UNITED NATIONS INDUSTRIAL DEVELOPMENT ORGANIZATION
Vienna International Centre, P.O. Box 300, 1400 Vienna, Austria
Tel: (+43-1) 26026-0 · www.unido.org · unido@unido.org

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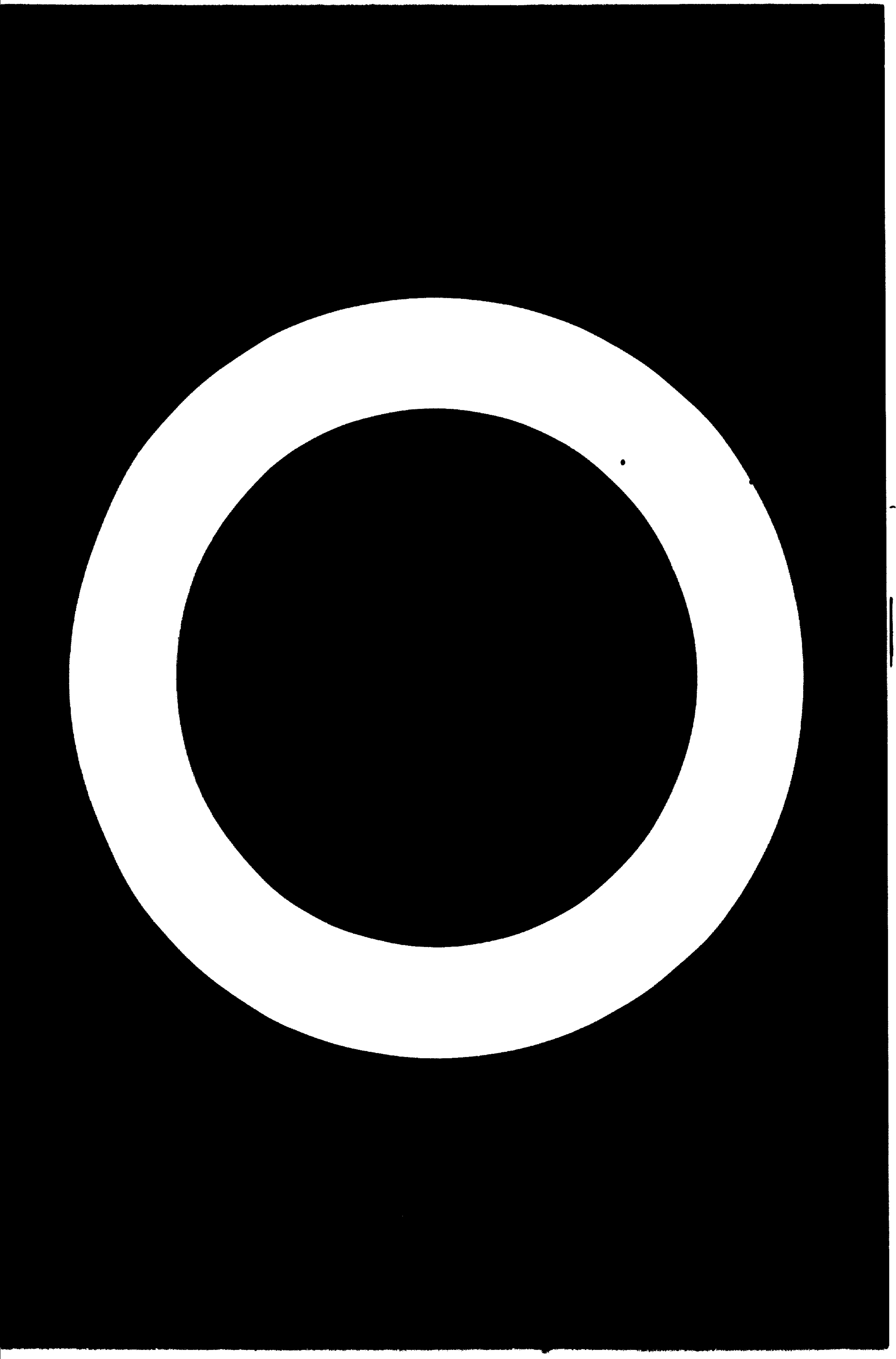
UNITED NATIONS INDUSTRIAL DEVELOPMENT ORGANIZATION

SAFETY IN THE DESIGN AND OPERATION OF AMMONIA PLANTS

Report of a Meeting
sponsored jointly by the
United Nations
Industrial Development Organization
and the Fertilizer Association of India

New Delhi, 20–24 January 1976



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EXPLANATORY NOTES

References to "tons" are to metric tons, unless otherwise specified.

Besides the common abbreviations, symbols and terms, the following have been used in this report:

BFW	boiler feedwater
FAI	Fertilizer Association of India
ILO	International Labour Organisation
MEA	monoethanolamine
SCC	stress corrosion cracking
TIG	tungsten inert gas (welding technique)

INTRODUCTION

The Meeting on Safety in the Design and Operation of Ammonia Plants, organized by the United Nations Industrial Development Organization (UNIDO) in co-operation with the Government of India and the Fertilizer Association of India (FAI), was held at New Delhi from 20 to 24 January 1976.

The production of ammonia in large quantities requires sophisticated technology and substantial capital investment. Developing countries look to this technology to satisfy their fertilizer demands and are thus concerned that ammonia plants be operated safely and efficiently.

The purpose of the Meeting was to examine various aspects of the safety of both personnel and equipment in the design and operation of ammonia plants. It specific objectives were:

(a) To provide information to engineers, specialists and operators on many aspects of safety in ammonia plants;

(b) To advise developing countries on methods of operating large ammonia plants safely;

(c) To define the role of UNIDO in aiding developing countries to achieve a high level of plant safety and performance.

CONCLUSIONS AND RECOMMENDATIONS

Conclusion

The use of improper material is a frequent cause of plant failure and the unexpected corrosion of the equipment and piping. The wrong grades of steel may be used during manufacturing or repair of the equipment in workshops if the material in stock is inadequately marked.

Recommendation 1

All countries should adopt a standard code for identifying alloy pipe and bar stock. All such items should be marked along their full length or at sufficiently close intervals to ensure proper identification of even small samples.

Recommendation 2

Manufacturers, contractors and subcontractors should use direct reading spectrographs to identify the proper metals to be employed in plant fabrication and construction.

Conclusion

Testing and quality control of equipment and machines employed in ammonia plants are essential for safeguarding trouble-free operation of new plants and those restarted after shut-down for maintenance or emergency repair.

Recommendation 3

Manufacturers of shop and field items should maintain proper equipment for testing incoming materials and the final product. The procedures for inspection and quality control should meet accepted industrial codes. Critical items of equipment should be tested and inspected according to these procedures and the results of the tests made available to the client or his representative.

Recommendation 4

Fertilizer manufacturers should carry out suitable periodic non-destructive tests to determine the safety status of their plants.

Recommendation 5

Each country should have at its disposal equipment and apparatus for testing high-speed rotating equipment.

Recommendation 6

Manufacturers of high-speed rotating equipment should make available to a client, for future reference, significant data characteristic of these machines.

Conclusion

International exchange of experience among plant managers and operators and transfer of know-how on plant safety procedures and standards need to be organized on a continuous basis and followed-up consistently by all parties concerned. Corrosion problems are of interest to all ammonia producers, since many hazardous situations occur after equipment has broken down owing to corrosion.

Recommendation 7

Seminars and symposia should be held in developing countries on specific topics related to ammonia plant safety. Special attention should be devoted to corrosion and failures of equipment.

Recommendation 8

A seminar should be organized on safety and maintenance problems in coal (solid fuel)-based ammonia plants.

Recommendation 9

Periodic review and status reports containing articles relevant to plant safety, corrosion and failure should be published by interested organizations in developing countries. Qualified authors should be invited to submit to these organizations papers dealing with these topics.

Note: Recommendations 7, 8 and 9 may be followed-up in close co-operation with UNIDO.

Recommendation 10

Standards for safe noise levels in ammonia plants that have been developed by other countries should be disseminated to all countries through one organization.

Conclusion

Efficient plant management and proper maintenance directly and indirectly contribute to safe working conditions.

Recommendation 11

Large fertilizer manufacturing companies should employ a computerized system of preventive and predictive maintenance control. Records of pressure tests, wall-thickness surveys, progress of corrosion etc. should be compiled consistently. The timing of maintenance and the management of spare parts stock should be organized and supported by a data-logging and cross-checking system.

Recommendation 12

A central pool of long-lead, capital-intensive spare parts should be maintained in each country and made available to subscribing companies.

Recommendation 13

A team investigating a plant accident should include a person thoroughly familiar with plant operation as well as specialists in selected fields.

Conclusion

International agencies and experienced national organizations in developing countries can stimulate technical co-operation among developing countries, particularly in improving plant operations in the chemical industry.

Recommendation 14

A central data bank for corrosion and failures in ammonia plants should be started in each country, and access to this information should be made available to all countries. The information to be collected will include, first, notification of any failure, to be followed by more complete data as the investigation proceeds. The dissemination of this information should be by periodic circulars and annual seminars organized by UNIDO.

Recommendation 15

UNIDO/FAI meetings should be held every two years to discuss safety in ammonia plants. These meetings may deal with other processes used in the fertilizer industry that give rise to numerous corrosion and safety problems.

Recommendation 16

Agencies such as UNIDO and the International Labour Organisation (ILO) should provide to interested parties information relevant to safety in ammonia plants. This information should be sent to a representative in each country who has direct and immediate access to all parties who would benefit from it.

PART ONE. REPORT OF THE MEETING

I. ORGANIZATION OF THE MEETING

The Meeting was opened by Paul Pothen, Chairman of FAI. Mr. Pothen was elected Chairman of the Meeting and G. Russell James and William R. Fox served successively as Rapporteur. The Officer-in-Charge for UNIDO was S. R. Panfil and for FAI, K. S. Chari.

During the five sessions of the Meeting, 27 technical papers were presented and discussed. The list of papers is given in annex I.

Participants from 10 developing countries presented a brief account of the present situation and future outlook of the fertilizer industry in their respective countries. The country participants also presented some further case studies on accidents in ammonia plants.

The complete papers and proceedings will be published by FAI and will be available on request to that organization.

The Meeting was attended by 78 participants from 17 countries, 2 UNIDO officials, 1 representative of the regional ILO office and 1 representative of the South-East Asia regional office of the World Health Organization.

The geographical breakdown by countries is shown below.

Region	Number of countries	Number of participants
Asia and the Far East	8	57
Middle East	4	4
Europe	3	13
North and South America	2	4
	17	78

P. C. Sethi, Minister for Chemicals and Fertilizers, addressed the assembled participants during the closing session.

II. SUMMARY OF THE PAPERS AND DISCUSSION

Session I: Design considerations in ammonia plants

The manager of an ammonia plant in a developing country is under great pressure to operate his plant efficiently because it occupies an important place in the industrial sector of the economy. The fertilizer it produces is vital to agriculture. However, while his country's technical infrastructure is developing, the plant manager is not likely to have as many qualified technicians and technical organizations ready to assist him when operating difficulties arise as he would in a developed country. His plant operators are often less experienced than those in an industrial country, and spare parts may not be so freely available. Therefore, some compromise must be made between the high technology in an ammonia plant and the available personnel to operate it.

Safety requirements for an ammonia plant must be anticipated by the designer. He must concern himself with the safety of both equipment and personnel. To perform this function adequately, he must have at his disposal all the available information about operating plants. Any data relating to past performance, particularly unexpected failures, should be brought to his attention. This requires close co-operation between the client and the contractor. At the start-up of a new plant, the contractor will be on the site to note and correct any difficulties during start-up and performance testing. If an unexpected failure of equipment and material occurs, it can be analysed at once. However, after he has left and normal operation has started, wear of equipment begins. If a failure occurs then, the competent personnel must analyse the cause and notify the engineering firm if a change in design appears to be necessary.

The maintenance log is an excellent source of raw material for the designer; however, under the pressure to maintain plant performance it is not always possible to analyse each failure. A catastrophic accident, with injury to plant personnel, invariably requires a lengthy and detailed examination as to its cause so that the defect can be remedied.

It has become common practice in large ammonia plants to incorporate elaborate safety devices, particularly for the protection of high-speed rotating equipment, and it is not uncommon for the complete operation of the plant to be under computer control. However, safety begins with the designer.

Compressor

The importance of the compressor in an ammonia plant singles it out for special consideration. Operating at high pressure and high rotating speed, it is a complex machine that requires careful design, manufacture and operation.

The Meeting discussed at length the synthesis gas compressor and the considerations involved in its design. Many participants felt that the results of testing of a compressor at the manufacturer's workshop should be made available to the user as a standard of comparison against which to check for deterioration or abnormal behaviour of the unit.

Synthesis loop

As important as the compressor is the synthesis section and particularly the ammonia converter. Along with the compressor, the converter operates at high pressure and elevated temperature and processes a particularly hazardous hydrogen-rich gas.

Very few failures are reported by converter manufacturers or users because of the constant analysis and critical re-evaluation carried out by the designers.

Reformer

Failures of reformer tubes and penthouse fibres are continuing safety and maintenance problems. However, these hazards can be minimized by proper design. The critical period for both the refractories and the mechanical parts of the reformer is during start-up and shut-down. Emergency shut-downs represent a particularly crucial phase when failures are likely to occur or begin.

The Meeting devoted special consideration to design parameters. For both materials of construction and instrumentation, the proper steps for safe start-up and shut-down were analysed.

Instrumentation

Measuring and control instruments link the individual processes together and monitor the safe operation of the plant. The Meeting discussed the proper location of sensors and the checking of equipment to ensure that it would be operating when needed.

Instrumentation must be reliable to ensure proper and safe process conditions even during abnormal events. Safety features of the plant depend on the controls, and the operator must be vigilant to see that these controls are operating and have not been deliberately bypassed.

In addition to issues presented in the papers and discussed as delineated above, participants of the Meeting commented on some of the topics in detail as described below.

The difference in cost between energized and de-energized trip systems in an ammonia plant is about 30-40 per cent, but both systems need an adequate supply of power and maximum reliability of the circuits. Although for general reliability the energized trip system is considered better, spurious trips are more likely to occur, resulting in loss of production. Some consider the de-energized system to be safer, but this system should be constantly checked for continuity of power supply.

One of the difficulties arising during start-up of the ammonia synthesis loop is that the water in the secondary condenser may freeze during the ammonia catalyst reduction, because after start-up the compressors are usually kept in service and the ammonia refrigeration system is charged.

Standardization of gaskets would be very helpful, but specific types of gaskets are required for different joints in the fertilizer plant. To conserve the more expensive specification gaskets, some maintenance craftsmen prefer to use temporary, readily available, non-specification gaskets, but this practice is not recommended, although some of these cheaper gaskets may stand up to the hydrostatic tests.

With regard to training clients' personnel in similar plants, the participant from Pakistan indicated that it would be possible for six trainees at a time from countries in the region to work 3 - 6 months in Pakistan's modern ammonia plants. Pakistan has developed schemes for the continuous training of its technical personnel through the joint efforts of the Government and one of the private companies.

Most of the large-scale ammonia plants are reported to have a very high degree of safe and trouble-free start-up and operation. Only two cases of failures are known to have occurred - one owing to wrong specification of piping in an ammonia loop and the other to use of a non-specification blind at the outlet of a double block valve at the converter. In these plants there are still a few areas where measures to ensure greater safety are needed. In some cases, there is no flare stack in the front end of the ammonia plant for example; in others, carbon-steel piping, which corrodes easily, is used from the separator to the CO_2 absorber. (There was mixed opinion on this point, since the pH of the condensate was reported to be 6 in some plants and 8 in some other plants.) In still others, at start-up the superheated steam temperature is higher than had been designed and desuperheating facilities are lacking.

More reliable vibration analysers and recorders are needed for the centrifugal compressors. The Bently Nevada system is increasingly being used for measuring vibration of centrifugal compressors in ammonia plants. The location and proper installation of these probes are very important and should be made by experts.

The discrepancy noted in the vibration readings at the control room and the portable analysers was discussed at some length. Keeping continuous track of all vibration readings is useful in such cases. If the probes are damaged, wrong readings are likely, especially of thrust bearings. Owing to aging, or change in position of the probe, readings will vary. Hence probe calibration has to be checked frequently. Interpretation of the vibration readings can vary from plant to plant based on one's experience of the machine characteristics and operating conditions. Any abnormal or irregular readings need checking for possible causes. Provision for automatic tripping of centrifugal compressors from the recorded readings at the control room may not always be necessary or desirable.

The wrong materials for constructing fertilizer plants, supplied by mistake, have led to many failures. Unfortunately, only the larger failures are usually reported. Use of coloured bands running the entire length of pipe at frequent intervals for identification may not always be a foolproof device, since the purchaser, the supplier and the manufacturer may have their own colour schemes and a mix-up is still possible. Hence a code for colour identification of piping is being thought of in the United Kingdom of Great Britain and Northern Ireland. A portable type of spectroscope is inexpensive and is useful for identifying most metals and alloys. It can be handled by an operator with little training. Sometimes valve internals may get changed on reassembly after inspection during the construction phase or maintenance of a plant. An incorrect internal material with the correct body material will lead to problems during operation.

Thorough inspection and rigid quality control of equipment and piping by a third party at manufacturers' shops are necessary to avoid differences between what was specified and what was manufactured. Some countries in the Middle East have considered blacklisting incompetent and unreliable inspection agencies. Because of inadequate checking, unmatched flange holes and bad piping welds may occur at manufacturers' works.

Regarding the use of high-quality refractory in the reformers, alumina bubble castable is reported to be strong enough at 200 ft/sec air blast even containing some particulate matter. If this refractory is cast with a minimum amount of water and cured properly, it is as good as brick work. However, if allowed to dry without proper curing, the results will be bad. For transfer lines in the reformer, internal metallic shrouds may not be necessary for additional protection if alumina castable alone is properly done. Alumina castable is resistant to hydrogen attack owing to its low silica content. Regarding hot spots in transfer lines owing to cracks in refractory, repair is not easy. The best solution is to avoid the problem of hot spots through proper installation.

High alumina dense refractory can also be used in partial oxidation gas generators. There is no degradation of the refractory owing to sulphur, but the steel sheet may be attacked by the acid if there are cracks in the lining. The life of the refractory in partial-oxidation units can be three or four years, but nobody will guarantee this life because of unknown conditions such as improper installation, runaway temperatures and other operating factors that can affect the life of the refractory. Also, the life depends on the number of shut-downs, the way depressurizing is done and temperature variations. Some partial-oxidation plants in Europe have reported a life of about five years, but experience in India shows an average life of only two years. The time required to rebuild completely the refractory work of a gas generator is about three weeks, including one week of curing.

The economics of installing computers in ammonia plants is difficult to calculate. With fully trained operators who can react to changes in operating conditions, there is no need for computer control. Even in the United States of America very few ammonia plants have computers. Though better control of certain critical operating conditions is possible with a computer, not all types of operating variables can be tackled. The purpose of a computer is not to decrease manpower, but to optimize operating conditions, whi ' can result in 2-3 per cent additional ammonia production. The cost of a computer system will be 20-30 per cent of the total instrumentation cost of the ammonia plant and will also depend on the extent of the computerization needed. The computer will be found economical if best operating conditions cannot be ensured otherwise.

Bowing of reformer tubes occurs more often in staggered two-row construction than in single-row furnaces, but this may be due to bad design also. Arch-supported tubes should not have this problem. Sometimes bowing is due to causes other than design, such as overheating, non-uniform firing conditions in the furnace, catalyst deterioration, increased pressure drop and sudden and frequent shut-downs and start-ups. Bored catalyst tubes may have better life because of less thermal stress than the ordinary thicker tubes. Operating reformer tubes at lower than design temperatures will minimize hot spots and lead to longer life. It was suggested that to learn more about and tackle the problems of hot spots, bowing and life of the catalyst tubes, the reformer designer, the catalyst supplier, the tube manufacturer and the plant operator should meet to share their experience.

To repair cracks in Incoloy pipes by welding, cleaning the old surface thoroughly by grinding or machining and then welding with Inco wire by TIG weld was recommended. It was also recommended that the tensioning of the spring supports for the tubes in the furnace should be checked more frequently during installation as well as during turnarounds, preferably by a qualified piping engineer.

Feedback information from plants was discussed. Most of the problems that arise during the commissioning stage in a well-designed plant are promptly attended to by the plant builders, who are at site. Subsequently, feedback from clients' plants is also looked into. Systems have been developed by most of the engineering firms to handle this information, since it is considered important and useful for plant designers. Seminars and meetings like the present one also furnish good feedback from plant operators, but it is essential that the talks and discussions are properly recorded and reviewed. Though engineering firms do not have a central computer system to handle and sort out reformer problems, published information on reformer failures and plant data from their clients are always used to improve design and performance. However, operating conditions and catalyst performance are considered major factors in reformer performance.

Reverse rotation in centrifugal compressors on shutting down is normally prevented by ensuring proper closing of the delivery valves and provision of non-return valves on the piping. Optimum labyrinth clearances are provided; these are a few thousandths of an inch according to experience based on the maximum shaft vibration permitted. The balancing of rotors is normally done at the shops after each impeller stage is fixed, at about 2,000 rev/min. If balancing is satisfactory, then higher speeds are tried. To avoid loose coupling between turbine and compressor shaft, it is necessary to ensure proper clearance before shrunk fit of the hub. Loosening may result from inaccurate checking of dimensions during alignment, from unbalanced conditions and improper lubrication. The question of changing existing couplings in a compressor for better ones can always be taken up with the suppliers.

Session II: Operation and maintenance considerations

Hazards in ammonia plants can be caused by:

Handling flammable gases at high temperature
Corrosion and erosion
Failure of large storage vessels
Noise and pollution
Intentional bypassing of instruments and controls

The Meeting examined stress corrosion cracking (SCC) and discussed specific guidelines for either preventing SCC or anticipating its effects. SCC was examined in relation to the variety of metals and atmospheres in an ammonia plant. Corrosion can result from an improper plant layout that fails to anticipate existing atmospheric conditions. An example of severe corrosion in the nitrogen coils and train liner of the regenerators of an air-separation plant was given. Prevailing winds were carrying ammonia fumes from one part of the fertilizer complex into the air intake of the tower in the air plant, and the accumulated ammonia caused corrosion in the copper liner.

The Meeting analysed corrosion and erosion in the boiler and the cooling tower and discussed preventive measures. Erosion and corrosion are common causes of failure in CO_2 removal systems. Papers dealt extensively with means of reducing these effects. Tables and charts were presented illustrating the effects of corrosion inhibitors in potassium carbonate CO_2 removal systems.

Hazards cannot always be controlled, and preparations must be made to ensure that quick and accurate steps shall be taken in the case of fire or catastrophic failures. Each plant should have trained staff to deal effectively with these situations, and their training should include actual fire-fighting.

Additionally, personal safety protection should be continually stressed by advertising and enforcing the use of safety equipment. Safety programmes are most effective when all levels of plant management are strongly behind them.

A well-defined programme of maintenance and the effective monitoring of subcontractors can reduce hazards. The following comments reflect the participants' contribution to the exchange of experience on issues covered by the papers presented at this session of the meeting.

SCC, defined as a non-ductible fracture resulting from the simultaneous application of a tensile stress and a specific corrodent, is responsible for failure of plant equipment and the resulting hazards. Since no specific relationship between the corrodent and the material in question has been established, SCC cannot be predicted. For example, until pure titanium was produced, there was no method of predicting its immunity to SCC with fuming red nitric acid. The general factors responsible for SCC, along with specific SCC systems, are known. However, although the average stress levels and corrodent concentrations may be low in the system, high localized stresses and/or local corrodent concentrations may result in SCC. Photographic analysis is also difficult, since the crack morphology can vary considerably. While SCC rarely leads to catastrophic failures, its importance, particularly when it leads to fatigue failure, should be appreciated. The only certain method of avoiding SCC is to use non-susceptible metals/alloys, but the cost may be prohibitive.

In ammonia plants, apart from process material, environment also acts as a corrodent for many systems. The SCC behaviour of brass is well known, and in most ammonia plants, copper alloys containing more than 15 per cent zinc are not used. In smaller pieces of equipment such as oil coolers, failure can lead to contamination or starvation of lubricant, and often cupro-nickel or stainless steel tubes are used. Benzotriazole coating coupled with lanolized tape wrap has been used satisfactorily for air fittings on instrument lines. Although relief of stress in large vessels is difficult, it must be done wherever possible, since SCC occurs even at very low stress levels. Although SCC is attributed to the presence of localized stresses, no means of measuring such stresses is readily available. Thus, the greatest care must be taken during the fabrication stage and stress-relieving operation to ensure that the minimum residual stresses are left in the equipment.

Mechanical design often plays an important part in preventing SCC. Use of non-metallics for fabrication/lining of equipment to prevent corrosion is coming into vogue with the development of new materials. However, lack of data on the properties required of the non-metallics for the duty in question as well as temperature limitations and fabrication problems have restricted the use of these materials.

Austenitic stainless steels are susceptible to chloride SCC. In fertilizer plants this type of cracking is often experienced in cooling water systems. It may also result from rain water on pipeline/equipment with lagging. Incoloy 825, though very satisfactory for chloride SCC duty, is rather expensive. Two families of alloys with properties similar to those of stainless steel but with better SCC immunity to chloride have been developed - mixed austenitic/ferritic stainless steels and fully ferritic stainless steels. The former alloys, containing larger amounts of chromium and nickel, are difficult to fabricate. The latter alloys, having an extremely low carbon content, are comparatively easy to fabricate.

SCC of carbon-steel tubes with caustic results from the presence of very high stress levels. Since most equipment is now stress relieved, the problem no longer exists in modern plants.

Vetrocoke solution is a specific SCC agent for carbon steel. The variable SCC rates experienced in Vetrocoke plants led one of the large European chemical companies to investigate the properties of Vetrocoke solution with respect to carbon steel. Results showed that Vetrocoke solution contains passivating ions (As^{+5}) and activating ions (HCO_3^-). The SCC properties of Vetrocoke solution are maximum when the activating ions and passivating ions are more or less in equal proportion. The presence of Sb and (Fe^{+3}) ions shifts the solution to the passive region and renders it harmless. Most cases of corrosion have been identified as being caused by depletion of Fe^{+3} ion owing to lack of air sparging. The temperature, Cl and other ions present also affect the SCC behaviour of the Vetrocoke solution. Continuous monitoring of electro-potential has been used successfully in this area to prevent SCC in Vetrocoke systems.

The company's experience with SCC of carbon steel with Vetrocoke solutions has led to a method of preventing the corrosion of carbon steel by passivating the solution through timely air sparging. At least seven plants have operated with this system of corrosion control - five in the United Kingdom and two abroad, some of them since 1966. No new cracks or extension of old cracks have been observed in these plants.

Benfield/Catacarb systems, using vanadium, do not suffer from SCC. Experience has shown that, even when Vetrocoke plants are converted to Benfield/Catacarb-type units through modifications, the adsorbed arsenic in the vessel wall reduces the vanadium in service initially and hence the high consumption of vanadium on changeover must be borne in mind. Several organic inhibitors are also available for the vanadium/arsenic system. The experience of another company having had no SCC failure of its Vetrocoke system, in operation since 1962, has been attributed to the air regeneration of the Vetrocoke solution, which eliminates the possibility of Fe^{+2} carry over. One of the participants presented the results of a systematic study carried out on the Vetrocoke system indicating the velocities and the construction materials in the various sections. SCC has been observed in atmospheric temperature ammonia storage vessels. In this case, oxygen and/or nitrogen acts as activator and water as the passivator. Work in this area is still being carried out in the United Kingdom and in the United States.

According to research carried out in the United Kingdom, both nitrogen and oxygen seem to have an effect on SCC of carbon steel in ammonia storage tanks. For commercial storage, 0.2 per cent of water is generally adequate to prevent SCC. The exact figure, however, depends upon the oxygen concentration. Although laboratory experimentation has shown that SCC can be produced at -33°C, there is no evidence of such corrosion in storage tanks.

One company has experienced situations where sulphuric acid corrosion of the cold end of the waste-heat recovery train has occurred when fuel oil with a high sulphur content has been used. The sulphuric acid dew point is lowered by ammonia injection into the flue gas duct to prevent corrosion. The ammonium sulphate and bisulphite formed has no corrosive effect. Use of fuel oil containing vanadium and sodium often results in the formation of a hard corrosive scale leading to damage. Addition of material containing barium or magnesium results in formation of metavanadates, which have high melting points and hence do not affect tube performance.

Cooling water is responsible for a large amount of the corrosion in a fertilizer plant. Chromate dosing has been used with success, but the disposal of the effluent creates ecological problems. Dosing with sodium hexametaphosphate/ sodium tripolyphosphate leads to the problem of calcium phosphate precipitation if not performed very carefully. Zinc organophosphates are likely to provide a satisfactory answer in the long term.

For cooling-water service, chromate dosing is considered the most satisfactory treatment, although accompanying environmental problems may impede its use. It has been reported that systems containing up to 600 ppm chloride operate satisfactorily. In another case experience with the synergized chromate system has been complete inhibition of corrosion even at 800 ppm chloride level; but, chromate-based systems have to be operated with clean cooling surfaces, and there must always be flow in the systems. Environmental restrictions may swing the balance in favour of organophosphates, which have been used with success in many plants.

Fatigue failure, particularly in the suction and discharge of ammonia and recycle solution lines, is a common occurrence. Recent use of centrifugal machines has eliminated such failures substantially.

In air-separation plants having copper internals in the cold box, the presence of ammonia in the atmosphere poses a serious corrosion problem. Apart from selecting suitable construction material, proper location of air-intake points, preferably two, would offer an optimum solution. While proper location of air-intake towers coupled with having two towers for operation, depending upon wind direction, may provide the solution to corrosion of cold-box internals, it may be advisable to look at the atmospheric inversion phenomenon as well. Experience has shown that minor traces of ammonia cannot be economically removed from the air by water or acid scrubbing, although some plants have reported success using acid scrubbing before the air passes to the turbo compressor. The main reason for using acid was, however, to remove dust particles rather than ammonia.

One expert reported that experience with the use of annealed brass tubes in ammonia plant steam turbine condensers has been satisfactory in his company.

Pretroleum refineries and fertilizer plants, by virtue of their large-scale operations and large amounts of explosive, hazardous and toxic materials, present major safety problems. Codes of safe practices have been drawn up as a result of research programmes undertaken in many countries. Apart from loss of production and equipment time, accidents result in economic and social loss to the community. Safety is, therefore, one of the prime responsibilities of management, but requires the active co-operation of the employees. The management of most large refineries and fertilizer plants has accepted this responsibility and has adopted a variety of training and educational programmes for personnel to ensure safe operation of the plants.

According to a survey carried out by ILO, 80 per cent of accidents are due to human factors in one form or other, with the remaining 20 per cent due to faulty design and unpredictable circumstances. The use of techniques such as "safety audit", "safety sampling of unsafe acts" and "ergonomic check lists for equipment operation in industries" has eliminated several unsafe designs and practices. Although safety committees, campaigns and posters do increase the workers' awareness of the importance of safety, the single most important factor contributing to a poor safety record is management's lack of commitment to ensuring safety. Unless safety is given at least an equal status with production, it will not be possible to make radical improvements in safety performance. Having joint worker-management teams carry out safety audits and assess the work environment and giving added weight to safety factors in the annual evaluation of the performance of the various managers would help to achieve safer operations. In Singapore, advanced legislation on safety has been passed that calls for the regular participation of external agents such as factory inspectors in ensuring safety in enterprises.

To maintain safety in large ammonia tank parks, bunding has been found desirable, but it is expensive. It may be considered necessary when the factory is located near large centres of population. For safe operation of fuel/naphtha storage tanks, foam has been found by and large to be adequate, provided that the foam-injection system can be operated from a convenient point.

A code for handling radioactive materials in case of fire or other disaster needs to be drawn up. ILO has some information on the subject. With the help of national atomic energy authorities suitable codes could be drafted.

Noise pollution is easier to eliminate at the design stage of the plant but will mean additional cost. However, contractors normally do not quote for eliminating noise unless specifically required to do so. It is, therefore, the responsibility of the buyer to specify at the design stage the noise levels desired in the plant. A broad estimate of the cost of keeping noise at a reasonable level may be 1.5-2.5 per cent of the basic plant cost. Normally, maximum noise occurs in fertilizer plants during start-up, shut-down and venting, and the steady running noise levels are considerably lower. In plants that are already operational, the use of sound-proof enclosures and personal protective equipment coupled with minimizing exposure may provide the best control, since remedial work may be extremely expensive.

Catalysts used in ammonia plants pose some safety hazards, particularly because of their pyrophoric nature. Special care has to be exercised in keeping the system free of any oxygen during operation as well as during discharging. Close liaison between the designers, catalyst manufacturers and the operators is essential in developing operating norms for the various catalysts.

Considerable work has been done on safety in ammonia plants by G. P. Williams and J. G. Sawyer. Several hazardous areas were identified in a survey carried out in 1972. A similar survey carried out in 1974 revealed that, while the number of hazardous incidents, e.g. fire, fell in 1974, the areas in which they occurred was the same. To contain the situation, it was, therefore, essential to know the areas of plant hazards, toxicity, explosive limits and other properties of the materials handled in these plants. A knowledge of these factors often leads to remedies.

Session III: Testing and control procedures and welding techniques

The accurate representation of the designer's drawings and specifications is not easily achieved without constant testing and control during manufacture. The control of incoming materials, preparation and production techniques and the continuous and final testing for quality are a necessary part of a reputable manufacturer's procedures. Proper testing equipment is necessary to ensure final compliance with codes and specifications.

Several destructive and non-destructive tests available to both the production and maintenance departments were outlined, including the requirements as to both personnel and equipment.

The discussion focused upon the relation between the equipment cost and its reliability. It is not fair to assume that equipment procured from outstanding suppliers of world-wide reputation at high cost will always be free from production defects and those obtained on the lowest-tender basis likely to be defective. Small and relatively unknown firms have often supplied equipment of the highest quality, while supplies from some of the world-famous engineering companies have contained some easily detectable defects. Plant failure arising because the manufacturer has supplied defective or the wrong material is not confined to developing countries; it has often occurred in the developed countries as well.

Such mistakes may be due to an accident or may occur for other reasons. An accidental case concerning gate valves may be cited. Gate valves are made of a variety of materials, such as carbon steel, chromium-nickel and chromium-nickel-molybdenum steels, with internal fittings of different materials. A reliable firm in the United Kingdom, which inspected thoroughly at all the intermediate stages of production, used to store the final products in one room, where large stocks of the different types of valves got mixed up. As a result, users who relied entirely on the supplier's tag marks encountered severe difficulties. In another case, one of the world's leading welding electrode manufacturers produced a long length of wire whose composition was dissimilar at its two ends. This happened because electrode bars of different grades of steel were accidentally used before the drawing process and were welded together to produce the whole length. Sometimes a particular batch or group of batches misses quality control inspection altogether.

Other mistakes may be due to deliberate cheating, lack of knowledge of the end result, and even good intentions. Fortunately, cheating is relatively infrequent. Lack of exact knowledge of the end users' requirements is perhaps more often the reason. Here, naturally, inspection by the buyers would avoid the trouble. Sometimes suppliers have generously offered to supply a costlier material for the same price, but it has often turned out that the more expensive material was not suitable for the job in view.

Regarding testing and control procedures, post-failure investigation should be given due emphasis. In the rush to resume production, considerable circumstantial evidence is destroyed, and often post-failure investigation is delayed purposely to facilitate repair action. Such a policy is short-sighted. Detailed laboratory investigation always helps to prevent such failures in the future. The investigation should be carried out by a group composed of specialists from the laboratories and one or two from management rather than by non-laboratory personnel alone. Predictive maintenance can be considered a supplementary function of preventive maintenance. Some control-room continuous monitoring devices for corrosion in specific equipment or pipelines have come into use in Western industrial countries, but their application is limited on account of their high costs. Similarly, signature analysis is also still limited in its application because of the enormous amount of data required before any analysis can be attempted.

With respect to testing centrifugal compressors and turbines, it was suggested that a data bank be established at one or two places in a country to pool together all types of vibration and noise data. Manufacturers of these machines should be requested to pass on to the user relevant data that may be helpful for analysing equipment behaviour during its operation.

While dealing with the subject of inspection, it was found advisable to emphasize the need for two types of inspectors: (a) those who have been trained in terms of the manufacturer's requirements and (b) those who are aware of the requirements of the particular process. Moreover, with each drawing, a separate sheet should be attached in which elaborate inspection methods are described in detail. This sheet should accompany the job at every stage.

A specific case of leakage of hydrogen through weep holes of an ammonia reactor was discussed. The question was how to explain the higher concentration of hydrogen in the leaking gas than in the process stream itself. Another problem was whether the leakage could develop into a hazardous situation. The gas, having a content of 85 per cent H_2, 12-14 per cent N_2 and some oxygen and carbon dioxide, was leaking through the weep hole at a rate of 1.0 ml/15 sec. One expert attributed the high concentration of hydrogen to the higher diffusion coefficient of the lighter gas, in which case there might have been a leak through corrosion cracks in the cartridge. It was felt that the rate of leakage should be considered significant and should be watched with care. In catalyst cartridges, metal deterioration owing to ferrite precipitation and nitriding followed by hair-line cracking was quite common. For inspection, dismantling would be necessary and Zyglow testing might be used to locate possible cracks.

The Meeting concluded that the reactor needed to be investigated thoroughly to prevent the already abnormal situation from becoming dangerous.

Session IV: Case histories

A major accident may mean not only loss of life and equipment but also loss of production. To a developing country, the loss of internal production and perhaps revenue from overseas sales can be severe. Often the delay in resuming production is prolonged if a replacement part must be secured from overseas.

Several case histories of accidents were presented to the Meeting. The cases included catastrophes in which a number of persons were injured owing to equipment difficulties. In some cases the causes were discovered. In others the cause of the failure could not be determined even after extensive examination and analysis. One major difficulty in tracing the cause of a large explosion was that much of the evidence was often destroyed.

In one case, a control-room explosion in an ammonia/urea complex, 4 persons were killed and 11 injured. The suspected cause of the disaster was seepage of natural gas into the instrument air lines in the control room. The discussion brought out a series of interrelated factors that might have led to the accident. It was felt, however, that connexions between natural gas lines and instrument or service air lines that might be justified during the initial period of start-up of plants had to be considered faulty design. Those connexions might permit uncontrolled leakage of gas into areas in which equipment was not explosion proof. The result was fire hazards, which were difficult to detect by the plant operators as soon as the leakage occurred. Even double-block and bleed arrangements could not be regarded as safe enough. Participants referred to their experience with similar plant failures, but none that had resulted in a catastrophe.

Frequently, nitrogen is used instead of instrument air in an ammonia plant. If the operation of the nitrogen supply network is faulty, hydrogen may leak into the system. An accident caused by this type of leakage, resulting in a hydrogen content of 28 per cent in the nitrogen used, was described. In the same plant a fire originated from naphtha leaking into the steam main. The prime cause was a leaky isolation valve between the naphtha line operated at 28 kg/cm^2 pressure and the steam header working under as low as 7 kg/cm^2 pressure. The naphtha coming out of the nearby steam trap caught fire. Another accident resulted from synthesis gas flowing into the nitrogen supply system during a power failure. The connecting point was the Syn-gas ratio control instrument where injection nitrogen was being used for maintaining the appropriate nitrogen control in the Syn-gas. During the emergency shut-down of the plant, the contaminated nitrogen was used for purging the process lines. An explosion occurred in the methane analyser room.

Failures of pipe elbows after control valves were discussed. The Meeting concluded that designers should be made aware of the risks inherent in placing piping and equipment that may erode and corrode close to control rooms. Distances between control valves and elbows have to be designed bearing in mind that the stream after it has passed the control valves will flow at a high velocity and cause severe erosion.

It was noted that in addition to providing safe velocities of fluids in the piping system, the temperature of CO_2 absorbing solutions should also be given due consideration, since rapid corrosion might occur if grades of steel inadequate for the operating temperatures applied were used. It was suggested that using stainless-steel instead of carbon-steel piping might solve the problem. One expert pointed out that in the Vetrocoke system higher velocities were permissible than with the Benfield/Catacarb process, which should not exceed one third of the velocity designed for the former system.

One case in the United Kingdom was cited, where the top of a vessel blew off owing to uniform circumferential corrosion. Continuous circumferential failures of vessels as a result of bubble release under submerged conditions are well-known in practice. However, pin-hole leaks are a warning of what is happening inside the vessel. Sometimes no pin-hole leakage can be observed. Because of an almost equal reduction of the thickness of a larger area, e.g. from 10 to 1 mm, the pipe or vessel is torn open as in an internal explosion.

Many cases of corrosion in the straight length of pipelines were mentioned. In monoethanolamine solution corrosion occurs near the weld joints. Ultrasonic testing alone has been found insufficient even if 20-25 per cent of the suspected areas are being covered. Radiographic tests are more reliable, and marking the places using lead wires when frequent testing is required is recommended. Non-destructive testing (NDT) has become regular practice in one of the developing countries and has prevented several severe accidents. Some tests are carried out during normal plant operation, but sometimes the plant has to be shut for safety considerations. In one of the large units, 2,000 points are routinely checked by NDT every year. About 5-10 per cent of these points are radiographed as well as tested ultrasonically. In ending the discussion on corrosion and erosion of piping, the Meeting concluded that regular NDT was indispensable and a sine qua non for safe plant operations, since many plant failures were due to a breakdown of equipment and piping, the likelihood of which could be detected in advance by NDT.

Failures of high-speed rotating machines were discussed.

Some comments were made on the permissible silica content in high-pressure steam; 0.02 ppm was mentioned as an acceptable level. Since the turbidity of the raw feedwater can cause colloidal silica to break through the water-treatment plant, it should be kept within 5 ppm.

Washing out of silica from turbine blades with condensate is being applied successfully in one country, and this operation has now become normal practice. Silica deposits are removed within a few hours.

Another topic covered the damaging effect of bubble erosion conditions in MEA solution pumps. Intergranular corrosion is caused in unstabilized 18/8 stainless-steel impellers of these machines. The combined effect of unstabilized 18/8 stainless-steel material and bubble erosion causes serious corrosion. Bubbles of CO_2 in the solution entering the pumps should be avoided.

Improper design of vent headers is responsible for some of the plant failures. Vent headers can develop, at times, pressures of up to 16 kg/cm^2.

Measures should be taken to prevent gases flashed into the header from backing up and causing excessive pressure in the process let-down piping or equipment that might not be designed to withstand the sudden increase in pressure. The experts reported on accidents of this kind, pointing out that a flow of flammable gases back into the vent system was a frequent source of pipe rupture and a subsequent fire and explosion hazard.

Carbon deposits and auto-ignition at discharge temperatures of compressors are another source of machine and piping failures. In one case the failure was caused by faulty operation of a check valve. An explosion occurred because hydrogen flowed back through the check valve into the process air line, which was being operated at 170^{0} - 180^{0}C. Discharge valves at compressors should be given careful attention, since these appear to be the ignition point in the case of unusual operating conditions either inside the machine (inappropriate grade of oil or high discharge temperature) or downstream of the valve (backflow of gases).

Oxygen compressors were mentioned as another source of explosions; however, no generalized recommendations could be made on how to prevent accidents at this section of plants where compressed oxygen is needed for the process The use of demineralized water for lubricating the machines has proved to be advantageous in some cases.

In the discussion of surge problems in process air compressors, the supply of spare parts was considered. Spare parts must obviously be ordered in the correct quantities. However, adequate facilities for balancing high-speed rotors are also needed for maintenance and repair purposes. For a new project under construction, it is useful to order the spare parts as recommended by the equipment vendor for a two-year operation. The value of those may be estimated at present at 8 per cent of the total equipment cost. In most cases the vendor's recommendations appear unrealistic. A thorough check should be conducted to determine that the required quantities of all critical spares are available. Balancing machines for high-speed rotors should be available or purchased on a joint basis for a group of companies. In one developing country a large compressor and turbine manufacturing company will make such arrangements. This company is endeavouring to ensure that services to the fertilizer industry shall be provided on a high priority basis to prevent fertilizer production loss.

In one country the Government has set a ceiling for the value of spare parts imports at 2 per cent of the equipment cost. The remaining requirements have to be procured from domestic manufacturers. A central warehouse for spare parts is already in operation, and similar common services on catalysts are being considered for several fertilizer factories. There are, however, limitations to this practical approach. Both old and new plants are in operation, most of which have been financed through credits from various sources. As a result, the machines in most of the plants are not of identical type and size. Thus it is difficult to organize a common pool of spares.

Session V: General considerations

The transfer of know-how and experience from the industrialized world to developing countries must take into account many factors that may affect the outcome. Hazardous situations are often due to the contractor's inadequate knowledge of conditions in countries having a weak industrial infrastructure or to the local investor's lack of awareness of the problems involved. It is therefore recommended that a modified approach to the transfer of technology be adopted to ensure that all pursuant safety factors shall be taken into account when modern, large-scale plants are being designed for a developing country. Technical and scientific issues relating to safety standards and the development of infrastructure will have to be considered long before new ammonia production facilities are established.

If the lack of skills of plant operators is considered responsible for most of the accidents encountered during start-up and after the commissioning of plants, human aspects should not be neglected during training programmes and the period of close co-operation between the contractor's staff and the local crew of operators and maintenance craftsmen. Staff engaged to run sophisticated chemical plants should be made aware of the inherent hazards and the severe consequences of a plant failure.

The discussion focused first on the human aspects of plant safety. Human factors relating to safe plant operations need to be evaluated and taken into consideration during the design stage of production units, especially in the chemical industry, since the designers do not always take into account the differences in anthropometric dimensions of operators or the differences in culture, religion and industrial background of those who are expected to operate plants in various parts of the world. The designer's inadequate knowledge of these factors may lead ultimately to fatigue on the part of the operator, which may lead to damage to the plant, its equipment and sometimes to the person himself. Limitation of human abilities to run chemical plants efficiently need to be examined, and appropriate guidelines should be established to make designers aware of all relevant factors that may differ in the various plant locations all over the world.

The Meeting discussed corrosion problems and the organization of corrosion control repeatedly. The Meeting agreed with the opinion of the corrosion specialist who stressed the need for assigning "corrosionists" to plants. It was pointed out that centralized laboratory and investigative services appeared to be helpless if severe corrosion occurred suddenly. The argument was that it took much longer to teach the experts at the centre the particular difficulties of the various plants than it did to teach corrosion technology to a single man at the plant.

Standardization of safety procedures, guidelines and permits was another topic of general interest. One expert from a developing country suggested pooling the experience gained so far and compiling relevant data in regional centres for the particular industrial sectors. These centres might also collect information on plant accidents in the chemical industry and disseminate brief reports on catastrophic plant failures. These reports should outline the assumed causes of accidents even before the official report was ready. The consensus was that early information, even if not comprising full details, would provide incentives for the plant management of other plants to launch a thorough plant check and hence prevent similar accidents in their countries. The need for close co-operation between technical staff of fertilizer plants was stressed.

The participants showed much interest in discussing general aspects of the contractors' and licensors' practices relating to plant costs and the selection of high-quality equipment. Since plant safety and proper layout of safety devices are closely interrelated, high investment costs resulting from appropriate design were discussed at length. The escalation of plant and equipment procurement prices was found to be interfering with the requirements of having plants equipped with better machines and vessels and more expensive, higher-quality piping that is crucial for plant safety in the long run. Participants were given the opportunity to exchange their views on the relevant price trends in equipment and fertilizers.

The discussion also covered asnects of co-operation between contractors and licensors on one hand and the plant users on the other. The experience gained by the plant owners during initial operations of the particular production units is being exchanged in various ways. In most cases, however, this kind of inter-company consultancy is kept confidential. Issues of appropriate design, operation and maintenance with respect to plant safety are constantly reviewed by some of the big contracting firms with the view to improving the design of subsequent plants.

PART TWO. SUMMARIES OF COUNTRY PAPERS PRESENTED TO THE MEETING

Brazil

The participant from Brazil provided some technical details on the ammonia/urea project being implemented by the Companhia Riograndense de Nitrogenados (CRN). The factory, owned by the State Government of Rio Grande do Sul, was the first fertilizer factory to be engineered and constructed by local staff in co-operation with the main contractor (Davy Power-gas, London). Previously, fertilizer plants had been contracted on a turn-key basis. Although Brazilian engineers had some experience in operating fertilizer plants, they did not have adequate knowledge of plant design.

A second large-scale, gas-based ammonia plant was already under construction in Brazil. This was the first unit with a capacity of 1,000 t/d to be set up. Four other ammonia plants, one based on natural gas, one on naphtha and two on fuel oil were under consideration or had already been decided upon. Therefore, indigenous know-how regarding safety in the design and operation of up-to-date large-scale units was greatly needed.

A huge investment programme had been started by the Brazilian fertilizer industry to make the country self-sufficient in fertilizers in the near future. The development of industrial infrastructure, mainly power generation, was recognized as being necessary. Priority was being given to local manufacture of equipment for the chemical industry with the aim of reducing imports. It was assumed that the extensive investment programme would offer engineers and operators of chemical fertilizer plants the best opportunity for training and for gaining experience in carrying out the necessary safety measures.

Egypt

The participant from Egypt described problems encountered in the operation of the Helwan ammonia plant with a capacity of 170 t/d based on coke-oven gas and showed how the main problems had been solved. These problems were:

(a) The rapid response of the cobalt molybdenum gas hydrogenation catalyst to excess oxygen content in the gas stream. The high corrosion rate was the result of frequent variations of the composition of the gas. Precise oxygen control needed to be maintained;

(b) Corrosion of the hydrogenated gas lines owing to high sulphur content in the gas stream necessitating replacement of carbon steel piping. Stainless steel pipes were now being used;

(c) Fire hazards in the coke-oven gas cracking units resulting from high oxygen-to-air ratio (39 per cent). Strict oxygen control and a dip unit in the gas line were provided to avoid the danger of an explosion;

(d) The level control in the copper-liquor-absorption column was very sensitive. A radioactive cobalt sensor was now being used in the interlock circuit of the high-pressure copper-liquor pumps;

(e) A series of minor problems in the ammonia synthesis units. Solving these problems, step by step, had improved on-stream time and the safety record of the plant.

It was recognized that safe operation depended to a large extent on training operators and on good maintenance scheduling. A safety check list for critical equipment, instruments and piping had been elaborated and was now being followed consistently. No major accidents had occurred.

Indonesia

The participant from Indonesia reported on the development of the PUSRI fertilizer complex, the largest fertilizer producer in Indonesia at one site. Ammonia production facilities had been installed in four phases since 1963, and the fifth expansion was under consideration. All the existing plants were operating at or above 100 per cent of the rated capacity; however, during initial operations accidents occurred. The following examples were cited:

(a) Explosion in the quench station of the secondary reformer (reason: inadequate quench-water supply);

(b) Cracking of pigtail piping in the primary reformer (reason: poor welding techniques applied at the manufacturer's workshop);

(c) Entrained liquid hydrocarbons in the natural-gas lines causing overflow at the knock-out drums and dangerous carry-over of liquids;

(d) Tube rupture in the waste-heat boiler at the secondary reformer owing to the poor quality of the boiler feedwater (BFW), which caused precipitation of solids in the pipes;

(e) Corrosion in the carbon dioxide absorber as a result of faulty manufacture. Carbon steel instead of stainless steel was employed for the gas distributor.

The experience gained through co-operation with the contractor's staff during construction and start-up of subsequent plants and good management demonstrated that such co-operation was a prerequisite for the safe operation and high efficiency of plants after start-up.

Iran

The participant from Iran traced the development and expansion of the fertilizer industry in his country.

The rapid increase of fertilizer production capacities had been outstripped by the even more rapid growth of fertilizer consumption during the past few years. Therefore, extensive development plans were under consideration to convert this industry from being a domestic supplier into a main exporter of fertilizers based on gas, oil and sulphur.

Since a large fertilizer industry in Iran, including several ammonia plants either operating or under construction, already existed, some experience in applying safety procedures had been gained. The expert presented details on the following plant failures and points of interest to the Meeting:

(a) The internal basket in the ammonia converter cracked during start-up. After repair of the damage caused by stress corrosion, the plant capacity was reduced by 10 per cent and a new converter ordered and installed;

(b) Serious problems had been encountered at centrifugal compressors throughout the Shapur plant. After the foundations had been reconstructed, the alignment improved, and the lubrication system modified, the machines were now running very well. Bently Nevada probes for vibration control were being applied and could be recommended;

(c) The lower-pressure steam system designed and operated at 600 psi was found more advantageous than systems operated at pressures of 1,000 psi and above;

(d) An accident occurred in the converter piping system, owing to a mistake in the specification and construction of a blind pipe end welded during plant modification. Although nobody was injured and only minor damage was caused to the plant after the pipe cap was blown out, a hazardous situation had existed that might have resulted in a catastrophe. The accident showed clearly that careful attention should be paid even when slight modifications were made;

(e) Another accident took place during maintenance inspection of a diethanolamine scrubbing tower in the feed gas desulphurization unit. Iron sulphide deposits caused the polyethylene rings to catch fire when they were exposed to atmospheric air after purging the tower with steam and opening the manholes for cooling down the vessel before inspection.

Kuwait

Following a concise description of the ammonia plants operated by the Petrochemical Industries Company, the participant from Kuwait stressed safety aspects. He presented a long list of modifications in the plant that had improved safety conditions and plant efficiency. A computerized system of maintenance records had been developed and was being used as a general data-logging and cross-check system on all matters relating to preventive and predictive maintenance. Timing of pressure tests, piping thickness surveys, machinery overhauls and inspection, lubricating programmes and spare parts stocks were being controlled by the computer. During the ensuing discussion, the Meeting concluded that such a computer system should be recommended for any large fertilizer and petrochemical complex.

The expert focused repeatedly on the appropriate organization of management and on training and retraining procedures that were deemed a sine qua non for preventing plant failures and hazards.

Poland

The participant from Poland discussed the safe operation of waste-heat boilers in ammonia plants. He made the following recommendations on how to prevent boiler failures:

(a) Additional alarms should be installed on safety valves in the BFW supply system in order to inform the operator if the water supply to the steam-drum is bypassed by the safety-valve and hence insufficient to keep the required level in the drum;

(b) Pressure drop in the suction line of the BFW water pumps should not cause stoppage of the pumps. Alarms must be provided instead;

(c) The drum capacity and the respective minimum water-level alarm should be taken into consideration when establishing safe procedures for shutting down the primary reformer.

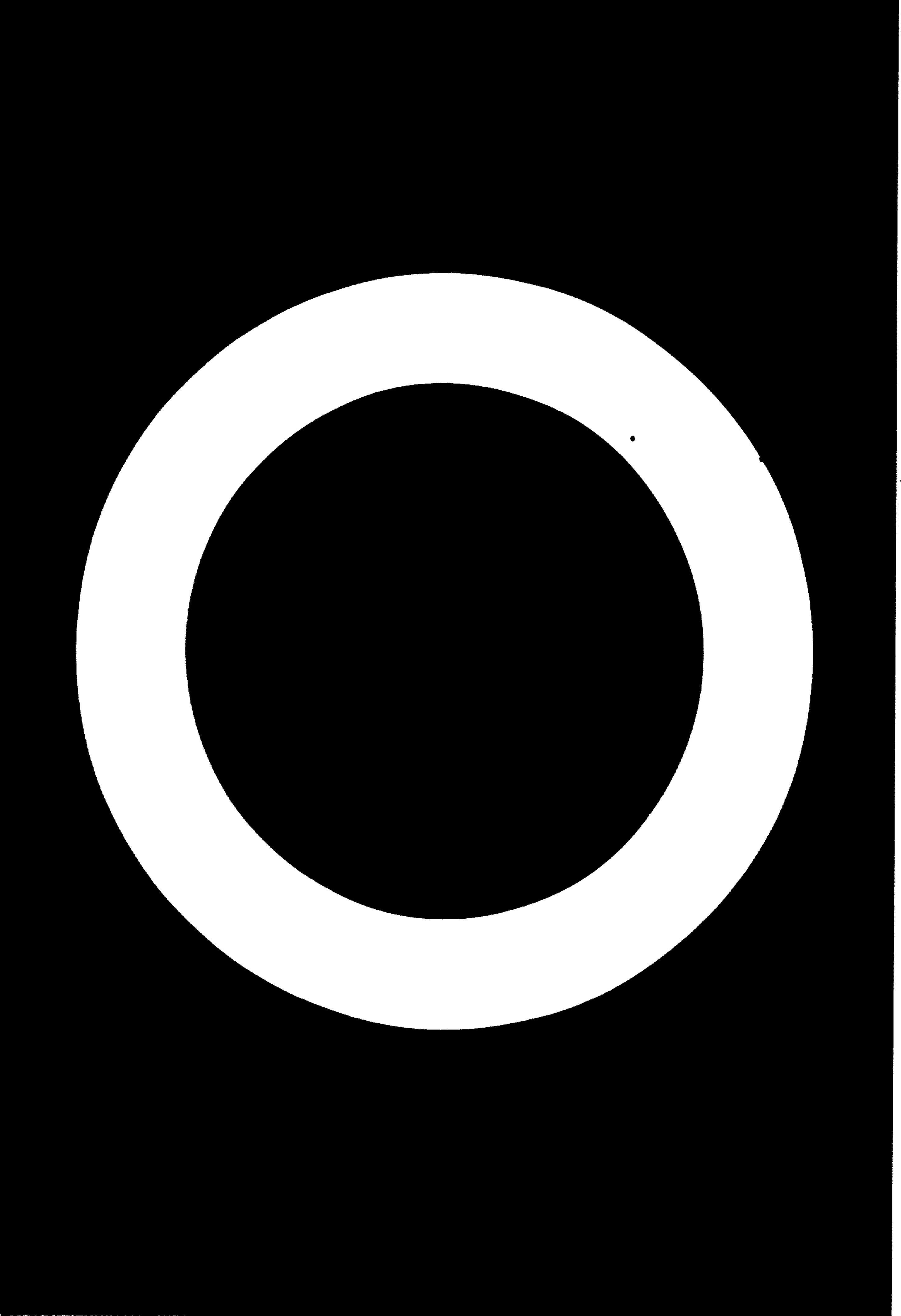
Republic of Korea

The participant from the Republic of Korea presented a brief outline of the status of the fertilizer industry in his country and displayed case histories of plant failures in units operated by the Korea Fertilizer Co., Ltd.

Stress corrosion in the carbon dioxide regenerator shell was observed for the first time eight years after start-up of a plant that had been operated efficiently at an average of 325 days per year. The crack grew slowly. After two months it was 1,100 mm in length, and the plant had to be shut down. Precise inspection revealed a large area affected by stress corrosion, which had begun at the reinforcing plates for the support pads.

The expert described repair procedures. While focusing on repair methods, particularly those needed for welding recracked shells, the expert pointed out that several problems had still not been solved, such as stress relief and heat treatment after welding and prevention of SCC.

Hydrogen leakage from control holes in a multilayer vessel was another problem that deserved to be considered at the Meeting. The expert described the construction and operating conditions of the ammonia converter. He pointed out, however, that no decision had yet been taken to remove the origin of the leakage, which was still very small. He hoped that the defect would not develop into a serious hazard.



Annex

PAPERS PRESENTED TO THE MEETING[a]

Session I: Design considerations of ammonia plants

ID/WG.221/2	Safe design and operation of ammonia plants M. Vos and A. C. Ludbrook, United Kingdom of Great Britain and Northern Ireland
ID/WG.221/19	Safety in design and operation of IEL ammonia plant K. Naray[illegible] and R. B. Dutt, India
ID/WG.221/4	Safety consideration in the design of ammonia synthesis loops A. Ward and A. Sunderland, United Kingdom of Great Britain and Northern Ireland
ID/WG.221/7	Special refractory materials for use in gas reforming R. R. Miner, United States of America
ID/WG.221/21	Safety considerations for design of reformer furnaces R. N. Saran, G. Venugopal, S. N. Wazir, India
ID/WG.221/25	A case study on Namrup flue gas boiler failure B. B. Chandra, India
ID/WG.221/12	Instrumentation and computer control for safe ammonia plants M. Nobue, Japan
ID/WG.221/10	Safety audits in ammonia plant design E. W. Owen and P. M. Sales, United Kingdom of Great Britain and Northern Ireland
ID/WG.221/20	Turbines and compressors for ammonia synthesis plants A. N. Venkatesan, India
ID/WG.221/14	Centrifugal compressors for ammonia plants - design and operation considerations W. A. Zech, United States of America
ID/WG.221/29	Design and operation problems of compressor systems L. Laboratore, Italy

a/ A limited number of copies are available from UNIDO upon request. Documents are listed by sequence of symbol in ID/WG.221/16/Rev.1.

Session II: Operational and maintenance considerations

ID/WG.221/8	Stress corrosion cracking in ammonia plants M. E. D. Turner, United Kingdom of Great Britain and Northern Ireland
ID/WG.221/23	Corrosion control in ammonia plants V. S. Pillai, India
ID/WG.221/22	Corrosion problem in air separation plant A. S. Chatha, India
ID/WG.221/5	Safety and fire fighting in refineries and fertilizer plants S. Maruthappa, India
ID/WG.221/13	Safety consideration in the operation and maintenance of ammonia plants T. M. Das, India
ID/WG.221/28	Catalysts in ammonia industry T. S. Nagarjunan, India
ID/WG.221/18	Safety in the design and operation of ammonia plants G. R. James, W. Fox and K. J. Stokes, United States of America

Session III: Testing and control procedures and welding techniques

ID/WG.221/3	Steps to be taken during fabrication of equipment to ensure safe operation of ammonia plants K. S. Sarma, India
ID/WG.221/24	Testing and control of service deterioration in ammonia plants: pipelines and vessels K. C. Banerji, P. K. Ghosh, C. Aravindakshan and K. V. Sundaram, India

Session IV: Case histories

ID/WG.221/9	Explosion in urea fertilizer factory Ghorasal - a case history Aminul Huq and A. K. M. A. Matin, Bangladesh
ID/WG.221/17	Madras Fertilizer Ltd. - case history of an accident in the CO_2 removal system T. R. Visvanathan, India
ID/WG.221/1	Safety in the design considerations of ammonia plants, FACT experiences at Cochin and Udyogamandal plants S. Chidambaram, India

ID/WG.221/11	Report on a fire in the ammonia synthesis unit M. L. Seth, India
ID/WG.221/26	Coromandel fertilizers ammonia plant - a case study M. R. Krishniah, India
ID/WG.221/27	A case history of surge problems in process air centrifugal compressor at Indian Farmers Fertiliser Cooperative Limited, Kalol, (India) L. R. Talwar, India

Session V: General considerations

ID/WG.221/6	General aspects of safety in ammonia and urea plants and UNIDO's technical assistance to the fertilizer industry of developing countries UNIDO secretariat

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