# Modeller for kvantitativ risikoanalyse av hydrogenanlegg – påtrengende svakheter og hvordan kan disse utbedres

Fremtidens energikilder – Sikkerhetsutfordringer med fornybar energi
ESRA Webinar

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01.02.2022

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# Content

**What do we know about modelling fire and explosion frequencies for hydrogen systems?**

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Safe Energy Carriers

A project initiative

to close

knowledge gaps

**What do we need to know to model fire and explosion frequencies for hydrogen systems?**

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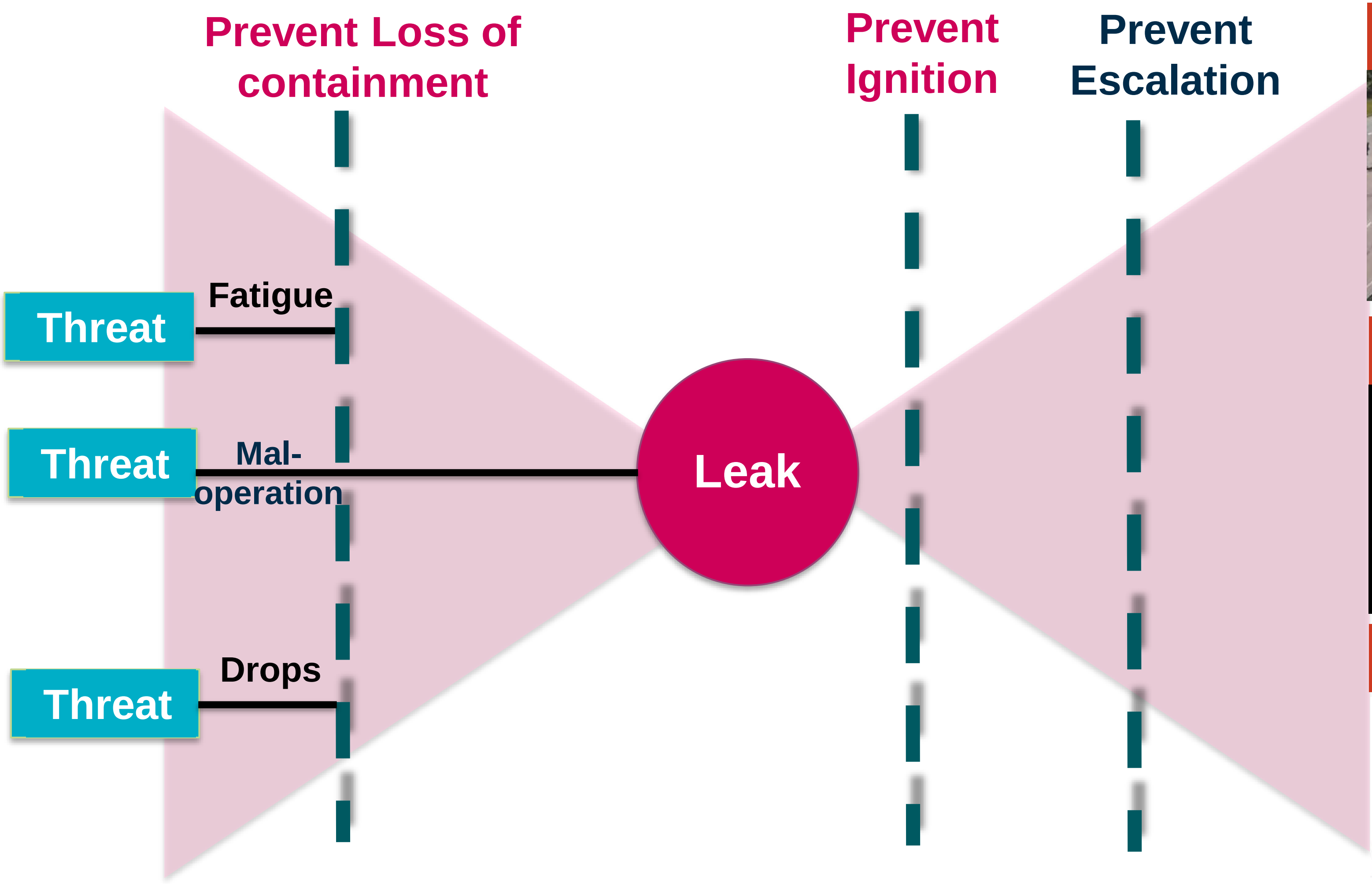
# The well-proven risk management principles apply also for the hydrogen industry…




**Consequence**

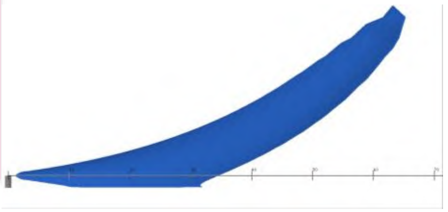
**Explosions**
Small amount of H2 may generate significant blast loads (about 1.5 kg in explosion at fueling station in Sandvika June 2019)

**Consequence**

**High momentum jet fire**

Leaks of pressurized $H_2$ is prone to ignition

**Consequence**



**Gas leaks**
Buyouancy important effect
NB! Momentum of leak push gas along surface before rising!

…but even more important to avoid leaks since ignition control is more challenging

# Risk-based safety zone


The trade-off between frequency and consequence based on quantitative risk analysis model

→ High probability → Long distance

→ Large consequence → Long distance

↓

Driving cost of land use

# General challenges for the risk analyst and safety engineer across sectors

**Maritime**
Need to prove that alternative solution is as safe as conventional technology (with reference to IMO MSC.1 Circ.1455).

Alternative

Conventional

**Land based infrastructure**
New technology and fuels introduced. Questions raised on safety in confined spaces (tunnels)

**All industries**
Storage of large amounts of $H_2$, $NH_3$ and $CO_2$


Challenging to state cost-efficient performance requirements and to optimize design using risk analysis

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# QRA as basis for standards

For standard equipment and events, safety distances can be prescribed by national regulations, and/or may be determined through quantitative risk assessment of a generic design. For any given fuelling station, one may also conduct a quantitative risk assessment, which can be used to understand the risks and the effects of station-specific mitigations; the result of the analysis may result in a recalculation of the safety distance to result in station-specific safety distances. If the safety distance is too large, additional mitigation or prevention measures should be considered and the safety distances may be re-calculated using a quantitative analysis.

NOTE 2 The benefit of conducting quantitative analysis is that it generates safety distances that are specific to the fuelling station/site that is analysed.

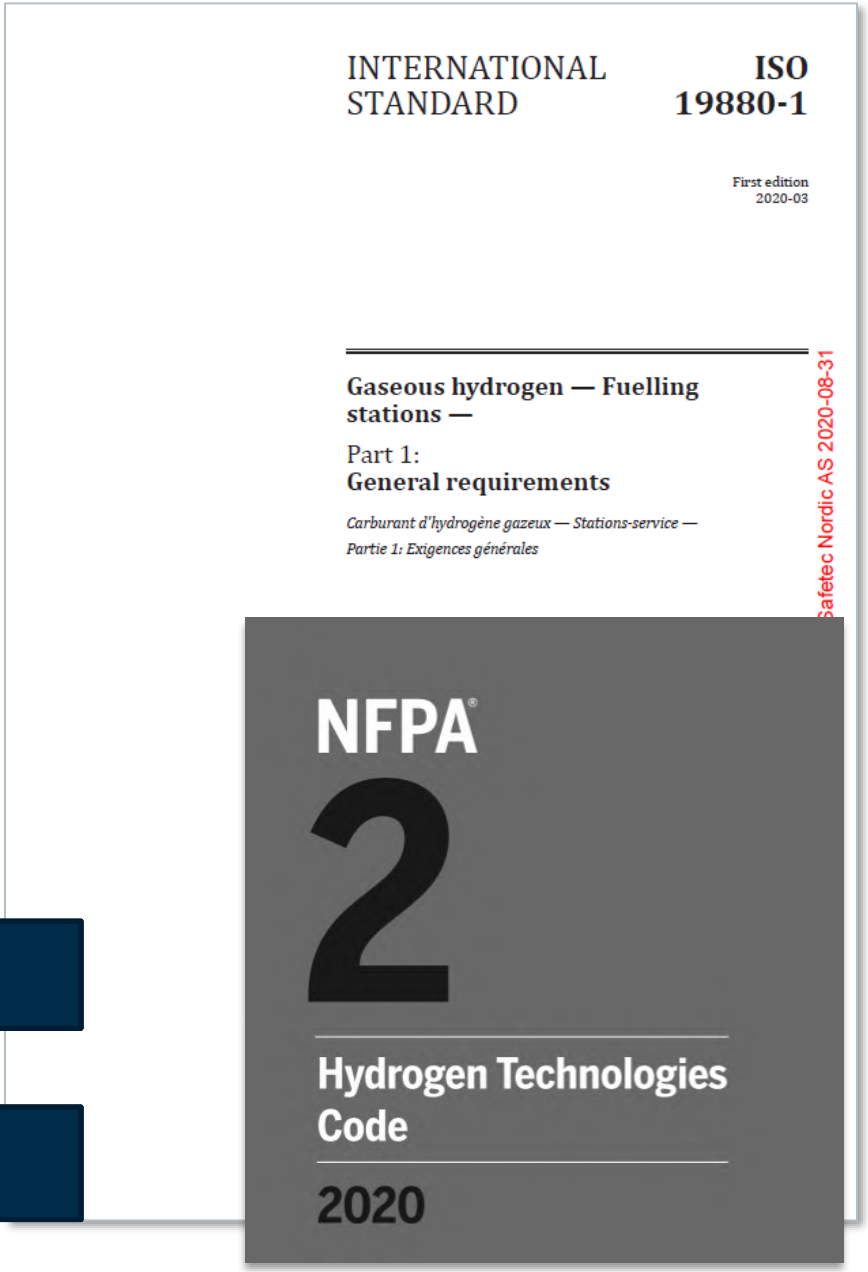


NOTE 3 The quantitative analysis is used to demonstrate that the fuelling station does not pose unacceptable risk to specific targets, taking into account the design and mitigation features of the actual installation. Acceptable quantitative techniques include quantitative risk assessment (QRA) and consequence modelling (i.e., a QRA without quantification of the probability of scenarios). The analysis uses a combination of information and data regarding the fuelling station design and operation, validated physical models, and probabilistic models that meet the criteria discussed in the remainder of this clause.

Use of a common toolkit, preferably validated for hydrogen, is recommended.

Do we have this? What are the uncertainties in the current toolkit?

NFPA suggest risk assessment for safety zone specification



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# Norwegian regulations

## *Risk-based regime for land use*

dsb

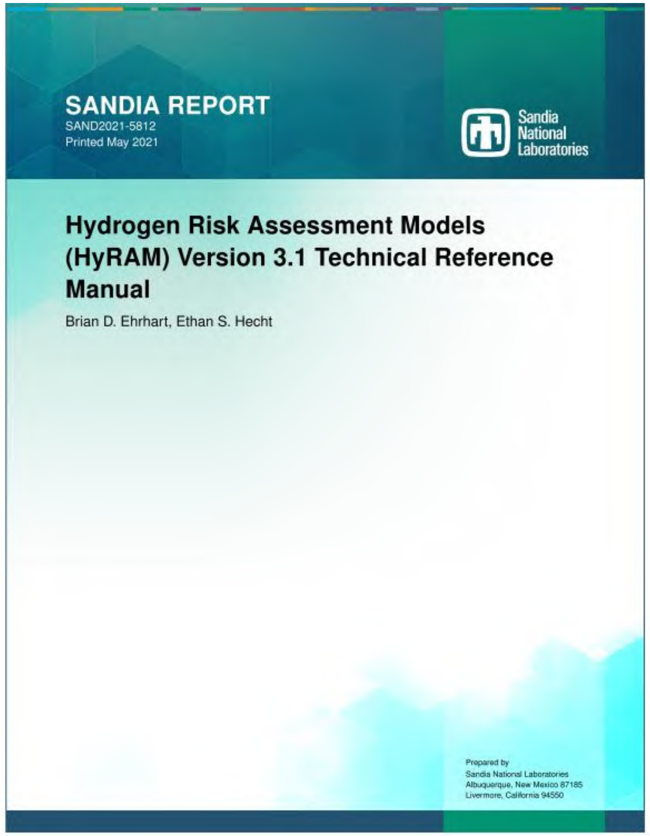
Lloyd's Register

Working together for a safer world

Retningslinjer for kvantitative risikovurderinger for anlegg som håndterer farlig stoff

Rapport til:
Direktoratet for samfunnssikkerhet og beredskap (DSB)

Rapportnr.: 106535/R1 Rev: Sluttrapport A
Dato: 18. oktober 2017



SANDIA REPORT
SAND2021-5812
Printed May 2021

Sandia National Laboratories

Hydrogen Risk Assessment Models (HyRAM) Version 3.1 Technical Reference Manual

Brian D. Ehrhart, Ethan S. Hecht

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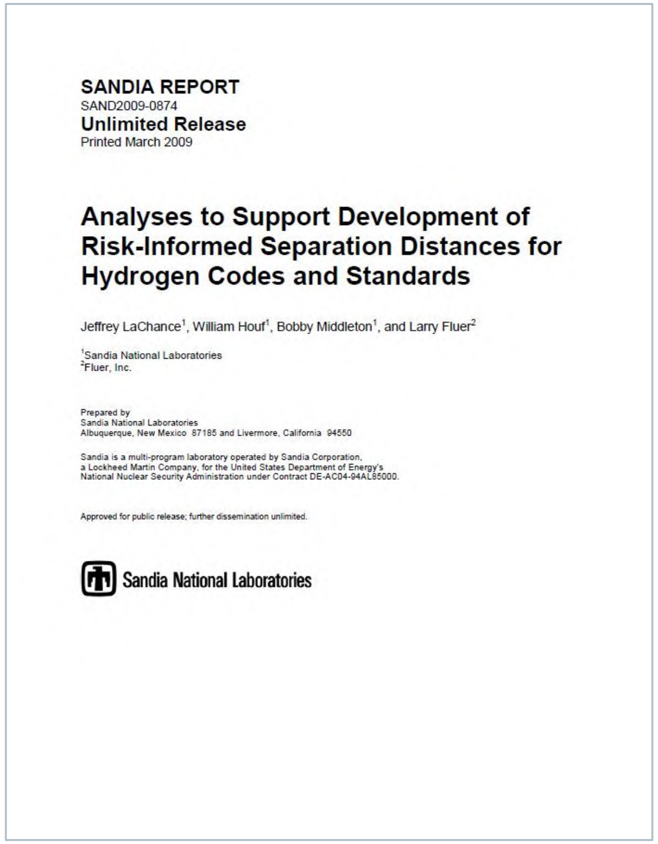

SANDIA REPORT
SAND2009-0874
Unlimited Release
Printed March 2009

Analyses to Support Development of Risk-Informed Separation Distances for Hydrogen Codes and Standards

Jeffrey LaChance[1], William Houf[1], Bobby Middleton[1], and Larry Fluer[2]

[1]Sandia National Laboratories
[2]Fluer, Inc.

Prepared by
Sandia National Laboratories
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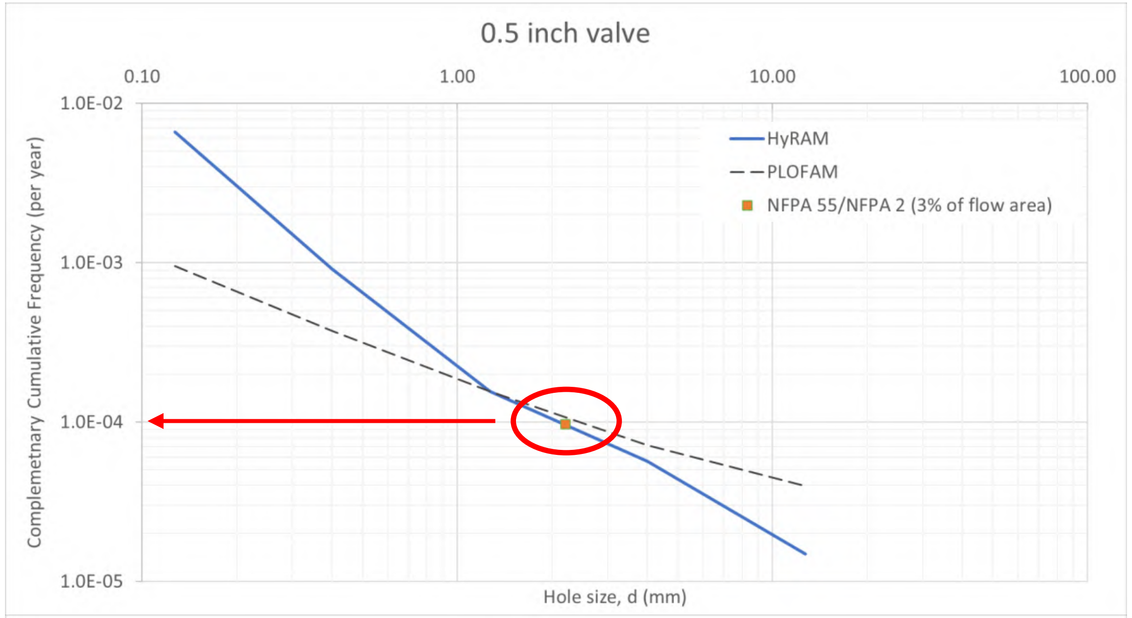
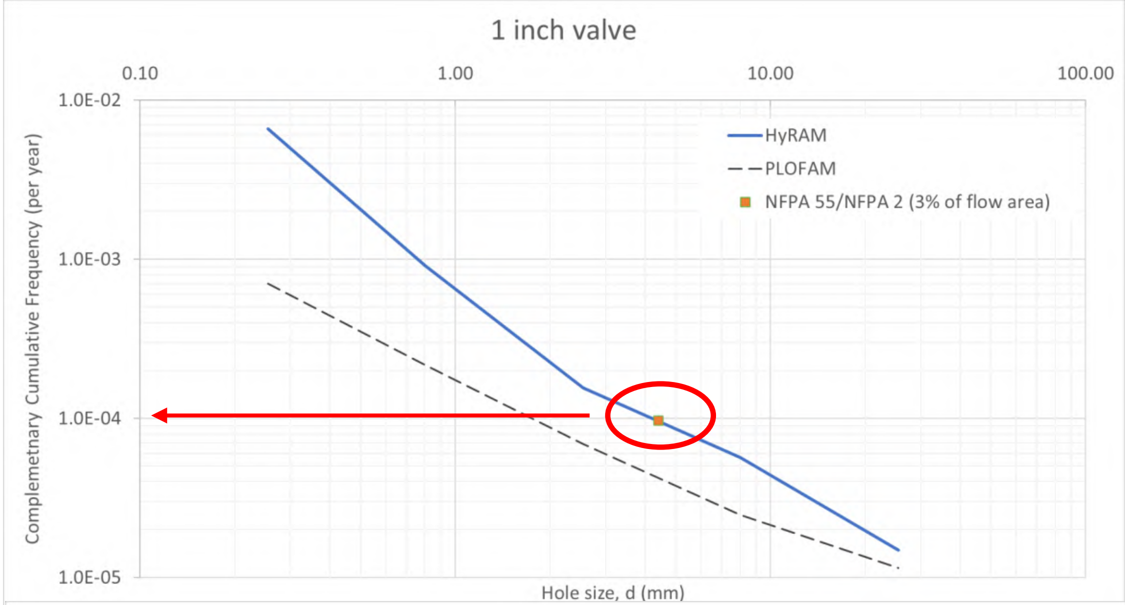
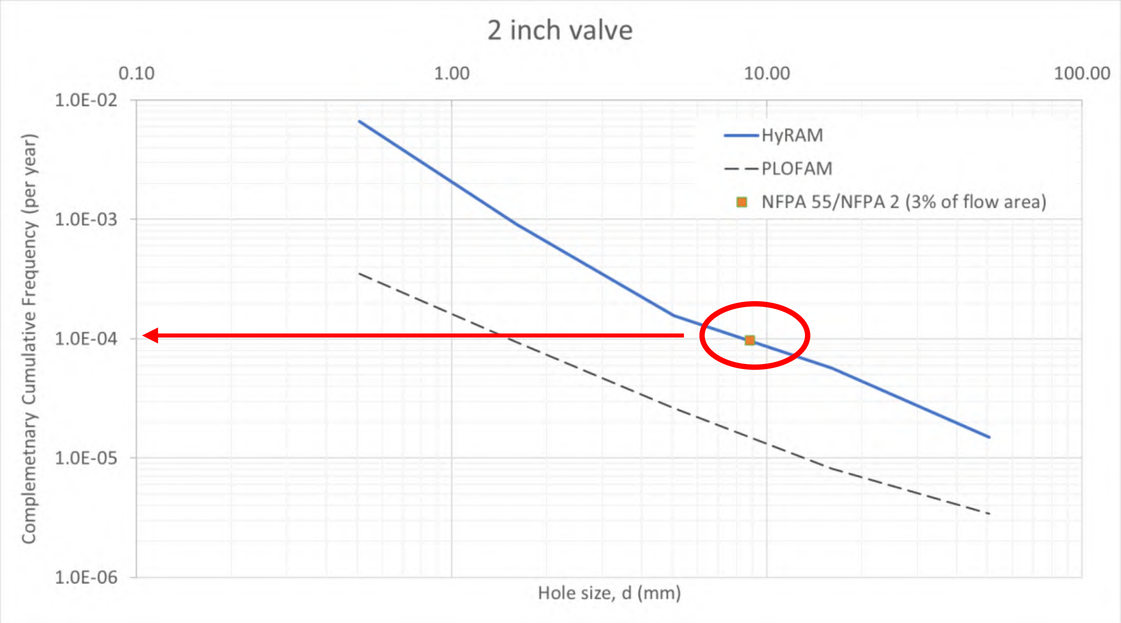
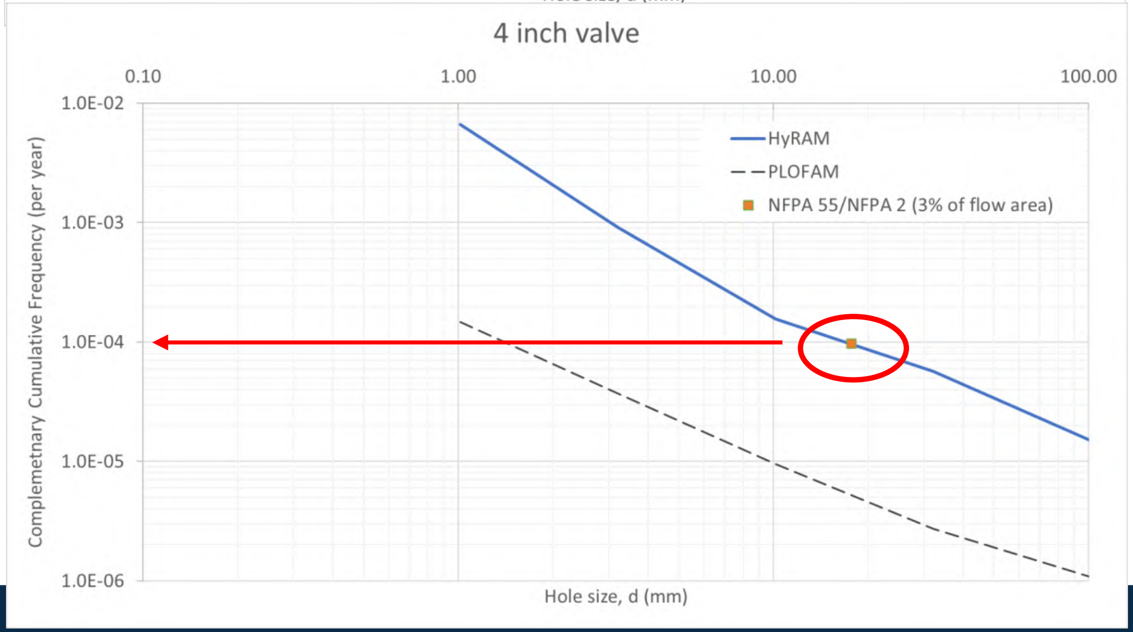
Guidelines recommend HyRAM for $H_2$

# Equipment size dependency in HyRAM compared with offshore standard model (PLOFAM)



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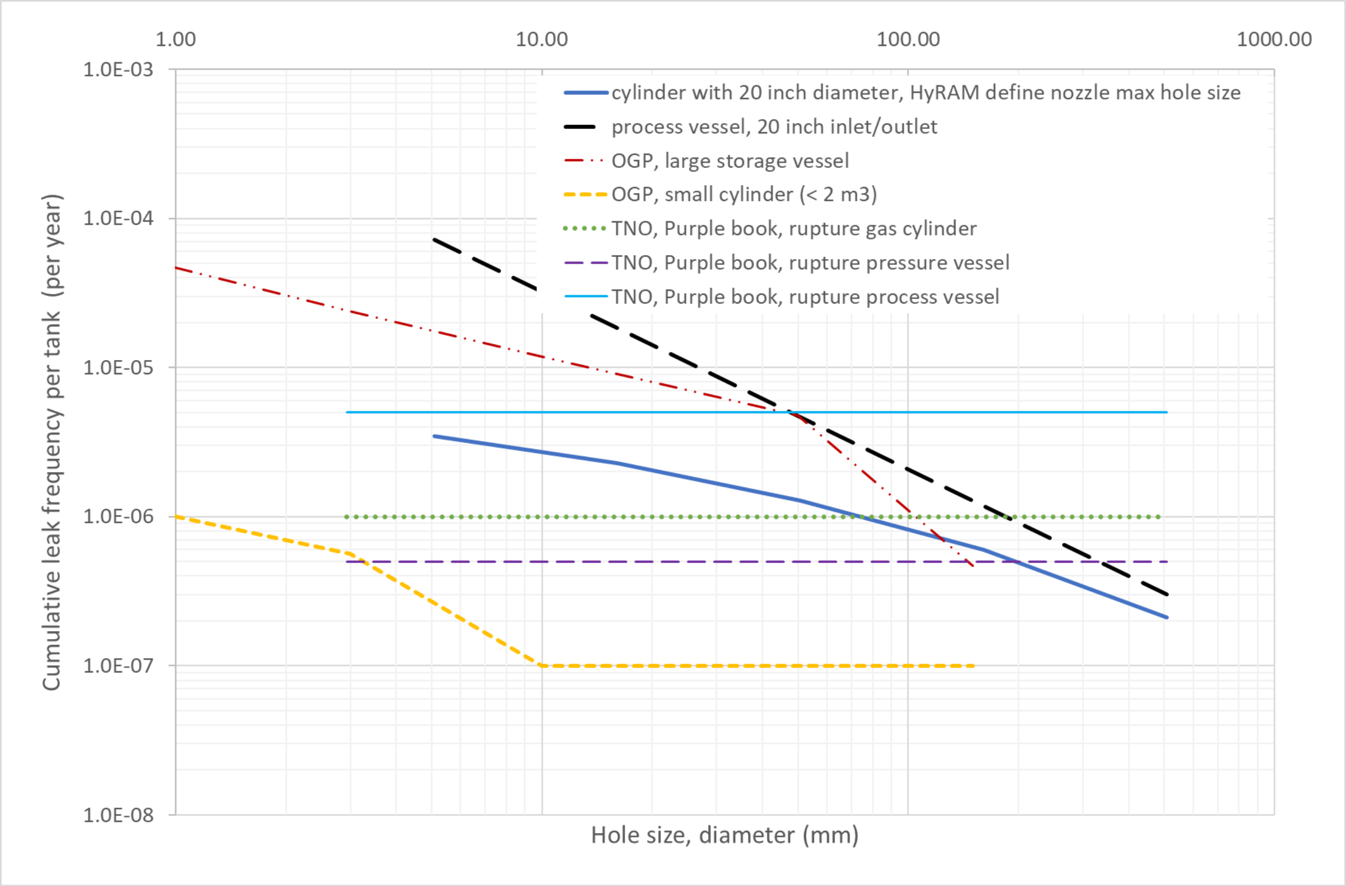
# Risk based safety distance due to tank ruptures?




What is the frequency for rupture scenarios for such a design, can we extrapolate from existing models; 129 tanks · X · $10^{-y}$ ruptures per tank/year?

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# Examples of what we need to copy from the O&G sector - the PLOFAM and MISOF projects

- As we speak, a project activity validating the PLOFAM and MISOF models for land-based facilities processing oil and gas including hydrogen rich streams is executed. The project will be finalized in Q1 2022
- PLOFAM hole size distributions derived for offshore installations appear to fit well with what we observed at the land-based facilities
- H2 rich systems does not appear to stand-out as particularly prone to leaks, but limited data and they are not entirely representative for green hydrogen.
- Investigation of H2 rich process gas stream at facilities processing oil land gas in Norway confirms that small leaks is likely not to ignite. The biggest one, filling a big process unit of combustible H2 gas did not ignite.
- A side note wrt objective of this presentation:
  in cases where the magnitude of our population data allow for an assessment of the hole size distributions, the data does not appear to fit with very well with models used in industry, for example (1) loading operations with fixed loading arm and (2) HyRAM applied for H2 rich process streams (grey hydrogen)

**High quality population data is required to derive models with appropriate accuracy**

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# What about ignition models?

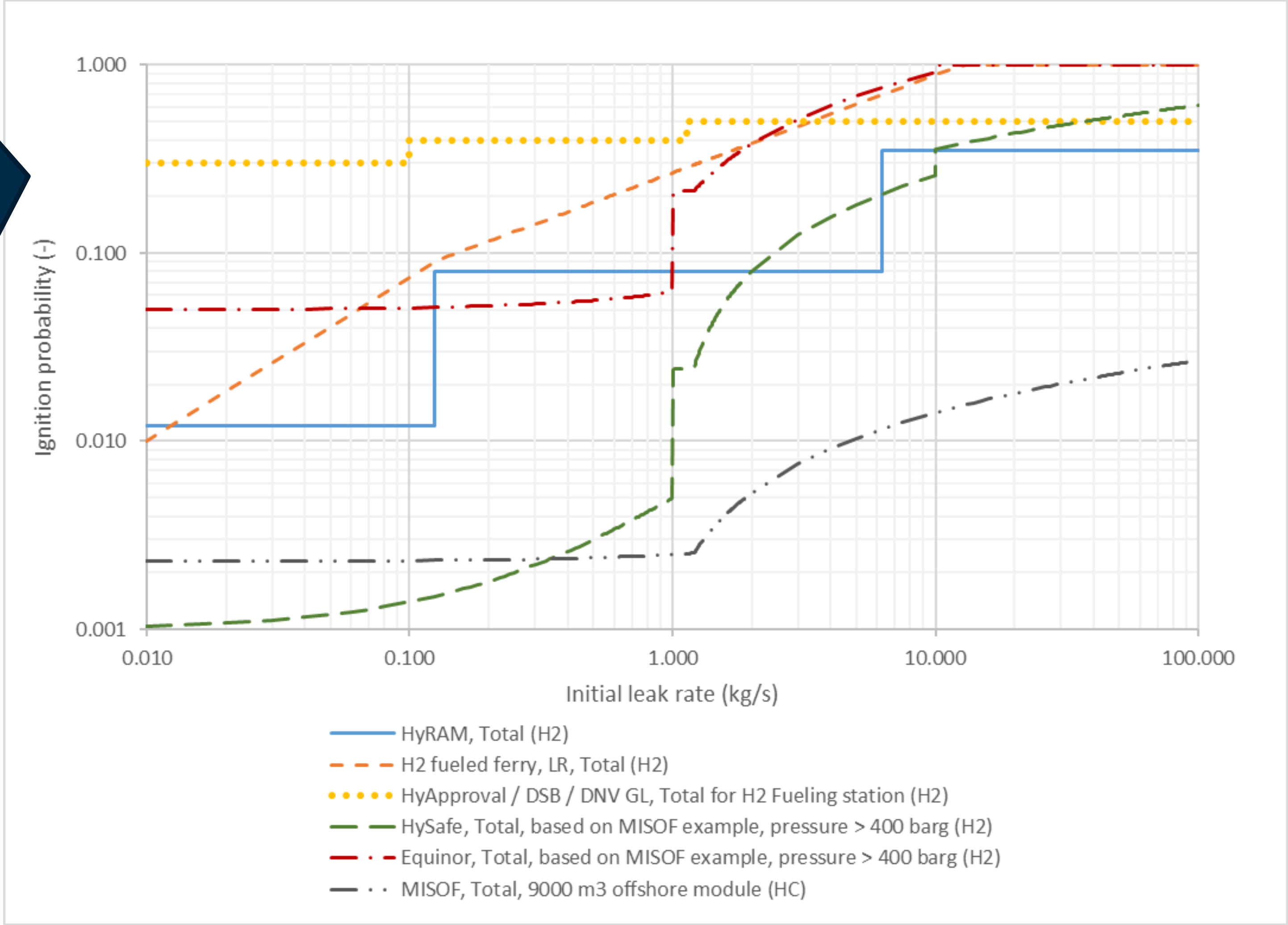
Do we have adequate knowledge about the ignition mechanisms? The importance of the pressure is debated.

Do we have statistical data to justify the ignition probability?

Will enhanced ignition control add value to H2 production units?

What about liquified hydrogen; should the ignition probability model be different?

**Overview ignition probability models**



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# Recipe: you take what you have and do the best you can

CLASSIFICATION OF HAZARDOUS LOCATIONS

*By A.W. Cox, F.P. Lees and M.L. Ang*

*A report of the Inter-Institutional Group on the Classification of Hazardous Locations (IIGCHL)*

**Member Institutions:**
The Institution of Chemical Engineers
The Institution of Electrical Engineers
The Institution of Gas Engineers
The Institution of Mechanical Engineers

INSTITUTION OF CHEMICAL ENGINEERS

IGNITION SOURCES AND PROBABILITIES

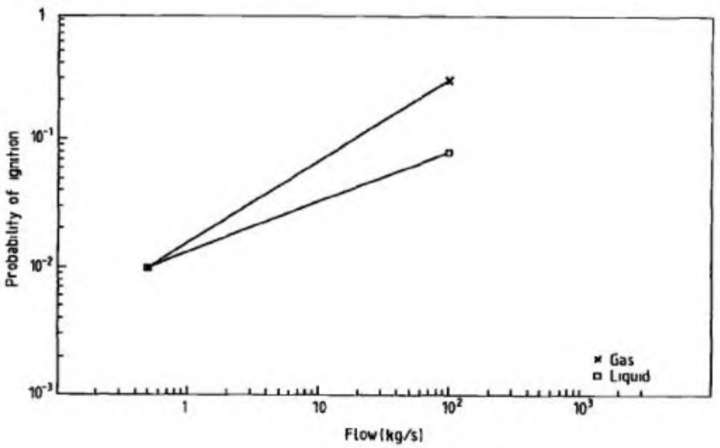


Figure 15.1 Estimated probability of ignition for leaks of gas or liquid

**Table 15.3 Estimated probability of ignition of leaks of flammable gas or liquid**

| *Leak* | *Probability of ignition* Gas | Liquid |
|---|---|---|
| Minor (< 1 kg/s) | 0.01 | 0.01 |
| Major (1 – 50 kg/s) | 0.07 | 0.03 |
| Massive (> 50 kg/s) | 0.3 | 0.08 |

Turning to offshore, Dahl *et al.* (1983) have analysed ignition data for gas and oil blowouts, which may be regarded as massive releases. The data are

| Blowout | No. of blowouts | No. of ignitions | Probability of ignition |
|---|---|---|---|
| Gas | 123 | 35 | 0.3 |
| Oil | 12 | 1 | 0.08 |


Dahl, E. (1983). *Risk of oil and gas blowout on the Norwegian Continental Shelf*. SINTEF, Trondheim, Rep.STF 88A82062.


HyRAM
HYDROGEN RISK ASSESSMENT MODELS

- Reduce leak flow ranges by a factor 8
  - Allowing for differential molecular weight CH4vs H2, which directly affects the size of flammable cloud
- Increase ignition probabilities by 16%
  - Allowing for the ratio of the flammable range of H2vs CH4
  - Allowing that 15-75vol% constitutes only 16% of total cloud size above LFL (from modeling)
- Assume immediate to delayed ignition probabilities are 2:1
  - Total ignition probability is immediate and delayed probabilities added together

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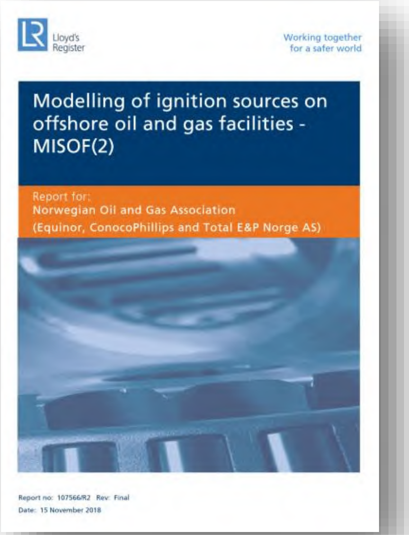
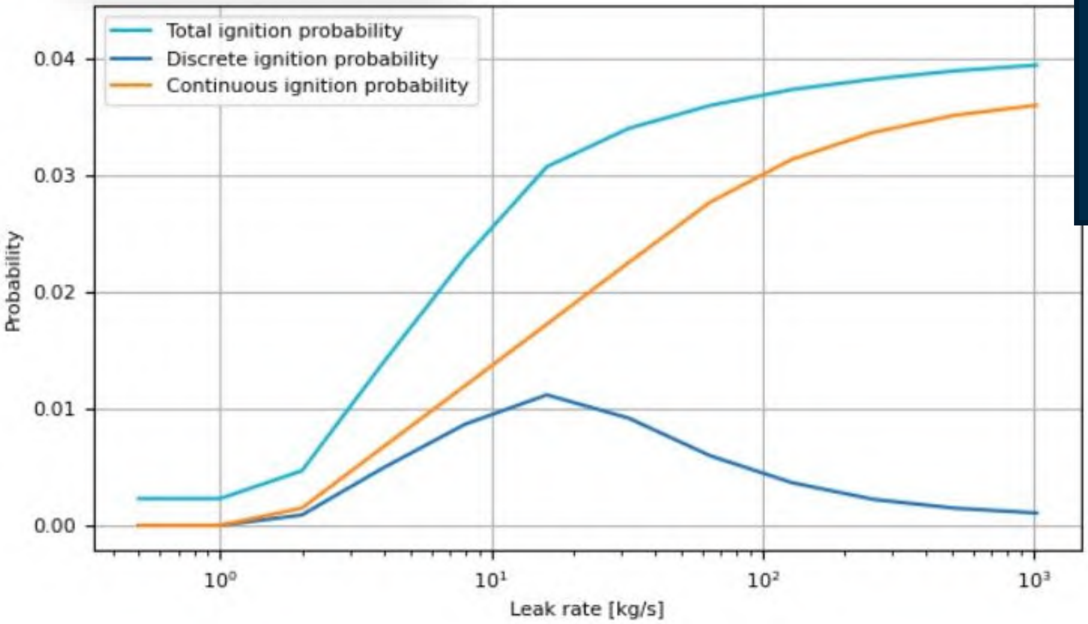
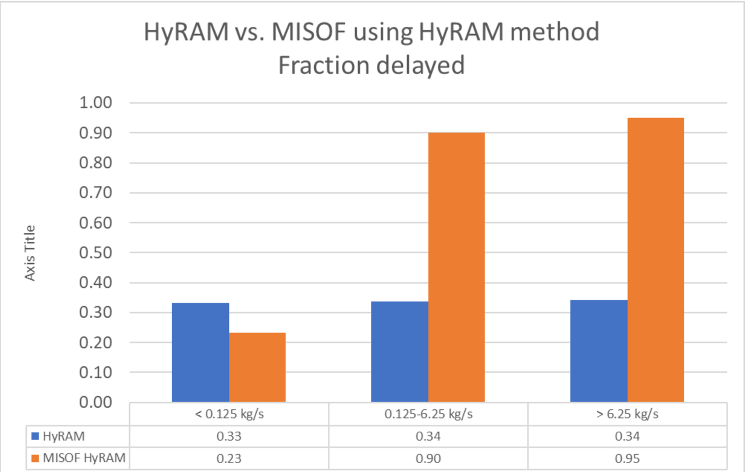
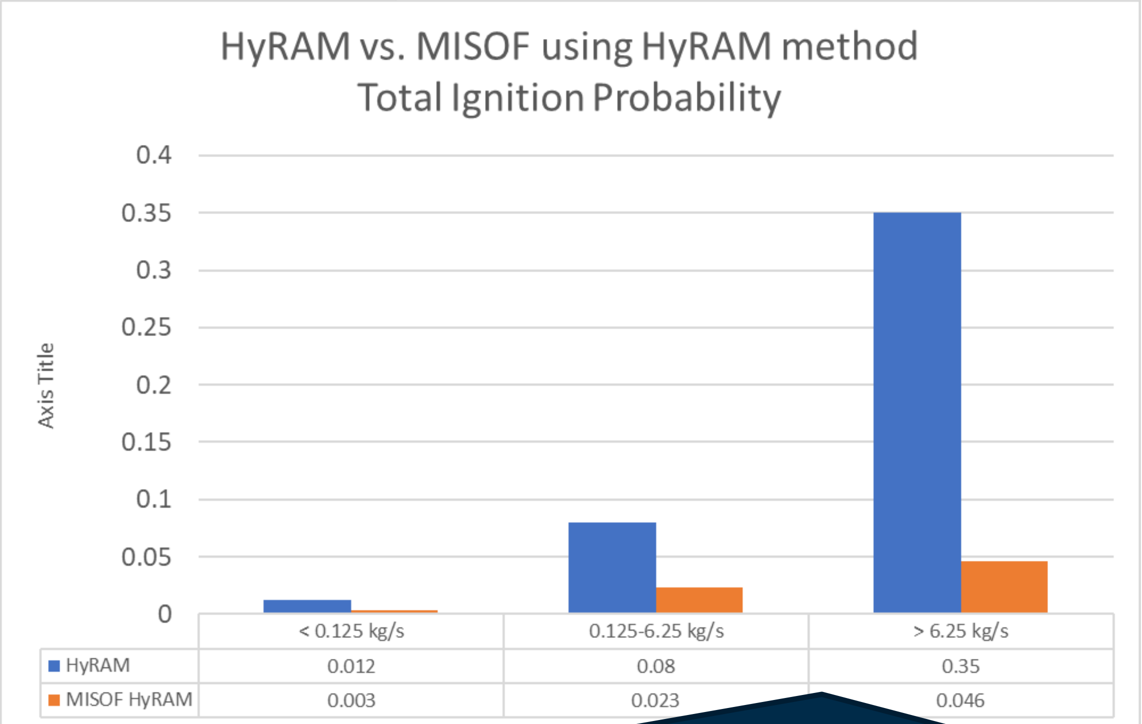
# Using updated high quality data from NCS and UKCS Oil and Gas Installations




Ignition probability for typical offshore module using PLOFAM and MISOF




Can only be answered by high quality data (ignited *vs* unignited events) and improved understanding of ignition mechanisms

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# Simple math, but hard work needed to find the numerator and denominator

$H_2$

$$\frac{\textit{Number of ignited incidents}}{\textit{Number of leaks in a controlled population}} = ?$$

O&G

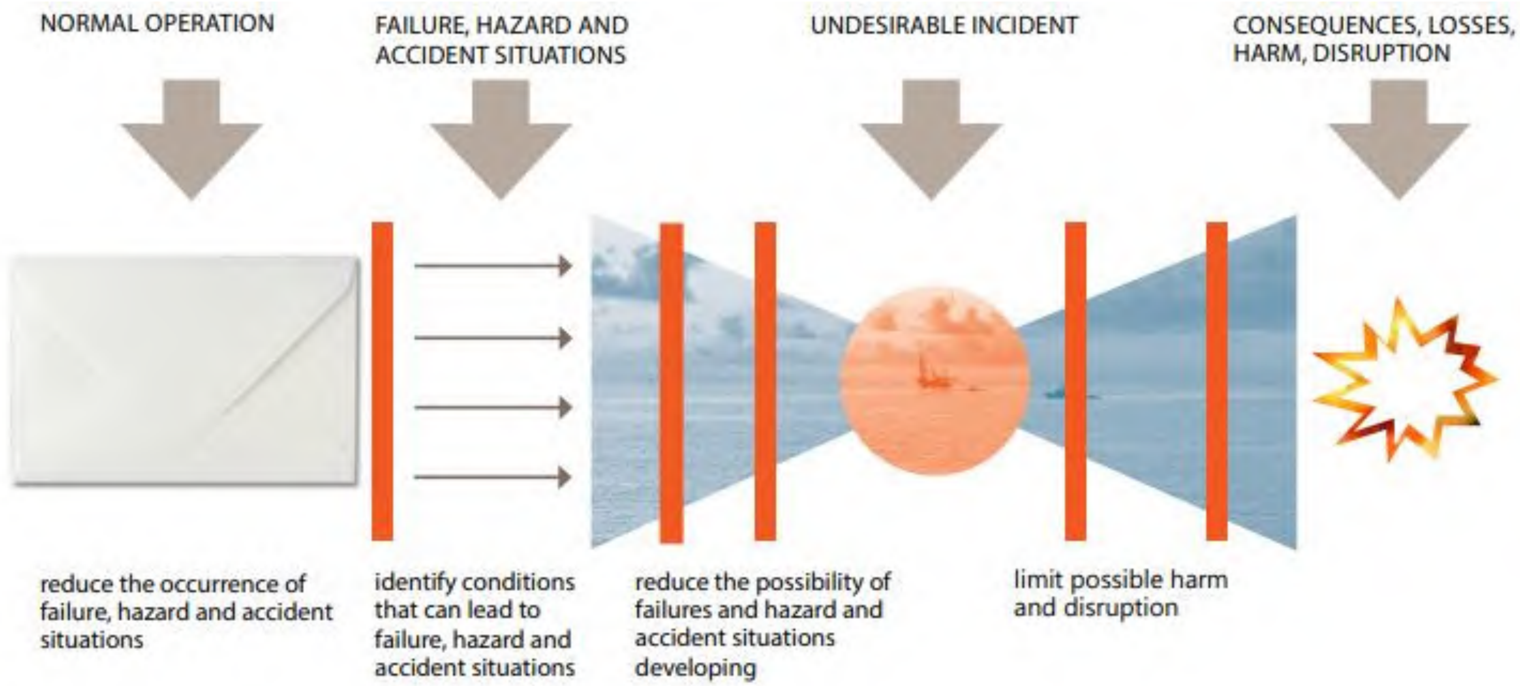
*UKCS & NCS*

$$\frac{3}{1200} = 0.25\%$$

# SAFEN will close knowledge gaps on how to avoid disruption of normal operation

First principle in risk management is to identify the solutions that avoid the undesirable incident

Barriers mitigating consequences are also fundamental, but always second to barriers controlling occurrence




There is a knowledge gap on understanding failures, hazards and accident situations in the renewable industry involving $H_2$, $CO_2$ and $NH_3$

Knowledge gaps on consequence modelling are not addressed by SAFEN. Where input is relevant, we utilize state-of-the-art knowledge on consequence modelling

*The figure is taken from PSA's barrier memorandum*

# SAFEN

## Safe Energy Carriers

### Cost-efficient risk-based methodologies across the renewable sector involving hydrogen, ammonia and $CO_2$

**Status**: JIP project under establishment

**Funding:** Industry partners and consultancies (in-kind)

**Budget:** 5 - 10 MNOK for Phase 1 (depending on number of paying partners)

**Schedule**: Start-up Phase 1 in Q1 2022 with 12 months duration

**Project owner:** Safetec

**Partners:**

- Consultancies (DNV, Proactima, Gexcon and Vysus Group)
- Authority: DSB (Norway)
- Industry partners with confirmed interest per 30. January 2022:
  Equinor, Yara, Vår Energi, Aker Clean Hydrogen, Origin Energy


**Activities:**

WP1 - Detailed definition of scope

WP2 - Compilation of statistical data

WP3 - Failure mode analysis

WP4 - Ignition mechanisms and ignition probability

WP5 - Methodologies and input to safety standards

What do we know about modelling fire and explosion frequencies for hydrogen systems?

# SAFEN

## Safe Energy Carriers

A project initiative

to close

knowledge gaps

What do we need to know to model fire and explosion frequencies for hydrogen systems?

**Want to join the team building the bridge?**

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# Thank you

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