

Ammonia Safety Guidelines

Safe handling, storage & emergency response

EDITION 01

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1 Introduction

1.1 Importance of Ammonia Safety

Ammonia is a well-established industrial chemical used in applications such as fertiliser production, industrial refrigeration and chemical processing. Its hazards are well understood and can be managed through good engineering designs, clear operating procedures, emergency preparedness and a strong safety culture.

Today, ammonia is gaining renewed attention as a carbon-free energy carrier and alternative fuel in the transition towards sustainable clean energy. While the fundamental properties and hazards of ammonia are well understood, its emerging use in new applications, such as marine fuel, power generation and hydrogen carrier systems, may involve larger quantities of ammonia, different exposure scenarios, additional transfer operations and new operational interfaces that require careful safety consideration. Its toxic, corrosive, and flammable characteristics require comprehensive safety management measures.

Within this scope, this guideline addresses fundamental aspects of anhydrous ammonia safety, including:

- Scope and regulatory requirements
- Physical and chemical properties and ammonia-associated hazards;
- Control measures essential for storage, handling, transfer and use;
- Release mitigation and emergency preparedness;
- Mechanical integrity and maintenance; and
- Risk assessment strategies to support safe operation across various applications.

This set of guidelines examines specific hazards associated with bulk ammonia storage facilities, including pressurised storage vessels and refrigerated storage tanks, as well as transfer operations and emerging energy fuel applications. It highlights ammonia-specific considerations that require particular attention, including toxic gas release, vapour dispersion, rapid flashing, corrosion control, material compatibility, emergency isolation, ventilation and gas detection.

Emphasis is placed on preventing and mitigating ammonia releases through safe design of storage and piping systems, effective detection, alarm and ventilation systems, and emergency response measures to protect personnel from toxic exposure, fire and explosion.

By understanding and applying these safety principles, this guideline aims to equip professionals with basic safety guidance for the effective management of ammonia-related risks across different applications.

1.2 Scope and Applicability

This guideline applies only to anhydrous ammonia, including:

- Pressure-stored liquefied form;
- Refrigerated liquid form; and
- Gaseous form.

Unless otherwise stated, references to “ammonia” in this guideline refer to anhydrous ammonia.

This guideline applies only to ammonia used as a clean energy carrier and fuel. While it does not cover ammonia production, it covers the storage, transport, distribution and end use of imported ammonia in Singapore.

This guideline does not apply to aqueous ammonia, ammonium hydroxide, ammonia solutions, fertiliser applications, industrial refrigeration systems using ammonia as a refrigerant, or ammonia production facilities, as these involve different operating conditions, hazards or regulatory considerations.

The field of ammonia technology is rapidly evolving, particularly in relation to ammonia as a marine fuel and hydrogen carrier. Users of these guidelines are encouraged to:

- Check for updates to this document and relevant standards on a periodic basis;
- Stay informed about new technological developments and safety research;
- Participate in industry forums and safety working groups; and
- Contribute to the continual improvement of ammonia safety practices.

2 Overview of Ammonia in Energy and Fuel Applications

2.1 Ammonia Lifecycle in Singapore

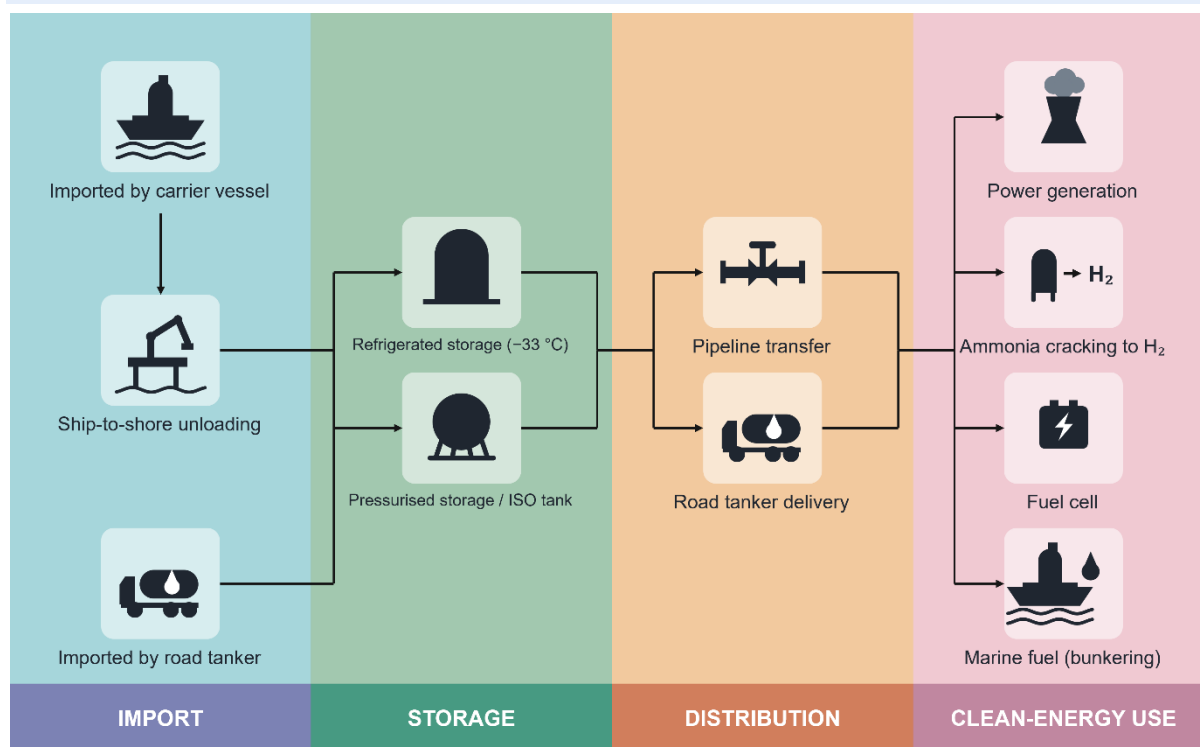


Figure 1: Ammonia Lifecycle in Singapore

2.2 Types of Ammonia Energy and Fuel Applications

Ammonia applications in the energy and fuel ecosystem can broadly be categorised as:

- Storage, transport and distribution (refrigerated terminals, pressurised spheres, iso tank, pipelines, marine vessels); and
- Use of ammonia (cracking for hydrogen, direct combustion in gas turbines or engines and fuel cells).

Ammonia is expected to be imported primarily by sea and supplemented by road transport to Singapore.

2.3 Storage, Transportation and Distribution

Ammonia must be safely stored and transported to users. Its physical and chemical properties, including toxicity, corrosiveness, pungent odour, vapour behaviour and ability to be stored as a liquefied gas under pressure or refrigeration, influence the design and operation of storage and distribution systems. Several established methods are used, including pressurised storage vessels, refrigerated storage tanks, road tankers, ISO tank containers, pipelines, marine vessels and bunkering systems. Each introduces different safety challenges, particularly in relation to

toxic release, rapid flashing, vapour dispersion, corrosion, pressure containment, transfer operations and emergency response.

2.4 Uses of Ammonia

Typical end-use applications of ammonia in clean technology include:

- Ammonia cracking for hydrogen production;
- Fuel for power generation;
- Fuel for marine vessels; and
- Ammonia fuel-cell applications.

3 Legal requirements

3.1 Quantitative Risk Assessment

Project developers should conduct a pre-consultation with the Major Hazards Department (MHD) to determine if their specific ammonia project requires a Quantitative Risk Assessment (QRA).

When a QRA is required under the Environmental Protection and Management Act (EPMA) and Fire Safety Act (FSA), it shall be conducted by approved QRA consultants and in adherence to the prevailing criteria. The QRA assesses potential hazard scenarios, their likelihood, and consequences, providing a comprehensive risk profile of the facility. Results of the QRA may inform critical safety design features, emergency response plans, and risk mitigation strategies.

3.2 Workplace Safety and Health regulatory requirements for Ammonia Facilities in Singapore

Under the Workplace Safety and Health Act (WSHA), ammonia facilities may be subject to specific regulatory requirements based on their operations and storage quantities:

3.2.1 Factory Classification

A workplace handling ammonia may fall within the definition of the factory under the WSHA, depending on the nature of the work activities and the type of premises.

Relevant examples include premises where hazardous substances are handled, stored, processed, manufactured or used, and premises specified in the Fourth Schedule to the Act, such as those used for processing or manufacturing flammable, corrosive or toxic substances, filling or washing containers that contain or had contained such substances, or storing gas, including liquefied gas, above the specified storage capacity of not less than 140 cubic metres.

3.2.2 Factory Notification or Registration

Where a workplace is a factory under the WSHA, the occupier should determine whether the premises are subject to factory notification, factory registration or Major Hazard Installation (MHI) registration under the applicable subsidiary legislation. Factories that do not fall within the prescribed registration classes are generally subject to notification, while factories falling within the prescribed classes under the WSH (Registration of Factories) Regulations must be registered. Premises that meet the MHI criteria, including those storing or handling ammonia at or above the prescribed threshold quantity, must be registered as MHIs.

3.2.3 Major Hazard Installation Registration

A facility storing or handling ammonia in quantities of 50 tonnes or more shall register as an MHI. MHIs are required to comply with the WSH (Major Hazard Installations) Regulations and maintain a Safety Case for the prevention and mitigation of major accidents.

To register a factory or an MHI, refer to:

<https://www.mom.gov.sg/workplace-safety-and-health/factory-notification-and-registration/requirements-for-factories>

4 Properties and Hazards of Ammonia

4.1 Characteristics of an ammonia release

4.1.1 Loss of Containment and Rapid Vapour Formation

- When ammonia is released from equipment, it may emerge as a pressurised liquid, refrigerated liquid, or vapour. A liquid ammonia release can rapidly vaporise and form a large ammonia cloud.
- Ammonia loss of containment may occur from tanks, pipes, valves, pumps, hoses, transfer connections or pressure-relief systems.
- A pressurised liquid ammonia release can flash rapidly and form a cold toxic vapour cloud.
- A refrigerated or liquid pool release can continue to evaporate and generate toxic vapour until the source is isolated, contained or removed.
- Even relatively small liquid releases can create large vapour clouds because of rapid liquid-to-vapour expansion.

4.1.2 Vapour Dispersion and Off-site Impact

- The behaviour of an ammonia cloud depends on the release conditions, weather and surrounding environment.
- Cold ammonia vapour or aerosol clouds may initially remain close to the ground before warming and dispersing.
- Ground-hugging clouds may travel considerable distances downwind before dispersing.

- Ammonia clouds may enter drains, trenches, basements, pits and other low-lying or enclosed spaces.
- Large releases may affect people both within and beyond the facility boundary.

4.2 Main Ammonia Hazards

4.2.1 Limitations of Odour as a Warning Sign

- Ammonia can often be smelled before it reaches a harmful concentration, as its odour threshold is much lower (below 5 ppm¹) than established occupational exposure limits (Refer to Table 1: Ammonia Toxicological Exposure Thresholds). Although ammonia has a strong pungent odour, olfactory fatigue occurs as people may become less sensitive to the smell after continued exposure.
- The sense of smell should never be relied upon as the sole means of detecting ammonia releases.

4.2.2 Corrosive and Contact Hazards

- Ammonia reacts with moisture: This can result in corrosive effects on people, equipment and material.
- Ammonia can cause injury through both its chemical properties and its low temperature when stored as a liquid.
- Contact with ammonia may damage the eyes, skin and respiratory tract.
- Liquid ammonia can cause severe chemical burns.
- Refrigerated liquid ammonia can also cause frostbite and cold burns.
- Eye contact can result in serious injury and may require immediate medical treatment.
- Direct contact may occur during storage, transfer, maintenance or accidental release events.

4.2.3 Toxic Exposure

- Ammonia is highly toxic when inhaled. Exposure can cause irritation, breathing difficulty, serious injury or death depending on concentration and duration of exposure.
- The severity of injury depends on both ammonia concentration and the duration of exposure.
- Exposure may cause irritation of the eyes, nose and throat, breathing difficulties, lung injury and, at sufficiently high concentrations, death.
- The following exposure values should be considered when assessing ammonia release scenarios and emergency response planning:

¹ ppm: parts per million; a unit of measurement used to describe the concentration of a pollutant or chemical in air, water, or other fluids. 100%vol is equivalent to 1,000,000 parts per million.

PEL 25 ppm Maximum time-weighted average (TWA) exposure over an 8-hour working day and 40-hour work week.		8-HR TWA	STEL 35 ppm Maximum exposure over any 15-minute period during a working day.	15-MIN
AEGL-1 DISCOMFORT	Acute Exposure Guideline Level 1 Discomfort or irritation; normally reversible effects.		30 ppm / 10 min – 8 hr	
AEGL-2 SERIOUS	Acute Exposure Guideline Level 2 Serious effects or impaired ability to escape.		220 ppm / 10 – 30 min 160 ppm / 1 hr 110 ppm / 4 – 8 hr	
IDLH VERY SERIOUS	Immediately Dangerous to Life or Health; used for emergency escape and respirator planning within a 30-minute window.		300 ppm 30-min window	
AEGL-3 LIFE-THREATENING	Acute Exposure Guideline Level 3 Life-threatening effects or death.		2,700 ppm / 10 min 1,600 ppm / 30 min 1,100 ppm / 1 hr 550 ppm / 4 hr 390 ppm / 8 hr	

Table 1: Ammonia Toxicological Exposure Thresholds

4.2.4 Fire and Explosion Risks

- Ammonia is classified as a Group IIA gas², with a high minimum ignition energy of about 680 millijoules – a strong ignition source is usually needed as compared to other common fuels.
- Ammonia is flammable in air at about 15% to 28% by volume and has an ignition temperature of about 630°C.
- Although ammonia can be difficult to ignite, it can still burn or explode under certain conditions if it accumulates in enclosed or poorly ventilated areas in the presence of an ignition source.

4.2.5 Material Incompatibility and Equipment Integrity Hazards

- Equipment failures can occur when unsuitable materials are used or when ammonia-specific degradation mechanisms are not properly managed.
- Incompatible materials in ammonia service can cause corrosion, leakage, equipment failure or loss of containment. Copper, brass, bronze, zinc and galvanised

² Gas group IIA are hazardous area classifications used to group flammable gases and vapours according to their explosion characteristics in which gas group IIA is the least easily ignited compared to other group II gas groups (i.e. IIB, IIC)

surfaces are generally unsuitable for ammonia service. Seals, gaskets, coatings, hoses and temporary fittings may fail if they are not compatible with ammonia.

- Stress corrosion cracking (SCC) may occur in carbon steel ammonia systems under certain conditions. These include the presence of anhydrous ammonia with very low water content (below ~0.1–0.2% by weight), trace amounts of oxygen (at ppm levels), and tensile stress in the carbon steel. While maintaining adequate water content is a recognised mitigation measure for SCC, it should be noted that water can also promote general corrosion in carbon steel ammonia systems. Ammonia should not be mixed or stored close to incompatible chemicals such as chlorine, bleach, calcium hypochlorite, hydrogen fluoride, iodine, bromine, strong acids, strong oxidisers or mercury.

5 Storage

5.1 Storage Hazards

Ammonia is commonly stored either as a pressurised liquid at ambient temperature or as a refrigerated liquid at approximately -33°C . Regardless of the storage method used, the following hazards should be considered during facility design and operation:

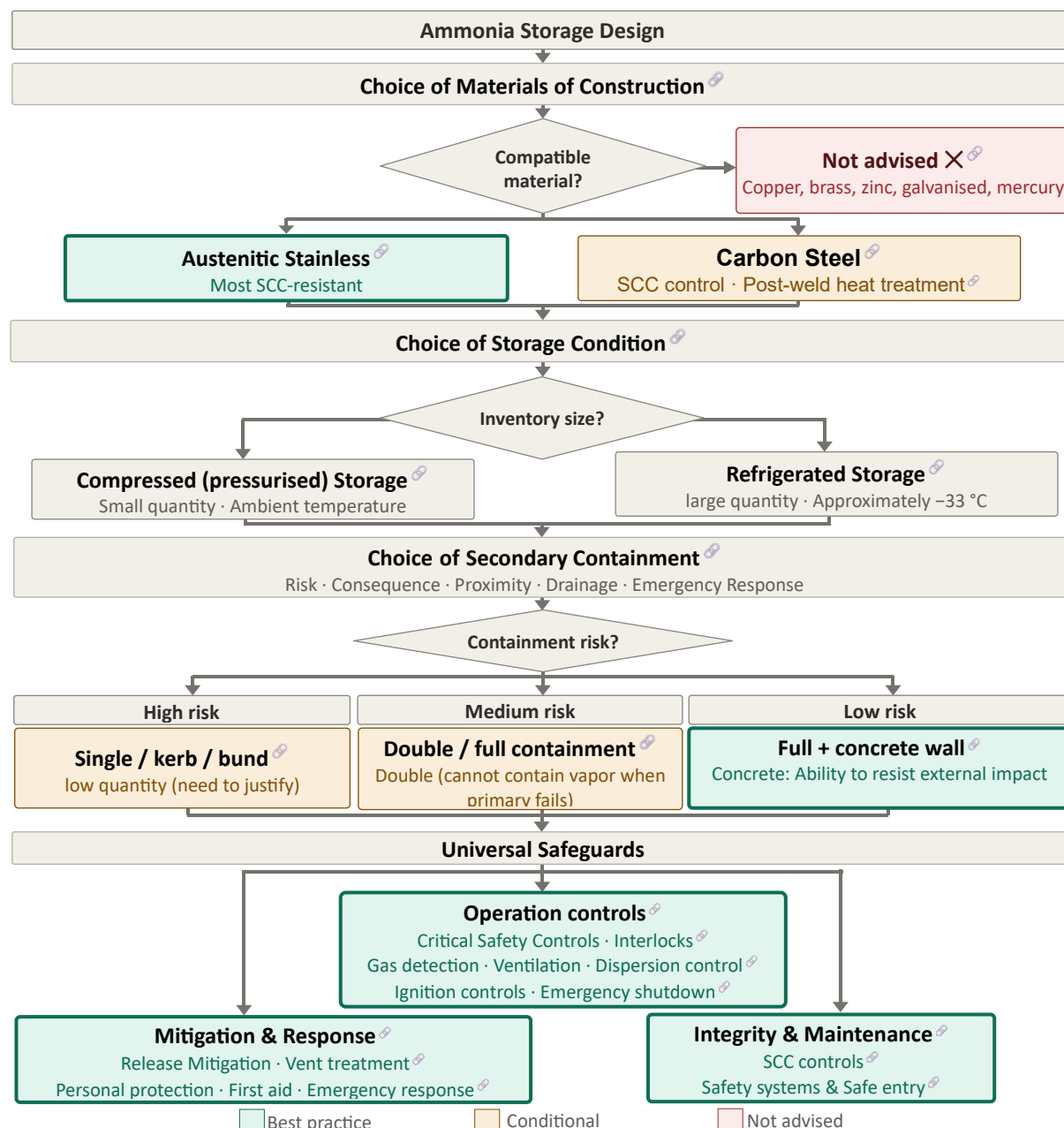


Figure 2: Types of ammonia storage containment designs

5.2 Design of Storage Containment

5.2.1 Choice of Materials of Construction

- Select materials in contact with ammonia that are suitable for ammonia service. Avoid copper, brass, bronze, zinc, galvanised materials and mercury-containing gauges or instruments in ammonia-contacting service.
- Select austenitic stainless steel as the preferred material where the service conditions, corrosion assessment, consequences of failure, or inability to reliably implement and sustain carbon-steel SCC controls throughout the equipment life indicate a higher SCC or corrosion risk. It generally offers good resistance to ammonia-related corrosion and is less susceptible to ammonia SCC than carbon steel, provided that welding, inspection and quality control requirements are properly specified and implemented.
- Select carbon steel only where compatibility with the defined ammonia service has been demonstrated and the required SCC controls can be reliably implemented, verified, and maintained throughout fabrication, commissioning, operation, and inspection. (see [5.4.1](#)).
- Consider aluminium or nickel alloys only where compatible with the service conditions and applicable codes.
- Confirm gaskets, seals, elastomers, coatings and hoses are compatible with ammonia and use blowout-resistant or low-emission types where leakage could cause toxic exposure.
- For refrigerated ammonia service, select materials that are suitable for low-temperature operation and capable of maintaining adequate toughness at the minimum metal temperature that may be encountered during operation, start-up or upset conditions.

5.2.2 SCC and Post-weld Heat Treatment Control

- Recognise SCC as a critical risk in carbon-steel ammonia systems, especially at welds, high-stress regions and unsuitable high-strength steels.
- Specify how SCC will be prevented during design, including suitable ammonia quality, water content, oxygen control, stress control, inspection access and repair requirements.
- Where water content is used to reduce SCC risk, specify the required ammonia water content, such as a minimum of 0.2% by weight, unless a lower value or alternative control is justified.
- Design the system to keep air and oxygen ingress out, including proper purging, filling, draining and return-to-service arrangements.
- Specify checks before first filling or return to service, to confirm that the system has been suitably dried, purged and is within the required oxygen and moisture limits before ammonia is introduced.
- Apply post-weld heat treatment (PWHT) or stress relief where required by the applicable code, design basis or SCC risk assessment.

- Avoid unsuitable high-strength steels, high-stress details and uncontrolled weld repairs in ammonia service.
- Provide access for inspection of welds, repaired areas and high-stress regions where SCC is credible.

5.2.3 Choice of Storage Condition

5.2.3.1 Compressed (pressurised) Storage

- Pressurised storage is generally more suitable for smaller ammonia inventories. Pressure-driven leaks can rapidly flash and form large toxic aerosol or vapour clouds that may be difficult to isolate or control.
- Assess high-pressure ammonia releases as flashing jets that may form aerosol and toxic vapour clouds.
- Protect pressurised ammonia vessels and their supports from impact, external fire and mechanical damage where failure could lead to a major ammonia release.
- Where pressurised ammonia release could produce a horizontal jet or spray, consider physical shielding, barriers or layout measures to reduce direct impact, escalation and exposure.

5.2.3.2 Refrigerated Storage

- Refrigerated ammonia storage is typically used for larger inventories because the ammonia is stored at low temperature and near-atmospheric pressure, resulting in different release characteristics and design considerations compared with pressurised storage.
- Select tanks, piping, pressure equipment and supports suitable for low-temperature ammonia service and capable of maintaining adequate toughness at the minimum design temperature.
- Design tank foundations to prevent ground freezing and frost heave, using foundation heating, elevated foundations or other suitable controls where required.
- Manage boil-off gas (BOG) from refrigerated ammonia storage by reliquefaction, return to storage, controlled use where specifically designed, or treatment.
- Size the BOG processing system for credible vapour generation scenarios, and provide suitable standby capacity and backup power where the system is relied upon for tank pressure control.
- Assess credible loss of refrigeration, power failure or BOG processing failure scenarios, as these may result in increased vapour generation and tank pressure rise.
- Size relief, vent treatment and release mitigation systems for credible vapour-generation scenarios, not only steady-state boil-off.
- Automatically stop or restrict tank filling when available BOG processing capacity is insufficient to manage the expected vapour load.
- Control the temperature of ammonia returned or transferred into refrigerated storage, as warm ammonia ingress can increase vapour generation and tank pressure.

5.2.3.3 Common Design Considerations for Liquid Ammonia Storage

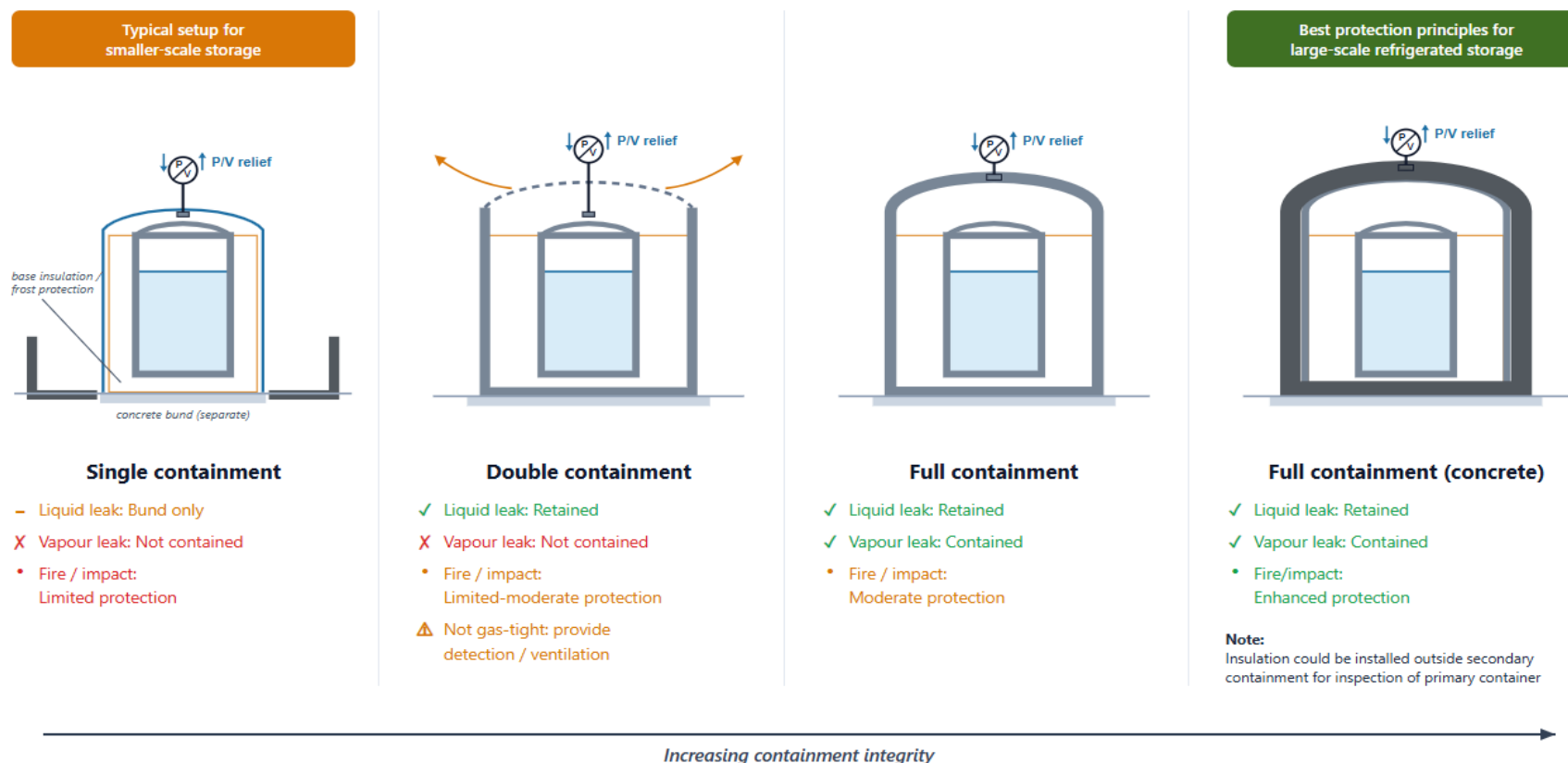
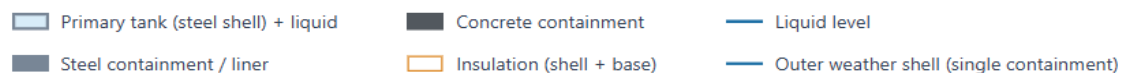
- Provide relief for blocked-in liquid sections, as trapped liquid ammonia can thermally expand and rupture equipment.
- Route pressure relief discharge to a scrubber, treatment system or safe discharge location, as ammonia relief discharge is toxic.

5.2.4 Choice of Secondary Containment

- Select the containment type based on inventory, storage condition, release consequence, proximity to occupied or public areas, drainage pathways and emergency response capability.
- Justify the selected containment type using recognised risk assessment methods, such as QRA, consequence modelling and likelihood or event-frequency assessment, with reference to guidance such as the TNO Coloured Books or UK HSE methodology where applicable.
- For large refrigerated ammonia storage, full containment should be considered as the preferred containment concept.
- Best practice is to provide full containment with a reinforced or prestressed concrete outer containment, where it is required by the inventory, location and release consequence assessment.
- Full containment is designed to retain both released liquid ammonia and vapour following failure of the primary tank.
- Double containment retains the released liquid ammonia but does not necessarily contain vapour if the primary tank fails. Where vapour is not fully contained, additional detection, ventilation, treatment or emergency response measures should be provided.
- For double-walled tanks, the outer wall should only be credited as secondary containment if it is designed for the expected liquid temperature, liquid load and vapour conditions following primary tank leakage.
- Single containment, kerbing or bunding should only be used where justified by small inventory, low release consequence and site-specific risk assessment.
- A system should be provided to detect leakage from the primary liquid container into the secondary containment or annular space. Detection may be based on temperature change, ammonia gas detection, differential pressure measurement or other suitable means.
- Provide containment to prevent liquid ammonia and contaminated runoff from reaching drains, sewers, watercourses, the sea, basements, trenches and occupied or public areas.
- Size containment for credible release volume, firefighting water, water spray/fog use and decontamination water.
- Direct contaminated runoff to a controlled collection point isolated from the site drainage system.

Containment concepts for refrigerated ammonia storage

Secondary function after failure of the primary tank



Conceptual schematic only; dimensions not to scale.

P/V = pressure / vacuum relief; discharge routed to a safe location or treatment system as required.

Figure 3: Containment concepts for refrigerated ammonia storage

5.3 Operation and Mitigation

5.3.1 Operation Controls

5.3.1.1 Critical Safety Controls and Interlocks

- Identify required Safety Instrumented Functions where a credible toxic release, escalation or major loss of containment may occur.
- Assign Safety Integrity Level (SIL) to specific Safety Instrumented Functions.
- Typical ammonia-related Safety Instrumented Functions may include overfill prevention, high-pressure isolation, gas-detection-initiated emergency shutdown, transfer shutdown and scrubber or ventilation activation.
- Design, test, maintain and proof-test safety instrumented systems in accordance with the applicable functional safety standard.
- Control bypass, override or impairment of safety-critical interlocks by permit, risk assessment and temporary safeguards.

5.3.1.2 Gas detection, Ventilation and Dispersion Control

- Provide ammonia gas detection at credible leak points, including flanges, valves, pumps, compressors, hose connections, relief outlets and enclosed spaces.
- Locate detectors at high level where warm ammonia vapour may collect, and at low level near vessels, transfer points, trenches and pits where cold releases may initially travel.
- Select sensors suitable for ammonia, the expected concentration range, site temperature, humidity, airflow and potential chemical interference.
- Set alarms based on toxic exposure risk, such as PEL, STEL where appropriate, with audible and visual warning.
- Ventilate indoor ammonia areas to prevent accumulation in pits, trenches, basements and ceiling voids.
- Route ventilation exhaust away from air intakes, occupied areas and escape routes.
- Monitor personnel exposure against applicable exposure limits during higher-risk tasks such as sampling, purging, draining, line breaking and maintenance.

5.3.1.3 Ignition Controls and Emergency Shutdown

- Control ignition sources where ammonia may accumulate in enclosed or poorly ventilated areas.
- Carry out Hazardous Area Classification (HAC) where a credible flammable ammonia atmosphere may occur, and document the classified zones. Use suitably rated electrical and mechanical equipment where a credible flammable ammonia atmosphere may occur.
- Apply hot work controls before welding, cutting, grinding or other spark-producing work near ammonia systems.

- Assess fire exposure as an ammonia overpressure, relief discharge, toxic release and escalation scenario.
- Protect vessels, piping, hoses and transfer areas from external fire, heat exposure and mechanical damage where loss of containment may occur.
- Provide emergency shutdown and isolation valves to limit ammonia inventory released from major storage and process systems.
- Initiate shutdown, isolation, ventilation or scrubbing by gas detection, high pressure, high level or other safety-critical conditions where required.

5.3.2 Mitigation and Response

5.3.2.1 Release Mitigation and Vent Treatment

- Isolate and contain liquid ammonia spills where safe to do so.
- Avoid routine or uncontrolled venting of ammonia to atmosphere.
- Treat relief, process, purge and emergency ventilation discharges by scrubbing or other suitable treatment before release to environment.
- Design scrubbers and vent treatment systems for credible ammonia venting or release scenarios, including emergency and upset conditions. Route relief vents, process vents and scrubber discharges away from air intakes, occupied areas, public areas and emergency routes.
- Consider ammonia-specific thermal treatment or flare only where specially designed for ammonia service and assessed by competent specialists. The assessment should address secondary pollutants and the potential for uncombusted ammonia release during emergency scenarios. Where these criteria cannot be verified, alternative mitigation systems, such as scrubbers, should be used.
- Apply water spray or fog from a safe location only to knock down or divert an ammonia vapour cloud. Avoid directing water spray at the leak source or liquid ammonia pool unless specifically assessed, as this may increase vaporisation. Where practicable, position water spray to intercept downwind vapour cloud movement, without diverting the cloud towards human traffic.
- A compatible cover or tarpaulin may be used to reduce vapour release from a contained liquid ammonia spill, but only by trained emergency responders using suitable Personal Protective Equipment (PPE).
- Prevent liquid ammonia and contaminated water (runoff) from entering drains, sewers, watercourses, the sea or low-lying areas. Where runoff is generated, direct it to a controlled collection point isolated from the site drainage system.

5.3.2.2 Personal Protection, First Aid and Emergency Response

- Select PPE based on ammonia concentration, task type and exposure route.
- Provide splash protection, including chemical goggles, face shield, chemical-resistant gloves, protective clothing and safety boots, where liquid ammonia or splash exposure may occur.

- Use respiratory protection where exposure limits may be exceeded or ventilation is inadequate.
- Use positive-pressure self-contained breathing apparatus (SCBA) for emergency response, major releases or unknown ammonia concentrations.
- Provide emergency showers and eyewash facilities where ammonia exposure may occur.
- Provide designated toxic refuge areas where required, with protection from ammonia ingress and emergency communication.
- Evacuate upwind during major releases.

5.4 Integrity and Maintenance

5.4.1 SCC Controls

- Check ammonia quality including water content by sampling, testing or supplier certification at suitable intervals.
- Check that air and oxygen are kept out of the ammonia system, especially after opening, maintenance, purging or return to service.
- Inspect welds, repaired areas and high-stress regions for SCC.
- Review weld repairs, material changes and stress-relief requirements before work is carried out, to ensure the repair or change does not increase SCC risk.
- Repair or replace SCC-affected equipment before continued service where integrity is compromised.
- Keep records of purging, drying, ammonia quality and return-to-service checks to confirm that SCC controls remain effective.

5.4.2 Safety Systems and Safe Entry

- Maintain relief devices, vent routing, scrubbers, gas detection, alarms, isolation valves and secondary containment available during ammonia service.
- Test safety-critical systems periodically and restore defects before continued operation where their failure may increase ammonia release risk.
- Control bypass, isolation or impairment of ammonia safety systems by permit, risk assessment and temporary safeguards.
- Include refrigerated ammonia storage components in the inspection programme, such as insulation condition, corrosion-under-insulation, tank supports, foundations and other low-temperature service components.
- Isolate, depressurise and drain ammonia systems before opening for inspection, maintenance or repair.
- Purge opened ammonia systems with nitrogen or other suitable inert gas before return to service to prevent air and oxygen ingress.
- Authorise vessel or confined-space entry only under a safe entry permit, with ventilation, rescue arrangements and suitable respiratory protection. Gas-test equipment before entry or intrusive work for ammonia concentration, oxygen level and other relevant hazards.

- Leak-test and re-commission ammonia systems after maintenance before returning them to normal service.

6 Handling and Transfer

6.1 Transfer Hazards

- Connection release: Ammonia may be released during connection, disconnection, purging, draining or line opening.
- Equipment failure: Hose, loading arm, coupling, valve or pump failure can cause loss of containment.
- Movement damage: Unintended movement during transfer can damage hoses, loading arms or connections.
- Trapped liquid expansion: Liquid ammonia trapped between closed valves can expand and rupture equipment.
- Uncontrolled venting: Venting during transfer releases toxic ammonia vapour.
- Cold contact: Liquid ammonia can cause both chemical burns and cold burns.
- Pressure surge: Rapid valve closure, pump start-up or sudden flow changes can cause liquid hammer or pressure surge.

The controls in [Section 5.3](#) also apply to handling and transfer activities.

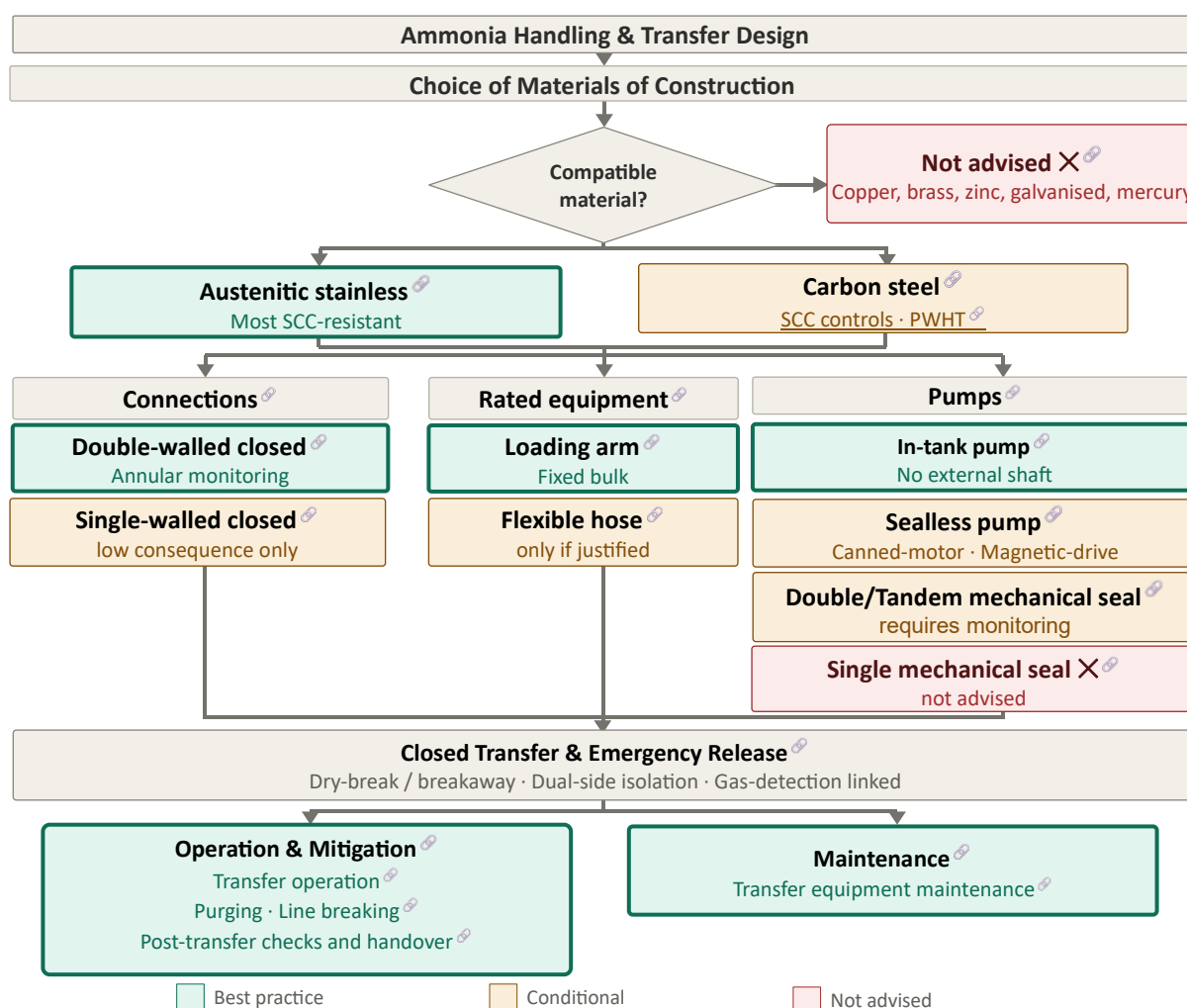


Figure 4: Types of ammonia handling & transfer systems designs

6.2 Design of Handling & Transfer Systems

6.2.1 Plant Layout

- Locate ammonia transfer points away from occupied areas, air intakes, unprotected drains and main escape routes where practicable.
- Provide kerbing, hardstanding or drainage isolation where liquid ammonia or contaminated runoff may occur.
- Allow safe upwind or crosswind access for operators and emergency responders where practicable.

6.2.2 Connections and Transfer Systems

- Use closed transfer systems with vapour return arrangements to minimise ammonia release during normal operation.
- Select double-contained, secondary-contained or single-walled closed transfer systems based on the consequence of a credible leak. Double or secondary containment should be used where a single leak could have high consequences, while single-walled closed

systems may be acceptable for lower-consequence applications, subject to risk assessment.

- Secondary containment may include double-walled hoses, loading arms or transfer piping, or a gastight enclosure around the connection.
- Provide leak detection or pressure monitoring in the annular space for double-walled systems.

6.2.3 Rated Equipment

- Hoses, couplings, loading arms, valves and gaskets should be rated and marked for ammonia service.
- Equipment materials should comply with [5.2.1](#), and copper alloys and other incompatible materials shall not be used.
- Loading arms should be used where possible for fixed bulk ammonia loading and unloading. Flexible hoses should only be used where justified, and should be ammonia-rated, inspected and replaced under a controlled programme.

6.2.4 Pumps

- Pump selection should minimise ammonia leakage from rotating shaft seals, as seal failure can result in a continuous toxic release.
- Use in-tank pumps where practicable, as the pump is submerged and does not require an external shaft seal.
- Use sealless pumps, such as canned-motor or magnetic-drive pumps, where practicable, to eliminate shaft-seal leakage. The associated transfer system should minimise leak points while still allowing inspection and maintenance.
- Where sealed pumps are unavoidable, use double or tandem mechanical seals with seal monitoring. Single-mechanical-seal pumps should not be used for ammonia service.
- Protect pumps against dead-head, low-flow operation and cavitation.

6.2.5 Emergency Release

- Provide dry-break, breakaway or emergency-release systems where hose failure or movement could cause loss of containment.
- Ensure emergency release systems isolate both sides of the transfer connection on activation.
- Provide accessible emergency stops and isolation valves at transfer points.
- Link transfer shutdown to gas detection where required by risk assessment.

6.3 Operation and Mitigation

6.3.1 Transfer Operation

- Confirm that gas detection, emergency isolation and containment are available before transfer.
- Check hoses, couplings, valves and connections before use.

- Start transfer slowly and monitor for leakage, alarms or visible vapour.
- Control filling, cooldown and transfer rates to avoid thermal shock to tanks, piping, valves, hoses and connected equipment.
- Stop transfer immediately if ammonia leak is detected or suspected.
- Avoid routine venting during transfer.

6.3.2 Purging and Line Breaking

- Isolate, depressurise, drain and inert-purge ammonia lines before opening.
- Gas-test and ventilate equipment before line breaking or intrusive work.
- Do not rely on odour to confirm that an ammonia line is safe, use suitable ammonia gas detectors instead.
- Prevent air ingress during purging and return to service to reduce SCC risk.

6.3.3 Post-transfer Checks and Handover

- After transfer, remove or recover residual ammonia from hoses, loading arms and transfer lines using approved drain, purge or vapour-return arrangement.
- Cap or seal transfer connections after disconnection.
- Check transfer points and transfer systems for leakage before leaving the area.
- Communicate active alarms, detector faults, isolation status, bypasses and residual ammonia in lines during handover.

6.4 Maintenance

6.4.1 Transfer Equipment Maintenance

- Remove any transfer equipment showing ammonia leakage, material degradation or compatibility concerns.
- Test dry-break, breakaway and emergency-release systems to confirm that both sides isolate on activation.
- Maintain annular leak detection, vacuum or low-pressure monitoring for double-walled transfer systems.
- Maintain pump seal monitoring and double/tandem seal support systems where sealed pumps are used.
- Leak-test transfer equipment after maintenance before returning it to ammonia service.
- Record defects, repairs, leak tests and return-to-service checks for ammonia transfer equipment.

7 Application-Specific Safety Considerations

Certain ammonia applications introduce additional hazards due to their operating environment, equipment layout and system interfaces. The following sections provide a simplified, broad and non-exhaustive checklist to guide early-stage safety reviews for selected ammonia uses.

7.1 Ammonia-Fuelled Power Generation

Tip: Refer to [Checklist](#) for more info

- Combustion instability: The low flame speed and poor ignitability of ammonia can cause unstable or incomplete combustion.
- NO_x and nitrous oxide formation: Ammonia oxidation during combustion can form nitrogen oxides and nitrous oxide, which are regulated air pollutants and may contribute to environmental impacts.
- Ammonia slip: Unburnt ammonia in the exhaust presents toxic exposure, corrosion and fouling risks.

7.2 Ammonia Cracking

Tip: Refer to [Checklist](#) for more info

- Ammonia-hydrogen mixtures: Cracking systems contain ammonia, hydrogen and partially cracked gas, presenting combined toxicity and flammability risks.
- High-temperature equipment: Crackers and reactors operate at high temperature, with associated thermal stress and failure risks.
- Air ingress: Air entering hydrogen-containing sections can form flammable mixtures.
- Incomplete cracking: Residual ammonia can carry over to downstream burners, fuel cells or storage systems.

7.3 Fuel-cell Interface

Tip: Refer to [Checklist](#) for more info

- Ammonia exposure hazard: Residual ammonia may be released during hydrogen purification, fuel-cell venting, purging or maintenance.
- Hydrogen-ammonia accumulation hazard: Leakage inside skids, cabinets or enclosed rooms can create toxic or flammable atmospheres.
- Mixed vent gas hazard: Fuel-cell purge, vent or anode off-gas may contain hydrogen and residual ammonia, creating toxicity and flammability risks.
- Maintenance exposure hazard: Residual ammonia in filters, catalysts, piping or purge systems can expose personnel during inspection, replacement or line opening.

7.4 Road Transport

Tip: Refer to [Checklist](#) for more info

- Transit release hazard: Ammonia may be released during road, ISO tank or vessel transport, away from fixed facility safeguards.
- Impact damage hazard: Collision, movement or mechanical impact may rupture the tank or damage transfer connections.
- Public exposure hazard: A transport release may expose the public and emergency responders outside the facility boundary.

8 Risk Assessment and ALARP Principles

To ensure that risks are kept as low as reasonably practicable (ALARP), a thorough risk assessment should be conducted.

8.1 Risk Assessment Methodologies

- Hazard Identification (HAZID): Systematically identify potential hazards in the ammonia system.
- Quantitative Risk Assessment (QRA): Evaluate the likelihood and consequences of potential ammonia release incidents.
- Hazard and Operability Study (HAZOP): Analyse process deviations and their consequences.
- Failure Modes and Effects Analysis (FMEA): Assess potential failure modes at the component level.
- Computational Fluid Dynamics (CFD)/dispersion modelling: Model ammonia vapour dispersion, ventilation and toxic gas accumulation in ammonia facilities with complex or congested geometries.

8.2 Risk Assessment Process

- Identify potential hazards and scenarios related to ammonia use in the specific application.
- Evaluate the likelihood and consequences of each identified hazard.
- Assess the effectiveness and independence of existing control measures.
- Determine whether additional control measures are required to reduce risks to ALARP.
- Implement and monitor the effectiveness of control measures.
- Review and update the risk assessment periodically and when significant changes occur.

8.3 ALARP Considerations

- Consider industry best practices and emerging technologies for ammonia safety.
- Ensure that residual risks are acceptable and justified.
- Proactively refine safety protocols by integrating new knowledge, operating experiences and best practices.

9 Applicable Standards (non-exhaustive)

9.1 General Ammonia Storage, Handling and Transfer

- CGA G-2.1: Requirements for the storage and handling of anhydrous ammonia.
- AIGA SP 27/25: Safe handling of liquid ammonia.
- PGS 12: Ammonia - Storage and Offloading
- EIGA Doc 188: Safe transfer of toxic liquefied gases.
- ISO 5771: Rubber hoses and hose assemblies for transferring anhydrous ammonia — Specification.

9.2 Storage Tanks, Pressure Vessels, Piping and Pressure Relief

- ASME B31.3: Process piping

- ASME B31.5: Refrigeration piping and heat-transfer components.
- API 620: Design and Construction of Large, Welded, Low-Pressure Storage Tanks
- API 625: Tank Systems for Refrigerated Liquefied Gas Storage.
- ACI 376: Code Requirements for Design and Construction of Concrete Structures for Refrigerated Liquefied Gas Containment
- API 520: Sizing, Selection, and Installation of Pressure-relieving Devices
- API 521: Pressure-relieving and depressurizing systems.
- API 2000: Venting Atmospheric and Low-pressure Storage Tanks
- ISO 4126 series: Safety devices for protection against excessive pressure.

9.3 Gas Detection, Ventilation, Hazardous Areas and Safety Systems

- IEC 62990-1: Workplace atmospheres - Part 1: Gas detectors - Performance requirements of detectors for toxic gases
- IEC 60079 series: Explosive atmospheres.
- IEC 61508: Functional safety - Safety instrumented systems for the process industry sector.
- IEC 61511: Safety instrumented systems for the process industry.
- API RP 752: Management of Hazards Association with Location of Process Plant Buildings

10 Application-Specific Safety Checklist

Checklist for facilities using ammonia fuel for power generation

- ☐ Was a QRA pre-consultation conducted to determine the need for QRA?
- ☐ Was a QRA completed before construction where required?
- ☐ Were the quantities checked against MHI threshold, and was the workplace registered?
- ☐ Was a process hazard analysis conducted on the ammonia-related system?
- ☐ Were past accidents and incidents involving ammonia combustion, ammonia slip or fuel changeover studied and understood?
- ☐ Were additional hazards related to ammonia assessed:
 - Ammonia fuel quality, impurity levels and physical state affecting safe fuel use
 - Toxic ammonia release from fuel supply, burners, exhaust or ventilation systems
 - Unstable combustion, flameout, delayed ignition or flashback
 - Ammonia slip leading to toxic exposure in exhaust or maintenance areas
 - Fuel changeover upset involving ammonia, hydrogen, natural gas or other fuels
- ☐ Was the facility designed, inspected and maintained in accordance with applicable codes, standards and manufacturer requirements?
- ☐ Were the following general control measures considered:
 - Ammonia gas detection at credible leak points
 - Ventilation of enclosed areas
 - Ignition control where ammonia may accumulate
 - Emergency shutdown and fuel isolation
 - Release mitigation, vent treatment and safe discharge arrangements
 - Safe purging, start-up and shutdown procedures
 - Gas testing before maintenance or entry
 - Emergency response systems
- ☐ Were the following ammonia-fuelled power generation control measures considered or implemented:
 - Combustion control, including flame monitoring, flameout, flashback and delayed-ignition protection
 - Exhaust ammonia (ammonia slip) monitoring and safe discharge
 - Fuel changeover control between ammonia, hydrogen, natural gas or other fuels
- ☐ Were material certificates, weld records, non-destructive examination records, PWHT records, Factory Acceptance Test /Site Acceptance Test documents and applicable inspection or test reports reviewed and accepted to confirm material integrity and suitability for ammonia service?
- ☐ Were ammonia quality and impurity data reviewed, including water, oxygen and other contaminants, to assess potential material degradation?
- ☐ Was a pre-start-up safety review completed before operating?
- ☐ Were all necessary risk assessments and work procedures for safe operation, inspection and maintenance, completed to ensure risk is kept to ALARP?
- ☐ Was a safety and health management system implemented?

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Checklist for facilities performing ammonia cracking or ammonia-to-hydrogen conversion

- ☐ Was a QRA pre-consultation conducted to determine the need for QRA?
- ☐ Was a QRA completed before construction where required?
- ☐ Were the quantities checked against MHI threshold, and was the workplace registered?
- ☐ Was a process hazard analysis conducted on the ammonia-related system?
- ☐ Were past accidents and incidents involving ammonia cracking, hydrogen generation or ammonia-hydrogen systems studied and understood?
- ☐ Were the following hazards assessed:
 - Toxic ammonia release from cracking, purification, venting or purge systems
 - Flammable hydrogen release from cracking or downstream systems
 - Combined toxicity and flammability from ammonia-hydrogen mixtures
 - Air ingress into hydrogen-containing sections
 - High-temperature exposure from reactors, heaters or hot surfaces
 - Overpressure or abnormal release from cracking equipment
 - Residual ammonia carryover to downstream users, fuel cells or storage
 - Maintenance exposure during catalyst handling, line opening or equipment cleaning
- ☐ Was the facility designed, inspected and maintained in accordance with applicable codes, standards and manufacturer requirements?
- ☐ Were the following general control measures considered:
 - Ammonia gas detection at credible leak points
 - Ventilation of enclosed areas
 - Ignition control where ammonia may accumulate
 - Emergency shutdown and fuel isolation
 - Release mitigation, vent treatment and safe discharge arrangements
 - Safe purging, start-up and shutdown procedures
 - Gas testing before maintenance or entry
 - Emergency response systems
- ☐ Were the following cracking-specific control measures considered:
 - Hydrogen leak detection in cracking and downstream sections
 - Hazardous area classification and ignition control for hydrogen atmospheres
 - Reactor and heater temperature, pressure and flow monitoring
 - Safe catalyst handling procedures
- ☐ Were material certificates, weld records, non-destructive examination records, PWHT records, Factory Acceptance Test /Site Acceptance Test documents and applicable inspection or test reports reviewed and accepted to confirm material integrity and suitability for ammonia service?
- ☐ Were ammonia quality and impurity data reviewed, including water, oxygen and other contaminants, to assess potential material degradation?
- ☐ Was a pre-start-up safety review completed before operating?
- ☐ Were all necessary risk assessments and work procedures for safe operation, inspection and maintenance, completed to ensure risk is kept to ALARP?
- ☐ Was a safety and health management system implemented?

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Checklist for facilities interfacing ammonia-derived hydrogen with fuel cells

- ☐ Was a QRA pre-consultation conducted to determine the need for QRA?
- ☐ Was a QRA completed before construction where required?
- ☐ Were the quantities checked against MHI threshold, and was the workplace registered?
- ☐ Was a process hazard analysis conducted on the ammonia-related system?
- ☐ Were past accidents and incidents involving fuel-cell systems, hydrogen vents or ammonia contamination studied and understood?
- ☐ Were the following hazards assessed:
 - Ammonia exposure during purification, venting, purging or maintenance
 - Hydrogen release from fuel-cell supply, purge or anode off-gas systems
 - Combined toxicity and flammability from hydrogen-ammonia vent streams
 - Gas accumulation inside skids, cabinets, containers or enclosed rooms
 - Unsafe discharge of purge, vent or anode off-gas streams
 - Maintenance exposure from residual ammonia in filters, catalysts, piping or purge systems
- ☐ Was the facility designed, inspected and maintained in accordance with applicable codes, standards and manufacturer requirements?
- ☐ Were the following general control measures considered:
 - Ammonia gas detection at credible leak points
 - Ventilation of enclosed areas
 - Ignition control where ammonia may accumulate
 - Emergency shutdown and fuel isolation
 - Release mitigation, vent treatment and safe discharge arrangements
 - Safe purging, start-up and shutdown procedures
 - Gas testing before maintenance or entry
 - Emergency response systems
- ☐ Were the following fuel-cell-specific control measures considered:
 - Hydrogen leak detection across fuel-cell supply, purge and anode off-gas systems
 - Safe routing or treatment of anode off-gas streams
 - Gas accumulation detection within skids, cabinets, containers and enclosed rooms
 - Ignition source control for hydrogen-containing enclosures
 - Control of residual ammonia in filters, catalysts, piping and purge systems during maintenance
- ☐ Were applicable test reports reviewed and accepted to confirm material integrity and suitability for ammonia service?
- ☐ Were ammonia quality and impurity data reviewed, including water, oxygen and other contaminants, to assess potential material degradation?
- ☐ Were all necessary risk assessments and work procedures for safe operation, inspection and maintenance, completed to ensure risk is kept to ALARP?

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Checklist for transport of ammonia

- ☐ Was a transport QRA conducted where required?
- ☐ Were past accidents and incidents involving ammonia road tankers, ISO tank studied and understood?
- ☐ Were the following hazards assessed:
 - Toxic ammonia release during loading, transit or unloading
 - Collision, rollover, impact damage or vessel movement
 - Public exposure outside the facility boundary
 - Emergency responder exposure during off-site incidents
 - Residual ammonia release during disconnection, inspection or return transport
 - Release in congested, remote or difficult-access locations
- ☐ Was the transport equipment designed, rated, inspected and maintained in accordance with applicable codes, standards and manufacturer requirements?
- ☐ Were the following control measures considered:
 - Ammonia-rated tanks, valves, hoses and fittings
 - Impact and mechanical-damage protection for valves and transfer connections
 - Leak detection or portable ammonia detection
 - Emergency shut-off and isolation systems
 - Safe unloading, purging and disconnection procedures
 - Emergency response systems
 - Route planning and journey management
 - Driver and responder training
 - Emergency response information for off-site incidents
 - Collision, rollover and vessel-movement protection
 - Securing and restraint of tanks and vessels during transit
- ☐ Were all necessary risk assessments, including arrangements for emergency response, completed to ensure that risk is kept to ALARP?
- ☐ Was a pre-use or pre-dispatch check completed before transport?

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