# Ammonia Tank Failure—South Africa

Detailed report on a major disaster in a fertilizer plant that took 18 lives, with a discussion of investigation results, and commentary on safety policies.

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On July 13, 1973, at a Potchefstroom, South Africa, fertilizer plant, one of four 50-ton (metric) pressure-storage tanks (horizontal bullet type) failed. The failure resulted from brittle fracture of a dished end. No specific source of cracking, or a "triggering incident" was identified.

An estimated 30 ton of anhydrous ammonia was released, plus another 8 ton from a tank car. The ammonia caused the deaths of 18 people. This is a summary of the information available to AE & CI Ltd. in July, 1974. It amplifies the information dated December 7, 1973, that had been issued on request to attendees at the 1973 AIChE Ammonia Safety Symposium.

The verdict of the formal inquest on the victims, presented July 19, 1974, was that no one, by action or negligence, was responsible for the fatalities. The insurance settlements have yet to be effected.

### Immediate resultant gas cloud reaches 150 meter diameter

The incident occurred at 16:15 on July 13, when the storage tank failed while being filled from a railroad tank car. One employee, 45 m. from the tank, was killed outright by the blast; 8 were killed by gas while attempting to escape from points within 100 m. of the tank; and three others died within a few days as a direct result of having been gassed. Outside the plant fence, four people died immediately, and two others died several days later. In addition to the 18 deaths, approximately 65 people required medical treatment in hospital and an unknown number were treated by private doctors.

The immediate resulting gas cloud from the failure was about 150 m. in diameter and nearly 20 m. in depth. Although the air was apparently still at the time of the incident, within a few minutes a slight breeze arose and the gas cloud began moving toward a nearby township. The visible cloud reached some 300 m. in width and about 450 m. downwind from the tank. Air temperature was approximately 19°C and relative humidity 30 to 35%.

About 350 people were working in the plant at the time of the incident, some 30 within 70 m. of the failure.

All personnel in the direct line of the blast (to the west as seen in Figure 1) eventually died. Two of these men had been able to climb out of a storage tank, 30 m. from the failure, and run 25 m. before collapsing. Those working on the phosphoric acid plant 40 m. to the north of the failure all escaped except one who had just had pneumonia. There was a report of breathable air near the plant's cooling tower.

Four men in an office 50 m. south of the failure ran into the open. Three made it to safety; one reported that he fell one meter down a railway embankment and found breathable air at ground level.

All occupants of the granulation plant control room, 80 m. southeast of failure, survived including one pulled into the room with clothes saturated with ammonia and coated with ice. They used wet cloths over their faces and were in the room some 30 minutes before being escorted to safety.

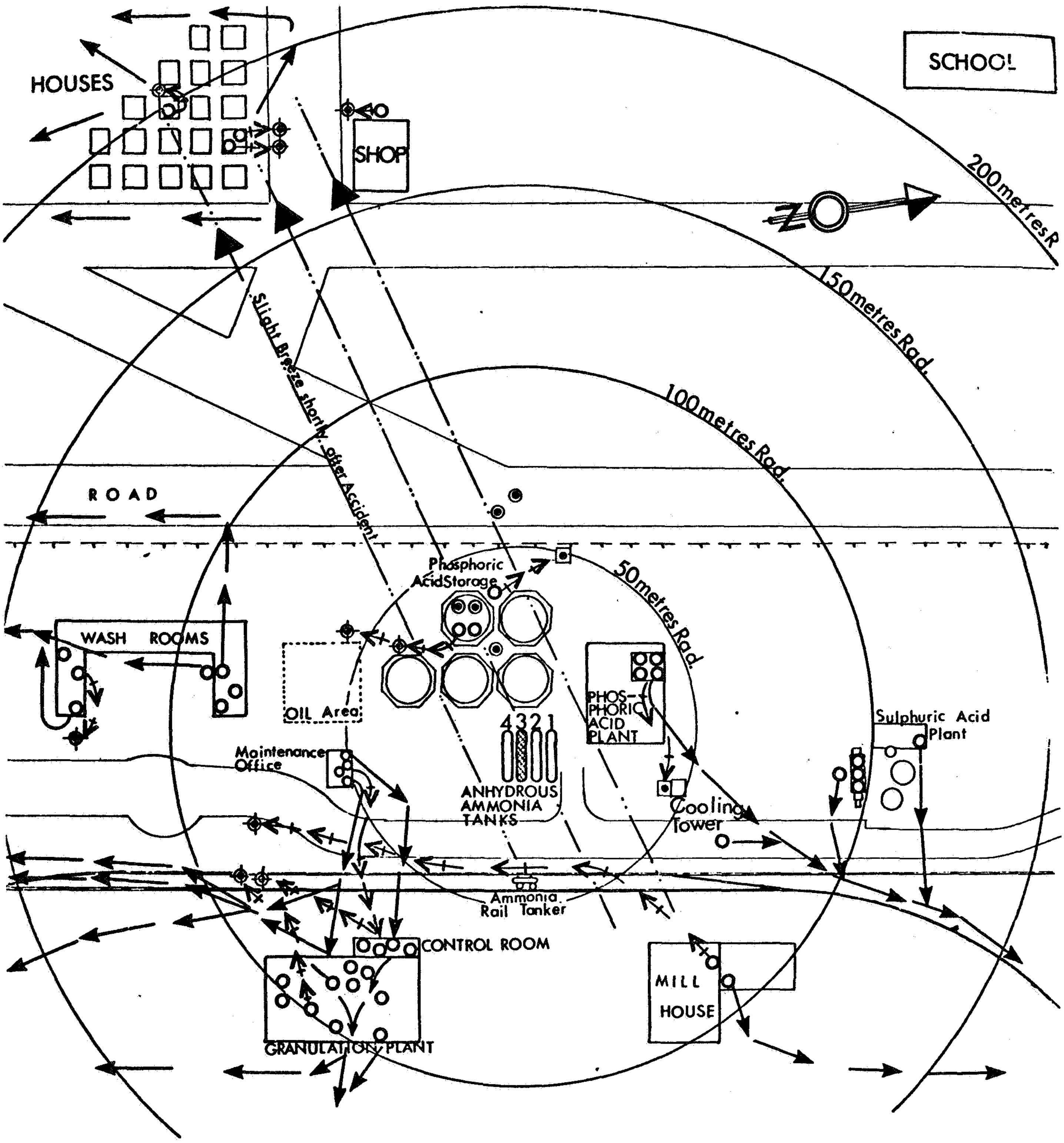
Two cars being driven through the dense gas cloud stalled but coasted to safety. A third car was driven through shortly afterwards, when the cloud had cleared, without trouble.

### Operating procedure and conditions at the time

Offloading equipment was in good order and procedure was in accordance with standard practice. The piping arrangement was such that two storage tanks (Nos. 3 and 4 in Figure 1) were being filled simultaneously. The pressure in the receiving tanks was noted to be 90 lb./sq.in. gauge approximately two minutes before the failure.

An excess-flow valve in the liquid line between the two tanks actuated and prevented the contents of No. 4 from being spilled through the hole in No. 3. The tank car was not fitted with excess-flow valves. The system as operated at the time of the accident was protected by a total of 7 safety relief valves, all in good working order. The two tanks each had one valve set at 230 lb./sq.in. gauge, one at 240 lb./sq.in. gauge and one at 250 lb./sq.in. gauge, the last being the design pressure of these tanks. The seventh valve, on the tank car, was set at 255 lb./sq.in. gauge start-to-discharge and 280 lb./sq.in. gauge fully open. None of these valves had been actuated; therefore, the tank failure could not be attributed to overpressure.

Heaters are not fitted to the storage tanks, therefore the temperature and pressure of the ammonia would normally be related to ambient conditions. This is confirmed by the pressure noted before the failure, i.e. 90 lb./sq.in. gauge, which gives an equilibrium temperature of 15°C. Some slight increase in the temperature of the ammonia can be expected during transfer by compressor, but it is unlikely that the metal temperature was subjected to sudden and significant change as a direct result of the operating conditions. However, at 16:15 in wintertime the local air temperature may fluctuate considerably, particularly in this case where the tanks were in an area of repeated changes between sunshine and shade.




o Positions where people were working or present at the time of the accident

—▶ —▶ Routes followed by people who escaped.

+▷+▷+▷ Routes followed by people who died.

[•] Positions of people who were found dead.

⊕ Positions where people who tried to escape, were found injured and who subsequently died.

⊙ Positions, where people who could not escape, were found injured and who subsequently died.

-·-·- —▶ Approximate direction of slight breeze that sprang up shortly after the accident.

Tank of which the West End failed.

**Figure 1. General layout of Potchefstroom plant.**

### Tanks were built in 1967

Storage tanks No. 3 and 4 were fabricated and commissioned in 1967. They were designed and fabricated in accordance with BS 1515 (1965), Specification for Fusion Welded Pressure Vessels for use in the Chemical, Petroleum and Allied Industries.

The dished ends were fabricated from two plates, cold-formed in the major radius, and hot flanged (at 850°C) at the knuckle. The plates had been passed as being in accordance with the requirements of BS 1501-151-28A. The butt welds in the end plates were checked by 100% X-ray after forming and flanging. (Expert metallurgists re-examining the X-rays of the failed dished end considered that two sections of the weld did not conform to the requirements of the BS code.) The Inspection Authority representative considered that conditions in the flanging furnace rendered subsequent heat treatment unnecessary.

The completed tank was not stress-relieved because it is not required by BS 1515. The tanks were given an hydraulic test at 1½ times the design pressure of 250 lb./sq.in. gauge.

Tanks No. 3 and 4 remained in service until late 1971, when they were taken off line for a statutory inspection and test. This normally would have included an hydraulic pressure test, but an exemption had been granted and suitable non-destructive testing accepted as an alternative. Ultrasonic testing by the Bureau of Standards, followed by radiography, indicated laminar type imperfections in the larger plate of No. 3 tank west, dished end. An approved inspection authority was employed to recommend and supervise the necessary repairs. The laminar defects were not considered serious, but two areas of the seam weld were recommended for repair.

One seam weld fault was ground out and repaired satisfactorily. The other, indicated as A in Figure 2, was considered to be lack of side wall fusion or slag entrapment 3/16-in. deep and 3/4-in. long. It was ground out and re-welded at least twice before being passed. Radiographs then showed a new crack 1-1/2-in. from the repair and 4-in. long: this was also ground out and rewelded. The report on this repair mentions some piping and porosity, but no further repairs were attempted. The final repair zone was some 8-in. long.

The tank was hydraulically tested to 347 lb./sq.in. gauge for 30 min. No stress relieving was carried out.

Following repairs to No. 3 tank level glass isolation valves, which had been passing, the tank was hydraulically tested to 325 lb./sq.in. gauge for a period of 3 to 4 hr. The test was uneventful and the tank returned to service. (The valves were on the opposite end to the failure.)

The west dished end of No. 3 tank failed in an explosive manner. The mild steel vessel measured 2.9 m. diameter x 14.3 m. long. The fracture propagated from the larger of the two plates making up the dished end (Point C in Figure 2), but mainly involved the smaller plate. The fracture progressed all around the main repair area but did not start in the welded seam. The broken-out section, equal approximately to one quarter the area of the dished end, was propelled a distance of 40 m., including two changes of direction after striking the ground and rupturing an acid tank.

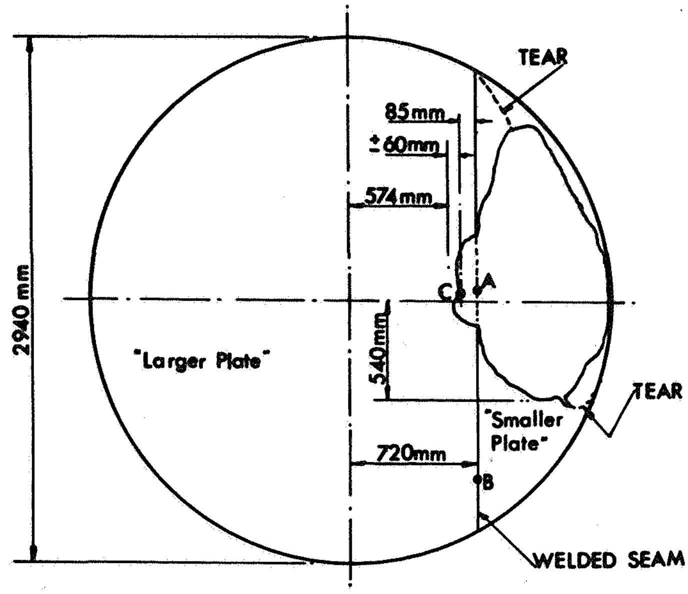



**Figure 2. View on outside of dished end.**

The photograph in Figure 3 shows the rupture. Figure 4 is a general view.

A summary of an independent expert metallurgist's findings is given in the following observations, the first being comments on preliminary visual inspection:

1. The failure was mainly in the smaller plate, although the broken-out section included a short length of seam weld and part of the larger plate.

2. There was no sign that deformation or thinning of the plates had occurred. The steel had fractured in a brittle manner.

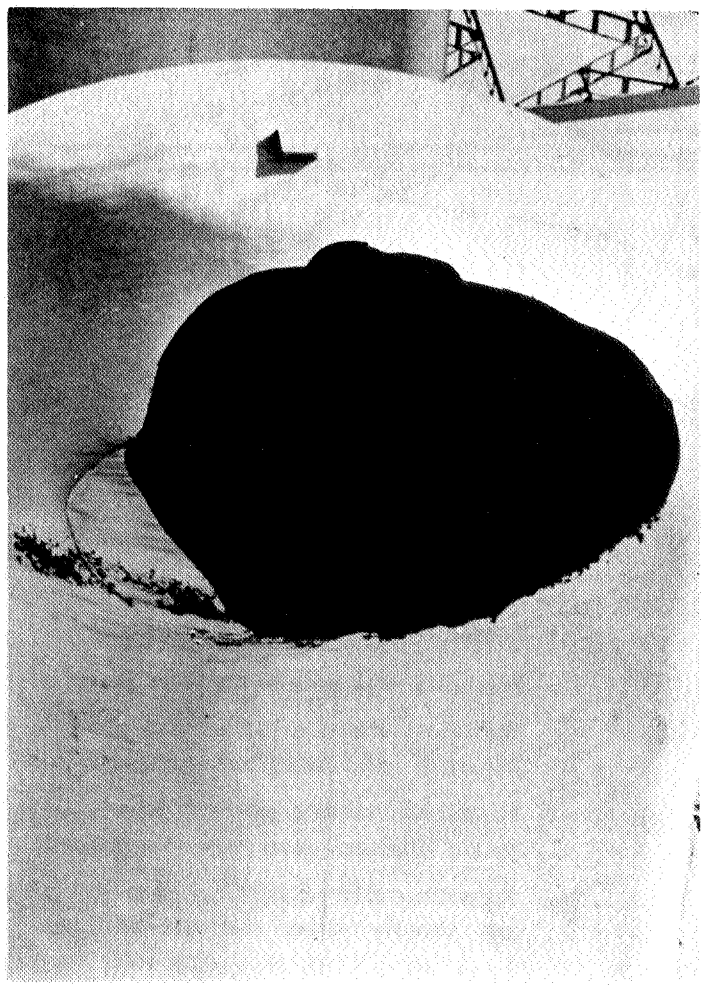


**Figure 3. Close-up photograph of rupture in dished end.**

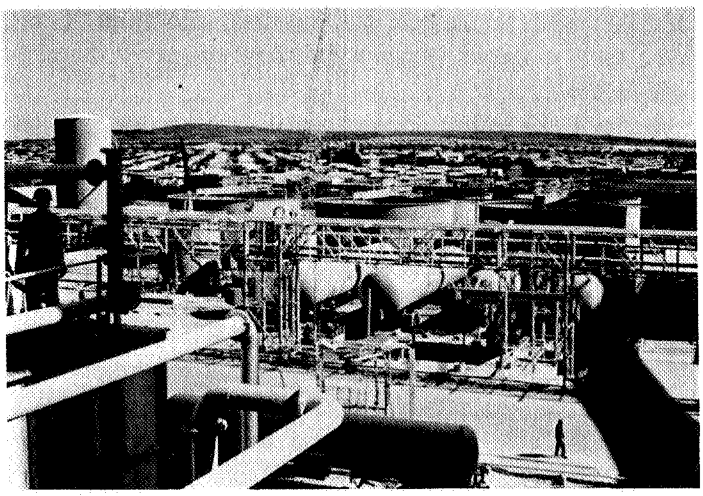


**Figure 4. View of the ammonia tanks, looking west in direction of ammonia cloud drift. Replacements for Nos. 3 and 4 tanks are seen in position.**

3. The length of seam weld in the broken-out section included the major repair zone.
4. Chevron markings were readily seen in the fracture surface.
5. There was virtually no corrosion on the inside surface of the storage vessel.
6. There were branching-off tears at the top and bottom of the main break. The mating surfaces of these fractures were however also brittle in appearance.

Composition of the steel is reported in Table 1, listing results of spectrographic analyses of the plates of the dished end.

The 1971 weld repair was found to contain piping and porosity, as reported at the time. The 1971 Bureau of Standards report of extensive laminar type defects in the larger plate was also endorsed. Examination of the fracture surface showed that the cracks were unbranching and proceeded in a direction transverse to the stringers of inclusions. At high magnification, the cracks were distinctly cleavage in appearance and free of entrapped corrosion products.

Results of hardness testing are shown in Table 2, and impact testing in Tables 3 and 4. The ductile-brittle transition temperatures for both plates in the longitudinal and transverse directions were determined and are given in Table 3.

In a further series of tests, samples of the two plates were subjected to a stress-relieving heat-treatment according to the requirements of the Code–heated at 620°C for 2 hr. and then cooled to room temperature at a rate of 250°C/hr.

The Charpy Impact values obtained on testing at 9.7°C are given in Table 4. Although the values had doubled as a result of this heat-treatment, the fractures obtained were still of a brittle nature.

Tensile tests were also performed on both plates of the dished end, using specimens machined according to SABS-54-1972. All four specimens were cut from a plate of full thickness, slight flattening being necessary. The nominal cross section of the test specimen was 23 by 25 mm. and the length used to determine the elongation calculated from the following relationship: $L = 5.65 \quad CSA$. An Amsler 500

**Table 1. Results of spectrographic analyses carried out on the plates of the dished end**

| Element % | Sample A | Sample B | BS 1501-151 |
|---|---|---|---|
| Carbon | 0.18 | 0.18 | 0.25 max. |
| Silicon | 0.07 | 0.07 | – |
| Manganese | 0.83 | 0.83 | – |
| Sulphur | 0.039 | 0.040 | 0.050 max. |
| Phosphorous | 0.031 | 0.032 | 0.050 max. |
| Chromium | 0.07 | 0.07 | 0.25 max. |
| Nickel | Nil | Nil | 0.40 max. |
| Aluminium | 0.01 | 0.01 | – |
| Molybdenum | Nil | Nil | 0.15 max. |
| Copper | 0.05 | 0.05 | 0.40 max. |
| Vanadium | Nil | Nil | – |
| Tin | 0.012 | 0.012 | – |
| Incidental Elements | | | 0.80 max. |

**Table 2. Results of Vickers Pyramid hardness tests carried out using a 20-kg load and 2/3x objective**

| Description | HV 20 | Approx. UTS ton/sq.in. |
|---|---|---|
| Adjacent to fracture surface | 199,200 | 44 |
| Sections through crack in plate | 200,200,205 | 44 |
| Sections following crack to weld repair | 209,212 | 45,5 |
| | 190,186 | 42 |
| | 168,166 (near end of crack) | |
| | 191,181 (weld) | |
| Broken off plate near top | 156,154,151, 150,149,169 | 33 |
| Opposite side adjacent to weld in vessel | 163,164,163,195, 178,207 (weld) | 35 |
| Top of vessel itself– but in HAZ | 187,175 | 40 |
| After stress relieving at 620°C. Smaller plate | 160,168 | 35.5 |
| After stress relieving at 620°C. Larger plate | 144,159 | 33 |

**Table 3. Charpy-V Impact testing transition temperatures**

| | Long. | Trans. |
|---|---|---|
| Small plate (i.e., broken-out part) | 20°C | 35°C |
| Large plate | 115°C | 115°C |

kN Universal Testing Machine was used for the tests. Results are summarized in Table 5.

The mechanical properties required according to BS 1501-151 Grade A are: tensile strength, 24-28 ton/sq.in.; yield stress, 12 ton/sq.in. minimum; and elongation, 25% minimum.

It was apparent from these values that both the main steel plates making up the dished end and particularly that

**Table 4. Charpy Impact values on testing at 9.7°C.**

| Plate | Direction | After heat-treatment (kg.) |
|---|---|---|
| Small | Longitudinal | 4.75 |
| Small | Transverse | 2.2 |
| Large | Longitudinal | 1.8 |
| Large | Transverse | 0.75 |
| | | **Before heat-treatment (kg.)** |
| Small | Longitudinal | 2.25 |
| Small | Transverse | 1.45 |
| Large | Longitudinal | 0.5 |
| Large | Transverse | 0.35 |

remaining on the vessel, were in a hard and brittle condition. Specifically it could be stated that the tensile strengths were all above the allowable maximum of 28 ton/sq.in.; and the elongation values, apart from being very erratic, were nearly all very much below the minimum of 25%. The larger plate was particularly brittle and the specimens broke almost without undergoing deformation.

The metallurgist's general discussion covered crack initiation and stress.

Regarding crack initiation the larger plate of the dished end was extremely brittle, having a transition temperature of 115°C in both directions. It was considered that the crack was initiated in this plate at a point directly adjacent to the weld repair and about 2-in. away. Chevron patterns on both sides pointed in that direction. The source of the crack was not positively identified. Crack propagation tended to be diverted, or actually stopped, by the seam weld.

It was noted that ultrasonic examination of the dished end in tank No. 4 showed the presence of numerous subsurface fissures (No. 4 has since been withdrawn from service). Defects of this type may have provided the notch from which the brittle fracture propagated.

In addition to the stress concentrations produced by the weld repairs which had not been stress-relieved, it was considered that cold working the plate and localized welding would result in strain aging of the steel. The hardening effect through strain aging would increase with time and could explain why failure occurred 1-1/2-yr. after the repair. Hydraulic testing would have tended to open up defects in the plate and also would have contributed to the strain aging process.

The result of these processes was a steel in a brittle condition while in service. No abnormal condition of service could be traced which would have triggered the ultimate failure.

In the 1973 public enquiry and follow-up, the opinion was expressed that the following factors played a part in the failure of the dished end:

1. The vessel was not stress-relieved after manufacture.
2. The metal of the vessel had been weakened by strain aging.
3. The weld repairs had induced additional stresses in the metal which had not been removed by stress relief.
4. Hydraulically pressure testing the vessel at the end of May, 1973, could have introduced further stresses in the metal.
5. The failure was triggered off on the afternoon of July 13, 1973, when possibly a fluctuation in temperature during the decanting operation had caused the already susceptible dished end to fracture in a brittle manner.

Subsequent to the enquiry, the Department of Labour has issued a directive to all approved Inspection Authorities in which it is laid down that "this office now insists that all vessels containing dangerous substances shall be given appropriate heat treatment irrespective of the (construction) code requirements."

The wording of the directive appears obscure insofar as "dangerous" and "appropriate" do not carry a specific definition. However, this is not the case since the onus of defining has been deliberately put on the user and the local Inspection Authority to ensure that every case is determined separately on merit.

Present attitudes within AE&CI Ltd. are embodied in the following:

*Pressure vessels:*

1. Stress-relieving should have been carried out on the dished ends, the completed vessel, and after the 1971 weld repairs at Potchefstroom.
2. Stress-relieving does not overcome fully the damage done by progressive cold-forming of a dished end. This is particularly so where seam welds have had to be made in the dished end. There is a strong case for avoiding the use of progressively cold-formed ends for pressure vessels because of the difficulty of controlling the final state of the metal.
3. Routine hydraulic pressure testing of vessels should be more stringently controlled. This in particular refers to raising the test pressure "a bit more to make sure," but the logic of some hydraulic testing is also under scrutiny.
4. The above comments apply in principle to any pres-

**Table 5. Summary of tensile test results**

| Plate | Direction | 0.2% Proof MPa (ob./sq.in.) | UTS MPa | UTS (lb./sq.in.) | UTS (ton/sq.in.) | Elong.% |
|---|---|---|---|---|---|---|
| Small | L | 405 (58700) | 507 | (73500) | (32.9) | 14.9 |
| Small | T | 327 (47500) | 475 | (68900) | (30.9) | 25.7 |
| Large | T | 554 (80400) | 588 | (85200) | (38.0) | 9.1 |
| Large | L | 577 (83700) | 604 | (87500) | (38.8) | 0.7 |

L = Longitudinal direction
T = Transverse direction

sure vessel, not only those used for "dangerous substances."

5. Plates to be used in fabrication of a pressure vessel are surveyed ultrasonically. Laminations are acceptable unless they cross a weld preparation area.

*Safety:*

Many well established policies were reconfirmed in the Potchefstroom incident and in the subsequent discussions aroused by it. On the basis that many of the following points could well still be subjects of discussion rather than action, they are listed below:

1. Training. Personnel must be taught to recognize the emergency alarm and run to safety without hesitation.

2. Gas-proof rooms. If the route to a safe area is unclear or blocked by a gas cloud it is safer to stay in a closed room. Wherever justified, strategically located rooms should be equipped as gas-proof rooms and clearly identified as such. Work permits should draw attention to escape routes, gas rooms, wind indicators, etc.

3. Air supply. All personnel can have escape masks; simple sponge rubber mask soaked in citric acid, for example. Wet cloths were used effectively at Potchefstroom. Breathable air was found in pockets at ground level and near a water cooling tower. Persons working in areas of restricted movement and who could be exposed to a gas cloud must have escape equipment.

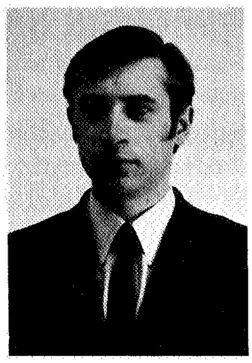
4. Rescue equipment. Apart from equipment immediately accessible at the relevant control centers in a factory, equipment must be stored well away from any potential hazard to be used to get into a plant. It was observed that a standard twin cylinder (90-min.) air-set was too heavy to allow the wearer to do any useful rescue work.

5. Communications. Ammonia users and producers should examine the worst conceivable failure situation and not just the bad leak situation. Plant control rooms must remain habitable, be able to communicate with other departments, and summon outside assistance.

6. Motor vehicles. Do not attempt to drive through a dense ammonia cloud.

**Acknowledgement**

The author wishes to thank the personnel at the Potchefstroom factory and his colleagues in AE&CI whose reports and views were used in compiling this report. #



LONSDALE, H.

# DISCUSSION

**Q.** Were any toughness measurements made of the metal at the temperature of the failure?
**LONSDALE:** You'll find in the report some hardness and impact test data. The Ductile-Brittle transition temperature was determined and portions of large plate in fact had a transition temperature of 115 degrees centigrade. In fact the best transition temperature was 20 degrees centigrade. So this dished end in its normal operating condition was in a brittle state.
**Q.** You mentioned that there was a temperature change from a decanting operation. Do you have an indication or an estimate of what that temperature change was?
**LONSDALE:** I didn't say there was one. I said it could only be assumed that this might have been an initiating factor in the final failure. The actual decanting operation was completely normal.
**R.M. OSMAN,** Exxon Chemical: Do you know what the water content of your anhydrous ammonia was? There's been quite a bit of discussion about the need for maintaining a certain minimum water level in the ammonia to avoid brittle failures.
**LONSDALE:** It would have been approximately 400 ppm.
**OSMAN:** Because I believe our practice is to maintain two tenths of a percent which would be 2,000 ppm.
**LONSDALE:** Our water content is not normally that high unless we have trouble on the plant.
**Q.** As I found from the paper, it's an unkilled steel that was used in the tank that has a silicon content of only 0.07 percent.
**LONSDALE:** It appeared to be a semi-killed steel.
**Q.** Semi-killed? It is even low for that, I thought. But okay. Your stress relief value, as you state in your paper, are stated in kilograms. What is the actual figure? If it's an impact value though, you don't say it in kilograms but in kilogram, meters or kilogram meters per square centimeter or something like that.
**LONSDALE:** It should be kilogram meters.
**Q.** My last question is—have you investigated transition temperatures after heat treatment?
**LONSDALE:** No, I haven't got that information.
**Q.** Did you find any evidence of stress corrosion cracking?
**LONSDALE:** None whatsoever.