DEMOKRITOS

ALMA MATER STUDIORUM
UNIVERSITÀ DI BOLOGNA

Interreg
ADRION
ADRIATIC-IONIAN
European Regional Development Fund - Instrument for Pre-Accession II Fund

14th April, 2022

NATECH
Natural-Technological Risks

Prof. Ernesto Salzano
ernesto.salzano@unibo.it

Natural-Technological risks

Flooding: Katrina and Rita Hurricanes (2005)

Main issues: **Environmental pollution, Economical losses,** But: **Long Early Warning**

Natural-Technological risks

Tupra refinery (Turkey) - Koaceli earthquake (1999)

Main issues:

Overloading of emergency system
Strategic goods (oil) losses
Environmental Pollution

Natural-Technological risks

Non-Nuclear scenario in Japan (2011), Ichihara – Chiba Refinery,

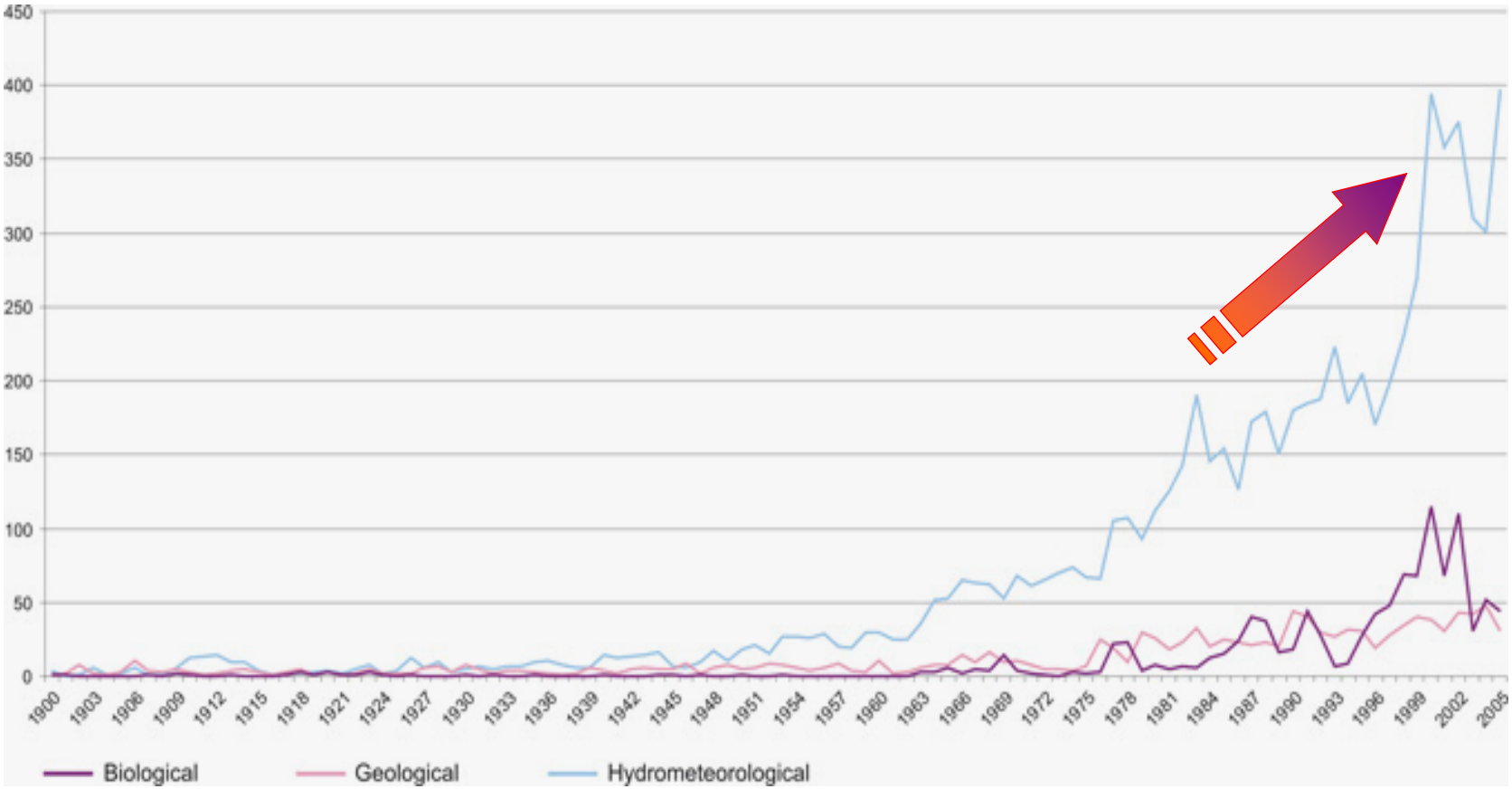
Main issues:

- Overloading of emergency system
- Post-event environmental effects
- Struggling population for the natural-tech event (eg. shelters)

DOMINO EFFECTS: Emergency response in Ichihara was still able to cope with industrial accident despite natural disaster hence avoiding further consequences in the industrial area

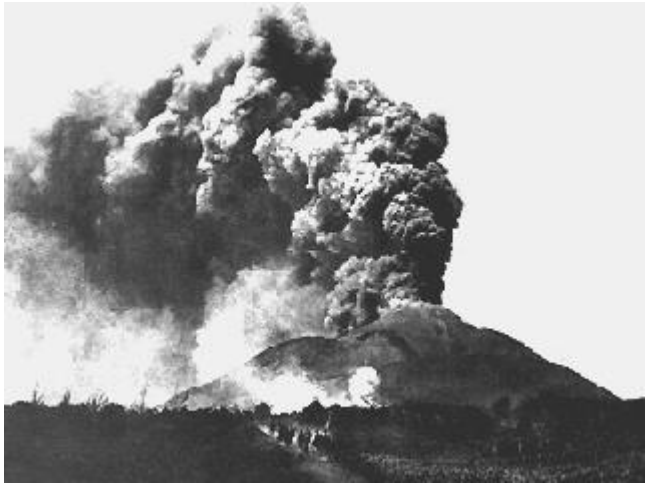
Natural-Technological risks

Disasters caused by extreme weather are constantly increasing

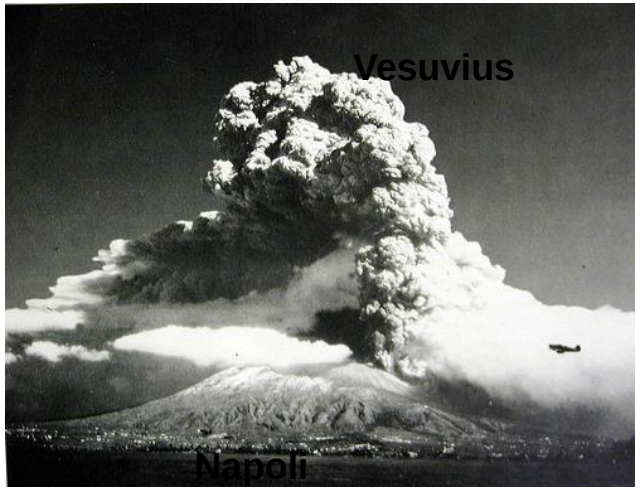


Publications and projects

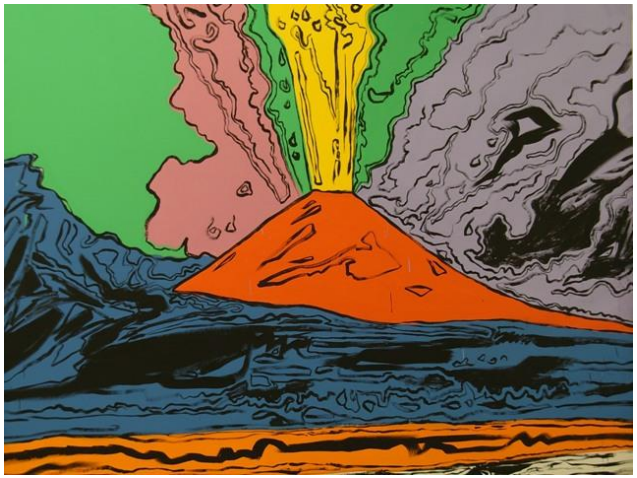
1872



1906



1944



Andy **Warhol**, Vesuvio (1985)

Publications and projects

E. Krausmann (JRC Ispra)
A.M. Cruz (University of Kyoto)
E. Salzano (University of Bologna)

NATECH RISK ASSESSMENT AND MANAGEMENT
Reducing the Risk of Natural-Hazard Impact on Hazardous Installations

Elsevier; 1st edition (2016)
Paperback: 320 pages
ISBN-10: 0128038071

Publications and projects

D1.5.2.1	related to the implementation of European safety legislation on SME´s and its application on companies working in Distributed Energy Resources (DER)	Catalogue of Emerging Risks
D1.5.3.1	Handbook of Good Practices for the Mitigation of NATECH risks	Catalogue of Emerging Risks
D1.5.4.1	Package of: Reference solutions for Emerging risks related to hazardous substances, impact on public health and relations with REACH and GHS	Catalogue of Emerging Risks
	Integrated reference solutions for D-ERRAs	

Publications and projects

STREST

Harmonized approach to stress tests for critical infrastructures against natural hazards

FP7/2007-2013

http://www.strest-eu.org/

From Greece and Slovenia

1. Kyriazis Pitilakis - Aristotle University of Thessaloniki
2. Matjaž Dolšek - University of Ljubljana

Publications and projects

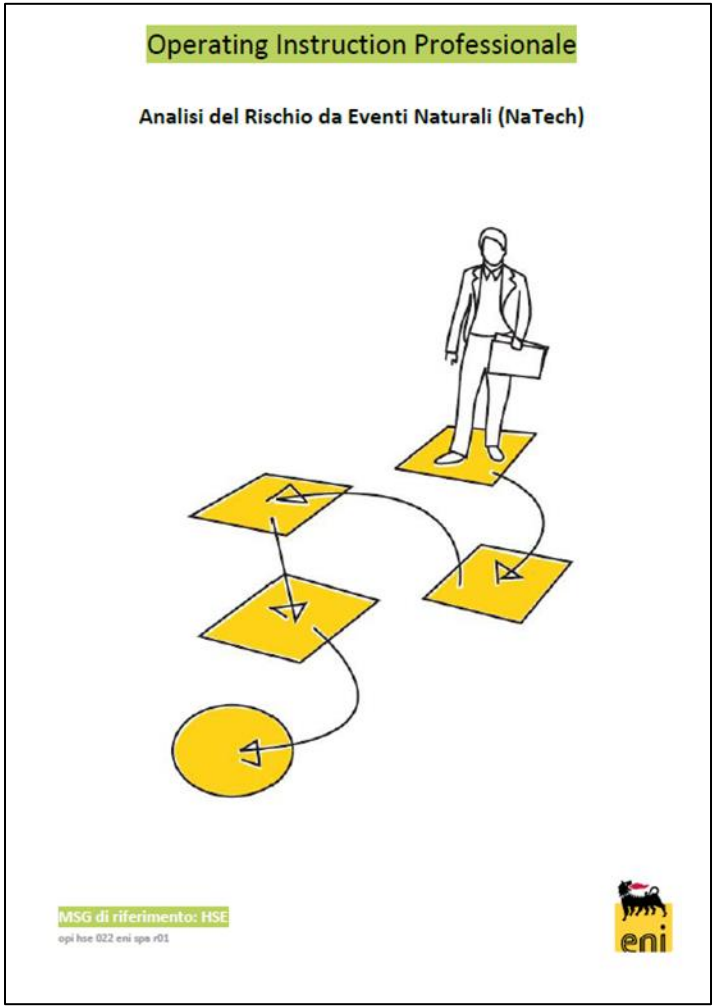
Joint venture between Q8/ENI
Capacity: 8.0 million tons/y

Milazzo Refinery, Sicily (Italia)

Publications and projects

E Salzano, I Iervolino, G Fabbrocino Seismic risk of atmospheric storage tanks in the framework of quantitative risk analysis, Journal of Loss Prevention in the Process Industries 16 (5), 403-409	176	2003
G Fabbrocino, I Iervolino, F Orlando, **E Salzano** Quantitative risk analysis of oil storage facilities in seismic areas, Journal of Hazardous Materials 123 (1), 61-69	171	2005
E Krausmann, V Cozzani, **E Salzano**, E Renni Industrial accidents triggered by natural hazards: an emerging risk issue, Natural Hazards and Earth System Sciences 11 (3), 921-929	146	2011
G Antonioni, S Bonvicini, G Spadoni, **V Cozzani** Development of a framework for the risk assessment of Na-Tech events Reliability Engineering & System Safety 94 (9), 1442-1450	150	2009
V Cozzani, G Antonioni, G Landucci, A Tugnoli, S Bonvicini, G Spadoni Quantitative assessment of domino and NaTech scenarios in complex industrial areasl Journal of Loss Prevention in the Process Industries 28, 10-22	148	2014

Natech Application (Seveso) in Italy



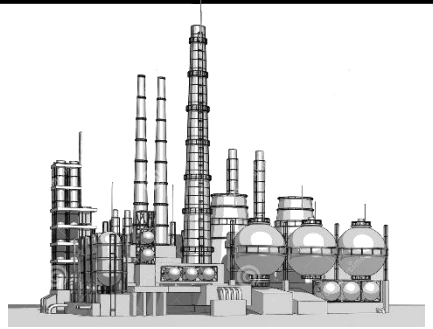
eni versalis

Ferrara and Ravenna

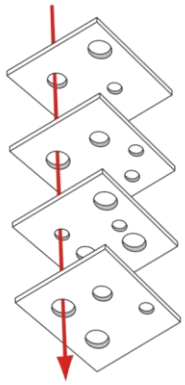
Natural-Technological risks

Natural disaster (earthquake, flooding, tsunami,..)

Technological failure



Protection barriers
Mitigation system
Emergency response



Technological barrier

Human/Management

Governance/Communication

Community level/policies

Consequences for workers, population, assets, environment

Natural-Technological risks

Natural disaster (earthquake, flooding, tsunami,..)

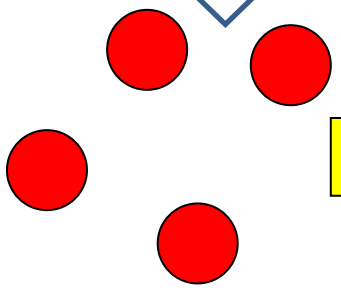
Early Warning
Emergency Shut-off

Total or partial unavailability of:

- Utilities: electric power, cooling water
- Safety barriers: firefighting water, ..
- Overloading of emergency services

Technological failure

~~**Protection barriers**~~
~~**Mitigation system**~~
~~**Emergency response**~~



Multiple event and domino effects

Consequences for workers, population, assets, environment

Natural-Technological risks

Several categories of natural events may cause Na-Tech accidents:

- Earthquakes
- Floods
- Lightning
- Wind (hurricanes, tornados)
- Waves (hurricanes, tsunami)
- Landslides
- Volcanic phenomena

Complexity

- *Different modality of damage to process equipment*
- *Different types of post-release scenarios*
- *Different effectiveness of safety barriers*

Natural-Technological risks

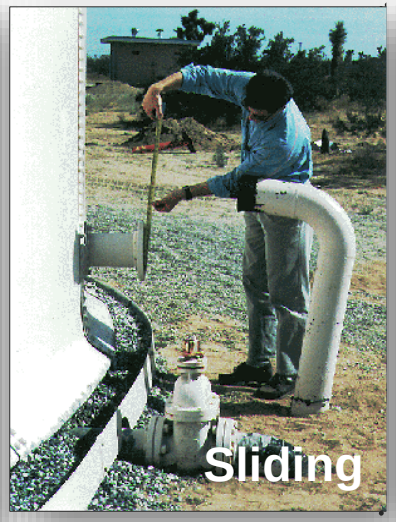
Damage State (DS): Performance levels based on structural damage

DS1 - absence of structual damage
DS2 - slight damages to structures
DS3 - moderate structual damages
DS4 - Extensive damage to structures
DS5 - total collapse of structure

Main scope:

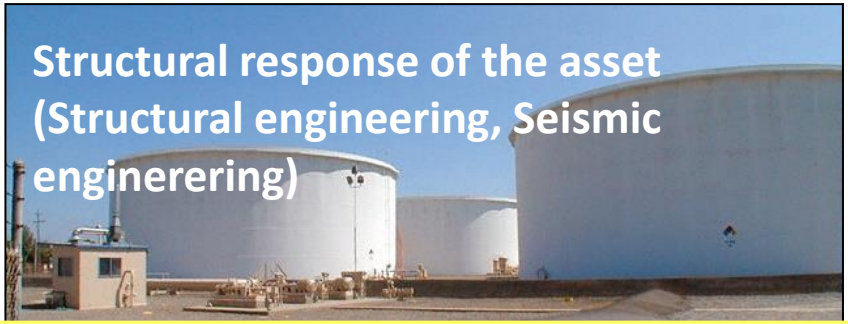
- Return-to-Service
- Evaluation of post-event economical losses
- Reconstruction
- Repair
- Upgrading

Natural-Technological risks

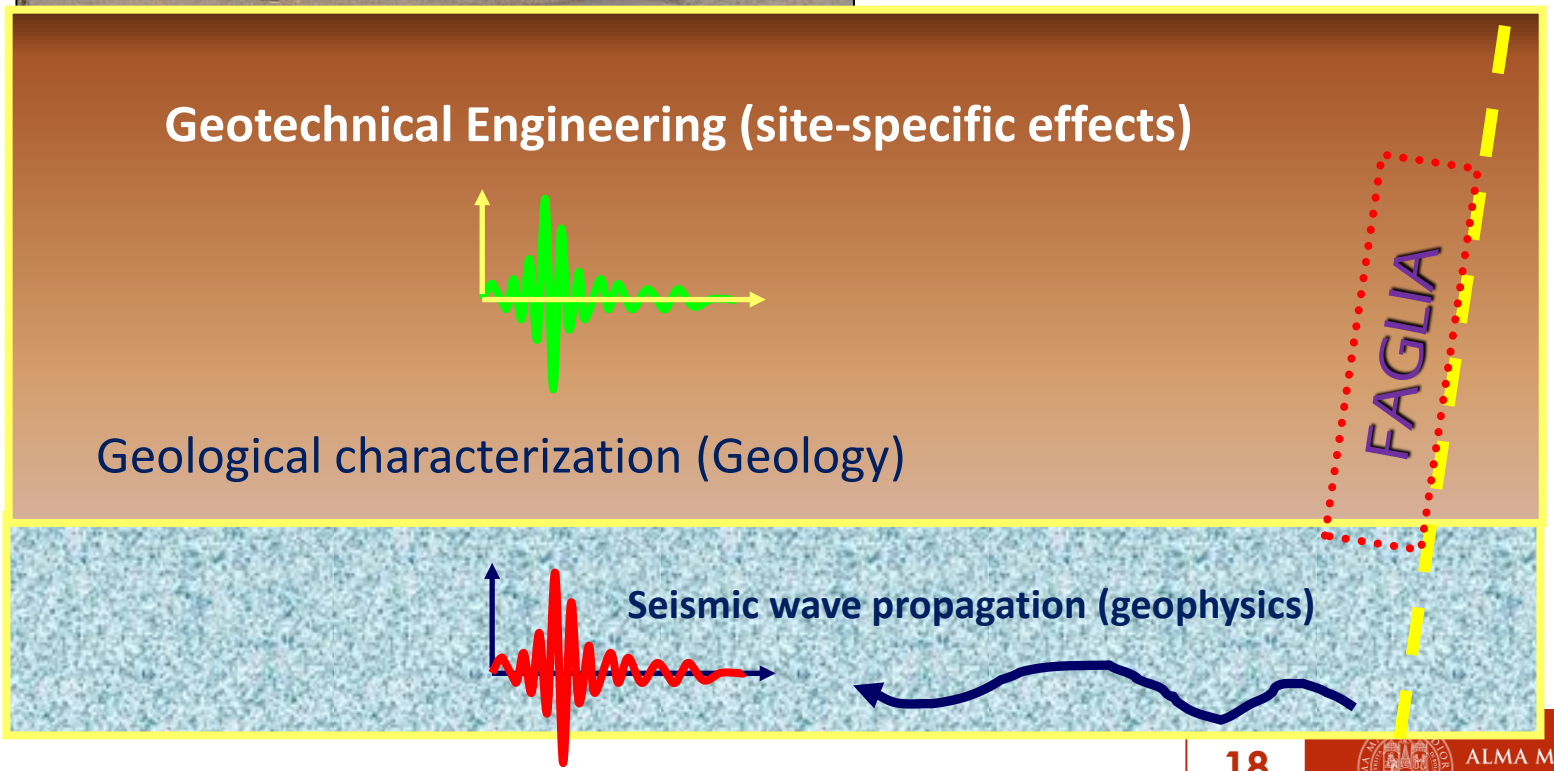


Natural-Technological risks

Dealing with complexity!



Effects (Consequence analysis, Risk recombination): industrial engineering



Natural-Technological risks

For any equipment containing hazardous material, in the time **T,** for each **Damage State DS_i** (performance level) the **probability of structural damage (P_{DS_i})** is given by the combination of the **structural vulnerability function P_f (or fragility)** and the **Natural Hazard h(IM)**, where **IM is the intensity measure**

$$P_{DS_i} = P_f(DS_i|IM) \cap h(IM,T)$$

Fragility ***Hazard***

Natural-Technological risks

The leakage (or Loss) of containment of hazardous materials is the key issue for the industrial and NaTech risk assessment

Cascading effects

Component Level

Industrial Accidental Scenarios

Release (Loss of Content)

Structural damage of equipment containing large amount of hazardous materials

Natural event

Earthquake
Tsunami
Wind
Ligthning

Structural Vulnerability

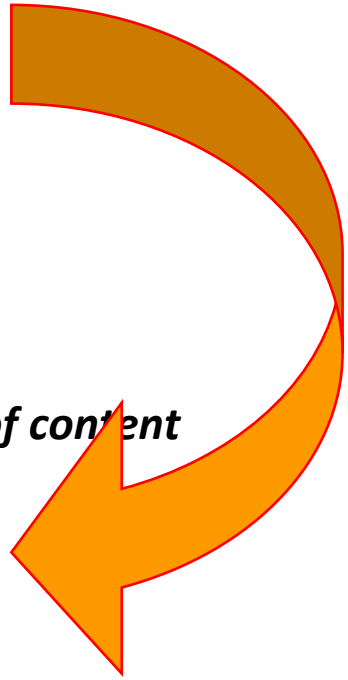
System Level

Natural-Technological risks

***Damage State (DS) : P*erformance levels based on structural damage**

DS1 - absence of structual damage
DS2 - slight damages to structures
DS3 - moderate structual damages
DS4 - extensive damage to structures
DS5 - total collapse of structure

Limit State
HAZUS



Main scope: **reconstruction, upgrading**

Risk State or Release State (RS): Performance levels based on release of content (consequences)

RS3 (Minor risk): release from a 10 mm equivalent diameter
RS2 (Severe risk): complete release of inventory in 10 min
RS1 (Instant risk): instantaneous release of entire inventory

Main scope: **reconstruction, upgrading, large-scale accidents, design priorities**

Natural-Technological risks

Given a specific equipment, for each Risk State, the annual cumulative probability of Loss of Content (P_{RS}), is given by the combination of the vulnerability function and the Natural Hazard function $h(IM)$:

$$P_{RS} = \int_{IM=0}^{IM=\infty} P[RS \geq RS_i | IM] \cdot h(IM)\, dIM$$

Natural-Technological risks

Performance and consequence-based levels

Damage states **DS is related to structural damage**

States	Hazard	Patterns (structural damage)
DS0	Slight	Investigated sections with negligible damage; pipe buckling
DS1	Significant	Longitudinal and circumferential cracks; compression joint break.
DS2	Severe	Tension cracks for continuous pipelines; joint loosening in the segmented pipelines.

Risk states ⇩ **RS is related to release of harmful content (e.g. natural gas)**

States	Hazard	Patterns (loss of containment)	
		Gas/Vapour/Liquefied Gas	Liquid
RS0	Null	No losses	Limited loss
RS1	Low	Very limited losses: -Toxic (Φ < 1 mm/m) -Flammable (Φ < 10 mm/m)	Limited, time-distributed loss of hazardous substance: multiple losses (Φ < 10 mm/m)
RS2	High	Non- negligible losses	Large loss (e.g. entire tube surface) or multiple losses (Φ > 10 mm/m)

Natech: natural hazard

The characterisation of the natural event, in terms of its intensity, is a key point for the Natech analysis.

An earthquake can be analysed in terms of the **time history**, for the:

- Ground acceleration
- Ground velocity
- Ground displacement

A flooding can be analysed in terms the **time history**, for the:

- Height of water
- Velocity of the water wave

Evaluating the structural fragility based on the complete knowledge of the natural event is a complex task, which is not sustainable for industrial aims (but also for other engineering fields) if local effects are of concern.

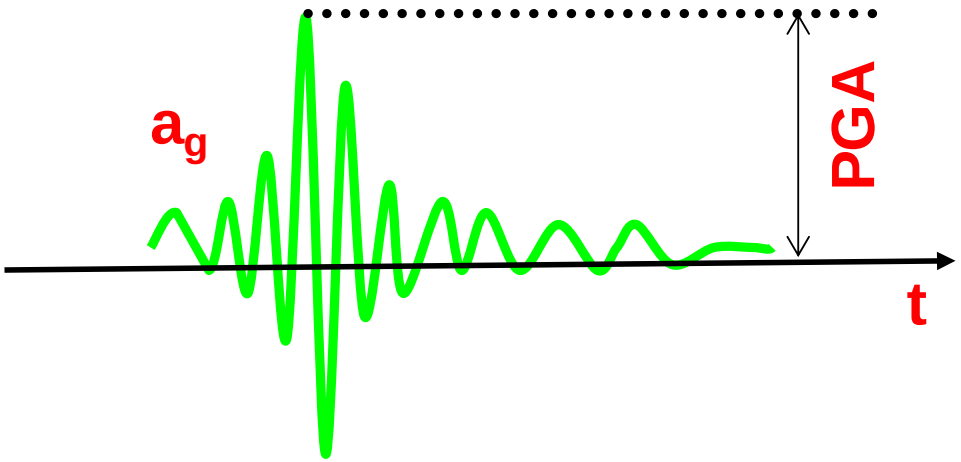
Natech: natural hazard

For earthquakes, different intensity measure can be considered:

- Ground Acceleration (PGA)
- Ground Velocity (PGV)
- Ground Displacement (PGD)

The most common option for the purposes of Natech risk assessment (but also for the analysis of civil structures) consists in taking into account the ground acceleration and in particular the peak value of the recorded or calculated ground acceleration at any location, i.e: Peak Ground Acceleration (PGA)

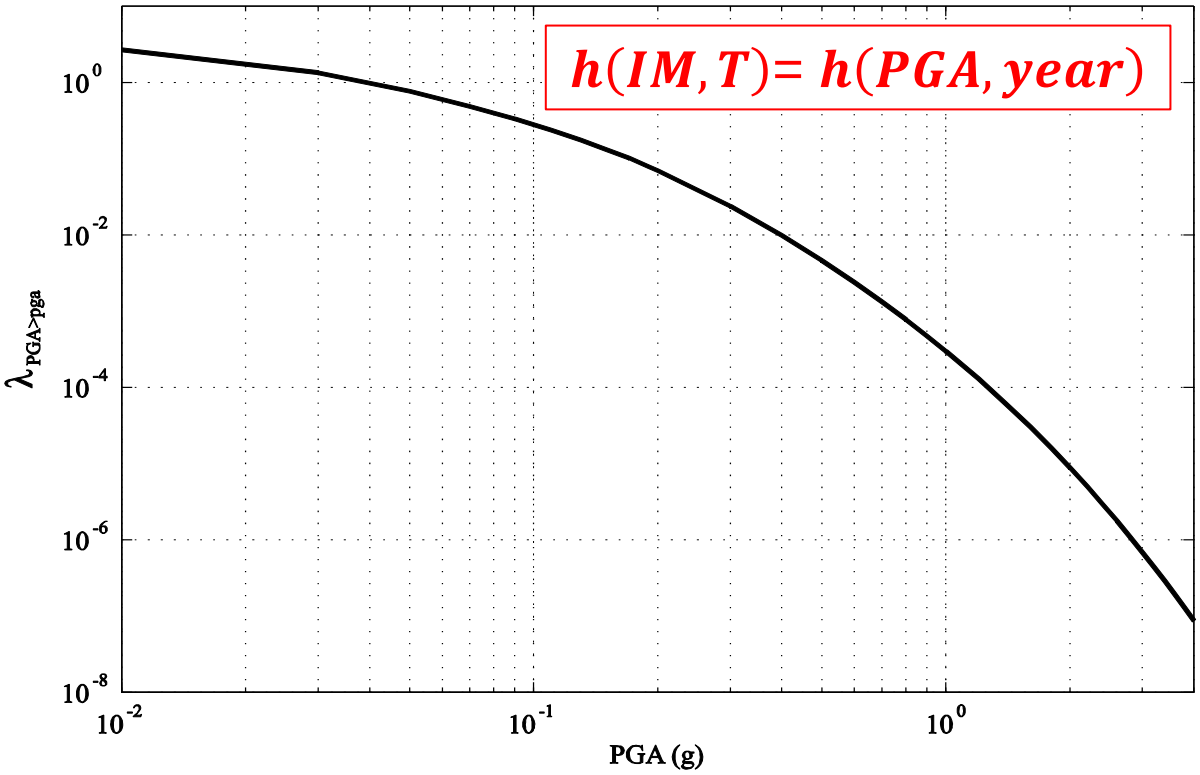
Natech: natural hazard



The Peak Ground Acceleration (PGA) is a simple measure of the earthquake intensity (also for hystorical database) and is nowadays the most widespread seismic intensity measurement parameter in the technological field. PGA can be considered as the reference for the evaluation of the seismic hazard.

Natech: natural hazard

Probabilistic Seismic Hazard Analysis



Natech: vulnerability

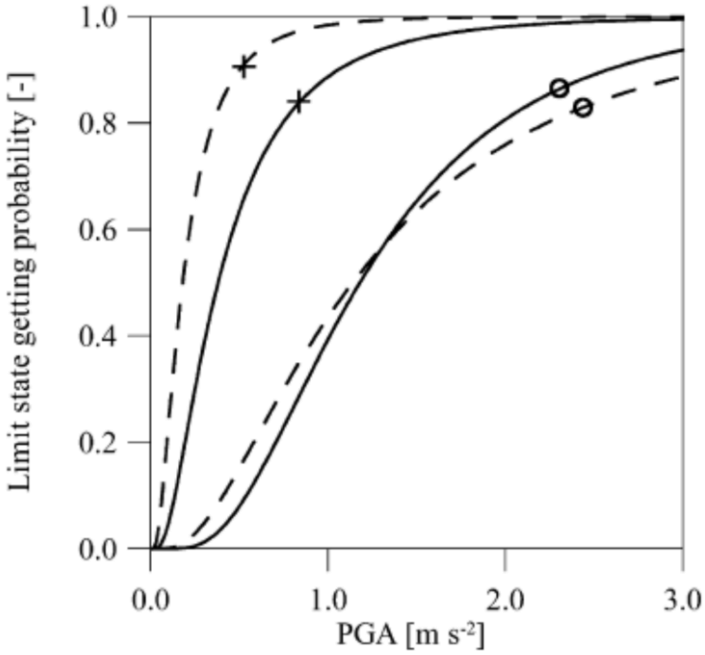
***Damage State (DS)* - Performance levels based on structural damage**

The typical correlation for the structural fragility is based on the cumulative distribution function for the intensity measure IM:

$$P_f(DS_i|IM) = \frac{1}{IM \cdot \sqrt{4\pi} \cdot \beta^2} e^{-\frac{(\ln(IM)-\mu)^2}{2\beta^2}}$$

The final vulnerability function for the structural damage due to the earthquake is then:

$$P_{DS_i} = \int_{PGA=0}^{PGA=\infty} \left[P_f(DS_i|PGA) \cdot h(PGA)\right] d(PGA)$$



HAZUS MH
EARTHQUAKE • WIND • FLOOD

Natech: atmospheric tanks

N	RS	DS	Tank	FL	Fragility	Fragility	probit	probit	probit
					μ	β	k_1	k_2	PGA_k
1	≥ 2	≥2	Anchored	Near Full	0,300	0,600	7,000	1,670	0,077
2	3	≥4	Anchored	Near Full	1,250	0,650	4,650	1,540	0,286
3	≥ 2	≥2	Anchored	≥ 50%	0,710	0,800	5,430	1,250	0,114
4	3	≥4	Anchored	≥ 50%	3,720	0,800	3,330	1,250	0,614
5	≥ 2	≥2	Unanchored	Near Full	0,150	0,700	7,830	1,430	0,028
6	3	≥4	Unanchored	Near Full	0,680	0,750	5,530	1,340	0,123
7	≥ 2	≥2	Unanchored	≥ 50%	0,150	0,120	20,820	8,350	0,114
8	3	≥4	Unanchored	≥ 50%	1,060	0,800	4,930	1,250	0,171

Natech: pipeline vulnerability

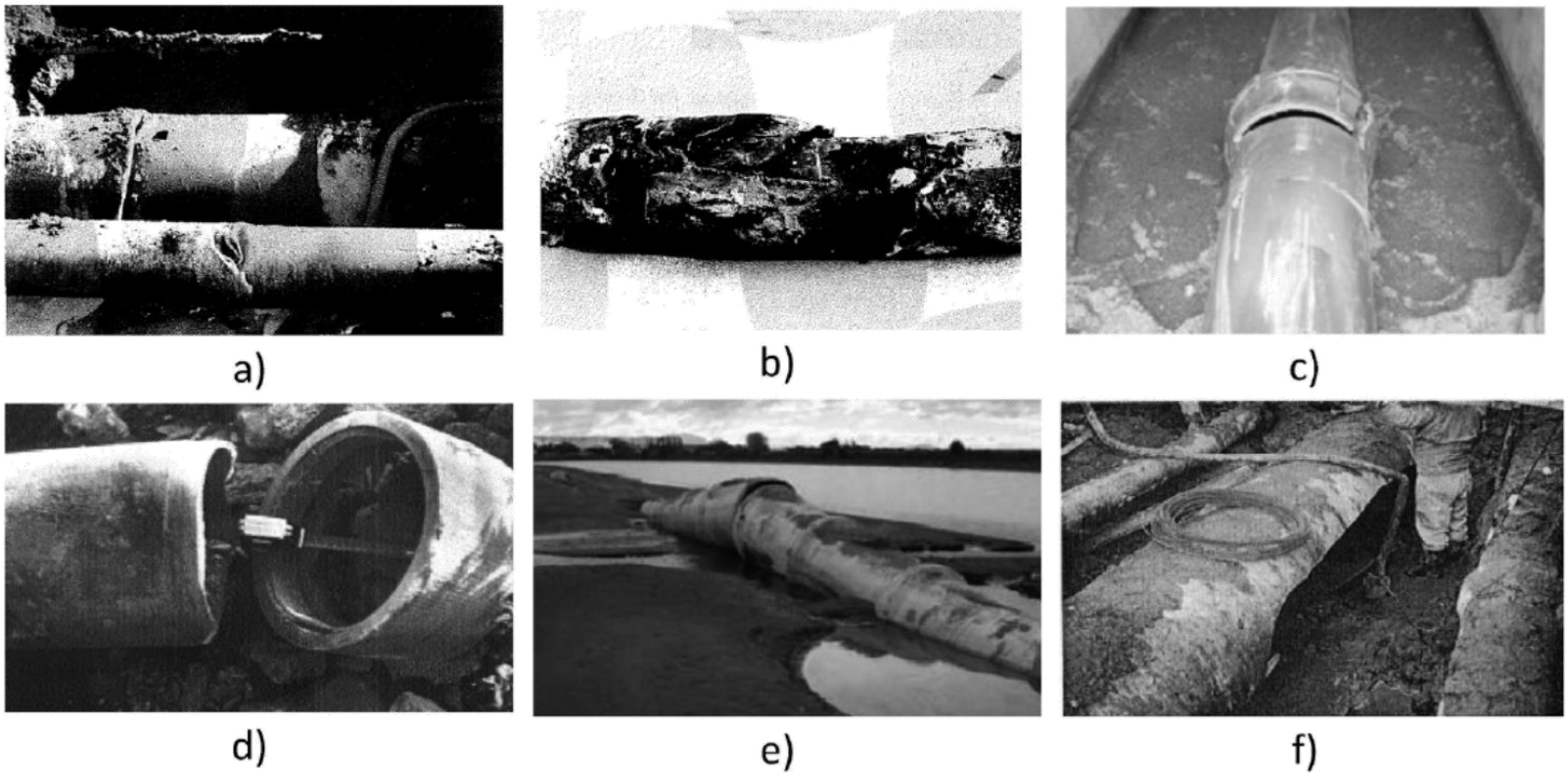
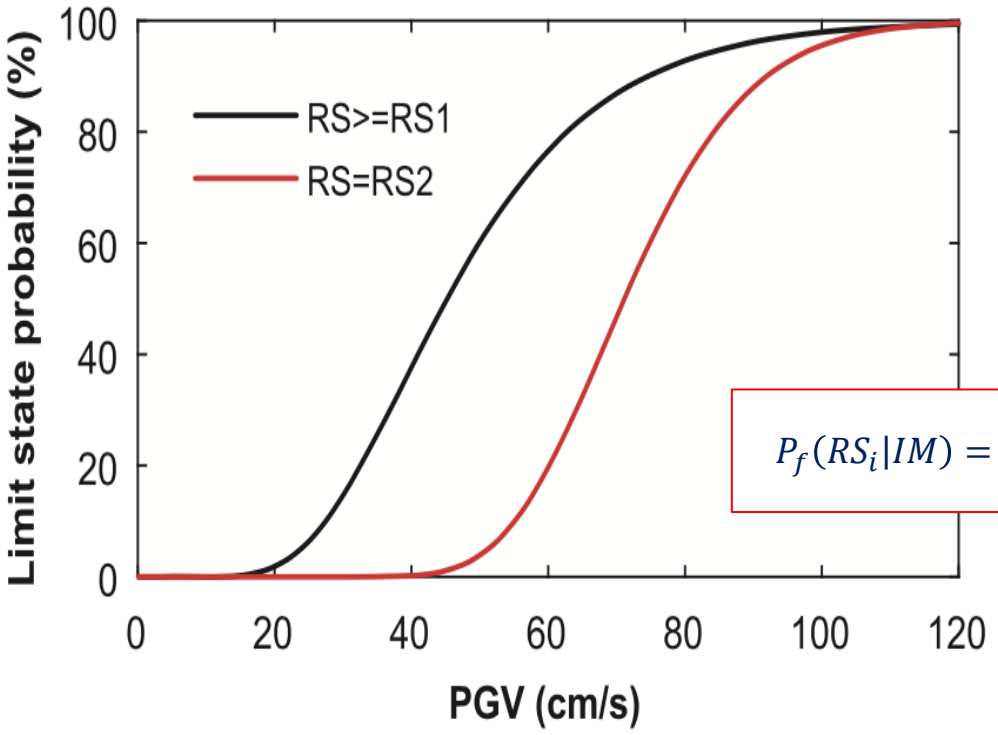


Fig. 1 - Damage patterns for pipelines: a) tension/compression cracks; b) local buckling; c) beam buckling; d) axial pull-out; e) crushing of bell end and spigot joints; f) cracks along the pipe body [Lau *et al.*, 1995 (a,b); Tanaka *et al.*, 2011 (c); Ayala and O'Rourke, 1989 (d); Allen *et al.*, 2010 (e); Kameda, 2000 (f)].

Natech: pipeline vulnerability

BURIED PIPELINE



$$P_f(RS_i|IM) = \frac{1}{2}\left[1 + erf\left(\frac{\ln IM - \ln \mu}{\beta\sqrt{2}}\right)\right]$$

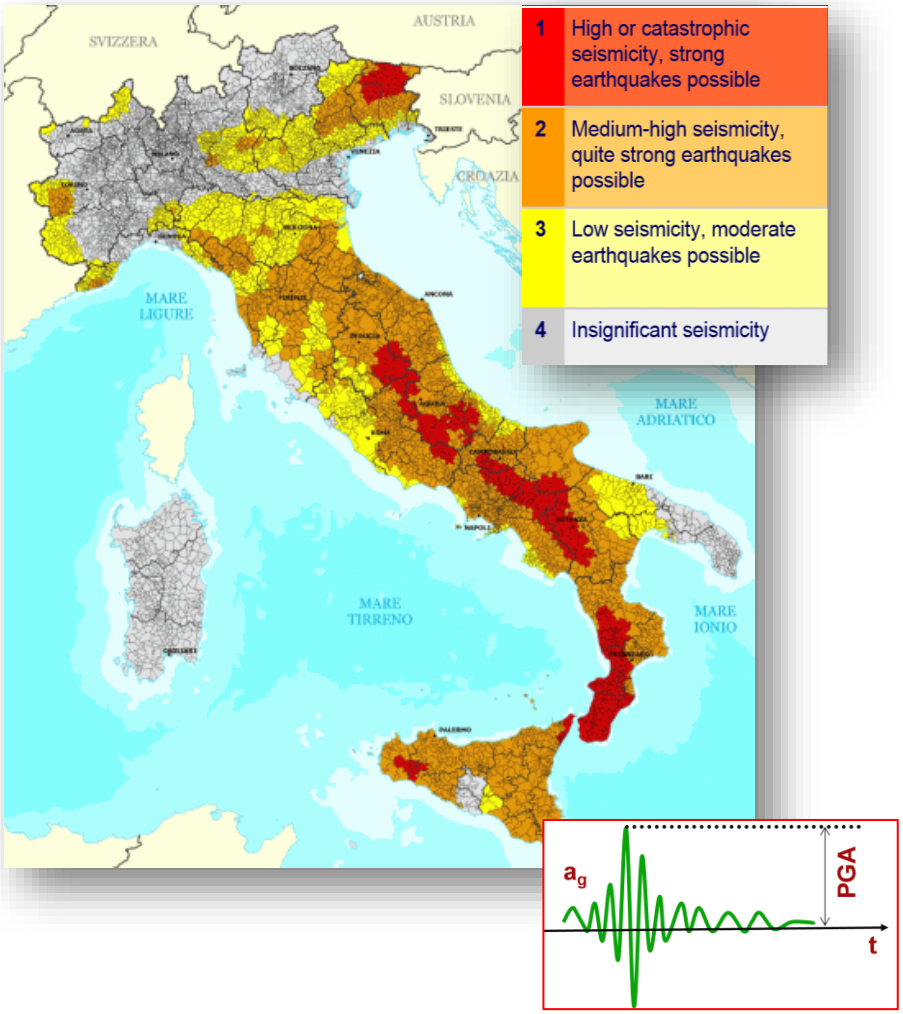
NOTE IM = PGV FOR BURIED PIPELINE!

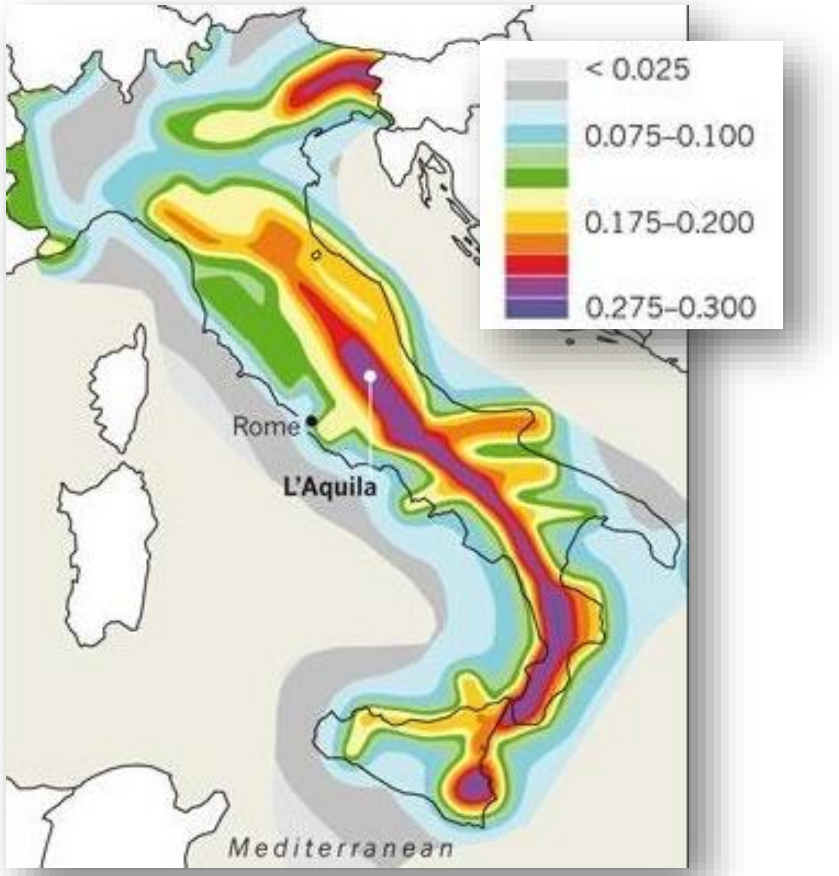
Natech QRA Study in Italy

Joint venture between Q8/ENI
Capacity: 8.0 million tons/y

Milazzo Refinery, Sicily (Italia)

Natech QRA Study in Italy





Peak Ground Acceleration (PGA)
10% Exceeding Probability in 50 y

Nature, 477 (2011) 264-269

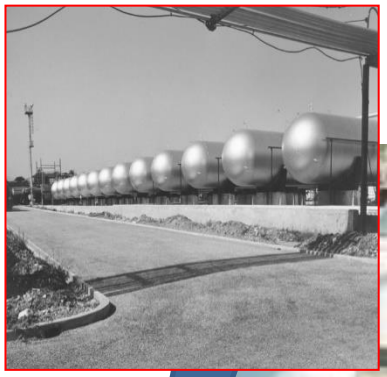
Natech QRA Study in Italy

Natech QRA Study in Italy

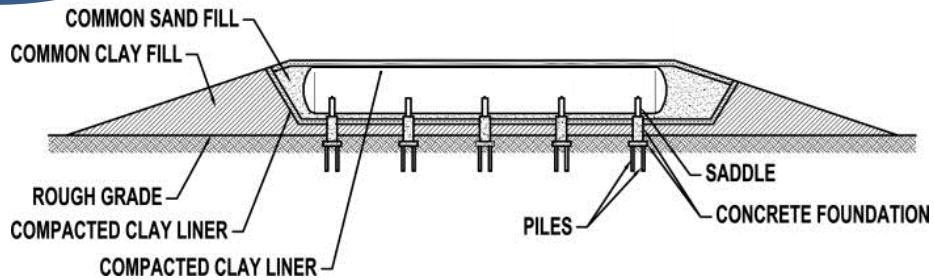
Natech QRA Study in Italy

TK 513 – Virgin Naphta
Large Fire on 27 - 30/9/2014

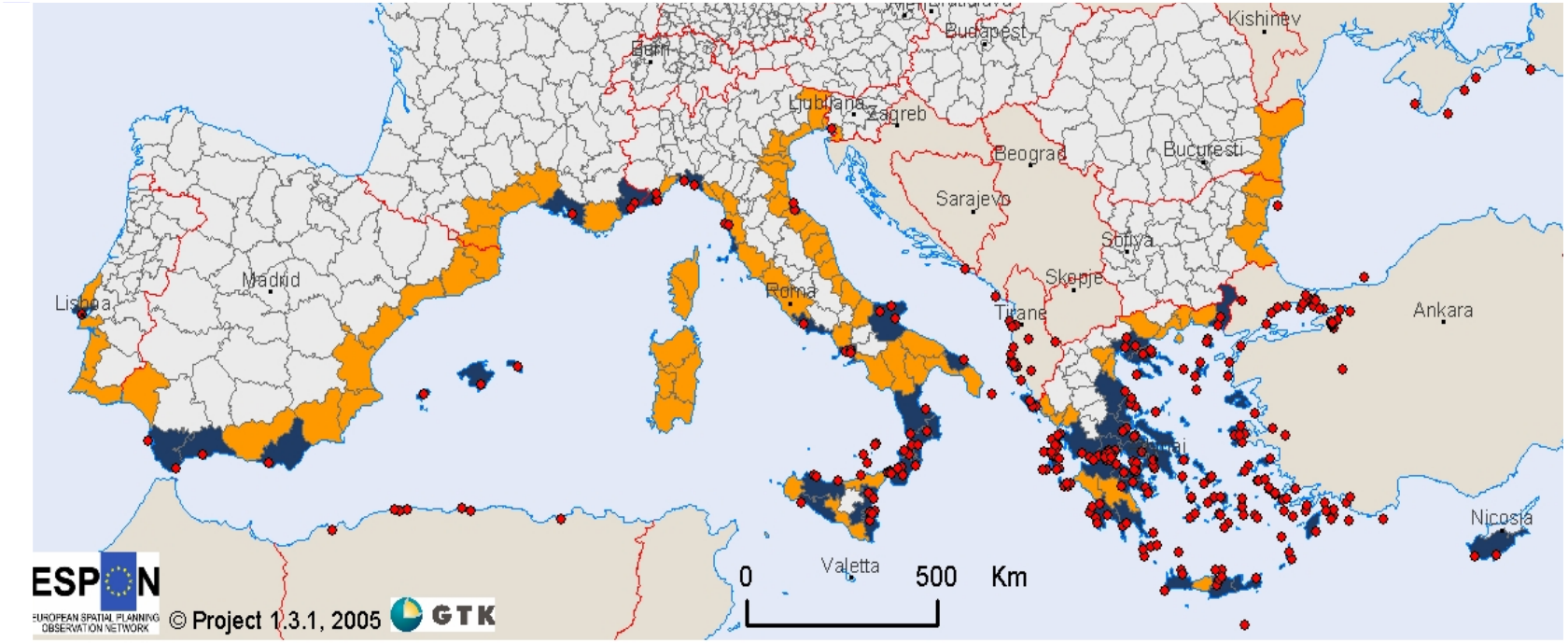
Natech QRA Study in Italy



Milazzo refinery: Buried Storage Units



Natech QRA Study in Italy



Historically recorded tsunami runups

Tsunami potential in coastal areas close to tectonically active zones

Regions that lie in vicinity to tectonically active zones and have experienced earthquake/volcano/landslide accociated tsunami

Natech QRA Study in Italy

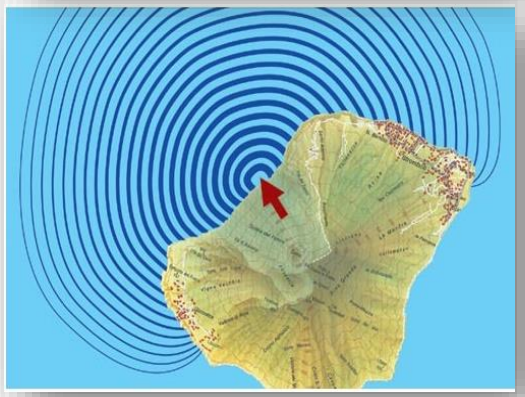
The **1908 Messina earthquake and tsunami took about 123,000 lives**, in Sicily and Calabria, southern Italy.

…**The gazometer was destroyed, with a dramatic fire fed by furious wind**...

[CdS 29/12/1908]

NaTech

Natech QRA Study in Italy



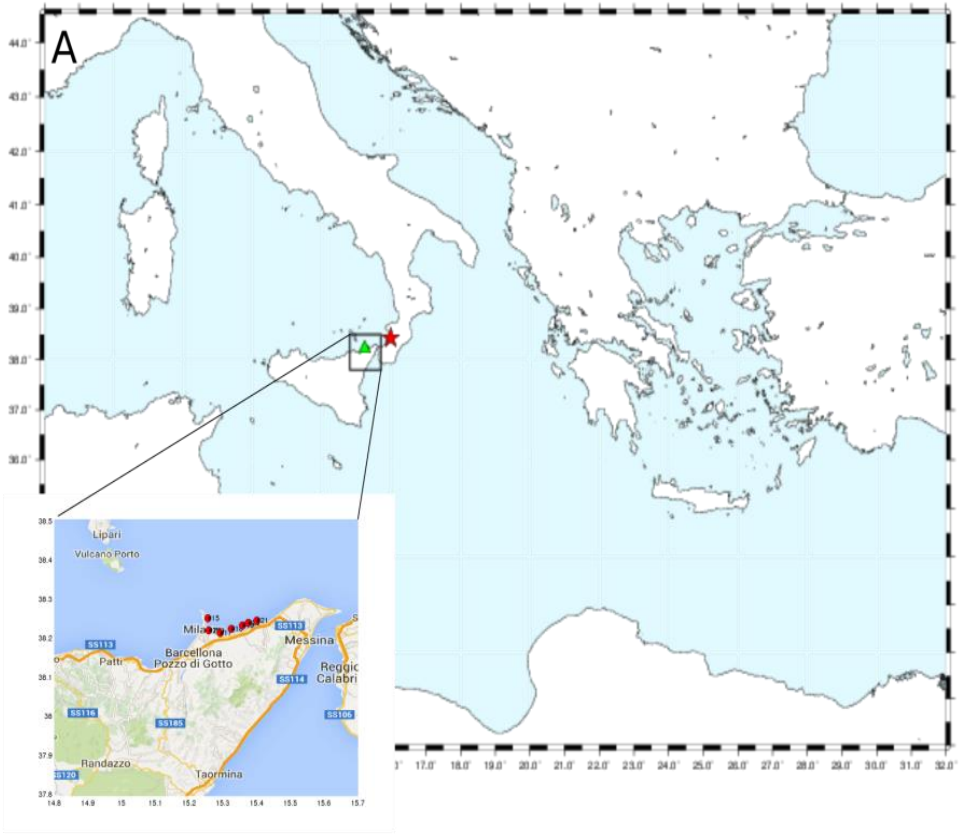
Tsunami in Sicily (Stromboli) in 2002, 30th Dec

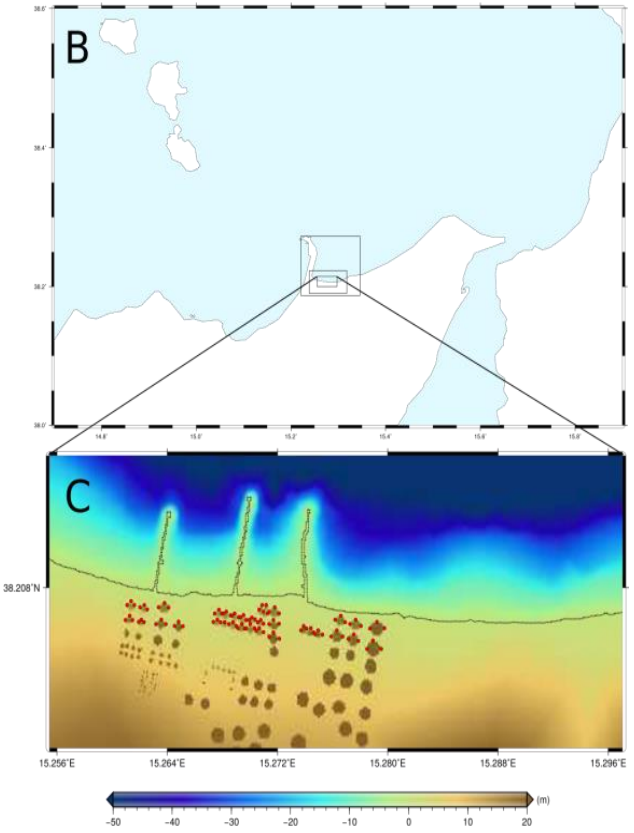
At 13:55, two petrol ships berthed in Milazzo moved laterally (slipped) for 10m, broke their moorings (4 wires) even disconnecting the loading arm, and eventually releasing diesel oil into the sea

Natech QRA Study in Italy

Probabilistic Tsunami Hazard Analysis (PSHA)

Numerical analysis of tsunami hazard in the area of Milazzo

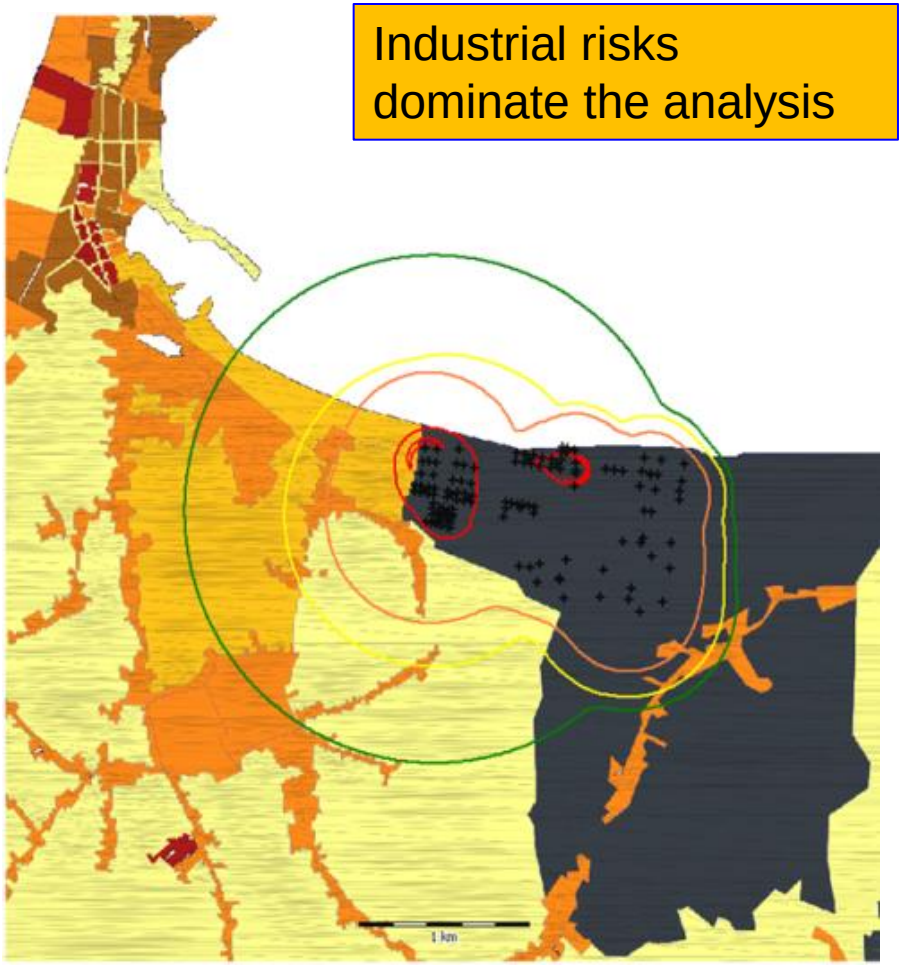




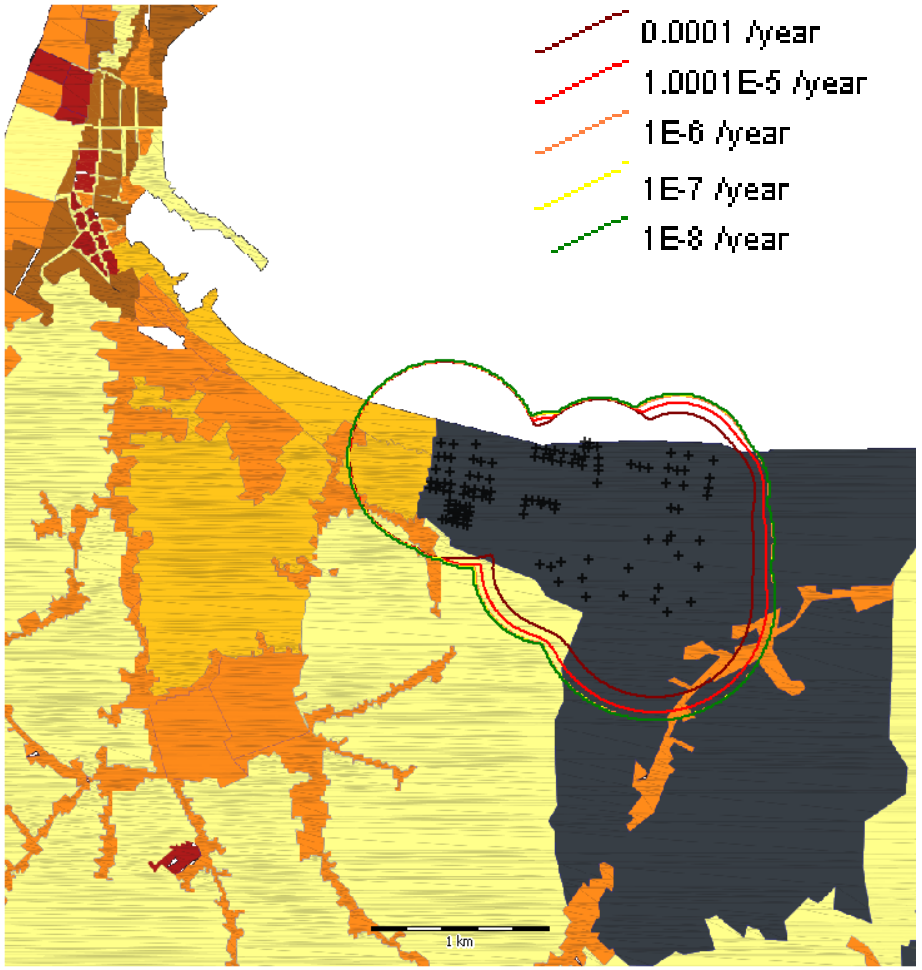
Italian National Institute of Geophysics and Volcanology

Natech QRA Study in Italy

Industrial risks dominate the analysis



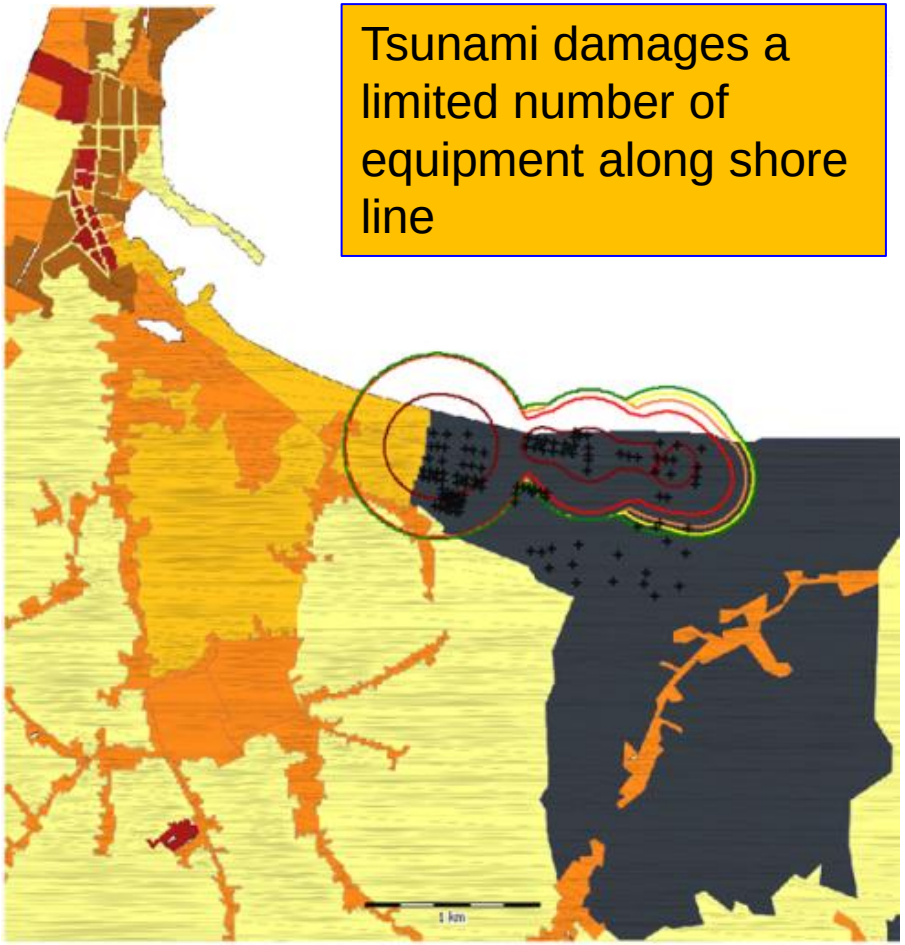
Industrial Risk



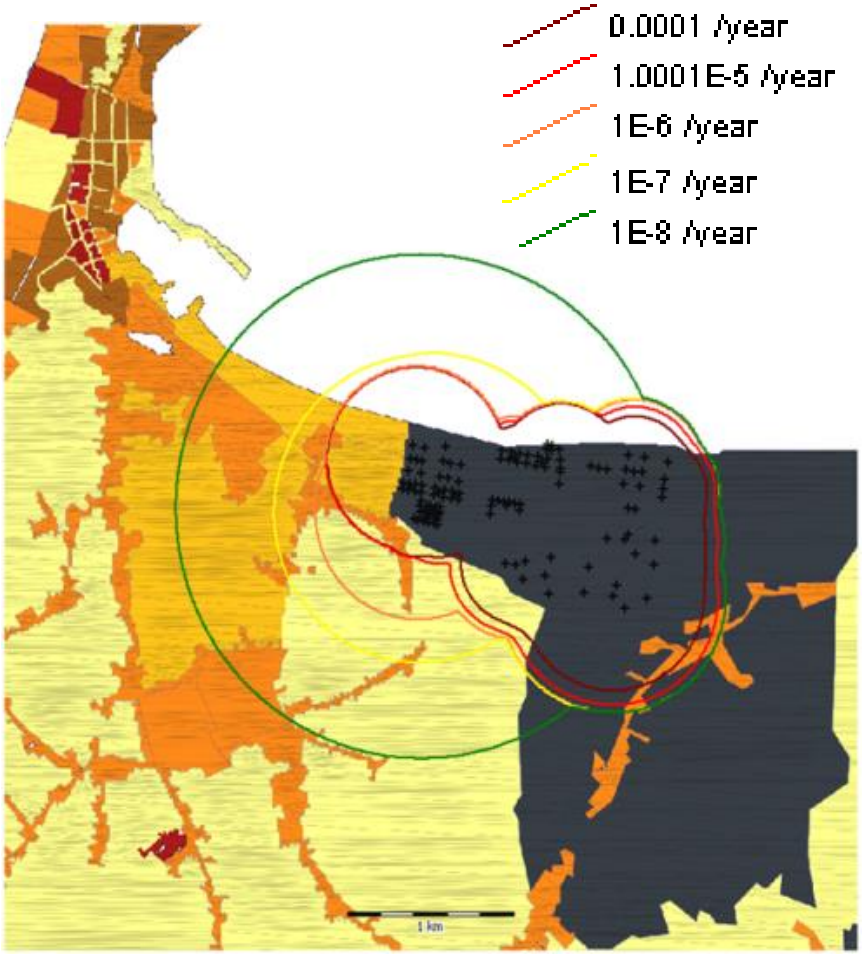
Seismic Risk

Natech QRA Study in Italy

Tsunami damages a limited number of equipment along shore line

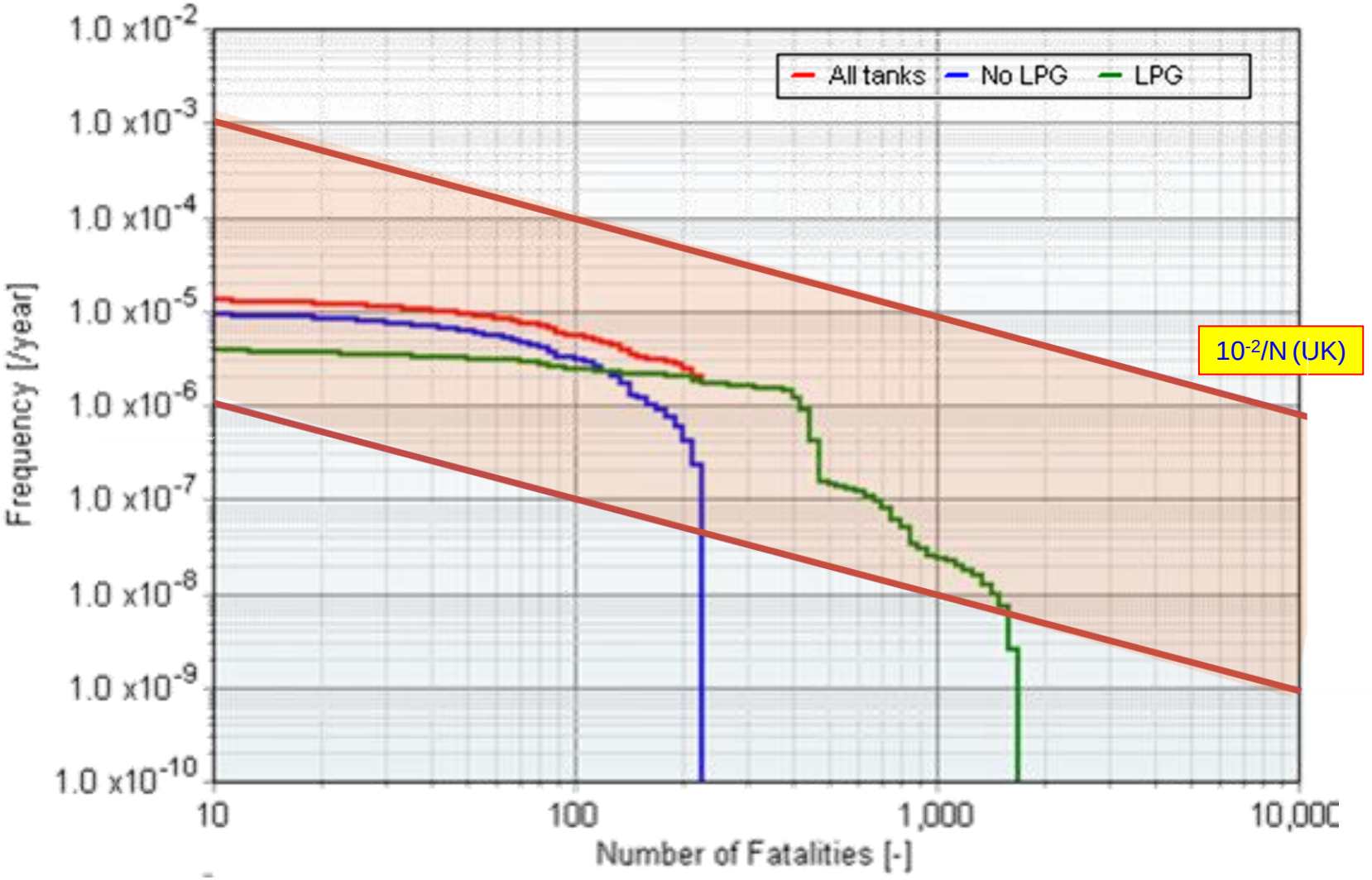


Tsunami Risk



Natech Risk

Natech QRA Study in Italy



Conclusions

- Detailed QRA analysis needs multi-disciplinary expertise
- Priority and pro-active methodologies and procedures should be adopted for the analysis of the loss of content of hazardous materials from process
- Acceptability criteria are the nub of the problem for industrial and NaTech risks

NATECH

Natural-Technological Risks

ALMA MATER STUDIORUM
UNIVERSITÀ DI BOLOGNA

Prof. Ernesto Salzano

Università di Bologna
Dipartimento di Ingegneria Civile, Chimica, Ambientale e dei Materiali
Via U. Terracini 28, 40131 Bologna
Email: ernesto.salzano@unibo.it
Tel: +39 0512090255; Cell: +39 3336295339
Website: https://www.unibo.it/sitoweb/ernesto.salzano