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A USER'S VIEW ON THE DATA OBTAINED AND THOSE WHICH MAY STILL BE REQUIRED

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Summary

This paper was written from the point of view of a user to indicate possible requirements in the field of modelling Heavy Gas Dispersion and with particular reference to the Thorney Island tests. A vast amount of data has been obtained, but great care is needed in its use, interpretation and application. Many further problems remain to be solved, most usefully in wind tunnels, but the release mechanism may require some full-scale testing.

1. Introduction

When invited to present an overall review paper on the subject of the Thorney Island Heavy Gas Dispersion Trials, it seemed difficult to avoid repetition of much material given in the many papers presented at the Symposium and reproduced in this volume. It did however become clear that not only was there great variety of topics, but there was also a considerable spread in viewpoint and motivation. So it was thought appropriate to review the tests and the papers with the long-term objectives in mind.

In doing so, it has possibly clarified uncertainty over some issues where objectives tended to be divergent. It has also highlighted the benefits of considering the subject at large with some significant degree of cooperation involved, both between countries and between disciplines and interests. This was particularly evident to members of the Technical sub-Committee throughout Phase I, where such cooperation was invaluable in the critical decision making stage. This must be an object lesson to others considering experimental work on this scale, since the success of such work relies as much to the cooperative contribution as to the finance itself. It is far easier to waste £1.5m than to spend the same sum effectively.

2. The sponsors

About 40 organisations, world wide, have sponsored either one or both of the two phases of the Heavy Gas Dispersion Trials organised by the

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Health and Safety Executive and conducted by the National Maritime Institute. These sponsors have a wide range of interests, and their involvement has come about for a variety of reasons. An attempt is made in this paper to give a broad overview on the tests as seen from the point of view of the sponsors. Clearly no single paper could ever hope to capture the wide variety of viewpoints, and also this paper could never speak authoritatively for any of the sponsors. Nevertheless, during the course of the trials, discussions have shown up some of these views, and the opportunity is taken to discuss in more detail some of the aspects which appear to have been important.

About half were manufacturing companies. About a fifth were either national or local public authorities having either a direct or indirect responsibility for public safety. Finally there were other organisations falling into neither of these two categories.

Of the manufacturing companies, the majority if not all are engaged, at some point in their operations, in the handling of flammable gases. The lower flammable limit (LFL) for flammable gases is normally above 1% by volume, so that risks in their handling are associated with at most a 100 fold dilution in the atmosphere. Past experience has shown this to be achieved relatively close to the point of release, at least when this is compared with toxic risks. Hence the majority of sponsors are interested in the region close to source.

Toxic risks could be very significant at concentrations as low as 10 ppm, and occasionally lower; so dilution in the atmosphere by 100,000 fold can take place before effects become insignificant. This is about 3 orders of magnitude greater than for flammable risks, and extends the safety interest in dispersion out to correspondingly greater distances. It was well known that at such larger distances the excess density plays an insignificant role, nevertheless the transition zone in which density ceases to play a significant role has been the subject of much debate, and thus there has been some interest in this aspect.

3. Test source

One of the first questions that needs to be asked about the trials is the relationship of the test source/release to those that may occur or indeed have already occurred in major accidents. The size and type of release that is possible in the oil, gas and chemical industries at the present time varies tremendously.

In Table 1 is given an outline of such a spectrum to illustrate the possible range. Clearly no set of tests at Thorney Island could ever hope to cover even a few of these, but the type and scale of release tested in these trials, together with earlier tests at Porton, Maplin Sands and China Lake, do cover part of the spectrum. There are however other parts of this spectrum where our knowledge is limited, especially when it comes to the

TABLE 1

Potential scale of releases that may occur in the oil, gas and chemical industries, based on typical vessels and installations

Type and Scale of Gas Release	Transportation			Fixed Installation	
	Marine	Land	Pipeline	Offshore	Onshore
Instantaneous					
10000 t	a				a
1000 t	+				a
100 t	+				+
10 t	+	+		+	+
1 t	+	+	+	+	+
Continuous					
10000 kg/s	b		b	b	
1000 kg/s	+		+	+	
100 kg/s	+		+	+	
10 kg/s	+	+	+	+	+
1 kg/s	+	+	+	+	+

[a]Large sudden releases of the order of 10^3 or 10^4 t are unlikely to occur over such a short period as to be effectively treated as instantaneous.
[b]Continuous release of 10^4 kg/s are unlikely, though releases of over 10^3 kg/s are possible in the initial stages.

largest sizes of releases (although these are also likely to be less probable than smaller releases). For reference, the Porton tests might be considered to correspond to a release of about 0.1 t of hazardous material and the Thorney Island tests to about 5 t of hazardous material. They are therefore several orders of magnitude below the largest credible releases from current sizes of pipe or vessel. The extensive extrapolation involved for the largest releases is therefore very uncertain, and there have been several authors who have suggested that other important mechanisms might occur on such a scale. At Thorney Island it was obvious that the dense low-lying cloud tended to move more slowly than the lower levels of the atmosphere even after acceleration from rest. A dense cloud several orders of magnitude larger would be expected to have a more profound effect.

One of the minor defects at Porton was the retention of the solid top to the cube which appeared in some releases to affect the slumping of the gas from the stationary state, and the removable cover at Thorney appears to have overcome this. An important problem of testing still to be understood is that of wake turbulence due to the presence in the air flow, right up to the moment of release, of a solid object some 14 m diameter × 14 m tall of circular plan. This is an important problem and the effect caused by the release of gas into a turbulent wake requires to be understood since it is essential to the proper verification of models used for predictive work.

In real accident situations, the instantaneous release usually produces a large gas cloud (containing air entrained during release) which, from unrestricted surroundings and position of orifice, would be expected to be spherical.

The initial cloud after release of 38 t of ammonia at Potchefstroom [1] was estimated at 350,000 m^3. If produced from an unobstructed source close to ground level, a hemispherical cloud would be expected, and this would have a radius of about 55 m. Compared to the size of tank this came from, the cloud would be expected to be largely in the free air flow. Consequently the wake from the tank would intrude into only a very small part of the cloud, so its effect would be marginal.

4. Instantaneous or continuous release

Much discussion took place during the planning stage whether or not to include continuous releases. It is perhaps worth mentioning some of the background problems to this. From the practical point of view, the original gas producing plant at Thorney Island could produce only at the rate of 2000 m^3/h, or about 1.4 kg/s for gas of density 2 relative to air. Such releases are relatively small, and could be discharged from suitable diameter pipe at little more than the velocity of the atmosphere. Thus the degree of air entrainment into the plume would be small, but the plume would also be small, and would slump rapidly due to its gravity effect, to the extent that it would probably be extremely shallow. The gas detectors would require extensive redeployment to measure this low-lying cloud, coupled with precise calibration of their true height above ground.

If the outlet nozzle were restricted to provide for a jet release, additional mixing in the turbulent jet would result, but the operation of the gas plant would be complicated and would require some reconstruction.

In practice the largest continuous type releases are invariably from pressurised sources, e.g. long pipelines or large holes in large pressure storage vessels, so turbulent jet discharges will always occur. In the case of the very largest, the rates cannot be sustained but will decay. It begs the question at what rate they should be considered in a risk assessment, or whether the effects of the first 5, 10, 15 s or so discharge should not be considered as part of the development of a large "puff" release. One could for example consider such releases initially to be "quasi-instantaneous" for as long as the cloud moves upwind by expansion forces as opposed to gravity forces. It is important to realise that if instantaneous were to mean a fraction of a second, there is in fact no truly instantaneous release.

5. Meteorology

At the time of selection of Thorney Island as the trials site, the project Technical sub-Committee were involved in a considerable discussion on meteorological classification schemes. A large number of these exist, and have been discussed elsewhere at the Symposium, but it was agreed that for the purposes of the trials data, all relevant information would be recorded for subsequent detailed examination. These data are now recorded, and are available for more detailed study.

As expected there has been a wide scatter in air stability classification obtained in each trial according to the method of assessment followed, and a problem very clearly exists. However it is worth examining the objectives of different models since this will help in deciding the appropriate method in many cases.

The more sophisticated hydrodynamic models are based very largely on an extensive treatment of turbulence. For these, stability classified by a method based on turbulence is a necessary choice.

The box or top hat model, being essentially a very much simpler model is frequently used for hazard analysis and risk assessment work. Much of this is of a predictive nature, assessing the chance for instance that a cloud of a particular concentration will extend a certain distance in a declared direction. Estimation of the probability of this occurrence is based largely on the recorded statistics of such weather conditions occurring. Such statistical data exist in many countries, being prepared usually by the national meteorological office from routine observations. The system used is usually based on Pasquill [2]. To use a box model for predictive assessment work requires the inclusion of statistical meteorological data, and to date this requires such models to be consistent with the Pasquill treatment of air stability.

In 1983 KNMI, the Dutch National Meteorological Institute, set up pilot schemes to record weather data at selected stations classified by other systems. It will be some years before enough data exist to allow this changeover to occur, but at least additional data collection has started. It will also be possible in the KNMI scheme to compare the results of using different methods over extended periods.

6. Measurement of concentration

Very considerable efforts were put into the development, selection and operation of an instrument array that would "capture" with adequate resolution the variations in concentration to be expected during the passage of a cloud. It was obvious from the Porton tests that improved time resolution was required, and the way it was achieved is described in another paper [3]. The discussion here will focus on what was achieved, and what it really means — often it means something different from what was intended or expected.

The use of a computerised data collection system enables a large number of sensors to be monitored and recorded at a frequency of 20 Hz. The majority of gas sensors have a frequency response of only about 1 Hz so that the data collection will be faster than the basic instrument speed. Hence with about 25 Mbytes of recorded data per test, much of the data are superfluous and the need for a data tape holding reduced data is obvious. It is, however, necessary to understand how such a tape was prepared when using data from a "reduced" data tape.

In the case of a continuous release, it should be possible, using reduced data, to produce a mean value averaged over whatever period is of interest, but usually of at least 3 minutes. The statistical variation in this mean can also be derived, and it would be expected to show up just how steady, or otherwise, the concentration at a point is. In comparison, models used for the prediction of dispersion from continuous sources predict only one value for the concentration at a point. This value has always been accepted as a mean value and as such has presented difficulties for assessment of ignition limits for flammable gases. One of the benefits of testing continuous releases will be to provide some very important data to assist in resolving this problem.

The problem of variation in concentration is much more complicated in the case of instantaneous releases since the concentration is expected to rise and fall as the cloud passes the detector, and as has been witnessed in the tests, the structure of the cloud is far from uniform albeit with a certain degree of symmetry. Again very short term peak concentrations are of importance for assessment of ignition risks, but the mass of material inside the flammable region is also required. Ideally the latter might be assessed if the entire cloud were to be measured at a very large number of points virtually simultaneously. The problem arises due to the absence of detectors in most of the cloud, and it is therefore necessary to assess this value from a limited set of observations. The reasoning behind interpretations of this type would help others in assessing the use of models for hazard assessment from flammable releases.

The problem is less complicated for toxic gas releases, at least as it affects the examination and interpretation of concentration data. Even the averaging time of 0.6 s for the reduced data is considerably shorter than any exposure time of interest, limiting the problem to choice of a longer averaging time. Griffiths and Harper [4] have drawn attention to the problem of intermittency in a toxic gas cloud which can affect the toxic dosage received. They suggest that the dosage affect when so integrated may be more critical than the simple averaged *ct* dosage. Whilst this may be true, it is vital that the same approach is also adopted when measuring the concentration of exposure, i.e. it will also require estimation of the intermittency and the concentrations experienced when the cloud is present in addition to any mean value. Thus their treatment is only valid if intermittency is similarly considered in both cases, concentration of exposure and toxic dosage.

For some time now the detailed examination of varying concentrations has occasionally been dealt with on the basis of peak/mean ratio. The current tests indicate that the peak value could be one data record, or a set of 12 values averaged over 0.6 s, or some other ensemble. More clarification of this issue is desirable, although the results from China Lake, Fig. 15 of [5], clearly indicate that the ratio is considerably greater than many expected, and more important it too exhibits a wide variation. It is worth pursuing if only because it may provide more useful information in respect of flammable clouds from the simpler models. Caution in use is obviously necessary.

7. Review of accident reports

Much interesting and useful data can be gleaned from the wide variety of reports which have been published on major accidents. Much of the older information of relevance was never properly understood at the time, but with hindsight it sometimes proves useful. Quantified data usually were not provided, although details of the source were often given which would now provide a better definition of release rate, the form of the release and its initial development into a cloud. But the absence of quantified data on the cloud dimensions rather nullifies any potential gain.

In a few isolated examples, there are enough data to make some crude match of release/source term with the cloud dimensions and/or effects. Two particular types stand out. First, flammable clouds which have ignited leave behind their telltale burn marks. This prompts the question to what concentration of flammable material does this correspond. The complications to be considered are the lack of homogeneity in the cloud, its intermittency as regards the presence of gas at or above its flammable concentration, and the temporal aspects such as the expansion of a deflagrating cloud. Nevertheless, there is potential for deriving useful information. Another important feature in this instance is the frequent lack of cloud symmetry caused by the additional factors affecting the development of the cloud source and its dispersion, e.g. the effects of obstructions. Two very interesting examples are those of the explosions at Flixborough and at Beek.

The second distinctive feature arises from clouds which do not deflagrate (even if flammable) but which attack plant life. There are in existence for instance excellent aerial photographs of the "bleached" ground in the vicinity of the ammonia truck release at Houston in 1976, the chlorine rail tank releases at Montanas, Mexico in 1981, and an ammonia pipeline release at Enid, Oklahoma. Two particular complications arise, firstly the concentration or dosage required to bleach chlorophyl or to attack certain species of plant has been unknown but is being investigated; and the temporal variation in concentration of a cloud being dispersed in the atmosphere requires more detailed data.

From the point of view of the Thorney Island tests, one is left with two key problems requiring resolution if such accident report data are to be used. Firstly, the influence of obstructions, which may not only deflect a gas cloud into a different direction (whilst perhaps not affecting its total area of downwind dispersion), but may also positively enhance dispersion through added turbulence. Data from Thorney Island Phase II will provide some very positive leads in this respect. The second problem is the temporal distribution, but with detection at a frequency of 20 Hz, subject to instrument response times, some better calibration of cloud concentrations should be available. However, these are only available for the specific sensor locations, and only perhaps one or two sensors for part of the cloud passage will be recording the particular concentrations close to notional LFL values of interest.

One must conclude therefore that very careful consideration requires to be given to the way in which the type of data produced at Thorney Island can be utilised in improving our understanding of real accident conditions.

8. Validation

One of the problems that has existed in the past is the wide variety of predictions of dispersion that have been possible. This was highlighted by the seven predictions of the maximum distance to the flammable limit from the release of 25000 m^3 LNG which ranged from 1 km to 50 km. These were reviewed in 1977 by Havens [6] who suggested reasons why the extreme values were untenable. Much of the further work at the University of Arkansas has stemmed from this initial review, and has concentrated on close examination of models and of test data, and their comparison.

For a mathematical model to be credible to a company or authority, it is necessary to have better confidence in the model used than was often possible in the past. However, as well as the early models improving over the years with further development, many new models have appeared and it has reached the stage where it is necessary to sort the sheep from the goats. Increasingly evidence of validation is sought and even demanded. What then is "validation"?. It means different things to different people, but bearing in mind the problems of variability within any defined common ensemble, a more general approach is needed. Blackmore et al. [7], when discussing some models, summarised in their Table 2 the types of comparison which have been claimed, but it would be necessary to refer to original papers for the details. Clearly some such demonstration is required, and from discussion with many modellers, it would appear that it is essential to demonstrate reasonable comparison with test (or accident) data over a wide range of conditions, e.g. of air stability, wind speed, and release size, in order to be sure that the applicability of a model is not restricted to a narrow set of conditions.

How close this comparison should be before acceptance is of course debateable, but this should normally be within an order of magnitude (which will eliminate a fair number of current models), and probably for most conditions it should be a lot closer than that. In any event, the comparison made, including details of what data are used in the comparison, will require documentation enabling a satisfactory examination and understanding to be made by those who will use the results. Those who use models without such a documented comparison may find that these models may be declared unacceptable.

9. Wind tunnels

Subsequent to the Porton tests, several organisations conducted in their wind tunnels repeat tests modelled on the Porton 40 m^3 cube.

Some of these examinations have given clear indication of the basis on which reasonable reproduction of full-scale tests can be made, but as always care must be taken not to extend this too far outside the region in which comparison has been made. One obvious difficulty comes in reproduction of air stabilities far removed from the neutral conditions of the great majority of wind tunnels. Another is in the lower limit to scaled wind speed, although true calm conditions can be reproduced.

Once a wind tunnel has been adequately calibrated against data from the several series of full-scale releases, it presents a major opportunity to progress very much further at reasonable cost, especially the ability to repeat tests as and when required. A further major advance in this work is possible with the introduction of digital image processing in conjunction with lasers. The particular advantages here lie in the rapid concentration data collection for any combination of two variables out of the three parameters x, y, and z, and for the ability to repeat a large number of times in order to establish variance. This is a major advance on the use of only a few cumbersome detectors each with its own sampling delay and problems in interpretation.

Wind tunnels are undoubtedly the best way forward, and one would expect that each organisation involved will follow its own particular approach, be it obstructions, density, variance etc. One of the outstanding advantages is the opportunity to model specific locations which is something virtually impossible to do at full scale. To be useful to others in this field, it would be considered essential for all experiments to establish properly and carefully their own tunnel's correct scaling characteristics, using the full-scale data now available, and to present their results with the reasoning and assumptions displayed.

10. Conclusions

There is no doubt that the heavy gas dispersion tests at Thorney Island have been a success. True, the amount of information which is immediately useful to the many who sponsored them may be restricted, particularly to the photographic aspects, but there is apparent confidence that a tremendous amount of high quality dispersion data has been recorded. This may take years to assimilate in full, as others have found at Maplin and China Lake beforehand, but the many objectives sought by the wide variety of sponsors will be largely satisfied now or more probably later.

Since the tests were of necessity conducted under only a few types of condition, e.g. atmospheric or topographic, there is a need to extend the knowledge more towards the enormous variety of situations likely to arise in practice. Those variations involving topography, obstructions, density etc. can be investigated further in (calibrated) wind tunnels in a way which is not possible at full scale. However, one of the major outstanding problems that will require solving in some other way, preferably at part or full scale, is concerned with release mechanisms. These can have such a profound effect on the type of source to be modelled for dispersion that it is necessary for this work to continue. It would be a positive recommendation for any group of experiments to concentrate on establishing better data on a variety of release mechanisms, rather than on general dispersion aspects which would currently be more cost effectively researched in wind tunnels.

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