Classification: General Business Use

Ex-LOPA method for the assessment of explosion risks in hazardous areas

Roald Perbal, SABIC
Paul van Norden, FrieslandCampina
Jeroen van der Prijt, Bilfinger Tebodin

Joint Working Group from Platform ATEX 153 and SIL Platform, under governance of the Royal Netherlands Standardization Institute (NEN)

Objectives of Ex-LOPA Method for Explosion Risk Assessment in Hazardous Areas

- Semi-quantitative risk assessment methodology, which allows for a consistent assessment of explosion risks in hazardous areas.
- The Ex-LOPA method distinguishes between the risk of ignition in a hazardous area and the assessment of explosion risks.
- This Ex-LOPA method is especially intended for:
  - identifying risk reduction measures in Hazardous Areas, i.e. Zones 1/21 and 0/20;
  - identifying risk reduction measures in case of explosive atmospheres in enclosed areas where an explosion overpressure can be expected;
  - evaluating risks from explosion scenarios with potential fatality consequences.
- The Ex-LOPA method is not intended for Control of Work (CoW) and managing risks of portable or mobile equipment used in hazardous areas

Platform ATEX153

Different types of explosion risk assessment methods

Normal Operation within Safe Limits

Hazardous Area Classification
- Expected leak/relief sources under foreseeable operations
- Leak/release rates, including relief locations to atmosphere
- Potentially Explosive Atmospheres inside equipment
- Likelihood P (frequency and duration) of Potentially Explosive Atmosphere
- Types and extent of the Zones

Process Deviations outside Safe Limits

PHA / HAZOP
- Unmitigated incident scenarios leading to catastrophic failure of containment, including Potentially Explosive Atmospheres inside equipment
- Types and rates of releases
- Likelihood P (frequency and duration) of identified potential releases
- Extent of Potentially Explosive Atmosphere & Consequences

Control of Work

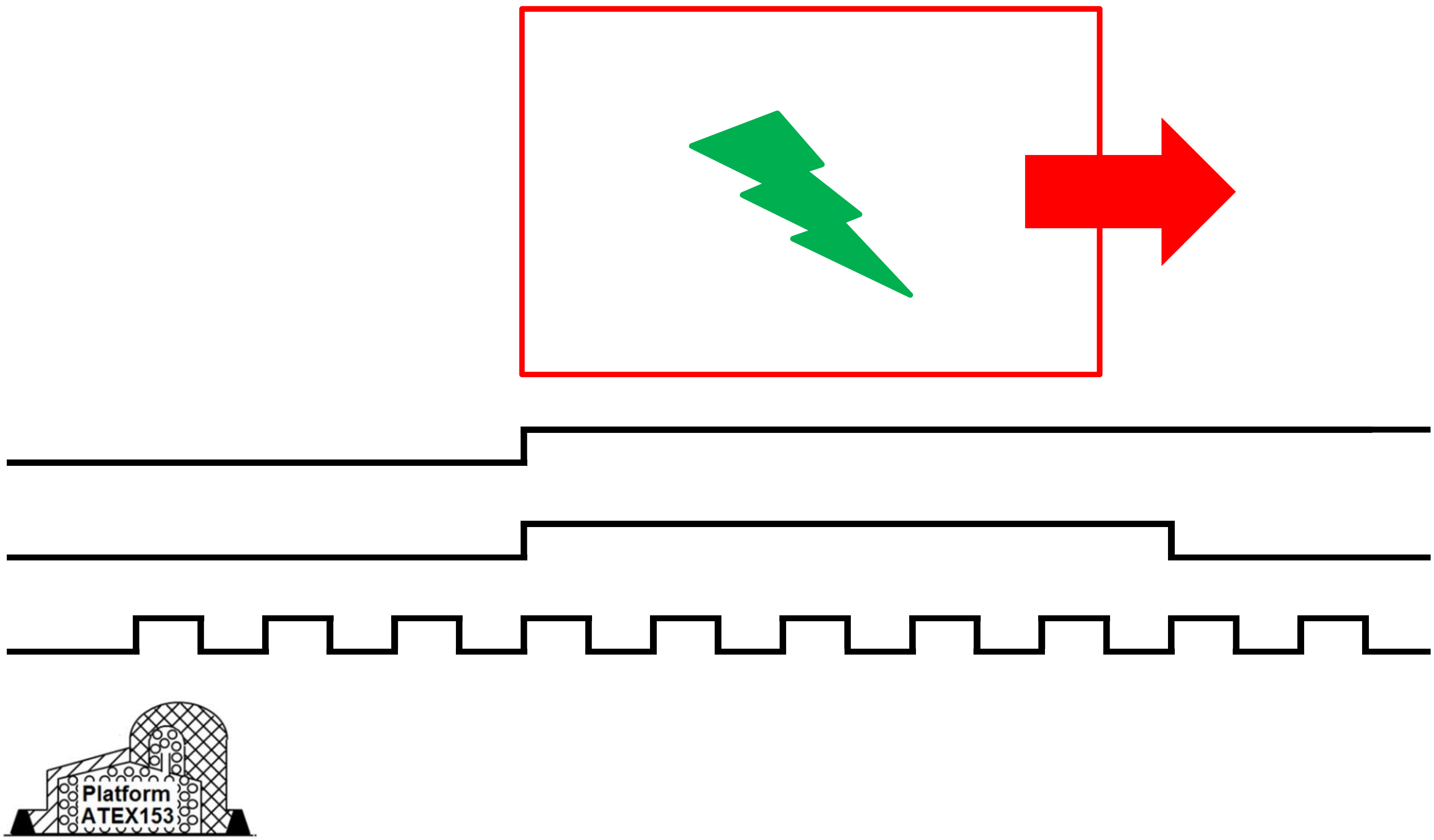
Job Safety Analysis (JSA) / LMRA
- Extent of Potentially Explosive Atmosphere & Consequences
- Possible formation of an Explosive Atmosphere & Consequences

Ignition Hazard Assessment
- Identify all possible ignition sources (electrical/non-electrical) within Potentially Explosive Atmospheres for:
  - Normal operation process and equipment
  - Malfunction of process or equipment
  - Work activities
- Required PM & Ignition Protection to prevent process or equipment malfunctions

Not Tolarable / ALARP Risk of Fire / Explosion (LOPA)

Platform ATEX153

PHA versus Zones: Frequency of Explosive Atmosphere (F_{Ex})



$F_{EX} < 1/yr.$

$F_{EX} = 1/yr.$
$T_{EX} = 10$ hrs.
$P_{EX} = 10^{-3}$

$F_{EX} = 10/yr.$
$T_{EX} = 1$ hrs.
$P_{EX} = 10^{-3}$

Frequency of Explosive atmosphere (F_{EX}) & Ignition Hazard Frequency (IHF)

PHA-LOPA (Process Deviations outside Safe Limits/Catastrophic Failures): $F_{EX} < 1/yr.$ $IHF = F_{EX} * P_{IG}$

Ex-LOPA Hazardous Area (Normal Operation within Safe Limits): $F_{EX} \geq 1/yr.$ $IHF = F_{IG} * P_{EX}$

Explosion Hazard Frequency (EHF): $EHF = IHF * P_{CM} * (\prod_{1}^{3} P_{IPL})$

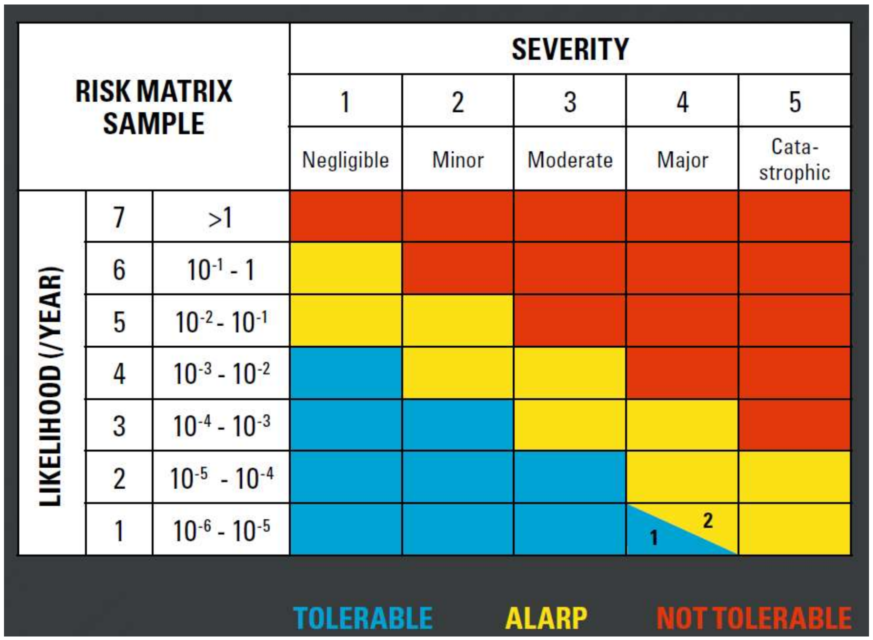
PHA-LOPA (Process Deviations outside Safe Limits/Catastrophic Failures):

- Initiating Event Frequency = Frequency of Process Deviation/Failures (F_{EX})
- Conditional Modifier = Probability of an effective ignition source (P_{IG})
- Conditional Modifier = Probability of personnel presence and injured (P_{CM})
- Independent Protection Layers = Risk Reduction Factor (P_{IPL})

Ex-LOPA Hazardous Area (Normal Operation within Safe Limits):

- Initiating Event Frequency = Frequency of Ignition Source/Malfunctions (F_{IG})
- Enabling Condition = Probability of a Hazardous Atmosphere/Zone (P_{EX})
- Conditional Modifier = Probability of personnel presence and injured (P_{CM})
- Independent Protection Layers = Risk Reduction Factor (P_{IPL})

Risk Matrix (SIL Platform Guide; October 2018) & Risk Tolerance Criteria for Ex-LOPA



Risk Matrix Calibration: Harms					
Injury or Death	At least 1 IRREVERSIBLE injury	Leave from work / Hospi-talization	Number of victims	Resulting Harm Grade	Advised Harm Grade Scale (simplified based on results)
I	N	First aid, no leave	0	Marginal	Negligible
I	N	Leave < 3 days	1 to 4	Minor	Minor
I	N	Leave > 3 days	5 or more	Medium	Moderate
	Y	Leave > 3 days	1 to 4	Moderate	
D	Y	1 death *	1	Major	Major
D	Y	2 to 5 deaths *	2 to 5	Severe	Catastrophic
D	Y	more than 5 deaths*	> 5	Catastrophic	

Table 4: Risk Matrix Calibration on Harms

(* or permanent disability)

Risk Tolerance Criteria for Ex-LOPA:

- Major Harm: ≤ 10^{-5}/yr.
- Catastrophic: ≤ 10^{-6}/yr.

Initiating event frequency (F_{Ig}): 4 main types of initiating events that can cause ignition

1. **Equipment failures:**
   e.g. expected or rare malfunctions of (non-)electrical Ex-equipment in the different zones
2. **Process related ignition sources:**
   e.g. prevent high temperatures via process control systems and/or safety instrumented systems
3. **Human related ignition sources:**
   e.g. frequency of activities or presence of personnel in a hazardous area, taking into account the effectiveness of administrative/procedural control of potential ignition sources
4. **External events:**
   e.g. for lightning strikes a typical frequency $F_{Ig} = 10^{-3}$/yr. is assumed

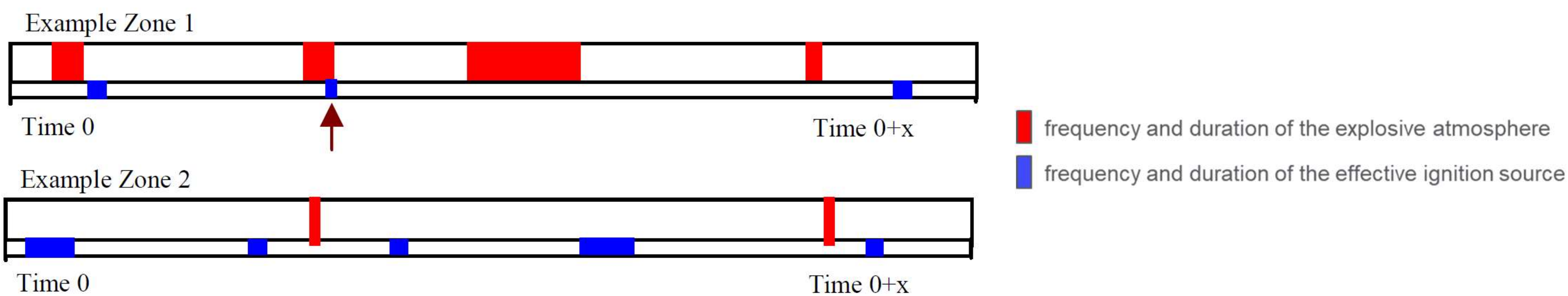
Unmitigated ignition frequencies (F_{Ig}) & IPL requirements for equipment in different zones

Unmitigated Potential Sources of Ignition (IEC 60079-0 / ISO 80079-36)				
Likelihood	**(F_{Ig} > 0.1/yr.)** Effective ignition sources to be expected during normal operation frequently or for long periods (T_{Ig} > 10 hrs.)	**(F_{Ig} ≤ 0.1/yr.)** Effective ignition sources only to be expected during single expected malfunctions	**(F_{Ig} ≤ 0.01/yr.)** Effective ignition sources only to be expected due to a combination of two independent expected malfunctions or during one rare malfunction	**(F_{Ig} = 0/yr.)** Not Relevant No own potential sources of ignition when operated as intended, including during any malfunctions
Zone 2/22 **(P_{Ex} ≤ 0.01)**	1 IPL: RRF ≥ 10	--- Detection of arising faults within 1 shift (T_{Ig} ≤ 10 hrs.)*	--- Detection of arising (rare) faults during weekly visits (T_{Ig} ≤ 100 hrs.)*	Assessment of equipment for the intended operation / safe use in the different zone types
Zone 1/21 **(P_{Ex} ≤ 0.1)**	2 IPL's: RRF ≥ 100	1 IPL: RRF ≥ 10	a Self-revealing (rare) faults (T_{Ig} ≤ 1 hrs.) or automatic detection of arising rare faults	
Zone 0/20 **(P_{Ex} ≤ 1)**		2 IPL's: RRF ≥ 100	1 IPL: RRF ≥ 10 In the event of two independent faults occurring independently of each other	

* Continuous Supervision (IEC 60079-17)
--- No Safety Requirements / Protection Layer is not needed
a No Special Safety Requirements (Unclassified Safeguard since PFD > 0.1) / Protection Layer is probably not needed
HFT ATEX Hardware Fault Tolerance of Equipment (ISO 80079-37) is not the same as SIS Hardware Fault Tolerance (IEC 61511)
<u>Ex Equipment Under Control (IEC TS 60079-42):</u>
Ex Equipment which contains a potential ignition source, which is controlled by an electrical safety device

Platform ATEX153

IHF for different zone types depending on frequencies and duration of ignition sources



$$IHF = F_{Ig} \times P_{Ex} + F_{Ex} \times P_{Ig} = F_{Ig} (P_{Ex} + F_{Ex} \times T_{Ig}) \quad \text{per year}$$

Zone	F_{Ex} (1/yr.)	T_{Ex} (hrs.)	P_{Ex}	F_{Ig} (1/yr.)	T_{Ig} (hrs.)	IHF (1/yr.)
2/22	10	1	10^{-3}	10^{-1}	10*	1.1×10^{-3}
2/22	10	1	10^{-3}	10^{-2}	100*	1.01×10^{-3}
1/21	10	100	10^{-1}	10^{-2}	1	1.1×10^{-3}
1/21	100	10	10^{-1}	10^{-2}	1	1.1×10^{-3}
0/20	10	1000	1	10^{-3}	1	1.001×10^{-3}
0/20	100	100	1	10^{-3}	1	1.01×10^{-3}

Platform ATEX153

Estimated failure frequency (hr^{-1}) for electric equipment in explosive gas atmospheres that may result in a potential ignition source for different types of Ex protections

Type of protection	Use in zone	Normal failure rate (hr^{-1})	Failure rate harsh environment
Ex ia	0	$3.3 \cdot 10^{-8}$	$1 \cdot 10^{-7}$
Ex ma	0	$3.3 \cdot 10^{-8}$	$1 \cdot 10^{-7}$
Ex ib	1	$3.3 \cdot 10^{-7}$	$1 \cdot 10^{-6}$
Ex mb	1	$3.3 \cdot 10^{-7}$	$1 \cdot 10^{-6}$
Ex d, only sparking	1	$1 \cdot 10^{-7}$	$1 \cdot 10^{-7}$
Ex d, sparking and hot surfaces	1	$3.3 \cdot 10^{-7}$	$1 \cdot 10^{-6}$
Ex e	1	$3.3 \cdot 10^{-7}$	$1 \cdot 10^{-6}$
Ex p	1	$3.3 \cdot 10^{-7}$	$1 \cdot 10^{-6}$
Ex n	2	$3.3 \cdot 10^{-6}$	$1 \cdot 10^{-5}$
Ex s*	0-2	$3.3 \cdot 10^{-6}$	$1 \cdot 10^{-5}$

* Assumed equal to Zone 2 equipment Ex n (IEC 60079-15) by Ex sc (IEC 60079-33) unless Zone Category is given

Kees van Wingerden, Electrical equipment on offshore facilities: residual risk for ignition, CMR GexCon AS Project No. 44162, 7-12-2010.

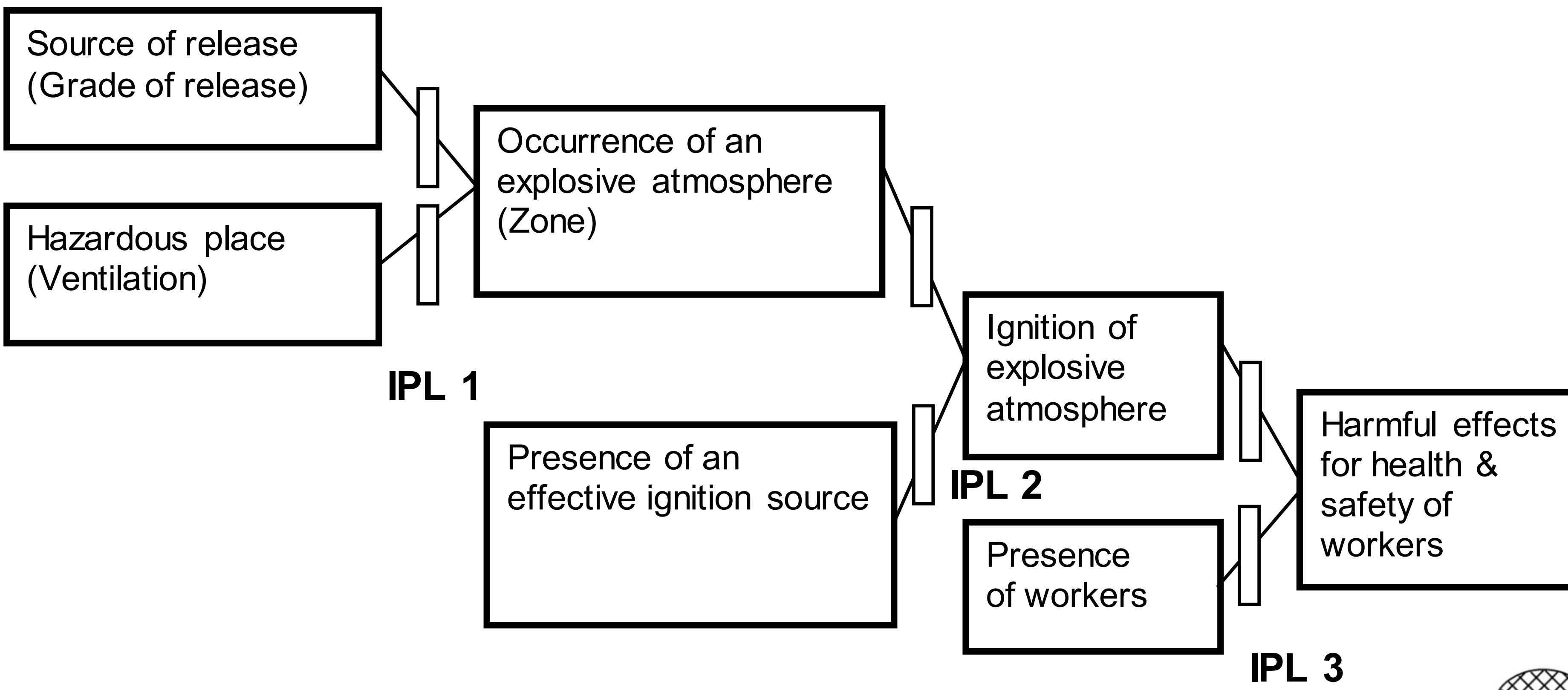
Platform ATEX153

Failure frequencies for electrical equipment in potentially explosive dust atmospheres

- **intrinsic safety "i":**
  the ignition frequency (F_{Ig}) of an explosive dust cloud (IIIA/IIIB) can be assumed to be identical as the estimated failure frequency of intrinsically safe electrical equipment
- **encapsulation "m":**
  the ignition frequency (F_{Ig}) of an explosive dust cloud can be assumed to be identical as the estimated failure frequency of electrical equipment protected by encapsulation
- **pressurized enclosure "p":**
  the ignition frequency (F_{Ig}) of an explosive dust cloud can be assumed to be identical as the estimated failure frequency of electrical equipment protected by pressurized enclosure
- **enclosure "t":**
  for dust ignition protection by enclosure "t" of equipment no generic failure rate data are available.

Platform ATEX153

Generic explosion scenario with independent protection layers (IPL)



Platform ATEX153

Explosive atmospheres prevention measures (IPL 1): Risk Reduction Factors (RRF)

Explosion prevention measures for avoiding the occurrence of explosive atmospheres	Standards & Guidelines	RRF *
Gas tight/fluid resistant physical barriers	IEC 60079-10-1	1000
Dust tight/ physical barriers/zone boundaries	IEC 60079-10-2	1000
Blind flange/leakage clamp to prevent formation of explosive atmospheres	IEC 60079-10-1	100
Safety Instrumented System (SIL 1) to prevent formation of explosive atmospheres	IEC 61511	1/PFD
Safety Instrumented System (SIL 2) to prevent formation of explosive atmospheres	IEC 61511	1/PFD
Safety Instrumented System (SIL 3) to prevent formation of explosive atmospheres	IEC 61511	1/PFD
Restriction orifice to prevent formation of explosive atmospheres	ISO 5167-2	100
Preventing ingress of explosive gas atmospheres by means of internal overpressure	IEC 60079-10-1	10
Opening Type B	IEC 60079-10-1	10
Opening Type C	IEC 60079-10-1	100
Opening Type D	IEC 60079-10-1	1000
Continuous local artificial ventilation (expected to be present during normal operation)	IEC 60079-10-1	10
Continuous local artificial ventilation (with automated performance monitoring and alarm)	IEC 60079-10-1	100
Continuous local artificial ventilation (with interlock and/or automated blower backup)	IEC 60079-10-1	1000
Fair inerting / purging systems (well designed and to be present during normal operation)	NFPA 69/CEN-TR 15281	10
Good inerting / purging systems (well designed and good availability with safeguarding)	NFPA 69/CEN-TR 15281	100
Displacement and evaporation suppression in enclosures/spaces by foam systems	NFPA 11	10
Non-Return Valve (single / double check valve in clean non-plugging service)	EN 16767/API 594	10 / 100
Single / Double Mechanical Seal	API 682/API 617	10 / 100
Liquid/Water Seals to prevent air ingress / to protect against air infiltration	API 521	10

Platform ATEX153

* Estimates

Ignition prevention measures (IPL 2): Risk Reduction Factors (RRF)

Technical explosion protection measures for avoiding the presence of ignition sources	Standards & Guidelines	RRF *
Safety Instrumented System (SIL 1) to prevent ignition source formation	IEC 61511	1/PFD
Safety Instrumented System (SIL 2) to prevent ignition source formation	IEC 61511	1/PFD
Safety Instrumented System (SIL 3) to prevent ignition source formation	IEC 61511	1/PFD
End of Line flame arrester	ISO 16852 ISO/IEC 80079-49 CEN/TR 16793	100
Fluid tight/fluid resistant thermal insulation with visible Ex warning	ASTM C1696-20	10
Fluid tight resistant thermal insulation with visible Ex warning (sealed & periodic inspection)	ASTM C1696-20	100
Lightning Protection System	IEC 62305 / NFPA 780	10
Electrostatic grounding detection with interlocking	IEC TS 60079-32-1	100
Electrostatic bonding via conductive solid metal bolt/flange connections	IEC TS 60079-32-1	10-100
Additional electrostatic bonding via separately mounted cable	IEC TS 60079-32-1	10
Ioniser (passive/active/radioactive)	IEC TS 60079-32-1	10
Insulating flange for preventing dangerous stray currents	IEC TS 60079-32-1	100
Spark extinguishing system	VdS 2106/EN 15233	10

Platform ATEX153

* Estimates

Explosion protection measures (IPL 3): Risk Reduction Factors (RRF)

Technical explosion protection measures to mitigate the consequences of explosions	Standards & Guidelines	RRF *
Explosion-pressure-resistant and explosion pressure shock-resistant equipment	EN 14460	1000
Inline deflagration/detonation arresters	ISO 16852 ISO-IEC 80079-49 CEN-TR 16793	100
Explosion suppression system Extinguishing barrier	EN 14373/EN 15233 EN 15089	100
Explosion pressure relief systems/Explosion venting devices on enclosures Highly reliable bursting plates	ISO 80079-50 EN 14797 EN 14994 EN 14491 EN 16009 NFPA 68	100 1000
Tanks with weak roof-to-shell seam / joint (frangible roof)	API 650/NFPA 30	100
Flame front diverters (passive)	EN 16020/EN 15089/NFPA 69	100
Passive explosion isolation system/passive flap valves Active explosion isolation system Rotary valves	EN 16447/NFPA 69 EN 15089/NFPA 69 EN 15089/NFPA 69	10 10 100
Explosion absorbing systems	EN 00305166	10
Screw conveyor/product receiver (material chokes for explosion isolation)	EN 15089 CEN-TR 17838	10
Remotely Operated Emergency Isolation Valves (ROEIV) / Shut-Off Valves (ROSOVs)	API RP 553/HSG 244	10

* Estimates

Platform ATEX153

Example Ex-LOPA: mechanical seal of agitator in zone 1

- The shaft seal of agitator in the vessel is intended for use in Zone 1 (Cat.2)
- Explosion of the potentially explosive atmosphere inside the vessel (Zone 1) due to seal overheating may result in a potential fatality

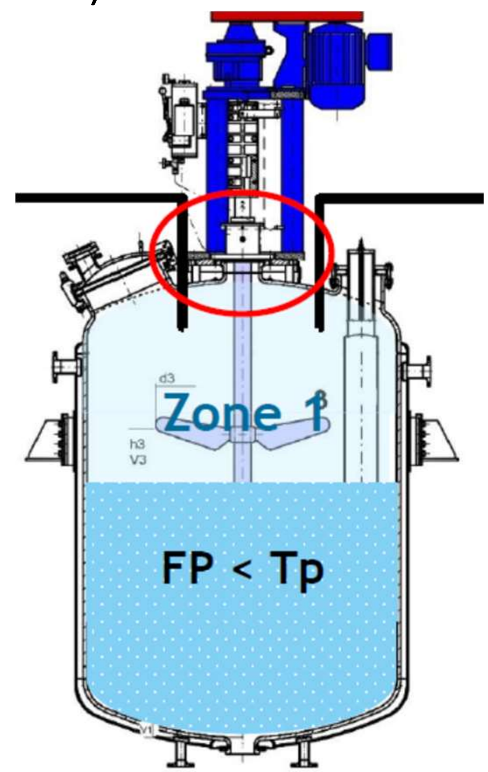
➢ LOPA target value for Major Harm: $\leq 10^{-5}$/yr.

➢ F_{Ig} for rare malfunction of shaft seal (Cat.2): $\leq 10^{-2}$/yr.

➢ P_{Ex} for presence explosive atmosphere (Zone 1): $\leq 10^{-1}$/yr.

➢ IPL1 prevention of explosive atmosphere by inerting: $\leq 10^{-2}$/yr.; or

➢ IPL3 explosion protection by installing venting device: $\leq 10^{-2}$/yr.



Platform ATEX153

Conclusions

- Ex-LOPA is complementary to the conventional PHA-LOPA and allows for a consistent assessment of explosion risks in hazardous areas.
- Practical application of Ex-LOPA method demonstrates the difference between the risk of ignition in a hazardous area and the overall assessment of explosion risks.
- For Ex-equipment suited for the different zone types, the residual ignition hazard frequency appears to be typically in the range between 10^{-3} and 10^{-4} per year.
- Additional measures may be necessary to reduce the explosion risk of hazardous explosive atmospheres to acceptable or tolerable levels, depending on the company's risk policy.
- The failure frequencies for Ex-equipment are based on general data found in literature. In practice, the failure frequencies of specific Ex-equipment may be better. The authors do welcome any additional data.
- This Ex-LOPA method is not applicable for risk assessment of mist explosions or dust explosions originating from dust layers.

Platform ATEX153

Disclaimer

- The contents, practices and guidance expressed in this paper are those of the ATEX 153 Platform - Joint Working Group Ex-LOPA and do not reflect those of employers, or member companies.
- The authors do not warrant that the guidelines are complete or accurate, and may not be suitable for your situation. Any use of this guideline is at the responsibility of the user. All liabilities for losses and claims for damage are excluded.
- This guideline on Ex-LOPA risk assessment method is for informational purposes only and shall not take precedence over implementation of legal requirements, international standards and/or recommendations from original equipment manufacturers (OEM).

Platform ATEX153