D'APPOLONIA

RINA GROUP

Industrial case study Nabucco pipeline Risk analysis

InnHF Zeroing course
Torino 22-25/January/2013

D'Appolonia S.p.A.
SOCIETA` CERTIFICATA ISO 9001 E ISO 14001
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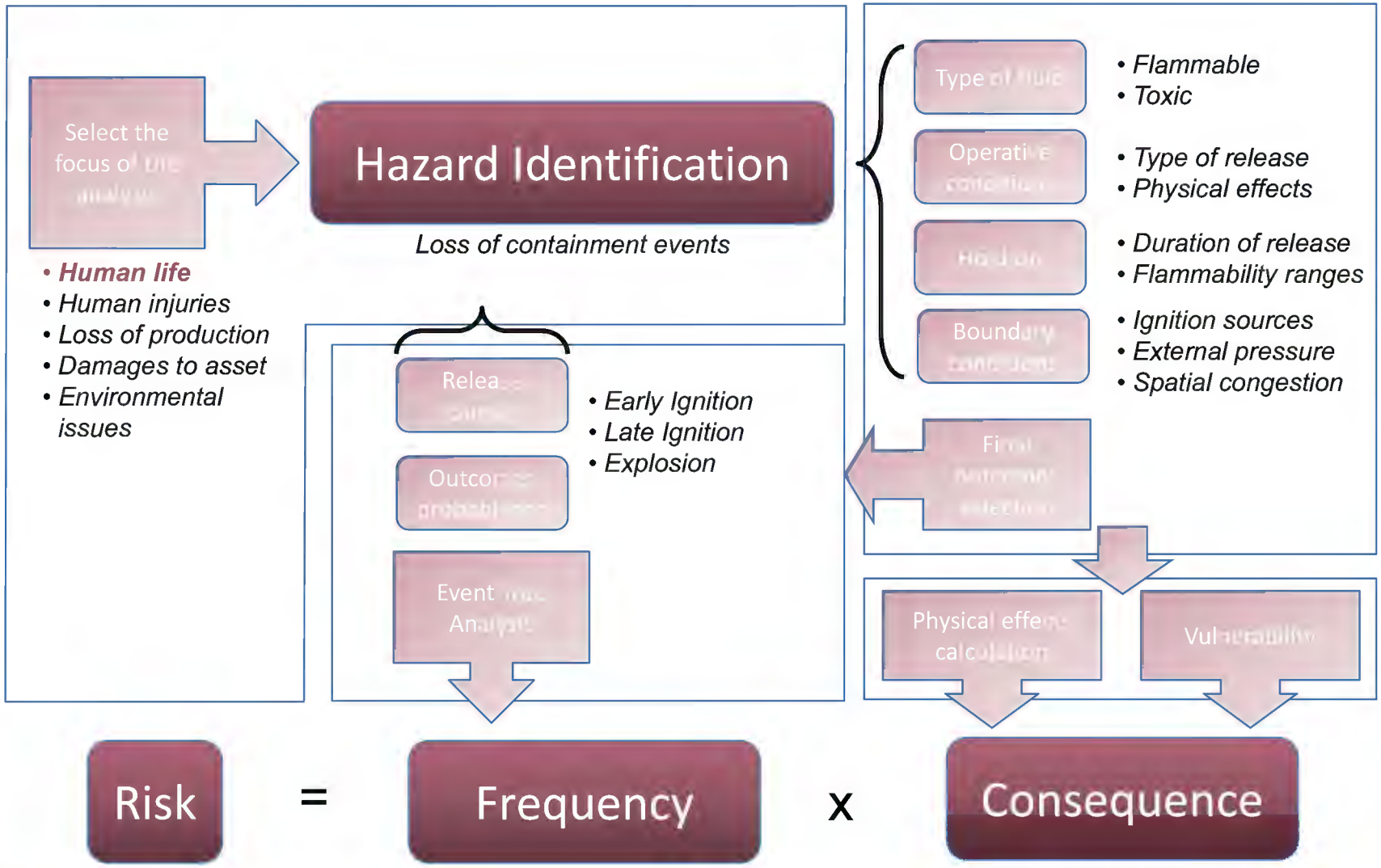
Nabucco Gas Pipeline overview

VIENNA
Baumgarten
BUDAPEST
Main pipeline
BUCHAREST
SOFIA
Istanbul
Georgian feeder
Erzurum
ANKARA
Marmara crossing
Iraqi feeder

- 4,000 km total length
- Different piping classes for feeders, Marmara crossing and main pipeline
- Large range of terrain types
- Pressure profile
- Population density

Risk assessment

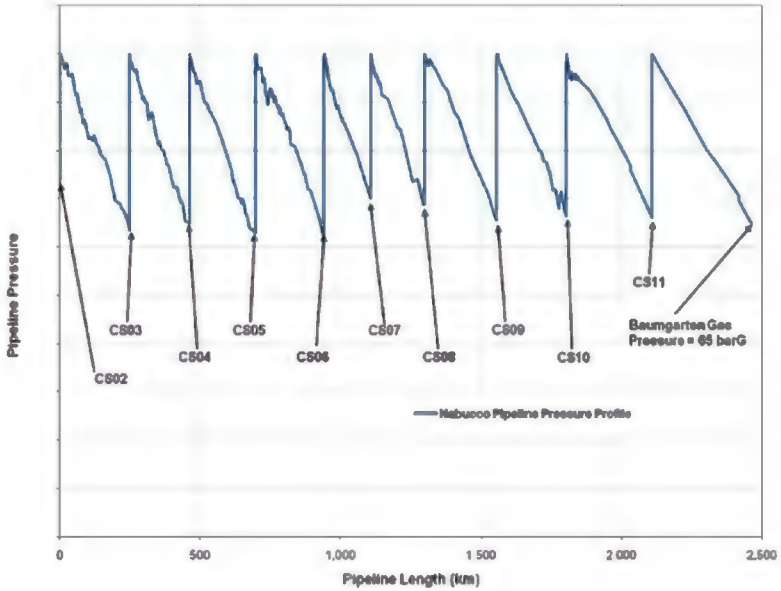


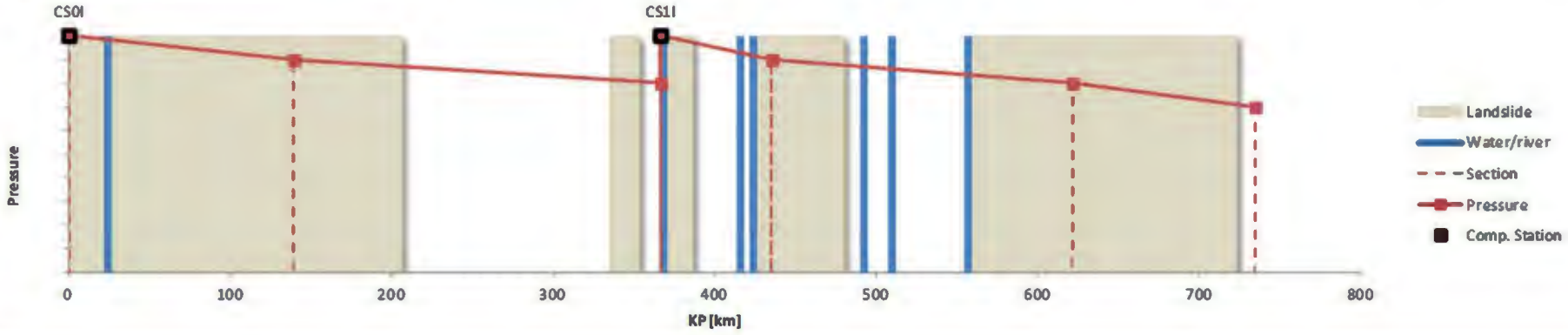
Hazard Identification

Onshore pipeline

- Corrosion and material defects
- Construction defects
- Ground movement
- Other and unknown

- Operative conditions (mainly pressure) vary along the pipeline
- Different gas composition in the feeders
- Land use and terrain conformation
- 3 hole sizes (pinhole, hole, rupture)
- 47 section identified
- Identification of potential causes is performed based on published literature (EGIG)



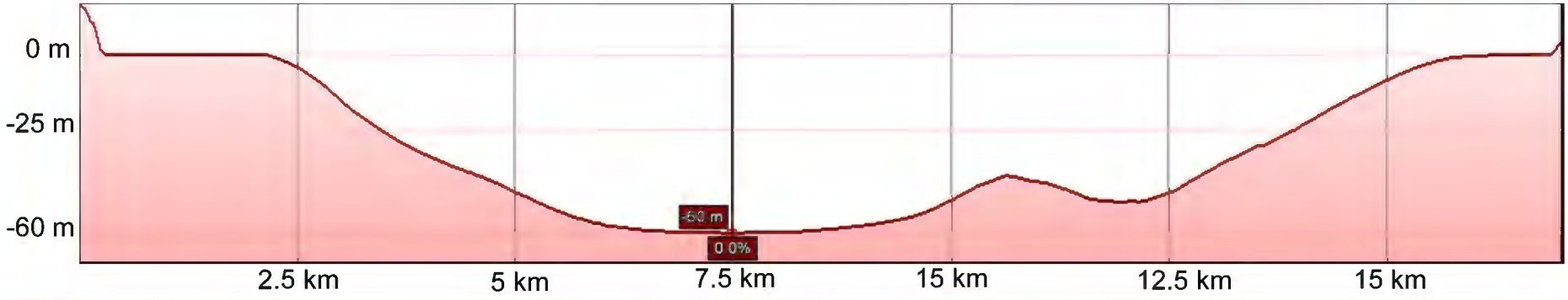


Hazard Identification

Offshore pipeline

- Corrosion and material defects
- Sinking ship
- Dropped objects
- Dropped or dragged anchors
- Fishing activities

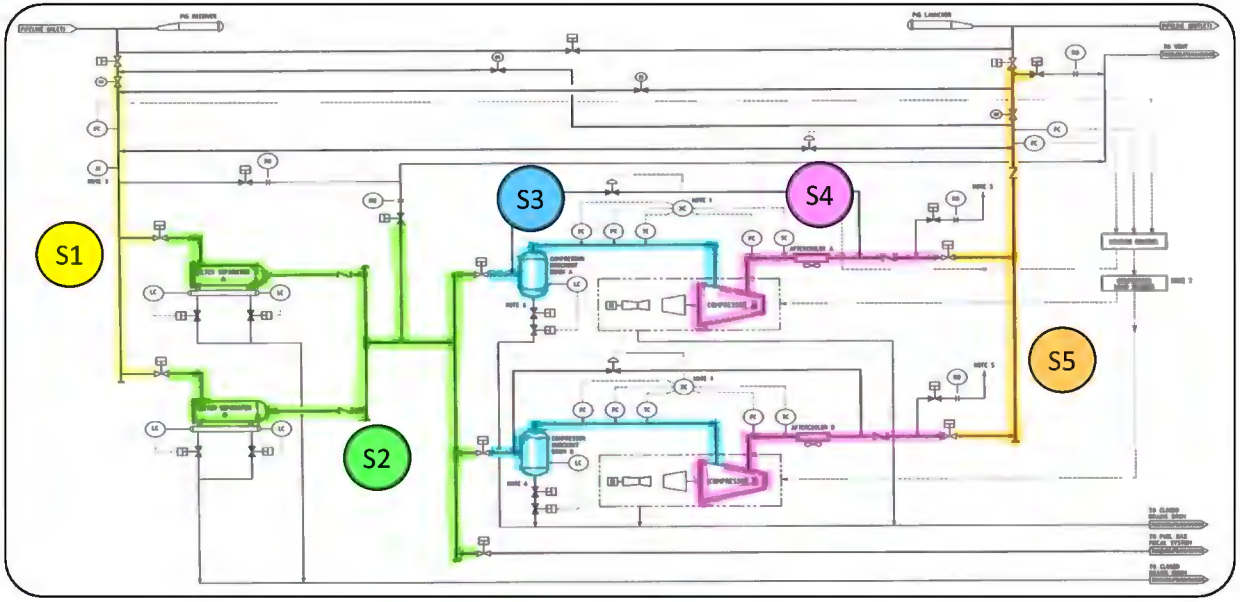
- Marmara crossing
- 17 River crossings
- 2 hole size (small breach and large breach)
- Identification of potential causes based on DNV-RP-F107 and PARLOC
- Maximum depth: 60 m
- 2 parallel lines
- High vessel traffic



Hazard Identification

Compressor station

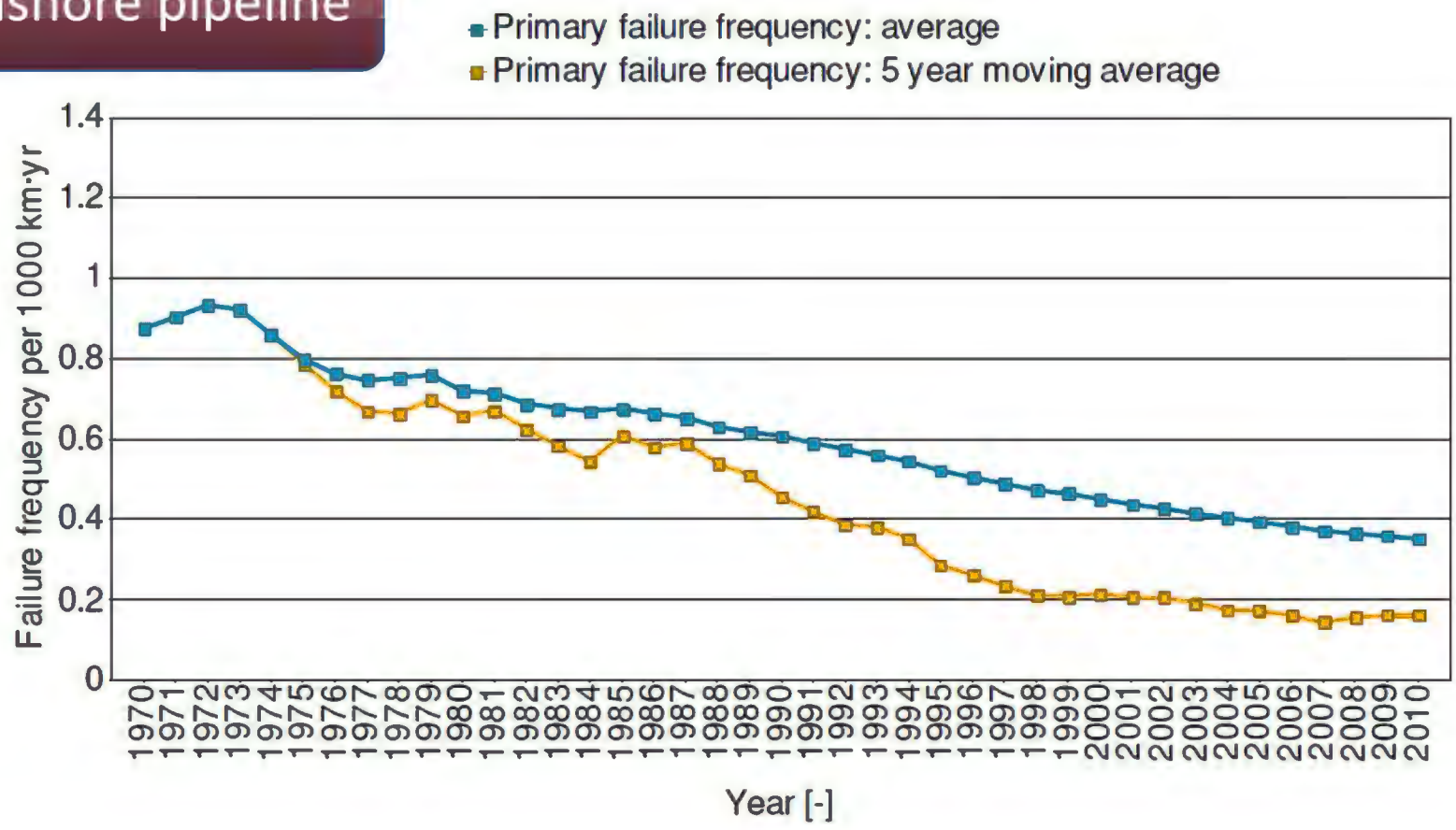
- Process deviations
- Random ruptures



- Compressor boost gas pressure
- UG/AG sections
- In building/Outside building
- Isolatable section (hold-up)
- Two hole sizes (1" and 4")
- Identification of potential causes based on API 581

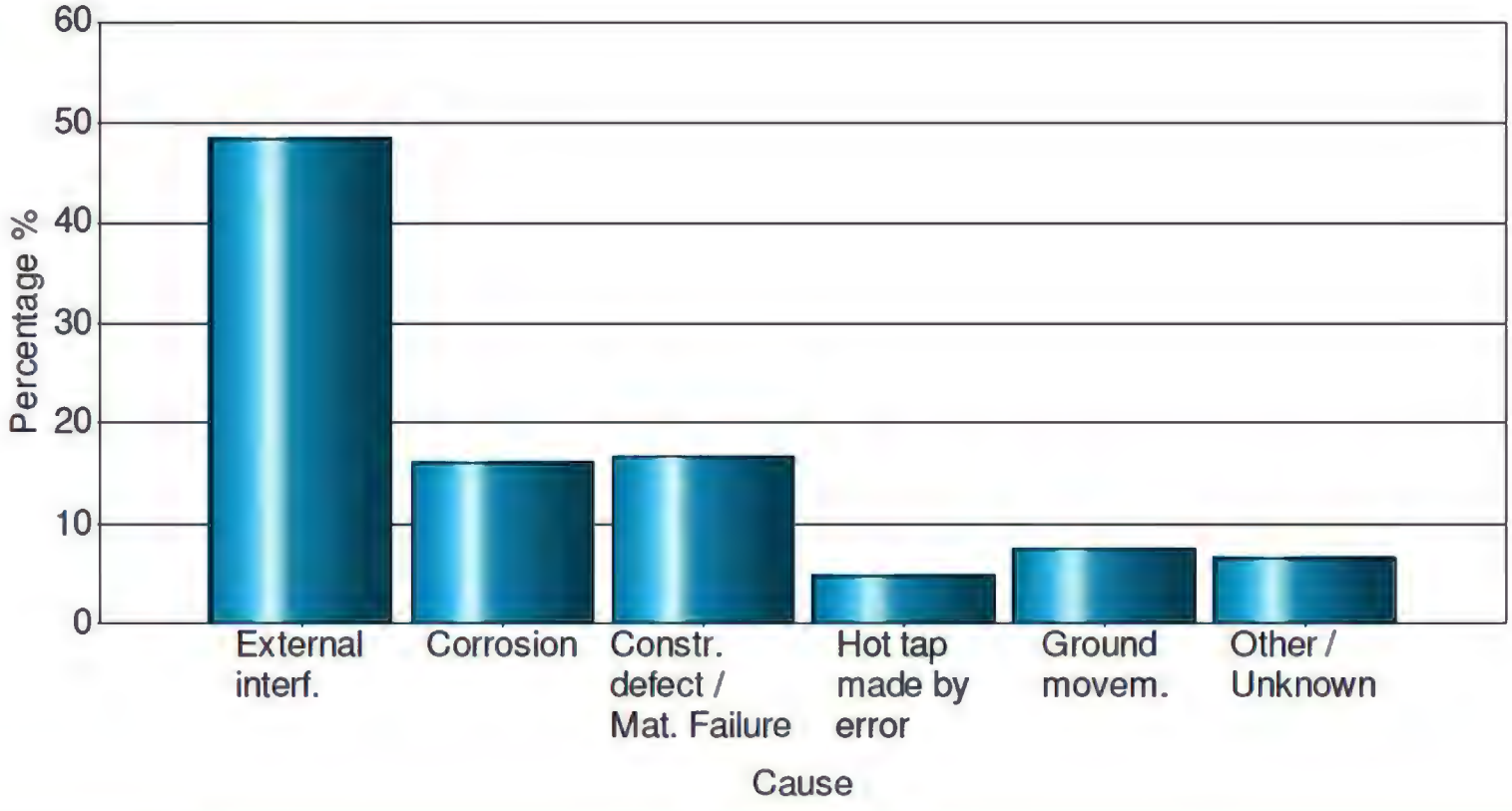
Frequency assessment

Onshore pipeline



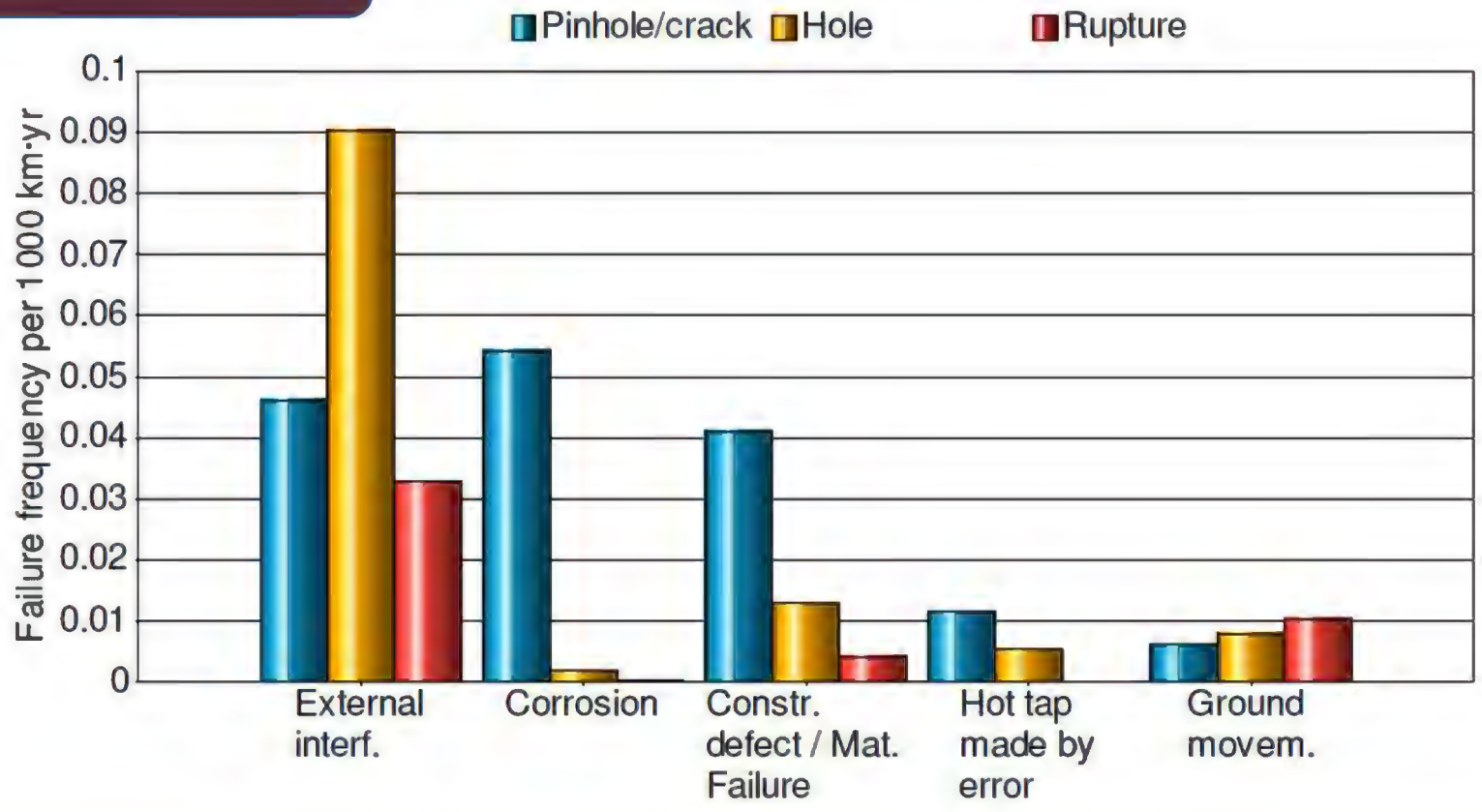
Frequency assessment

Onshore pipeline



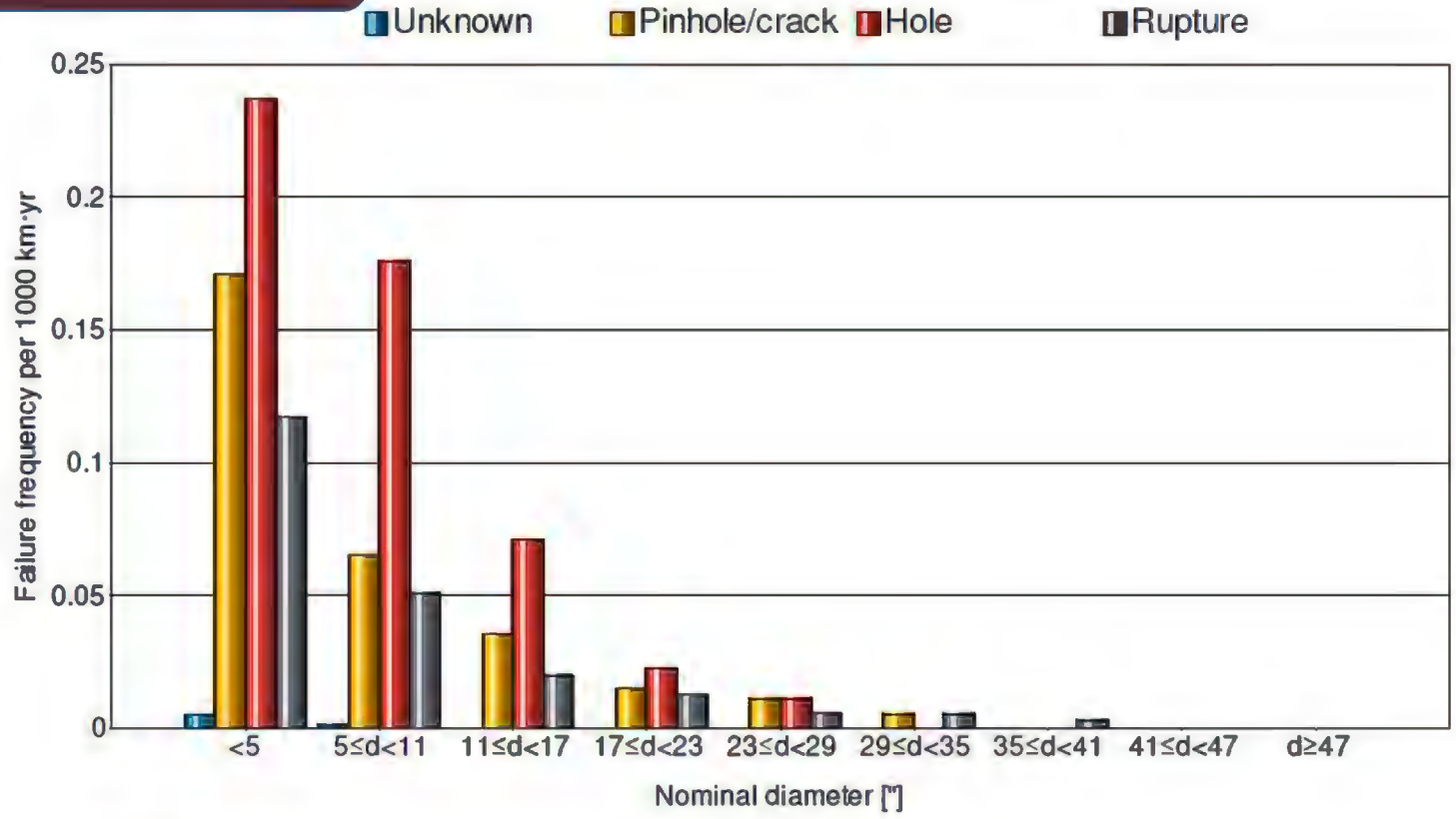
Frequency assessment

Onshore pipeline



Frequency assessment

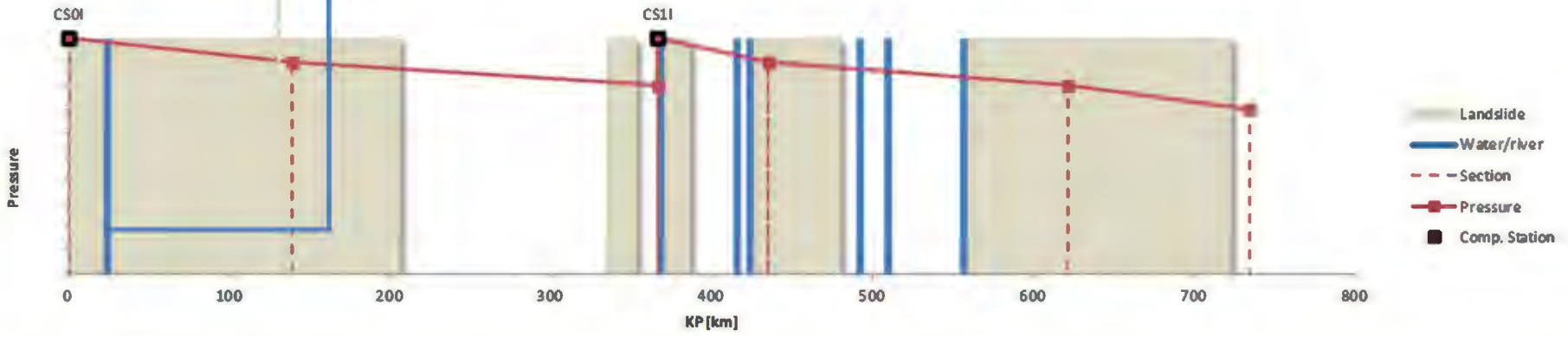
Onshore pipeline



Frequency assessment

Onshore pipeline

Cause	Frequency [ev/km/yr]	Pinhole	Hole	Rupture
External interference	-	-	-	-
Corrosion	-	-	-	-
Construction defect/ Material failure	**3.1E-05**	**71%**	**22%**	**7%**
Hot tap made by error	-	-	-	-
Ground movement, Landslide	2.5 E-06	-	-	100%
Ground movement, Water	9.3 E-07	-	-	100%
Ground movement, Other	**6.0 E-07**	**-**	**-**	**100%**
Other and unknown	**8.0E-06**	**90%**	**10%**	**-**



Frequency assessment

Offshore pipeline

- Internal causes are assessed through specific frequency databases (PARLOC)
- Interactions with third parties are assessed through dedicated models

Number of vessels relevant to the ith scenario intersecting the pipeline in 1 year
Research for published data

Specific failure frequency (events/total ships/hour of navigation)
Research for published data

$$F_i = n_i \cdot \mu_i \frac{L_i}{v}$$

Interaction length:
- Ship length
- Container length
- Anchor dragging length
- Trawling length

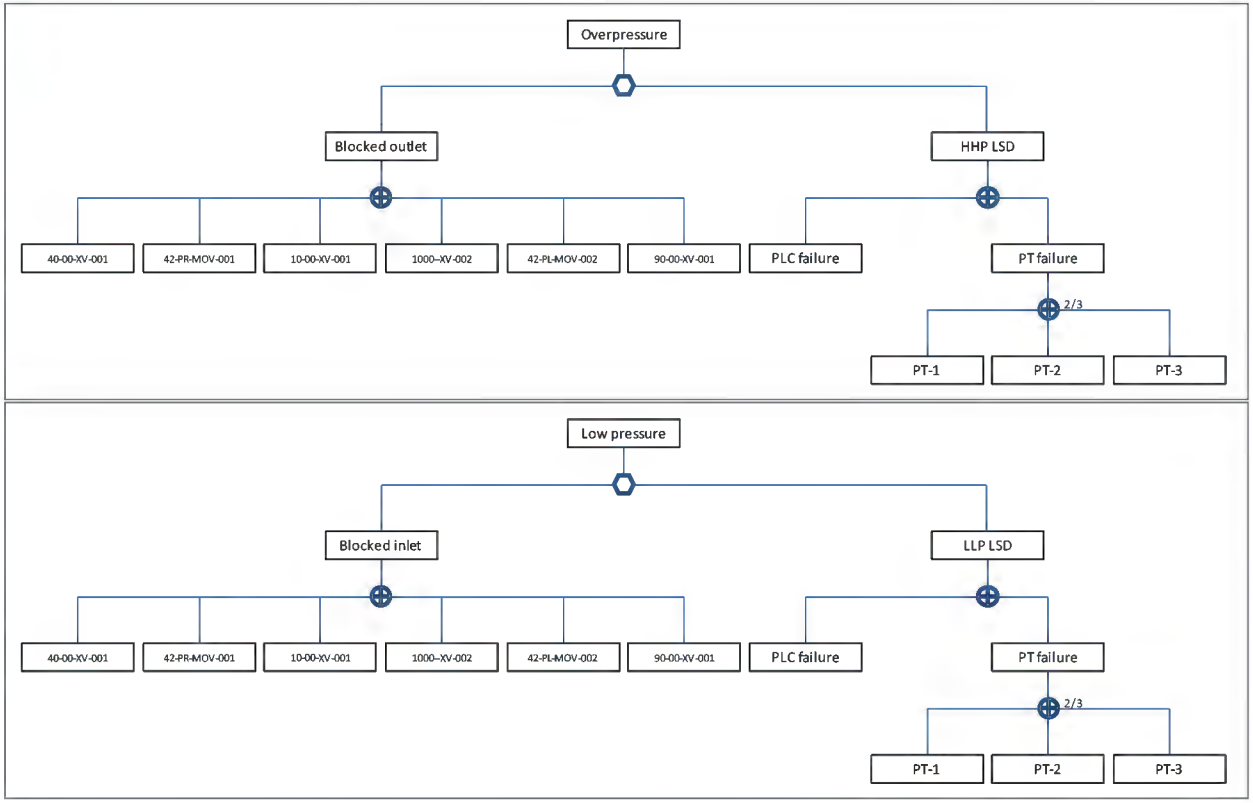
Average ship speed

Frequency of interaction with ith scenario:
- Sinking ships
- Dropped objects
- Dropped or dragged anchors
- Fishing activities

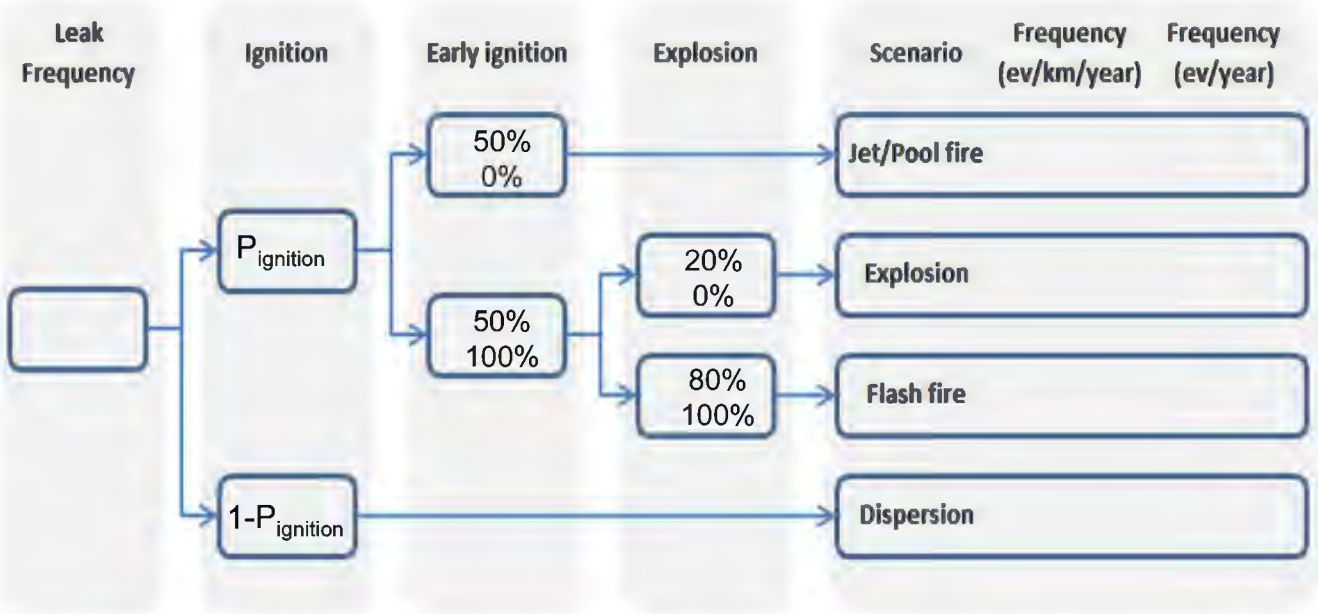
Frequency assessment

Compressor station

- Internal causes are assessed through specific frequency databases (API 581)
- Process deviations are assessed through Fault Tree Analysis



Event tree analysis



Onshore ignition probability $P_{ignition} = 10^{0.64 \cdot Log_{10}\dot{M} - 1.81}$ IP-UKOOA

Offshore ignition probability $P_{Ignition} = \frac{L_{cloud}}{v} \cdot n_{vessel} \cdot \frac{L_{cloud}}{L_{strait}}$

Consequence assessment (onshore)

Internal conditions based on H&MB

Pressure, temperature and gas composition

Hole size

Three hole sizes are considered: Pinhole, Hole and Rupture.
Ruptures have been neglected within compression station.
Pinhole and Hole discharge rate are retained as constants, specific model applies to Rupture case.

Release direction

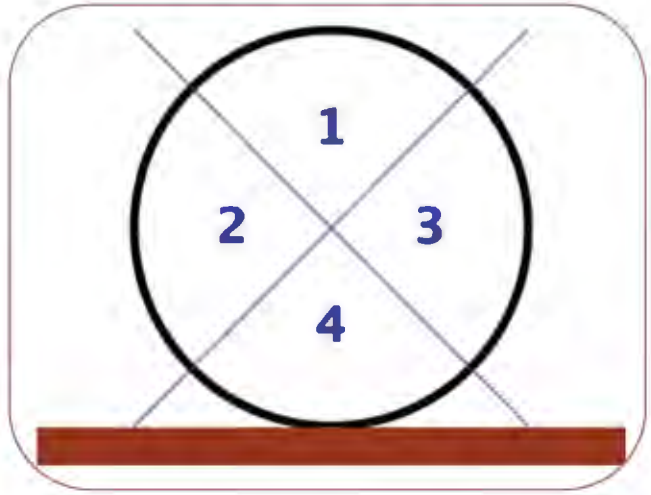
Pipe has been divided into 4 quadrants:
#1 vertical upwards
#2,3,4 impinged

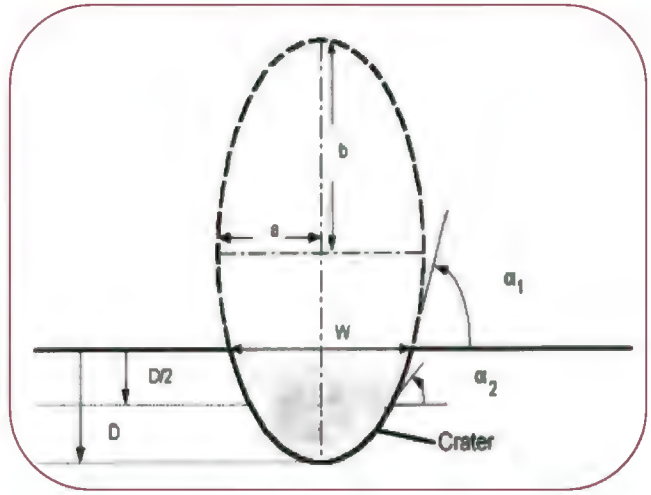
Dispersion/Fire simulation

Simulations have been performed with DNV PHAST

Consequence assessment (onshore)

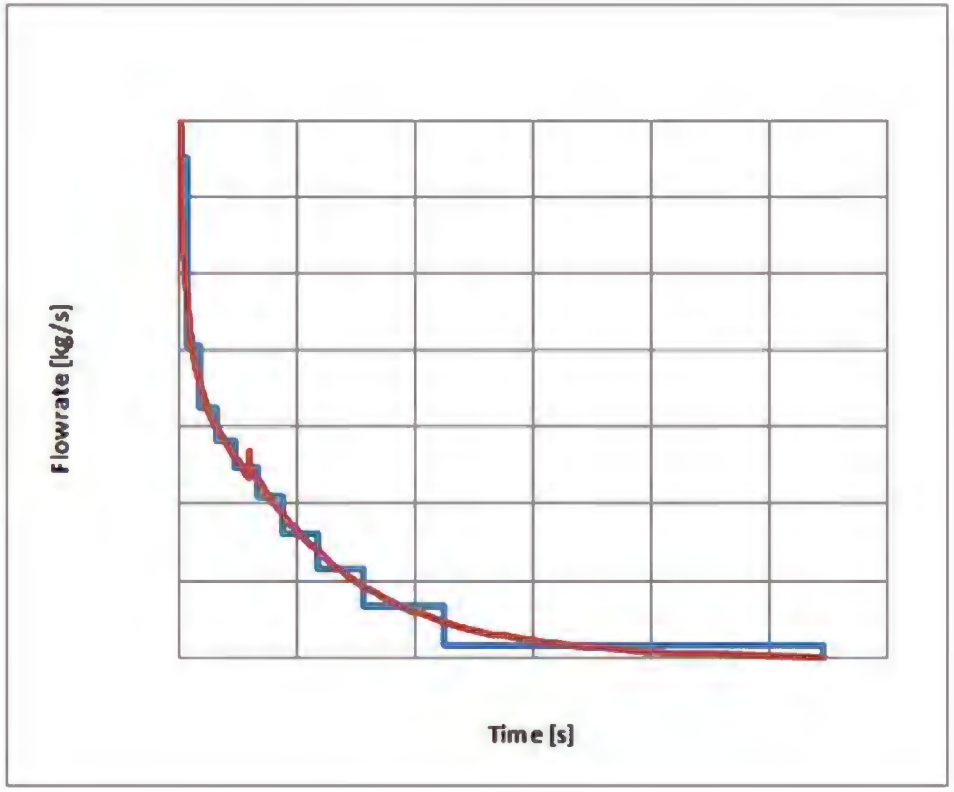
Hole size / Quadrant	Pinhole	Hole	Rupture
#1	Impinged (minimum gas velocity)	Vertical upward	Crater formation
#2, 3, 4	Impinged (minimum gas velocity)	Impinged (minimum gas velocity)	





Consequence assessment (onshore)

Full bore rupture release rate

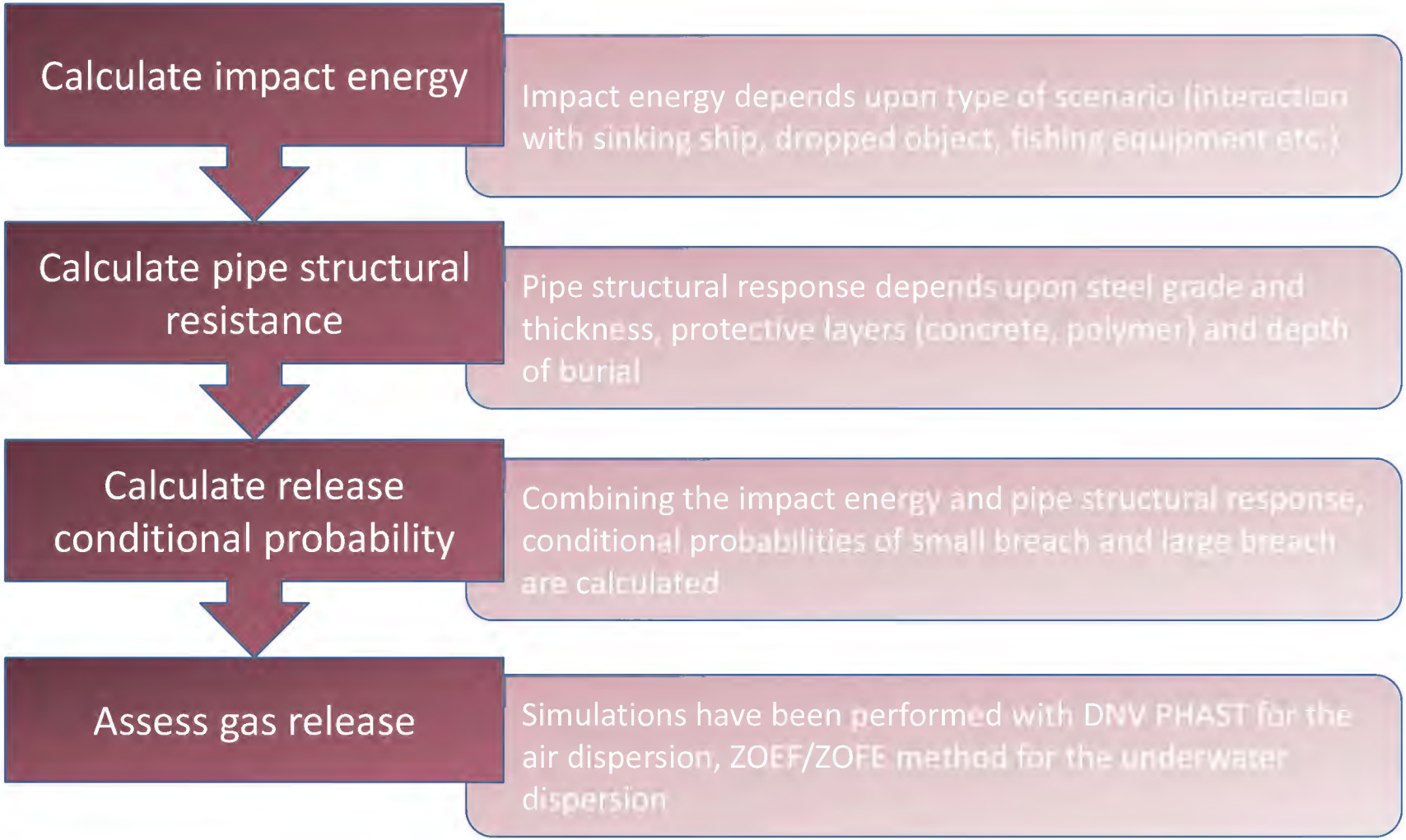


Blue line represents the interpolation steps used in dispersion evaluation

Red line represents the discharge flow rate evaluated by Long pipeline model in PHAST

For Jet fire calculation, flow rate at 30 second has been selected

Consequence assessment (offshore)



Consequence assessment (offshore)

$$E_E = \frac{1}{2} \cdot (m + m_a) \cdot v^2$$

$$v = \sqrt{\frac{2 \cdot m_i \cdot g}{\rho_{water} \cdot C_D \cdot A_i} - \frac{2 \cdot g \cdot V_{a(i)}}{C_D \cdot A_i}}$$

- m: mass of the sinking object (ship, container, anchor)
- V_a: volume of the sinking object
- A_i: projected area of the sinking object in the flow direction
- C_d: drag coefficient
- g: gravitation acceleration

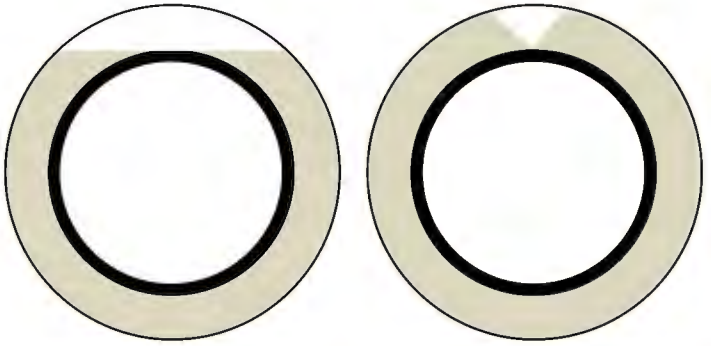
$$E_D = 16 \cdot \left(\frac{2 \cdot \pi}{9}\right)^{\frac{1}{2}} \cdot m_p \cdot \left(\frac{D}{t}\right)^{\frac{1}{2}} \cdot D \cdot \left(\frac{\delta}{D}\right)^{\frac{3}{2}}$$

- E_D : absorbed energy for steel pipelines
- m_p: plastic moment capacity of the wall (¼ σ_y t^2)
- δ: pipe deformation, dent
- t: wall thickness (nominal)
- σ_y: yield stress
- D: steel outer diameter

$$E_K = Y \cdot V_P$$

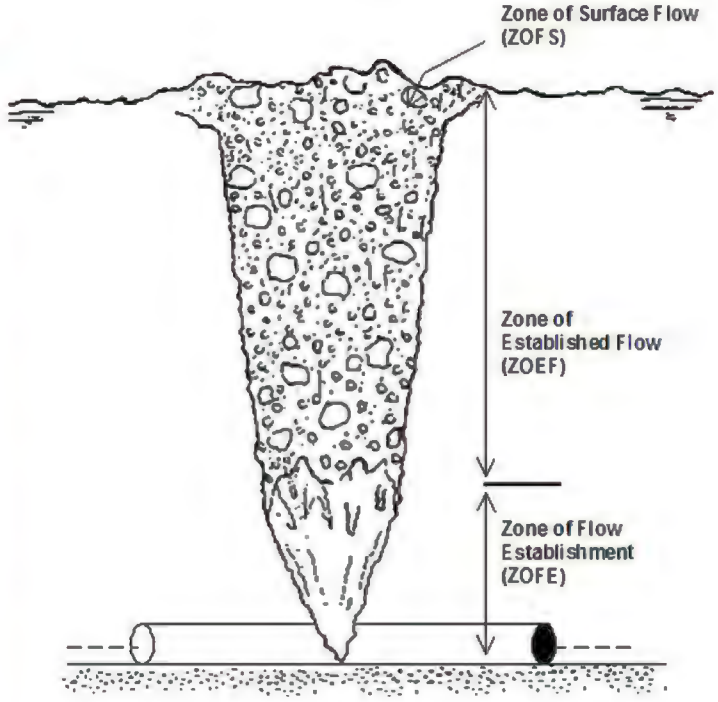
$$E_P = \frac{2}{3} \cdot \gamma' \cdot L \cdot N_\gamma \cdot z^3$$

- Y: crushing strength of the concrete
- V_P: penetrated volume (m^3).
- γ': effective unit weight of the fill material
- L: length of the impacting side (m);
- N_γ: bearing capacity coefficient
- z: penetration depth (m).

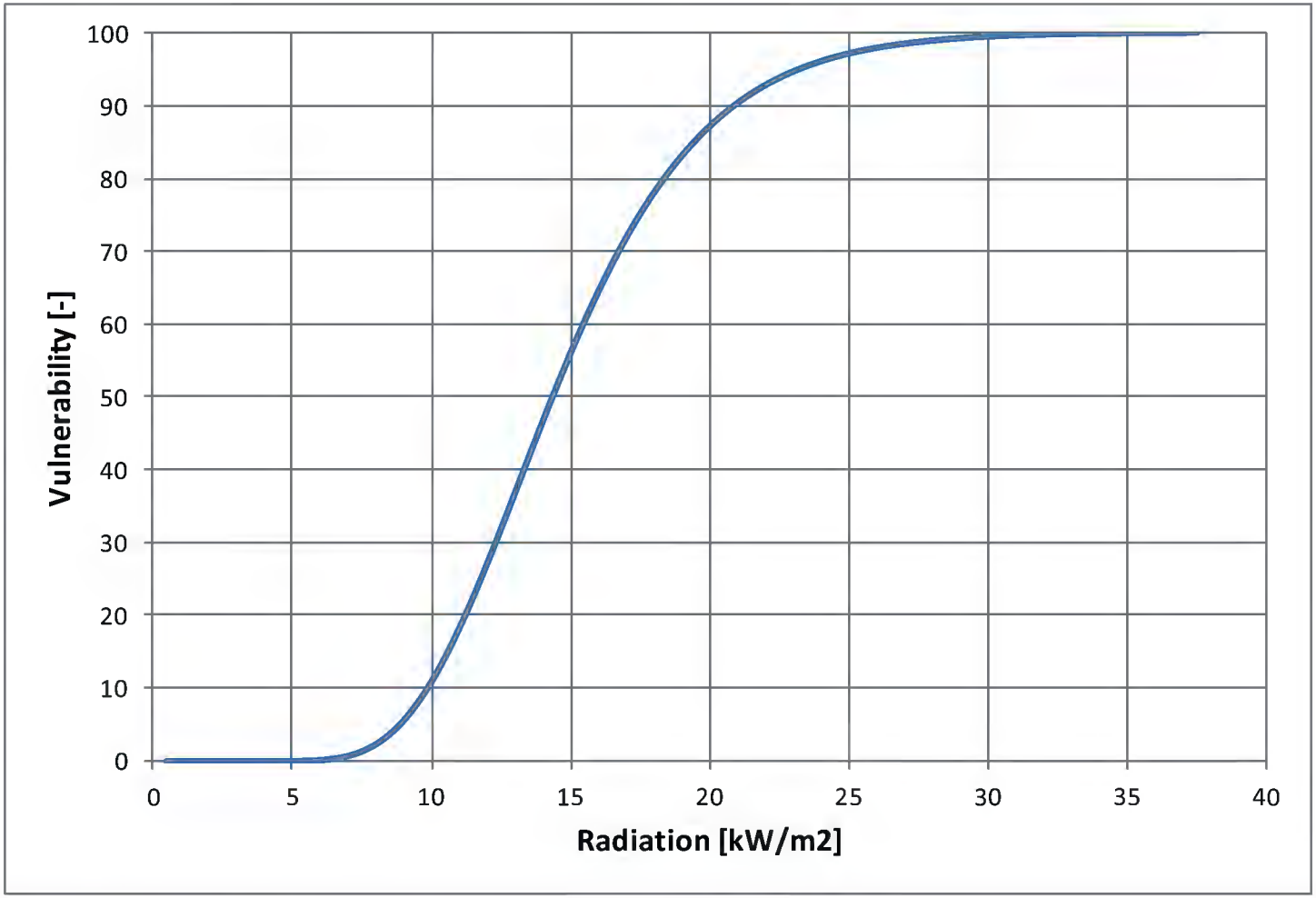


Consequence assessment (offshore)

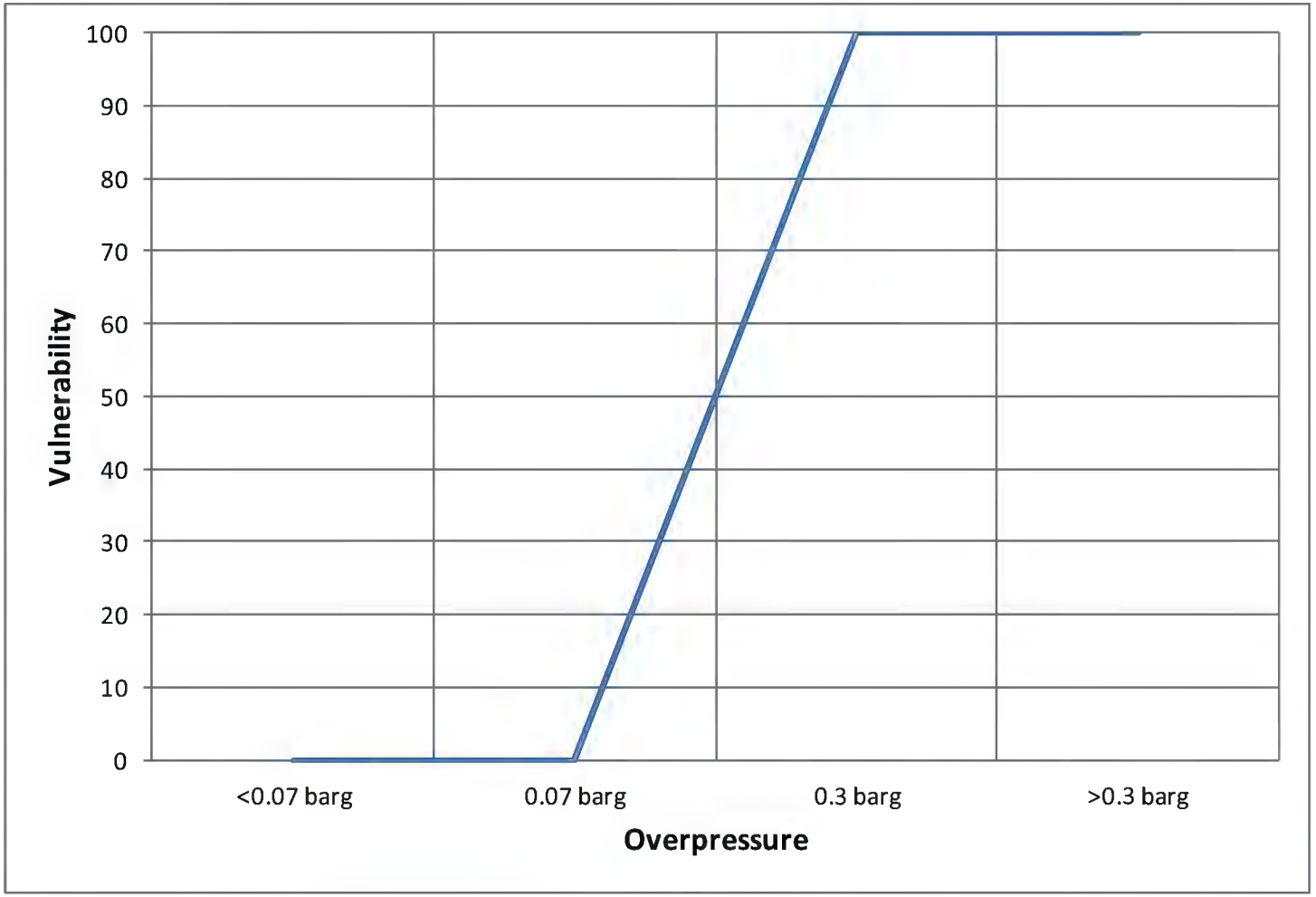
DENT/ DIAMETER (δ/D, in %)	DAMAGE DESCRIPTION (Ref. DNV-RP-F107)	CONDITIONAL PROBABILITY	
		Small breach	Large breach
< 5	Minor damage. No release	0	0
5 – 10	Major damage. Small Release possible	0.1	0
10 – 15	Major damage. Release possible Small releases more likely than large releases	0.2	0.05
15 – 20	Major damage. Release possible Small releases more likely than large releases	0.5	0.25
> 20	Major damage. Release possible Large releases more likely than small releases	0.2	0.7



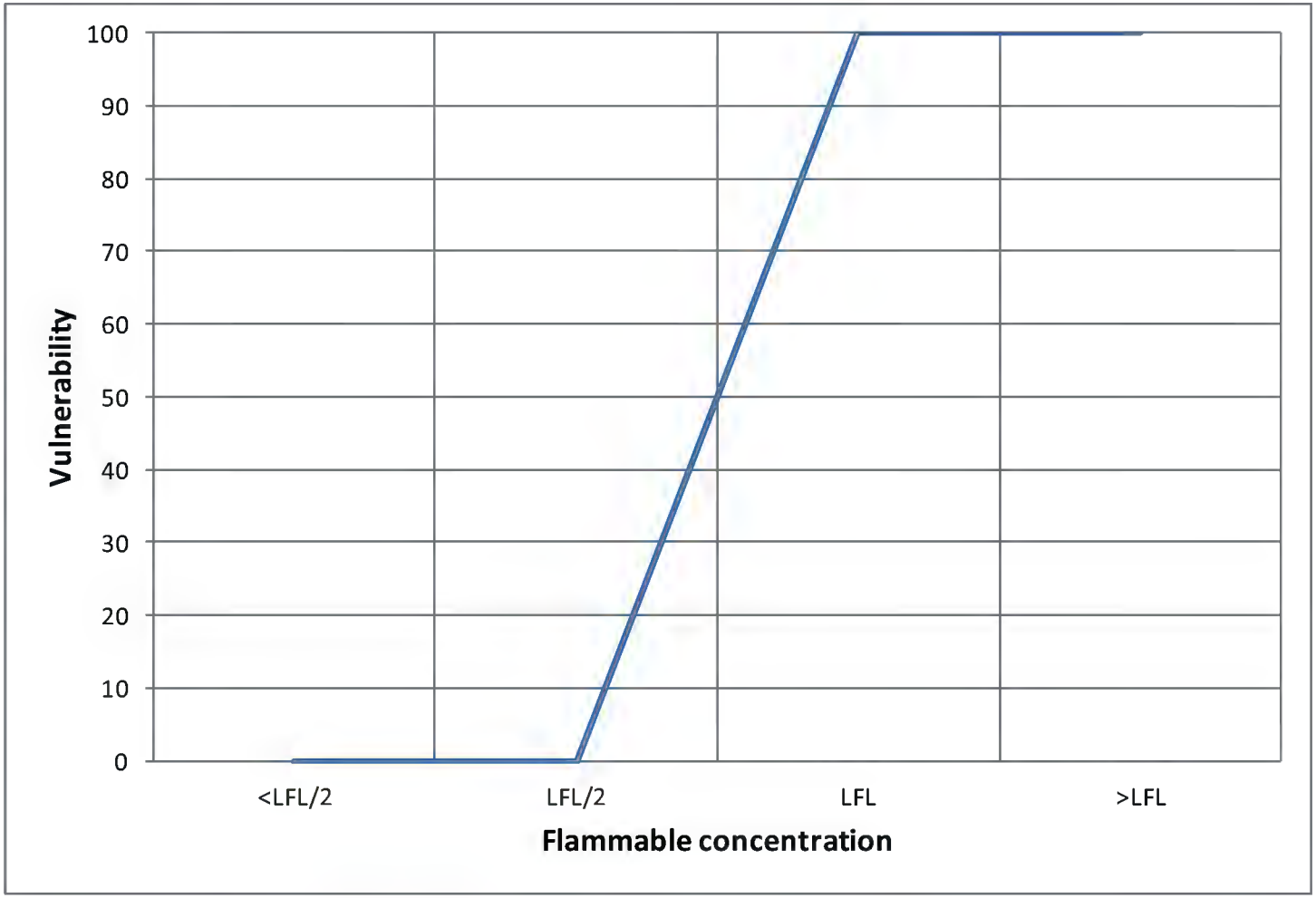
Vulnerability



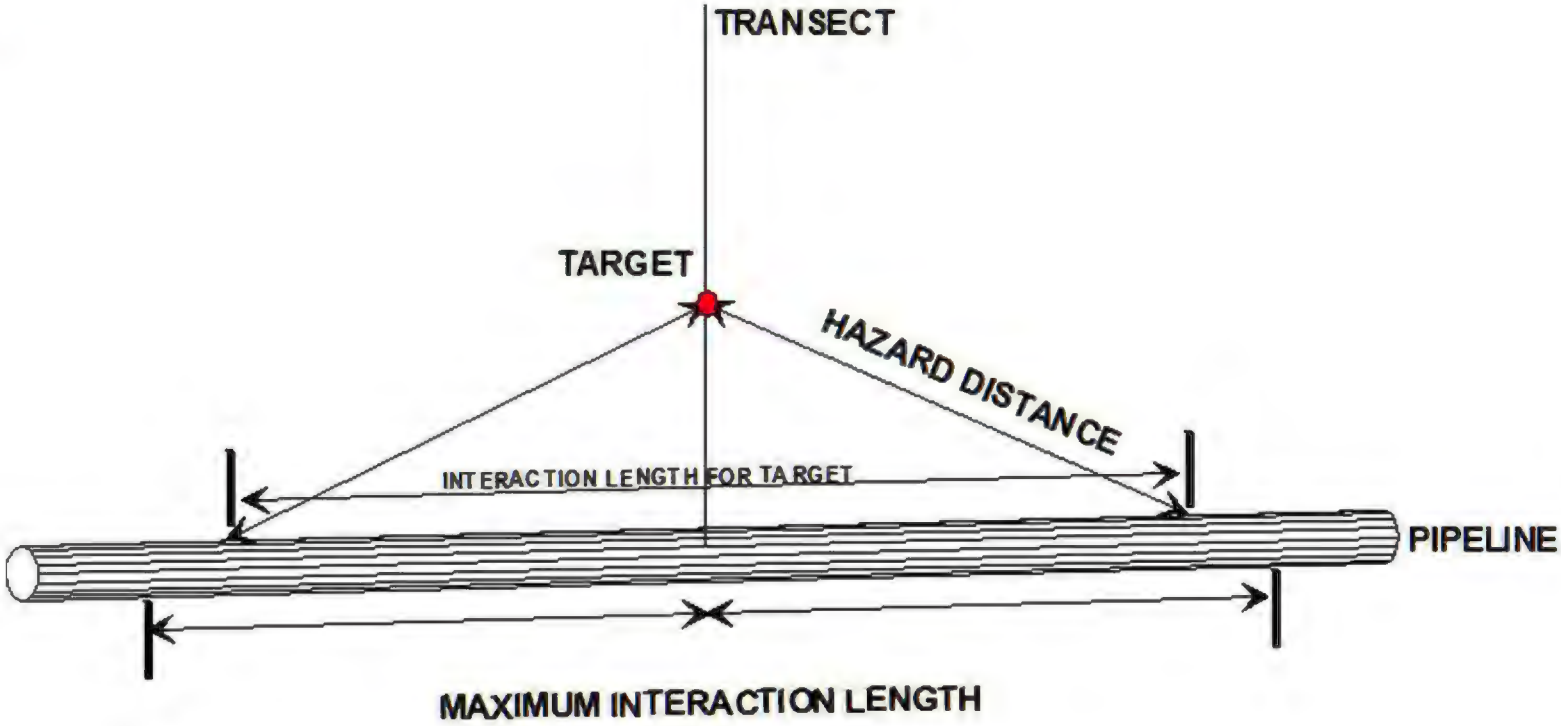
Vulnerability



Vulnerability

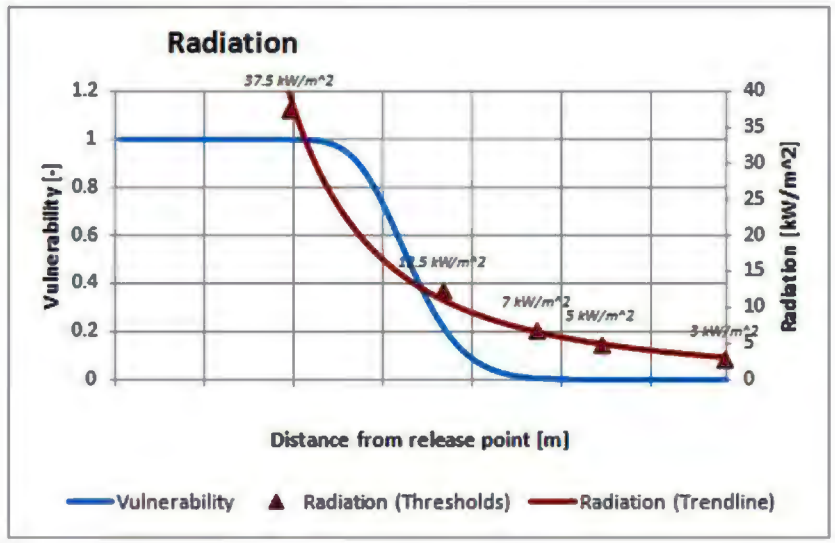


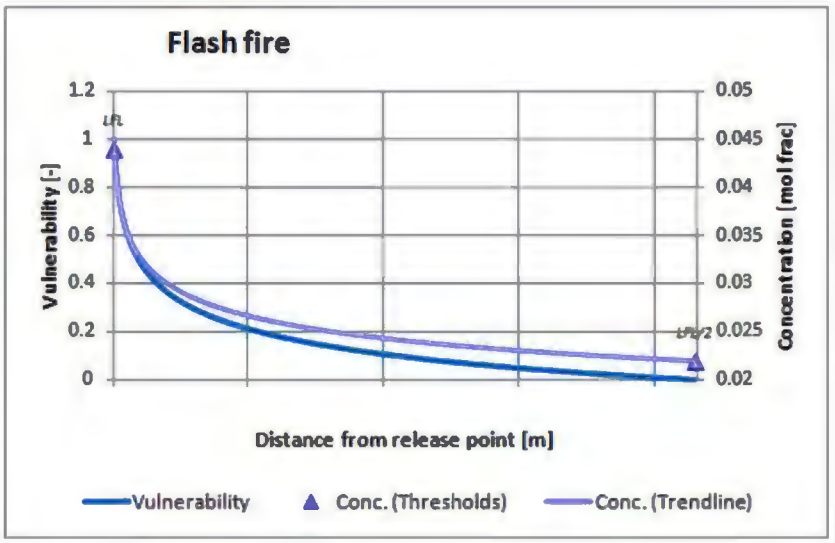
Individual risk

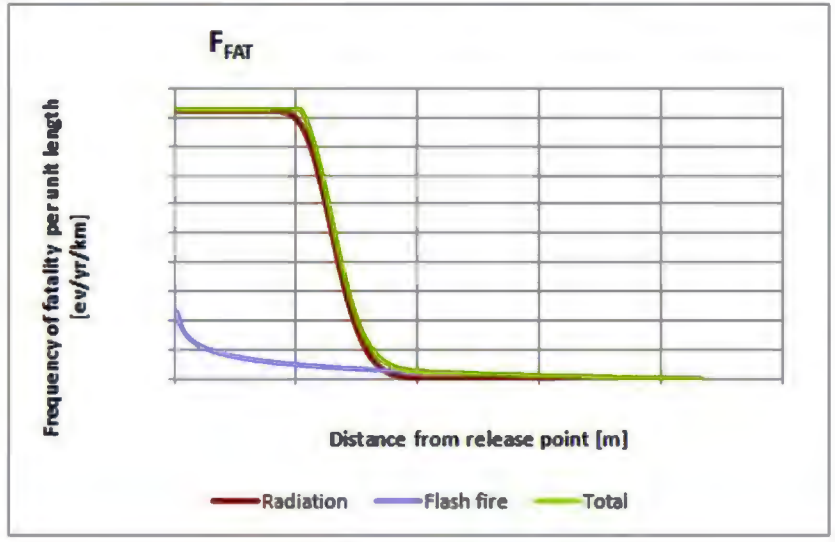


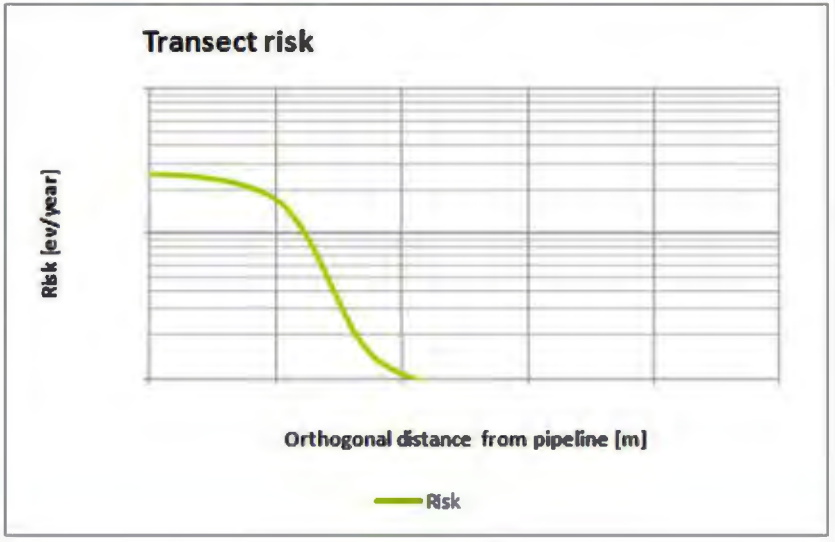
- LSIR (Location Specific Individual Risk): risk of death for an individual who is present at a particular location 24 hours per day and 365 days per year
- Interaction length concept is introduced in order to evaluate the pipeline length able to affect a specific location

Individual risk



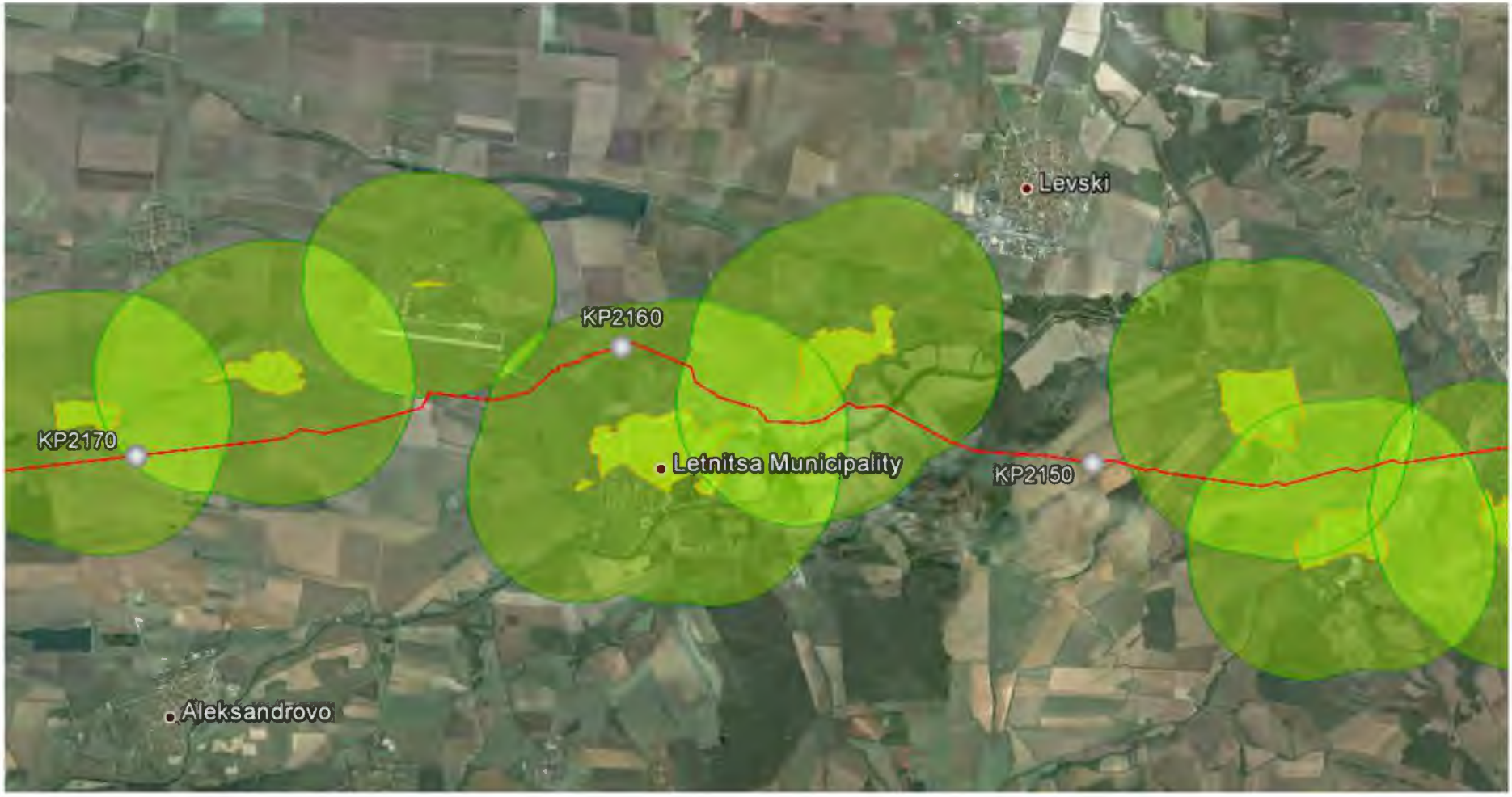






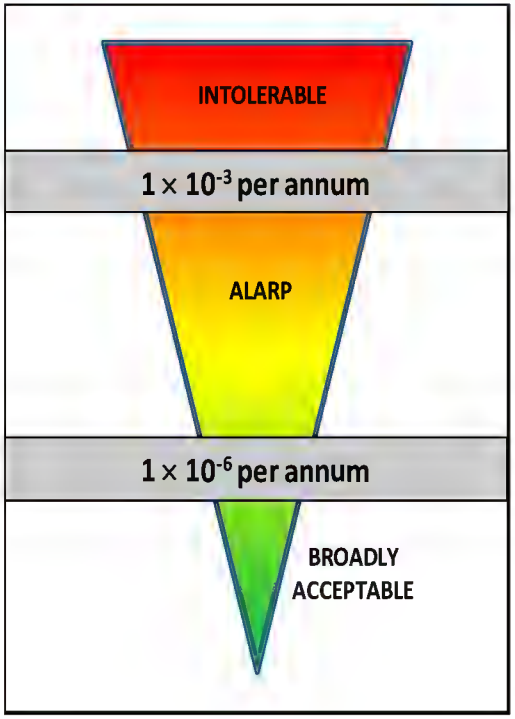
Individual risk

Single scenario risk



Tolerability criteria

Quantitative



Semi-quantitative

Frequency	Consequence Level				
	1	2	3	4	5
Improbable	Acceptable region				
Unlikely				Acceptability limit	
Seldom			ALARP region	Tolerability limit	
Probable					
Frequent					Intolerable region

Conclusions

- A QRA were performed for the Nabucco pipeline
- Risk assessment is performed through the following steps:
  - Hazard identification
  - Frequency calculation
  - Consequences calculation
  - Risk calculation and assessment
- Boundary conditions vary along the pipeline, thus requiring several different approaches to model risk
- Data searching is a key factor in risk assessment
- Assumptions based on the expert know-how still apply

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