Journal of Hazardous Materials, 12 (1985) 323—335
Elsevier Science Publishers B.V., Amsterdam — Printed in The Netherlands

Meeting Report

THE ASSESSMENT AND CONTROL OF MAJOR HAZARDS:

A REPORT ON EFCE EVENT NUMBER 322

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(Received May 17, 1985; accepted June 11, 1985)

Summary

This three-day meeting on Major Hazards was held at the University of Manchester Institute of Science & Technology (UMIST) on 22—24 April 1985, having been organised by the Institution of Chemical Engineers (North Western Branch) in association with the Safety and Reliability Society as Event No. 322 of the European Federation of Chemical Engineering. Approximately 200 participants attended, coming principally from European countries, but also from America, Australia and Japan. The mix of interests was wide, including representatives of regulatory bodies, the chemical, petrochemical and nuclear industries, researchers in universities, polytechnics and national laboratories, insurers, and numerous consulting engineers. Twenty six papers were presented, dividing into three main groups covering Integrity and Reliability of Plant, Consequence Assessment, and Risk Analysis and Case Studies. Full details are given in the reference list. With such a wide range of interests represented the papers and discussion were naturally of many different types, some reporting specific results of research, others more concerned with the practicalities of plant operation, and some providing a more general framework for discussion on the current position and what future directions should be sought. In the following sections the papers are briefly described in the groups of topics referred to above, and salient points are highlighted as they were perceived by this particular participant.

Integrity and reliability of plant

Barrell [1] started the meeting with a keynote paper reviewing the developments that had taken place in the decade since the Flixborough disaster, referring to the regulatory developments as well as to the contributions made to plant safety and to land use planning by the recent scientific advances in the field of major hazards in Europe. Although these developments were subtantial, the problems of major hazard control were still significant. The disasters of 1984 at Mexico City and Bhopal demonstrated the scale of the problem worldwide, although in the U.K. for example it seemed that the risk of such accidents was lower. Even so the social climate was one in which the benefits of technology were being questioned, with a preponderance of concern directed towards the possible consequences of accidents

0304-3894/85/$03.30

rather than on their probability of occurrence. Fear and worry were significant social consequences. Barrell emphasised the crucial importance of reasonable practicability in plant safety requirements, and the danger of making processes uneconomic.

Turning to the new Control of Industrial Major Accident Hazards (CIMAH) regulations, which implement the CEC directive in the U.K., Barrell referred to the new requirements concerning the preparation of safety cases, the preparation of on- and off-site emergency plans, the giving of information to the public, the notification of sites and the reporting of accidents. The existing notification regulations that came into effect just over two years ago had produced about 1750 notifiable installations. This had enabled the U.K. Health and Safety Executive (H.S.E.) to provide information to local planning authorities and to emergency services, and additional changes in planning law had established a statutory basis for the arrangements concerning consultation about developments on or near hazardous sites, which had previously been conducted on a less formal basis. The CIMAH regulations could be expected to involve about 250 large inventory sites and 1000 with smaller inventories in these new requirements.

The HSE's approach had changed in response to these developments, particularly as regards the use of consultation zones. These had originally been based on a blanket "cordon sanitaire" concept, but now there was a much more structured approach which considered the type of hazard, the type of development, the nature of the population at risk, and included some judgements as to relative probabilities of various types of event. This enabled the advice to be based more on the particular circumstances of each case. However, it was important to realise that these considerations were only some of the many aspects that had to be addressed by local authorities in making decisions on planning applications, and the responsibility for such decision-making lay with the local authorities. Barrell was of the view that no single target of acceptability could be established given this wide range of factors requiring judgement.

Thinking of the future, Barrell nominated a number of topics for research effort, namely consequence modelling (in which much had already been done, but where a few topics should now be emphasised), improved use of data bases for failure rates to determine probabilities, human vulnerability to harmful exposures, the influence of mitigating factors, and measures for avoidance and prevention. The problem of how to incorporate human factors in the overall assessment was one that was generally agreed to be important, but which as yet had attracted no agreed method as to how to treat the problem. The importance of hazard control by positive intervention and corrective action seemed considerable, and this suggested that training and the development of a deeper understanding of safety had much to contribute. Additionally, Barrell echoed the view expressed by the Advisory Committee on Major Hazards that we need to consider the risks not only of static installations, which have received much attention, but also those associated with the whole of the transport operation, including transit depots and loading/unloading sites, including major ports. Finally, Barrell judged that we needed no more legislation for a while, but that what we had to date was a sufficient basis for industry to use as a means of becoming positively and overtly involved in the risk debate, with the aims of lessening the probability of accidents, and fostering society's confidence.

The paper by Gregory [2] described current developments in computerised corrosion monitoring. Failures caused by corrosion were costly in terms of plant downtime, and had also caused some major fires, explosions and other releases. The current practice in corrosion monitoring was based on manual methods, which had serious disadvantages in that being very labour intensive they were limited in their effectiveness by the rather low frequency of inspection that was possible in practical terms on a big plant. The computerised system described in the paper was at a mid-stage of implementation, with a combination of manual and automated methods being used in the phased progression to a fully automated computerised scheme. The advantages expected were several, but principally the removal of the limitations of the manual scheme should result in a higher quality of plant-condition information being more readily and rapidly available to the plant operators, who it was thought would find this more useful than the traditional methods.

Fearnehough [3] described the risk control measures currently applied to the British Gas Corporation's network of gas transmission pipelines. The network is located in a country with many areas of high population density, yet the system has now logged over 200,000 km years with no major failures apart from one incident during commissioning, attributed to a construction fault. This safely record is believed to be due to the risk control scheme adopted, which consists of a set of design and operational recommendations drawn up by the Institution of Gas Engineers. The scheme involves a two-level set of limits to operating conditions whereby pipelines in rural (R) areas may be operated at higher stress levels than those in suburban (S) areas. The R and S categories are based on a population density criterion of less than 2.5 persons per hectare for R, and greater than that for S. The stress levels are chosen to ensure a low probability of failures involving rupture in S category pipelines, leaving punctures and pinhole leaks as the most likely failure mode. Additional guidelines on permitted proximity of pipelines to property, in terms of the thermal radiation flux and consideration of the importance of wall thickness, are applied. The argument was then developed to give an estimate of the annual individual risk of death due to pipeline failures. Using simple assumptions the result given was 2×10^{-7} per year for a rural area, and 3.6×10^{-7} per year in a suburban area, the latter figure being for a pipeline of wall thickness less than 9.5 mm. Corresponding societal risk estimates were produced and point estimates of 10^{-2} per year for 5 deaths and 10^{-3} per year for 88 deaths were incorporated into a frequency—consequence graph drawn from the 1983 Royal Society report on Risk Assessment, where they fell at a level comparable with risk estimates for transport systems.

The next paper, by Braithwaite [4], described the British Gas Corporation's method of operational pipeline inspection. The network contains about 17,000 km of high pressure pipeline of several different standard diameters. In-service hydrostatic testing would cost about £600 million to make feasible, due to the necessity of duplicating and reinforcing the network to enable supplies to be maintained. The requirement therefore was to devise a method that would detect and locate all significant defects, determine the defect size, distinguish between true defects, spurious signals and unimportant features, whilst not interfering significantly with pipeline operations. The solution developed by the corporation consists of a system of pipeline inspection devices (known as PIGs) using magnetic flux leakage as the detection method. These devices are inserted into the pipeline and are driven along at a speed of about 3 m/sec by the gas pressure. The system is self-contained, and a vehicle package includes the detection system with on-board data logging and power supplies. The system as a whole also makes use of geometric measurements and ultrasonic testing. The data system utilises a specially developed 42 track tape recorder controlled by an on-board microcomputer which temporarily stores the data before consigning it to the tape, thus enabling considerable economy of tape use where the pipe is free of defects. The data analysis technique permits defects to be graphically reconstructed for production of reports to the pipeline operators. The inspection system is deployed according to a strategy for determining maximum intervals between inspections. This is based on a weighting system that takes into acount the probability of occurrence of external interference, corrosion rates, ground movement, age and construction standard of pipeline, operating stress and population density of people who might be at risk, and security of supply. The three grades of priority thus established result in maximum intervals of 2, 6 or 10 years. So far about 6,000 km have been inspected, and the current rate of inspection is about 800 km/year. The development costs were about £60 million. This paper gave a very impressive account of a successful engineering response to produce a system that would operate within severe constraints, and in a difficult environment.

Hunt and Ramskill [5] gave details of a computer code that had been developed to model the behaviour of tanks containing liquid and engulfed in fire. The model was based on a simple description of the tank as a cuboid, and made use of empirical heat transfer correlations from flat-plate experiments. The model assumed a uniform temperature distribution in the liquid, and losses via a pressure relief valve (PRV) that would be either fully closed or fully open. There was no allowance for liquid phase loss through the PRV. Predictions of the code were compared with experimental data obtained in field tests on LPG tanks reported in the following paper by Moodie et al. [6]. Although the agreement was overall quite good, it was recognised that the model could be improved by allowing for such additional factors as water spray cooling, partial engulfment, the effect of outer wall insulation material, other geometries, and the behaviour of the PRV, particularly where liquid is included in the release.

Moodie et al. [6] reported field experiments on fully fire-engulfed uninsulated LPG tanks of 1/4 and 1 tonne capacity. The fires were set in a bund and were of kerosene. The tanks were instrumented for temperature and pressure, and the conditions were such that the PRV opened at about 50°C superheat. Five tests were conducted, three on the 1 tonne tank and two on the 1/4 tonne. The second 1/4 tonne test resulted in a catastrophic failure due to the PRV failing to close. The other tests resulted in the fire terminating without serious damage, the LPG being progressively boiled off with multiple activations of the PRV. The PRVs were fitted with 1 m flare pipes, and the ignited flame from the PRV appeared to give no enhancement in terms of additional ventilation of the engulfing fire, or of back-radiation to the tank. The PRV behaviour was evidently quite complicated, with evidence of liquid droplet carry-over in the first discharge, even in the test with an initial filling of only 20% of the tank capacity. Further tests with a 5 tonne tank are to be carried out.

Smith [7] reviewed the possibility of cold whole-vessel failure in terms of concepts of fracture mechanics applied to LPG tanks. The three approaches selected were the Stress Concentration Theory, the Linear Elastic and Elastic—Plastic Fracture Mechanics guide to the sizing of tolerable flaws incorporated in the BSI document PD6493, and Crack Opening Displacement measurements. The author emphasised the importance of stress relief measures as a means of ensuring that leak-before-break failures would dominate. However, local chilling could defeat this objective. Acknowledging that the different approaches yielded very different results for the number of cycles required to lengthen a defect from one to two wall thicknesses, Smith nevertheless concluded that the number of full stress range cycles seen by a tank in practice is not sufficient to make fatigue a significant failure mode. More measured data would be of great value.

This presentation prompted a lengthy response from representatives of the LPGITA and BP International, who took the view that the Stress Concentration Theory approach was outmoded, having been displaced by the Crack Tip Stress Intensity Method. They also emphasised their view that LPG vessels are conventional, and that LPG was a benign substance as far as its importance in fracture mechanics was concerned.

The paper by Trbojevic and Maini [8] was concerned with a numerical fluid mechanics solution scheme to the problem of estimating the loadings on the outer wall of a large double-walled refrigerated liquid gas tank following failure of the inner wall. Two cases were treated, one essentially involving the rapid failure of the entire inner wall, and the second allowing for a failure of only part of it, so that the problem is three-dimensional rather than axisymmetric. The solution scheme employed a finite difference method with additional features to treat discontinuities and boundary deformation. The axisymmetric case could be treated with more confidence because of the coarseness of the mesh that was used for the 3-D case. Further work was needed in order to assess the usefulness of this method for design purposes, particularly in terms of validation and comparison with field tests.

Consequence assessment

Havens [9] gave an up to date review of work on modelling of dense gas dispersion, also presenting results of experiments conducted at laboratory scale to investigate the initial buoyancy driven flow and air-entrainment behaviour in zero wind conditions. This work had been conducted in order to provide the U.S. Coast Guard with a well validated model for use in connection with their hazard assessment work. Havens reported the development of a new model called DEGADIS, which was a synthesis of the best features of 18 other models that had been reviewed, with an additional sub-model to describe the initial behaviour. The program was adapted from the HEGADAS model of Colenbrander, and could treat continuous or transient releases. The model allowed for heat transfer to the cloud and enhanced vertical mixing due to unstable temperature gradients resulting from such heating. Havens drew upon experiments at field scale, including the Shell Maplin Sands tests, the China Lake Burro tests and the Thorney Island tests, to test DEGADIS against a variety of types of release. The agreement in respect of concentration versus distance was surprisingly close. Comparisons were made with a large number of tests in relation to the distance to the UFL, LFL, and LFL/2 levels, and these showed agreement between data and prediction to no worse than a factor of 1.8, and mostly much better, with a slight tendency for the model to overpredict the distance. The conclusion was that for flat unobstructed terrain this model was adequate in the case of prediction for flammable gases, with little room for improvement. However, Havens recommended that further validation was needed for the air-entrainment models and for vertical mixing rates for non-isothermal flows, and cautioned that field experiments give little idea of the variability to be expected in an ensemble. Complicating factors, such as terrain features and obstacles, and aerosol formation, still needed to be treated, and the confidence applying to the prediction of LFL levels for flammable release could not be simply transferred to the problem of toxic releases.

Barrell and McQuaid [10] reviewed the wideranging programme of research and development engaged in by the HSE, covering experiments in wind tunnels and at field scale, the development and validation of models both physical and mathematical, and related work such as hazard range reduction by the use of water spray curtains. McQuaid largely agreed with

Havens' remarks on the current position, but emphasised the importance of relating concentration predictions to travel time rather than distance. Future needs included improved understanding of the effect of source conditions, and matching them with the dispersion modelling, the time dependency of source behaviour, non-isothermal releases, the use of physical modelling, co-ordination of data analysis, and the specification of meteorological conditions.

Bridges [11] brought the toxicologist's approach to bear upon the problem of how to assess toxic hazards for the great variety of materials that are of significance in this context, which display a very wide range of types of toxic effect. He emphasised the importance of considering the intrinsic toxicity of the material alongside such factors as the exposure conditions, species variation, and the route of exposure (inhalation, ingestion, via the skin and so forth). He drew attention to comparisons made between some 25 classification schemes for toxicity and showed that the consistency of such intercomparisons was poor. On the use of the LD_{50} as an indicator of toxicity, Bridges was particularly critical, pointing out that the ratio between the minimum lethal dose and the LD_{50} varied widely between substances, so that two substances with the same LD_{50} could be assessed very differently on the basis of the minimum lethal dose. Other effects were also important, such as irritancy, narcosis, mutagenicity and carcinogenicity. On the problem of extrapolating animal test data to man, he pointed out that not only were there problems in estimating equivalence in lethal doses, but that the cause of death was known to differ between species for the same substance. He identified factors that need to be taken into account in assessing a toxicity rating for human exposures, and underlined the need for a more developed approach to this problem than has been applied to date.

Lynskey [12] described the practical problems encountered in developing an effective emergency plan for a site with toxic hazards. His company had an in-house training scheme designed to develop awareness and preparedness for emergency response. He stressed the importance of practice and simulation exercises for management and workers, and cited a number of lessons that had been learned, such as the need to make the key personnel readily recognisable so that everyone, particularly the police, fire and medical teams from outside, could spot them quickly. Lynskey emphasised the need for advance planning in the development of emergency response, and was of the view that it was unlikely that the full requirements concerning off-site plans under the CIMAH regulations would be achieved by the deadline of October 1985.

Catlin [13] presented a comparison between predictions of a model of the overpressure field due to the deflagration of a point-ignited flat vapour cloud of small height-to-base ratio, and results from small scale experiments on centrally-ignited flat circular clouds. The model was based on the acoustic approximation that all pressure waves travel at the same speed. Model parameters that were varied included the aspect ratio, the shape of the cloud (ellipse, circle) and the position of the ignition. The comparison of predicted overpressures with results from laboratory scale tests was very good. Some important conclusions were drawn from this work. First, far-field overpressures for interior ignition of a flat cloud are dominated by overpressures attributed to the hemispherical phase of combustion, and for a given vapour and burning velocity that implies that the far-field overpressure is determined by the height of the cloud above the ignition point, and is not related to the total volume of vapour in the cloud. Second, the overpressures for an edge-ignited cloud are significantly less than for interior ignition. Catlin was of the view that there were no severe problems of scaling involved in applying this model to full-scale vapour clouds.

Holden and Reeves [14] gave an interesting detailed analysis of the missile hazards experienced in liquefied gas pressure vessel failures, mainly for LPG tanks in BLEVEs. In such circumstances failure was usually due to thinning of the vapour-space wall at temperatures above about 500°C. Their analysis was based on a detailed examination of accidents involving LPG, vinyl chloride monomer, ethylene oxide, and ammonia, and included failures other than in fires. The main conclusions drawn were as follows. For cylindrical vessels the probability of fragment projection was 0.8 once a major fire was established. For fire events no more than 4 fragments were projected, whilst for non-fire events the largest number recorded was 7. End-tubs tend to travel further than other sections, and display a preferential axial distribution. Smaller vessels tend to project fragments further than larger ones. As a rough guideline about 80% of fragments travel less than 200 m, the remainder travelling up to about 1 km. Spherical vessels tend to produce a greater number of fragments, with bigger vessels producing more than smaller ones, 19 fragments being the largest number recorded in the sample. Case histories show that there is a substantial risk of damage to other plant items from impacting fragments.

Muir-Wood [15] gave a presentation illustrating the value of reconstructing earthquake characteristics from contemporary accounts dating back to 660 AD. He pointed out that earthquake hazards have a remarkably patchy distribution, some parts of the U.K. having been earthquake-free for the last 700 years. However, there were evidently a larger number of areas which were attractive as petrochemicals sites because of the conjunction of flat land and deep water, and on which plants had been built, but which were also high risk sites for earthquakes. Numerous examples, particularly in the Mediterranean area, were given. Muir-Wood urged that other industries follow the example of the U.K. nuclear industry in assessing earthquake risks in the process of site selection.

The work of Brown and Nolan [16] involved exposing stainless steel models of tall cylindrical structures at 1/40 scale to blast overpressures generated in an instrumented explosion gallery. The shock front had an average speed of 470 m/s, and a duration of 1/8 s. Three classes of damage were observed, large buckling of greater than 85°, small plastic deformations of less than 5°, and small elastic deformations. The results were consistent with the approach developed by Roberts for the Flixborough investigation, and with the mode summation technique for elastic deformations. It was suggested that current blast damage correlation methods need improvement.

Bradley and Nolan [17] described an interactive computer program designed to optimise plant layout for safety and land use. The essence of the program is a comprehensive evaluation scheme for estimating the probability of failures of plant items, and the probabilistic treatment of consequences in terms of interaction leading to further failures, and other detriments. The scheme permits the incorporation of preventive and protective measures, and the optimisation is in terms of minimum land use and maximum safety. The authors acknowledged the limitations of the method, particularly in terms of the non-availability of relevant data on such factors as the probability of failure. This situation has probably not altered much since this work was started in 1978. Clearly the optimisation will be dependent on the influence of uncertainties such as those associated with estimating hazard range for a particular set of failures. The scheme had value in identifying weaknesses in knowledge of the characteristics of various hazards.

Risk analysis and case studies

Holden [18] presented a review of the development of risk assessment for process plant over the last two decades, referring to the emergence of tools such as HAZOP and Event and Fault Tree analysis in the 1960s and 1970s. He noted that the application of probabilistic risk assessment, whilst not required in any regulatory schemes in the U.K., had nonetheless become part of the received practice in producing safety cases, as exemplified in the Sizewell B Inquiry, and the series of Canvey Island inquiries. Holden pointed to benefits that could arguably be attributed to the application of these techniques, quoting the reduction of process based risks in chemical plant as evidence. He cautioned against a too rigid use of PRA, which could inhibit the introduction of safety improvements. For example, undue emphasis on low probability/high consequence events would be counter-productive if the other parts of the risk spectrum were underplayed as a result. However, even given the uncertainties in quantification, the methods were proving their use in siting, layout and emergency plans, and the specification of trip system performance requirements. He concluded that criteria for acceptance could not be based solely on risk considerations, and that quantitative methods were best used where they aided understanding of the risks.

Helsby and White [19] tackled the difficult problem of proposing quantitative criteria for risks to workers, individual members of the public and the population at large exposed to the risk of chemical plant accidents. The starting point on which they based their proposals was the adoption of a value of the Fatal Accident Rate as currently manifested for process plant workers of about 2 deaths per 100 million man-hours for the special hazards, i.e. excluding the common accidents which occur in most plants due to causes not specific to the particular plant. Using this as a means of estimating the frequency of occurrence of accidents that might also affect the public, they derived criteria in terms of the familiar measures of individual and societal risk. Their approach attracted criticism on a number of points, but particularly in respect of the lack of any inherent factor to improve on past experience in developing the criteria, and a number of allegedly optimistic features of the strategy.

The review by Davies [20] covered much the same ground as that by Holden [18] in referring to the various techniques available for the identification of hazards and their quantitative assessment. He emphasised the crucial importance of properly categorised data on failure probabilities, and concluded that lack of such data, or uncertainty as to its applicability constitued major limitations on the use of quantitative methods.

The paper by Whitehouse [21] gave an insight into the way the Insurance Technical Bureau has responded to the need to assess the expected average loss from fire and explosion for plant handling flammable materials, a field in which the historical data are not sufficient to give a reliable picture for insurance purposes. One aspect of the scheme described consists of a conventional synthesis of the steps and their probabilities of occurrence and consequential effects, much as considered by Bradley and Nolan [17]. However, coupled with this is a scheme of assessment of management quality, based on the response to a questionnaire designed using the results of psychological research. The questionnaire is used to assess whether the particular management is above or below average. The author did not present details of this part of the scheme, but clearly this is an important issue, since most people are agreed that management quality has a major part to play in risk control, as emphasised by Barrell [1]. As to the validation of this scheme, Whitehouse concluded that experience in the field would show whether changes would be needed.

Human factors was the subject of a review by Watson [22], who discussed the existing framework of understanding based on the work of various approaches in psychology, ergonomics and engineering. He emphasised the existence of a crisis that had been reached, in that there was no clear agreement as to what are the fundamental issues to be addressed, and what should be the priorities in the development of the subject. Underlying this difficulty was the lack of any robust scientific understanding of mental processes. However, it was clear that most people in the field agreed that good management, operation and maintenance had a large positive contribution to make to safety, and there was a need to explore systematically the basis for this conviction so that it could be exploited more fully.

Williams and Willey [23] reported the results of an investigation which aimed to quantify the incidence of human error in a practical situation. The study had been undertaken by a painstaking process of checking the work of a large group of apprentices in training schools who had to perform set tasks in milling, welding, electrical installation, wiring and multimeter construction, and design draughting. Various measures of error incidence were devised according to the nature of the task. Although much has yet to be done in terms of validation and the framing of a model of error production, a number of important overall points emerged. First, there seems to be a practical limit to the degree of improvement achievable by long experience, but that up to that point a 10-fold increase in experience reduces the error rate by a factor of about three. Second, experienced maintenance staff are about 8—20 times less error producing than apprentices learning their trade. The method seemed to hold much promise of yielding results of practical use in risk assessment.

Pape and Nussey [24] described the use of the HSE's in-house methods for the quantitative assessment of risk in support of their advice to local authorities and other requirements where quantification has a role to play. The approach involves a full description of risk in terms of probability of occurrence and consequence magnitude for a spectrum of accident categories, and is implemented in a computer program that enables specific sensitivity analysis to be explored. The output includes individual risk contours and societal risk curves. The use of the program was illustrated for the case of a hypothetical chlorine plant. The authors emphasised their acknowledgement of the numerous uncertainties involved, but, like many other authors, endorsed the use of such quantitative methods for such purposes as examining various options and the sensitivity of the results to different assumptions. By way of illustrating this point they concluded that in their model there was little sensitivity to the likelihood of being outdoors, or the slope of the concentration versus duration curve for toxic response, but the results were more sensitive to building air-change rates and the absolute position of the C vs. t curve for chlorine.

The question of chlorine toxicity arose again in the paper by Harris and Roodbol [25] who reported the results of a study on the risks involved in rail transport in the Rijnmond area. A significant feature of the analysis was the use of a toxic response relationship for chlorine that is significantly different from that used in the well known Eisenberg vulnerability model.

The final paper by Vaija et al. [26] dealt with the development of an expert system for accident analysis utilizing fuzzy mathematics. The authors believed that this approach offered considerable scope for predicting accident consequences. It was clear that this was a method that had not been widely considered previously in this context, and there was considerable scope for further examination of its utility for risk assessment of hazardous installations.

Conclusion

The single most important message that was understood by this participant at the meeting was that quantification of risk had matured considerably. Although many difficult problems remained to be tackled, they were recognised, and the necessary approaches were emerging to various degrees. In spite of the uncertainties, quantification had made important contributions in many ways, and could be expected to continue to do so provided there was a willingness amongst the many interest groups involved to tackle the problems in an open and constructive way. The meeting gave encouragement that such a willingness does exist.

References

The papers presented at the meeting are listed below in the order that they appear in the preprint publication, I.Chem.E. Symposium Series No. 93, ISBN-0-85295-189-2, Institution of Chemical Engineers, Rugby, Warwickshire, England, and distributed by Pergamon Press Ltd. The text of the paper by Bridges was not included in the preprints, but was distributed at the meeting.

1 A.C. Barrell, Developments in the control of major hazards.
2 R.W. Gregory, Computerised corrosion monitoring steps towards preventing unexpected corrosion failures.
3 G.D. Fearnehough, The control of risk in gas transmission pipelines.
4 J.C. Braithwaite, Operational pipeline inspection.
5 D.L.M. Hunt and P.K. Ramskill, The behaviour of tanks engulfed in fire — The development of a computer program.
6 K. Moodie, K. Billinge and D.P. Cutler, The fire engulfment of LPG storage tanks.
7 T.A. Smith, An analysis of a 100 te storage vessel.
8 V.M. Trbojevic and Y.N.T. Maini, An approach to the assessment of double containment RLG storage tanks under abnormal liquid loads.
9 J.A. Havens, The atmospheric dispersion of heavy gases: An update.
10 A.C. Barrell and J. McQuaid, The HSE programme of research and model development on heavy gas dispersion.
11 J.W. Bridges, The assessment of toxic hazards.
12 P.J. Lynksey, The development of an effective emergency procedure for a toxic hazard site.
13 C.A. Catlin, An acoustic model for predicting the overpressures caused by the deflagration of a ground lying vapour cloud.
14 P.L. Holden and A.B. Reeves, Fragment hazards from failures of pressurised liquefied gas vessels.
15 R. Muir-Wood, Problems of seismic hazard at British and Mediterranean petro-chemical installations.
16 D.M. Brown and P.F. Nolan, The effect of external blast on cylindrical structures.
17 C.W.J. Bradley and P.F. Nolan, Criteria for plant separation distances and location.
18 P.L. Holden, Developments in risk assessment and its applications in process plant safety studies.

19 G.H. Helsby and R.F. White, Criteria for use in the assessment and control of major hazards.
20 K.R. Davies, Techniques for the identification and assessment of major accident hazards.
21 H.B. Whitehouse, IFAL — A new risk analysis tool.
22 I.A. Watson, Review of human factors in reliability and risk assessment.
23 J.C. Williams, Quantification of human error in maintenance for process plant probabilistic risk assessment.
24 R.P. Pape and C. Nussey, A basic approach for the analysis of risks from major toxic hazards.
25 N.C. Harris and H.G. Roodbol, A risk assessment model applied to transportation problems.
26 P. Vaija, M. Jarvelainen and M. Dohnal, Fuzzy based expert system for analysis of accidents.