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WIND TUNNEL MODEL COMPARISONS WITH THE THORNEY ISLAND DENSE GAS RELEASE FIELD TRIALS

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Summary

The report describes comparisons made between the field trials of a suddenly released cloud of dense gas carried out at Thorney Island during 1982/83 and wind tunnel model experiments. The model experiments were a validation exercise made previous to the trials mainly as a simulation of similar field experiments made at Porton Down, but some were sufficiently close in type and operating conditions to allow comparison with the Thorney Island trials, also as a validation exercise. The project was funded by the Health and Safety Executive as part of their research programme into accidental releases of heavier-than-air gases of a hazardous nature.

Notation

g	acceleration due to gravity
k	molecular diffusivity
H	weight of source container
L	length scale
Re	Reynolds number $U\rho L/\mu$
Ri	bulk Richardson number = $g\,(\Delta\rho/\rho_a)H/U_r^2$
T	time
U	wind speed
$U^\star$	Friction velocity, appearing in logarithmic wind profile equation $U/U^\star = (1/0.4)\ \ln\ (Z/Z_0)$
U'	root mean square of velocity fluctuation in wind direction
X	distance along surface in wind direction
Y	distance along surface normal to wind direction
Z	height above surface
Z_0	aerodynamic roughness height appearing in logarithmic wind profile equation (see above)
ρ_a	air density
ρ_g	released gas density
$\Delta\rho$	$\rho_g - \rho_a$
μ	viscosity

1. Introduction

In some previous work [1] a wind tunnel model comparison was made with field trials of a suddenly released cloud of dense gas, carried out at Porton Down, the object being to validate the wind tunnel model of a much larger scale event. Within the limits of accuracy with which such a comparison was possible, the results were generally satisfactory. The wind tunnel appeared to produce a very realistic and reliable model of the field trial. However, because of the relatively small scale of the Porton trials and the limited nature of some of the measurements, particularly of concentrations within the cloud, there was felt to be a need for further comparative work.

At the time the model experiments were being carried out, plans were being considered by the Health and Safety Executive for the much larger scale field trials at Thorney Island. The proposed form of release was very similar to that of the Porton trials, a release from a cylinder of approximately equal height and diameter at Thorney Island compared with a cube in the Porton trials. The experiment was therefore extended to include predictions of the Thorney Island trials for a number of hypothetical operating conditions as part of a general request by the HSE for model predictions of the results of the trials. In the event, the actual trials did not produce precisely the hypothetical conditions previously modelled. However, the combination of model data for the Thorney Island trial predictions and the Porton trials covered a considerable range of operating conditions and, on investigation, it was found that particular model experiments could be matched to five of the Thorney Island trials on a Richardson number basis to an accuracy of around 10%. It had been found from the earlier experiments that, within the accuracy of the measurements, Richardson number appeared to be the major governing scaling parameter of the flow. It was found in each of these cases that a number of concentration measurements had been made sufficiently closely in position between model and full scale to be worth comparing. Thus it would be possible to compare cloud appearance, growth and travel rates and internal concentrations. This has been done and the results are described in full in [2]. The present paper is a resumé of this work and presents a representative selection of the results together with the full conclusions.

2. Details of comparable trials and basis of comparison

The Thorney Island trials that could be compared with the earlier model experiments were Trials 7, 11, 13, 15 and 18. Essential details of the operating conditions for these trials are shown in Table 1 together with the model experiments to which they could be matched. The table also shows the differences in bulk Richardson number between model and full scale, a typical value is around 10%, the largest being 12.8%. These differences were not thought to be large enough to affect the comparison in any major way. Trials 13, 15 and 18 are all of similar bulk Richardson number and are suffi-

TABLE 1

Operating conditions for Thorney Island trials and comparable model experiments

Thorney Island trial							Wind tunnel model, 1/90 scale						
Trial No.	Stability	Wind speed at 10 m height, U_r ($m\ s^{-1}$)	$\frac{\rho_{gas}}{\rho_{air}}$	$\frac{\Delta\rho}{\rho_{air}}$	Z_0 (mm)	Bulk Ri $=\frac{g\Delta\rho H}{\rho U_r^2}$ $H = 12.6$ m	Ref. No.	Wind speed at 110 mm height, U_r ($m\ s^{-1}$)	$\frac{\rho_{gas}}{\rho_{air}}$	$\frac{\Delta\rho}{\rho_{air}}$	Z_0 (mm)	Bulk Ri $=\frac{g\Delta\rho H}{\rho U_r^2}$ $H = 140$ mm	Ri difference from full scale (%)
7	E	3.2	1.78	0.78	10	9.4	T33	0.425	2.08	1.08	0.4	8.2	−12.8
11	D	5.1	2.03	1.03	10	4.9	T29	0.895	3.56	2.56	smooth wall	4.4	−11
13	D	7.5	1.96	0.96	10	2.1	P3	0.84	2.0	1.0	smooth wall	1.9	−9
15	C/D	5.4	1.41	0.41	10	1.7	P3	0.84	2.0	1.0	smooth wall	1.9	−11
18	D	7.4	1.87	0.87	10	1.9	P3	0.84	2.0	1.0	smooth wall	1.9	0

ciently closely matched to be considered as repeat runs of the particular operating condition. They are all compared with the same model experiment and thus form an interesting set of data which gives some impression of repeat run variability in the trials.

Only essential details of the trials and wind tunnel experiments are included here. Full details of the trials can be obtained from the HSE [3], a resumé can be found in [4]. Full details of the wind tunnel experiments and the methods of scaling used can be found in [1], a resumé can be found in [5].

Since the model experiments were designed to reproduce the Porton trials exactly, rather than those at Thorney Island, there are some differences between the model and the Thorney Island trials which require further comment.

The shape of the heavy gas source in the model was of a cube (of 140 mm side) with collapsing sides, the top remaining fixed in place during a release. The precise shape of the source for the Thorney Island trials had still to be decided when the model experiments were carried out, but finally took the form of a near cylinder (a twelve-sided polygon) 14 m across and 13 m high. During a release the flexible top cover was withdrawn by collapsing it into a bundle. Sketches of the two gas sources are shown in Fig. 1.

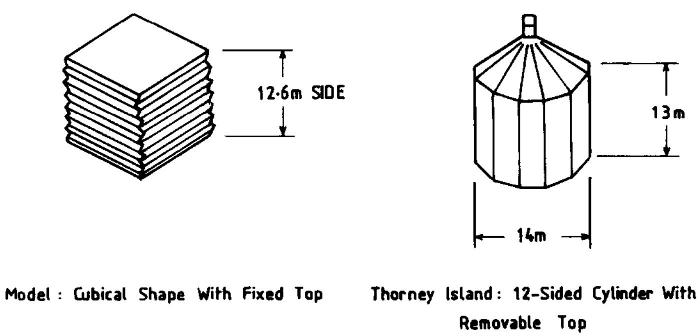


Fig. 1. Model and full scale gas source containers.

Scaled on a basis of the volume of heavy gas released, the model scale became 1/90 and the equivalent size of the model source was of a cube of 12.6 m side. Thus the model source had a slightly lower aspect ratio than that of the trial. In principle the aspect ratio of the source is important, since its mean height governs the initial potential energy of the gas cloud and thus affects the strength of its density driven flow component, but in the present case it seems doubtful if the small difference between model and full scale is significant.

The shape of the container from which the gas cloud is released may also affect its initial dispersion. Hunt, Rottman and Britter [6] have pointed out that in the initial stages of gas cloud 'slumping' in a wind the cloud rapidly deforms to follow the flow pattern and pressure distribution of the solid form that initially encloses it. The flow pattern around a cube and a truncated cylinder are broadly similar, though there are some differences in detail. Mainly the cube shows slightly lower pressures along its sides and somewhat greater lateral spreading of its separation boundary. Also a pair of trailing vortices are formed off the top of the cylinder but not from a cube square on to the flow.

The presence of the fixed top of the source container in the model, which is removed in the trial, also affects the initial dispersion of the cloud. It was pointed out in [1] that the initial collapse of the cloud in still air is affected by the presence of the top of the container. As a part of the first rapid deformation of the cloud following the wind flow pattern around it there is an upward motion from its upwind face of a tongue of material. This motion must be inhibited by the top of the container, though the cloud photographs in [1] still show some initial upward motion of the cloud at the moment of release.

In the case of the comparison with Thorney Island trial No. 7, the model experiment used a significantly greater surface roughness than the full scale (a value of Z_0 equivalent to 36 mm at full scale compared with 10 mm for the trial). This should only change the mean velocity profile and turbulence levels by a small amount. In addition there is the possibility of the surface roughness, which is relatively large compared with typical gas cloud thicknesses (about 20% of cloud height) affecting the cloud's dispersion, though evidence from the same experiments suggests that the effects of surface roughness on the cloud's development are not large and mainly act to slow down and dissipate the cloud's gravity front more quickly than would otherwise occur. Trial 7 was also the only one of those compared here with the model for which the atmospheric stability conditions were non-neutral, estimated at Pasquill 'E' stability. The wind tunnel experiments were all for neutral stability. The precise effect of atmospheric stability on heavy gas cloud dispersion is, at the time of writing, uncertain.

Apart from the specific differences mentioned above, the model experiments followed the same procedure that would have been used if they were specifically reproducing the Thorney Island trials. However, in the light of the results of [1] indicating that modelling based on Richardson number seems to be acceptable, the opportunity probably would have been taken in a retrospective experiment to increase source gas densities and wind speeds in order to increase model Reynolds numbers.

It seems doubtful whether any of the differences between the full scale trials and the model experiments mentioned here are sufficient to affect the results of the comparison in a major way, though they would doubtless have some small effect on the general level of accuracy of the comparison.

The ensuing sections of the paper discuss the trial/model comparisons. Comparisons are made, in a similar fashion to the earlier work, between model and full scale values of:

(i) The peak gas concentration along the cloud's centre line.

(ii) The rate of spread and downwind travel of the cloud.
(iii) Individual concentration/time traces where they can be compared, and
(iv) The visual appearance of the cloud from side elevation and plan view photographs.

For reasons of brevity, full details of the comparison are not included here, but all parts of it are discussed. Complete results can be found in [2].

The comparisons are dealt with in numerical order of the Thorney Island trials. This also coincides with the order of reducing bulk Richardson number for the releases. All dimensions, times etc. refer to full scale values. Most of the concentration measurements referred to are values "at the ground". In the model experiments these measurements were from flush sampling probes effectively on the ground, whilst those for the full scale were from samplers 40 cm above the ground. The data in [1] indicate that this height difference may sometimes be sufficient to give a lower reading than actually occurred at the ground in the trial, typically by 10%.

Trial concentration measurements use the same sensor identification system used in the trials, data terminal number followed by channel number, e.g. 26/0.

Measurements of the width of the gas cloud were obtained from an analysis of the overhead cloud photographs carried out by the Safety and Reliability Directorate as a part of their own work on heavy gas releases [7].

3. Thorney Island trial No. 7

	Trial	Model
ρ/ρ_{air}	1.78	2.08
Wind speed (m s^{-1})	3.2	0.4
Surface roughness length (mm)	10	0.4
Pasquill stability class	E	D
Bulk Richardson No.	9.4	8.2

This trial had the highest bulk Richardson number of those used here. It was also the only trial used here that was carried out in non-neutral atmospheric stability. The wind direction was about 45° off the array axis and this line passes through or near four sampling masts which closely matched sampling points from the model experiments. At the nearest of these sampling points to the gas source some model measurements above the ground were available. Figure 2 shows the layout of those sensors recording gas during the trial, together with the positions of the comparable model data.

Figure 3 shows the variation of peak ground level concentration along the cloud's centre line with distance from the source. The model and full scale data show the same general trends, but the model results show consistently lower peak concentrations by about a factor of two. Figure 3 also shows a comparison of peak concentrations above the ground at two stations

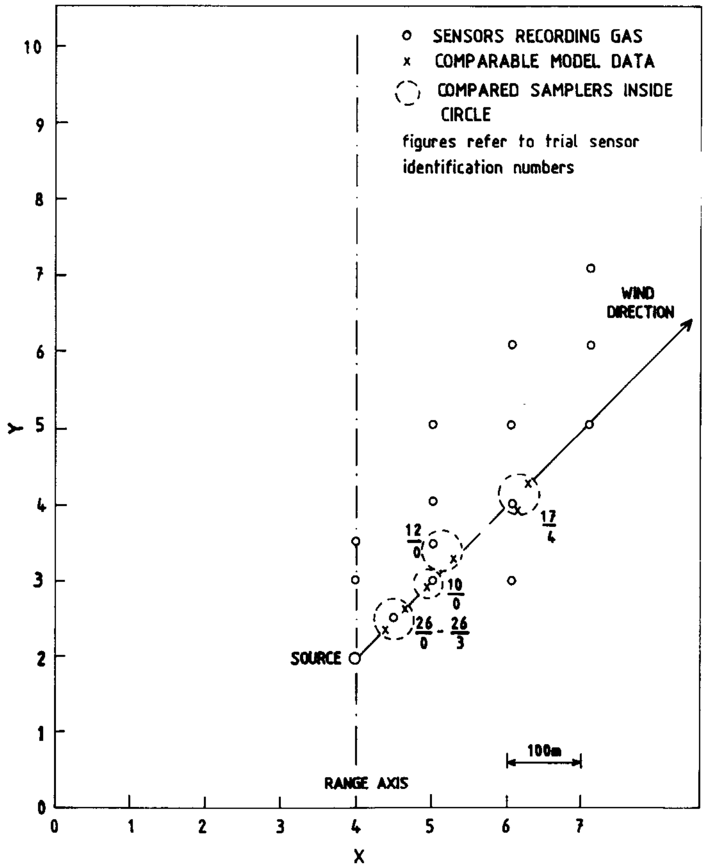


Fig. 2. Thorney Island trial No. 7: Layout of comparable gas samplers.

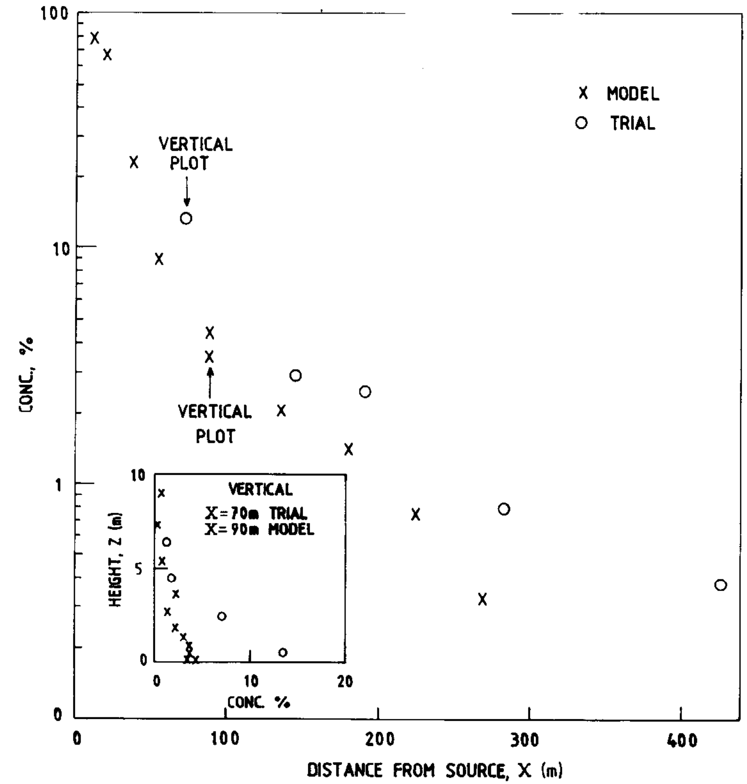


Fig. 3. Thorney Island trial No. 7: Comparison of peak ground level.

close to one another, 70 metres from the trial source and 90 m from the model source. For this difference in distance from the source, the model results should be about 30% lower than for the trial. Allowing for this the model measurements nearer the ground are still about half those for the trial, the same as for the ground level measurements. The vertical profiles do, however, show the trial and model clouds to be about the same thickness.

Figure 4 shows comparisons of the rate of travel of the up and downwind edges of the cloud away from the source, together with its rate of lateral spreading. Lateral spreading times cannot be estimated to better than about ±2 second accuracy because of uncertainty in the precise moment of the tent collapsing. Model and full scale values of the rate of lateral spreading of the cloud and the 'arrival' time of the cloud front agree very well, to within the level of accuracy of the data. Values of the 'departure' times of the passage of the trailing edge of the cloud show distinct differences, the model cloud appears to persist for far longer than the full scale.

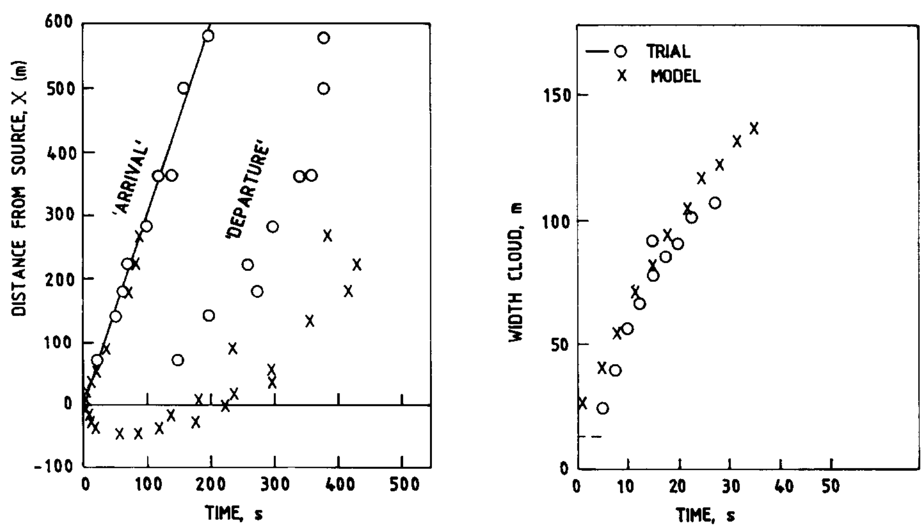


Fig. 4. Thorney Island trial No. 7: Comparison of model/full scale cloud travel times and spread rate.

The same effect is apparent in Fig. 5 which shows comparisons of model and full scale concentration/time traces where respective samplers fall close together. All the ground level traces show the model cloud persisting distinctly longer than the full scale. The trial measurements all show a sharp initial rise in concentration at the front of the cloud which only occurs on the model comparison closest to the source, trial sampler 26/0, though in this case the very sharp concentration peak at the front of the cloud is not reproduced by the model. Despite these differences, peak ground level concentrations from the model are all within a factor of two of the trial values. The

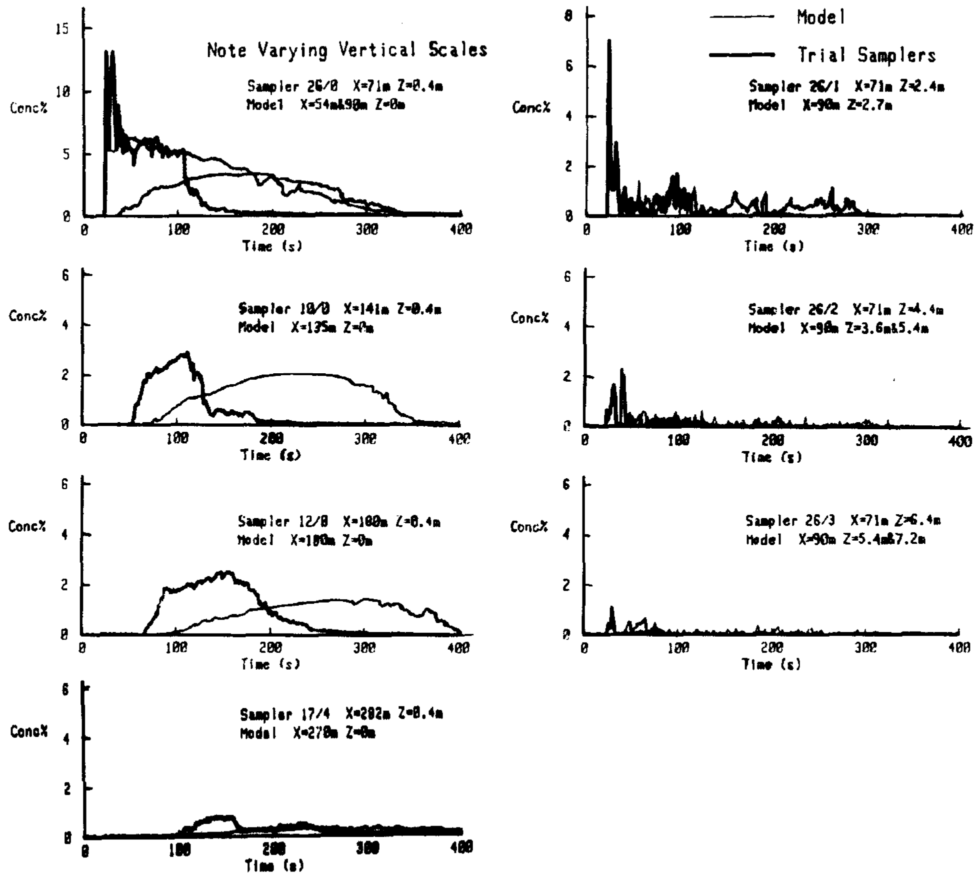
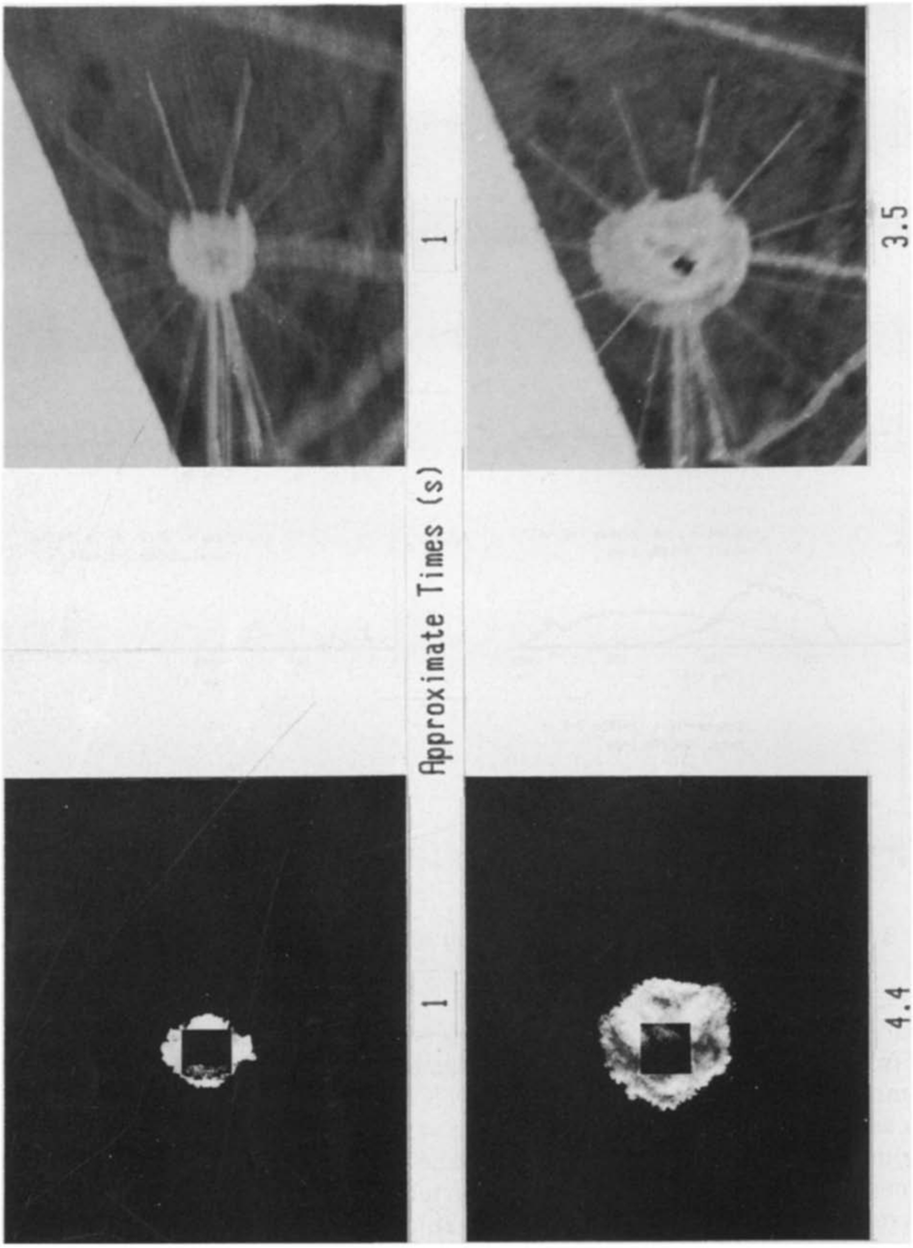


Fig. 5. Thorney Island trial No. 7: Comparison of concentration samplers with model results.

comparison with the above-ground samplers, 71 m from the trial source and 90 m from the model source, shows the same high degree of intermittency in both model and full scale with similar levels of fluctuation, indicating that in both cases there are considerable random variations in the local depth of the gas cloud. Beyond this it is difficult to make meaningful comparisons of one-shot measurements of such highly intermittent events.

There are several factors which may explain the characteristic differences between the model and full scale concentration measurements; these are discussed later in the paper.

Finally Figs. 6 and 7 show photographic comparisons in plan and elevation respectively of the development of the gas cloud. There is an approximate but not perfect match of times for the compared photographs. Model and trial cameras did not operate at comparable rates and a precise estimate



Approximate Times (s)
1
1
3.5
4.4

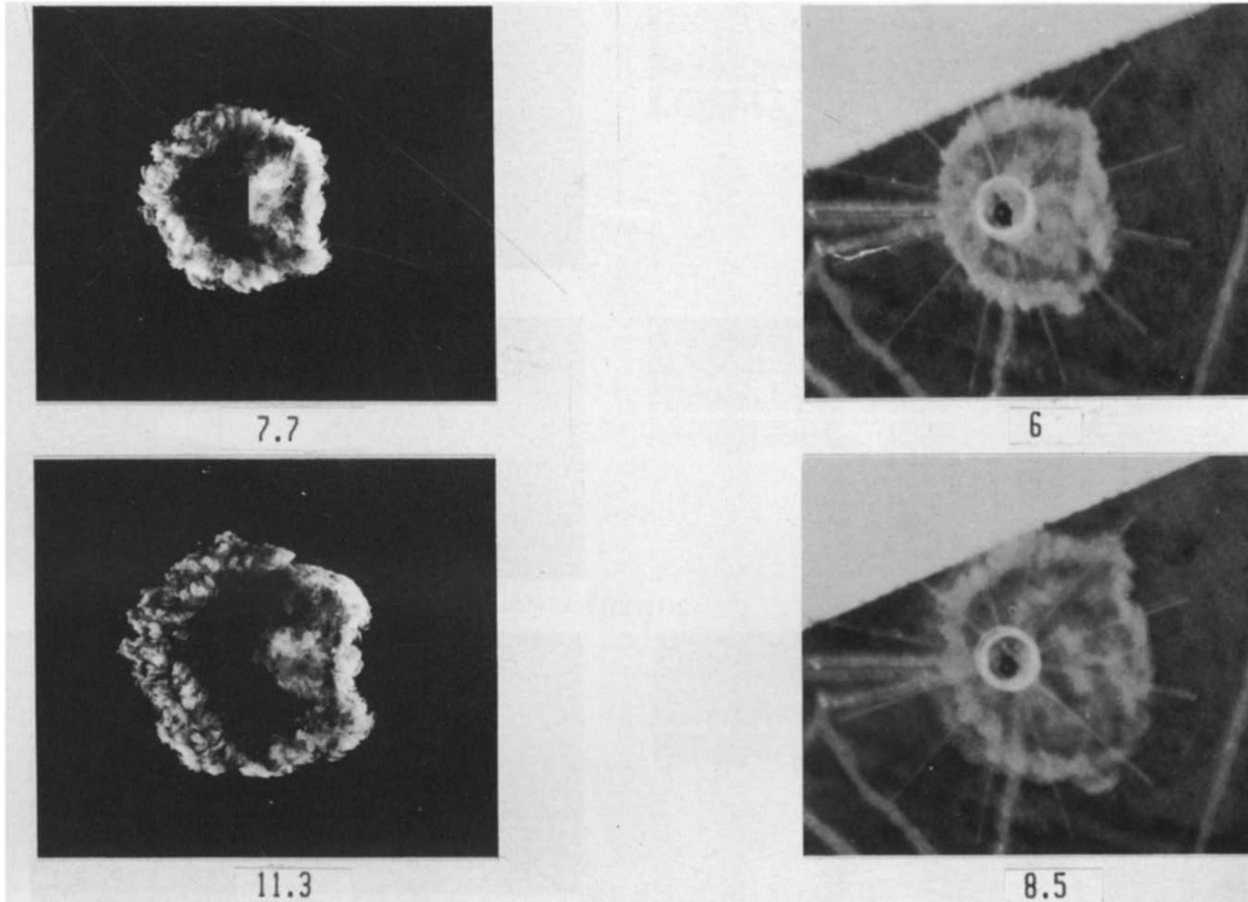
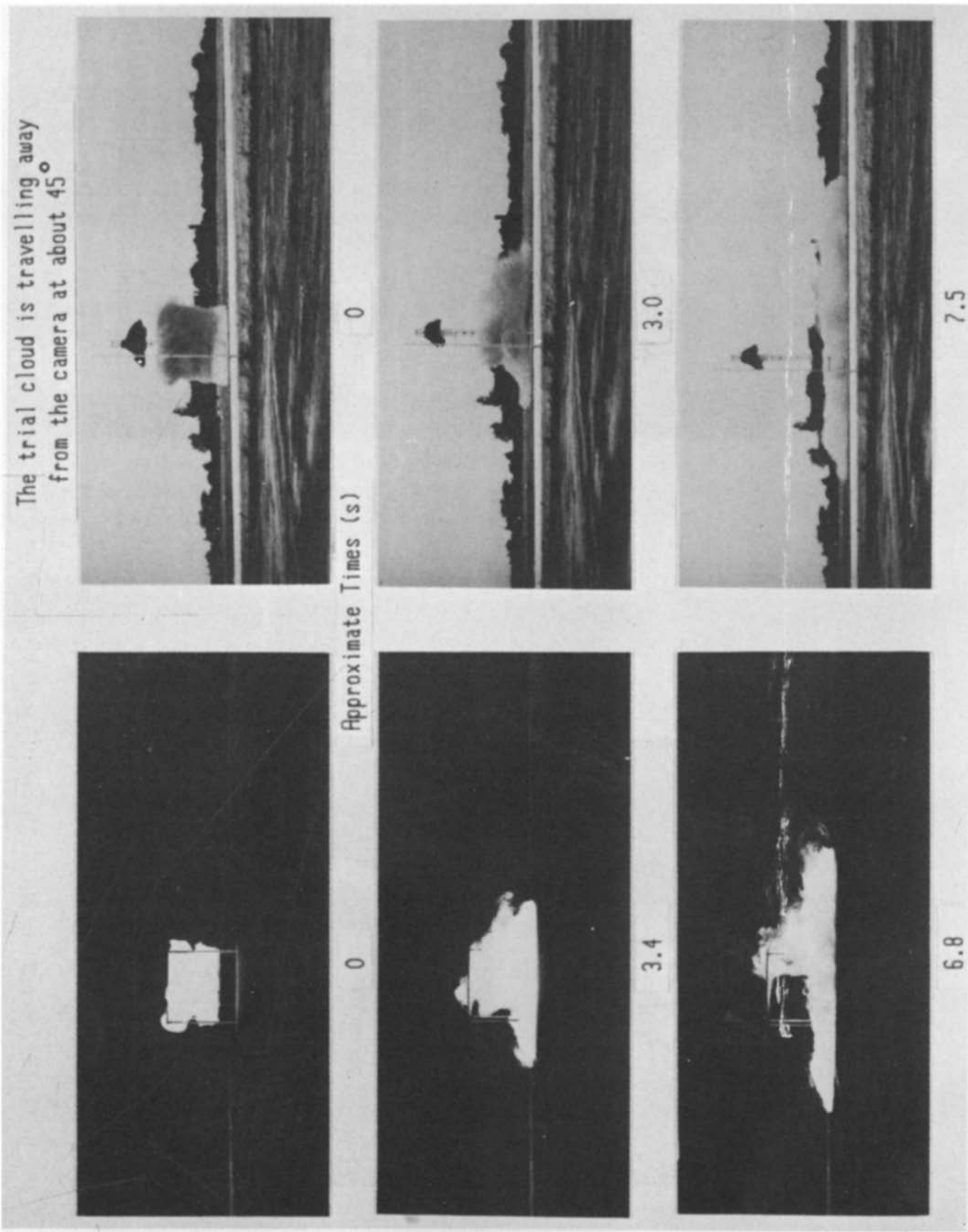


Fig. 6. Thorney Island trial No. 7: Model/full scale visualisation comparison: Plan.



The trial cloud is travelling away from the camera at about 45°
Approximate Times (s)
0
3.0
7.5
0
3.4
6.8

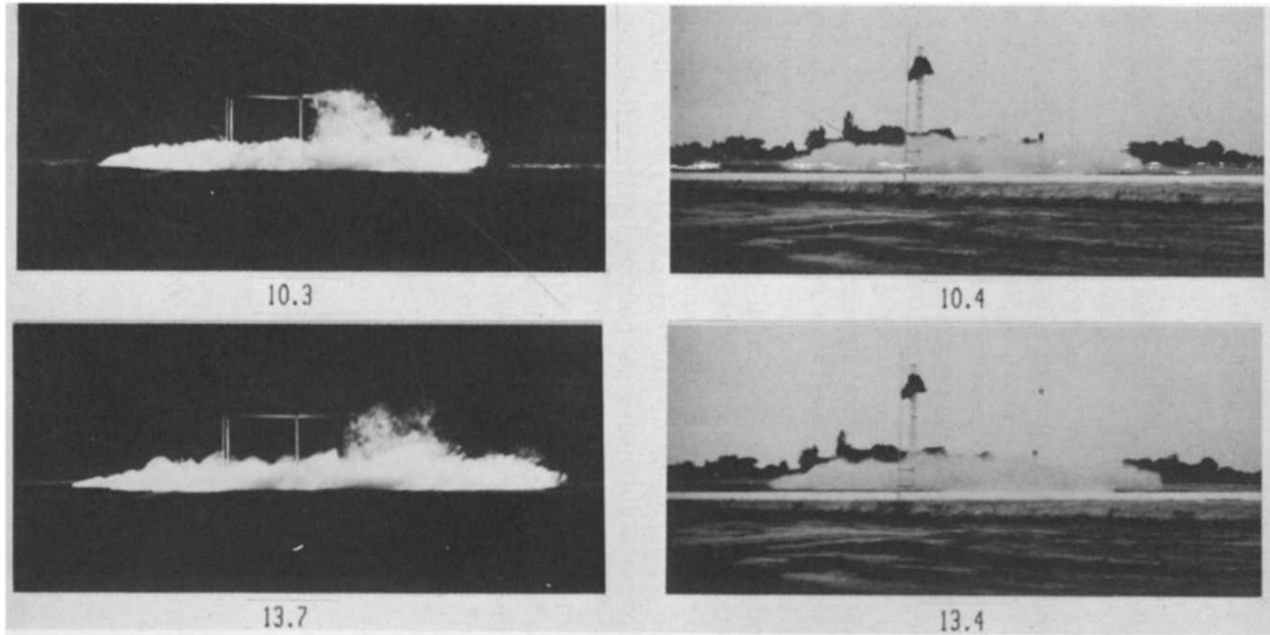


Fig. 7. Thorney Island trial No. 7: Model/full scale visualisation comparison: elevation.

of the starting time of the cloud is not available for the model or for the overhead trial photographs. Errors of up to two seconds in the estimates are possible in some cases, particularly the plan views.

There are also different perspective distortions in both model and full scale photographs that must be allowed for. In the model plan view photographs, the tilt of the camera produces converging parallels in the downwind direction, so that the gas cloud spreads more quickly than is apparently the case from the photographs. In the trial elevation photographs of the gas cloud, the cloud is travelling away from the camera at about 45°, so it also is travelling and spreading more quickly than it appears.

Making allowance for these factors the general impression in the two figures is that the model is a very realistic copy of the trial both in terms of the size of the gas cloud and in its structural appearance. The horseshoe shape of the cloud in plan view and the raised upwind edge of the gravity front are clearly apparent in both sets of photographs. The elevations show the model and trial clouds collapsing rapidly to similar heights and the model shows the same characteristic gravity current slopes of the upwind and downwind edges of the cloud as occur in the trial and which are remarked upon by Hunt et al. [6]. The model elevation photographs also show clearly the fluid which is removed from the collapsing gas column by the wind, containing only about 1—2% of the gas concentration of the main body of the cloud, and which is blown along as a passive puff on top of the main body of the cloud. The same feature is observable in the full scale trial though it is not well marked by smoke and is difficult to discern. Its presence is clearer in the original colour slides of the trial gas clouds than in their reproductions in Fig. 7.

4. Thorney Island trial No. 11

	Trial	Model
ρ/ρ_{air}	2.03	3.56
Wind speed (m s^{-1})	5.1	0.895
Surface roughness length (mm)	10	smooth wall
Pasquill stability class	D	D
Bulk Richardson No.	4.9	4.4

For reasons of brevity, full details of the comparison with this trial are not included here. Because the trial gas cloud was carried about 70° off the sampling axis only a limited number of trial sensors detected gas and only two comparable model measurements could be found. Comparisons of these two stations, and of cloud travel times, spread rates and peak concentrations along the cloud axis, showed generally good agreement. Complete results of the comparison are available in [2].

5. Thorney Island trials Nos. 13, 15 and 18

	Trial 13	Trial 15	Trial 18	Model
ρ/ρ_{air}	1.96	1.41	1.87	2.0
Wind speed (m s^{-1})	7.4	5.4	7.4	0.84
Surface roughness length (mm)	10	10	10	smooth wall
Pasquill stability class	D	C/D	D	D
Bulk Richardson Number	2.1	1.7	1.9	1.9

These three trials are considered in a single group as their bulk Richardson numbers are nearly the same and they are all compared with the same model experiment. Trials 13 and 18 are in fact nearly identical in all respects of the release. The three trials thus form an interesting set of results from the point of view of repeat run variability, which can be considerable in some circumstances. Where possible in the ensuing comparisons, results from all three trials have been plotted together.

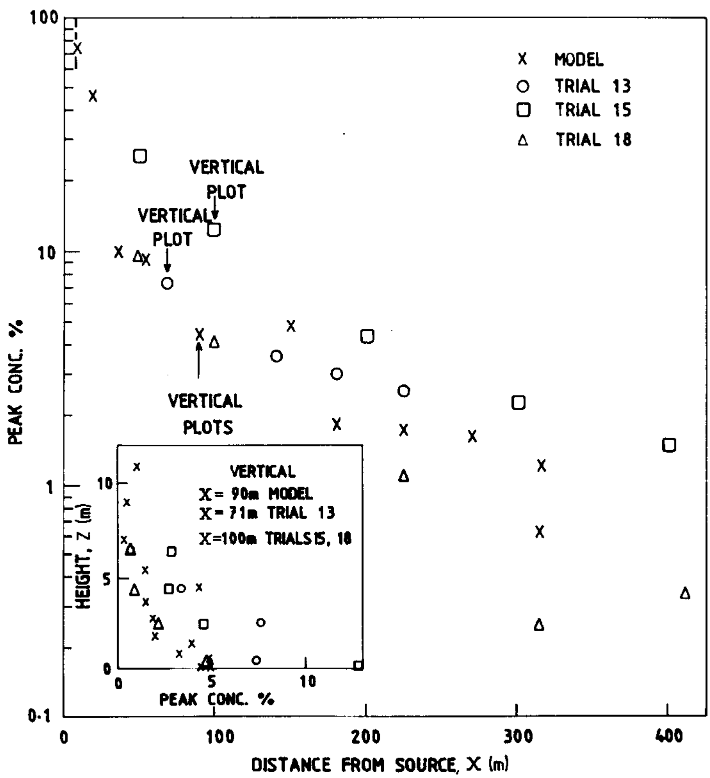


Fig. 8. Thorney Island trials Nos. 13, 15, 18: Comparison of peak ground level concentrations along cloud centreline.

Figure 8 shows a plot of peak concentrations along the cloud centre line for the three trials, together with the model data. The three trials show variations in peak concentration typically by a factor of three and the model measurements all lie within this spread. The vertical measurements about 90 m from the source also show the same degree of variation, again with the model measurements falling between them. The model data appears to agree most closely with Trial 18. All the clouds are of similar thickness.

Figure 9 shows cloud travel times and spreading rates for the three trials and for the model. Trial 15 was run at a different wind speed to trials 13 and 18 (5.4 m s^{-1} against 7.4 m s^{-1}) and travel times for this trial have been scaled by the ratio of these velocities (0.72) to reduce the time scales of the three releases to the same basis. 'Arrival' times for the three cloud fronts at different downwind distances are virtually identical and are in excellent agreement with the model. 'Departure' times for the passage of the trailing edge of the cloud show more scatter, Trial 13 having the longest persisting cloud and Trial 15 is the shortest. The model measurements are of the same order as in the trials, agreeing most closely with the longest persisting cloud of Trial 13. Comparisons of the cloud's lateral spreading rate are also shown on Fig. 9. The model measurements fall in the centre of the range of the trial measurements, which show some differences that are most probably due to errors in starting time estimates of the release from the trial overhead photographs.

Comparisons between model and full scale concentration/time traces are only shown here for Trial 18 for reasons of brevity, complete results can be found in [2]. Figure 10 shows the layout of gas sensors recording gas in Trial 18 together with the positions of comparable model measurements. Com-

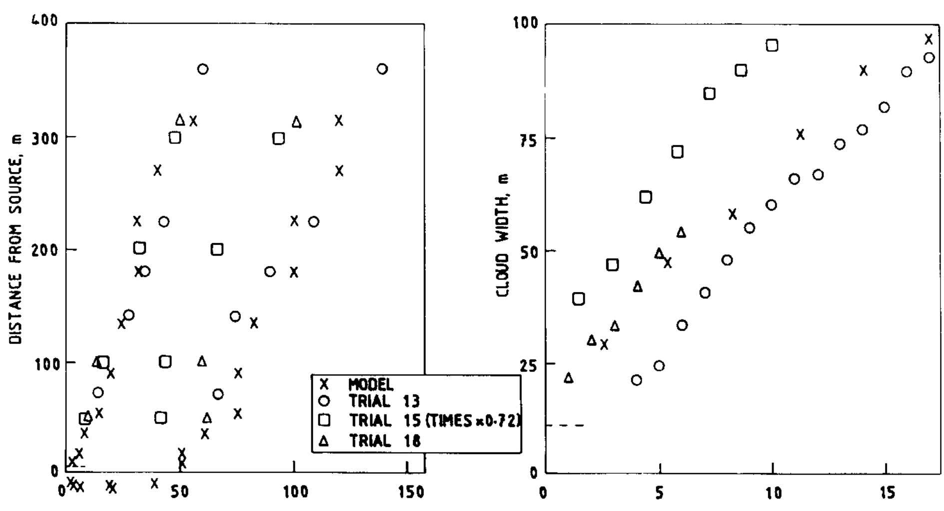


Fig. 9. Thorney Island trials Nos. 13, 15, 18: Comparison of model/full scale cloud travel times and spread rates.

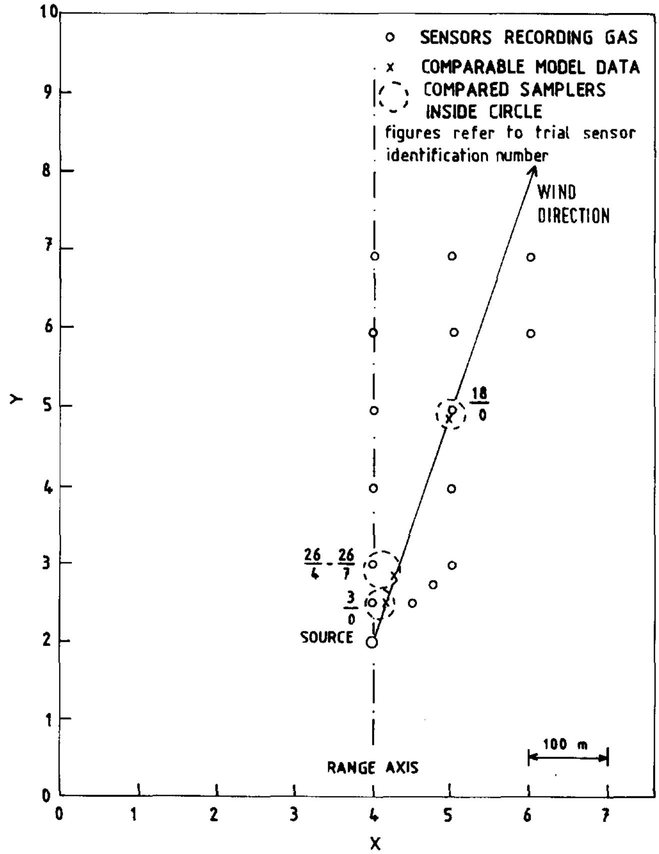


Fig. 10. Thorney Island trial No. 18: Layout of comparable gas samplers.

parisons are possible at three sampling stations, at one of which vertical data are available. Figure 11 shows the results of the comparison which was the best of those made. For the ground level measurements the general standard of agreement is excellent, for the above-ground measuremnts both model and full scale measurements show high levels of intermittency of a similar order as closely as such a comparison can be made.

Comparisons of concentration/time traces for Trials 13 and 15 (not shown here) were generally good, all predicted peak concentrations being within a factor of two of trial measurements.

Considering that the three trials, being of similar bulk Richardson number, should therefore have been expected to show similar levels of agreement with the model results, it is clear that high levels of repeat run variability have occurred in these three trials. Whether repeat run variability exists to the same degree as indicated in the model experiments [2] is not certain, but it remains quite possible that this may be the case.

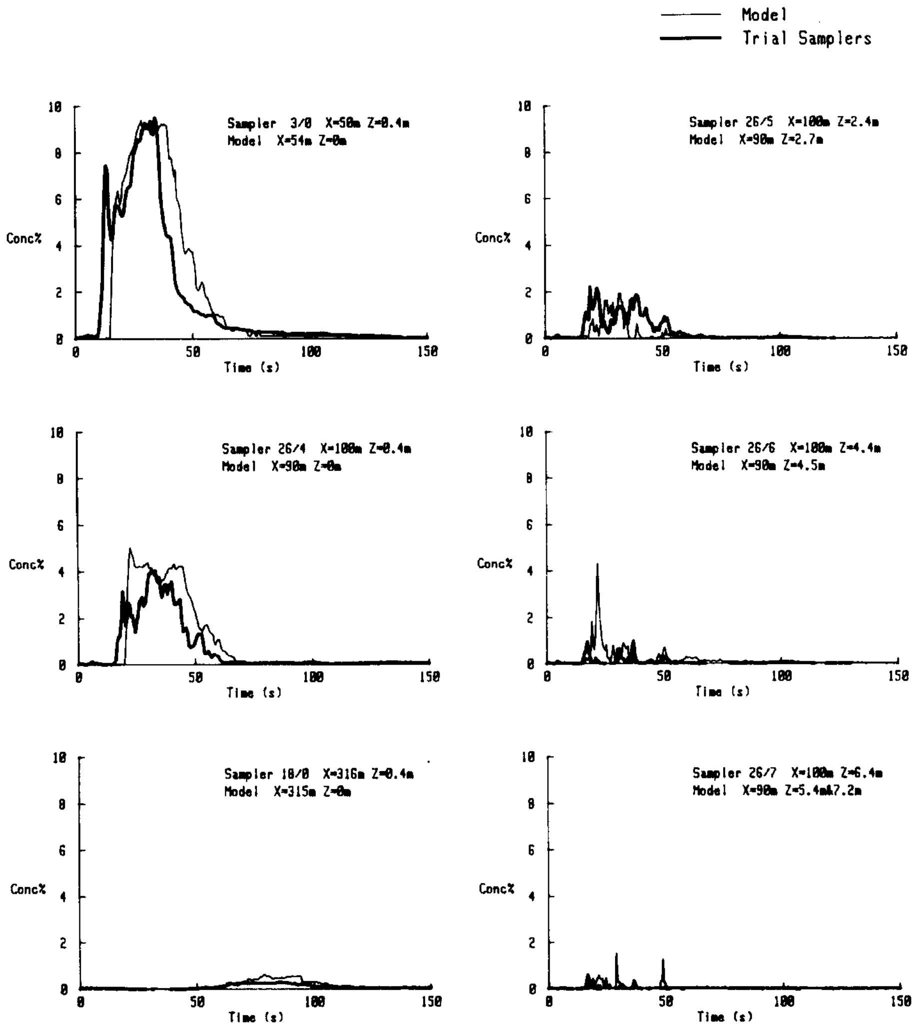


Fig. 11. Thorney Island trial No. 18: Comparison of concentration samplers with model results.

Figures 12 and 13 show photographic comparisons between the model and Trial 13 in plan and elevation respectively. Because of various failures in the photographic apparatus during Trials 15 and 18, only limited photographic data were available and adequate photographic comparisons with these trials were not possible. The comparison with Trial 13 is, as before, generally very good. The model cloud reproduces all the essential characteristics of the trial very well, and the observed rates of travel and spread, and the cloud thickness are generally very similar.

6. Effect of release bulk Richardson number on downwind dispersion

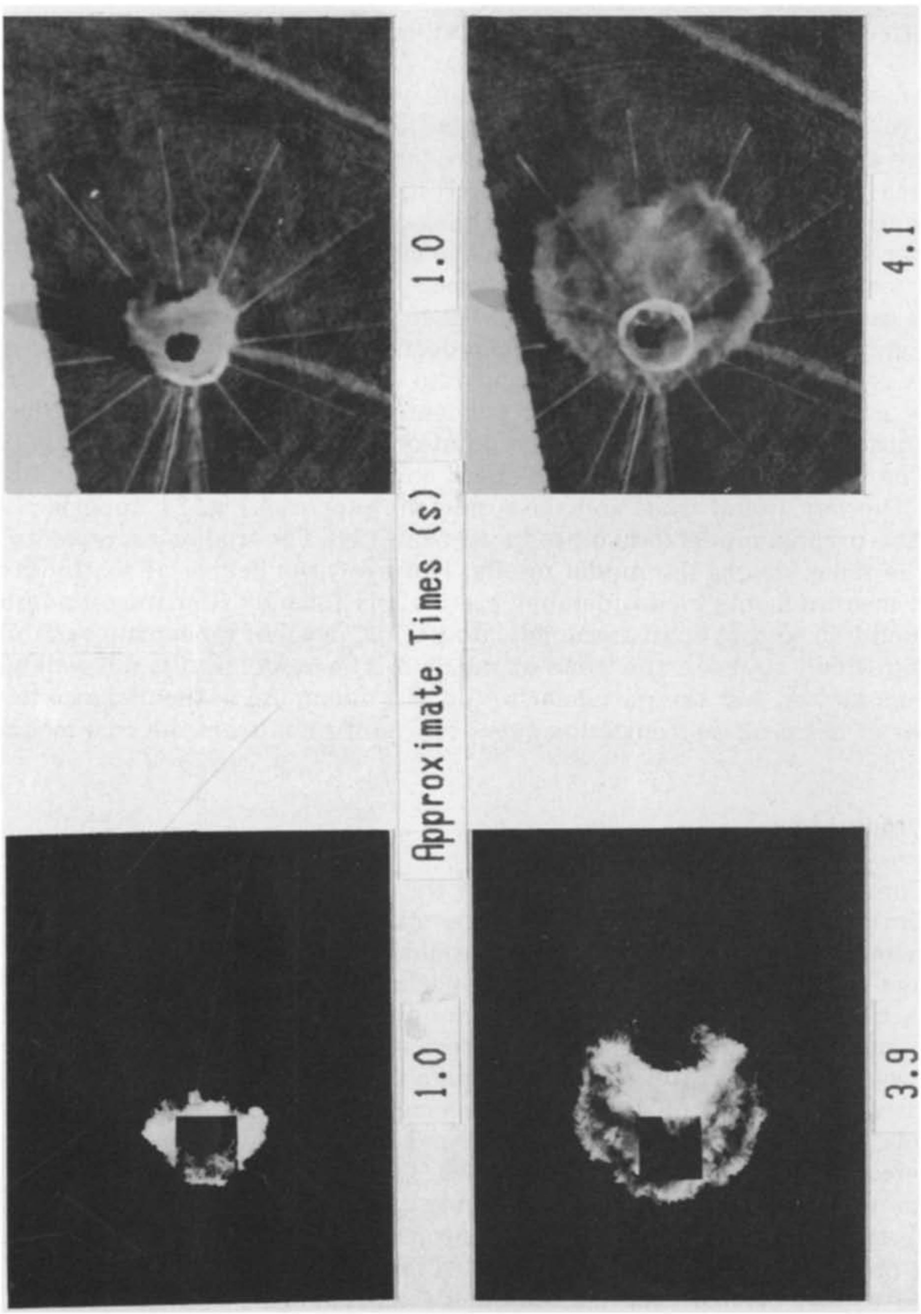
An attempt was made in the previous work [1] to make some practical use of the model data by using it to predict the downwind distance to the point at which peak concentrations in the cloud had fallen to 2% of the source value. This produced the interesting result of a maximum in this distance corresponding to bulk Richardson numbers of about three. For higher values of Richardson number the cloud behaved much as a release in still air being driven along but not greatly dispersed by the wind, thus the high gas concentrations present in a still air release are largely advected along the ground. At lower values of Richardson number atmospheric turbulence considerably increases the dispersion rate over that from the gravity driven flow in the cloud, thus reducing concentrations in the cloud and reducing the distance from the source to the point of 2% peak concentration.

The distance to the value of 2% peak concentration has been found for all the Thorney Island trials and the results are shown in Fig. 14, superimposed on the original model data reproduced from [1]. The trial measurements fall in the same area as the model results. However, the degree of scatter in the trial measurements is considerable, particularly for bulk Richardson numbers around 2.5, so that apart from indicating a high level of repeat run variability it is difficult to assess the trend of the data. The model results fall well within this scatter, but the particular result of a maximum in the distance to the point of 2% peak concentration cannot be confirmed from the trial measurements.

7. Discussion

Considering that in this comparison the model was not an exact representation of the trial either in form or operating conditions, the general level of agreement is remarkably good. The model has, in general, reproduced all the salient features of the full scale. Its appearance in the photographic comparisons is remarkably lifelike. The gas clouds also are generally of the correct size and spread and travel at the correct rate. Concentration measurements between model and full scale at comparable, but not usually identical, positions within the cloud show good agreement. In some cases, Trial 18 for example, the agreement between model and trial concentration measurements is remarkably good, to better than 20%. Overall, nearly all the peak concentrations in the model are within a factor of two of the trial values. The commonest trend is for the model concentrations to be lower than in the trial. For one-shot comparisons of a variable event this standard of agreement is as good as can be expected and would be adequate for most hazard analysis work.

There is only one part of the comparison in which model and full scale show consistent differences in a significant way, and that is in Trial 7 with the concentration measurements within the cloud and in the persistence of


Approximate Times (s)
1.0
4.1
1.0
3.9

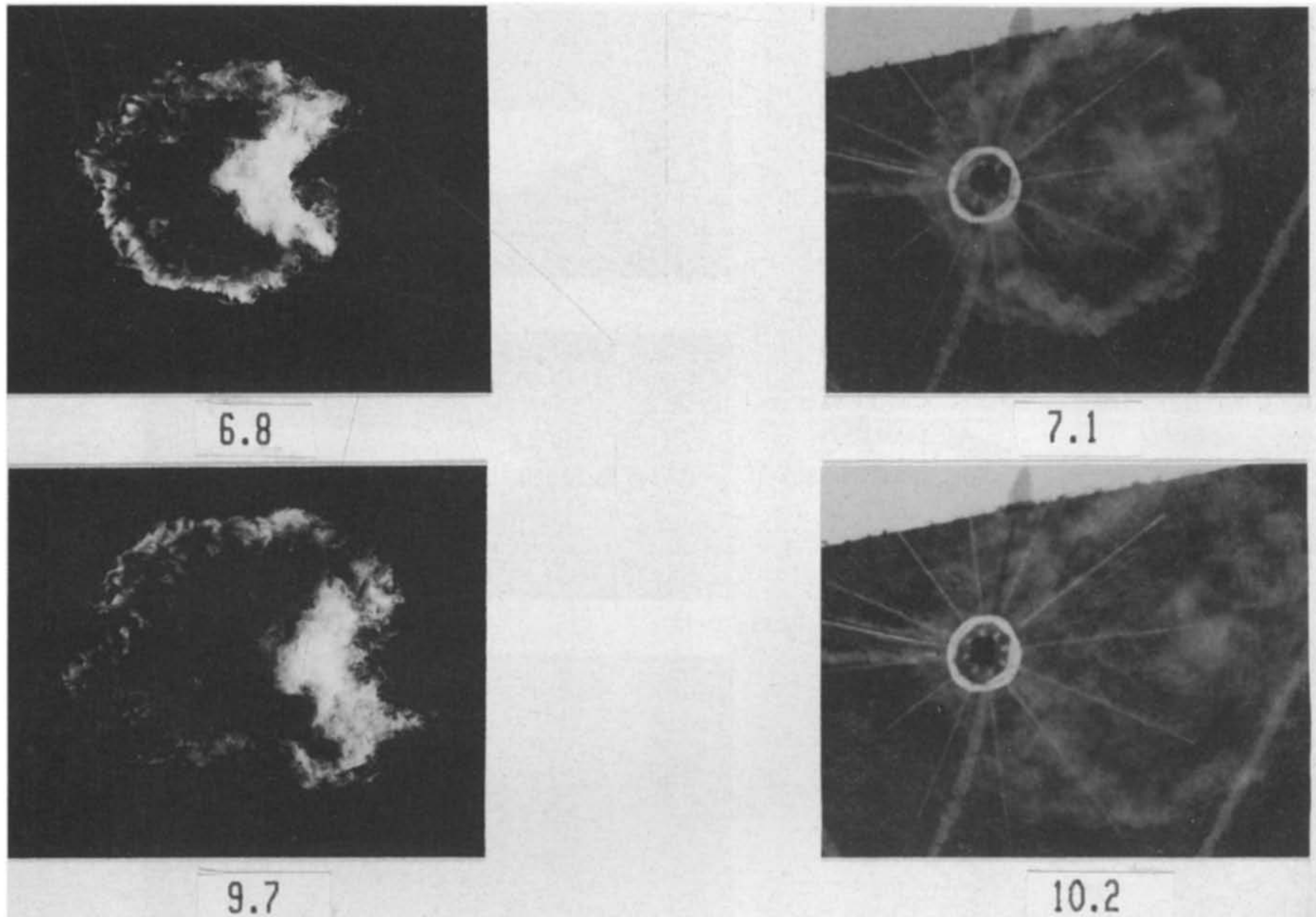
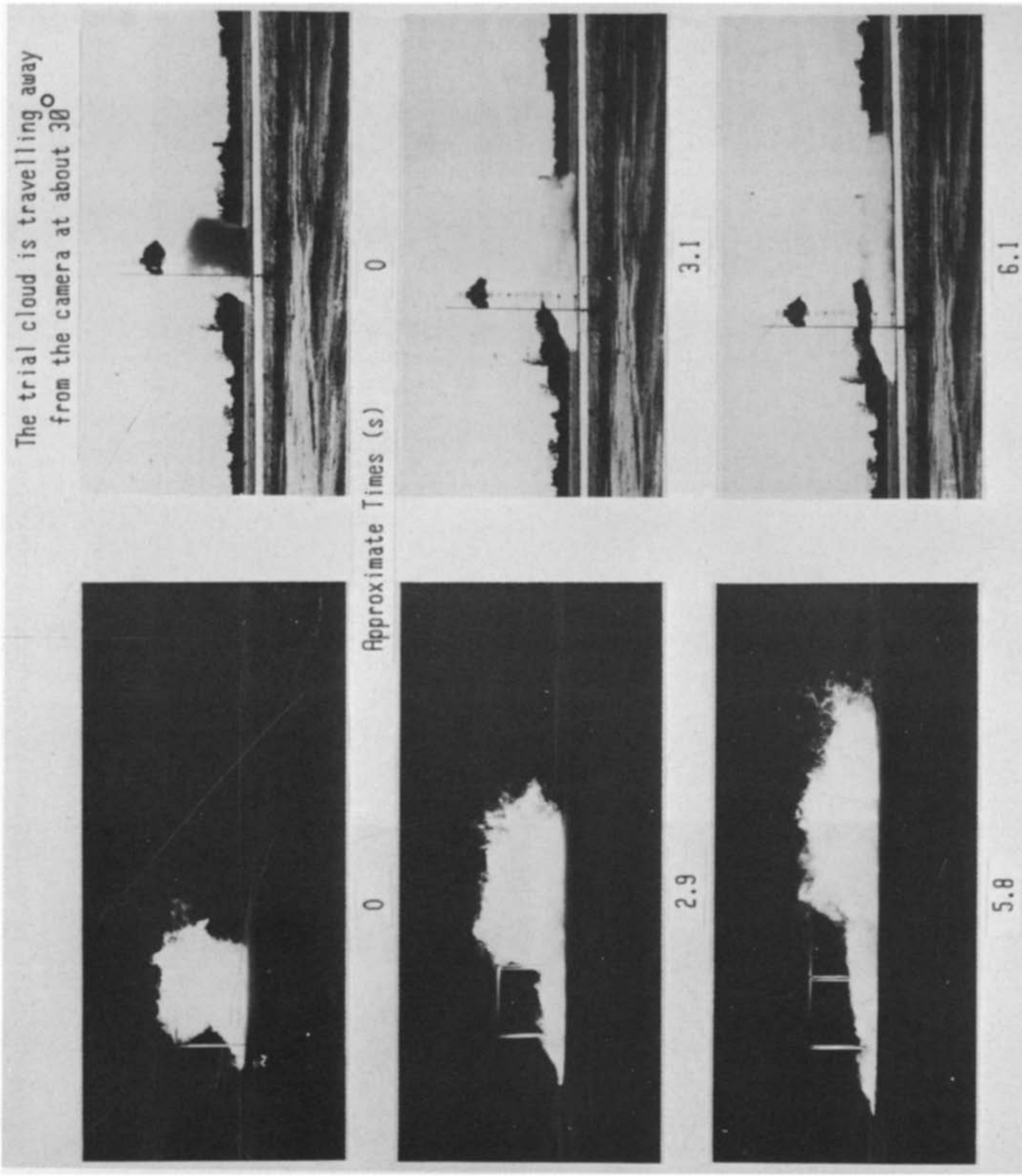


Fig. 12. Thorney Island trial No. 13: Model/full scale visualisation comparison: Plan.


The trial cloud is travelling away from the camera at about 30°
Approximate Times (s)
0
2.9
5.8
0
3.1
6.1

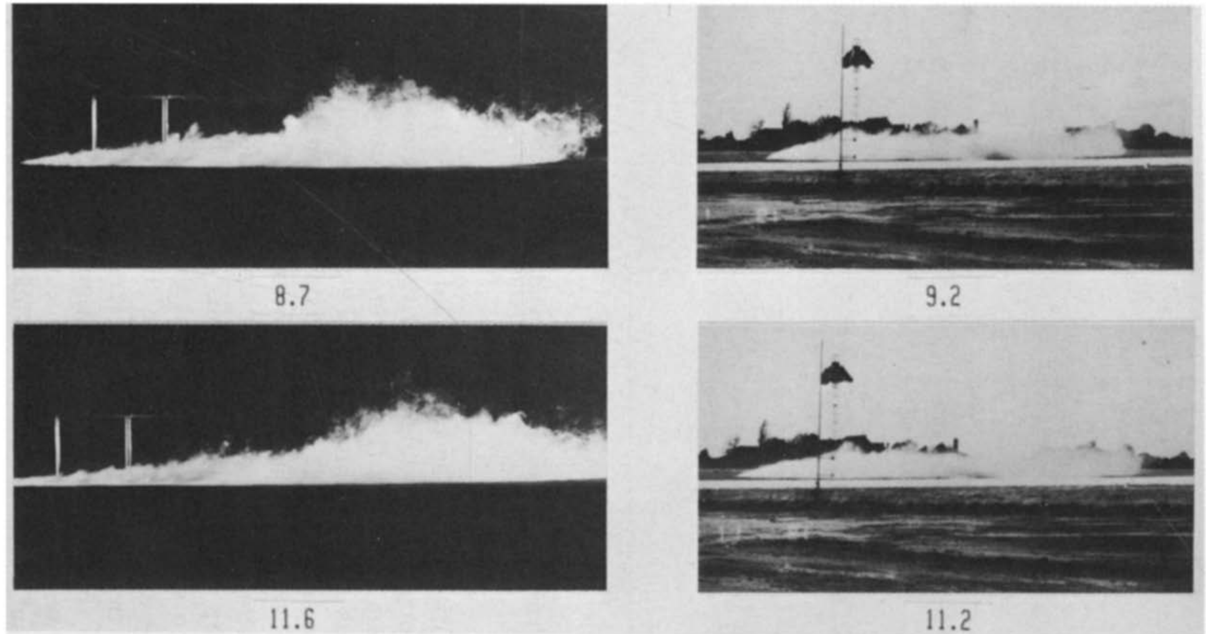


Fig. 13. Thorney Island trial No. 13: Model/full scale visualisation comparison: Elevation.

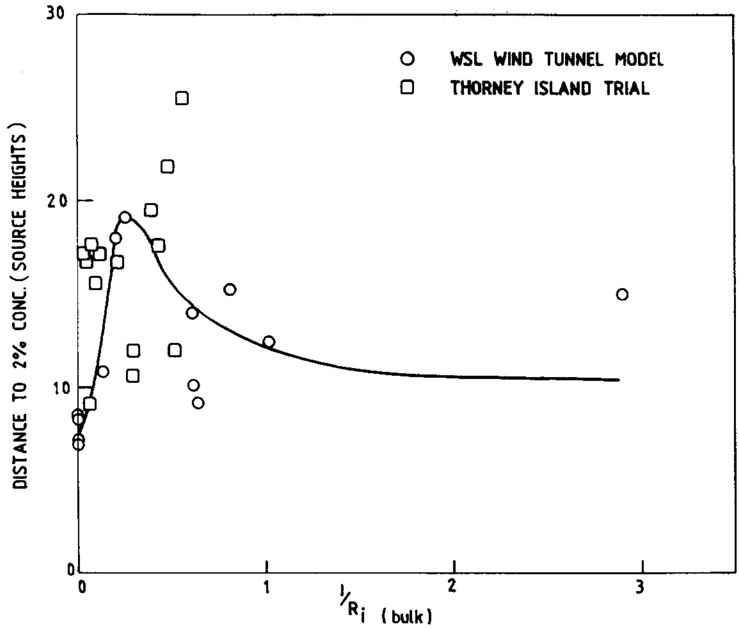


Fig. 14. Effect of spill bulk Richardson number on downwind distance to 2% concentration.

the cloud in the windward direction. The model cloud appears to persist far longer than in the trial. Though the leading edge of the model cloud travels at the correct rate, 'departure' times on the model are considerably greater. Concentration measurements at the ground show the model measurements to be persistently lower than in the trial and also to have a different character. The trial concentration measurements in Fig. 5 show a compact cloud with a sharply defined upstream edge with a steep concentration gradient and in some cases large sharp peaks in concentration, while the model measurements tend to show a more diffuse cloud without sharply defined edges.

The main reason for the difference seems to be that in the model the gravity front at the head of the gas cloud, with its strongly anti-rotating flow component which produces the sharp concentration gradient at the front of the cloud, loses its internal energy and collapses to a more diffuse and passive front more quickly than occurs in the trial. This is apparent in Fig. 5 where the ground level concentration measurements closest to the source show a steep concentration gradient at the front of the cloud for both the trial and the model, indicating the presence of a strongly working gravity front in both cases (there are also some sharp concentration peaks in the trial which are not reproduced by the model, this will be discussed later). At greater distances the model measurements show a much gentler concentration gradient, indicating that the gravity front has dissipated. Some of the causes of this can be attributed to the relatively large surface roughness used on the model which was not present in the trial. One of the conclusions from the model experiments [1] was that an effect of surface roughness is to dissipate the energy in the gravity front causing it to collapse more quickly than would otherwise be the case. However, this cannot explain the effect totally and the remaining cause seems most likely to be that the Reynolds numbers in the model were a little too low in this case. The model experiment used to compare with Trial 7 had the lowest wind speed of any of the experiments, 0.4 m s^{-1}. Wind speeds of this order are normally used out of necessity rather than virtue, being imposed by the buoyancy scaling requirements, and experiments carried out at model wind speeds significantly below about 1 m s^{-1} invariably show signs of Reynolds number effects in the simulated atmospheric boundary layers. Whether this affects the results depends upon the nature of the experiment, in this case it appears to have. All the other model experiments were carried out at model wind speeds around 1 m s^{-1} and the comparisons of these concentration measurements with the trials show generally very good results. Effects due to too low Reynolds numbers would also explain the long persistence of the model cloud in the trial comparisons. There is a tendency for the boundary layer sub-layer to grow excessively in thickness, this is encouraged by the stability of the heavy gas layer and produces a residual 'tail' of material on the downwind edge of the cloud which persists in the thickened sub-layer for longer than should be the case.

In the light of the results of the previous model experiments indicating that Richardson number based scaling is acceptable, it would have been perfectly practicable to run the model comparison for Trial 7 at a higher wind speed and higher source gas density, and therefore a higher Reynolds number, similar to that for the other experiments. This was deliberately not done in the earlier model experiments since the validity of the modelling technique was not established, model scaling was based on use of the correct source gas density and Froude number scaling.

Sometimes the model fails to reproduce very well the very sharp concentration peaks that often occur in the trial, particularly those associated with the gravity front at the leading edge of the cloud. The two comparisons at the top of Fig. 5 are typical examples. The same difference occurred in comparing the model experiments in still air [1] with those of Havens and Spicer [8] who obtained significantly higher peak concentrations at the leading edge of their gas cloud. The reason for this seems to be simply that the time response and sampling rate used for the detector in the model experiments were fractionally too slow to always pick up the maximum concentration in these short duration peaks. In the catharometer type of detector used, there is a trade-off between the spatial resolution of the sampler and its time response. In our own experiments this was set to give a good spatial resolution and a time response amply fast enough to cope with the levels of concentration fluctuation indicated by the Porton trial results; typically with response time constants of 2—3 seconds (equivalent to about 10 seconds at Thorney Island scales) which are much smaller levels of fluctuation than were found in the Thorney Island trials or the model experiments. Improving the time response of the detector is a simple matter.

In spite of all this it must be noted that the model measurements have predicted the peak concentrations in the gas cloud in Trial 7 to within a factor of two.

Finally, it is worth repeating that the comparison presented here has used predictive model measurements that were made well before the event and are thus entirely without the benefit of hindsight. Hindsight indicates only two changes in the modelling technique that might usefully be made. Firstly, keep model Reynolds numbers as high as possible with the aid of Richardson number based modelling. Secondly, ensure that the detector response is adequate to follow the very sharp concentration peaks that occur particularly at the leading edge of the cloud.

8. Conclusions

(1) It has been possible to compare five of the Thorney Island trials with similar, but not identical, model experiments (intended as a model of the Porton trials) carried out before the full scale trials, using Richardson number scaling.

(2) The level of agreement obtained between model and full scale trials in the comparison is generally very satisfactory. The model clouds are very similar in appearance to the full scale and generally spread and travel at the correct rates. Measured 'arrival' and 'departure' times and cloud widths generally agree very well. Measured concentrations within the gas cloud also compare very well, nearly all peak concentrations are correctly predicted to within a factor of two, adequate for most hazard analysis work, and in some cases the level of agreement is excellent.

(3) There are indications that the model experiment run at the lowest wind speed, the comparison with Trial 7, was affected by operating at too low a value of Reynolds number. It would have been possible to avoid this by using Richardson number scaling to run at a higher model wind speed using a greater gas density.

(4) The trial results indicate the presence of high levels of repeat-run variability in some cases, a characteristic also indicated by the model measurements.

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