AEA Webinar

Ammonia Safety

The Maritime Decarbonisation Hub

Presenter: Samie Parkar

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Decarbonisation Objectives as Questions

Does the fuel result in decarbonisation?

Does the fuel work as a fuel?

Can the fuel be used safely?

What is the risk to a ship's crew of using ammonia as a fuel?

Is that risk acceptable?

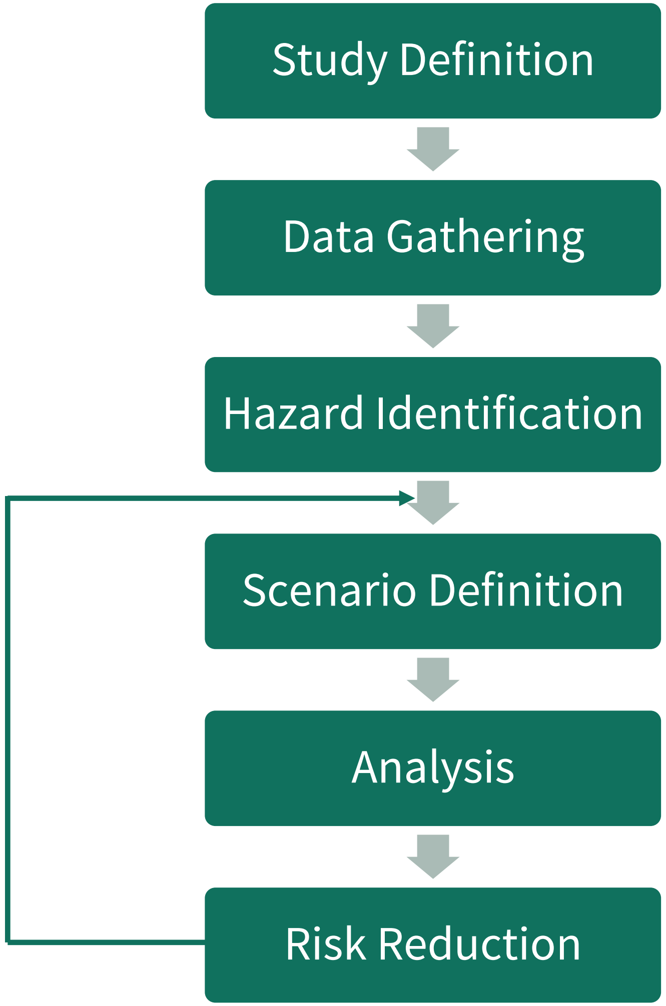
What safeguards can be applied to bring the risk down?

What is the risk?

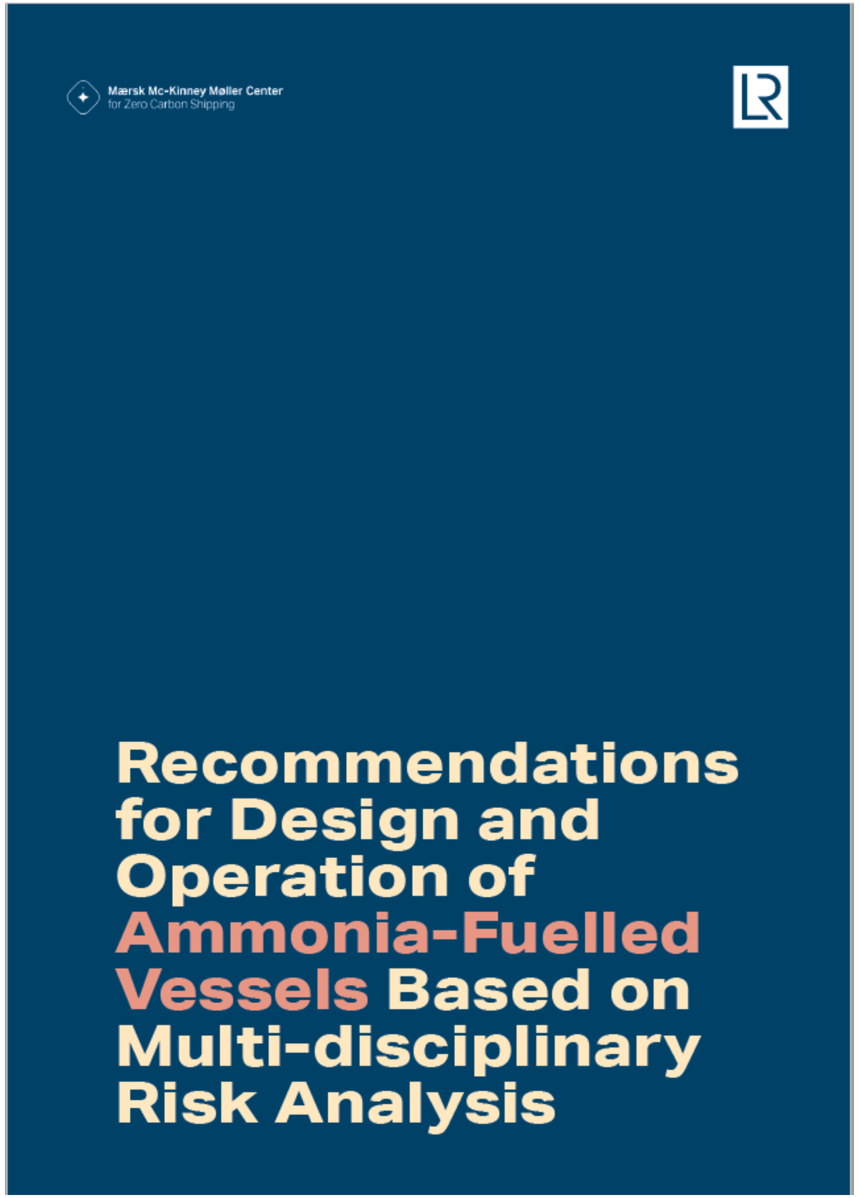
We used Quantitative Risk Assessment (QRA) to get numerical estimates of crew risk

QRA has been used for a long time in the Offshore Oil & Gas and Onshore Process industries but its use in Marine is relatively new

It is very detailed and can give useful insights into the main factors driving the risk



Ammonia Safety Project



LR/MMM Centre - Ammonia Study

Joint project with MMMCZCS, Maersk, MAN ES, NYK, MHI, Total Energy, BP, Stolt, Cargill, V.Group, ABS and CF Industries.

Three different vessel types.

Focus on risk to the crew.

Two main elements:

- Detailed, quantitative risk assessment (QRA).
- Analysis of human factors considerations.

Vessel Designs

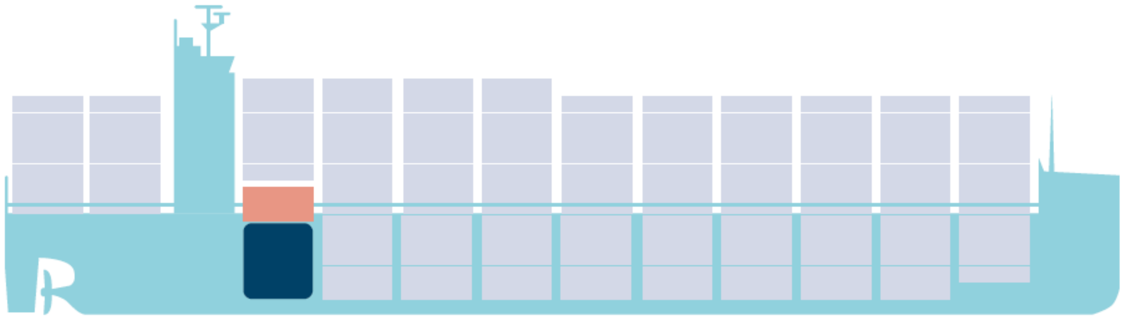


Figure 2: Simplified schematic of container ship reference design (fully refrigerated).

FPR (fuel preparation room)
Fuel storage tank

Figure 3: Simplified schematic of tanker reference design (semi-refrigerated).

FPR (fuel preparation room)
Fuel storage tank

Figure 4: Simplified schematic of bulk carrier reference design (fully pressurized).

FPR (fuel preparation room)
Fuel storage tank

What is the risk?

- QRA
  What is the risk?
  - Review of HAZID Findings and Accident Experience
    - Ship Collision Study [ABS]
    - Inclusion of ‘external events’
  - Gas Dispersion Studies
    - Dispersion from Vent Mast & Ventilation Exhausts
    - CFD Analysis – Engine Room [ABS]
  - Risk Reduction Workshops

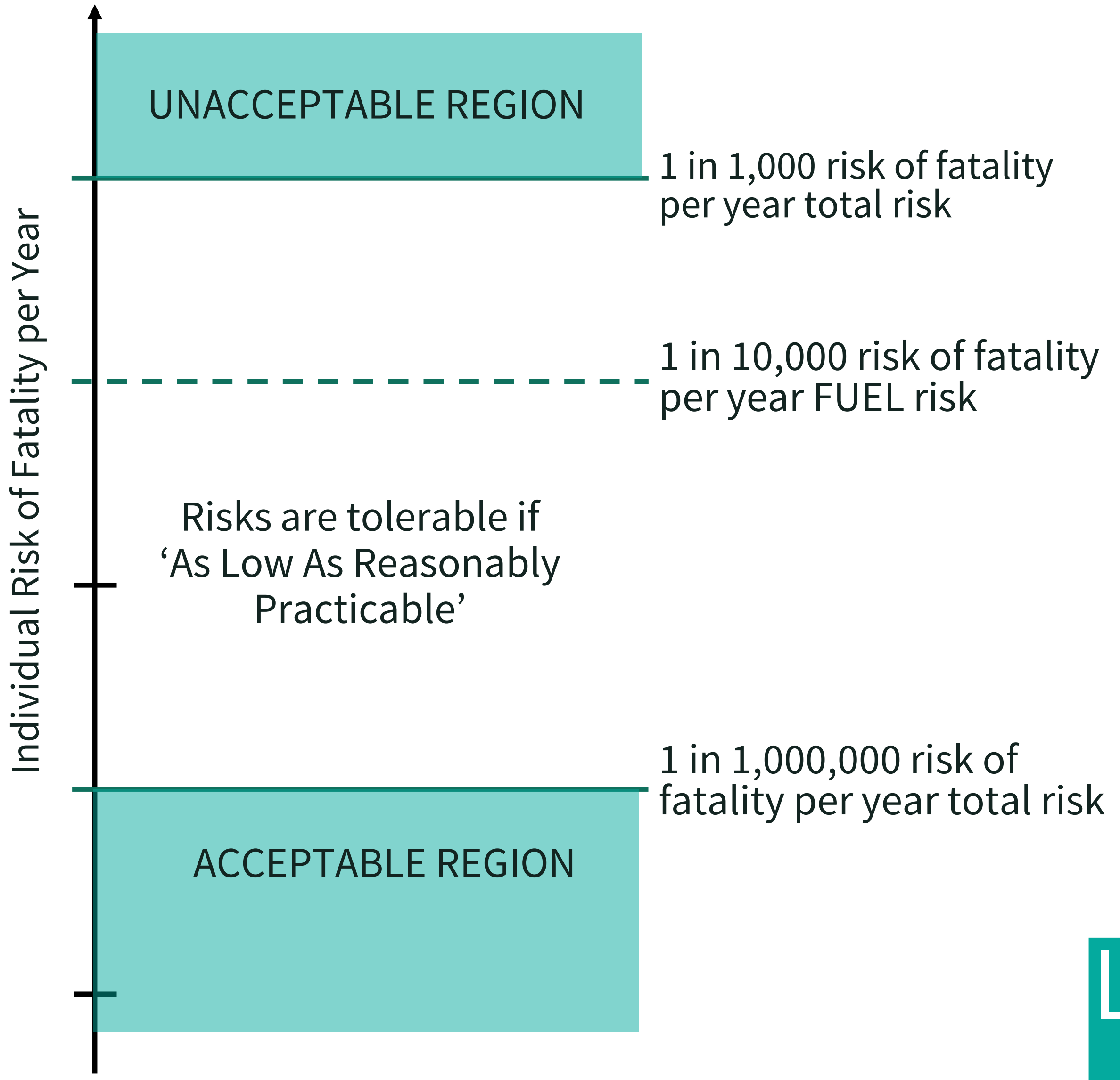
Is the risk acceptable?

How safe is safe enough?

We used well-established, internationally recognised risk criteria as a framework for judgement

To this we added a more stringent project target

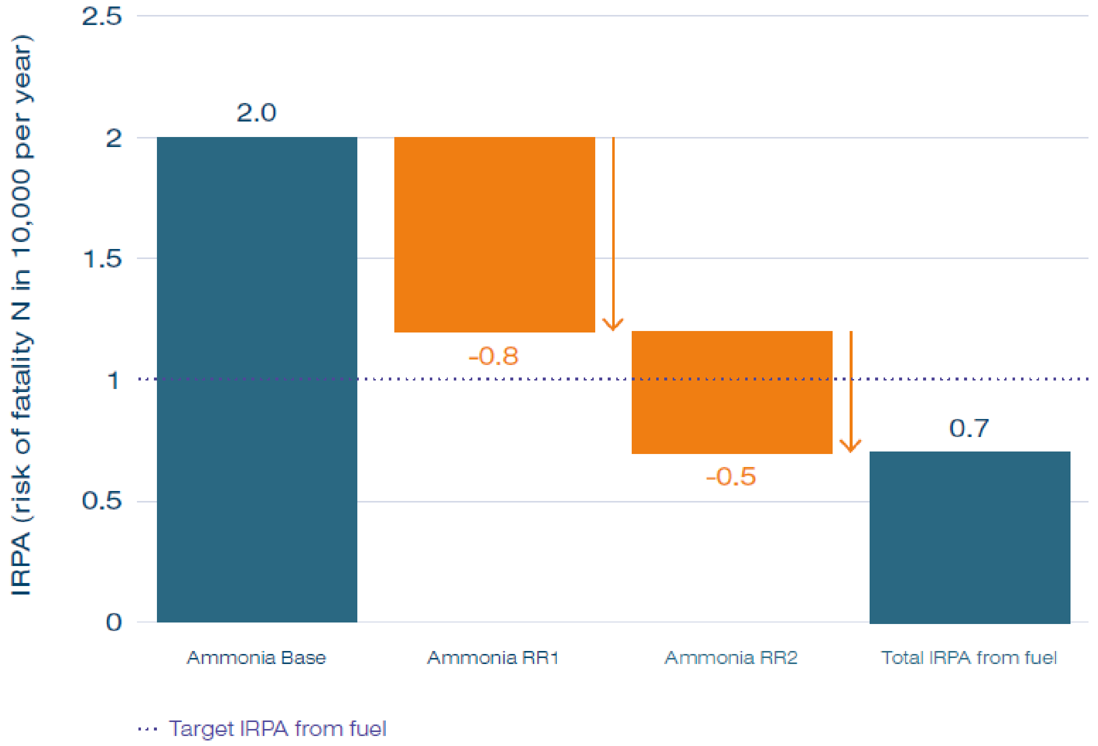
‘As Low As Reasonably Practicable’: risk mitigation is applied until the cost of doing more would become very large compared to the benefit you would get



What safeguards can be applied?

Process:

- Take a design, analyse it.
- Look at the results to find the highest risks and what's driving them.
- Propose measures to mitigate risks, focussing on the risk drivers.
- Incorporate into the design and re-analyse.



What safeguards can be applied?

Reduce the impact of a leak

- Store at a lower temperature (tends to give lower risk / less risk mitigation effort required)

Reduce the time of exposure

- Access to and length of time spent in spaces containing ammonia equipment should be minimised, monitored and controlled

Reduce the exposure to leak sources

- Divide the fuel preparation room into two or more separate rooms containing different groups of equipment

Safe by location

- Ventilation outlets from spaces containing ammonia equipment should be placed in a safe location adequately separated from areas accessed by crew

Rapid, reliable leak detection and isolation

- Multiple sensors of different types to detect ammonia leaks should be installed

Thank you

Contact details:

Andrew Franks
andrew.franks@lr.org

Samie Parkar
samie.parkar@lr.org

Foundation

The **Lloyd's Register Maritime Decarbonisation Hub** is a joint initiative between Lloyd's Register Group and Foundation.

The mission of the Lloyd's Register Maritime Decarbonisation Hub is to accelerate the sustainable decarbonisation of the maritime industry.

www.maritimedecarbonisationhub.org

Ammonia Properties

Property (Units)	Ammonia Value	Methane Value
Odour (-)	Pungent, suffocating odour	None (unless 'stenching agent' added)
Boiling point (°C)	-33.35	-161.5
Autoignition temperature (°C)	651	537
Lower Explosive Limit in air (volume %)	15	5.3
Upper Explosive Limit in air (volume %)	28	14
Minimum Ignition Energy (mJ)	680	0.3
Acute Exposure Guideline Level 1 (AEGL-1), 30 minute exposure (nondisabling)	30	n/a
Acute Exposure Guideline Level 2 (AEGL-2), 30 minute exposure (disabling)	220	n/a
Acute Exposure Guideline Level 3 (AEGL-3), 30 minute exposure (lethal)	1,600	n/a
Solubility in water at 25C (g / 100ml)	32	n/a

Much less flammable, harder to ignite

53,000 ppm

Toxic

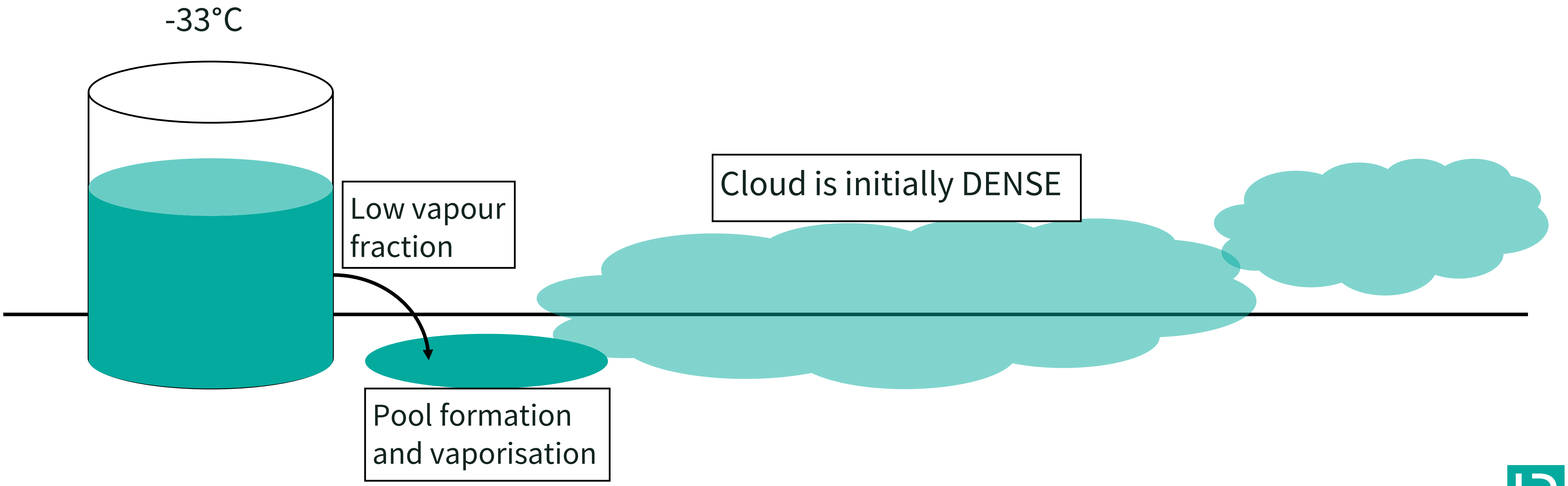
Soluble

AEGL-1: irritation, discomfort, reversible effects.
AEGL-2: irreversible, serious, long-lasting effects.
AEGL-3: life-threatening health effects, death

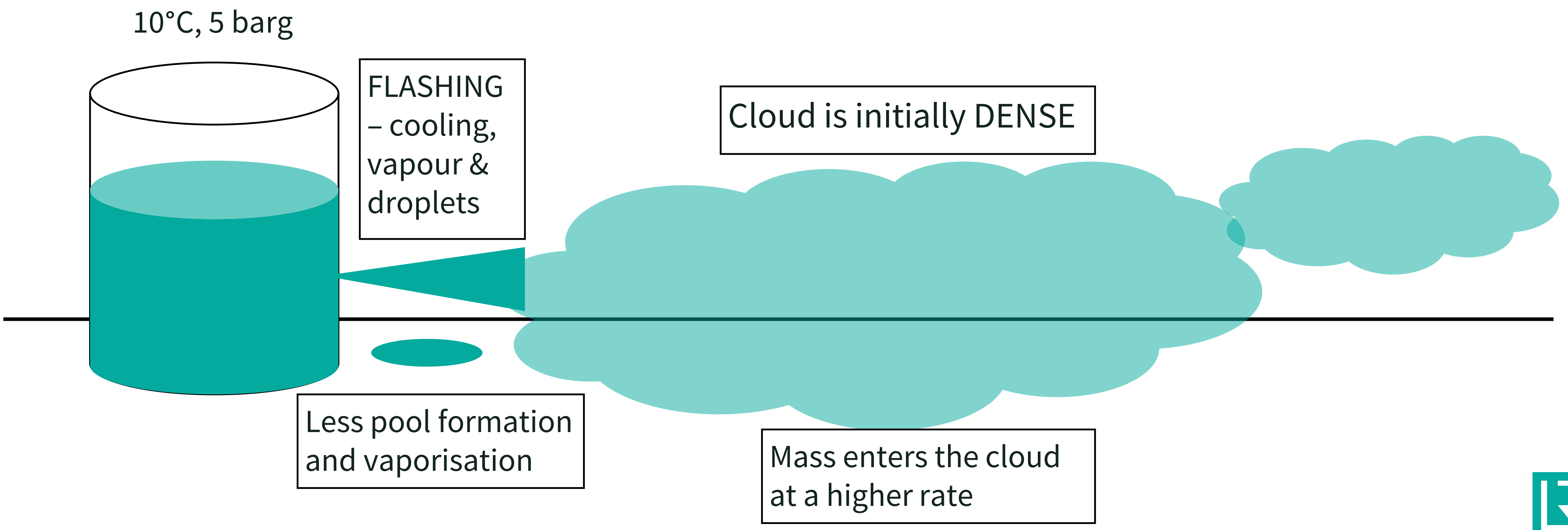
Recommendation 1

Store at a lower temperature (tends to give lower risk / less risk mitigation effort required)

Ammonia Behaviour - Refrigerated



Ammonia Behaviour - Pressurised



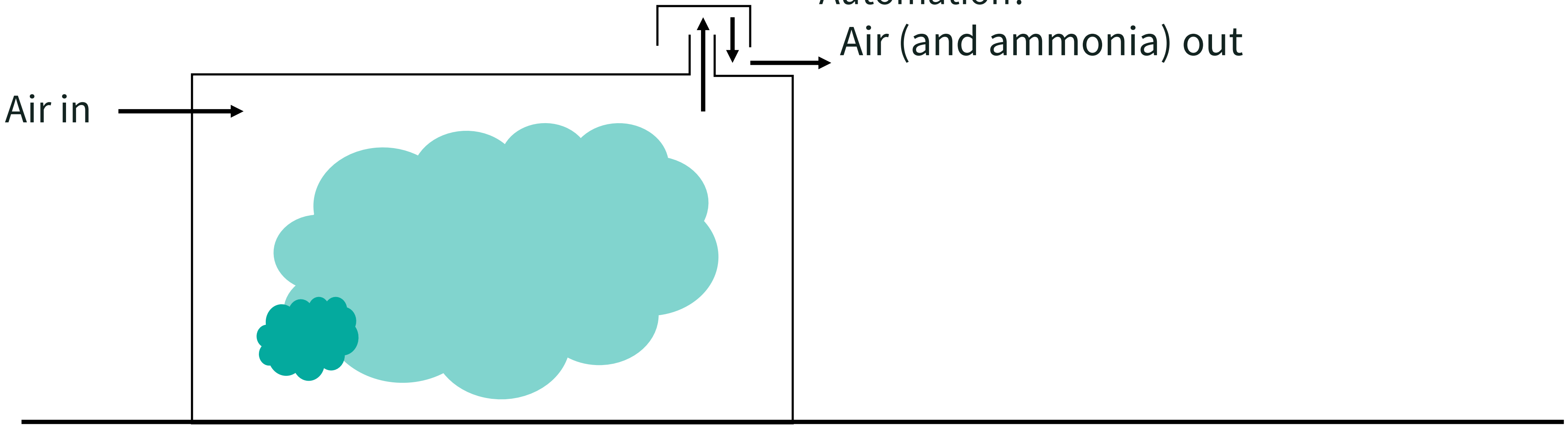
Recommendation 2

Access to and length of time spent in spaces containing ammonia equipment should be minimised, monitored and controlled

Ammonia in Spaces

Even with ventilation, concentrations increase rapidly. Ventilation is effective mitigation for FLAMMABLE effects, much less so for TOXIC effects

Detection, alarm, shutdown
Control access
Minimise presence
Maintenance when shut down
PPE
Automation?

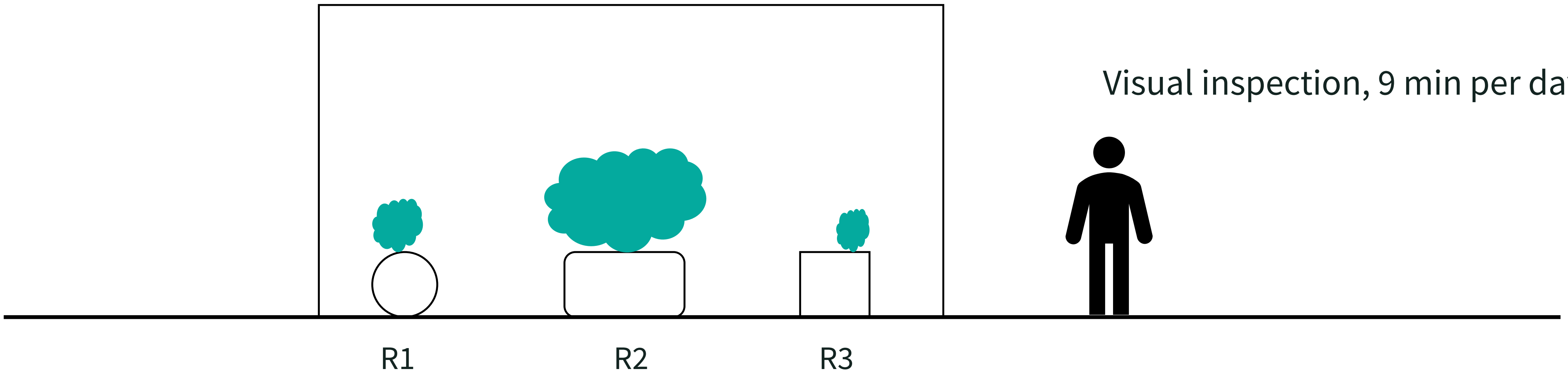


Ammonia in Spaces

How many leak sources in any one space?

Risk = (9/1440) x (R1 + R2 + R3)

Visual inspection, 9 min per day



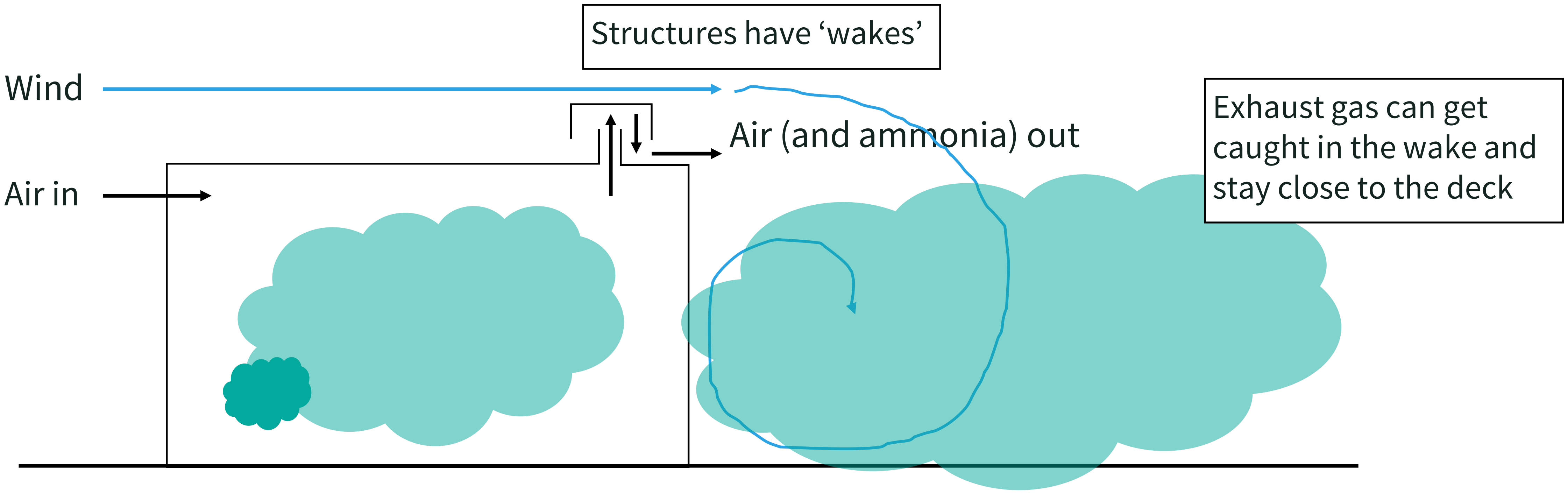
Ammonia in Spaces

How many leak sources in any one space?

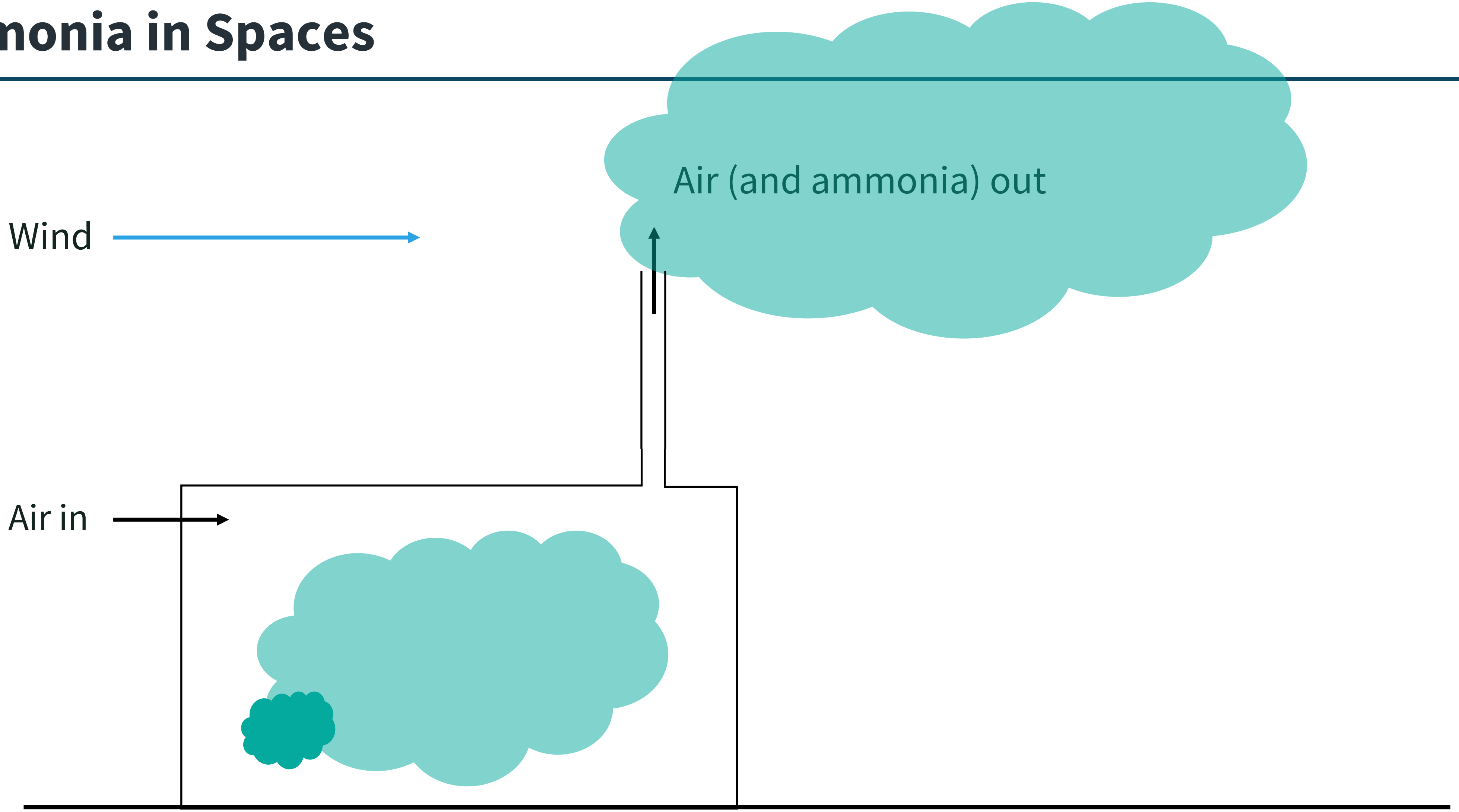
$$
\begin{aligned}
\text{Risk} &= (3/1440) \times R1 \\
&\quad + (3/1440) \times R2 \\
&\quad + (3/1440) \times R3 \\
&= (3/1440) \times (R1 + R2 + R3)
\end{aligned}
$$

Visual inspection, 3 min / day EACH

Ammonia in Spaces



Ammonia in Spaces



Ammonia in Spaces

Ammonia leaking into a space may not be evenly mixed throughout the space

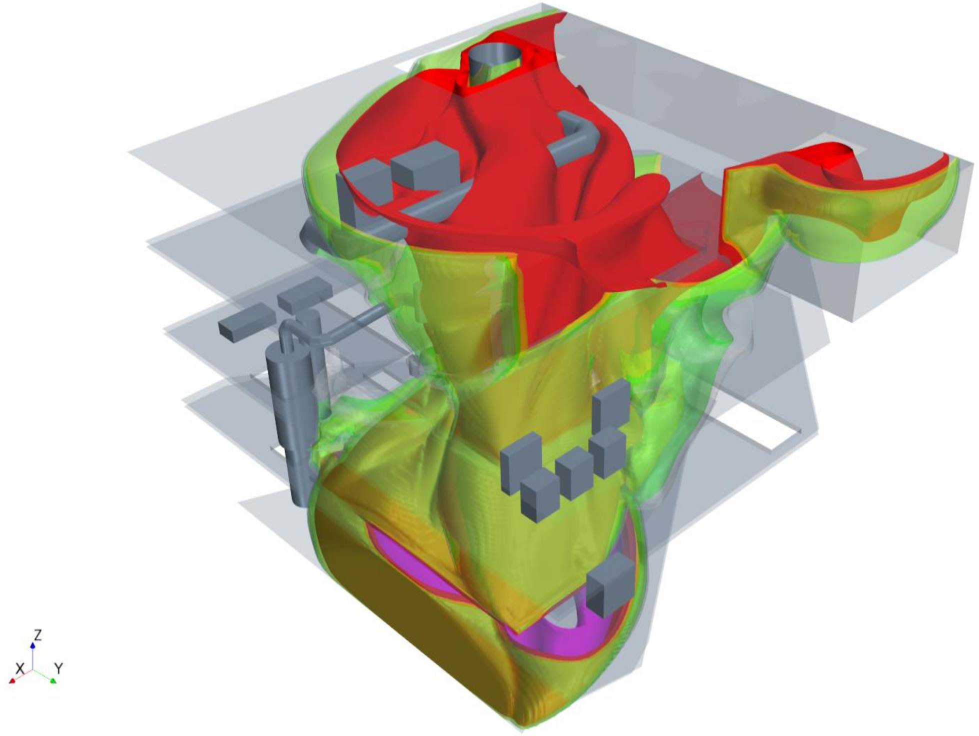
This may lead to regions of high and low concentration

Detectors may not be exposed to sufficient ammonia to trigger them

This is especially the case in large, complex spaces like an engine room

Therefore, use multiple sensors of different types

SOURCE: CFD analysis by Zhongfu Ge, American Bureau of Shipping



CFD simulation of 0.23 kg/second leak of ammonia for 300 seconds into an engine room ventilated at 30 air changes per hour, against the ventilation air flow.

Matt Dunlop,
Secondee, MMMCZCS

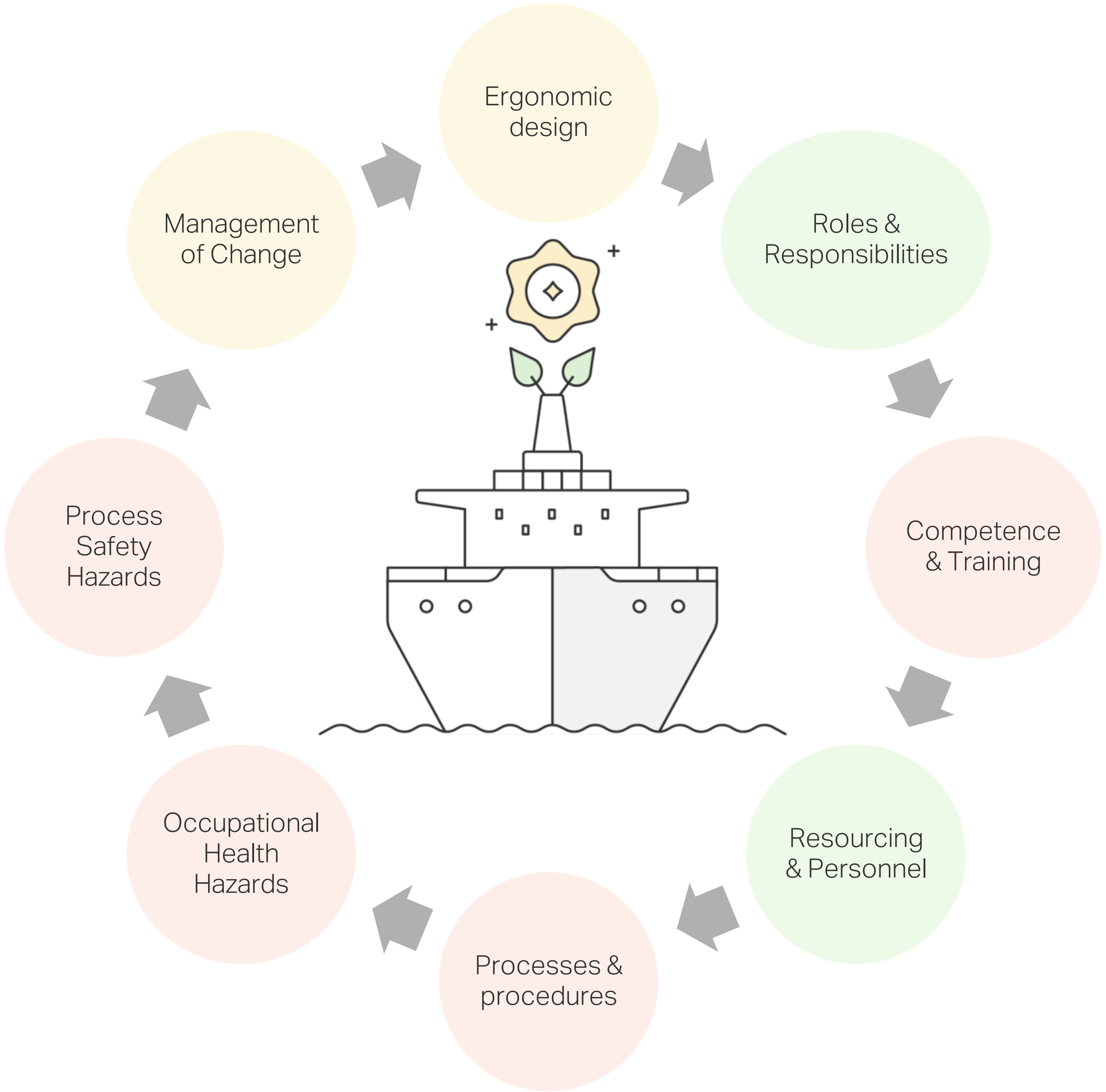
Human Factors

matt.dunlop@zerocarbonshipping.com

Why Human Factors

" The scientific discipline concerned with the understanding of interactions among humans and other elements of a system, and the profession that applies theory, principles, data, and methods to design in order to optimize human well-being and overall system performance "

Human Factors - analysis outcome



Impact criteria

- Low – Minor Changes
- Medium - Changes
- High – Significant Changes

- If we are to **reach consensus on the safe implementation of ammonia** as an alternative fuel, the industry will need further detail on the high-impact human factors areas identified in the report.
- **We call for** specific Human Factor studies to **address implications of high impact considerations.**

Focus - high impact themes

	Description	Anticipated to impact the following areas:
Competence & Training	• Technical and non-technical skills, knowledge, understanding and application	• New technical skills for specific operations and maintenance • General ammonia risk awareness across crew
Process Safety Hazards & Management	• Human involvement in the contribution, exacerbation, and recovery of a major accident	• Changes to and management of ammonia system parameters such as those associated with tanks and fuel handling system including level, temperature, and pressure.
Occupational Health Hazards	• Exposure to toxicity, fire, noise, musculoskeletal risks, trips and falls, etc.	• Materials / substance hazards (e.g., toxicity) • Mechanical (energy of components of a mechanical system e.g., crushing, motion, falling) • Thermal (e.g., hot surface, flames, cold stress)
Processes and procedures	• Documented processes and work practices	• New ammonia-specific policies, procedures, and processes. • Updates to operational and maintenance work practices, procedures, and plans • Review and, where necessary, change of emergency response processes

Summary

Safety risks of ammonia fuel can be kept within tolerable limits, if…

Safeguards

Suitable and sufficient **technical barriers and administrative safeguards are implemented** to protect the crew against various ammonia risks

Human Factors

Human factors considerations, such as those outlined in the study, are **addressed**

Apply industry learnings

The maritime industry **build upon existing maritime industry experience** with gas as fuels and cargo and **carry over learnings from other industries with considerable experience** in safely handling, transferring, and storing ammonia

Phase 3

Recommendations identified in this study is further investigated and **developed into tangible guidance and actions** for the industry.

Detailed guidance and regulatory frameworks addressing the technical, engineering, and human factors aspects is **needed to mature the ammonia fuel pathway**.