

# Safety Guide of Ammonia Refrigerating Systems

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## **Foreword**

This Guide is the product of the research project "Safety of Ammonia Refrigerating Systems" sponsored by The Finnish Work Environment Fund, The Finnish Safety and Chemicals Agency (Tukes), VTT Technical Research Centre of Finland and companies using or producing refrigerating systems. In the compilation of the Guide, results from safety analyses of the refrigerating systems of the participating companies, expertise of the companies in refrigerating systems and that of VTT in risk analyses were utilized.

The companies representing the users of refrigerating systems were Lännen Tehtaat Oyj, Ingman Foods Oy Ab and Valio Oy. Producers of refrigerating systems were represented by Sabroe Finland Oy and those of sensors by Vaisala Oyj.

The purpose of the project was to promote the safety of refrigerating systems and the control of hazards from ammonia releases.

The first edition of the Guide with the photos by Kimmo Virolainen was published by VTT in 2000. Suomen Kylmähdistys ry. updated the information taken from the standard SFS-EN 378, made some minor revisions and published the second edition in 2004. In this translation, the references to the Finnish regulations and safety guides have been revised.

## **1 Introduction**

The purpose of this Safety Guide of Refrigerating Systems is to promote the safe operation and use of ammonia refrigerating systems. The central subject is the assessment and prevention of different risks associated with an ammonia refrigerating system. Another central subject is the safe management of incidents. The Guide concentrates on the risks due to ammonia. General safety issues concerning machinery and equipment are not discussed. The Guide has been written primarily for the operators and designers of ammonia refrigerating systems. Thus, the basics of refrigeration technique have not been presented.

## **2 Ammonia as refrigerant**

The use of ammonia as refrigerant is increasing due to the restrictions on the use of halogenated hydrocarbons. Ammonia as refrigerant has e.g. the following assets:

- ammonia neither harms the atmospheric ozone layer nor contributes to global warming
- ammonia is a cheap refrigerant
- ammonia has suitable thermodynamic properties
- ammonia can be used both at refrigerator and freezer temperatures
- ammonia causes neither cancer nor mutations
- already harmless concentrations (5 to 50 ppm) can be detected with the sense of smell
- compressor lubricants separate from ammonia and settle on the bottom.

The drawbacks of ammonia as refrigerant are

- toxicity to humans and aquatic life
- an ammonia release indoors can result in an explosion
- ammonia corrodes certain metals.

### **3 Properties of ammonia**

#### **3.1 Physical and chemical properties**

At ambient temperature and pressure, ammonia (NH<sub>3</sub>) is a colourless gas. Ammonia is lighter than air and has a characteristic pungent smell. Ammonia can be liquefied by pressure for transportation and storage at ambient temperatures. Ammonia is highly soluble in water. Ammonia is a toxic gas, which forms a flammable mixture with air in the range from 16 to 25 %. Such a mixture, however, does not ignite easily. Toxic nitrogen oxides are formed as combustion products of ammonia. Ammonia properties are presented in Table 1.

Ammonia corrodes, for instance, copper and aluminium and their alloys. Iron and steel do not react with ammonia. The halogens (fluorine, chlorine, bromine and iodine), hypochlorite and ethylene oxide may cause an explosion when mixed with ammonia. Ammonia may also form explosive compounds with gold, silver and mercury as well as their compounds.

Ammonia and its decomposition products are nutrients that make water systems eutrophic. Ammonia is highly toxic to fish. Already the concentration of 1 mg/l may kill fish. For this reason, ammonia is classified as very toxic to aquatic life.

*Table 1. Properties of ammonia*

Molar mass, g/mol	17.1
Density gas/liquid, kg/m <sup>3</sup>	0.68/609
Boiling point, °C	-33.3
Melting point, °C	-77.7
Autoignition temperature, °C	about 650
Flammability range, % gas in air	16-25
pH (1 N solution)	11.6
Odour threshold, ppm	5-50
Solubility, g (NH <sub>3</sub> )/100 g (H <sub>2</sub> O)	
0 °C	89.9
20 °C	51.8
40 °C	33.8
100 °C	7.4

### 3.2 Health effects and first aid

Ammonia is a highly irritating and toxic gas. Below are some of the guideline values of ammonia:

HTP (Finnish occupational exposure limit) 20 ppm (14 mg/m<sup>3</sup>) /8 h  
50 ppm (36 mg/m<sup>3</sup>) /15 min

IDLH (Immediate Dangerous to Life and Health) 300 ppm (210 mg/m<sup>3</sup>) /30 min

AEGL (Acute Exposure Guideline Limits)

AEGL-1 30 ppm (21 mg/m<sup>3</sup>) /10 min  
30 ppm (21 mg/m<sup>3</sup>) /30 min  
AEGL-2 220 ppm (160 mg/m<sup>3</sup>) /10 min  
220 ppm (160 mg/m<sup>3</sup>) /30 min  
AEGL-3 2700 ppm (1900 mg/m<sup>3</sup>) /10 min  
1600 ppm (1100 mg/m<sup>3</sup>) /30 min

AEGLs represent threshold exposure limits for the general public and are applicable to emergency exposure periods ranging from 10 minutes to 8 hours. They are airborne concentrations of a substance above which it is predicted that the general population, including susceptible individuals,:

**AEGL-1** could experience notable discomfort, irritation, or certain asymptomatic non-sensory effects. However, the effects are not disabling and are transient and reversible upon the cessation of exposure.

**AEGL-2** could experience irreversible or other serious, long-lasting adverse health effects or an impaired ability to escape.

**AEGL-3** could experience life-threatening health effects or death.

### **Effects of liquid ammonia and ammonia solution**

**Effects** Liquid ammonia and ammonia solution irritate and corrode mucous membranes, eyes and skin. Liquid ammonia causes corrosion and frostbite injuries on skin.

**Symptoms** Pain, inflammation, blistering, swelling of eyelids, injuries in the cornea.

**First aid** Remove the contaminated clothing rapidly and wash with copious water immediately. Cover the affected skin area with a clean bandage, do not apply any ointment. If ammonia has contacted the eyes, wash them thoroughly with clean water. During the washing, the eyes should be open and blinked.

### **Effects of gaseous ammonia**

**Effects** Gaseous ammonia can cause serious eye injuries already at about 0.5 % and irritate the skin above 1 % concentration. The gas irritates and at high concentration corrodes the mucous membranes of the mouth, throat and respiratory organs. Ammonia has a characteristic pungent smell. Already at low concentrations, running nose, sneezing, coughing and lacrimation occur.

Irritation of airways increases directly proportional to the ammonia concentration. Irritation and inconvenience start at 20-25 ppm (14-18 mg/m<sup>3</sup>). The concentration of 400-700 ppm (280-500 mg/m<sup>3</sup>) causes severe airway and eye irritation. A short exposure to a concentration exceeding 5000 ppm (3600 mg/m<sup>3</sup>) may be fatal due to laryngeal swelling or pulmonary oedema.

**Symptoms** Exposure causes pain in the eyes, nose, mouth and throat. Additional symptoms are lacrimation, sneezing and coughing. In difficult cases, the latter may be convulsive. Exposure to high concentrations causes

a sensation of suffocation, difficulty in breathing and, possibly, unconsciousness.

**First aid** Move the patient to fresh air. If the patient does not breathe or has difficulty in breathing, give artificial respiration and oxygen, if possible. In the case of cardiac arrest, give cardiac massage. The patient must be taken to medical care or hospital, as soon as possible.

## 4 Typical incidents

The Finnish Safety and Chemicals Agency (Tukes) maintains an incident and damage data base called VARO. VARO contains descriptions of incident and damage cases in the field of competence of Tukes since 1978.

One third of the releases from ammonia refrigerating systems occurred through a pressure relief valve due to different process and equipment failures. In many cases, the release was the result of several causes (e.g. human error and equipment failure). The most common single cause was a malfunction of the safety system e.g. the relief valve had been set to open at a pressure lower than the compressor stop pressure.

Descriptions of ammonia incidents abroad were searched in literature as well as the MHIDAS, ARIA and HSELINE incident data bases. In the following, some incidents during the operation, maintenance and repair of ammonia refrigerating systems and their consequences are presented. Except for the fires and explosions, all incidents have occurred in Finland.

### 4.1 Incidents during operation

The most common cause for an ammonia release during the operation of a refrigerating system is the opening of a pressure relief valve due to some failure. In most cases, the primary cause has been an erroneous set pressure of relief valve opening or compressor stopping.

Typical incidents:

*The set pressure of a pressure relief valve had decreased below that of compressor stop. The relief valve opened, releasing ammonia into the atmosphere through the relief line. The gas entered the compressor room through the air intake.*

*The overheating protection of a condensate pump tripped. The resulting reduction of condensation power increased condenser pressure. Because the pressure switches did not operate, compressor pressure rose and pressure relief valves opened.*

The functioning of pressure switches must be tested regularly, e.g. by lowering the set value temporarily, or throttling the condenser line. Then the resulting pressure increase must stop the compressor.

Some ammonia may enter the cooling circuit if the heat exchanger of compressor cooling circuit or that of hot gas heat recovery is leaking. The reason for this is that, in the heat exchanger usually, ammonia has a higher pressure than the cooling medium. The leaked ammonia may increase the cooling circuit pressure which, in turn, opens the relief valve. If the relief valve is in a room without gas sensors, the release may not be detected immediately. If the room is poorly ventilated, the release may result in high ammonia concentrations.

## **4.2 Incidents during repair and maintenance**

Ammonia leaks during repair and maintenance are usually connected with human action. Human errors e.g. due to lack of skill are common. In such incidents, there is a high risk of injuries since the repair or maintenance staff is working in close proximity to the release point.

An ammonia leak may occur e.g. when an oil separator is emptied or when the refrigeration lines are defrosted. An oil drain valve may be left open e.g. when it has been plugged by oil congealed in the cold container. Because no oil flows out, it is believed that the valve is closed. When the oil is heated and becomes viscous, some ammonia is released. Appendix 1 contains instructions for repair and maintenance operations.

Typical incidents:

*A cold room evaporator was defrosted with hot water. Due to the temperature rise, the pressure in the isolated part of the refrigeration system exceeded relief valve set pressure. Ammonia was released into the machinery room through a hole in the relief line.*

*A refrigerating system was defrosted with hot gas circulation and partially melted ice was removed by tapping it with a fork spanner. A coolant pipe ruptured when hit by the spanner and an ammonia leak resulted. Due to panicking, the compressors were not stopped immediately and an ammonia release followed.*

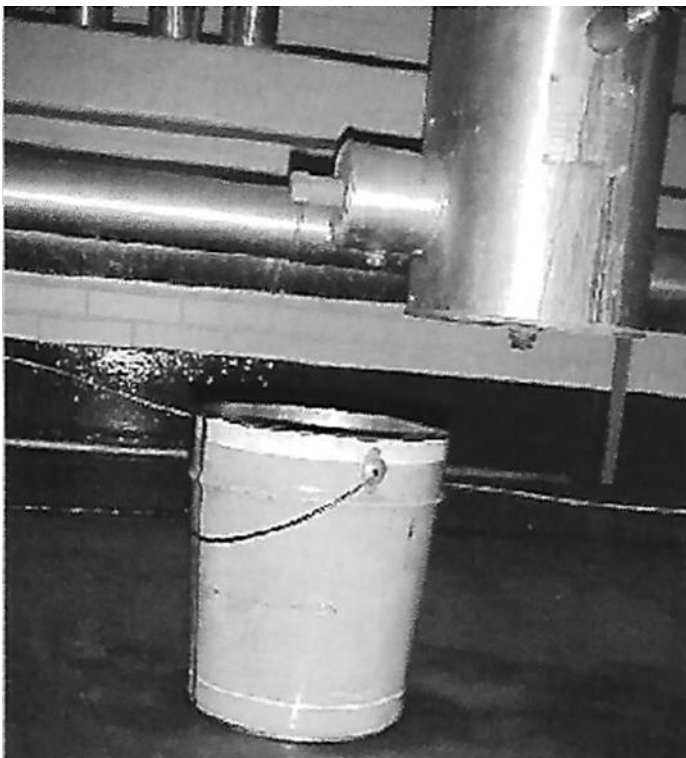


*A maintenance worker was emptying an oil separator of an ammonia container. To be able to remove the oil drain hose for maintenance, he closed the valve. The valve, however, was not fully closed and ammonia leaked to the machinery room.*

*During maintenance, a leak was detected at the main valve of a refrigeration system. A worker started to empty the ammonia piping at the high pressure side of the system and the adjacent oil separator tank. The low diameter drain pipe froze up. The worker believed that the piping was empty and started to remove the main valve bonnet. Since the piping was still pressurised, the valve stem and disk were ejected and liquid ammonia was released.*

The oil collection bucket should never be placed right below the oil separator drain valve (Fig. 1). In an unexpected situation, such as a sudden release of liquid ammonia, high gas concentration and liquid splashes make valve closing difficult. The drain valve handle should be attached during the entire oil change operation. Then the valve can be closed rapidly in an emergency. A safer alternative is to install a spring-return (dead man's) valve at the drain connection.

The oil drain pipe should be lead to a vat further away, preferably outdoors. If possible, the oil recovery vat should be isolated from the ammonia tank. Then the maximum amount of released ammonia is no larger than the oil recovery vat volume. If the oil recovery vat is indoors, it should be lidded and have a vent pipe to lead any ammonia released from the oil to a safe place outdoors (Fig. 2).

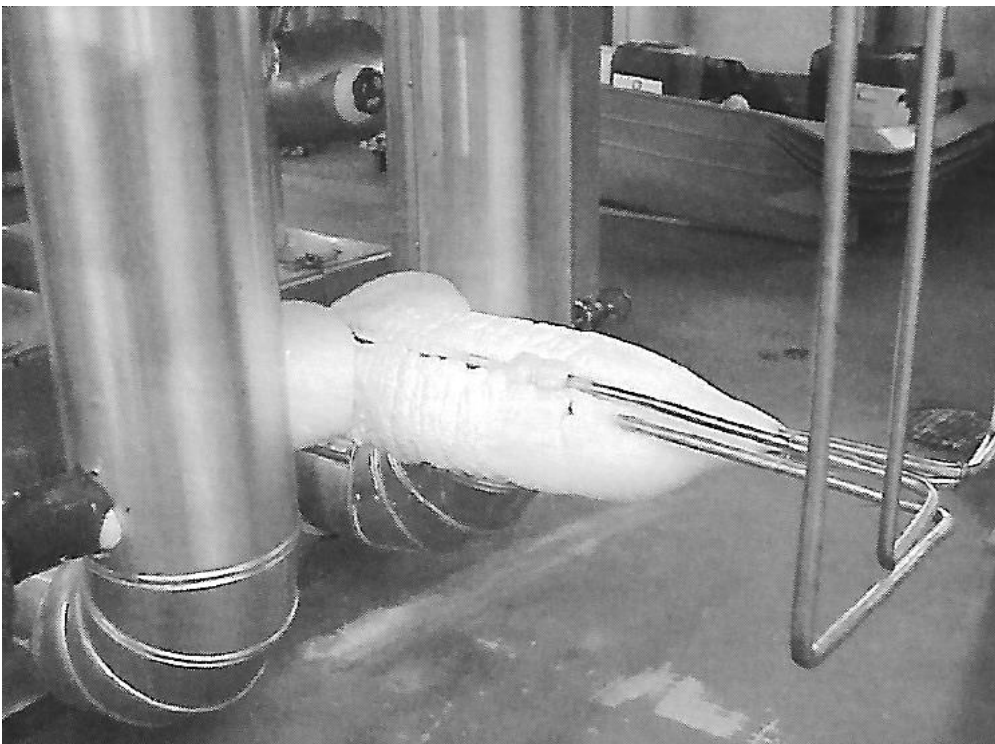


*Figure 1. An example of an oil recovery arrangement. To avoid ammonia splashes on the worker, the drain connection should be further away from the valve.*



*Figure 2. An oil recovery vat equipped with overfill prevention and a vent pipe leading outdoors.*

During repair or maintenance, the ice layer on equipment must not be removed mechanically. This is due to the reduced toughness of cold metal. Besides, there may be gauge connections and other fragile components inside the ice layer. In Fig. 3, some small diameter pipes are seen partly inside the ice layer.



*Figure 3. An example of frozen components of a refrigerating system. Do not remove the ice mechanically due to the risk of equipment failure.*

If it is not possible to defrost the pipes with hot gas circulation, the defrosting has to be done by pouring warm water on the ice. Before doing this, one has to ascer-

tain that no liquid ammonia is trapped between two closed valves. When trapped liquid ammonia is heated, the result is high pressure which can cause equipment or gasket failure.

### 4.3 Incidents due to installation errors and external factors

Incidents are mainly caused by different erroneous ways on installing gaskets. Also in the long run, defective insulation or support of refrigerant pipes may cause leaks. Corrosion is accelerated by moisture condensation on the pipes. External factors cause leaks mainly by damaging parts of the refrigerating system.

Typical incidents:

*Ammonia was leaking from the gasket of a feed valve. The aluminium gasket had been damaged due to overtightening.*

*Ammonia was leaking from the slit between a pump flange and gasket. The flange had been just installed but its tightening had not been checked at operation temperatures.*

*A compressor gasket had been installed erroneously and had broken.*

*An ammonia pipe was leaking due to external corrosion at the lead-through between the cold room and the upper piping room. The cause of corrosion was the lack of insulation at the lead-through and repeated temperature changes during defrosting.*

Proper ways to support and insulate pipes are presented in Chapter 5.4.

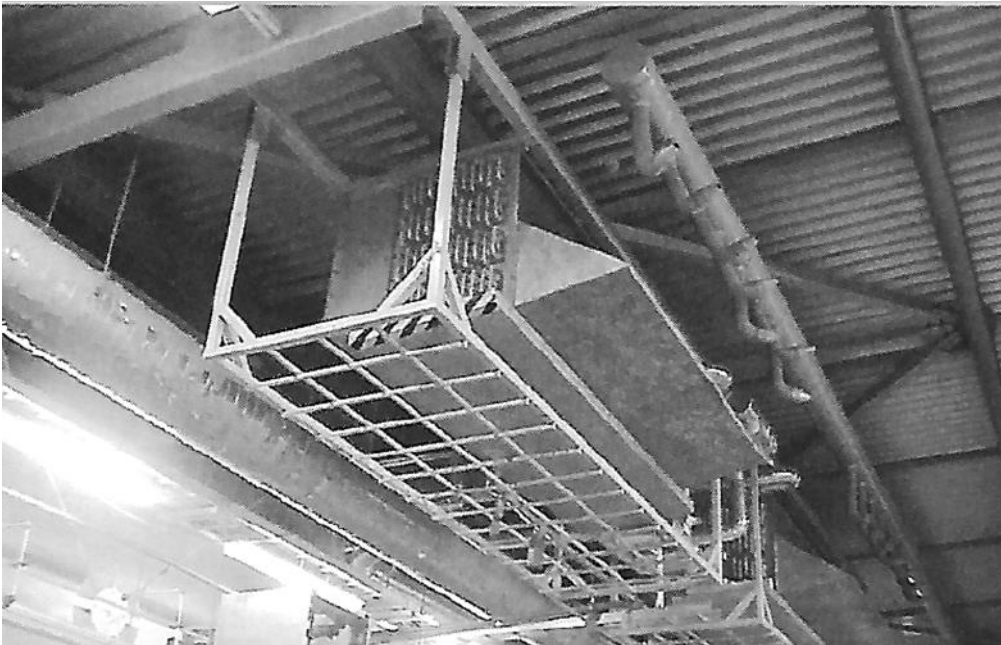
Typical incidents caused by external factors:

*A forklift truck impacted a finned tubular evaporator on the ceiling. The latter failed, causing a leak of liquid ammonia.*

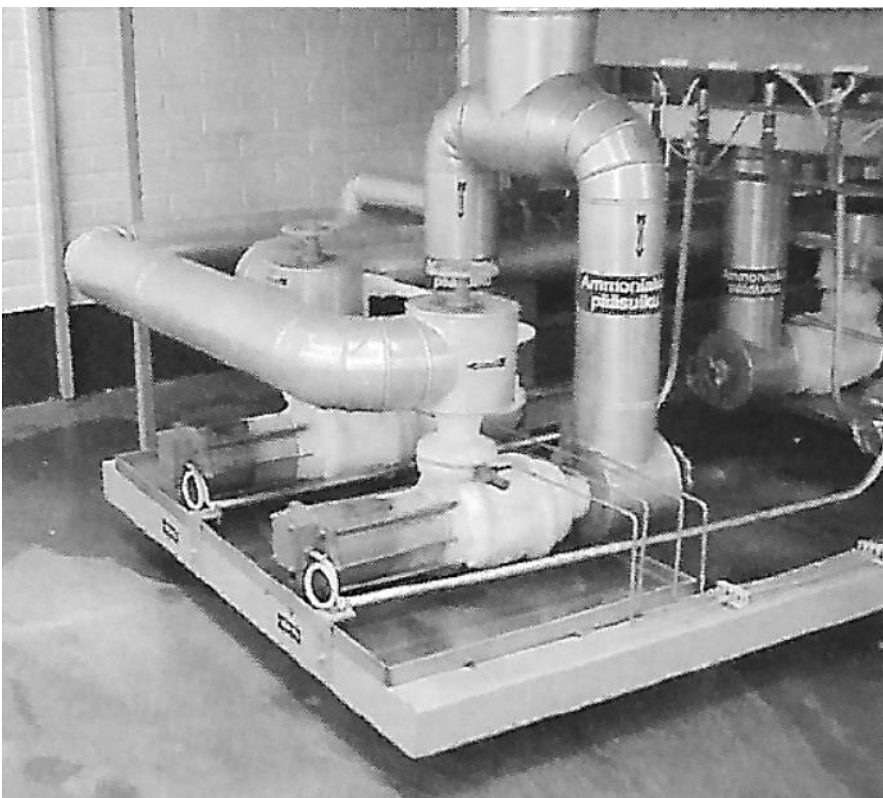
*The snow load caused the roof to collapse on ammonia piping. A pipeline was severed, causing an ammonia leak.*

*An interchangeable platform fell upon the oil drain pipe of a droplet separator. The pipe fractured, causing an ammonia leak.*

The components of a refrigerating system vulnerable to impacts or collisions should be protected. Fig. 4 shows an evaporator on the ceiling that is protected from knocks with a barrier. Fig. 5 shows ammonia pumps that should be protected from collisions.



*Figure 4. A barrier protecting an evaporator on the ceiling from impacts.*



*Figure 5. Pumps that should be protected from collisions.*

## 4.4 Fire and explosion incidents

The VARO data base contained no fire or explosion incidents at ammonia refrigerating systems. Such incidents, however, have occurred abroad.

A common factor in most ammonia explosion incidents was the insufficient ventilation of the machinery room or some other space, which made the formation of a flammable ammonia-air mixture possible. In many incidents, it was not possible to identify the ignition source conclusively. The most common ignition source, however, was a spark at an electric motor or other electric apparatus.

Typical explosion incidents:

*A valve at the evaporator in cold storage was leaking. Although the evaporator had been isolated, ammonia concentration in the insufficiently ventilated room kept rising. Ammonia leaked either from the pipe section next to the leaking valve or the isolation was not properly done. The employees tried to reduce the ammonia concentration by spraying carbon dioxide from a 23 kg cylinder. This method had been used for minor leaks. In this case, however, the carbon dioxide condensed air moisture and ammonia. The fog droplets and the ammonium carbonate particles greatly reduced visibility. Also the floor became very slippery. Firemen protected with chemical suits and compressed air breathing apparatuses tried to replace the leaking valve. One fireman was lifted with a forklift truck to work with the valve, about 5 m above the floor. Near-zero visibility and the slippery floor caused the truck collide on the wall and an explosion followed.*

*An engineer heard a noise and saw a vapour cloud in the machinery room. He shut the main liquid valve and notified the fire department. When the first fire engine arrived, the engineer loaned a chemical suit and breathing apparatus, and volunteered to point out the valve which he expected to stop the release. Before the men were ready to enter the building, an explosion occurred. The explosion raised the floors and roof and moved reinforced concrete support columns. Portions of the brick wall collapsed in the street. It was impossible to stop the ammonia release because the overhead ammonia lines were severed. The total amount of ammonia in the system was approximately 1800 kg of which about 200 kg was released. The time between leak start and explosion was estimated at 30 min. The ignition source could not be identified.*

At fire incidents where refrigerating systems had been involved, ammonia did not ignite but the fire often damaged ammonia piping, causing releases.

Typical fire incidents:

*At an ice-cream factory, a metal plate was flame cut. The polystyrene insulating panel behind the plate ignited. Half of the 12 000 m<sup>2</sup> warehouse was devastated by the fire that burned for 16 hours. Because the refrigeration system contained 18 000 kg of ammonia, the fire brigade evacuated all residents within a radius of 500 m. Only a small amount of ammonia was released. The fire brigade used a water curtain to mitigate the release.*

*A fire in a cold storage resulted in an ammonia release. The amount of ammonia released was 900 kg. Presumably, most of it was burned in the fire.*

Thermal insulation is often involved in fires at cold storages. The smoke from an insulation fire often contains toxic gases, providing an additional risk. Besides, a burning and melting insulation material may spread the fire effectively.

Action in fire and explosion incidents is described in Chapter 6.5.

## **5 Accident prevention and safe operation**

The present chemical legislation requires industrial companies to evaluate the hazards associated with plant operation, accident consequences and mitigation methods. To reach the goal of the safe operation of refrigeration systems, the technical standard of equipment as well as the skills of operating and maintenance staff must be adequate for accident prevention. On the other hand, it is necessary to plan and exercise the different actions in accident situations (alarms, evacuation, leak control etc.). In this way, the actions in an eventual accident situation can be performed effectively and safely, and the damage will be as low as possible.

Appendix 2 contains check lists that can be used to estimate the factors contributing to the safety of the refrigerating system.

### **5.1 Operator guidance and instructions**

According to the standard SFS-EN 378, the supplier or installer of a new refrigerating system or unit system must give the necessary training to the operating staff. The training must cover all the equipment of the refrigerating system or unit system as well as their functioning.

The training must emphasise the compliance with the operation instructions. The operating staff should be present when the equipment is assembled, evacuated, filled with the refrigerant and tested.

The operating instructions should be prominently displayed. According to the standard SFS-EN 378, the operating instructions should contain e.g. the following information:

- the name, address and phone number of the supplier and/or installer
- the name, address and phone number of the maintenance company
- the refrigerant name and fill amount for normal operation
- the use of the system
- the description of equipment
- the part list, process and instrumentation diagram and electric diagrams
- short instructions for the starting and stopping of the system or unit system
- the highest operating pressure
- instructions for the filling and draining of the refrigerant
- instructions on the handling and related risks of the refrigerant
- warning about the freezing of water in the condenser, evaporator etc. at low ambient temperatures or due to an abnormal decrease of system pressure and temperature
- the causes of the most common failures and the required actions
- advice to wear personal protective equipment
- first aid instructions for injuries
- warning about erroneous readings of pressure gauges (if the reading is abnormally high, the gauge must be retested)
- a reference to the operating manual
- the log book
- warning against storing more than 20 % of the fill amount and more than 200 kg of refrigerant in separate containers in the machinery room

In addition to the items mentioned in the standard, the instructions should contain the contact information of the person responsible for the operation of the system and that of the maintenance company or their person on duty as well as the emergency number and instructions for emergencies outside working hours.

Besides, the Material Safety Data Sheet of ammonia must be available for the personnel at the workplace. The supplier of ammonia must hand it over with the deliveries free of charge.

## 5.2 Isolation valves and safety devices

### Isolation valves

The standard SFS-EN 378 contains directions for the proper realisation of isolation valves. Compressors and other equipment of the refrigerating system must be equipped with drain valves. To reduce hazard situations and refrigerant leaks, it must be possible to isolate the equipment individually or in groups with manual or automatic isolation valves.

Isolation valves that are used continuously must have a fixed hand wheel or other manual device. Those not used during normal operation but used to facilitate e.g. repair or maintenance work must be such that a hand tool is required for valve operation. An isolation valve with a protective cap satisfies this requirement if the cap cannot be used to turn the valve stem.

Branches of the ammonia main should have isolation valves which can be used to isolate parts of the system from the main, if necessary. Even minor parts of the system can be isolated in this way. Then e.g. repair or maintenance work can be performed without emptying or shutting down the major part or the entire system. The valves can also be used to isolate a leaking or failed part of the system without a shutdown.

The designer should pay attention to the proper selection of isolation valves. Valve maintenance such as the change of gasket should be easy. The gaskets of some isolation valves can be changed only after the system has been emptied of refrigerant.

The locations of ammonia pipes and, above all, those of isolation valves must be marked clearly so that even a person unfamiliar with the system can find them, if necessary. Ammonia pipes must be marked with the flow direction and, preferably also, physical state (liquid/vapour) and temperature. A more specific marking can be the name of the equipment that the pipe leads to e.g. "liquid ammonia (-33 °C) to freezer storage evaporators". The Finnish standard SFS 3701 contains detailed instructions for pipe marking. Fig. 6 is an example of the proper marking of an emergency stop valve in production area.

Sewer systems, especially those near compressors and ammonia tanks, should be equipped with isolation valves to prevent any leaking ammonia from entering the sewer system. A drain connection should be installed next to the isolation valve for the recovery of the ammonia accumulated in the sewer.





*Figure 6. An example of the proper marking of valves and piping.*

## Gas sensors

When ammonia is used as refrigerant, gas sensors must be installed in the machinery room, valve group rooms and every closed cold room. The workings of the sensors are monitored at the control panel of the machinery room. Room geometry, air flow and the most probable leak positions must be considered when placing the gas sensors. No unmonitored "pockets" should remain. Besides, it must be remembered that, in certain conditions, cold ammonia vapour can accumulate at floor level.

A gas sensor should also be installed next to the end of any relief line. In this way, the message that a relief valve has opened will be available immediately. If the plant operator is not present, the message should be forwarded automatically to the plant operation control.

A gas sensor can be integrated in the control system of the refrigeration plant to limit the consequences of an ammonia leak. Suitable automatic functions are e.g.

- starting ventilation or increasing ventilation rate

- stopping evaporator recirculation fans
- stopping refrigerant pumps and compressors
- closing isolation valves (also those in the sewer system)

The problems in the use of gas sensors are false alarms e.g. due to humidity, other gases (exhaust gas, gases at the fork truck battery charge chamber, flavourings etc.). Gas sensors can be maintained in working order by regular calibration, the correct setting of action limits and the correct placing. Repeated false alarms must not lead to the shutoff of the gas alarm system.

Gas sensor normal functioning is affected by variations in temperature and humidity, high air flow velocities, various interfering gases and the drift due to aging. If the conditions at the sensor position are known when the sensor type is being selected, it is possible to provide for the known disturbing factors. In some cases, they can even be eliminated with different compensations and preconditioning.

Gas sensor users should know the conditions, capable of damaging the sensor. The sensor may be damaged when the sensor crystal or cell moistens, as a result of erroneous calibration or when affected by certain chemicals (e.g. by the high concentrations of certain gases emitted by sealants).

Gas sensors should be calibrated frequently enough by an expert. A sensor may be damaged if it is calibrated or tested with an unsuitable gas or with a too high concentration (e.g. undiluted ammonia gas). Suitable calibration gases are available from instrument manufacturers.

Ammonia sensors are either electrochemical or semiconductor ones. The main properties of these two sensor types are presented in Table 2.

*Table 2. Main properties of the gas sensor types*

Sensor type	Electrochemical	Semiconductor
relative humidity*	20–80 %	> 50 %
the pros	selectivity, tolerates humidity better	long service life, shorter response time
the cons	expensive, short service life	sensitivity to other gases

\* Based on the ranges of relative humidity given by some manufacturers

## **Pressure relief valves**

The pressurised parts of a refrigeration system must be protected with pressure relief valves to prevent the system pressure from exceeding the maximum operating pressure. The refrigerant released by a relief valve must be led to such a place where it causes no risk to people and the environment.

In most cases, it is sufficient to place the end of a relief pipe high enough above the roof and, as far possible, away from the air intakes. All ammonia releases can be avoided by leading the relief to a gas scrubber. The functioning of pressure relief valves should be secured by lubricating them frequently. Also, a supply of reconditioned pressure relief valves should be available.

The opening of a relief valve should stop compressors and pumps, and close isolation valves. Then the amount of ammonia released into the atmosphere will be as small as possible. Relief valve opening can be detected by e.g. installing a gas sensor next to the end of the relief line or by equipping the relief line with a pressure or temperature gauge.

Sometimes, the cause of short blow-off times of pressure relief valves may remain unclear, especially when several relief valves are connected to the same relief line. A solution to this problem is to install a device similar to a water seal (equipped with a sight glass) filled with oil or another non-volatile liquid at different lines. This device shows the relief valve that opened or the piece of equipment that caused the opening.

### **5.3 Water-hammer caused incidents and their prevention**

Water-hammer is one of the possible causes of refrigerant leaks which, however, has not always been identified as the cause of an incident. Below, some of the factors that cause water-hammers, possible ways to decrease their probability and some of their consequences are presented.

Water-hammer signifies a sudden stop of liquid flowing in piping. Liquid incompressibility and the high kinetic energy of moving liquid can together cause a very high pressure surge. A water-hammer can occur in the following conditions

- a sudden closing of a liquid valve
- a liquid plug is accelerated to a high speed by vapour flow
- evaporator defrosting with hot gas is started before the solenoid valve of the suction line has closed completely

- vapour in piping condensates suddenly, which increases the flow velocity of the surrounding liquid
- long and complicated piping, which collects liquid easily.

Liquid entering the compressor from an overfilled container can cause a severe damage due to the large forces involved in compressor operation and liquid incompressibility.

The occurrence of water-hammer effects can be detected from various symptoms such as

- bangs and clatter are heard from the piping
- loosened insulations
- the pressure gauge needle goes off-scale (and possibly stays there)
- leaks.

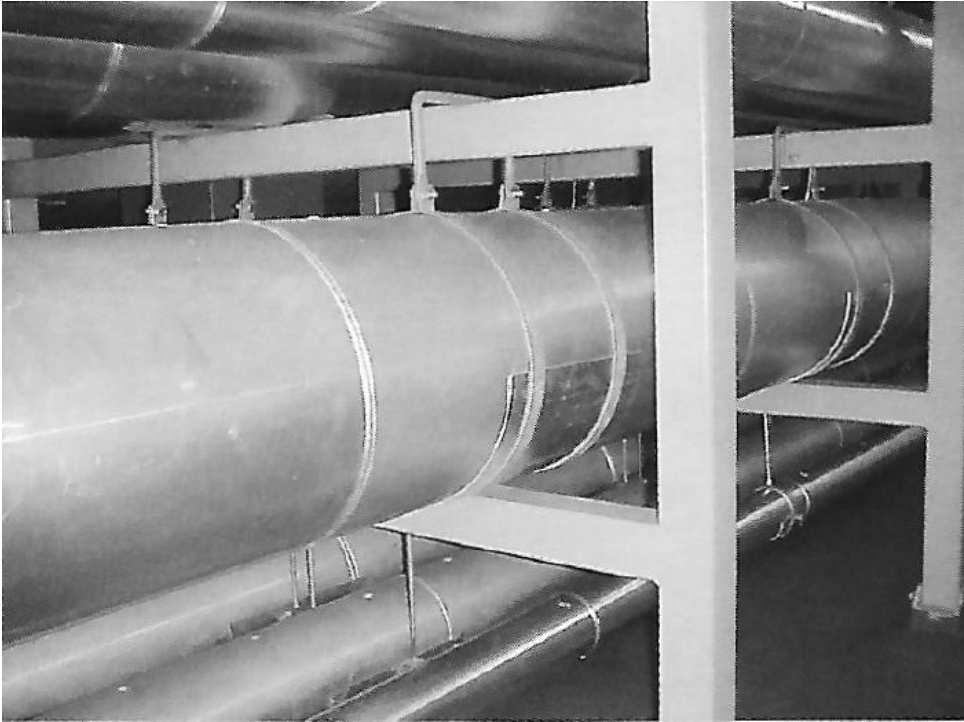
The first water-hammer seldom causes a leak, but repeated ones stress the piping, especially the welds, flange connections and pipe supports. The generation and consequences of water-hammers can be prevented with the following measures:

- valves that open and close slowly
- the gas pressure is increased and decreased slowly during the defrosting phase (hot gas defrosting)
- avoid any liquid traps when designing the piping
- ascertain the strength of welds
- during the start and operation of the system, be careful not to let any liquid refrigerant or oil enter the cylinders of the compressor. Liquid separation can be avoided by a high enough suction rate of refrigerant vapour
- if the compressor is located in a cold room, any suction of refrigerant into the crankcase must be prevented e.g. with a crankcase heater. Suction and high pressure lines must be equipped with check valves or located in such a way that no liquid refrigerant or oil can collect in the pipes adjacent to the compressor.

#### **5.4 Pipe supports and insulation**

Pipe supports must sustain all loads on them. Stresses are caused by the weights of the pipe proper and insulation as well as thermal movements and hydraulic impacts. The spacing of pipe supports should be such that the forces acting on the pipe do not bend the latter. Pipe supports must be outside pipe insulation to avoid heat bridges. If the pipe support is in contact with the pipe, the support will

be cold and condense air moisture. Besides, it is difficult to achieve a perfectly tight lead-through in the insulation and there is a risk of moisture penetration into the insulation. Pipe supports should allow the free motion of the pipe or they should be flexible. Then the thermal expansion does not cause pipe bending or breakage. Fig. 7 shows an example of a well-realised pipe supporting.



*Figure 7. An example of a well-realised pipe supporting; the supports are outside the insulation and the pipe is hanging upon a "support collar", permitting free motion e.g. due to thermal expansion.*

The condition of insulation must be monitored with regular checks. This can be done e.g. with thermal imaging. Thermal imaging, however, may be difficult to carry out if the insulation has a metal cladding. Hot gas pipes and other pipes subjected to continuous temperature variation have the largest corrosion risk.

The moisture absorbed into the insulation reduces thermal insulation capacity and increases the risk of external corrosion. In certain conditions, even polyurethane can absorb moisture. The absorbed moisture can usually be detected from frost on the insulation surface or dripping.

Fig. 8 is an example of a hot gas pipe insulated with polyurethane where the moisture condensed in the insulation has caused corrosion damage. The damage was detected when the insulation externally in good condition was removed during scheduled maintenance. The insulation was drenched. To avoid moisture and corrosion, the metal cladding must be as tight as possible. For the sealing, e.g. weather proof silicone can be used.



*Figure 8. The hot gas pipe with the wet insulation removed.*

Insulation must be continuous also at lead-throughs. Also the possibility of thermal expansion must be considered when designing lead-throughs. Fig. 9 is an example of well-realised lead-throughs of pipes. The brick wall has a large opening through which the insulated pipes have been led. The opening has been sealed with mineral wool within the metal cladding.



*Figure 9. An example of lead-throughs of pipes. The pipes have been led through a large opening, allowing a continuous insulation. Besides, the opening has been sealed with mineral wool within the metal cladding.*

The behaviour of insulation must also be considered when designing tank supports. If foam glass is used to support a tank, there is a risk of spalling due to

humidity variation. Then the tank may sink, causing stresses and even fractures in the pipes. To cut the heat bridges between the steel supports and the tank, e.g. a rigid plastic can be used. If the tank rests on foam glass, the tank position in relation to the pipes must be monitored with regular checks.

## **5.5 Familiarising the fire brigade with the function of the system**

Fire brigade assistance may be required at various incidents and accidents. In the case of an ammonia release, the fire brigade is required e.g. to search for and rescue the victims, to close valves, to locate and to plug the leak, to ventilate rooms and to control the released ammonia. When a refrigeration system is involved in a structure fire, the fire brigade must consider the possibility of ammonia release. The fire brigade also isolates the hazard area of a gas release and warns the people present in this area.

Finnish fire brigades use the so-called TOKEVA Instructions (Mitigation Instructions for Chemical Incidents), which include a Tactical Guide for a release of toxic gas, Method Guides for mitigation methods and a Chemical Diving Guide. The Tactical Guide has been written primarily for the releases of a pressure liquefied gas (such as ammonia) from a transportation or storage tank. However, it was not possible to consider the special characteristics of process equipment when drawing up the Guide.

To be able to accomplish its tasks in the best possible way, the fire brigade must be familiar with the function of the refrigeration process as well as with the control and safety devices. The latter include the gas detection system, pressure relief valves, emergency stop devices and the main isolation valves.

The fire brigade must also know the systems for the normal and emergency ventilation of the rooms as well as the measures by which the spread of an ammonia spill in the sewer system can be prevented. This information is entered in the internal emergency plan and the fire brigade attack plan, where necessary. Besides, the valves and other control devices must be clearly marked.

A characteristic feature of process plants is that it is often difficult to localise the cause of the failure. Since typical refrigeration systems involve long pipelines, the impact of the failure may be detected far from the defective device. Below, some ammonia leak incidents are described. The fire brigades responding to these incidents were not sufficiently familiar with the refrigeration systems.

*A pressure switch did not stop the compressor due to a defective pressure gauge. A pressure relief valve opened and ammonia vapour was released into the atmosphere through the relief line. The fire brigade "stopped the leak" by blocking the relief line with a wooden plug.*

*The isolation valve between a liquid level detector and a tank had been closed due to the replacement of level sensors. The maintenance worker forgot to reopen the valve. Because the level detector was isolated, liquid level in the tank kept rising until a water hammer blew out a gasket at the compressor. The release continued for an hour because the operators were unable to point out the correct isolation valve to the fire brigade.*

*The condensation water pumps did not restart after a breakdown caused by a thunderstorm. Probably, a pressure gauge was dirty, causing the system pressure to increase above the pressure relief valve set value. The fire brigade closed the wrong isolation valve which contributed to the pressure rise on the delivery side of a screw compressor, opening a pressure relief valve.*

## 5.6 Ventilation installation

An appropriate ventilation of the rooms of the refrigeration system can be used to prevent an ammonia release from spreading to other rooms. It can also prevent the formation of flammable ammonia-air mixtures in the room where the release occurs. The machinery room and other rooms with ammonia piping must be designed in such a way that the gas spread to other rooms can be prevented.

The formation of flammable mixtures is prevented with emergency ventilation. The latter is accomplished either by an independent fan or by increasing the air exchange rate of the ventilation installation. Emergency ventilation can be started by the alarm of a gas detector in the room. The motor of the emergency ventilation fan must have an explosion-proof construction and must be controllable also from the outside of the machinery room.

Air intakes in the factory area must be located in such a way that the ammonia released from the machinery room or a pressure relief valve never enters the buildings at any wind directions. If this is not possible, the ventilation fans can be made to stop when the pressure relief valve opens, or equipped with a gas detector of their own whose signal stops the fans.



## 5.7 Safety analyses

The present chemical legislation provides that industrial plants must assess the risks associated with their operation and risk consequences, and provide for the risks. In practice, different safety analysis methods are used to assess the risks and to prepare safety reports. A safety analysis – also called risk analysis – is a method of identifying from technical equipment, human action and environmental conditions those factors that, possibly, may cause an accident or incident. The analysis includes also consequence assessment and the search for possible improvements. With the help of analyses, it is possible to provide for possible risks in advance already.

The most profitable time to perform a safety analysis is the design phase. At this phase, it will be the easiest and cheapest to realise the proposed changes. Most often of a working plant also, it is possible to point out unidentified risks that can be reduced with relatively simple and cheap measures.

The general view of the risks associated with the equipment and attained with a safety analysis provides a better starting point for the planning of improvements and preparation of operating instructions and emergency plans.

Different identification methods consider mainly the hazards, their causes and consequences. In addition to the causes and consequences of a hazard, one should also review the preparations for it and evaluate their adequacy. If the preparations are considered inadequate, measures to rectify the situation or to perform a more thorough evaluation should be considered.

A single analysis method neither applies to all kinds of subjects nor provides a comprehensive understanding about all possible hazards. More information on different risk analysis methods, their scope of application, advantages and limitations is given e.g. in the publication "Risk control in chemical industry" and on the website of VTT.

## 6 Emergency instructions

One of the most important factors in the accident prevention of refrigeration systems is the training of operating and maintenance personnel. An essential part of the implementation of an internal emergency plan is the training of the entire personnel for emergencies. Depending on the duties of the person, the training may consist of the following items:

- behaviour and impacts of leaking ammonia
- positioning and action of gas sensors
- fire hazards and the function of fire alarm system
- detection of a leak or fire, making an emergency call and raising the alarm
- use of escape routes and other action in case of an alarm
- location and use of personal protective equipment and fire extinguishers
- rescuing of and giving first aid to victims
- sufficient familiarity with the equipment (isolation valves, emergency stop devices, pressure relief valves etc.)

## 6.1 Internal emergency plan

The Finnish decree on the supervision of the handling and storing of hazardous chemicals (855/2012) provides that enterprises carrying on an extensive activity must draw up an internal emergency plan. Enterprises whose refrigeration systems together contain more than 10 000 kg of ammonia must draw up an internal emergency plan. According to the decree, the following objectives must be considered when preparing the internal emergency plan:

1. containing and controlling incidents so as to minimise the effects, and to limit damage to man, the environment and property,
2. implementing the measures necessary to protect man and the environment from the effects of major accidents,
3. providing for the restoration and clean-up of the environment following a major accident.

The internal emergency plan must present, among others, the following items associated with the refrigeration system and ammonia releases:

- assembly areas in case of an ammonia release
- the emergency access roads of the fire brigade
- internal emergency organisation
- gas detectors and actions to be taken when they alarm
- instructions on how to detect gas releases and to make an emergency call
- instructions on how to raise the alarm
- instructions on how to act when a gas alarm is raised
- informing of an emergency
- connection with the regional rescue services and cooperation with the fire brigade
- instructions on how to control an ammonia leak and to limit its consequences

- personnel training and exercises for the action in incidents and emergencies
- damage prevention after the incident and cleaning the environment, e.g. the processing of water contaminated with ammonia
- an estimate for the effects of ammonia releases in the surroundings.

The Finnish Safety and Chemicals Agency (Tukes) has issued instructions on how to prepare an internal emergency plan (Ohje K2-11). The internal emergency plan is dispatched to the regional rescue services department. In the case of a new facility, the internal emergency plan is attached to the licence application dispatched to Tukes.

In addition to the operating instructions and the internal emergency plan, at least rough estimates should be made of gas dispersion for different releases of ammonia. This enables one to estimate the areas that will be at risk when a release occurs.

Sections 6.2 to 6.6 below contain more detailed information on the behaviour of ammonia in different leak situations as well as on the search and rescue of victims, leak control, explosion prevention, firefighting and damage prevention. This information can be used to evaluate the possible release scenarios of an individual refrigeration system.

In addition to the gas dispersion estimates, also the situation of personnel in different premises of the plant must be known. This refers e.g. to the number of workers and their locations, their possibilities to protect themselves by staying indoors, or by exiting safely from the buildings and the plant area.

An internal emergency plan and instructions can be prepared by combining the data of hazard areas from gas releases with the data of the plant, personnel and the main parts of the refrigeration and ventilation systems. When the severity of an accident is evaluated, the eventual risks of an ammonia release to the people outside the plant area must be considered along with the risks to the plant and its personnel. In case the release causes risk to the local residents, the incident commander is responsible for informing and instructing them. Besides, the eventual risks of a refrigeration system must be considered in the external emergency plan prepared by the regional rescue services department.

The general principles of actions in gas release incidents can be based on the results of analyses. The gas dispersion modelling shows the area where an accidental ammonia release can cause a health hazard. When ammonia is released

into the atmosphere, the people outdoors have to go indoors or go crosswinds away from the hazard zone, and those indoors have to stay there. When ammonia is released indoors, the people indoors have to go to a safe place either outdoors or in safe parts of the building. Outside the plant, several emergency assembly areas must be specified, taking into account the local conditions and different wind directions.

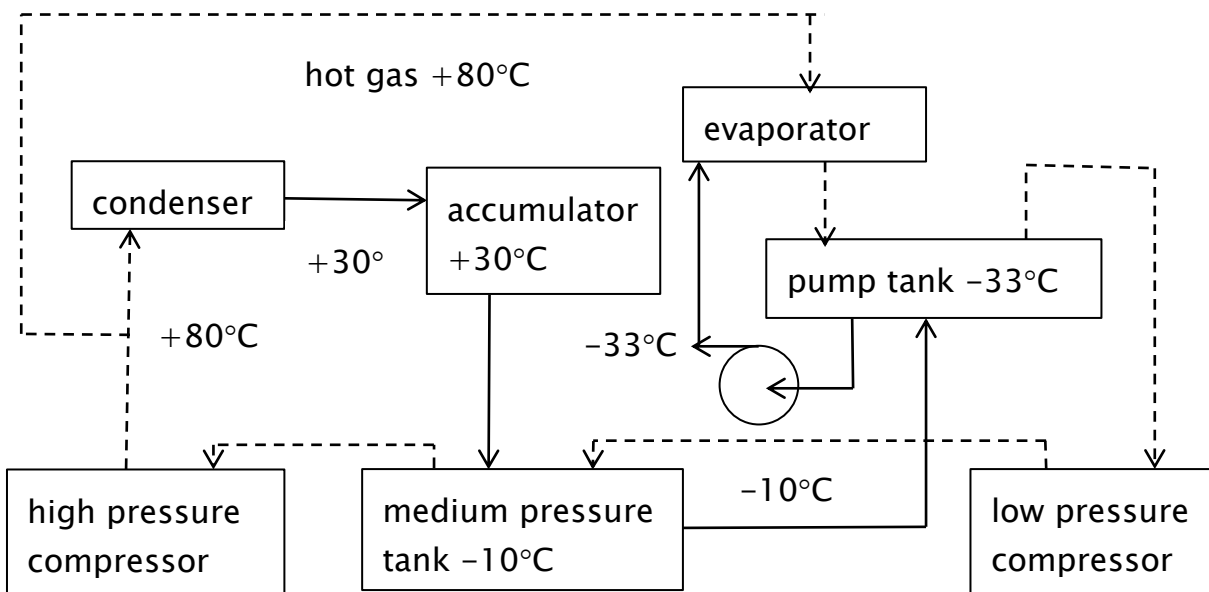
## 6.2 Ammonia leaks

Usually, liquid ammonia is transported and stored at ambient temperatures in tanks under pressure. In very large storage tanks, ammonia is stored as refrigerated liquid at the boiling point  $-33\text{ }^{\circ}\text{C}$ . In different parts of a refrigerating system, ammonia is either liquid or vapour. Different parts can have significantly different temperatures. Fig. 10 is a simplified flow chart of an ammonia refrigeration system. It shows typical temperatures in the different parts of the system. All systems do not have an accumulator or a separate medium pressure tank but only the pump tanks.

Examples of different types of leaks from an ammonia refrigerating system:

- **Minor leaks from valves or flange connections.** The leaks can be detected easily from smell.
- **Gas leak from the pipe connecting the compressor with the evaporator or from the hot gas pipe used to defrost the evaporators.** The pipe contains warm compressed gas. The leak can be detected from the whistling sound due to the high outflow velocity. The released gas will be diluted effectively outside the leak. Thereafter it will rise upwards, indoors towards the ceiling. Indoors, a large release forms a life-threatening concentration rapidly. If the room is poorly ventilated, a flammable mixture may be formed.
- **Liquid leak from the pipe connecting the condenser with the medium pressure tank or from the accumulator.** The pipe contains warm (about  $+30\text{ }^{\circ}\text{C}$ ) pressurised liquid. About 20 % of the released liquid is flashed to vapour. Simultaneously, the remaining liquid cools to the boiling point  $-33\text{ }^{\circ}\text{C}$  and the liquid jet is shattered into droplets. If the jet does not impact on any obstacle, the evaporation of ammonia droplets cools the air entrained into the jet. Then the atmospheric humidity condenses into a dense fog. Usually indoors, the liquid jet impacts on some obstacle. Then part of the liquid forms a pool on the floor. Indoors, a large release forms a life-threatening concentration rapidly. If the room is poorly ventilated, a flammable mixture may be formed.

- **Liquid leak from the pipe connecting medium pressure tank with the pump tank.** The pipe contains cold (about  $-10\text{ }^{\circ}\text{C}$ ) pressurised liquid. About 8 % of the released liquid is flashed to vapour. Simultaneously, the remaining liquid cools to the boiling point  $-33\text{ }^{\circ}\text{C}$  and flows through the openings in the insulation to a pool on the floor or the ground. The release cools the air and some fog may be formed. Indoors, a large release forms a life-threatening concentration rapidly. If the room is poorly ventilated, a flammable mixture may be formed.
- **Liquid leak from the pipe connecting the pump tank with the evaporator.** The pipe contains very cold (about  $-33\text{ }^{\circ}\text{C}$ ) pressurised liquid. The liquid flows through the openings in the insulation to a pool on the floor or the ground.
- **Liquid leak from the pipe connecting the evaporator with the low pressure compressor.** The pipe contains very cold (about  $-33\text{ }^{\circ}\text{C}$ ) ammonia gas. The gas may be under partial vacuum. Then some air may enter the refrigerating system through the leak. After the pressure has equalised, the pipe will leak cold gas that rises upwards, indoors towards the ceiling.
- **Behaviour of an ammonia spill onto the floor or the ground.** A minor part of the spill boils off due the heat conducted from the substrate. A spill onto the floor or pavement can end up in the sewer system. When the cold liquid comes into contact with sewer water, 67 to 90 % of it dissolves and the remaining 10 to 33 % evaporates.



*Figure 10. A simplified flow chart of a refrigeration system. The temperatures refer to a certain facility. Dashed line = ammonia vapour, solid line = ammonia liquid.*

### **6.3 Behaviour of an ammonia release**

Both the gas leaking from a pipe and the vapour evaporated from a spill are lighter than air. A release of warm pressurised liquid, however, can form a mixture that is denser than ambient air (because the evaporation of ammonia droplets cools the air). If the liquid jet impacts on an obstacle or the leak is underneath the insulation, the release will be lighter than ambient air.

A gas lighter than air released into a room will rise towards the ceiling. Between the leak and the ceiling, a layer with approximately constant gas concentration will be formed. For a long release, the concentration will reach a steady state value that depends on the gas release rate and room ventilation rate. This value can be reduced either by controlling the release or by increasing the ventilation rate.

A gas lighter than air released into the atmosphere can rise several metres above the release point. This so-called plume rise depends on wind velocity and other weather parameters, among others. Besides, the release point, e.g. an exhaust fan grille, is often above ground level. The gas plume, however, will touch the ground further away where it has been diluted, already. This fact reduces the health risk to people downwind. Usually, emergency ventilation does not cause risk to people downwind, but nevertheless they have to be warned and advised to stay indoors.

Close to the release point, a release denser than air will sink to the ground. Due to dilution, the density difference disappears gradually, but the plume will not lift.

If there is a large building immediately upwind of the release point, the release will be diluted in the wake formed by the building. This effect reduces the hazard range. Large buildings downwind of the release point divert the surface wind locally, causing the plume to move sideward.

If liquid ammonia enters the sewer system, it may flow a long distance until it encounters water. The reaction between liquid ammonia and water evaporates 10 to 33 % of the ammonia, which creates an overpressure in the system. The overpressure may raise the water level of floor drains and traps so much that ammonia gas will bubble through. Then the ammonia gas entering rooms through traps and the atmosphere through vent pipes may pose a risk at unexpected places.

### **6.4 Rescuing and other emergency measures**

The main hazard of an ammonia release is due to irritation and respiratory protective devices must be worn. At low concentrations, a filter respirator is sufficient, but at high concentrations (above 10 000 ppm or 1 %), a compressed air

breathing apparatus must be worn. At least one such apparatus must be available at a refrigeration plant containing more than 500 kg of ammonia. At concentrations above 1 %, the ammonia will irritate moist skin and may cause burns. A gas-tight chemical protective suit must be worn at high concentrations. Contacts with the cold liquid or equipment may cause frostbite injuries.

The first measure is to find out whether everyone both indoors and outdoors have gone to a safe place. If the release is indoors, everybody must exit the building to a safe place. The plant must have some emergency assembly area for the personnel. A suitable area can be e.g. the gate or car park. Several emergency assembly areas can be specified and the most suitable one will be selected, based on the prevailing wind direction. In the emergency assembly area, it is the task of superiors to make sure that everybody is safe. Nobody is allowed to leave the emergency assembly area without permission.

If there is any doubt that people are still indoors or in the hazard area, they must be searched and rescued. The rescuers wear respiratory protective devices. If necessary, the rescued patients are given first aid. The following first aid measures may be required:

- artificial respiration mouth to mouth or with bellows if the patient has stopped breathing
- cardiopulmonary resuscitation in the case of cardiac arrest
- eye rinsing with running tepid water (eye wash bottle) if the patient has received splashes of liquid ammonia or ammonia solution into eyes
- rinsing with (emergency) shower and removing clothing contaminated with ammonia. The injured skin area is rinsed with running tepid water. The contaminated clothing is left outdoors or packed into sealed plastic bags
- the patients are taken to the emergency department for medical examination.

Usually, an ammonia release from a refrigeration system can be stopped by closing the right isolation valves. In some cases, these valves will be closed when the emergency stop device is activated. In other cases, these valves must be closed manually with a handle or hand wheel.

A major release into a small and poorly ventilated room may raise the concentration of ammonia to the flammability range (16 to 25 %). The oil mist released from a compressor mixed with ammonia may be flammable already at ammonia concentrations significantly lower than 16 %. According to one study, the mixture of oil mist with only 4 % of ammonia may be flammable.

For the ignition of ammonia–air mixtures, however, a strong ignition source, such as a spark of electric apparatus or open flame, is required. An electrostatic discharge does not have sufficient energy. A faulty electric device, for instance, can ignite the mixture. Ammonia explosions, however, are rare.

For activities in a room with a high concentration of ammonia, the Chemical Diving Guide of TOKEVA Instructions can be followed, when applicable. Due to fog formation, the visibility in the room may be poor. To improve visibility and to remove a possible explosion risk, the room should be ventilated (TOKEVA Guide M7a) before the responders enter it. Besides, it has to be kept in mind that the isolation valves to be closed may be difficult to access and that any ammonia spills must be passed, if possible.

Spray jet covering with a tarpaulin (TOKEVA Guide M8a) is a relevant mitigation method only for a leak of warm pressurised liquid. A cold liquid spill is prevented from getting in contact with water by damming, plugging or covering floor drains or manhole covers or plugging the sewer pipe (TOKEVA Guide M8b). A release of ammonia gas can be diluted and absorbed by fog streams (TOKEVA Guide M8c). Liquid ammonia collected into a plugged drain well can be transferred into a container with a submersible or hose pump (TOKEVA Guide M10a).

Major ammonia leaks (several kg/s) from a refrigeration system are improbable. Besides, such a leak will probably drain the accumulator before the fire brigade arrives. Thereafter, only the rate of ammonia circulation (no larger than 1 kg/s) will flow out.

The most common point of ammonia release of a refrigeration system is the relief pipe of a pressure relief valve. The corresponding release rate was estimated at 0.83 kg/s with release duration no longer than 10 min. In the Finnish OVA Guide of ammonia, the hazard instruction for a release from a refrigeration system is:

*Immediate isolation 50 m in all directions. Ammonia may cause irritation symptoms up to 250 m downwind. People in this area are requested to remain indoors, close windows and doors and to stop ventilation fans.*

If in the vicinity there are industrial plants, residential areas, schools, kindergartens, businesses etc., it is necessary to inform them of possible ammonia releases, how to detect a release and to protect oneself. Annex VII of the degree (855/2012) details the contents of an information leaflet for the residents. It is the duty of the regional rescue services department to prepare an external emer-



gency plan, where the hazards of ammonia releases outside the factory area are estimated.

## **6.5 Fire and explosion**

A refrigeration system is an additional risk when the building catches fire. The pipes and tanks containing cold ammonia are insulated whereas those containing warm ammonia are not. Probably, the first ammonia releases come from pressure relief valves. Fire-caused thermal stresses on pipes can open flange connections, resulting in leaks.

The major risk is the rupture of tanks heated by the fire. The most common insulation materials in modern refrigeration systems, polyurethane and polystyrene, are easily combustible. A good practice is to absorb a fire retardant into the insulation and to place gypsum boards between the insulation plates.

The pipe leaks occurring in a fire do not cause a significant risk outside the plant area since part of the ammonia may burn in the flames and the remaining part mixes with the smoke and is lifted high with the smoke plume. The rupture of ammonia tanks, however, is a hazard to firemen. Besides, tank contents will form a large vapour cloud that causes a risk to people outside the factory area. Usually, tank insulation will retard the rupturing.

In a structure fire, the refrigeration system should be stopped e.g. with an emergency stop device. The other actions depend on the fire situation. The isolation valves of all pipes leading to the fire area should be closed to prevent the entire system from emptying through the leaks generated by the fire.

In a fire, the firemen wear compressed air breathing apparatus, firefighting gear, rubber boots and protective gloves. A gas-tight chemical protective suit cannot be worn in the hot environment. Usually in a fire, no situations arise where the risk of liquid splashes or skin irritation would require the use of a gas-tight chemical protective suit.

## **6.6 Decontamination of the area**

If possible, the ventilation of rooms should be started already during the release. After the release has stopped, all the rooms, especially those of the basement, where ammonia may have entered with ventilation, must be ventilated. Part of the liquid in a contained spill can be pumped to a container with a submersible or hose pump. The remaining liquid can be allowed to evaporate under control. The

evaporation rate can be reduced by covering the spill with plastic sheeting or similar material.

Any waste containing ammonia is classified by the Finnish decree on wastes (179/2012) as hazardous waste. Such waste must be delivered to a hazardous waste disposal plant. With certain types of waste, it is possible to get exemption from this classification by sending a report with justification to the Finnish Environment Institute.

It may be permissible to lead waste water containing diluted ammonia to the municipal wastewater treatment plant. Such waste water must be conveyed to the sewer in a controlled way so that ammonia concentration is not too high. High concentrations and pH changes may cause major trouble in the operation of a biological water treatment plant. In some cases, dilute ammonia solutions can be used as nitrogen fertilisers. Ammonia is classified as very toxic to aquatic life. Never release any water containing ammonia to a watercourse.

## **6.7 Reporting and investigation of accidents**

The Finnish decree on the supervision of the handling and storing of hazardous chemicals (855/2012) gives the following guidance on the reporting of accidents. If an accident in an industrial plant causes a fatality, serious injury or major damage to property or the environment, the company must report it to Tukes immediately.

The report by the company must contain the following items:

1. Description of the accident and the conditions preceding it.
2. The quantities of chemicals involved and the amount of the possible release.
3. The impacts on the environment and property that have been observed or are to be expected.
4. Description of the rescue and mitigation measures taken due to the accident.
5. An evaluation of the causes or causal factors of the accident.
6. An account of the actions that the company will take to prevent any long-term effects and the recurrence of similar accidents.

When the accident occurs at a plant that handles or stores only limited amount of chemical, the report is sent to the regional rescue services department, which forwards the report to Tukes.

Even minor incidents and near misses should be reported to Tukes. Especially incidents of general interest e.g. the typical faults of certain devices or problems caused by certain construction practices should be reported. This enables Tukes to assess the importance of the observations and to consider eventual further actions.

Although minor incidents and near misses need not be reported to the licensing authority, their causes must be investigated by the company. When the causes and consequences of an incident are investigated, it is possible to develop improvements to prevent the recurrence of such situations. The improvements may concern e.g. equipment, operation modes, personnel training and emergency measures. Thus even minor incidents can be instructive and improve the safety.

## **7 Rules and regulations for refrigeration systems**

Several standards, rules and regulations concern the design, construction, operation and maintenance of ammonia refrigeration systems. Their aim is to further the safe operation of the system. The main Finnish standards, rules and regulations are listed below with short descriptions of their contents. [The list is omitted].

### **Literature**

TOKEVA 2012 Instructions for the Response of Incidents Involving Chemicals (in Finnish) [www.pelastusopisto.fi](http://www.pelastusopisto.fi)

OVA 2014 Safety Instructions for Hazardous Substances (in Finnish) <http://www.ttl.fi/ova/>

Risk control in chemical industry (in Finnish). Helsinki: Chemas Oy, 1991.

Refrigeration systems and heat pumps (in Finnish). Standard SFS-EN 378.

Aittomäki, A. Refrigeration technology (in Finnish). Helsinki: Kylmätuki Oy, 1992.

## **Appendix 1 Safe maintenance of refrigeration systems**

### **1 Maintenance**

Various types of maintenance work can be required such as repairs, installations, replacements, oil change, replenishing the refrigerant and inspections. The work is often done by external contractors. Maintenance work, however, is not done daily, which emphasises the need for clear instructions and training.

### **2 Information, guidance and training**

Information, guidance and training are essential factors in safety. Advanced safety systems and instructions are useless unless the personnel are familiar with them. It is also necessary to make sure by supervision that instructions are observed and tasks are done safely.

Both those working with the refrigeration system and their supervisors must be trained. Also other workers in the area should be trained, especially for the emergencies. It should be emphasised that personal protective equipment must be worn when performing emergency measures. Emergency measures should be practised regularly. During an emergency drill, the smooth cooperation of different teams (operation, maintenance etc.) should be emphasised.

The need to inform and train company's subcontractors and other external parties must be considered separately. Sometimes, also employees of other departments or other units of the company may require a similar training as the outsiders. The outsiders cannot know the local conditions and practices as well as the employees and this fact increases their accident risks.

### **3 Risks**

The main risks associated with the maintenance work of refrigeration systems are:

- accidental ammonia release (into air, onto the floor or ground, and subsequently to the sewer)
- poisoning
- frostbite burns
- accidental start
- electric shock

## 4 Work permits and instructions

Serious industrial accidents are often due to inadequate securing and preparation. The prevention of such accidents requires that work permits are implemented and strictly complied with. A general type of work permit can be used for all maintenance tasks of a refrigeration system. For a problematic or otherwise atypical object, a detailed specific work permit can be written.

Work permits can be completed with detailed operating or work instructions. The instructions must be revised and completed based on operating experience, incidents and near misses or changed conditions. The instructions may also include detailed safety instructions e.g. isolation plans with the corresponding piping diagrams.

The work permit procedure may be impractical when the plant has a small staff. In practice, the person competent to issue a work permit may also perform the tasks. In such cases, it is preferable to prepare only a clear stagewise check list to be used to assure the safety during all stages of work.

The necessity for written operating and safety instructions is emphasised when external contractors are responsible for performing the work, or when new personnel are trained in their tasks. In drawing up instructions and check lists, the first step can be to write down the current practice and recast it as instructions or a check list. Drawing up instructions and their structure should be incorporated in the quality system. If necessary, a safety analysis can be done of the work before drawing up instructions.

The aim of work permit procedure and check lists is to ascertain that certain safety measures will be done to the refrigeration system and linked systems before the work is started. In practice, this means that the necessary measures are listed in the work permit form or check lists and the worker confirms with his signature that they have been done.

With a work permit and check lists, it is possible to control that the preliminary, preceding and actual tasks will be done properly. Below, these tasks will be discussed in more detail.

### **Purging**

The system or its part must be purged as well as possible before opening it. The suction of the system compressor can be used in purging. When the system has been purged carefully, there will be less need to ventilate the working space and

the working conditions will be better as regards industrial hygiene during the proper maintenance work.

The pipe system should have enough connections that can be used to purge the system parts in a controlled way. To purge the parts containing gaseous ammonia, the suction of a small compressor can be used. The ammonia gas from the delivery side of the compressor is led e.g. to a water filled container or a safe place outdoors. Then air is permitted to enter the part to be purged and also aspirated out of it. By this procedure, the system can be purged of ammonia gas.

There is a risk of liquid ammonia splashes when an oil separator is emptied. If the oil collection bucket is right below the oil separator drain valve, the sudden unexpected ammonia splashes may incapacitate the worker. In such a situation, the drain valve may remain open and a large amount of ammonia may be released into the room.

This stage of operation will be safer if the oil is led with a hose or fixed piping to a vat further away from the drain valve. If the oil recovery vat is indoors, it should be lidded and have a vent pipe to lead any ammonia released from the oil to a safe place outdoors. Then this sudden release will occur further away and the worker is able to shut the valve safely.

In spite of all safety precautions, a respiratory protective device with a face covering mask must be worn to protect from ammonia releases. At high concentrations, however, a filter respirator does not provide sufficient protection and a compressed air breathing apparatus must be worn.

### **Work site isolation from piping**

If a part of the piping system must be opened e.g. for valve replacement, compressor maintenance or some other reason and the task takes a long time, all ammonia releases to the work site must be prevented by isolating the opened pipe section in a reliable way. Suitable methods are e.g. blanking and a double block-and-bleed system. The latter involves the use of two closed valves and an open drain positioned between them.

The closed valves must be locked in closed position or be marked with the label **"Do not open, men at work"**. Closing only one valve is not a safe enough isolation method. Detailed instructions on isolation, including a blanking plan and piping diagrams as well as information on the parts to be isolated, should be drawn up.

When a flange connection is opened, the nuts behind the pipe must be loosened first to allow any ammonia in the piping system to be released away from the worker.

### **Disconnecting electrical devices**

Often, also electrical devices require maintenance. Typical electrical devices that can pose a risk are e.g. pumps and compressors, along with their motors. An accidental start of electric devices is best prevented by removing fuses or locking a safety switch and with the label "**Do not switch on, men at work**". For the disconnection of electrical devices, detailed instructions should be drawn up. The latter should contain all the devices to be disconnected or switched off as well as the correct ways of disconnecting or switching off.

### **Personal protective devices**

When a piping system purged of ammonia is opened, nevertheless one has to provide for ammonia releases. The necessary personal protective devices for respiration and eye or face protection should be kept at the ready. A full face mask gives the best protection. It has to be kept in mind that at high concentrations a filter respirator does not provide sufficient protection. If the ventilation system cannot maintain a low enough ammonia concentration, a compressed air breathing apparatus must be worn.

### **Ventilation**

The aim of ventilation is to create such working conditions that respiratory protective devices are not required. If this is not possible, adequate personal protective devices must be worn. When planning the ventilation of the work area, any unnecessary spread of ammonia to other spaces must be avoided. If necessary, the hazard area must be marked off with labels e.g. "Ammonia hazard, do not enter without a respiratory protective device."

### **Replenishment of ammonia**

From time to time, the refrigerant must be replenished. Usually, the pressure difference between an ammonia cylinder or container and the system can be used to transfer the liquid. In practice, the pressure in a cylinder or container at the machinery room or ambient temperature is higher than those in the coldest circuits of the refrigeration system. However, liquid must never be replenished to compressor suction line since then some liquid may enter the compressor, which will

be damaged. The best places to feed ammonia are the pump tank or suction side of a liquid pump.

During replenishment, the ammonia cylinder or container must be placed in such a way that it cannot overturn and no vehicle can collide with it. To provide for leaks, it should be outdoors. In winter, however, to ensure a sufficient pressure difference, it may be necessary to bring the cylinder or container indoors. If necessary, the replenishment area is isolated with sealing-off line or warning signs.

After the transfer hose has been connected, it is pressurised by opening the cylinder or container liquid valve slightly. All connections are tested for leaks e.g. with a soap solution. After the connections are found tight, ammonia transfer can be started by opening the valve at the system fill connection.

Initially, the cylinder or container liquid valve should be opened only slightly because the flow rate will be high due to the large pressure difference. The valve spanner or handle must be kept attached during the replenishment. Then the valve can be closed swiftly in case of a leak. If for some reason, the liquid transfer must be interrupted, the liquid valve of the cylinder or container must be closed first. Then the partial vacuum of the system will drain the hose. The system fill connection valve is closed only thereafter. If the liquid transfer is interrupted for a longer time, the transfer hose is disconnected and the cylinder or container is moved to a safe place.

### **Special actions**

Depending on the local conditions, the work may involve some special hazards or situations. Special instructions must be drawn up for them. If there is a risk of an ammonia spill onto the floor and subsequently to the sewer, the floor drains can be covered in advance to prevent the spill from entering the sewer.

A work permit or check list can also include the actions to be performed after the task has been finished: e.g. cleaning the work site, the actions and checks required to make the system ready for operation and reporting procedure on a finished task.



## **Appendix 2 Check lists to secure the safety of an ammonia refrigeration system**

Below, some factors are listed that can be used to assess the safety of ammonia refrigeration systems and reduce accident risks. It is preferable to consider most of them already at the design phase, since it may be difficult or impossible to make modifications at later phases. Several factors in the list are prescribed by law, but the list is an easy way to identify the main shortcomings related to the safe operation of the system.

### **Design and construction**

#### **Rooms**

- Have the compressors and refrigeration equipment been placed in large enough rooms that have good ventilation and good escape routes?
- Are the rooms spacious enough to allow work, wearing a chemical protective suit and compressed air breathing apparatus?
- Have the electric equipment in the compressor room been selected and placed in such a way that they will not ignite the flammable mixtures created by possible leaks?
- Has the machinery room been constructed as a separate fire compartment?

#### **Refrigeration system**

- Have all the ammonia pipes and valves been marked in an appropriate way?
- Do all the ammonia valves have correct dimensions and types?
- Do the valves open and close slowly enough to avoid water-hammer effects?
- Are all the pipes sloping to prevent liquid accumulation?
- Have all the seams and welds of the piping been inspected before installing the insulation?
- Are all the pipe supports such that the pipes will not bend, are they outside the insulation and has thermal expansion been considered in the design?
- Is the equipment and pipe layout such that the risk of impacts and collisions is minimal?
- Is the pipe insulation at lead-throughs sufficient to prevent moisture condensation and corrosion?
- Have the fragile components such as sight glasses been protected from impacts?

- Have the pipes and equipment been protected from impacts and collisions (e.g. by a forklift truck)?

### **Safety and relief systems**

- Are there enough gas sensors and have they been placed in an appropriate way?
- Can the fire and gas alarms be heard also in the cold rooms e.g. the freezer storages?
- Have the emergency stop devices of compressors and pumps been placed also outside the machinery room?
- Can the (emergency) ventilation of the machinery room be started outside the entrance to the room?
- Can the doors of ammonia storages, cold rooms and machinery rooms be opened easily from the inside?
- Have the vent pipes of pressure relief valves been led to safe places outdoors?
- Is the air intake placed in such a way that no ammonia released from the machinery room or a pressure relief valve can enter the building?
- Can the ventilation of work areas be stopped in case of an ammonia release?
- Is the machinery room ventilation rate sufficient to prevent the formation of flammable mixtures?
- Is room heating sufficient to prevent e.g. the cooling water from freezing when the compressors are not running or the ammonia vapour from condensing where it should not?
- Is the air compressor inlet placed in a safe place, considering potential ammonia releases?
- Is the oil change system closed, preventing all ammonia releases?
- Are the oil drain valve and oil recovery vat in sight of each other?

### **Operation, maintenance and training**

#### **Training**

- Are the personnel familiar with the required instructions and standards related to refrigeration apparatus and ammonia?
- Do the personnel have sufficient expertise for the risky stages of operation (emptying oil separator, defrosting pipes etc.)?
- Have clear working instructions been drawn up for the main tasks?

- Have the personnel been trained in the safe operation and handling of ammonia?

### **Maintenance**

- Is the refrigeration system undergoing regular corrosion testing?
- Is the condition of insulation monitored with e.g. thermal imaging?
- Are the maintenance and repair work as well as operating times recorded?
- Is the draining and purging of ammonia piping verified before starting maintenance and repair work?
- Is the machinery room maintained clean and tidy?

### **Operation**

- Is the amount of ammonia in the system as small as possible?
- Is the system under control round the clock?
- Can a person familiar with the operation and function of the system be reached any time?

### **Emergency preparedness**

#### **Safety equipment**

- Does the plant have personal protective devices for ammonia releases and are they safely available even during a release?
- Has a person responsible for the maintenance of personal protective devices been named?
- Are the alarm devices inspected regularly?
- Are there enough emergency showers or eye wash bottles available (Additional information in the standard SFS 5411)?

#### **Emergency actions**

- Have the actions in potential emergencies been planned together with the local fire brigade and, possibly, also with the local hospital or community health centre?
- Does the plant have an alarm system and evacuation plan for ammonia releases and fires?
- Are leak control and evacuation drills organised regularly?
- Is the wearing of personal protective devices drilled regularly?
- Are all incidents and near misses investigated and reported?