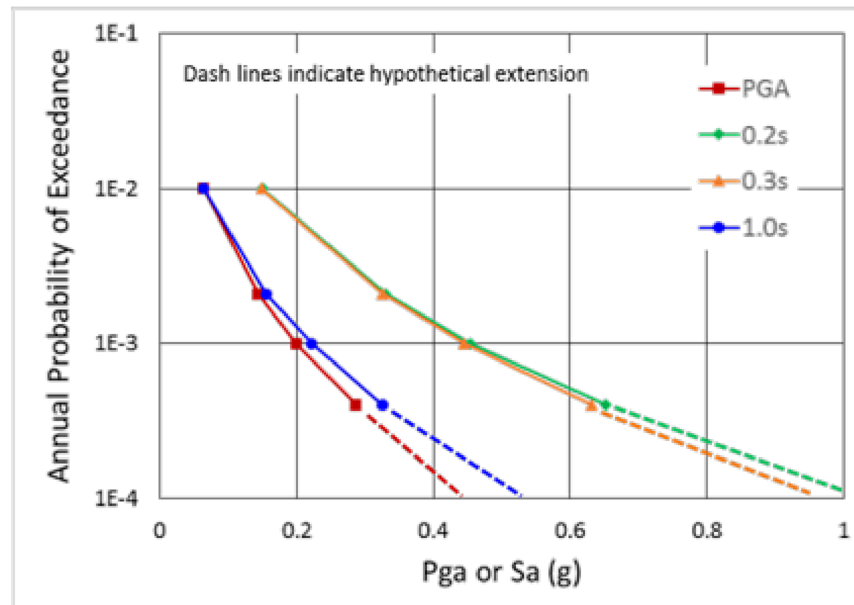
Frekans Analizi – Sızıntı Frekansı (Leak Frequency)

KOCAELİ SANAYİ ODASI PROSES EMNİYETİ SEMPOZYUMU

- **Then why use these offshore databases?**
  - Availability
  - Conservative
  - Leak freq analysis can be conducted quickly
  - Client wants to compare other assets using same methodology

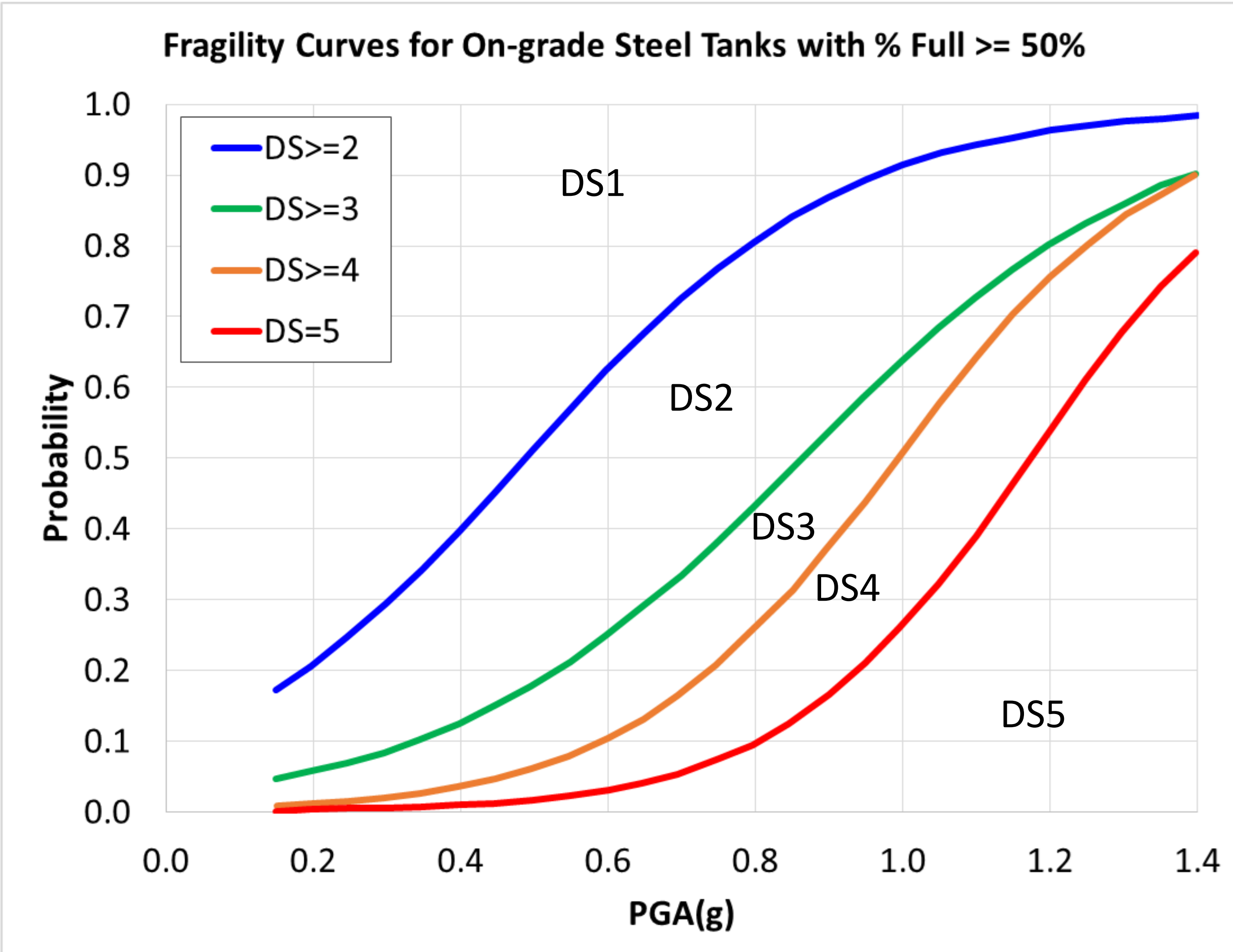
Seismic Response of Storage Tanks - Site Seismic Hazard Curves

- Site seismic hazard curves can be developed for a specific site; or
- Can also be obtained from the 2015 National Building Code of Canada (NBCC) and modified based on local soil characteristics.



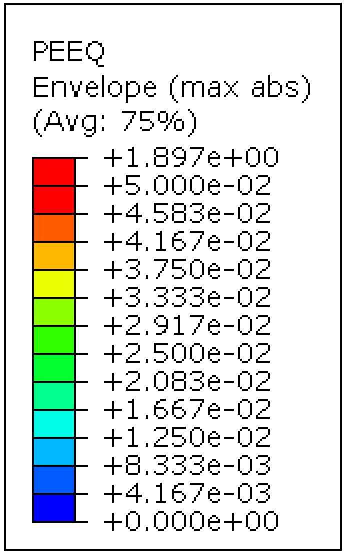
http://www.earthquakescanada.nrcan.gc.ca/hazard-alea/interpolat/index_2015-eng.php

Fragility Curves for On-grade Steel Tanks with % Full > 50%



* Michael O'Rourke and Pak So, 2000

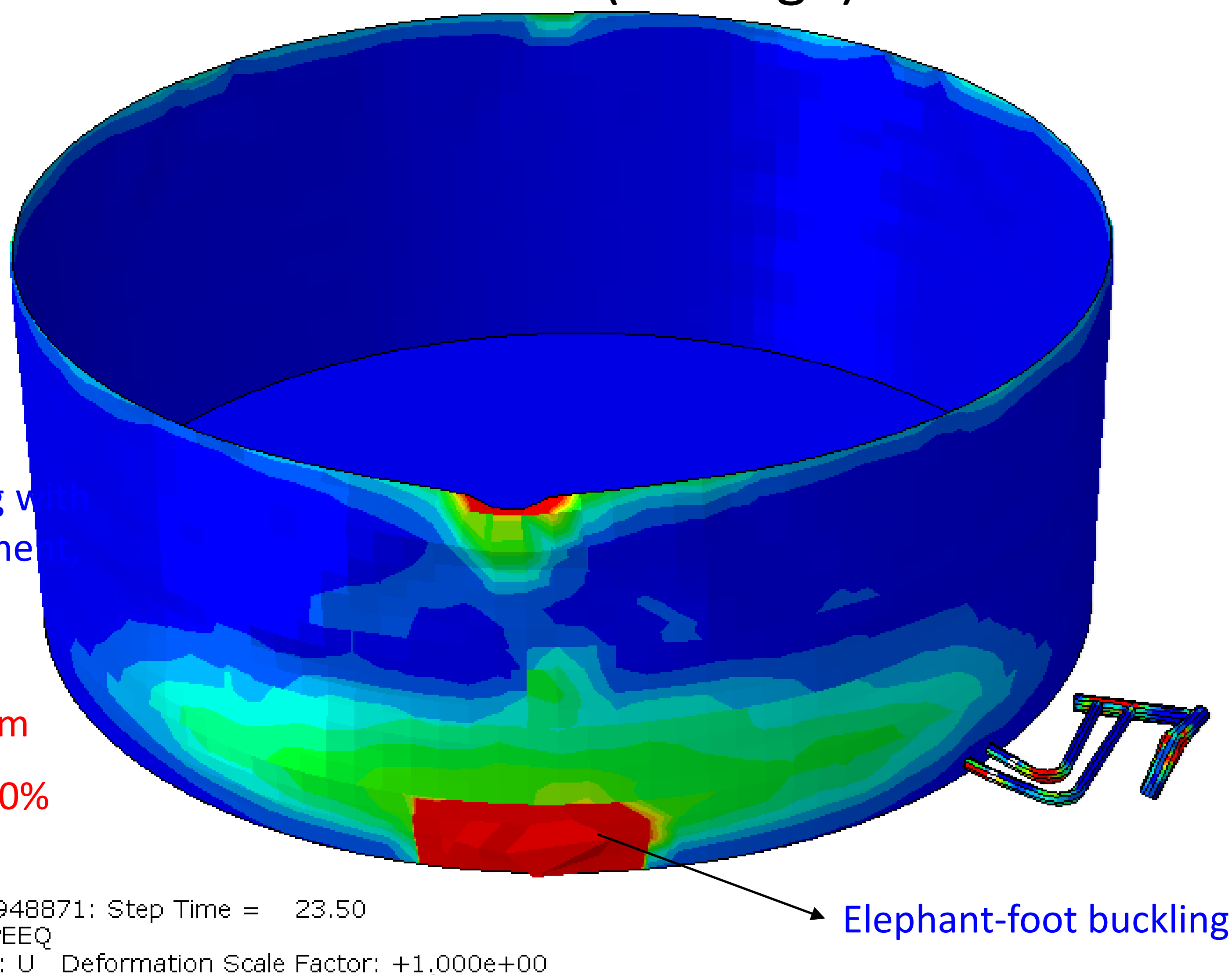
Kern County Earthquake – 1.0g
Plastic Strain Contours (Damage)



Red color indicates
5% plastic strain
Max = 189%
Elephant-foot buckling with
major loss of contentment:
severe damage
Damage = DS4

Rupture size = 11×4.5 m

Containment loss = 100%



Fragility Curves Damage State Definitions

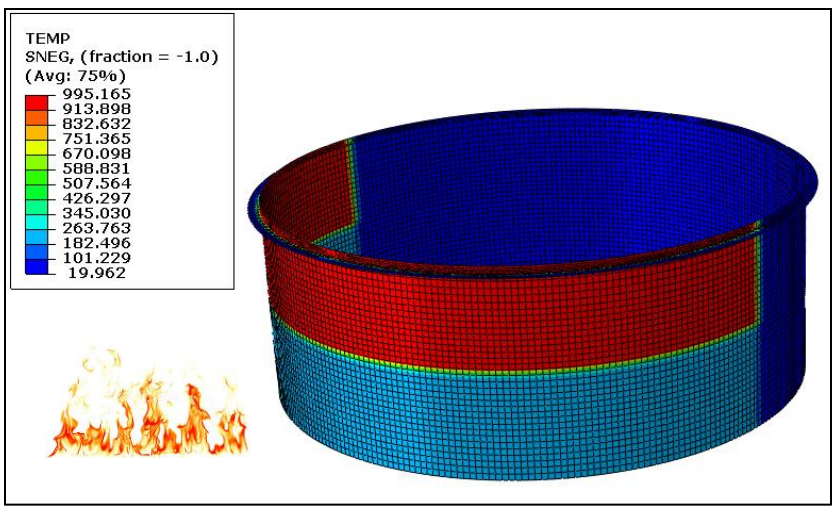
Damage State	Description
DS1	No damage to tank or I/O pipes
DS2	Damage to roof, minor loss of contents, minor damage to piping, but no elephant-foot buckling
DS3	Elephant-foot buckling with minor loss of content
DS4	Elephant-foot buckling with major loss of content, severe damage
DS5	Total failure, tank collapse

Overall Modeling Procedure

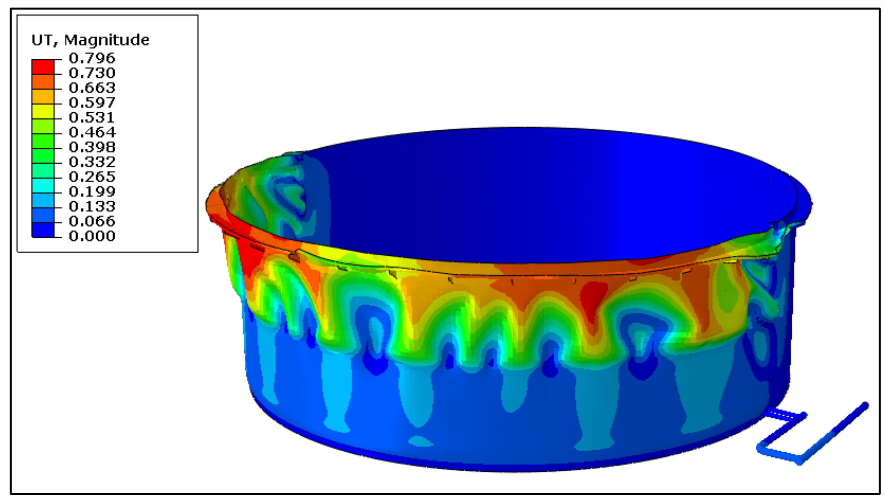
The modeling procedure includes following steps:

Step 1: Carry out a coupled heat transfer-CFD analysis to quantify the temperature evolution over the fire exposed side of the tank.

Step 2: Carry out structural analysis to predict the performance of the tank at elevated temperature.



Thermal Analysis



Structural Analysis