DISCUSSION AND WRITTEN CONTRIBUTIONS

NOTES

1. Q/C means question or comment
2. R/A means response or answer by presenter
3. Separate points made by the same speaker prefixed (a), (b) etc.
4. Name of author(s) actually presenting paper underlined - normally the respondent - second author named where appropriate
5. Chairman given after session number

SESSION 1 (A.M. Chairman: J.H. Burgoyne)

PAPER 1 (J.H. Burgoyne)

Reflections on Process Safety

Q/C **(D. Napier)** Agrees with author's views on education/training. At Univ. Toronto have an Occupational Health & Safety programme for Master's degree, mainly part-time students. In Canada full-time courses exist in Community Colleges (like British Polytechnics). Would you distinguish between undergraduate and postgraduate courses?

R/A At undergraduate level, awareness rather than specialisation is needed - the scope being the same - which I include in undergraduate courses. Undergraduate and postgraduate courses will cover similar ground to different depths.

Q/C **(K.W. Palmer)** Legislative requirements can be too restrictive in methodology. Two methods of resisting this were described. A third way is for engineers to keep ahead of universally accepted basic requirements which move slowly. I'm concerned that we should not see out-of-date mandatory requirements. The non-mandatory guidance notes can be and are updated more frequently - thus recommend this approach.

Q/C **(M.C. Jones)** When presenting fundamental information as a basis for training to post-experience people, resistance is often encountered - is this true of safety training?

R/A Yes indeed - much resistance does arise. However when given at post-graduate level, the need for fundamentals becomes accepted in post-experience training.

Q/C **(R.C. Gray)** (a) There is a need for all engineering institutions to insist on basic safety training - some are not doing. Can I.Chem.E. do something about this? Recently the Technical Affairs Board produced guidelines that oculd be taken into account. Professional engineers should observe their code of conduct (comparable to the Hippocratic Oath) and though everything they do involves risk, all that is reasonably practicable should be done to ensure safety. (b) The preparation of operating, maintenance and emergency response instructions demands a highest level of responsibility - particularly to see that the operator understands what you have designed and constructed.

R/A Firstly, agree entirely with this. Secondly, I.Chem.E. have been very much involved in this area and are in a position to talk to other senior institutions - perhaps a tactful way can be found.

Q/C **(D. Napier)** Talking of Master's or other specialised Safety Courses, what primary disciplines are required in first degrees and would all candidates reuqire to be just brought "up to scratch" in basics?

R/A Basis could be fairly broad - containing essential principles of science and engineering. Maybe one should provide a unifying preliminary course in addition - very difficult to generalise without looking at cases but one to be faced.

PAPER 2 (M.R. Marshall and F. Stewart-Darling)
Bouyancy Driven Natural Ventilation of Closed Spaces

Q/C **(J. Burgoyne)** Could the same principles be applied to the ventilation of heavier-than-air gases? Would be model apply?

R/A Yes except that for larger pipes being required because of lower explosion limit of dense gases. Ventilate to a lower concentration -potential problem is pipe size. For example, for leak rates of 10-20 ft^3/h down to 25% L.E.L. may require 6 inch pipes - the larger tanks would rquire 12-15 inch pipes.

Q/C **(D.H. Napier)** (a) What are effects of temperature - particularly important in situations where ambient temperature is very low (eg. Canada). The temp. differential can be affected by cold "pits" and warming up of them in early spring.

R/A No, the model did not take temp. into account but we made some observations. With some reservations, I think that the calculations would stand.

Q/C **(A. Jones)** What is the reason for, and effects of, the chimneys and what happens if the inlet pipe is heated (by the sun) more than the outlet?

R/A The pipes are not necessary except for protection for and from persons. It seems unlikely that one pipe would in fact be heated more than the other.

Q/C **(R.C. Santon)** Results were quoted for quite high gas concentrations (say 20%). Can they be entrapolated down to low concentrations?

R/A Yes, tests were done with low leak rates when concentrations were reduced to 20% of L.E.L. thus covering a wide range.

Q/C **(G. Artingstall)** Two pipes are not required. In earlier work buoyancy-driven flows were described. With inclined pipes two layers -one upflow and one outflow were observed and unstable flow with one vertical pipe was this observed in present work?

R/A No, not when the flow was stable. We did get flow reversal with very high gas release rates and with very windly conditions.

(Chairman) Paper referred to is complementary and was published in an earlier Process Hazards Symposium.

Q/C **(D.A. Lihou)** (a) In going from equation (7) to (8) the factor (1-S) seems to have been omitted? (b) Were the experiments to test equation (9) which is for 25% L.E.L.

R/A (a) Gas density was 0.6 hence (1-S) = 0.4 which appears as a numerical constant in (9). (b) We were testing equation (8) for a whole range of gas leak rates, pipe lengths and diameters.

Q/C **(A. Mjaavatten)** What is the basis for choice of release rates for design - published standards are not much help?

R/A Glad to have point about standards raised - very few standards state what the ventilation is designed to cope with. The 10-20 c.f.h. are typical of those found in the type of installation considered - it can easily be 20-30 c.f.m.

PAPER 3 (K.N. Palmer and P.F. Thorne)
Estimating the Hazard Round a Vent

Q/C **(D. Napier)** (a) When liquids are present, would droplets be emitted? (b) If ignition occurs, what sort of flame would it form?

R/A (b) is a hypothetical question - no practical experience since refuelling indoors only recently became fashionable. In such an event fuel pumping could not stop instantaneously and flame propagation could ensue. Regarding (a), some liquid is carried over but not enough to cause a pool - not taken account of in momentum jet and unlikely to sustain a fire.

Q/C **(R.E. Evans)** Would it not be better to instal local mechanical ventilation system to extract and remove vapour?

R/A Extra work connecting it would not be popular with the military because in an emergency planes have to be turned round in about 15 minutes -with many functions in parallel. Millions of pounds have been saved by elimination of specialist electrical equipment and for other simplifications following this laboroatry investigation.

Q/C **(N. Maddison)** What is the effect of vapour being cooled in very cold weather - risk of condensation?

R/A The hangars are heated in very cold weather - above freezing point. This probably helps the situation.

Q/C **(R.B. Thorpe)** Is there a risk of a flame going back into the aircraft tank and wold it be better to fit an arrester?

R/A Fuel pumping rate is such that air-vapour velocity is too high for a flash-back. There is an extremely short interval when the pump is stopped and there could be some risk depending upon the flash point of the fuel. However, rapid closure of valves is another safety factor.

(Chairman) In case of a flame on vent, probably better to extinguish flame first, then stop fuel flow.

Q/C **(F. Roper)** For the case of dilution of a small diameter turbulent round jet, as the velocity increases: (i) residence time to a given distance decreases, (ii) turbulent diffusion rate decreases. The two effects balance so the distance to a given dilution is independent of flowrate (provided velocities are high enough for turbulent flow).

SESSION 1 (P.M. Chairman: D.A. Lihou)

PAPER 4 (R. Fearon and J.H. Burgoyne)

The Flash-back Hazard in Stacks Discharging Flammable Gases

Q/C **(G.A. Whyte)** How important is the plate thickness?

R/A One would not require a very thin plate because there is an entry and outlet effect - would recommend a minimum thickness equal to hole diameter. J.H. Burgoyne would say 2-3 times diameter and/or 'flare' the inlet to avoid separation at sharp edge.

Q/C **(M.C. Jones)** Re Figure 1, what was tube diameter - needed to convert total volumetric rate to velocity.

R/A You need to have number of holes and diameter. There is a specification for pure hydrogen containing sufficient information for calculation - and gave reassurance that the method is satisfactory because we never fell below require velocity.

Q/C **(R.L. Rogers)** In non-flared vents for H_2, inert dilution is used rather than flame arresters - but expensive. Could savings be effected by using the perforated plant concept?

R/A H_2 disperses in the atmosphere extremely rapidly and there should be no need for prior dilution provided no air can get into the stream before the outlet. Ignition would start a flame at the outlet that may or may not be tolerable.

Referring to hydrogen admixed with N_2 in the generating process, what is the situation?

Yes, the perforated plate would be suitable for impure H_2.

(Chairman) The basic idea is to subdivide the stream by an increasing number of smaller holes.

Q/C **(R.F. Evans)** Can you get flash-back owing to reversed flow?

R/A The combination of dilution and use of a perforated plate ensures that there is no risk of flash-back whatever the velocity and regardless of how air is drawn in - calculations based on worse case, i.e. stoichiometric ratio. Using a fixed diluent flow, as the hydrogen (or other gas) increases, the velocity is increased thereby counteracting the effect of less diluent on flash-back velocity.

PAPER 5 (H. Phillips and D.K. Pritchard)
Performance Requirements of Flame Arresters in Practical Situations

Q/C **(D. Napier)** (a) We seem to be a long way from having standards for arresters - are they attainable? (b) From the list is it possible to select for stopping detonations?

R/A (a) Much effort will be needed because of the wide range of types and applications but standard should be attainable.

Q/C In the meantime shall we have to test piece by piece?

R/A Yes, especially where there are commplex volumes upstream and downstream *- affect performance. Re (b), each configuration* must be tested for particular detonation - tendency to test for stable detonation which may not apply. There's also a tendency to go for shorter pipes whereas for a stable detonation, longer pipes are needed.

Q/C **(A.D. Craven)** A further pitfall regarding overdriven detonation is that weak mixtures were more prone to overdrive than are stoichiometric.

R/A This adds another parameter making the testing more difficult.

(Chairman) If you test for certain situations, arrester would work for less demanding cases.

R/A Can predict performance for such cases but flame speeds, pressures are not freely available for comparison.

PAPER 6 (N GIBSON, N MADDISON, J S ROUSLEY and P S N STOKES)

Assessment of Dust Explosion Hazards: Effect of Changes in the Test Methods and Criteria

The following two written contributions were presented:

(A) A. Mitcheson and A D Craven, Burgoyne Consultants Ltd

The Problems of Assessing Marginal Dusts

1. Introduction

For over three decades, members of this practice have been consulted on a variety of matters relating to catastrophic combustion phenomena, including the evaluation of the hazards of dust explosions, and the protection of plant and equipment from such hazards. In regard to this, there has been an unprecedented upsurge in the amount of information and advice published in the literature in the form of text books, guidelines and Codes of Practice which are intended to remove some of the mystery from the subject for the plant operator. However, we have continually been consulted on the matter and we have found increasingly that advice is sought on the meaning of test data and their interpretation within the published guidelines. In particular, a recurring problem which we have identified concerns the treatment of materials which we have here termed marginal dusts, that is, dusts which are borderline between the traditional A (explosible) and B classifications. The problem concerns the criteria adopted to define "explosible". Obviously, the correct interpretation of the test observations is vital to the plant operator: he neither wants to incur costs of installing unnecessary protection measures, nor does he want to risk a potentially catastrophic explosion in his unprotected equipment.

Furthermore, the same criteria are used to determine the minimum explosible concentrations of materials. Since it is practical to operate a plant "safely" provided that the dust concentration is at all times significantly less than that required to support explosive flame propagation, it is essential that the values of minimum explosible concentration chosen are reliable. These, of course, depend on the criteria of "explosible" used to evaluate results from the standard tests.

Two standard test apparatus are widely used, viz. the vertical tube and the 20 litre sphere. Our experience with these has revealed anomalies with both of them, either in terms of the subjective assessment of *observations, or in the precise interpretation of the parameters* measured. In this note we discuss some of the problems we have encountered with both test apparatus.

2. Marginal Dusts in the Vertical Tube

We were recently consulted by a prominent brewer who handled grain in four basic conditions. In the receiving section of the brewery grain from road tankers was taken by bucket elevator and then transferred by belt conveyor to any of a number of concrete silos, into which the grain was allowed to fall freely under gravity. On further examination, we found that the beam from a flash light could be seen clearly through the discharging stream down to the bottom of the silo, some 80' below. Intuitively, it was felt that the concentration of the dust in air was well below that required to support explosive flame propagation, and so there was probably no primary explosion hazard with this section of the plant. To confirm this, this discharging stream was sampled under a variety of conditions, and the maximum dust concentrations thereby measured ranged between 0.7 mg/litre to 2.3 mg/litre (or oz/1000 cu.ft.) depending on the type of grain.

From thermochemical considerations, it is possible to calculate an approximate flame temperature which will be produced by given reactants which are in given proportions. By postulating limits of flammability in terms of minimum flame temperatures, it is therefore possible to work backwards and estimte the corresponding concentrations of the reactants. For the majority of organic gases and dusts at ambient temperature in air, the LEL thus defined is typically between 40 and 50 mg/litre. This compares very well with the published values of gases, Reference 1, and those obtained by the U.S. Bureau of Mines for dusts in the vertical tube apparatus, References 2-7. In the context of the process under consideration, the literature values of the LEL of malt barley and maize grits are 55 mg/litre and 45 mg/litre, respectively, and so the maximum measured concentration of 2.3 mg/litre is seen to be only one twentieth of the minimum explosible concentration, thus confirming our initial conclusions.

However, Field, in Reference 7, quotes a value of 9 mg/litre for "brewer's grain". On this basis the margin is greatly reduced and serious consideration would have to be given to implementing explosion protection measures.

Reference 2 contains test data obtained from 220 dusts of agricultural origin of which only seven had lower limits below 40 mg/litre. None of these were cereal dusts. In fact, the two lowest values at 25 mg/litre were lycopodium powder and a chemical derivative of starch, and there was nothing as low as 9 mg/litre.

The experiments carried out on "brewer's grain" are reported in more detail by Monica M. Raftery in Reference 8, who carried out the tests at FRS. A comparison of the results of this work with similar tests carried out at U.S. Bureau of Mines (References 2-3) is interesting because it reveals an almost consistent difference between the two: the

FRS results are often about one third of the U.S. Bureau of Mines results, as indicated in a few examples in Table 1.

Both these testing stations used the same vertical tube apparatus although the U.S. Bureau of Mines refer to it as the Hartmann Apparatus. Both used the equipment in the same manner by placing a powder sample in the dispersion cup and blowing up a cloud into the tube with air whilst a continuous stream of electric sparks passed between the electrodes. The difference between the results quoted by the two laboratories arises directly from the criterion of explosibility. On the one hand, the FRS criterion is based on the sighting of any flame in the vicinity of the electrodes, no matter how shortlived or even whether it propagated away from the ignition source to any extent. On the other hand, the U.S. Bureau of Mines took a more pragmatic approach and, accepting that the mere prescence of flame did not necessarily represent an explosion hazard, they sought verification of a propagating flame. Their criterion of explosibility was that flame should either fill the test vessel, or generate a pressure which was sufficient to rupture a filter paper diaphragm used to seal the top of the tube.

The FRS criterion has been adopted in this country to differentiate between Group A (explosible) and Group B materials. In the case of materials submitted to FRS a subjective assessment of flammmability behaviour is made. Materials may be described as "very weak" in which case a flame is sighted in the vicinity of the electrode, but hardly propagates away from the source, or "weak" in which case the flame is seen to travel one or two inches before dying out. Flame propagation described as "very weak" qualifies the material as being explosible, Gorup A.

3. Marginal Dusts in the 20 litre Sphere

By way of another example, we were recently approached by a tissue paper manufacturer who had been made aware of a possible explosion hazard involving the paper fly inevitably thrown off the product during manufacture. The potential of flash fires is well known in the industry, but the possibility of an explosion hazard was not one that had been considered by that particular manufacturer and, moreover, I know of no authenticated incidents where an explosion of tissue paper dust had occurred.

Samples of the dust were collected and tested at FRS. The material was subjected to the standard explosibility tests and was classified as Group A, explosible, but exhibiting weak flame propagation. The material, therefore, posed a prima facie explosion risk and so the relevant explosion parameters were determined in the 20 litre sphere. The results obtained from testing three samples are reporduced in Table II. Of particular relevance in explosion relief design is the K_{st} value, which is derived from the maximum measured rate of pressure rise. This latter in bar/sec is plotted against dust concentration in Figure 1. The enormous scatter in the measured values of dp/dt will immediately be seen. Even more disturbing the highest rate of pressure rise and significant maximum explosion pressures were measured, and this from a dust which exhibited weak flame propagation in the classification test. *In each case the minimum explosible dust concentration was given as 5* gm/litre as compared to the literature values of between 30 mg/litre and 125 mg/litre (7).

As a further example of apparently anomalous 20 litre sphere results, a series of samples of "dried vegetable material" were subjected to a similar test programme and the results are reproduced here as Table III. It will be seen that three of the four samples which were tested fully gave no flame in the vertical tube with hot coil ignition, and only a very weak flame with continuous electric spark discharge, and yet all three produced potentially catastrophic overpressures and significant rates of pressure rise in the 20 litr sphere. In this respect it should be recalled that the term "very weak flame" indicates that although a flame is observed in the vicinity of the continuous spark during the test, sustained flam propagation exceeding a few centimetres away from the spark does not occur.

4. Discussion

From the practical view point, the purpose of the various standard tests should be to:

(a) identify whether the material poses an explosion hazard, and

(b) evaluate those properties which will allow the determination of the requisite protective measures.

The vertical tube has long been used not only to classify materials into explosible (Group A) or non-explosible (Group B), but also to determine minimum explosible concentrations. The problem we have highlighted here is the definition of explosible. The mere appearance of flame in the immediate vicinity of the ignition source confirms that the material is flammable, but does not necessarily indicate that it has flammability characteristics of the type where a flame propagates and invades a volume sufficiently to cause an explosion.

The hallmark of an explosion is the generation of pressure, and so the U.S. Bureau of Mines criterion of explosiblity is attractive in that it certainly differentiates between flammable and explosible. After all, if the dust cannot even lift or burst a sheet of filter paper, the hazard it presents to the industrial plant must be minimal. In this respect, a more suitable test might be based on the "flip-top" Hartmann apparatus, i.e. a vertical tube with a lightweight, hinged cover over the top. The criterion of explosibility might then be the observation of either movement or the flip-top, or flame propagation away from the electrodes at least to the tube walls. In view of Gibson's findings (9), a more energetic ignition source that the one currently employed might be considered (see later).

With regard to the present interpretation of the vertical tube test, Field (7) recognises that the mere appearance of flame does not necessarily mean that the dust poses an explosion hazard in practice:

> "........ dusts producing extremely weak flame propagation, i.e. in which small, thin, fragmented flames only just move away from the ignition source, are also regarded as explosible; in such cases this classification may be qualified by labelling them as marginally explosible, with the expectation that no serious explosion pressure would result".

However, we have found a reluctance to regard marginal Group B dusts as anything but extremely hazardous. The problem seems to be in accepting that a dust need not be black (Group A) or white (Group B), but can be grey, i.e. marginal - certainly flammable but not necessarily explosible. Perhaps there is a need for a third classification to include such dusts.

In terms of evaluating explosion parameters, the vertical tube justifiably attracts criticism because its size and shape influence the flame *propagation process, the ignition source is not particular energetic and* a uniform dust suspension with repeatable turbulence levels cannot be guaranteed. Thus the $1m^3$ cylinder and later the 20 litre sphere were proposed as standard test vessels. In the 20 litre sphere, the ignition source comprises 2 x 5kJ chemical igniters. In this Symposium Gibson et al (9), have demonstrated that such an ignition source is significantly more energeteic than would be encountered in industry. Moreover, it evidently affects flame propagation in marginal dusts in that it appears to drive a flame in materials which have been previously found to be Group B. The present results for tissue paper fly illustrate this tendency also. It will be seen that the lowest concentration studied, which was only 5 mg/litre, produced the highest rate of pressure rise. For "standard" dusts the "standard" test supplies sensible, reproducible and pertinent data. *However*, for marginal dusts, say, $K_{st} < 100$, and for Group B dusts, the ignition source is clearly too severe.

How does this conclusion affect the determination of minimum explosible concentration, since such mixtures might be regarded as marginal and should produce low rates of pressure rise? *We have taken values from* Reference 7 for ostensibly identical dusts, measured byU.S. Bureau of Mines in the vertical tube and by Bartknecht in the $1m^3$ cylinder. These are reproduced in Table IV, and it will be seen that in only five cases are the $1m^3$ cylinder values lower than the U.S. Bureau of Mines vertical tubes values. It would appear, therefore, that values of minimum explosible concentration measured in the vertical tube are conservative and can be used with confidence. Of course, this conclusion does not necessarily extend to other parameters measured in the Hartmann apparatus.

The anomaly highlighted above could be explained in either of two ways. Firstly, it might indicate that the concentration of dust at the ignition source of the vertical tube is significantly higher than the average concentration computed on the basis of the full volume of the tube. Alternatively, it might indicate that since the volume of material which is required to produce a lower limit mixture is so small compared with the volume of the external dust chamber and sparge pipe (perforated dispersion ring) of the 1 m^3 cylinder and 20 litre sphere, then a significant proportion of the dust remains trapped in the pipework and fittings and is never actually dispersed into the apparatus during the test.

5. Conclusions

5.1 The present criterion used to differentiate between Group A and Group B dusts in this country is based on flammability rather than explosibility.

5.2 A more suitable criterion might be the observation of either sustained flame propagation, or evidence of the generation of pressure. With regard to the latter, a modified (flip-top) Hartmann apparatus might be suitable.

5.3 A third category of explosiblity might be adopted to encompass marginal dusts, i.e. dusts which are flammable in the standard test, but do not exhibit properties of sustained flame propagation or pressure generation.

5.4 Because of the criterion of explosibility, values of minimum explosible concentration measured in the vertical tube in this country might be unrealistically low.

5.5 However, values of minimum explosible concentration measured by U.S. Bureau of Mines in the vertical tube appear generally conservative compared with those measured in the 1 m^3 cylinder.

5.6 The ignition source used in the 20 litre sphere test is too energetic for marginal dusts in that it appears to drive a flame through a dust cloud which would otherwise not support sustained flame propagation.

5.7 Explosion parameters measured in the 20 litre sphere test for marginal dusts must be interpreted with caution.

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TABLE I

Comparison of literature values of minimum explosible concentrations in mg/litre

	F.R.S.	U.S.B.M.
Benzoic acid	11	30
Sugar	15	45
Soap	20	75,85,60,45
Sulphur	20	45 and 35

TABLE II

Test data from 20 litre sphere for 3 samples of tissue paper dust

Dust Concentration mg/litre	Pmax bar	dP/dt bar/s
0	.89	83
5	2.23, 2.52, 2.23	71, 102, 70
10	2.19, 2.15, 2.36	57, 86, 77
20	2.4, 2.48	65, 66
25	2.15	50
50	1.99, 2.44	33, 74
75	2.64, 2.88	100, 83
100	2.4	47
250	2.76, 3.21, 2.84	72, 60, 70
500	2.68, 3.74, 3.25	94, 92, 73
750	3.01, 3.61	99, 88

TABLE III

Test Data for Dried Vegetable Material From Vertical Tube and 20 litre sphere

	Vertical tube		20 litre sphere	
Sample	Hot Coil	Spark	Pmax	dP/dt
G	NF	VWF	3.59	97
H	VWF	WF	6.55	277
K	NF	VWF	3.31	84
Q	NF	VWF	4.77	211

KEY:
NF - No Flame Propagation
VWF - Very Weak Propagation
WF - Weak Flame Propagation

Pmax in bar
dP/dt in bar/s

(N.B. As we understand, none of the tests relating to samples G, H, K or Q gave sustained flame propagation in the vertical tube test)

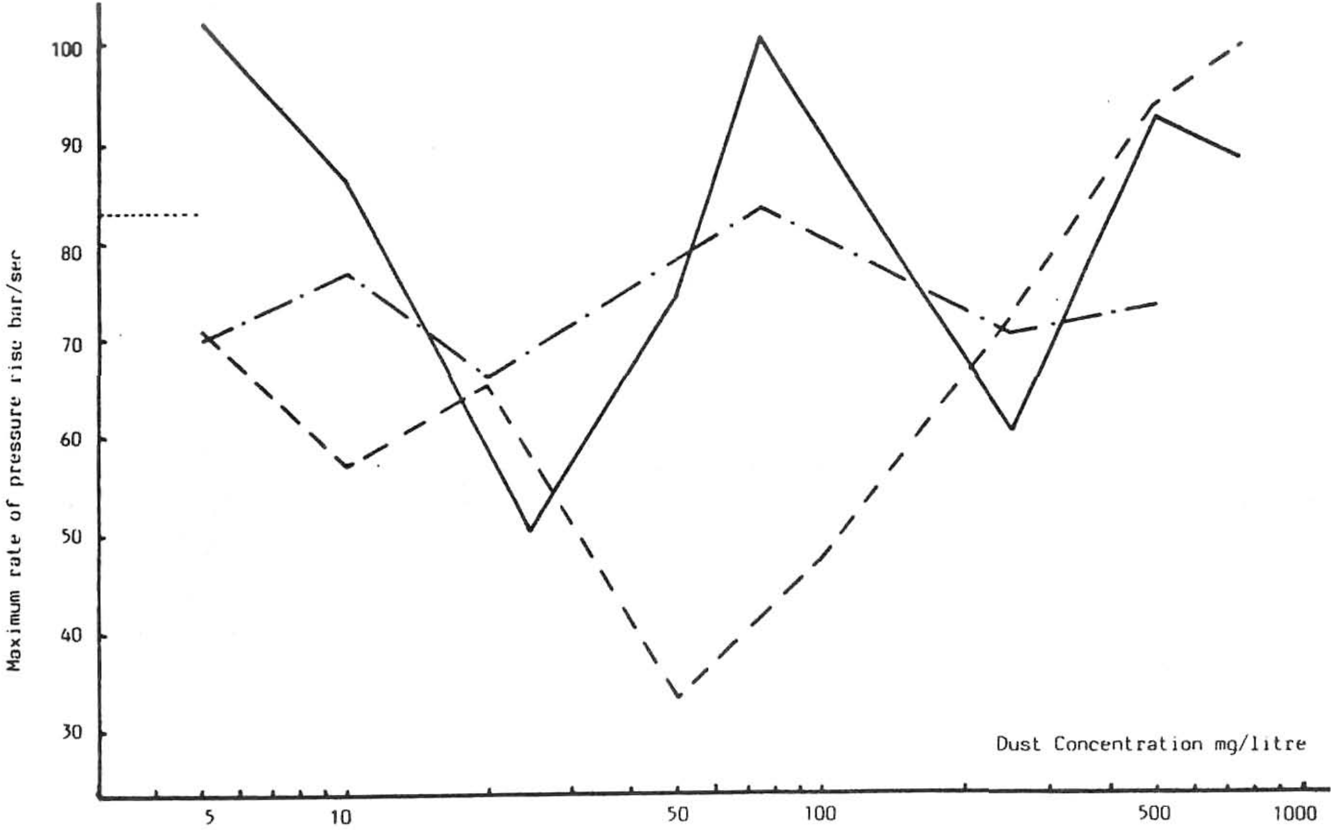

Figure 1 : Explosion Data For Tissue Paper Dust Measured in 20 litre Sphere

TABLE IV

Values of Minimum Explosible Dust Concentration, from Reference 7

All values in mg/litre.

Material	U.S.B.M.	$1m^3$ cylinder
Acetoacetanilide	30	30
Adipic Acid	35	60
Calcium Stearate	25	30
Carboxymethyl Cellulose	60	125
Cellulose	45	60
Cork	35	30
Cotton Flock	50	100
Dextrin	50	60
Di-tert-butyl-p-cresol	15	15
Epoxy resin	12	30
Ethyl Cellulose	25	125
Grain, mixed	50	125
Iron Carbonyl	105	125
Iron, sponge	100	200
Lignite	30	60
Magnesium	30	30
Milk, skimmed	50	60
Paraformaldehyde	40	60
Pentaerythritol	30	30
Phenolic Resin	20	15
Polyvinyl Acetate	40	30
Soya Meal	180	200
Sulphur	20	30
Wheat	60	60
Wheat Starch	45	60
Yeast	50	30
Zinc	400	250

(B) **K.N. Palmer**, Fire Research Station, Boreham Wood

Dust Explosibility Testing: Comments on (A)

Introduction

The paper by *Gibson, Maddison, Rounsley and Stokes*[1] raises certain questions on the methodology for dust explosibility testing and comments by Mitcheson and Craven[2] raise further points on the applicabilty of the results of small-scale tests to practical situations. The comments raised are basically technical, and need to be discussed, but it is important at the same time that the general methodology for dust explosibility testing in the UK is not called into question. This methodology has been in existence for several decades, and has served both industry and the regulatory authorities well. It would not be productive to cast doubt upon the basics of the methodology, or to introduce subjective criteria in place of objective methods. But technical reappraisal should take place at intervals, to take account of new knowledge and methods, but on the understanding that modifications would evolve rather than being imposed discontinuously. This note considers some of the more basis issues raised in the two references.

Why are classification tests necessary?

Of all the countries in Western Europe and North America it is only the UK that has had in existence for many years a set of qualitative tests for determining whether or not a dust is to be regarded as explosible. The fact that the UK is unique does not mean it is wrong. The need for the tests arises principally from the requirements of the 1961 Factories Act, particularly Section 31, where it may need to be decided by laymen, particularly lawyers, whether a dust is liable to explode on ignition. To decide this point standard tests are prescribed in which the operator has to decide whether or not flames propagate away from an ignition source, a spark or a hot coil, in a vertical tube[3]. This decision is objective and, indeed, may be made by a layman. In the report, the person carrying out the test is enabled to give guidance as to whether the flame propagation was weak, very weak, or strong, but these are subjective assessments and are included for a guidance and are not part of the formal test criterion.

Gibson et al, in their Table 1, give a classification for nine dusts but it is not clear whether these were tested in both versions of the vertical tube apparatus or whether a hot coil was used in a horizontal tube for part of the work. The horizontal tube would be a less severe test than a vertical one, both with a hot cell[4], so the number of dusts attributed to Group A may be underestimated.

It is the case as stated by Gibson et al that the classification criteria only apply to dusts dispersed at ambient temperature, but the classification is customarily extended to cover temperatures up to 110°C to cover low temperature dryers. If the dust is to be dispersed at temperatures significantly above 110°C then the classification methodology should not be applied and an individual assessment is needed. The present dust expxlosibility testing methodology[3] derives from original work on both laboratory bench scale and in a large scale vertical tube, 25cm diameter and 5.2m long, in which a range of dusts of varying explosibilities was examined and mixtures of phenol-formaldehyde resin with magnesium oxide, in varying proportions, were dispersed at known concentrations. The ignition source was a propane/air flame injected into the lower part of the tube forming an approximately spherical ignition source occupying the tube diameter. The criterion for flame propagation was that the dust should support flame for at least 60cm from the mid-point of the ignition flame. Flame propagation in the tube could be either partial, or full length. As a result of this work it was concluded that the current Group A/Group B explosibility classification was valid. As the explosion pressure was attempted. A further investigation in the same experimental equipment, using coal dust, and mixtures of coal dust with stone dust[5], gave results that were consistent both with the phenol formaldehyde/magnesium oxide investigation and also with reported work from coalmine gallery experiments. It was therefore concluded that the test apparatus was of sufficient scale to be realistic representation of industrial conditions.

More energetic sources could have been used, as Gibson et al did in the laboratory bench scale apparatus, and such sources would tend to drive the explosion over a longer distance, but not necessarily to convert a partial propagation into one that was complete throughout the dust suspensions. The energy of the propane/air igniter was about 16,000J and on the industrial scale would not be considered excessive. Indeed, in industrial plant, the possibility of flame propagating from one vessel into another, injecting a large ignition source in the process or the use of a gas/oxygen cutting flame which could ignite dust in a heavily enriched oxygen atmosphere could be far more energetic sources.

The results obtained by Gibson et al on explosibility classification would seem to indicate that if any changes are to be made, then a more stringent classification is required. Pratical experience does not support this conclusion, and further evidence would be necessary before such a development could be seriously contemplated.

Pressure characteristics

Gibson et al studied explosion pressures in the 20 litre sphere with the standard ignition source (10,000J) and other sources of lower energy. With the standard system they measured significant maximum explosion pressures with Group B dusts but they then cast doubt upon the applicability of this ignition source in the circumstances. The case of unplasticised pvc is particularly interesting since although this is officially classified as in Group A, no significant pressure effets are found in the Hartmann bomb equipment[3] and industrial practice has followed this line. However with the standard source in the 20 litre sphere, significant pressure measurements are obtained and this fact was indeed noticed by the originators of the 20 litre sphere but the findings do not appear to have been fully implemented in the practical situation. Current practice appears to be justified, but if there is to be any change then it is likely to be in the direction of greater stringency.

Hartmann bomb and 20 litre sphere

Gibson et al are ambivalent towards the use of the Hartmann bomb claiming that significant cooling takes place during the course of the test (Figure 3). In fact this is a misunderstanding, the kink in the pressure/time curve arises at the instant when the initial flame propagation which is of spherical shape reaches the walls of the cylinder and thereafter can propagate only aong the axis, at a different rate of generation of volume. This has been demonstrated using propane/ air mixture in the Hartmann bomb thus avoiding complicaitons due to dust dispersion and turbulence[6]. It is likely that the Hartmann apparatus will continue to have use in the future, particularly for dusts that are difficult to disperse in the 20 litre sphere. Application of the results to practical systems will still have validity.

Gibson et al point out that in making explosion pressure measurements with the 20 litre sphere with weakly explosible dusts enhanced values of maximum pressure and maximum rate of pressure rise are obtained. As they indicate this could well be due to the powerful ignition source overdriving the explosion in its early stages, in a similar manner to the behaviour of Group B dusts in non-standard small-scale tests. But with the 20 litre sphere another factor operates in that the ignition source itself generates pressure, in the absence of dust. The maximum explosion pressure due to the source alone, in clean air, is about 1.0 bars and the Kst value is about 20, giving for this apparatus a maximum rate of pressure rise of about 75 bars/second. Thus, in any case, Kst values found for dusts that are below 100 will be affected by the contribution from the ignition source. In industrial plant, in special cases, an argument could be made for using with reservation the 10,000J source, for reasons described earlier. However, a pragmatic approach requires that local circumstances be taken into account and a reasonable compromise be reached. However it is unreasonable to expect the test to do this objectively since it has been designed for use in the chemical industry, with fine powders that can be dispersed by the mechanism provided in the sphere.

Some dusts are difficult to disperse and the paper dust described by Mitcheson and Craven is an example. This is fibrous tissue rather than a powder and has a tendency to hold up in the dispersion equipment. This clogging process could reduce the amount of paper in suspension, and also the air pressure at the time when the igniter is automatically fired. One would expect the effect to become greater at higher paper concentrations.

Inspection of Mictheson and Craven's Figure 1 indicates that at low dust concentratioins the maximum rate of pressure rise may be above the 75 bars per second expected from the igniter itself. However, with difficult dispersion, erratic results would be obtained and at higher concentrations lower rates of pressure rise may be obtained even though there is in principle more combustible in the system to burn. This paper dispersion problem could be the reason for the erratic shapes of the lines in Figure 1, spanning both sides of the 75 bar per second ordinate, and could also explain why a relatively high value is obtained with a low concentration of dust.

Minimum explosible concentration

Mitcheson and Craven[2] comment on low values quoted for minimum explosible concentration with certain dusts, and question the validity of the measurements. They quote the possibility of making thermodynamic calculations, as is the case for gas mixtures, from which values of minimum explosible concentration of 40 to 50 mg/litre are obtained. However this calculation assumes that the system is homogeneous and this is not the case with dust suspensions where, firstly, a homogeneous suspension is practically impossible to obtain and an average value has to be taken, and secondly the dust is in motion relative to the flame because of gravity. A straightforward example is given by Palmer and Tonkin[4] for phenolformaldehyde resin. In the small-scale test apparatus the minimum explosible concentration was found to be 0.015g/litre whereas in the large-scale vertical tube, the value was about 0.03g/litre. The small-scale tube thus appeared to give about half the value in the larger scale tube. Both apparatuses would be subject to the action of gravity and the motion of particles relative to the flame in the small-scale tube would be difficult to assess. In the large-scale tube it was measured and was found to double the value apparently measured ie. the minimum explosible concentration in the large-scale tube was about 0.06g/litre. This sounds a reasonable value being about half the stoichiometric concentration.

However, a different picture emerges with polyethylene dust[7]. This dust had the sizing analysis shown in Table 1 and a moisture content effectively zero. A specific investigation of the lower explosibility limit was made in the large-scale tube, with the top closed and bottom open, and the results are summarised in Table 2. Similar results were obtained with the bottom of the tube closed and the top open. Unde both sets of conditions the concentrations were low and the dust clouds were almost transparent. Visibility was certainly many metres. ALso, the flame was fragmented and it did not propagate at a steady rate. After allowing for gravitational fall of dust into the flame, the minimum explosible concentration in the large scale tube was about 0.015g per litre. With the stoichiometric concentration of 0.088g per litre. Thus the minimum epxlosible concentration for polyethylene was about one sixth of the stoichiometric concentration, compared with about half for phenol formaldehyde resin, and thus illustrating the wide range of behaviour that may be obtained with different dusts. It is therefore not legitimate to conclude that low values of minimum explosible concnetration are necessarily unrealistic.

Whether a mixture at the minimum explosible concentration, whether of dust or gas, should be regarded as flammable rather than explosible is a very debatable point. Certainly, with gas mixtures, no such distinction is made and all mixtures that will propagate flame are regarded as potential epxlosion hazards even though at the flammability limits the pressure rise may be negligible. To introduce a distinction between flammability and explosibility for dusts would be a deviation from current practice, would probably involve some subjective decision by the test operator as to whether pressure development was significant or not, and would remove the simplicity of the present criterion. It is not the case, as Mitcheson and Craven claim, that there is a reluctance to regard marginal Group B dusts as anything but extremely hazardous. This is not even the case with marginal Group A dusts, as shown by current practice in the UK for unplasticissed PVC dust.

Conclusion

The explosibility classification criteria curently in use in the UK are generally satisfactory, dealing with marginally explosible dusts in practice does not cause great difficulty. If, following further work, a change were to be introduced it would probably be in the direction of increased stringency.

In measuring the explosion pressure characteristics both the Hartmann bomb and the 20 litre sphere have some limitations. The Hartmann bomb is perhaps suitable for a wider range of types of dust, whereas the 20 litre sphere may be preferable for the fine powders for which it was designed, provided account is taken of the energy of the ignition source.

The minimum explosible concentrations of dusts can be low, as compared with gases and vapours, and explosion protection measures must take account of this. Good visibility through a dust suspension is not a guarantee that the concentration of dust is below the minimum for flame propagation.

Attempting to distinguish between flammable and explosible dust clouds, and particularly the changeover from one to the other, would involve subjective judgement and would complicate the currently simple situation.

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TABLE 1

Sizing analysis of polyethylene dust

B.S. Mesh	Percentage by weight
- 60 + 72	20.2
- 72 + 120	62.5
- 120 + 240	16.5
-240	0.5

TABLE 2

Lower explosibility limit of polyethylene dust; ignition near open end of tube

Dust Concentration g/l	Extent of flame propagation
0.008	None
0.011	Part tube length
0.017	" " "
0.019	" " "
0.021	" " "
0.024	Whole tube length
0.034	" " "
0.041	" " "
0.046	" " "

Q/C **(N. Maddison)** Responding to Mitcheson, says that he has highlighted problems of interpreting statutory regulations to be agreed with H.S.E. Problem re. ignition source in 20 litre sphere. With spark discharge, electrodes can be white hot and can create flammable gases from dust which in turn propagate flame. If when tested in the 20 litre sphere a K_{st} of 100 is found, then possible sources of ignition in the industrial environment should be identified and testing done with similar sources: if no pressure effect - no need to protect.

R/A **(A. Mitcheson)** Agrees that some tests with the sphere have a zero error but any correction not simple and cannot be allowed for.

Q/C **(N. Gibson)** Quoted case of UK plant not requiring protection following tests done in vertical tube and similar plant for Europe requiring protection following tests done in sphere. What do we do when the sphere gives a very positive answer? Suggests we choose an ignition source between 500 and 1000J because this is realistic in relation to industrial sources of ignition such as sparks and friction.

R/A **(A. Mitcheson)** Many problems exist outside the process industry and other sources of ignition may exist. He gave reasons for using higher energy sources of ignition.

Q/C **(J.H. Burgoyne)** The relevant measurement of the lower flammability limit is the ratio of fuel to air actually entering the propagating flame front - not the same as the instantaneous fuel concentration in a given volume of air. This applies to any situation where fuel and air travel at different velocities (For explanation, see: J.H. Burgoyne, I.Chem.E., 1963, Symp,. Series 17, p1-5). Some discrepancies between L.F.L. measurements for dusts are no doubt due to ignoring this point.

<u>(TRAINING FILM)</u> (I.Chem.E.: K.J. Myers)

Introduction stressed the Institution's more active role in Safety and Loss Prevention and referred to the Loss Prevention Bulletin. It mainly deals with case histories.

SESSION 2 (A.M. Chairman: N. Gibson)

PAPER 7 (H.C. Jaggers, D.F. Franklin, D.R. Ward and F.G. Roper)

Factors controlling burning time in non-premixed clouds of fuel gas

Q/C **(R.L. Rogers)** Does the position of the ignition source affect the burning time?

R/A No significant effect observed.

Q/C **(Chairman)** What is the density value used?

R/A The density of ambient air used because the length dimension used is the diameter of the fire ball in the fuel bubble - hence cube root of fuel mass divided by air density. This choice leaves least dependence on factors such as density ratio (fuel gas/ambient air).

Q/C **(Chairman)** Fairly clear boundary between lines A and B - which was done with soap bubble?

R/A Both done with same soap bubble technique, the difference being a change in regime as one increases the mass of gas for quiescent releases. For line B we suspect viscous effects and line B represents fully turbulent conditions.

Q/C **(Chairman)** Does the mushroom shape indicate different factors operating in the two parts?

R/A A difficult question! The top of fireball rises at a constant velocity, the rest at a rate proportional to fuel mass. The head becomes a sphere as a result of fireball spreading into surrounding air. Chairman appreciated that several factors operate simultaneously.

Q/C **(R.C. Gray)** Larger spills of liquid cause heavier-than-air gas pancake clouds and are more likely than bulk liquid incidents. Do tests show pancake shape explosions to be less damaging than spherical?

R/A Depends on how the cloud lifts off the ground and study is still needed - violent release is needed to cause lift. Preliminary work (not in paper), compares with Lewis's work (illustrated by slides). There is little evidence that fuel gal can lift off ground unless propelled -large scale tests show that fuel burns on ground. With scale-up of buoyancy - controlled release, burning time increases as 1/6 power of mass and time for flame to spread across the cloud increases as 1/3 power of mass hence cloud is burned out before it can form a fireball.

Q/C **(J. Moorhouse)** What is the potential influence of release velocity (similar fuel mass) on radiant emission characteristics? Have any differences been observed?

R/A Emission would depend on surface emissive power variation of which seems small, also on growth rate. Fireballs released from a high pressure source grew more rapidly than from quiescent source and emission depends on time at large diameter. The high pressure release grows very rapidly at first, then slows down because of dilution with air.

Q/C Initial release of a liquid hydrocarbon is denser than air - will tend to form pancake cloud so this is probably the way large releases would burn in practice.

R/A Only evidence of fireballs in practice is a B.L.E.V.E. The pancake cloud is more relevant but first we need to know more about the simpler case.

Q/C **(A. Mitcheson)** Does the fireball diameter vary with the method of release - as does the burning time?

R/A No - this is predictable from thermodynamics.

PAPER 8 (I. Swindells, P.F. Nolan and D.B. Pratt)
Safety aspects of the storage of heated bitumen

Q/C **(R.L. Rogers)** Results for auto-ignition arise for small scale tests - what is effect of scale-up on ignition temperature of coke-like deposits because of self-heating?

R/A No evidence found of self-heating at lower temperature.

Q/C Presumably you were looking for self-heating below ignition temp?

R/A Yes, we use DTA and DFC to look for exothermic reactions - employing standard tests and temps. possible within bitumen storage tanks. No weight loss was found below 200°C, 25°C was needed to get any weight loss and much higher to detect exotherms.

Q/C **(T.J. Dye)** Installations you reported used hot oil heating, others use steam. Is there any correlation between fire incidents and method of heating?

R/A Experience is that steam is less of a problem than oil, direct fired, or electric - if available on site. Fires have occurred due to heating being left on after drain-down ; particularly with mobile tanks. Even steam can cause boil-over.

Q/C **(J.H. Burgoyne)** By analogy with lagging fires, self-heating and ignition of deposits are likely to be favoured by adsorption of less volatile, higher molecular weight components - less likely to be driven off and more easily oxidised. Since special combination of conditions is required, actual occurrences may be rare.

R/A Mass spectrometer, G.C. analysis has shown C_{10} hydrocarbons have been found in the residues.

Again stressed the relatively rare occurrence of all factors to favour ignition.

Q/C **(D. Napier)** Quoted a blown bitumen tank that "went over the top" partially removing insulation and leaving some insulation impregnated with bitumen. Four hours after the fire had been extinguished this re-ignited!

PAPER 9 (J.F. Siddle)

Fire hazards of flammable liquids in plastic containers

Q/C **(A. Jones)** Did you investigate the bursting pressure of individual containers of flammable liquids.

R/A No but U.S. Coastguard authorities have made tests because they are very concerned about BLEVE's. With plastic containers, they fail very quickly so you don't get a BLEVE but you may lose a sprinkler-fitted building.

Q/C Did you measure radiation levels from the fires?

R/A Yes, some values given in Appendix 2 - radiant heat levels on target surfaces were measured.

Q/C **(D.B. Pratt)** (a) You seem to prefer indoor storage of flammable liquids in plastic containers - is this so? (b) Do you recommend ventilation in stroage buildings?

R/A (a) Indoor storage is recommended where necessary for protection of consumer products - otherwise outdoor (b) We recommend ventilation for Class 1 liquids and where there is dispensing of liquid, with heavier-than-air vapours, provide low level ventilation. For Class 1A liquids, ventilation is not needed.

Q/C When there is a risk of leakage ventilation is needed.

R/A With flammable liquids we should eliminate sources of ignition, prevent spillage and also provide a sprinkler. Generally experience is good but extra care is needed with the most volatile liquids.

Q/C **(T.J. Dye)** Would it be better to provide a primary means of extraction triggered by fire detectors with sprinklers (slow to act) as secondary, also noting their ineffectiveness shown in the video.

R/A Depends upon the builidng and location. Yes, provide a primarly system in cases where for example the risk is surrounded by other plant, backed-up by sprinklers to prevent spreading - they are very reliable and cheap to operate.

Q/C The video showed a case where the pool fire was not affected by sprinkler because of equipment falling over.

R/A We are working on early repression, fast response sprinkler systems -difficulty in avoiding oversensitivity and storing so that fire is "seen" early.

Q/C **(K.N. Palmer)** Once the fire is burning fiercely, all forms of extinguishing agents are pushed aside by the flame buoyancy. It's better to attack early whilst packaging is burning. Alternative is to use some independent detection system to cause sprinkler or other device to operate.

R/A You could do that in a small warehouse.

Q/C You must do it for a mixed warehouse containing different materials such as a D.I.Y store.

R/A I think you have lost that building anyway because you have to cut off the deluge.

Q/C **(J. Moorhouse)** (a) Is the flame from a large alcohol pool fire luminous? (b) Have you to be able to estimate the mass burning rate?

R/A (b) I do not know - our work was done for another company and we do not have that information. (a) likely to be luminous often packaging, etc. burns.

Q/C **(M. Selway)** Why do you not recommend the prohibition of storing Class I, II, IIIA products in plastic containers?

R/A We are not in that position - can only warn clients of the risk if they do certain things. Industry wants to use the containers to save weight, etc. We need to find protective methods if possible and more knowledge is needed.

Q/C **(F. Millar)** Please elaborate on your reference to U.S. Coast Guard interest in 200 l plastic barrels.

R/A They sponsored tests because one company wanted to use them - the C.G.

being very worried about BLEVE's (see above) - most of their risk being outside (docks, etc.). When we are thinking about containers burning in warehouses, you will probably lose the building anyway and results of plastic containers' failure is probably no worse than that from metal containers.

Q/C **(A. Jones)** Re the last comments, we tested the effect of fire engulfment of 210 l steel drums of acetone. Violent projectile and fireball combustion resulted - one drum rocketing to 130m and bursting at pressures up to 90 psig were measured. With blow-moulded polythene drums, containing acetone the drums melted, spilling contents into the fire with no evidence of projectiles or fireballs - bursting pressures up to 1 psig were measured.

R/A Agreed with conclusions saying that one would not be able to save the building.

PAPER 10 (T.K. Wright and R.L. Rogers)
Adiabatic Dewar calorimeter

Q/C **(J.L. Cronin)** Will you comment on control characteristics?

R/A One of the best features - launched at low temp. and soon equilibrates and then under good adiabatic control giving a smooth curve. Drift rate is 1-2 deg/day (but increased by stirrer) - hence good for low power outputs.

Q/C **(Chairman)** Will you comment on the value of the Dewar operated without a constant temperature oven, compared with the ARC?

R/A A 200ml Dewar in the atmosphere can only similate a 500/700 l reactor (heat loss 0.8 W/l deg) and not large storage vessels.

Q/C **(N.J. Jones)** (a) Comment please on use of Dewar for heterogeneous systems? (b) Can the kinetic data be interpreted for systems dominated by mass transfer effects?

R/A (a) First, the need to agitate solid/liquid systems puts heat in.

Secondly, secondary effects such as increasing solubility can, by increasing concentration, give apparently different activation energies and different chemical reactions may appear. One can examine a number of effects.

Q/C How then would you extrapolate the data for chemical engineering design?

R/A Depending on data required may retreat to isothermal heat flow calorimetry - for example when designing cooling system for semi-batch addition isothermal flow calorimetry would give an isothermal simulation. We are simulating what will happen on the plant scale with the adiabatic Dewar

Q/C **(B.J. Thomson)** Can you give an idea of costs (a) for setting-up from scratch, (b) for further study for plant conditions?

R/A This was in-house constructed equipment. Dewar vessels in glass or SS are readily available. Control is affected by a computer system which performs many other duties and is not limited to this work.

Q/C **(R.L. Rogers)** Using a standard glass Dewar, fan agitated oven and the analogue control system described in the paper the cost is £1000-2000. This will provide decomposition onset temp. related to plant scale.

Q/C **(G.A. White)** Was any work done on effect of agitator speed?

R/A We normally use low speeds - eg. 200 R.P.M. to keep solids suspended. High speeds with the Silverson will easily boil water.

Q/C **(R.J. Granville)** Low values of ϕ can be obtained using the ARC -possible to match the value of the adiabatic Dewar with a 5g titanium bomb it is possible to get similar ϕ values with a maximum operating pressure of 500-600 psig.

R/A We would pre-screen and those that would "frighten" us would not be done in the Dewar - looking for systems that would not produce more than 200-300 psig.

Q/C **(C.H. Steele)** To what extent does isothermal heat flow calorimetry supplement adiabatic Dewar calorimetry?

R/A They are doing different jobs. Isothermal is simulating the normal plant process, giving power output profiles enabling diagnosis of induction periods, accumulation and power output related to cooling capacity. Adiabatic Dewar is really for stability but will give information on normal chemistry.

You cannot do in Dewar what you can in heat flow calorimeter -eventually you want to simulate. The two are to some extent complementary. Adiabatic scans across the temp. range giving effect of temperature as well as concentration.

Q/C **(R.J. Granville)** Is the heating control (Adiabatic Dewar) ramp control or step-wise?

R/A Screening test determines the launch temp. and gives a feel for how the test should be done - either way. Internal heater may also be used to raise temp. to starting point.

Q/C **(J.L. Cronin)** (a) Are the "natural heat loss" values based on reactors full of water and would significant variation occur with organic *materials? (b) Are there spurious variations in heat generation in* early stages of a runaway?

R/A Yes, works vessels were filled and cooled from about 90° to 70° ie. a temp. difference of about 60°. We have no similar data for organics but O.H.T.C. data for jacket-cooled reactors is available.
(b) There are none.

The following written contribution was presented.
F. Millar, Environmental Policy Institute, Washington, D.C., USA
The state of major hazard regulation in the U.S.

Good morning. I appreciate Dr. Greenwood's kind invitation to participate in your symposium, and I only regret that no American chemical engineers have come to learn from your sessions. We in the

U.S. are at a more primitive stage of regulation of major chemical hazards than you are here, partly because of the impetus afforded your efforts by the Flixborough explosion in 1974. We therefore have much to learn about the state-of-the-art in hazard assessment and control as well as public sector involvement in mandating and encouraging chemical safety. I appreciate this opportunity to meet you concerned experts from industry and academia in the UK.

I have just had the good fortune of meeting in Holland with chemical safety experts from industry, research bodies like TNO, and national and local government. Some of these were contacts suggested by Dr. Roger Batstone of the World Bank in Washington, whose chemical safety program has been an important model for US. policymakers. I wold like to mention here also that my attendance at this meeting would not have been possible without the support of the German Marshall Fund of the United States.

Until recently considered a "safe" industry and allowed to set its own safety standards, the U.S. chemical industry now faces the prospect of new regulation by states, cities, and the federal government. New Jersey and Los Angeles already have new laws: state legislatures in California and New York State are considering similar bills this session. The industry's safety structures have been undermined by hte pressures of fierce competition and crippled by the liability fears of company lawyers. The new government role in prevention of chemical accidents is based on a widespread loss of confidence in the industry's ability to assess the risks of ultrahazardous chemicals, to learn essential safety lessions from past accidents, and to implement state-of-the-art risk reduction technologies in a timely fashion.

Chemical companies worldwide and a newly attentive public are haunted by someone who is getting to be a stock character in the news media: the ashen-faced manager shaking his head in disbelief and grief at the site of his disaster. One of the most poignant and visually dramatic episodes was the British television interview with the manager of the Flixborough, England NYPRO (U.K.) Ltd. petrochemical plant that exploded in 1974 in a blast heard 30 miles away, killing 29 workers and levelling every building on the site: "There was never the slightest suspicion in the minds of all the safety poeple that something like this could happen....See that rubble over there? That was my office, the closest one to the plant. Our plans in case of a toxic emergency called for us all to gather there and count noses before evacuation. If we had, we would all be dead". Shortly before this accident, caused by a hasty and careless modification to the plant, the British Health and Safety Inspectorate officials had directly told the company to install shatter-proof windows in the plant's control room.

On-site workers are at greatest risk when the managers and operators of the ultrahazardous chemical facilities are complacent or ill-trained, and when government regulators are so glaringly inadequate to assess and deal with the risks. Community residents near chemical plants are increasingly worried about the disaster potentials demonstrated in late-1984 accidents such as the Union Carbide toxic cloud release which killed 2500 at Bhopal, India and the Mexico City liquified-gas storage tank explosion which killed 450.

Chemical accidents are getting more dangerous every year. Since the 1974 Flixborough explosion, the chemical industry worldwide has suffered 60 disastrous accidents with property damage losses of more than $10 million each. Every decade of chemical plant operation shows a doubling of the number of such huge accidents: in 1979 and 1980 there were ten such accidents each year. The accidents are also getting much bigger. Of the five big accidents in 1984, the average losses were $53 million in each. Increased losses are partly due to bigger chemical vats and storage tanks. The size of some storage tanks has increased from 100,000 to 1,500,000 barrels. When a tank overflows or a pipeline breaks, the quantity of hazardous product released can be tremendous.

In 1984 property damage consultants Marsh & McLennan added several record-breaking fires and explosions to the list of 100 worst chemical plant accidents in the last 30 years, including the most destructive refinery fire, the largest natural gas processing plant fire, and the $50 million Mexico City LNG terminal tank farm explosion and fire. Vapour clouds which drifted with the wind and later ignited caused one-third of the accidents and the most devastating property losses.

By sheer luck in recent years the U.S. has been spared large losses of life from similar chemical accidents of awesome proportions. In 1970, for example, a vapour cloud from a broken propane pipeline filled a ten-acre valley near Port Hudson, Missouri, and then exploded with the force of 50 tons of TNT, damaging buildings five miles away. Four farm families had fled in terror from the leak. Twenty minutes later, they witnesses from their cars the ensuing firestorm. If a similar accident had occurred in a populated area, any such effective evacuation would have been extremely unlikely.

A key question for the new government cop on the chemical safety beat is whether chemical company management pressures for meeting tight production schedules are too many times overriding serious safety concerns and cutting short essential hazard assessments. How often are chemical safety engineers told, like the Morton Thiokol official under pressure to approve the NASA shuttle launch decision, "Take off your engineer hat and put on your management hat"? The highly visible NASA program was admittedly not using the most rigorous risk assessment method which was available to the agency (see NEW YORK TIMES, FEBRUARY 5, 1986, "NASA'S RISK ASSESSMENT ISN'T MOST RIGOROUS METHOD") because it was "such a very extensive and time-consuming application". Chemical industry managers are faced with very similar cost-risk decisions every day. Public officials are intent upon putting a regulatory floor under chemical plant practices and limiting the discretion of company managers to discount the risks.

The U.S. chemical industry has constantly touted its worker safety record as evidence of how safety-concious the companies are. Now some investigations by the U.S. Occupational Safety and Health Administration have revealed that some companies with the most effective safety public relations efforts (Shell, Union Carbide) have been not reporting workers' accidents, in violation of law.

Even more ominous than the sloppy chemical management practice revealed at accidents like Flixborough and Bhopal is mounting evidence of the serious flaws in the design of essential safety features in the most hazardous facilities. In 1981, for example, a Farmlands Industries storage tank vented into the countryside - as it was designed to do - a staggering 40 tons of deadly ammonia through its emergency relief valve. Reportedly hundreds of U.S. chemical plants likewise vent directly to the surrounding community instead of having back-up overflow tanks.

Chemical safety researchers recently concluded a ten-year, $1.6 million study (Design Institute for Emergency Relief Systems, or DIERS) of emergency relief systems that revealed several areas of design deficiency. According to Dr. Ian Swift, co-chair of the DIERS effort: "It is conceivable that many existing relief systems may not be adequate for a worst case (accident)... and are most likely grossly undersized... (Safer new) technology has not been widely disseminated". A European analyst (Haastrup) says that fully 25% of 860 major chemical plant accidents surveyed worldwide have been caused by design deficiencies.

Government could stay out of the chemical plant safety business only if chemical companies could argue that there is a credible and effective professional safety structure in the industry. Instead, there is disarray.

° According to a Monsanto study published in an academic journal, Management Science, in April 1984, chemical companies make only "limited applications of risk assessment techniques ...Expertise in risk assessment of chemical plants is limited to a few consulting firms and chemical companies". Complacency with outmoded risk analysis methods and a lack of consensus on acceptable levels of hazard plague the industry.

° Chemical engineering graduates joke that in their graduate training there is "as much emphasis on hazard assessment as on ethics: zero".

° There is no industry-wide agreement on several basic safety standards and on essential methods of risk reduction. If the medical profession demanded to be self-regulatd but admitted that it knew nothing about the chemical composition of blood, we would no doubt term that "voodoo" medicine. Yet consider that the chemical industry lacks essential scientific and practical knowledge of the ultrahazardous materials and processes they handle. It does not know how to characterize runaway reactions or to choose the correct size for emergency relief valves. Existing national codes in the U.S. - for example, the National Fire Protection Association codes - are voluntary, incomplete and admittedly minimal. The better companies use safety measures that go far beyond the codes other companies handling the same dangerous chemicals are free to use varying levels of safety.

° The insurance industry is not adequately assessing risks, much less exerting sufficient pressure to prevent serious accidents. On the contrary, the industry has badly miscalculated risks in recent years, and paid out huge settlements in major chemical accidents. So premiums have been raised dramatically and coverage cancelled for some companies handling ultrahazardous chemicals.

° The chemical safety engineers in Company XXX cannot learn essential lessons from serious accidents at Company ZZZ's chemical plants because accident details are kept secret by Company ZZZ's laywers, fearful of liability claims. For one example, industry reports say the cause of the $111 million refinery tank farm fire in 1981 "has not been disclosed". Chemical company lawyers naturally want to withhold information from competing companies on their special processes.

In the Spring 1986 meeting of the American Institute of Chemical Engineers in New Orleans, the last session was to include papers on "Accident Case Histories an Miscellaneous Topics". The chairman of the session introduced it by complaining that only miscellaneous topics papers would be presented, because none of the attending engineers had submitted any accident case histories. He surmised that this was due to warnings from industry lawyers about liability concerns, and lamented that the flow of information about accidents and their cause had thus been so obviously choked off.

Only a strong preventative regulatory role by government, it seems, can ensure an adequate flow of "lessons learned" information from serious chemical plant accidents, a function only an underfunded U.S. National Transportation Safety Board performs in the area of transportation accidents.

The U.S. federal government is only beginning this year to inspect a few chemical plants. There are currently almost no federal or state standards governing chemical plant safety. New laws will be necessary before many U.S. public officials even think they have the authority to find out what level of safety exists at chemical facilities in their communities.

The U.S. Environmental Protection Agency's first comparison of chemical *plant practices at Allied Chemical's South Works plant in Baton Rouge* -the plant uses extremely toxic hydrogen fluoride and had a release "beyond the fenceline" on July 5, 1985 - with another company's similar plant has already shown what an initial role government can play: in several areas, Allied's practices need to be "ratcheted up" to the higher available standards of safety practice used by their competitors. New Jersey state regulators from the Department of Environmental Protection, beginning to implement their brand-new 'Toxic Catastrophe Prevention Act', are similarly beginning to "grade chemical plants on a curve". Local officials in the South Coast Air Quality Management District in the Los Angeles area did on-site audits of 19 companies and found serious problems involving lack of dikes for storage tanks, lack of adequate backup systems, and the "distinct possibility" of deaths from toxic emissions within a two-mile radius from some chemical facilities and transportation corridors. Such investigations are showing that some existing facilities need extensive retrofitting with state-of-the-art safety features in order to pose an acceptable level of risk to surrounding communities. Any sensible regulatory program will as usual involve assessing permit fees on the industries whose risks make necessary the public regulation.

American policymakers' awareness of how to prevent acutely hazardous chemical accidents is being increasingly influenced by the experience of European nations and international agencies which has taken a head start in adopting a strong regulatory posture, mandated by the European Community's 1982 Seveso Directive. A new and stringent program for chemical risk reduction and accident prevention is in operation at the World Bank's Office of Environmental and Scientific Affairs in Washington, D.C. The newly available World Bank Manual for hazard asessment is providing an important and workable model for U.S. public officials faced with the post-Bhopal "Can it happen here?" concerns of many citizens. If the World Bank can establish an aggressive, low-cost program for regulating the chemical companies on acute chemical hazards, it seems likely that public officials in high-risk states like California, New York, Texas and Illinois will find it technically and politically possible to do likewise.

The U.S. has within living memory seen large-toll chemical catastrophes in our cities, both in fixed facilities and in transportation. For example, in 1944 a liquified-natural gas tank exploded in Cleveland and the blast and fire killed 131. The largest U.S. chemical disaster to date, in 1947, began as a transporation accident, when a ship loaded with ammonium nitrate fertilizer blew up at Texas City, Texas, a port town on Galveston Bay, causing a nearby Monsanto styrene plant to explode. Subsequent fires the next day cause another nitrate freighter to explode in the harbour. The toll: 576 dead, 2000 seriously injured.

The U.S. EPA has reported that at least 6928 accidents occurred in the U.S. with acutely toxic chemicals in the last five years, killing 135 and injuring nearly 1500. These accidents cannot be blamed on small, underfinanced chemical companies - fully one-third of them were at facilities operated by chemical giants like Dow, Dupont, and American Cyanimid.

Many American cities have chemical plants that produce, use and store the 403 chemicals that U.S. EPA recently listed as acute chemical hazards. Typically U.S. zoning laws have been lax, so that in many urban areas, dense residential housing and shopping centres have been allowed to be built within danger zones for toxic cloud releases and explosions. In 1985 EPA suggested that localities find out for themselves what chemical facilities, including transportation routes, put their populations at risk in case of sudden releases. The EPA's suggested methodology reveals that it would take only 2.5 pounds of chlorine or 6.5 ounces of phosgene - and comparably small amounts of many other chemicals - to harm people ove the fence 200 feet away.

As people outside the chemical industry learn more about what is state-of-the-art practice inside the fence, there should be a voluntary "ratcheting" effect - the most lax companies will hastily improve their equipment and practices, pushed by the chill breeze of laibility threats, Liability courts have held that the practice of a single company may be considered evidence of what ought to be done, in this case, in handling inherently dangerous chemicals. Thus the U.S. Court of Appeals, in an opinion written by Judge Learned Hand:

> "Indeed in most cases reasonable prudence is in fact common prudence but strictly speaking it is never its measure: a whole calling may have unduly lagged in the adoption of new and available devices.... Courts must in the end say what is required: there are precautions so imperative that even their universal disregard will not excuse their omission...."

SESSION 2 (P.M. Chairman: D.E. Williams)

PAPER 11 (C.P. Cutler)

Current techniques for the assessment of unstable substances

Q/C **(D.H. Napier)** Does the E.E.C. test give a value for induction time and temperature?

R/A No it does not. It is a dynamic test with increasing temperature -useful when comparing pure materials with contaminated materials.

PAPER 12 (N.J. James, J. Rutherford and G.T. Sheppard)

Zircalloy hazards in nuclear fuel reprocessing

Q/C **(J.H. Burgoyne)** Regarding the case for safety from dust explosion based either upon the ratio of inert (UO_2) to zircalloy dust or upon the concentration of zircaloy dust being below the L.E.L., I would think the former to be the more reliable precaution.

PAPER 13 (W.P. Crocker and D.H. Napier)

Thermal radiation hazards of liquid pool fires and tank fires

Q/C **(J.A. Laming)** Would you comment on the adequacy of the codes as a result of your analysis?

R/A This work arose from discussion with a major H.P.I. contractor -showing confusion about which code to use: API, Factory Mutual, N.F.P.A. - no consistency. Disagreement appears between them for specific cases when spacing tanks (illustrated with examples). We concluded that the codes probably do not do the job - hence the investigation.

Q/C **(R.C. Gray)** To what extent do the codes take into accont, for example, water deluge systems?

R/A Credit is often given but we ignored this in the first instance - credit varies with the code chosen.

Q/C **(A. Mitcheson:** written contribution) Regarding the recommended spacing of storage tanks, am sure that the committees responsible for the various codes would claim the spacings to be based on experience. (a) Can you claim that your computed results agree with data from large scale tests? (b) An obvious weakness in the model is the use of average flame temperature and the ratio of output, radioactive/combustion. Can this be improved? (c) Does the use of average flame temperature make much difference to incident radiation?

R/A Although existing codes arise from experience, the lack of agreement amongst them gives cause for concern (vid. Tables 15 and 16). Models have not been either fully developed or fully validated.

The fourth power dependency of thermal radiation upon T_f, emphasses the importance of this value. In view of the nature of the flame, T_f is usually adequate. This may not be so at ground level and near to the flame. The PSM (η refers) is of limited value (vid. p175) but it provides an adequate estimate in the far field based on T_f.

At this juncture the main requirements are for:

i) a more detailed model that includes variation in T_f and the effects of wind on combustions and of soot formation

ii) measurements of temperature profiles and their variation with time

iii) validation of SFM (and of the advanced model from (i)) against actual fires.

Q/C **(I.W. Clark)** (a) Have you considered any other flame length correlations? (b) Under what circumstances are the quoted formulae valid in terms of fire dimensions?

R/A (a) No, we looked at Thomas and Heskestad (see Refs) (b) - basically the luminous length. Heskestad checked his correlation for a wider range of fuels.

PAPER 14 (R.M.J. Withers and F.P. Lees)

Assessment of major hazards: factors affecting lethal toxicity estimates and associated uncertainties

Q/C **(D.H. Napier)** This is very useful work regarding irritants. Can the approach be extended to materials where the effects change with concentration, eg. metthyl mercury in bread following treatment of the wheat grain.

R/A This may depend on whether the effect is of concentration alone no concentration-time and may be related to metabolism - whether absorbed or excreted. The body can often deal with toxins up to a limit - above which it fails completely. Consideration of effects of solids taken in is already compared by medical techniques.

Q/C **(D.A. Lihou)** Will you comment on the effect of breathing rates? Children and elderly perople probably have a lower rate but are considered at greater risk. Also, the psychological effect of fear can increase the rate by 40%.

R/A Whilst accepting the point made, we have not taken the study far enough to add any more - generally assume 24% of population to be at greater risk.

Q/C **(N.J. James)** (a) For risk assessment, the nuclear industry tends to use a fixed breathing rate - may e realistic since people can't see and react to radioactive release (b) the delayed (stochastic) effects of small doses of potential carcinogens could also become significant in the chemical industry studying very small releases.

R/A (a) During investigations widely varying inhalation rates have been studied. (b) Long-term effects vary as shown by examples: Cl_2 either kills or leaves little permanent harm; Br leaves more permanent damage; HF is worse still; Methyl isocyanate is clearly bad. Cl_2 was chosen for its high toxicity, industrial importance and to be studied in terms of fatalities.

Q/C **(F. Millar)** Following Bhopal, the U.S. E.P.A. provided a monogram (based on computer calculations) to determine risk to communities at specified distances from specified releases, - eg. 2.5lb Cl_2 or 6.5oz phosgene at 200 m. Do you think this useful?

R/A Usefulness of approach is entirely dependent on accuracy of toxicity data - eg. values from 2 sources for Cl_2 vary by an order of magnitude.

Q/C **(J.W. Curtis)** You have defined a method for assessing the range for 50% lethality for Cl_2. Could you compare this distance with that given for "consultation and ratification under CIMAH regulations (Major Hazard Installations) - usually 1000/1500m.

R/A We have not actually done that. We have kept out of actual gas models. Our model given at the end makes assumptions about decay. We can see what can be got from consequence modelling and how it can be used to assess societal risk with regard to physical event and injury models.

SESSION 3 (A.M. Chairman: E.S. London)

PAPER 15 (L.M. Rogers)

The detection and monitoring of cracks in structures, process vessels and pipework by acoustic emission

Q/C **(J.H. Burgoyne)** Would you comment on use of acoustic emission to detect and locate points of discharge of high pressure fluids in vessel and pipelines through joints and seals?

R/A This has identified a well-established application now covered by standards and guidelines - eg. European Working Group on Acoustic Emission, A.S.T.M. Very small leaks to produce high frequency sound similar to micro-displacement processes such as growing cracks. Leaking gas is difficult to locate - can be detected over many metres - possibilities are being studied for offshore installations and in France it is a statutory requirement for PWR's primary pipework. One cannot just use standard equipment - much preliminary work is needed such as identifying the frequency pattern. This may need artificial creating of leaks but there is a great potential for the method.

Q/C **(R. Dooner)** Acoustic emission is often criticised because if there is no emission (say from a vessel) it does not necessarily mean no cracks - was especially true in the early days.

R/A If you get a micro-displacement producing a stress wave it will be detected. If, however, there is plastic deformation as in tensile strength testing of ductile materials emission will not be detected until the piece falls. Brittle fracture modes of course will produce a "big bang" with early warning. In structural steels micro-cracking associated with heat effets and triaxial stresses in thick walls are always detected.

Q/C **(S.D. Brown)** Are the advances in recognising characteristic data from very noisy data finding applications in detecting faults in bearings of rotating machinery?

R/A Yes is is generally possible to resolve the emission produced within the perimeter encompassing the array from outside noise. The system is sensitive to particles of grit in hydraulic systems, journal bearings and it detected for example a failure of a high tensile stud holding a specimen.

Q/C **(D.H. Napier)** (a) What number and array of transducers are required for a complex steel structure? (b) Noting that emission is detected several metres away, over what distance would a pipeline fluid leak be detected?

R/A This raises a number of questions. For a large structure, the problem is one of sampling. In the example of the large vessel, the Dept. of Energy stipulates a detailed inspection of 25 welds every 5 years - ie. a branch-to-leg weld of which there are 9 per mode and 256 modes. So the problem is one infinitessimally small sampling. Acoustic emission could give 10x the coverage with a reasonable number of transducers. A minimum of 3 transducers are required for triangulations and with complex filet welds or box structures the transducers need very careful spacing. We avoid spacing of more than 3m or sound travelling 3m to reach 3 transducers. With slightly more advanced cracking, secondary emission arises from friction between two surfaces - hence emission level and number of frequencies increase. With cracking advancing to fractions of a mm rather than grain size, just one transducer per mode is needed and in case of pipeline (continuously welded) 50 to 100m distance is possible. Equipment can receive signals from 32 transducers and if 2 are hit by the source 1-3km could be monitored.

Q/C **(R. Dooner)** After installation of system, do you retain control or leave it to the operator?

R/A You retain control - all support services retained onshore this influencing design. A very high level of data reduction and diagnostics are built in and artificial sounds have to be created for checking -black box, data logging, high intelligence, minimum supervision, linked to shore via satellite. The chief maintenance engineer on shore can call up any part at any time.

Q/C **(V. Sender)** In aggressive environments (eg. pulp industry) plastic construction is used but plastics age and corrode creating hazards. Is acoustic emission applicable?

R/A In reinforced plastics AE is used widely as they are intense emitters. But for plastics alone, totalising transducers are necessary to detect a wide range of effects whichare not strictly the type of emission arising from metal cracking.

Q/C **(R.C. Gray)** Have you any experience of detecting ammonia-induced SCC growth to show when such cracks grow in the commissioning and day/night operation of ammonia storage spheres?

R/A We have good experience of detecting nitrate-induced SCC in boiler plate steels - a very good process to study.

Q/C It seems then that the technique would show when crack growth is taking place in ammonia spheres. (Agreed).

PAPER 16 (A.S. Fulton and D.J. Barrett)

PES - an opportunity for better safety systems

Q/C **(P. MacDonald)** You mentioned an approaching common mode failure via a drifting voltage on a low voltage power supply. Please say how close the approach and how the problem was detected?

R/A Problem occurred because of bad earthing on 24V supply external to the computer. A whole group of inputs went low and a series of alarms went off. Controls went out of the envelope of operation and the process shut down.

Q/C Did you expect that situation?

R/A We investigated the problem and corrected it by better installation practice so that it cannot happen again - the fault being external to the programmable system.

Q/C **(S.D. Brown)** Experienced a similar failure with a Texas sytem where: (1) all analogue siganls failed to 30%, (2) all signals oscillated betwen closed and open. In both cases, self diagnostics failed to close down the system.

R/A There is a problem with Texas. We have a unit where we feed key outputs back to the input together with an external timer which "pulls the plug" if the system fails to recognise the fault. It requires an input for every output that needs checking.

Q/C **(P. Baybutt)** Do you use fault tolerant approaches now used in military installations?

R/A We use our own fault tolerant software - so that if any software fails the other one comes in. This is really programming fault tolerant system - also tolerates a processor fault but not, obviously, an input fault.

Q/C **(L.M. Rogers)** Regarding the measurement equipment reliability, the problem is not one of detecting error and fault conditions using watchdog or self-check routines but deciding which of these fault conditions are potentially fatal and should be brought to the operator's attention, and those which can simply be noted without affecting the process control or monitoring funtion of the equipment.

R/A Commercial systems have been watchdog systems. If processor does not complete all tasks successfully, the last thing it does is re-set the watchdog timer. If this fails, all the outputs are set to fail-safe.

Q/C **(J.M. Morgan)** I'm not quite so optimistic about computer (or PES) control. Do you feel that the major benefit is that the operator becomes more involved with the operation by being provided with information on process transgressions? He can thus take remedial action before the plant enters trip condition - ie. it provides better alarm handling facilities.

R/A Yes we have put PES into closed-loop systems where the operator was previously in the loop - thus freeing him from the situation so he can think about the operation. We also provide derived information.

PAPER 17 (D.B. Pratt)

The fire and explosion hazards of hydraulic accumulators

Q/C **(J.H. Burgoyne)** What degree of compression of the enclosed air would take place during the normal functioning of the accumulator.

R/A The amount of fluid involved is small (say) 50 gal. so the pressure change is only a few psig - not enough to cause adiabatic heating particularly with the large heat sink.

Q/C The latter would not be significant.

Q/C **(A. Mitcheson)** A colleague who investigated the Lakenby incident thought it more likely that a combustion event occurred inside the vessel - some form of flame propagation process - rather than a pool fire. (a) Did you estimate the rate of volume increase due to a pool fire and compare it with the relief valve capacity? (b) In such fires generally, how does one size the relief valve?

R/A The theoretical relief rate was estimated but I have no details. it is very difficult to calculate for a fire inside a vessel of that type -bad enough for a process vessel.

Q/C You are looking at either one of two different events: pool fire or flame propagation process. The pool fire is easier to deal with.

R/A Unlikely any standard relief valve would be satisfactory for the latter - many valves may be needed. A method may come from long term studies. We prefer to look at control rather than multiplicity of values, possibly ineffective.

Q/C **(R.C. Gray)** In view of small change in level is it possible to separate the oil from the air by a membrane?

R/A Yes, a possibility for small vessels at least but the engineering of it for large high pressure vessels would be very difficult. In some cylindrical vessels a piston can be used but there is a difficulty due to liquid getting past it. In our research it is too early to go down that road!

Q/C **(R.J. Evans)** A pool fire in these conditions is different from one in the open - by increasing the pressure, the fire will self-accelerate to a very high rate. This is the possibility that further heating is caused because the compressor keeps running.

(Chairman) There was evidence that heating occurred for a measurable time before the burst.

R/A Yes this is so.

(Chairman) If there is a pool fire, what is the cause of pressure rise?

R/A The products of combustion plus evaporation - agreed that this led to a 3x increase.

PAPER 18 (S.P. Whalley and J.K. Maund)

Improving human reliability by design

Q/C **(B.W. Robinson)** In hazard studies would use 2 extra words: for delay, "later than" and use "sooner than" to identify situations that may not otherwise be.

R/A Yes, good!

Q/C **(D.A. Lihou)** People are generally using these terms now. There is a danger of subjective judgement in selecting P.S.F.'s Guide, needs to bring us to a concensus view.

Q/C **(K.R. Davies)** Did you apply weighting factors?

R/A Attempts to apply weighting to the situation - eg. type of indidivual response expected; errors likely. This produces a cascade effect through to the individual P.S.F. associated with other causes. One error causes a particular P.S.F. Look at those P.S.F.'s coming up most frequently and relate to each task. This will show which P.S.F. will mostly contribute to the error in that situation - then one can allocate effort to get it right.

Q/C **(M.C. Jones)** (a) Is there any experimental evidence relating P.S.F.'s to performances? (b) How could data acquisition be improved - eg. from plant records?

R/A (a) Have not been able to correlate rigorously but some have related, others only hypothesis. We do need to go back to the laboratory for basic research. (b) More information relating to human performance needs to be recorded in a systematic way - as we do for equipment performance. In accident reports there is a list of information about the accident circumstances but very little about normal operation.

Q/C **(G.B. Whyte)** (a) How can you build into the equations the person's intelligence? (b) If a PSF is "wrong", how is this fact fed back into the system?

R/A (a) We need to stress the positive effect of a person's intelligence rather than the negative (making mistakes). (b) We are trying to establish a computer program that will enable us to feed this information back following the setting-up of a data base.

Q/C **(D.A. Lihou)** After examining a number of cases I have identified effects of poor management and of procedures which have been allowed to slip so producing negative P.S.F.'s - quite unexpected at design stage. It is important to highlight the impotance of these in the HRA.

R/A So far we are looking at faults and accidents that have occurred. The purpose is to identify P.S.F.'s that can be taken into account at design. A P.S.F. can be either negative or positive provided we design so that it will have no effect or least a positive effect.

Q/C **(H. Farari)** I believe that P.S.F.'s should be divided into design and operation sections - it is dangerous to generalise them.

Q/C **(P. Baybutt)** (a) Many factors affect P.S.F.'s; what uncertainties are handled by HRA? (b) What about cognitive modelling? (c) Can you comment on the positive role of operators?

R/A (a) I am trying to give guidance to designers so a different use of P.S.F. than human error. What aspects can have an effect on performance? How people tend to make the same sort of error when in the same situation. I try to link factions back to human error to analyse "what would you expect to happen?, does it matter?" (b) If it is an error, can it be linked back to certain causes. This is not traditional cognitive modelling but an attempt to introduce the idea that the way we look at things has an effect on our actions. When we work up to judgement processes we are in the cognitive modelling area. (c) Yes, we do need to look more at the positive role but so far have looked mainly at the negative. This brings in the psychologist (which I am not).

Q/C **(K.R. Davies)** I believe that the main problems affecting human reliability are outside factors (eg. domestic circumstances). Did you identify P.S.F.'s as the major factor relating to human reliability from the Albright's accident data?

R/A Without commenting on Albright's data, I agree that outside factors are important. Whilst I have been looking at factors that can affet design, I see the outside factors as a managerial problem. People who have had a bad day at home might well have to be relieved of certain responsibilities when hazards are concerned. In fact some airline operators are already doing this for their pilots.

Q/C **(D.A. Lihou)** It is often not so much the person but that certain management procedures have slipped. There is a balance between positive and negative P.S.F.'s. Good design will increase the positive, poor management will increase the negative - eg. a man repremanded for dangerous practice stated that this was normal practice and examination showed the instruction totally inadequate. We must ensure that positive P.S.F.'s right down the line (design-operation) are applied.

Q/C **(H. Farabi)** The P.S.F.'s must be related to the type of person who will operate the process.

R/A That is why it is important to look at total plant systems including selection procedures - meaning that, if you have designed for a particular sort of person, that sort must be used. If not possible, re-think the operation - that is the responibility of management.

PAPER 19 (M.S. Jones and D.A. Lihou)
CAFOS - the Computer Aid For Operability Studies

Q/C **(J.M. Morgan)** Other programs have been developed to automatically construct fault trees - eg. RIKKE (Risϕ, Denmark), FAULTFINDER (Loughborough University). Main drawback is their inability to effectively deal with the two-way propagation of process deviations. Can CAFOS deal with such events?

R/A At present it cannot do so. We are grappling with the problem of the best representation of process information to overcome the problem - whether propagation is forwards or backwards.

Q/C **(H. Farabi)** (a) Why do you use codes (numbers) when you might find it easier to use string variables? (b) Why did you choose the value '10' as a limit for your repeated events?

R/A (b) '10' is an arbitrary number. The computations through the whole tree is 2^n where n = number of repeated events (ie. 1024). If we took n = 15 many more computations are required.

Q/C You could investigate whether taking (say) 5 or 15 would make any significant difference to the result.

R/A '10' is a number one would not like to exceed if one is to get computing efficiency. One could choose a value by other criteria. (a) One can translate from code at either input or output and it is better to compute in code and then change to the variables from the H and O studies.

Q/C **(Lihou)** It is relatively simple to have two tables of codes: one as indicated in the paper and one relating to equipment. It is less confusing and much quicker to write down numbers rather than letters -where one has to choose which letter or combination ot use. Much depends upon personal experience and the amount you use the system.

Q/C **(S.D. Brown)** How are failure rates (events/year) converted to probabilities for quantification of fault trees when using CAFOS?

R/A The probability of failure is related to the time not working, ie. fractional dead time. There can only be one continuously operating item coming into an "AND GATE", the rest "AND GATES" must be fractional dead times.

Q/C Your time base may not keep changing, eg. a component with a failure rate more than once per year, what would probability be?

R/A If failure rate was say 5 per year, the probability of failure is $100e^{-\lambda t}$.

PAPER 20 (P. Baybutt)

Decision support systems and expert systems for risk and safety analysis

Q/C **(J.M. Morgan)** (a) Why did you choose IBM PC for developing CADET? (b) Was the software written in-house or otherwise?

R/A The IBM PC is the standard PC in U.S. including APPLE and nearly every computer is IBM PC compatible - also adopted by Battelle, and NRC have formally adopted it. It is not an EXPERT system. The program was written in BASIC but we will probably re-write in MODULAR 2 or C - application languages for PC.

Q/C **(H.F. Hopkins)** The CADET system contains much information and incorporates results of studies and experience. What man effort was required to produce it?

R/A About 2 man-years. However it started as a research project - much effort going into examining possibilities and ways of doing it before actually writing it. Probably 1 to 1.5 man-years went into it and a similar program now, in a different area, would require less effort.