The Safety and Integrity of Ammonia Storage Tanks

-by Venkat Pattabathula, Incitec Pivot Ltd, Brisbane, Australia
-by Raghava Nayak, Process Safety Expert, Sydney, Australia &
-by D.H. Timbres, D. & E. Consulting Inc., Fort Saskatchewan, Alberta, Canada

1. Introduction
Ammonia is an important raw material for the fertiliser industry and more than 150 million tonnes of ammonia is produced worldwide per year. About 20 million tonnes of ammonia is traded every year at the international level and the rest is consumed locally for the manufacture of fertilizers and industrial chemicals. Storage of liquid ammonia had been a practice for almost 100 years right from the time ammonia was made on an industrial scale. In the earlier stage of ammonia production, ammonia was stored in pressurised systems such as bullets and in Horton spheres. Typically, spheres were used to store up to 2000 tonnes whereas atmospheric ammonia storage tanks are used to store up to 50,000 tonnes at plant sites and also at separate distribution terminals near to where liquid ammonia is applied directly. Low pressure ammonia storage has been widely accepted for two reasons. First, it requires much less capital per unit volume. Second, it is safer than sphere storage using pressures higher than atmospheric. With the large scale industrial production of ammonia, it has become common to store ammonia at atmospheric pressures at -33°C.

2. Types of ammonia tanks
The main types of atmospheric tanks operating at -33°C are:
- Single-wall steel tanks with external insulation, commonly known as single wall tanks, (Figure 1). Some of these tanks have concrete bunds surrounding the tank to contain the full contents of the tank.
- Steel tanks with double walls and perlite insulation in between the walls are known as double-wall tanks or double-containment tanks [Figure 2].

![Figure 2: Double-wall tank (double containment)](image)

There are two types of double-wall, double-integrity (DWDI) tanks: those with insulation in annular space [Figure 3] and double-wall, double-integrity tanks with insulation on outer tank [Figure 4].

![Figure 3: Double-wall, double-integrity tank (full containment) with insulation in annular space](image)
The main difference between the two types of DWDI tanks is that the one with insulation on the outer tank can be operated for a longer time in the case of an inner tank failure, whereas the one with insulation in the annular space needs to be de-commissioned upon inner tank failure as its outer tank is not insulated. DWDI tanks with insulation in the annular space cost less than the tanks built with insulation on the outer tank. All of the double-wall style tanks are designed to contain the full contents within the inner tank, and both styles of DWDI tanks are designed with the same materials of construction. In the figures, the different tank designs are shown standing on piles. This is the generally accepted standard for newly designed tanks. However, single-wall tanks have been known to be placed directly on compacted soil/sand foundations which then require under tank heating coils (foundation heaters) to prevent frost lens and possible ground heaving.

Single-wall tanks were built at many sites in the past, but the current practice, based on quantitative risk assessment (QRA), recommends that DWDI tanks be used for bulk storage to achieve an 'As Low As Reasonably Practicable' (ALARP) risk level. Note that the failure rate for DWDI full containment tanks is nearly one hundredth of that for single wall tanks (based on failure rates published by HSE UK, Purple Book /SGS 3 published by VROM, Netherlands, and the Failure Rates Handbook by Belgium). Atmospheric ammonia tank standards are still evolving. For example, risk assessment was not previously included in the above noted standards. Now API 625, which cross references to API 620, states that risk assessment should be conducted by the purchaser of the tank to determine the tank configuration.

Tank design, installation and operation should comply with the best available operating procedures based on HAZOP, bow-tie analysis and/or similar process-risk evaluation tools. The design of individual storage tanks and their associated ancillary equipment can vary. Items that require systematic attention during a tank's lifetime include; relief valves; nozzles; drainage systems; roof, wall, and bottom insulation; piles and foundation (elevation surveys); tank integrity inspection (especially weld joints); piping inspection and fitness-for-service assessment.

3. Tank design and safety aspects

The following design features are recommended for high integrity ammonia tanks:

• the atmospheric ammonia storage tank should be of double-wall, double-integrity type with insulation on the outer wall and be designed for 14 kPag internal pressure.

• the tank should be designed, fabricated, erected, and tested in accordance with the generally accepted standard, API 620, Appendix R. A new code API 625, published in 2010 describes the various tank systems (single, double and full containment). It refers to the updated API 620 2012 edition for steel tank construction and ACI 376 2010 edition for concrete tank construction.

• the tank should be erected on an elevated piled concrete slab foundation to prevent the ground freezing below the tank, since this design will negate the potential damage of the foundations or the tank itself due to frost heave. The top of the concrete slab shall be at an elevation of about 2 metres above the surrounding area.

• the foundation and tank should be designed to withstand a full hydrostatic test of the tank. Both inner and outer tanks should be hydro-tested.

• the tank design should accommodate movements of the tank due to thermal changes and minimise induced bending stress in the shell.

• for installation in a region of seismic activity, a seismic analysis of the tank and associated pipe work should be carried out.

• the design should include the required allowances for cyclonic wind and earthquake conditions per country standards.

• the design should be suitable for a marine environment, as many sites may be close to the sea.

• drain lines are to be provided both for the inner and outer tanks.

Tank materials

The inner and outer steel tanks should be of all welded construction and fabricated from normalised carbon-manganese steel. API 620 Appendix R lists acceptable
materials for tank construction together with code designations and material properties. Materials for atmospheric ammonia tanks should be selected to satisfy the requirements specified in the design code. The standard type of material is low temperature certified carbon-manganese steel, impact tested at or below -40C. Welding and any Charpy V-notch testing will be carried out to meet the quality requirement of the tank plate and the welding procedures at the tank design conditions.

The supporting/load bearing rings underneath the tank walls should be a treated wood (lignostone) or equivalent type of material. Treated wooden blocks are preferable to Perlite concrete blocks for insulation at the bottom of the tank. The outer tank anchoring material should be identifiable against mill certificates giving chemical analysis and mechanical properties. Any components welded directly to the tanks should be fabricated from the acceptable materials listed in API 620 Appendix R. All nozzle/manway welds in the lower strakes should be PWHT (post weld heat treated - stress relieved) to remove residual stresses from the welding process. No hard stamping of materials is allowed, as this causes stress raisers.

**Pressure relief**
As a minimum, at least two pressure relief valves and two vacuum relief valves are recommended for each atmospheric storage tank to protect against over-presuring or vacuum conditions which may occur. The design configuration of the relief valves should be such that any one valve can be removed for examination or maintenance without losing the protection of the tank. An isolation valve between the tank and each relief valve and a mechanical linkage system should be incorporated so that only one valve can be isolated at any time (a Nederlock/Castel Key system can also be used). Relief valves and safety devices should be assessed (sized) according to the requirements of API 2000.

A permanent nitrogen connection to maintain tank pressure as one (additional) layer of protection is recommended in case of a low-low pressure scenario (nitrogen addition instead of air ingress avoids the potential for stress corrosion cracking). An emergency shut-off valve in the liquid supply line is needed to activate on high-high pressure in the tank.

**Instrumentation**
Tanks should be fitted with three independent level and pressure indicators. There should be an independently activated high level shut-off valve to close the feed to the tank at very high level in the tank (a 2 out of 3 level transmitter safety trip system).

**Electrical**
Tanks should be fitted with earthing bosses, and tanks over 30m in diameter should have three earthing bosses. The earthing bosses should be constructed of austenitic steel for the studs and washers and protected copper conductor strips to prevent contact with ammonia. Earthing bosses need to be evenly spaced around the tank. Where personnel need access for maintenance, adequate lighting shall be provided.

**Piping**
All flanges should be of minimum 150# rating. Bottom liquid nozzle connections should be of minimum 300# rating. Screwed connections are not allowed.

**Insulation**
External insulation should be covered with a continuous flat aluminium vapour barrier. Single profiled sheets for the aluminium vapour barrier must not be used. External insulation procedure and design must be evaluated at a specialist insulation designer to insure nil water ingress which would allow ice to form on the tank shell or the base, potentially causing heaving. The ambient temperature for design of the insulation system is a maximum temperature of 50C and minimum temperature of -40C.

**Tank Non-Destructive Testing (NDT)**
The primary NDT used on the NH3 tank throughout its life should be the acoustic emission (AE) method. The tank design should include all permanent fittings/modifications required to minimise time and disruption during set-up and testing. The tank should be installed with waveguides for AE tests during initial fabrication. The initial AE test must be conducted at the hydrotest stage so that any construction defects can be fixed prior to placement of the tank into service. A second AE test also needs to be carried out during first fill of liquid ammonia into a new tank.

Following the hydrostatic and AE tests, water should be held in the inner tank at the height equivalent to the maximum operating level for a period of seven days to ensure that future foundation settlement does not occur. The constructor inspection test plan (ITP) should also allow for witness points during construction.

**General Requirements**
The stairway to the top of the tank should be a spiral type, with the separate stand-alone access tower as its
access. Platforms with access from the main stairway should be provided to ensure necessary maintenance access. The design and coverage of this platform should consider the safety of personnel working in the platform area.

Ammonia Storage Facility
When designing and building the ammonia storage system, a layer of protection analysis (LOPA) study should be used to determine the following safety instrumented functions:
• remote shut-off valves are provided on the liquid ammonia main inlet and outlet line to/from ammonia storage tank.
• the refrigeration system should be based on recognised and proven industrial compressors.
• there must be an auto compressor loading/unloading facility for tank pressure control.
• a review of stand-by equipment for critical duties and utilities is required.
• the design should take into account a closed vent and drain system for ammonia.
• redundancy in critical instrumentation and control is required.
• thermal relief valves must be installed on the ammonia lines where there is a possibility of blockage or heat ingress.
• any fugitive ammonia emission should be minimised. Where ammonia venting is needed from relief valves or from maintenance activities these must be piped back to the ammonia storage tank.
• any venting of ammonia to the flare shall be avoided or minimised.
• an ammonia leak detection system in the storage area is necessary.
• lightning protection and earthing protection for the tank is mandatory.
• emergency power to one of the refrigeration holding compressors to maintain tank pressure during power failure is required in the design package.
• a flare is needed for controlled venting under extreme emergency situations.
• a wind direction indicator is suggested.
• emergency plant lighting is necessary.

5. Decommissioning
For decommissioning, empty the tank to the absolute minimum liquid level. Evaporate the remaining ammonia in a way that ensures uniform and slow heating, not exceeding 2°C/hour. Purge with warm ammonia until all liquid ammonia is removed. Remove the ammonia gas in the tank by purging with nitrogen and not with air, to prevent the formation of an explosive mixture. To prevent environmental issues, flare all the ammonia vapour containing streams. Remove the nitrogen atmosphere by purging with air until the oxygen content is >19%. If ammonia is still measured in the gas phase due to residual oil, breathing equipment must be used when entering the tank. Residual oil remnants may require additional clean methods and additional personnel safety requirements and equipment.

6. Risk Based Inspection (RBI)
As noted above, the primary inspection method for the tank should be the acoustical emission method. AE testing is a non-destructive testing technique that has been successfully used in industry for many years as a means of detecting and locating defects in process equipment. As a global inspection technique, AE is capable of detecting and locating defects in the area being monitored. The standard practice is to use the periodic inspection either on-line or off-line, depending on the operating conditions of the equipment and the ability of the process to create the pressure increments necessary for the test. In essence, for a successful AE test the tank must be capable of being 'stressed.' AE testing only detects active cracking conditions. Signals which indicate the potential for cracking will require follow-up examinations using UT for confirmation and sizing.

AE testing is based on the detection of high frequency sound waves generated by 'active' cracks and other flaws in equipment when they are stressed. Structurally significant defects produce relatively intense AE activity as the equipment is subjected to a test load. Notwithstanding recent advances in equipment, software and the internet have made this technology a very good method of monitoring the integrity of equipment on-line while in normal operation.

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Additional inspection must include routine in-service observation and periodic inspection according to API 653. RBI assessments should be conducted by trained and qualified individuals knowledgeable in RBI methodology and experienced in tank foundation design, construction, properties of materials, corrosion, stress-corrosion cracking, fatigue cracking, fracture mechanics, and techniques for storage tank inspection. The RBI assessment is performed following the procedures in API 580/581/EFMA guidelines.

Risk based inspection involves planning of an inspection based on the information obtained from a risk analysis. The purpose of the risk analysis is to identify the potential degradation mechanisms and threats to the integrity of the tank and to assess the consequences and likelihood of failure. Risk is a function of likelihood and consequences. The inspection plan can then target the high risk equipment and be designed to detect potential degradation before mechanical integrity and fitness for service could be threatened.

It is vital that a storage tank owner/engineer be familiar with the known agents of failure, especially ammonia stress corrosion cracking (SCC), where and how they may be active, and methods of identifying a mode of failure early enough to prevent a catastrophic failure. Stress corrosion cracking (SCC) of carbon steel in refrigerated ammonia service has been found in several tanks. Research has shown that the probability of occurrence, as well as the rate of crack growth is substantially affected by operating conditions, as well as conditions during shutdown before an internal inspection and conditions during start-up after an internal inspection. Refrigerated ammonia temperatures reduce the probability of SCC occurrence as compared with ambient storage temperature and pressure. SCC is promoted by the presence of oxygen in combination with ammonia. There is an increased cracking tendency with increased oxygen in the product or in the vapour space.

Conditions that initiate or promote SCC can be introduced during the decommissioning and re-commissioning of a tank, including blending oxygen with ammonia and changing tank temperature, pressure, and stress levels. Steps should be taken to minimize these effects. Welds and the adjacent heat-affected zones are the most probable sites of SCC due to high hardness as well as high residual welding and fabrication stresses in these areas. Higher strength materials of construction are more prone to SCC. Very low water content (<0.2%) in the product also increases the risk of SCC.

SCC is minimized when the following actions are taken:
- Special efforts are taken to quickly reduce the oxygen content of the tank when re-commissioning the tank following opening or ventilation.
- Tank commissioning is carried out under controlled conditions such that the tank cooling rate does not exceed 2°C per hour.
- Stress relief or stress reduction techniques are used when making repairs to the tank.
- Use of lower strength weld materials that are compatible with the materials being welded.
- Water (>0.2%) is intentionally added to the product in storage.

Certain design features and operating conditions may result in damage during service. The damage may occur due to failure of roof supports, excessive stresses on nozzles, a shift in the tank foundation and failures in the tank insulation system. An inspection program should address these potential problems.

The notch toughness of steels at low temperature is a concern due to brittle fracture. The owner should consider conducting a fracture mechanics study to determine suitability for service in accordance with the procedures in API 579-1/ASME FFS-1.

**Observation and inspection frequency**

Owner/operator personnel should routinely observe the external surfaces of the tank for cold spots, bulges, leaks or any unusual conditions in accordance with the requirements of API 653. Records of such routine observations shall be maintained. Changes and unusual occurrences in the tank operation shall also be recorded and evaluated to determine if immediate or future inspection and/or additional actions are required.

A periodic in-service visual external inspection should be performed by an inspector qualified in accordance with API 653 Appendix D and with experience in refrigerated ammonia storage tanks. The inspector should make a thorough visual inspection of the tank exterior in accordance with API 653.

Internal inspections must also be conducted periodically. It is reported that 10% of all refrigerated ammonia storage tanks may develop SCC after some years of operation. It is also well known that decommissioning for inspection and recommissioning tends to increase the risk of SCC. Applying RBI allows the assessment of all risks.
and tailors the inspection programme and frequency for each individual tank. Fertilizer Europe (European Fertiliser Manufacturers Association) has developed an inspection frequency diagram based on current regulations and standards and on a survey of the status of 37 in-service ammonia tanks representing approximately 75% of European capacity. This risk matrix is provided in Figure 5.

The Fertilizer Europe (EFMA) website provides a spreadsheet containing the risk factors, weighting for each risk factor. A diligent site could assess each tank and determine the consequence score and the score for the probability of failure. Based on these scores, the inspection frequency in years is derived from the above risk matrix. For example, if a consequence score of 70 and probability score of 40 indicates a medium high risk (orange level) and hence recommends an internal inspection in 5 to 10 years. The RBI assessment of an ammonia storage tank facility may increase or decrease the internal inspection interval prescribed by the EFMA guidelines or failure. Historic tank leakage and failure data and information are also important for this assessment. Some of the factors that should be considered in a RBI assessment of a tank include the following:
• the material of construction relative to the product temperature and ambient conditions.
• design codes or standards used in the construction and repair (including tank bottoms).
• methods used for determination of the shell and bottom plate thickness.
• availability and effectiveness of the potential inspection methods and the quality of the data collected.
• analysis methods used to determine the product-side, and external corrosion rates and the accuracy of these methods and corrosion rates.
• availability, accuracy, and need for leak detection methods and procedures.
• the effectiveness of corrosion mitigation methods such as cathodic protection systems.
• quality of the maintenance, including previous repairs.
• the probability of and type of failure, i.e., slow leak to the environment, tank bottom rupture or tank shell brittle fracture.

![Risk Matrix Diagram](image)

**Figure 5: Inspection frequency**

Should an internal inspection be necessary, such inspection should be made by an inspector qualified in accordance with API 653 Appendix D and with additional experience with refrigerated storage tanks. The API 653 inspector should review the design of the tank with an experienced API 620 design engineer prior to the inspection. The results of the inspection shall also be reviewed with the API 620 engineer and the owner/operator.

An alternative internal inspection interval and inspection program may be developed using risk-based inspection (RBI) procedures in accordance with API 580/581. The procedures combine and assess the likelihood of tank leakage or failure and the consequence of tank leakage or failure. The RBI assessment results can also be used to establish a tank inspection strategy including (but not limited) to the following items: better definition of the most appropriate inspection methods; determination of the appropriate frequency for internal, external, and on-stream inspections; establishing prevention and mitigation steps to reduce the likelihood and consequences of a tank leak.

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or failure.

It is essential that all RBI assessments are conducted by trained and qualified individuals knowledgeable in RBI methodology and knowledgeable and experienced in tank foundation design, construction, and corrosion. RBI assessments shall be thoroughly documented, clearly defining all the factors contributing to both the likelihood and consequence of tank leakage or failure. The initial RBI assessment should be reviewed and approved by an authorised inspector and an engineer who is knowledgeable and experienced in tank design (including tank foundations) and corrosion.

**Inspection criteria**

For periodic in-service inspection it is necessary to review the operating history, including information on periods when the tank sat empty or near empty; the fill-empty cycle frequency, and the number of under-pressure or overpressure occurrences. For routine in-service inspection records, it is suggested that the inspector visually inspect and record the following observations:
- inspect foundation for cracks and general deterioration.
- inspect pipe, valves, and nozzles for signs of cracking, corrosion and pipe stress.
- inspect stair and structural pipe supports for signs of stress and under insulation corrosion.
- inspect tank insulation for frost spots, leaks, seam leaks, and general deterioration.
- inspect bellows and supports in adjacent piping for signs of differential settlement.
- inspect all nozzles for deflection, rotation, and other signs of distress.
- verify proper operation of relief valves, level gauges and level switches.
- verify that the foundation heating system is working for a tank on grade or that there is proper air circulation under an elevated pile cap.

Additional guidance can be found in API 653 and API RP-575.

**Internal inspection**

The following should be considered as the minimum requirements for a complete and thorough visual examination for SCC and original construction flaws. It is recommended that this inspection be performed at least once in the tank's service history:
- inspect corner weld for signs of corrosion from inside the tank.
- inspect all areas of potential corrosion, especially where standing water may have puddled.
- inspect 100% of all shell and floor plate surfaces for original construction related flaws.
- inspect all shell and floor plate welds for cracks, undercutting, and arc strikes. Be especially aware of copper that has alloyed into an arc strike area, which will result in cracking.
- inspect the roof support structure and frame to shell connections.
- inspect the shell for signs of buckling.
- inspect floor plates for signs of settlement or heave; provide a level survey map.
- provide a level survey of the exterior circumference top of floor plate. In general, a minimum of 16-point elevations should be taken, unless more frequent survey points are required. Check for planer tilt. Specific guidance can be found in Appendix B of API 653.

**WMT**

Internal inspection using wet florescent magnetic particle inspection (WMT) in accordance with the requirements of API 620, using AC yoke only, should cover: 100% of all internal bottom welds; 100% of internal shell to bottom welds; 100% of all shell welds stressed over 10% of the minimum specified tensile strength of the shell material (Reference API 653); 100% of internal construction attachment areas; 100% of the internal nozzle to shell welds; 100% of all internal stiffeners and attachment to shell or bottom welds; and 100% of all external anchor straps to shell welds if the insulation is removed. If insulation is not removed, a minimum of two evenly-spaced strap-to-shell welds shall be exposed and examined. The owner/operator must decide the level of anchor strap inspection required for a double wall tank based on their inspection results of the interior floor plate and shell.

**Vacuum box**

Vacuum box inspection in accordance with the requirements of API 650 should cover: 100% of bottom welds; 100% of shell to bottom welds; 100% of roof plate welds if insulation has been removed. If insulation has not been removed the inspection may be deferred until the roof plate is exposed.

**Thickness testing**

Ultrasonic thickness testing and/or ultrasonic 'B' scan in accordance with the requirements of API 620 requires six readings taken at defined locations on each floor plate referenced to a floor plate map, six readings taken at defined locations on each shell plate referenced to a shell plate map, and four readings taken at defined locations...
on each roof plate referenced to a roof plate map if insu-
lation has been removed. If insulation has not been
removed the inspection may be deferred until the roof
plate is exposed. Additional point readings should also
be as needed in corroded areas.

For an ultrasonic "B"-scan on various tank components,
scan across the diameter of the tank in an "X" pattern
with 0.3 to 0.6 meter wide paths; scan across the diam-
eter of the roof in an "X" pattern with 0.3 to 0.6 meter
paths; scan the full height of the tank in 4 quadrants
with 0.3 to 0.6 meter wide paths, and scan all corroded
areas.

Alternative techniques
It is important to recognise that alternative inspection
methods exist. The API 653 inspector in conjunction
with the owner/operator and an engineer experienced in API
620 Appendix R may develop an alternative inspection
procedure that addresses the concerns of these guide-
lines.

Pressure relieving devices
Pressure-relieving devices shall be sized in accordance
with ANSI K-61.1. All pressure relieving devices ex-
cept weighted manways should be inspected and tested
to the requirements of API RP 576. The sizing of fire
protection defined in API RP 576 shall be adjusted to
protect against the worst plausible fire exposure.

Weighted manway
Functional testing/verification of a weighted manway
shall be done in conjunction with the internal inspection
cycle of the tank. Moving parts and sealing surfaces
shall be visually inspected annually to insure that they
are free and will not inhibit the relieving capability of the
weighted manway.

Evaluation
The owner/operator must use sound engineering judg-
ment to evaluate the findings of the inspection against
the design criteria of the tank, the current body of knowl-
dge, API 579-1/ASME FFS-1 fitness for service stan-
dard and the current consensus codes, as they apply.
Different storage tank applications have unique condi-
tions that must be considered when evaluating these
tanks. It is, therefore, very important that experienced
and competent engineers and inspectors are involved in
evaluating existing tanks, otherwise an important prob-
lem area may be missed. It is also important to be famil-
lar with and consider any local conditions that may influ-
ce the tank inspection: i.e., local wind, snow loads, soil

conditions, airborne contaminants, seismic loading to
name a few.

Repairs and alterations
The owner/operator must decide the repairs or altera-
tions required, method of repair, and the ultimate suit-
ability for continued service of the tank. All repairs and
alterations to ammonia storage tanks should be by weld-
ing. When repairs or alterations have to be performed,
the applicable requirements of the API 620 code or the
codes to which the storage tanks were built should be fol-
lowed. Before any repairs or alterations are performed,
all proposed methods of execution, all materials, and all
welding procedures that are to be used must be approved
by the API 653 inspector and the experienced API 620
design engineer. Shallow cracks and other surface de-
fects may be removed by light grinding. Grinding should
be such as not to overheat the metal adjacent to or un-
derneath the area ground, with the ground area flared
into the surrounding metal. The metal thickness under
the ground area should be equal to or greater than the
required minimum thickness per the original design code
or API 620. When crack or defect removal results in the
remaining thickness is being less than the required mini-
mum thickness per the original design, API 620 or API
579-1/ASME FFS-1 local thin area requirements, then
the ground location should be repaired by welding. Leaks
in the tank's nozzles and sidewalls resulting from non-
crack-like defects may be temporarily stopped. Perma-
nent repairs are required within six months for non-crack-
like defects and immediately for crack-like defects. Peen-
ing the defect closed, driving in a plug or welding a scab
patch over the leak are not recommended temporary
repairs but may be employed after careful consideration
of the potential to enlarge the defect. Emergency mea-
sures should be employed to mitigate harmful health and
environmental effects, and then only until the tank can
be secured by other means. Repairs should be made
immediately to any defects requiring emergency
measures. The API 653 inspector or an authorized local
jurisdiction inspector must authorise all repairs and al-
terations before the work is started by a repair organization.
The authorized API 653 inspector or an authorized
local jurisdiction inspector should approve all specified
repair and alteration work after an inspection of the work
has proven the work to be satisfactory and any required
pressure test has been witnessed. The repair organiza-
tion shall use qualified welders and welding procedures
qualified in accordance with the applicable requirements
of ASME Section IX, latest edition, and maintain records
of its qualified welding procedures and its welding per-
formance qualifications. These records shall be available to the API 653 inspector or an authorized local jurisdiction inspector prior to the start of welding. The organization's qualified welding procedures and welding performance qualifications shall be in accord with API 620. The material used in making repairs or alterations shall conform to the applicable section of API 620. The material shall be of known weldable quality and be compatible with the original material. Carbon or alloy steel with carbon content over 0.35 percent shall not be welded. Acceptance criteria for a welded repair or alteration should include non-destructive examination techniques and testing that are in accordance with the applicable sections of API 620. Where use of these non-destructive examination techniques or testing is not possible or practical, alternative non-destructive examination methods may be used when approved by the API 653 inspector.

7. Incidents
As a cautionary tale as to the potential consequences of tank failure, we would like to draw readers attention to some 23 incidents which have been reported in the AIChE Ammonia Safety Symposium's proceedings. Four examples are summarised below;

I) Rupture of a cryogenic ammonia tank on March 20th 1989
Jonova, Lithuania (USSR)
On 20 March 1989, an accident took place in a Lithuanian fertiliser plant at Jonova which destroyed a 10,000 tonne ammonia storage tank. The whole ammonia tank was dislodged from its foundation, smashed with great force through the surrounding wall of reinforced concrete and finally landed about 40 meters from the foundation. Devastation around the tank was enormous and liquid ammonia around the plant site was 70cm deep. Large quantities of ammonia evaporated, the ammonia gas caught fire and the whole plant area was engulfed in flames.

About 32,000 people were evacuated from a nearby town, the rescue operation continued for three days and the total fatalities were seven, with 57 people injured. It was reported that ammonia tank overpressured due to rollover of its contents resulting from the warm ammonia being supplied to the bottom of the tank, while at the same time tank refrigeration compressors were out of service.

II) Stress Corrosion Cracking, 1989
During its first inspection of a 12,000 tonne tank in Middlesbrough, England, after nine years in operation, BASF Chemicals found SCC had occurred. The material and weld procedures had produced microstructures susceptible to both SCC and hydrogen cracking. All the defects were repaired and the tank was recommissioned. The experience showed that, wherever possible, temporary construction attachments should be made on the outside of tanks and welders inside the vessel should adhere to proper procedures.

III) Failure of the Inner Shell of a Double Integrity Ammonia Storage Tank, 2001
Coromandel Fertilisers' 5,000-tonne tank in India, which was originally commissioned in 1998, needed to be decommissioned and repaired. A level transmitter with a high-level alarm measured the liquid level in the tank's annular space, but was falsely reading zero because as-built drawings were incorrect. The operators took no action to drain the annulus because they thought the tank did not have a high level. In fact, the level was 6.5 meters. Splashing from the inner cup during ship unloading had diverted ammonia to the annulus. The inner cup was drained to 0.813 meters before ship unloading began. The hydrostatic head of ammonia in the annulus acting on the bottom plate fractured the bottom side plates and circumferential weld. The decision was made to decommission the tank for inspection when the liquid level in the annulus came to light. The tank repair included removing and refilling the bottom sand-layer, repairing and replacing shell courses and the bottom plate, and other modifications. To prevent a recurrence, the tank was de-rated to 4,865 tonnes and the settings of alarms and trips were changed to provide at least 500mm of freeboard between the maximum allowable liquid level and the overflow level. A separate instrument was added to record the tank inner cup and annulus levels. A parallel independent level indication was also provided for the annulus. All indicators were changed to fail-safe. A temperature indicator with low temperature alarm was installed to monitor the annulus temperature. An interlock was set to trip the ammonia pumps at an annulus ammonia depth of 400 millimetres. The annulus drain line was permanently connected to the drain pot and routine draining of the annulus every weekend was instituted. The siphon breaker in the tank's liquid inlet line was modified so that the top hole of the dip pipe was above the tank's maximum liquid level. All documents were updated to reflect as-built conditions.

IV) Tank Failure at Yara, 2005
While recommissioning a repaired atmospheric ammonia storage tank, overpressure ruptured the tank during
the cool-down step. The ammonia release caused injuries and a fatality. The tank was being recommissioned after a drain valve had been replaced. The tank had been drained and purged. The incident occurred in 2005 at Yara's Rostick plant in Germany.

Yara followed the European Fertilizer Manufacturers Association (EFMA) guidelines for decommissioning and recommissioning atmospheric ammonia storage tanks. The EFMA guidelines, Appendix 9, in Recommendations for the Safe and Reliable Inspection of Atmospheric, Refrigerated Ammonia Storage Tanks, state that a sufficient volume of an ammonia water (aqua) mixture (20 percent ammonia) should be placed in the tank to entirely cover the bottom before introducing liquid ammonia for cool-down. The purpose of the water is to prevent liquid ammonia from impinging on the floor plates and causing them to cool rapidly in the presence of oxygen and resulting in SCC.

After cooling the tank, Yara began draining the aqua and the tank failed. The failure occurred on the floor at the outer tank seam and allowed liquid ammonia to escape. Yara had introduced enough aqua to fill the tank to 25 centimetres to ensure covering the entire bottom regardless of slope. However, a layer of oil had floated to the top of the aqua. The draining disrupted the oil film, allowing liquid ammonia to mix with the aqua and to generate enough heat to rapidly boil off liquid ammonia. The ammonia vapour overwhelmed the pressure relief system and caused the floor-to-outer-cup seam to fail. An investigation found that the pressure in the tank had possibly reached two barg.

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