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THORNEY ISLAND TRIALS: SYSTEMS DEVELOPMENT AND OPERATIONAL PROCEDURES

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Summary

Following experience gained in providing and operating an extensive multi-channel data capture system for Shell Research Ltd. on trials involving LNG and LPG spillages over water, the National Maritime Institute agreed to undertake a series of field experiments for the Health and Safety Executive on the dispersion of heavy gas over open flat terrain with responsibility not only for the data system but also for the engineering of the gas supply and release, and the conduct of all site operations.

Plans laid in 1980 for a programme initially consisting of five instantaneous releases steadily evolved until by the time activity on the chosen trials site at Thorney Island ceased in mid 1984 a total of 29 gas releases covering three different aspects of heavy gas dispersion had been completed.

This paper describes the approach to the gas storage and supply, the staged development of the 2000 m^3 gas container and release mechanism through various model evaluations, the field measurement and data collection systems, especially the environmental sensors, and the procedures evolved for trials operations and supporting site activities. Some indication is given of how effectively the various trials systems performed.

1. Introduction

In April 1980, the National Maritime Institute (NMI), then a research establishment within the U.K. Department of Industry, was invited by the Health and Safety Executive (HSE) to consider undertaking the next stage in a programme of field trials on the atmospheric dispersion of heavy gas clouds, which formed a major part of an extensive investigation into the behaviour of large accidental releases of toxic or flammable gases [1] .

The proposition entailed continuing the field work begun by the Chemical Defence Establishment (CDE) who had earlier conducted experimental releases of up to 40 cubic metres at Porton Down [2] and also prepared for HSE a design study for larger scale releases but were not in a position to continue any further with the work. Releases of 2000 cubic metres of heavy gas over an unobstructed range and under certain specified environmental conditions were initially planned with NMI providing for the storage and preparation of the gas, the mechanism for its near instantaneous release, the measurement of gas concentrations and associated meteorological factors,

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and the general conduct of all trials operations and site activities. Much of the envisaged work meant breaking new ground for the NMI trials team whose experience lay primarily in the realms of measurement services and all the complexities of the associated data capture, collation and recording systems. Indeed, during the summer months of 1980 while the HSE heavy gas dispersion project was being implemented, this very aspect of NMI's experience was being used to assist Shell Research Ltd. with their liquified gas spills on water at Maplin Sands [3].

After further consideration of the requirements and in particular some helpful consultation with members of the Porton Down team, NMI submitted a detailed technical appraisal and estimate of costs to HSE, adopting and modifying where deemed appropriate the original CDE concepts for the various trials systems and proposing a limited series of five trials for an estimated total budget in the region of £1 million. The conditions for the five trials, which included one release at neutral buoyancy, had been selected by HSE from a matrix of fifteen [4], on the basis that those of lesser priority would be met progressively if and when additional appropriate funding became available.

Following detailed discussion of NMI's proposals within the Technical Sub-Committee established to guide the work and further reference back to the project sponsors, NMI were asked in March 1981 to proceed with the development of a suitable gas release system and the installation of an advanced measurement station to monitor weather conditions at the trials site on Thorney Island, whose selection is described by Davies and Singh [5] . The authority to proceed with the trials was received in July and throughout the remainder of 1981 equipment procurement and system development proceeded with a view to commencing trials in early Spring 1982.

2. Project organisation

To make the running of the total project as smooth as possible, working responsibilities were divided into four main regimes (see Fig.1) each with its own budget allocation. Project Management, apart from clearly exercising overall technical and financial control also handled all general administration, liaison with HSE and other project sponsors, public relations and trials reporting. Engineering Works primarily covered all aspects of the gas handling system namely the bulk liquid storage and vaporisation plant, supply pipework, field container and release mechanism and also the structural features of the field measurement stations. The Data System regime embraced the measurement transducers, except for the provision and servicing of gas sensors which were dealt with by HSE, and all elements of the data capture, transmission, processing and recording including the relevant software packages. Lastly under the Operations umbrella lay all the site work other than those specialised activities peculiar to either engineering works or the data system, the all important actual conduct of the trials themselves and all aspects of safety on the trials site.

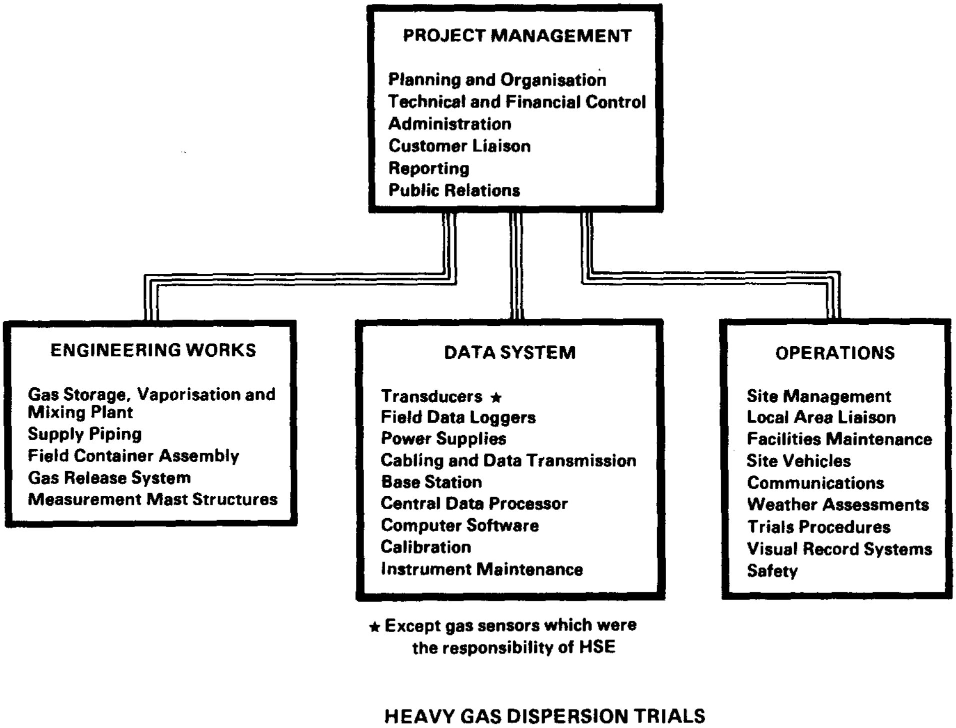

Fig.1. Allocation of responsibilities.

It is beyond the scope of this paper to dwell on the complexities of administering a project of this magnitude but one aspect of the project management function does deserve particular emphasis here, namely public relations. The underlying nature of the proposed trials coupled with lively local environmental interests already debating the possible future use of Thorney Island, made it essential to ensure adequate consultation about the trials with local authorities, Members of Parliament, community organisations, residents associations, sailing clubs and the like. Within this public liaison, the various procedures for seeking and securing local planning approval were also followed where approriate and once the broad objectives of the trials programme were known and understood, support for the use of Thorney Island airfield as the trials site seemed generally favourable.

3. Engineering works

3.1 Gas storage and vaporisation

The source gases selected to cover release densities within the envisaged range were Refrigerant-12 (R12 — dichlorodifluoromethane) and nitrogen (N_2), for reasons described by McQuaid [4] and by Leck and Lowe [6]. Because of the logistics of the gas handling operations and in particular the requirement to keep the overall time for supplying the full 2000 m^3 of source gas down to about one hour in order to allow reasonable probability of the wind conditions on site remaining within acceptable limits, the detailed design and construction of a suitable plant for vaporising the gases from the liquid state in which they were stored, was sub-contracted to a firm of chemical engineers. This also had the distinct advantage of employing established industrial expertise to deal with construction and safety standards aspects.

The salient features of the gas plant installed by the sub-contractors are shown in Figs.2 and 3. It was erected in a convenient and safe location some 300 m from the chosen gas release point on an existing area of hard-standing within sight of the disused airfield control tower. It provided independent evaporation and subsequent mixing of nitrogen and Refrigerant-12 gas in the required proportions. The liquid N_2 tank was an upright vacuum insulated cylindrical vessel which stored up to 16 m^3 under pressure at about −190°C, approximately equivalent to 10,000 m^3 of gas at normal ambient conditions. The N_2's vapour pressure of around 6 atmospheres at this temperature, provided the working head for filling the release container with source gas mixture. An adjacent low pressure vessel, also of cylindrical section but mounted horizontally, stored up to 24 tonnes of R12 under sufficient pressure bled from the N_2 system to keep it in the liquid state at or close to ambient temperature. The N_2 was vaporised by heat transfer from outside air drawn through three fan-assisted vaporisers (FAV) while the R12 was driven under N_2 pressure into a vertically aligned shell and tube heat exchanger through which low pressure hot water was circulated from a

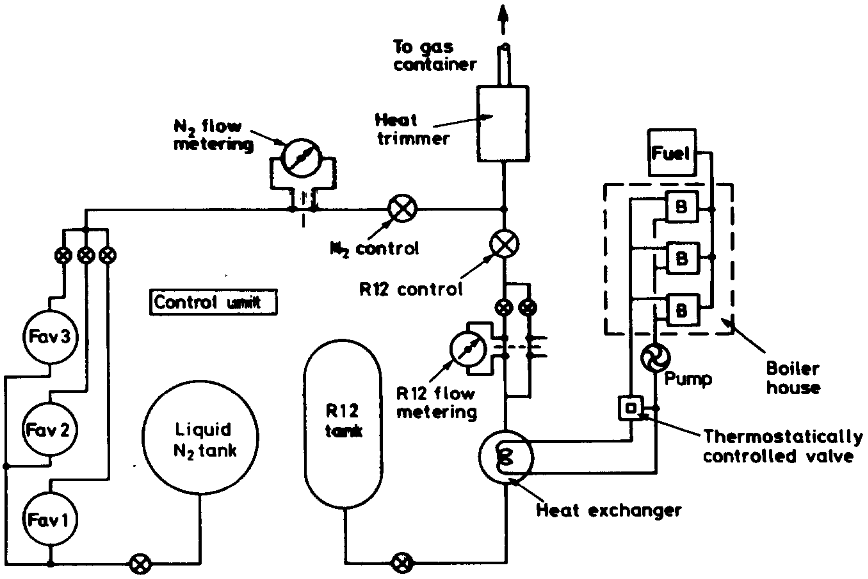

Fig.2. Diagrammatic layout of gas plant.

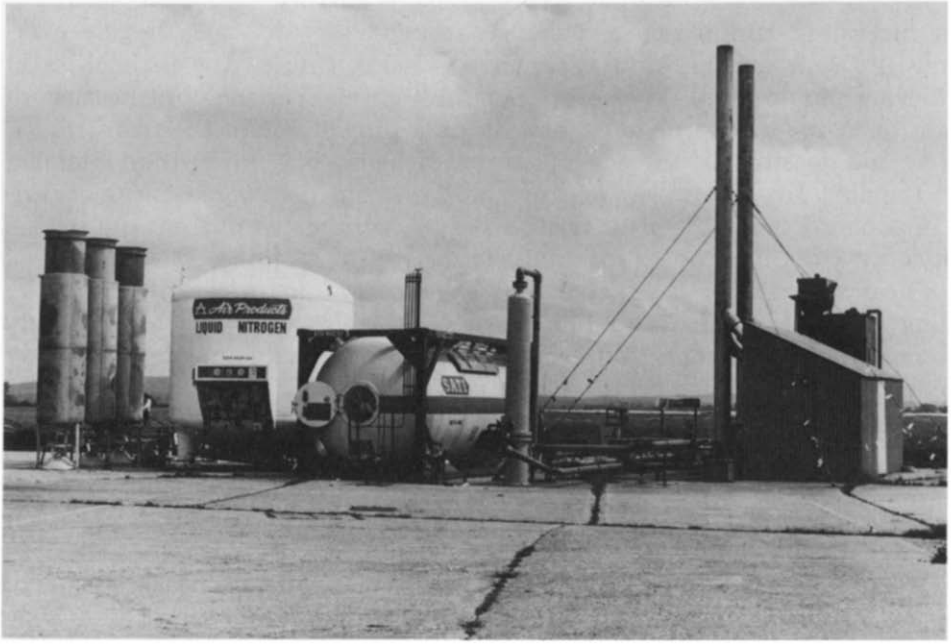

Fig.3. General view of gas plant.

bank of four oil-fired boilers, any three of which together had sufficient capacity to meet the heat requirements. The separate gas flows on each side of the plant could be continuously monitored by measuring the pressure drop across calibrated orifice plates set in the pipelines immediately beyond the vaporising units.

The correctly proportioned mixture was discharged from the plant via a small electrical heater which could fine trim the temperature of the blend so that it arrived at the release point at about outside air temperature, after travelling the 300 m or so across the surface of the airfield through a 0.2 m diameter plastic pipeline. This main supply pipe terminated just below ground level in an eight legged 'spider' of evenly spaced outlet pipes so as to spread the upward discharge of gas as uniformly as possible over the base area of the release container.

Acceptance tests demonstrated that the plant satisfactorily met the requirement to supply 2000 m^3 of source gas within one hour, either as N_2 or R12 alone or as a mixture of the two proportioned to achieve a limited range of densities around twice that of air.

Throughout the trials programme, standards of serviceability and reliability of the gas plant were generally very high. Some minor difficulties occurred with actual plant operations particularly over controlling gas flows, more so in the early stages of the trials and largely due to inexperience in working the plant. With gas costs a significant contributor to overall trials expenditure, it was not realistic to run the plant for training purposes alone but increasing confidence and skills through usage in trials largely overcame problems of the kind experienced earlier. One of the difficulties in achieving required gas flows arose not through inexperience but because of an error in the orifice plate calibration data provided with the plant, which led to the densities of the gas mix supplied being 20% lower than intended for the first five heavy gas releases, before it was discovered and rectified.

In some of the subsequent trials however, it became apparent during the course of the filling operation that the density of gas initially supplied was too heavy to achieve the target relative density. To redress the situation filling was continued by bubbling neat N_2 through the heavier gas already present in the container with, if necessary, later adjustments by further mixing with R12 gas. From subsequent analysis of the container filling operation in these circumstances, it was deduced that the stirring action set up by the addition of N_2 alone with density almost the same as air, had caused some entrainment of air within the gas column. Due allowance for this effect was made in determining the relative density of the released gas cloud so that its physical characteristics could be properly represented. In consequence appropriate corrections must be made to the measurements of any gas sensors in the field responding to oxygen depletion.

In extended periods of dry weather it was found that during the filling operation gas leaked through the ground in the vicinity of the gas container. This was overcome to a large extent by prolonged watering of the surrounding area in the period between trials. Occasionally gas supply operations were interrupted for a short time by unacceptable leaks developing at pipe joints. These tended to occur more towards the end of the trials programme, when the gas plant was run in extremes of outside temperature beyond its normal operating range in order to increase the opportunities for trials in specified wind conditions. In this respect the second winter period was particularly notable when in any case the plant usage had already far exceeded the expected working life of nine months or so for which it was designed.

3.2 Gas container and release systems

In trying to solve the problem of providing a gas container which could be removed almost instantaneously, it was essential to bear in mind that the general shape, volume and physical conditions of the released gas cloud had to be repeatable to within reasonable limits, and that consequently any energy input or disturbance of the cloud by the actual release mechanism must be kept to a minimum. The container had to be strong enough to hold 10 tonnes of the Refrigerant-12 gas and to withstand winds of up to 10 m/s given the requirement to perform trials in winds up to 8 m/s.

Several techniques for achieving the gas release in accord with these requirements were examined including the destruction of a semi-rigid plastic bag with inflatable double wall sections by exploding line charges concealed in its seams. This technique had been successfully demonstrated with a

160 m^3 model during the earlier evaluation exercises by CDE at Porton Down. However, the likely impact on project costs of having to replace the full-size container after each release led to an alternative concept which offered fair prospect of an adequate working life and embodied a re-usable flexible cylindrical bag that could be collapsed rapidly to the ground in concertina fashion.

This principle of operation was first proved with a simple working model about 0.6 m high (see Fig.4). This was made out of ordinary household netting, lined with polyethylene film to act as an impervious membrane and formed into the shape of a bucket by four wire hoops which were restrained by external guy lines and supported by wires attached to a ring that slid up and down a central broomstick, the whole being mounted on a circular wooden base. Some dry ice placed in the 'bucket' and dowsed with hot water created a visible cloud which when the container collapsed on release of the central support ring, was left momentarily as a free standing column of heavy gas before it too slumped to the floor where it spread in a characteristic doughnut pattern under the action of gravity.

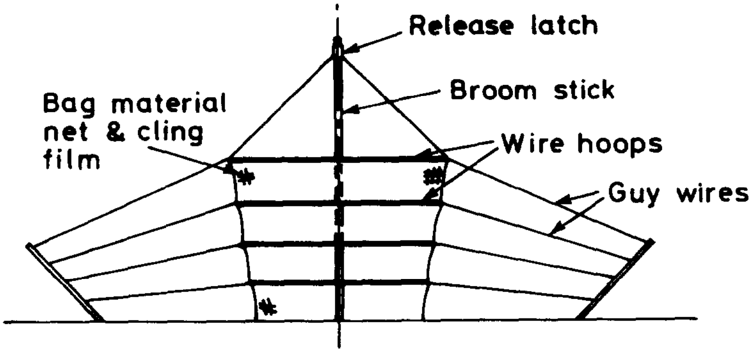

Fig.4. Gas container development — preliminary 'bucket' model.

The results obtained with this model were sufficiently encouraging for a larger version to be built 3 m high or about one fifth of the envisaged full-size container (see Fig.5). It was fabricated from tent nylon and like its predecessor also a working model. In addition to providing endorsement of the design concept, by allowing several options to be examined for stiffening and weighting the fabric of the walls and for rigging the guy lines and restraining wires, it played a vital role in the development of the structural detail and release mechanism for the eventual full-size container.

While the final configuration of the field container and gas release system was emerging and arrangements for its manufacture were being put in hand, a complementary model 1 m high of non-collapsing rigid construction, was tested in the NMI's large boundary layer wind tunnel to assess to what extent the presence of the container might disturb the surface wind profiles. The results showed that instruments placed more than about two diameters

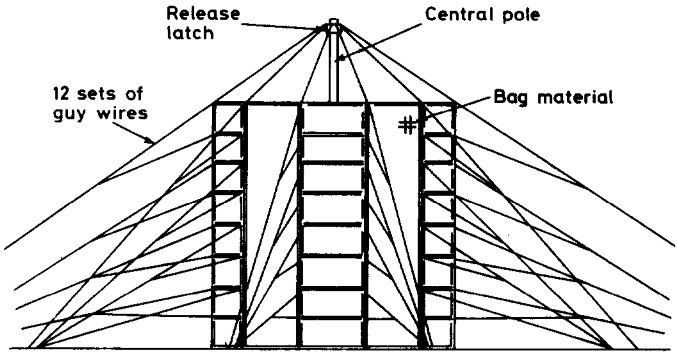

Fig.5. Gas container development — dodecagonal 1/5th scale model.

downwind would be virtually free of container wake influences. However, they also revealed that the wind flowing over the container rapidly advected a large proportion of the stored gas out of the open top. Various adjustments or additions to the upper lip of the container were made in an attempt to spoil the flow over the top and so reduce this effect but with little success and it was concluded that the only solution was to fit a lid which could be retracted just a few moments before collapsing the container.

The lid configuration which seemed most likely to provide an acceptable seal while deployed in the expected wind conditions and to allow a fairly practical solution to the retraction problem, was a conical shape with a short circular skirt attached and overhanging the top edge of the erect container, giving the whole assembly the characteristic appearance of a giant size bell tent (see Fig.6). Both lid and container were made from suitably shaped panels of plastic material. The panels used for the container walls had an integral fabric reinforcing and were welded together to form a twelve-sided symmetrical prism about 14 m in both cross-section and height when fully extended. This was supported by a central lattice steel tower about 22 m high, up and down which ran a sliding trolley to which the main rigging lines that held the erect tent in shape were anchored by quick-release latches. A vehicle and towrope were used to hoist the trolley up the tower, automatically raising the container complete with its conical lid. The rigging consisted of internal restraining wires and external guy lines into which pre-tensioned elastic sections had been inserted to enhance the downward acceleration of the collapsing container. Once the anchor latches were released, it took just over one and a half seconds for the container to fall completely to the ground. The principal engineering features of the container assembly are shown in Fig. 7.

Despite much folding and unfolding in a concertina fashion, the thick reinforced plastic material making up the body of the gas container stood up well to the overall range of environmental conditions, showing little sign of wear throughout the trials. Its ability to withstand repeated exposure

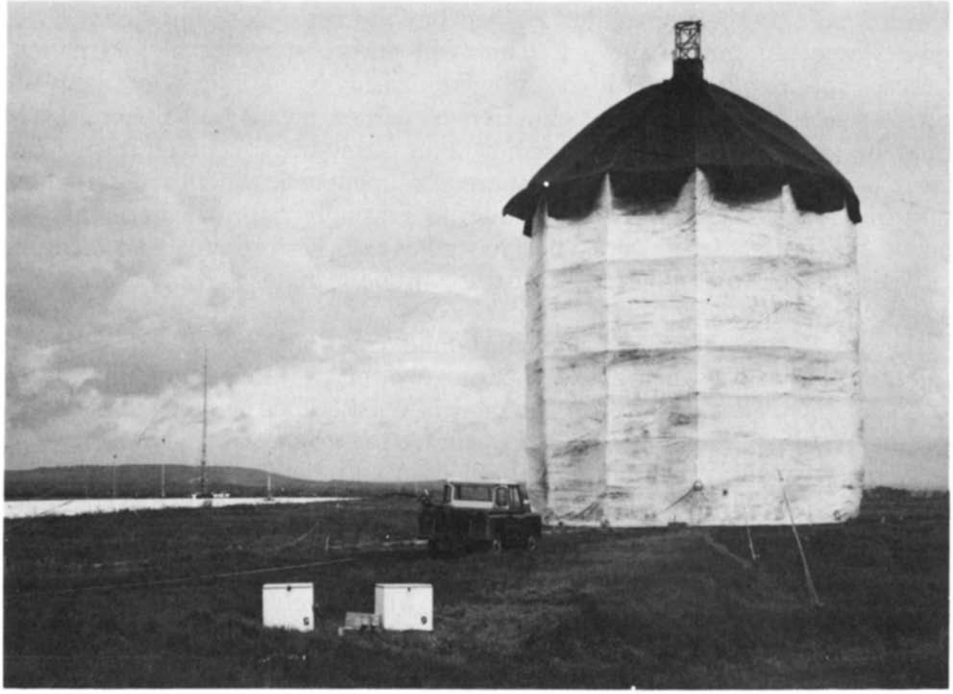

Fig. 6. Full-size gas container.

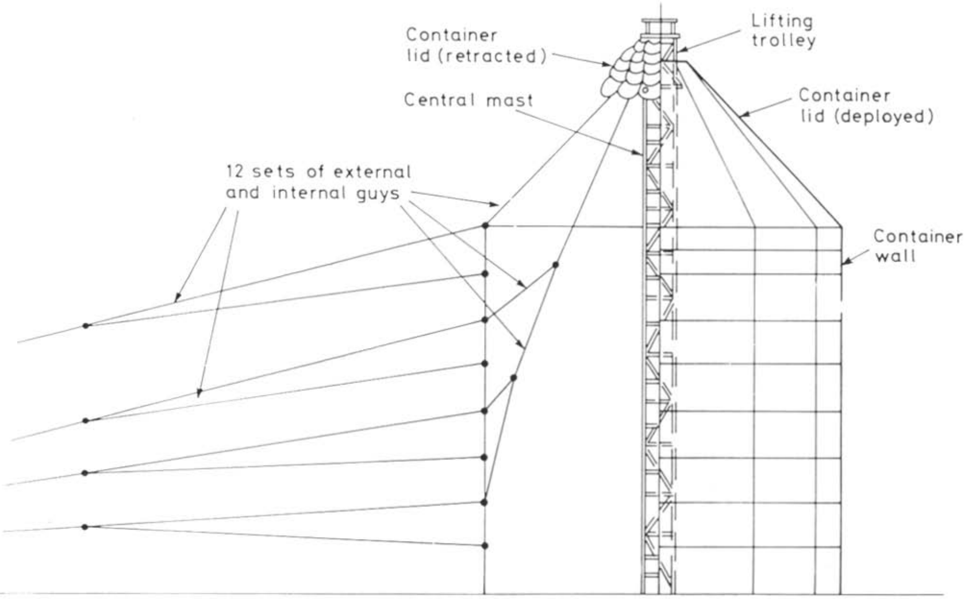

Fig. 7. Principal engineering features of the gas container.

to windforces at the upper limit of and beyond those for which it was designed was often put to the test. The need on occasions to take advantage of trials opportunities afforded by winds decaying late in the day from strong or gale force conditions experienced earlier, meant that the container would be subjected to stronger winds than ultimately occurred during the trial if it was erected with time to spare. The manner in which the container stood up to these conditions became an increasingly impressive commendation of the initial design and its achievement. Provision had been made in the trials budget for replacement of the container material, but in the event this proved unnecessary.

The top rim structure, which maintained the dodecagonal shape of the container, as well as being the anchorage point for the connecting wires to the lifting trolley sliding on the central mast, was originally made from sections of a lightweight perforated angle. After several trials it was obvious that some stiffening was required, and accordingly rigid aluminium brackets, welded to maintain the correct angle in plan view at each corner, were made and fitted to the rim structure. This arrangement proved successful and obviated the need for constant repair.

Throughout the trials period a number of the external restraining wires attached to the container at its vertical corners came away and had to be replaced, and as might be expected the shock cord used to accelerate the container drop also required some renewal.

The container lid material suffered considerable damage during the trials. Originally of a thin plastic, shaped to lap over the container rim, and resting on the connecting wires between the rim and the sliding trolley, this material was subjected to a lot of chafing on the upwind side, especailly in the higher wind conditions. Significant time was often spent between trials in repairing the lid. During the lull in trials activity over the winter of 1982/83 a new lid of reinforced lightweight nylon tent cloth was purchased. Although the supporting layer of wide-meshed netting which had originally been fitted over the container rim lifting wires in the upwind sector, helped to prevent undue damage to the new lid and reduced the amount of repair work required, this problem was never completely overcome.

On a few occasions, particularly in higher wind conditions, it was found that the volume of gas released had been significantly less than the nominal capacity of the full container, although no deliberate action had been taken to curtail the filling operation. This was due to gas being advected by the wind out of the top of the container, largely during the rather unpredicable delay between retracting the lid and collapsing the container but also to some extent dependent on the wind strength, in the period before the lid retraction because of the imperfect seal made by the lid over the container rim. The elimination of this problem would have required a complete redesign of the container, lid and gas release system, which was prohibitive on cost grounds alone, even without regard to the time factor involved.

The landrover used at first to pull the trolley lifting rope for hoisting the container, eventually developed a faulty clutch. As a result a tractor was substituted for this vehicle, and proved to be highly successful.

The complex arrangement of restraining wires within the container caused some difficulties by fouling with the trolley lifting ropes, which led to occasional jamming of the hoisting and release system. In one instance early in the trials programme this resulted in container arrest immediately after release, giving rise to a two stage drop. Once this problem had been tackled by the field team, and a suitable sequence of erecting procedures mastered, taking no more than one hour to complete, a clean container lift and drop was always accomplished.

3.3 Field measurement stations

The layout of fixed and mobile measurement stations and the vertical disposition of all the various gas and environmental sensors have been given by McQuaid [4]. Normal roadside lamp standards 10 m tall without their lantern fittings were used as simple but effective fixed masts. In all, 38 of these were implanted in the ground at the chosen grid locations which had been fixed by theodolite survey, resulting in eight stations on the hard disused runway surface and the remainder on the rough grassland. Steel brackets of suitable section clamped by U-bolts to each lamppost provided standoff mountings for sensors at various heights and all lampposts were fitted with vertical extension poles to allow a maximum height of 14.5 m for the top sensors. Each mobile station consisted of an extendable steel lattice mast of maximum height between 15 and 20 m, mounted on a mobile trailer. Examples of a lamppost and a mobile mast are shown in Fig.8.

The main meteorological station consisted of a trailer mounted lattice mast similar in type to the mobile stations but 30 m high and guyed in a fixed position 150 m uprange of the spill point (see Fig.9). The field layout was completed by the two eddy forecasting stations, these being portable telescopic masts, which could be pumped up to the required height of 10 m.

The installation of four standard gas sensors at the lower heights required on one of the lampposts nearest to the container is shown in Fig.10. In this view, the mounting brackets hold the gas sensors at a distance of 0.8 m from the lamppost centre and indeed for the first three gas releases, this was the stand-off distance for all standard gas sensors except those positioned at either 10 m or 14.5 m height which were held by 0.19 m stand-off brackets attached to extension poles with a specially devised telescoping action to allow rapid adjustment of the topmost sensors to any height between these limits. In the event, these poles were only ever fully extended in the last transverse row of seven masts because of the general lowering of sensors to a maximum height of 6.4 m which followed the cloud depth observations during these early trials. The extra mounting brackets which had to be manufactured to hold the re-positioned uppermost sensors, were made with shorter 0.33 m stand-off distances. Occasionally when later in the programme further re-arrangements of sensors were required, in a few locations for

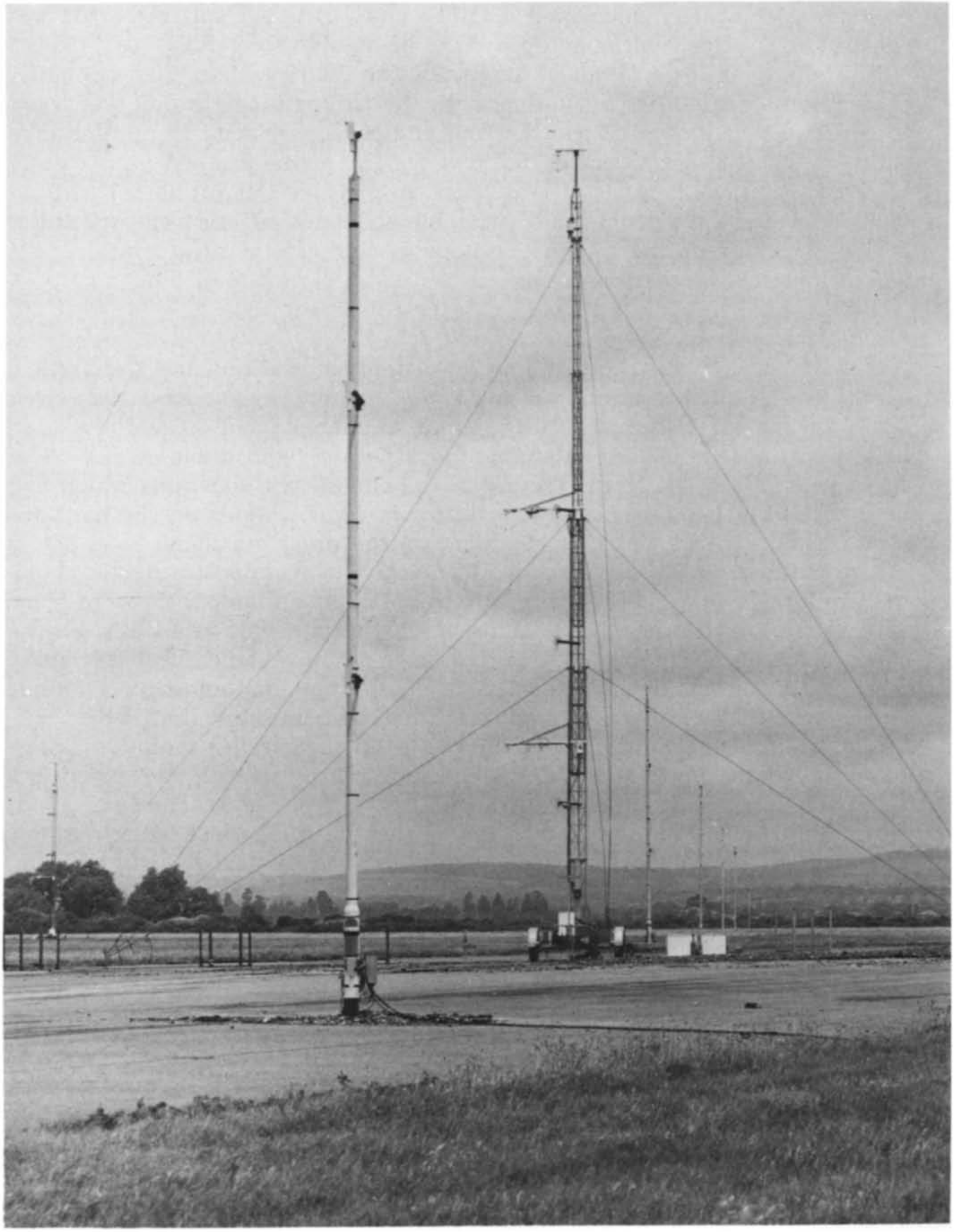

Fig.8. Fixed lamppost and mobile trailer-mounted masts.

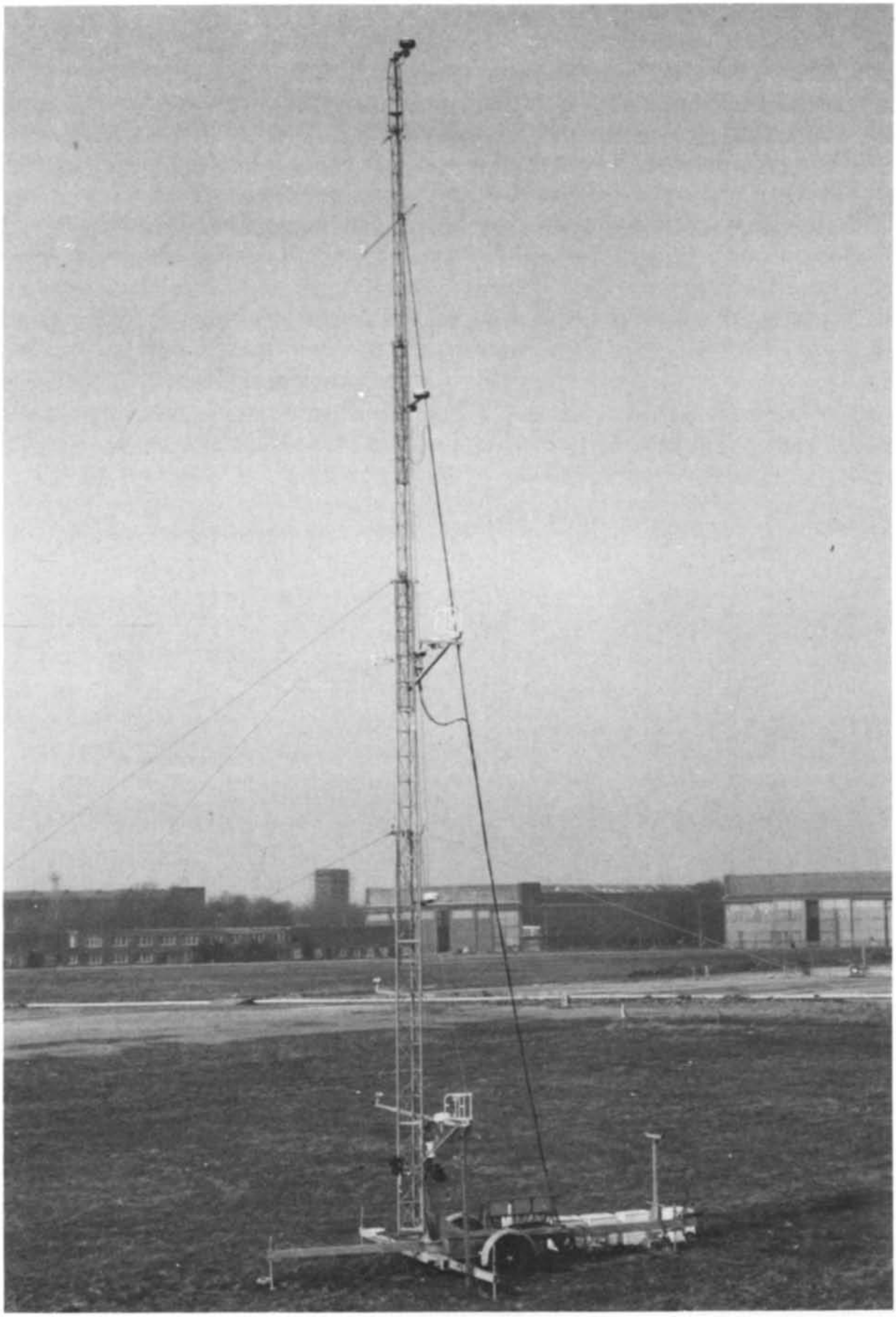

Fig.9. Meteorological station.

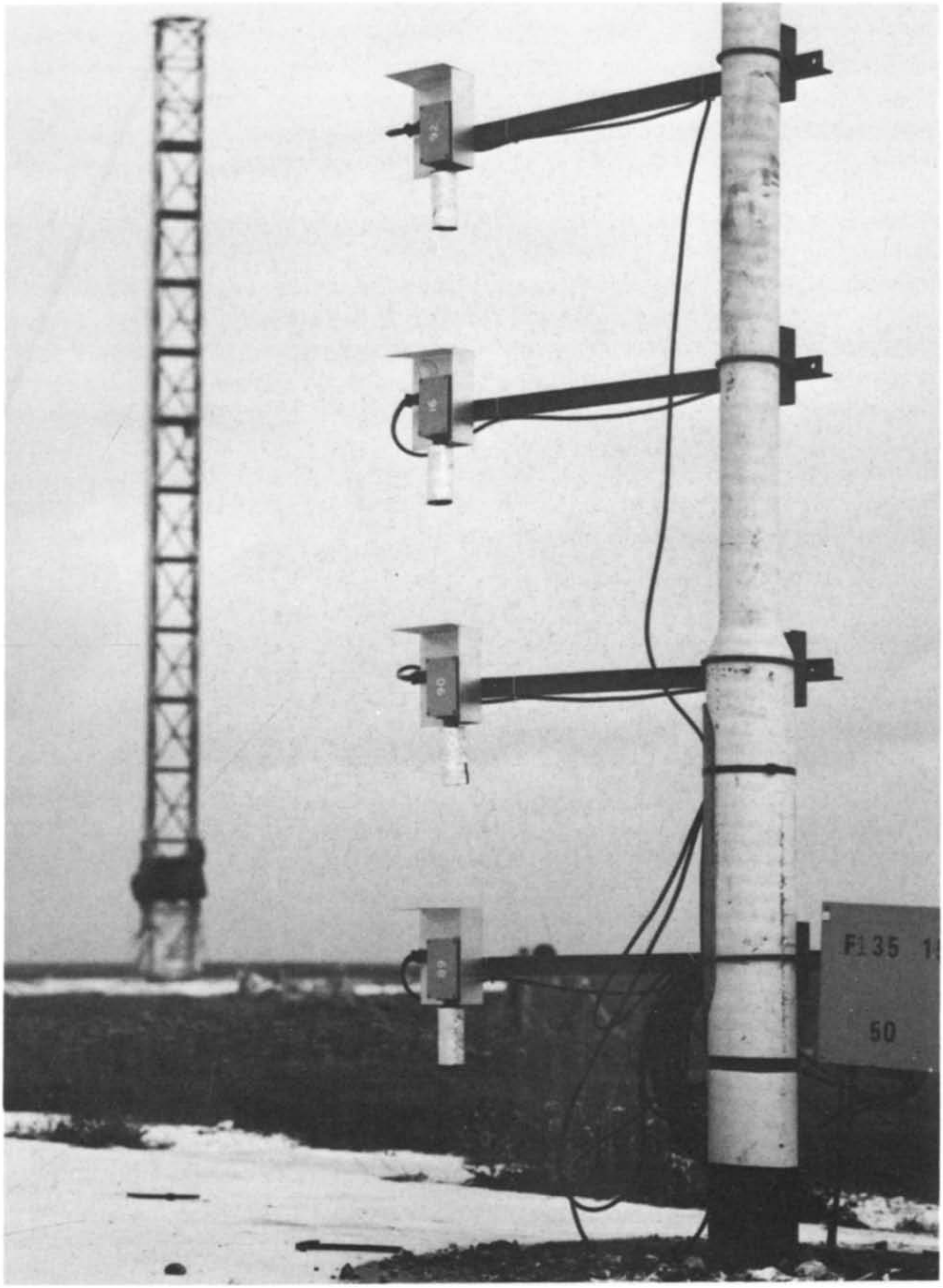

Fig. 10. Gas sensor installation on lamppost.

expediency the 0.8 m and 0.33 m stand-offs were unwittingly interchanged. To ensure that the gas sensors were not measuring concentration levels in the 'shadow' of any lamppost, all of their mounting brackets were set to point uprange and parallel to the range centreline, save at the two stations immediately uprange of the container, whose brackets were aligned in the reverse direction.

Over half of the environmental sensors were installed on the uprange meterological mast. Eight of the three-axis anemometers however, were deployed within the anticipated gas dispersion area downwind of the container on the mobile masts, mostly alongside fast response gas sensors to form a number of 'high-speed' instrumentation pairs. An example of the installation of one of these pairs is shown in Fig.11 in which the mounting

Fig.11. Fast response instrumentation on mobile mast.

arrangement for a standard gas sensor, in this case with an adjacent fast response sensor, can also be seen. As with the lamppost arrays, the sensors on the mobile stations were mounted in positions stood-off sufficiently from the mast centre to avoid any significant interference with the measurements, by the main vertical structure. The stand-off distances of the three-axis anemometers were 0.65 m for those located at the 15 m or 20 m masthead heights and 1.75 m for all those at lower heights. Where, as in the illustrated case, one of the lower instruments was paired with a fast response gas sensor the latter was positioned 0.5 m 'inboard' of the anemometer mounting. All the anemometer brackets were orientated transversely to the range centreline and projecting to the left when viewed downrange for the first three gas releases following which those on mobile masts to the left and on the centreline of the range were re-aligned to point to the right. Because of the transverse mounting of the anemometer brackets and the triangular cross-section of the mobile mast structure it proved impractical to assemble the standard gas sensor brackets projecting directly uprange as on the lampposts. Instead they were all installed at 30° to the range centreline with the sensors held at 0.85 m from the mast centre but with the sideways bias from the uprange direction, wherever possible to the side of the mast on which the three-axis anemometers were located. In the situation depicted in Fig.11, where fast response and standard gas sensor performances were being compared, the reference fast response instrument was mounted 0.3 m nearer than the standard sensor to the mast.

4. Measurement system

4.1. Transducers

In the fully developed field of 45 measurement stations there were altogether 215 transducers. Every one of the 38 lamposts and the four mobile masts initially carried four standard gas sensors at various heights making the number of this type deployed 168. The mobile masts also carried the only eight fast response gas sensors deployed in the field together with seven of the optical smoke detectors specially developed by HSE. This brought the total number of gas sensing devices up to 183. In addition to these, there were 32 environmental sensors in the measurement field consisting of 6 thermometers, 10 three-axis anemometers, 6 cup anemometers, 4 wind vanes, 3 humidity probes, 2 solarimeters and 1 barometer. However, because each three-axis anemometer provided a temperature output which was connected to the data system on all but two of these instruments, altogether 60 data channels were needed for the environmental measurements.

The transducer inventory was completed by a number of sensors deployed on the container support tower for use during the filling and release operations. Initially two standard gas sensors and two thermometers were fitted at heights of 0.4 m and 12 m and also a container release event marker which was triggered by the opening of the main rigging anchor latches.

The sensors inside the container proved so helpful in monitoring the gas filling that a further three were added after the first few trials making gas detection available at levels of 0.4, 4.5, 9.0, 12.0 and 13.5 m, and a total of eight data channels required at the container position. These, together with the 60 environmental measurements and the 183 gas sensors brought the overall capacity required of the data collection system to 251 channels.

The operating principle and characteristics of the gas sensors have been described by Leck and Lowe [6] . The three-axis anemometers used to measure turbulence both within and above the gas cloud and also in the incident surface wind, operated on an acoustic basis by detecting the very small changes induced by local air movement in the speed of sound travelling between pairs of ultrasonic transducers separated by a set distance in two horizontal directions 120° apart and also vertically. The anemometers responded to fluctuating airflows over a frequency range which more than matched the nominal 0.1 sec response time of the 'high-speed' gas sensors. The set measurement range for horizontal components of velocity was 0 to 30 m/s and for the vertical 0 to 10 m/s with an expected measurement accuracy in both planes of ± 1% . The ambient temperature output facility which derived from the speed of sound measurement, was used on a number of the instruments, set generally to measure over a 10° C range around the expected outside air temperature.

The more familiar rotating cup anemometers used to record mean wind speeds at various heights were of the Porton type approved by the Meteorological Office and had a useful working range of 0.15 to 50 m/s with an accuracy of ± 1 m/s. Two of the wind vanes were also of similarly approved Porton type and incorporated fixed reference segmented commutators providing instantaneous readings of wind direction in steps of 11.25 degrees which by time averaging could be resolved to ± 2 degrees accuracy. A minimum wind speed of 0.2 m/s was required for these instruments to respond. The other two wind vanes, used to indicate the approach of eddies, were simple potentiometric units of lightweight construction primarily intended for yacht use. Unlike the outputs from the two Porton instruments the data from these eddy forecasting vanes, although included in the main data files, were not regarded as part of the validated trials records.

The thermometers used for measuring temperature on the site and also inside the gas container, and in particular to determine the temperature gradient up to 30 m above ground level, consisted of platinum resistance elements housed in metal probes. Accuracy claimed by the makers was ± 0.2° C over the range experienced during trials. All of the thermometers that were located in the open were protected from direct sunlight by radiation shields.

The operation of the relative humidity sensors relied on the measurement of electrical capacity changes in the sensing head induced by variations in moisture content. The probes were stated to be accurate to ± 2% RH at 20° C. They were generally fitted with a sintered filter to protect them from air movement which also helped to prevent salt contamination. To overcome a known problem of preserving the instrument's calibration under relative humidity conditions continually approaching 100%, the sensors were equipped with heating elements which prevented exposure above 80% , due allowance being made in the calibration for the effect on the sensors' response.

The two solarimeters incorporated thermopile transducers which responded to the total incoming radiation of the sun in a bandwidth from 0.3 to 2.5 μm. They operated linearly to within 1% over the whole of this range with a stated accuracy also better than 1% . Finally the system barometer was an electronic transmitting device which relied on detecting the a.c. signals produced in a differential transformer when movements of its ferromagnetic core were caused by very small distortions of a pressure sensitive capsule on which the core was supported. Calibration stability was guaranteed to with 0.25% for up to one year. The instrument measurement range was variable from 100 to 300 mbar with a claimed resolution of 0.02% and accuracy of ± 1% of its output span.

During the trials programme, the performance of all transducers was checked many times using techniques specially devised for convenience in the field. The procedures developed by HSE for ensuring the satisfactory performance of gas sensors have been separately described by Leck and Lowe [6] . In general these did not require the gas sensors to be removed from their installed positions except when in need of repair, although with standard gas sensors in particular, a sufficient number were available to cycle them in groups of ten at a time through a routine procedure of preventive maintenance by HSE while always keeping the required complement deployed in the field.

On the other hand, the methods used for environmental sensors did entail the removal of all the instruments to a common location which, to enable expedient use of the data transmission system, was situated close to the main meteorological mast. The scale of the operation of lowering all the mobile masts and removing environmental sensors was such as to make it only practicable to carry out performance checks on them at the beginning and end of each major phase of the programme and occasionally when convenient during prolonged interruptions between trials. These checks were essentially of two kinds, in the first of which the outputs of all sensors of similar type were closely monitored and compared over a period of up to 48 hours continuous exposure to the environmental conditions at the common location. In the second, as many instruments as possible were subjected to span checks covering the specific responses to controlled inputs at zero and one other point representative of the upper measurement limit of the range of conditions judged to be met during actual trials runs. From the results of these span checks it was generally possible to identify readily those instruments for which it would no longer be reasonable to assume the manufacturer's calibration.

The serviceability record of all the environmental transducers was very good with the exception of the relative humidity probes which were highly prone to failure when exposed, as they frequently and inevitably were, to extremely wet conditions. Fortunately, back-up measurements of relative humidity were usually available from direct readings of wet and dry bulb temperatures taken on the site around the time of each trial. The continuous monitoring of the site environment allowed real-time comparisons to be made between the responses of like sensors to the known weather conditions experienced. This generally enabled instruments with suspect performance to be readily identified and, if necessary and as far as possible either repaired, or replaced from spares held in reserve. The data provided by the span checks were intended to determine the extent of measurement deviations between sensors of similar type, responding over the same range of environmental conditions, and nominally assumed to perform to the manufacturer's declared specification and calibration. These are currently the subject of detailed analysis the outcome of which it is planned to report separately in the near future.

4.2. Data handling

The overall requirement for measurement channels was met by a network of 34 microprocessor controlled data loggers, each with its own eight channel multiplexer, analogue to digital converter and mains fed power supply so that it could convert measurement samples which were acquired at the rate of 20 per second from each of eight analogue input channels into a single

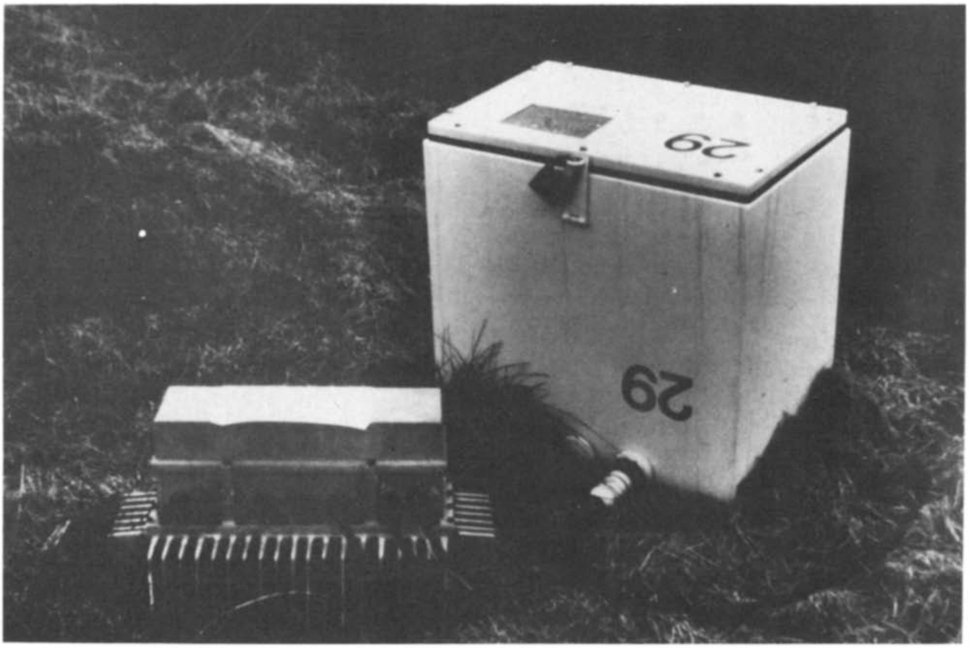

Fig.12. Data logger and power supply.

serial digital data stream. The data loggers, protected by their strong waterproof housings (see Fig.12), were distributed around the field in such a way as to minimise the distances over which analogue signals had to be transmitted while making the most efficient use of channel capacity and cabling. For example, each pair of neighbouring lamposts holding four gas sensors generally shared one unit between them. All the cabling and connectors were required to withstand prolonged exposure to the prevailing weather conditions at the site. The field was divided into five convenient sectors in each of which the balanced transmission lines carrying the multiplexed signals from up to seven data loggers were loomed into one multi-way cable (see Fig.13) which conveyed the data stream from that sector to a central base station located in the control tower.

The base station provided the interface between the data collection system and the main computer (see Fig.14) which sorted and recorded all the appropriately coded incoming signals onto a 50 megabyte disc on which

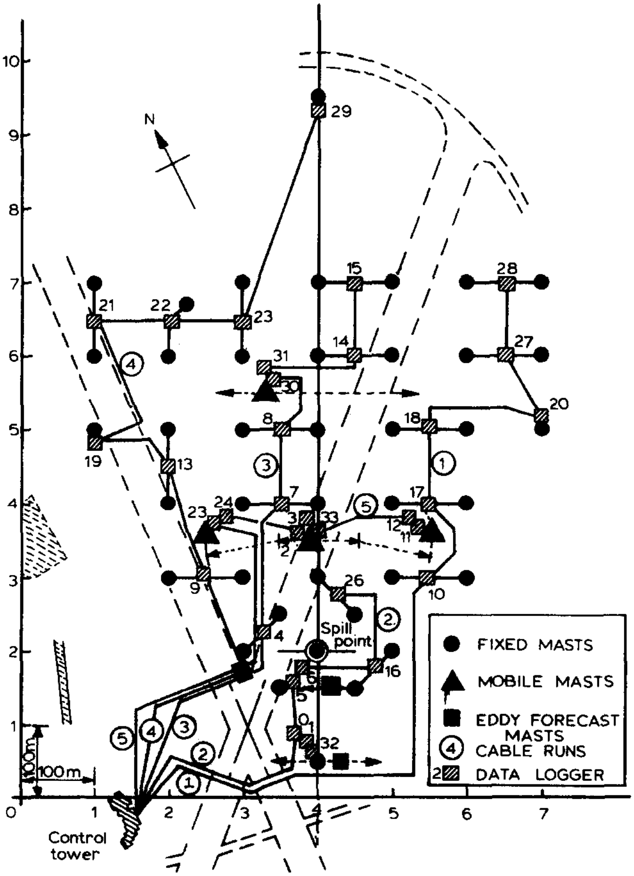

Fig.13. Arrangement of cabling and data loggers.

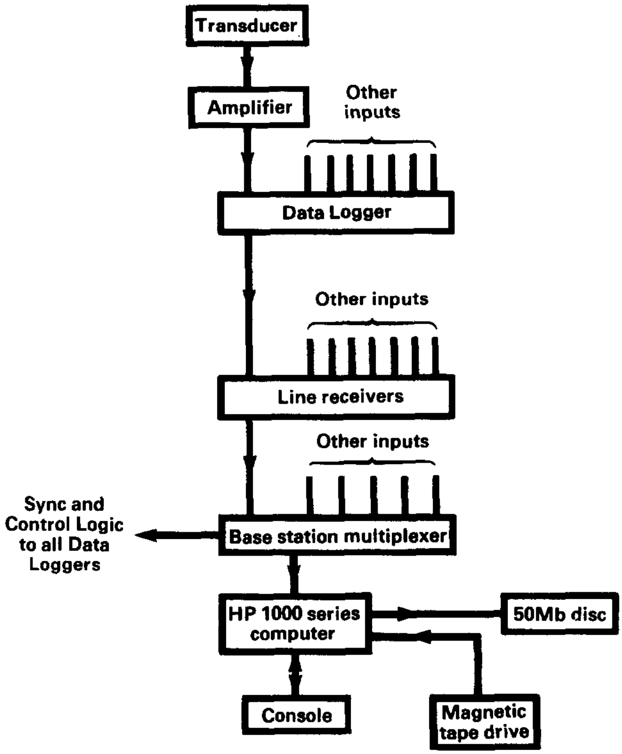

Fig.14. Block schematic of data system.

were also stored files of current information on channel allocations and the position and calibration of all sensors, identified for simplicity as 'housekeeping' files.

The base station also fed time synchronisation pulses to the whole field and could send control signals to any specified data loggers and receive status signals back from them via the data cabling runs. A range of software options developed for the central processor, allowed data to be manipulated and presented during routine system checking or actual trials operations. Two on-line computer terminals were provided for this purpose, one in the operations room at the top of the control tower for the Trials Manager and another with the base station on the ground floor for the Data System Manager.

The general reliability and serviceability of the data system have been excellent with no major breakdowns ever being experienced during trials and relatively few delays through minor faults. An especially noteworthy feature has been the ease and speed with which the data handling system could be re-instated following damage caused by electrical power surges induced through lightning strikes or unheralded mains supply interruptions, just by replacing vulnerable circuit components in the base station and data loggers. A selection of spare transducers and data system components was normally held in stock.

5. Operational procedures

While the actual conduct of trials was clearly the primary feature of operations on Thorney Island, a working presence was required on the site for much of the time during the far longer intervals between trials to cover all the general maintenance and repairs of facilities and systems as well as more dedicated routine tasks such as the periodic checking of instrumentation already mentioned above and ensuring the regular acquistion of site meteorological data for analysis described by Davies and Singh [5] . Any major engineering work or change in the field layout of the data system always brought a significant upsurge in the level of site activity. During periods when the site was unoccupied, potential intruders were deterred from entering by appropriate warning notices and safety signs, and as the airfield remained throughout the property of the Ministry of Defence, security patrols operated on a full 24 hour basis.

The trials operations themselves can be identified in four successive phases, trials preparation, countdown, gas release and dispersion, and post trial activities. The first move in preparing for trials was to establish the probability of favourable weather conditions and in particular wind speed and direction, occurring at the trials site. Throughout the project, the local Meteorological Office in Southampton provided daily weather reports giving the general synoptic situation for the area and specific guidance on what to expect on Thorney Island over the next 72 hours. If there seemed to be a

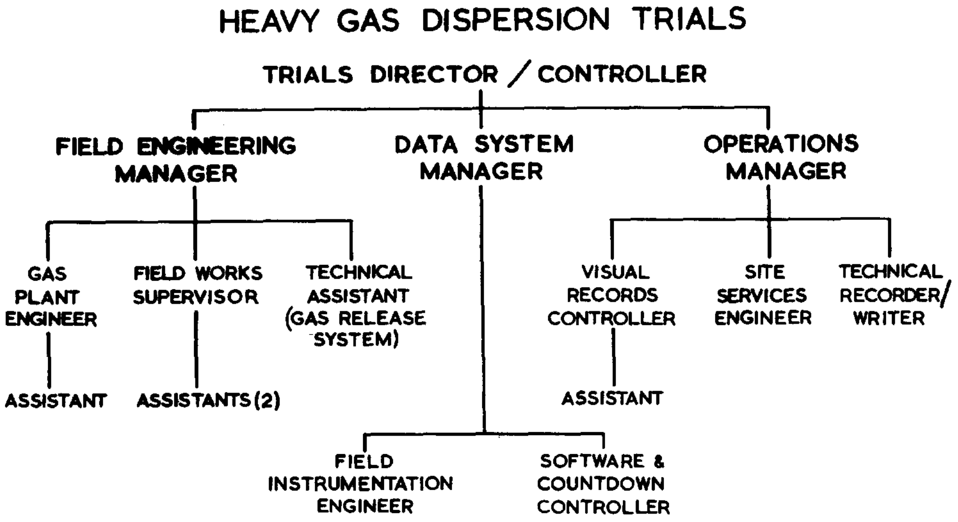

Fig.15. Field trials team.

strong possibility of southerly to southwesterly winds in an acceptable speed range, a trials team would be selected and put on stand-by. This would consist ideally of 16 persons to fulfill the roles indicated in Fig.15.

Later in the preparation stage, direct liaison with the duty forecaster at the Meteorological Office combined with the evolving experience of our own trials personnel of local influences on site such as sea breezes [7] and katabatic winds [8] , would indicate the most likely period for achieving one or more of the required gas release conditions. A working party would then be sent to the site up to six working hours in advance, which was generally adequate to ensure that the field sensors and data system were working satisfactorily, replacing or repairing any indispensable instruments giving suspect performance and also to check the serviceability of the gas plant, the release system, site vehicles, intercommunications and safety equipment. At this stage too, a commercial helicopter would be reserved for providing the overhead visual record of the gas release.

With a few hours remaining before the scheduled spill time, the rest of the team gathered on site and supervision of the trials preparations continued from the operations centre in the disused airfield control tower buildings (see Fig.16). The immediate major task was the erection of the gas container. Attempts were made early in the programme to raise the container with its lid already in position while the gas was being admitted, matching the in-

Fig.16. Trials operations centre.

creasing height of the container to the rate of gas supply, with a view to minimising the risk of air entrainment. However, once gas sensor measurements made inside the container during filling had shown that this was not happening to any significant extent, this rather exacting and lengthy technique was abandoned and thenceforward the container assembly was lifted to its full height before filling commenced. With the progressive refinement of the filling procedure, direct reading pressure sensors were introduced to monitor the head of gas at ground level and about halfway up the container. These 'weighings' of the gas column coupled with assessments of its height based on responses from the gas sensors within the container as the gas level progressively passed each of them and corroborated by direct observations of the container's exterior profile, provided a means of determining the density of the gas supplied, independently of the flow measurements made at the gas plant.

Other preparatory work within the container included the laying of the coloured smoke grenades to mark the cloud for visual records as specified by McQuaid [4] and the deployment of gas sampling units. To achieve the smoke marking, the procedure originally planned had been to fire all the grenades simultaneously a few minutes before releasing the gas. Early trials experience, however, revealed that, without any provision for mixing the smoke with the gas beyond that induced by the jet action of the burning charges, uncertainties in forecasting the release time could result in significant smoke layering effects. The occasional presence of a virtually smoke free zone towards the base of the gas column was among the more obvious of these. Some improvement was achieved by staging the firing of the smoke grenades but in the absence of any facility for repeatedly viewing the smoke distribution within the container, the extent to which this techniques could be refined in the light of experience, was very much at the mercy of unpredictable features in the filling operations and local environmental conditions. Fortuitously, the slumping of the gas column and the vigorous mixing it induced, ensured the rapid elimination of any non-uniformity in the smoke marking in all but the most severely affected instances.

The gas sampling units were specially developed by NMI to grab gas specimens for laboratory analysis after each trial. The operating principle of these 'gas grabbers' was that of a simple gravity pump in which the falling action of a weighted plate glued to the flat underside of a special plastic bag, caused gas to be drawn in and inflate the bag (see Fig.17). When setting each grabber in preparation for a trial, the plate was held in place by a pair of solenoid operated latches. The original intention had been to use these units to provide independently from the main data collection, a check on the response of gas sensors in the field by arranging for the sensor output signals at some preset threshold level of concentration to trigger adjacent gas grabbers automatically. Unfortunately it proved in practice much more difficult than expected to establish reliable triggering conditions and the concept had to be abandoned. However a valuable alternative function was

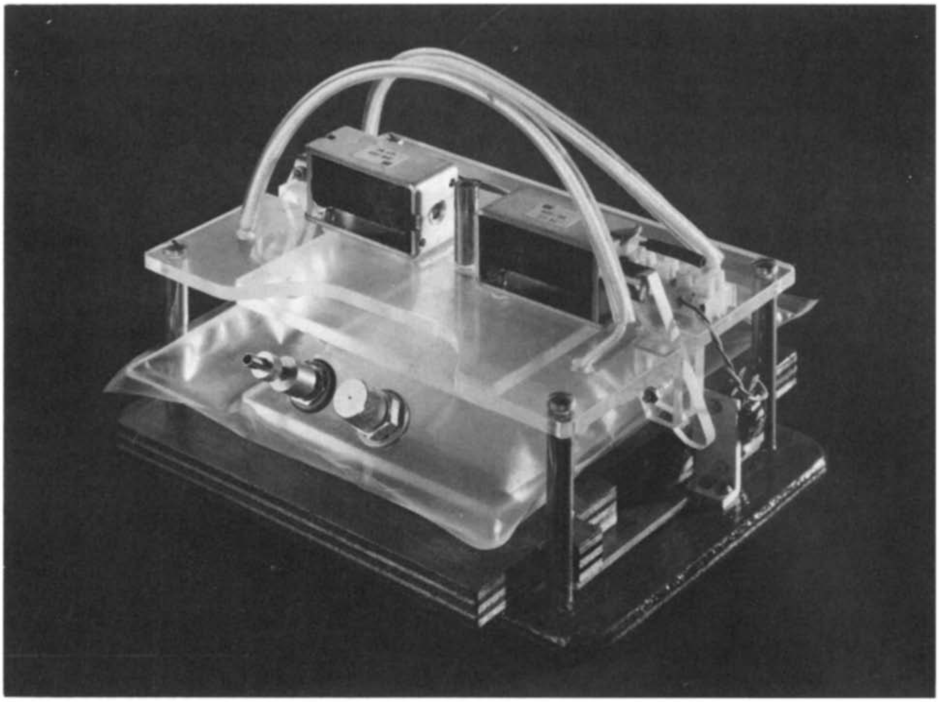

Fig.17. NMI 'gas grabber'.

readily identified for the gas grabbers, which, deployed at four different heights up the central tower of the gas container and manually triggered shortly before each release, provided an independent means of determining the proportions of source gas present and hence of making a further check on the density of the released gas.

The last but not least important aspect of the trials preparation was the setting up of photographic and video recording equipment. Three camera positions were on the ground at about normal viewing height and one airborne overhead in the hired helicopter (see Fig.18). A 35 mm still camera, high speed 16 mm cine-camera and a video set consisting of camera, recorder and monitor made up the master station to one side of the spill point at right angles to the range centreline. Still camera only stations were located to one side downrange a few hundred metres and uprange looking directly along the centreline of the measurement field. All visual record units were time synchronised with each other and, except for the cine-camera displayed real time within their fields of view although this did not include seconds indication until a later stage of the trials when a more fully developed system became available. The operation of the ground still camera units was controlled by a central radio transmitter. The airborne package consisted of a video and still camera assembly mounted in a single purpose-built frame aligned to look vertically downwards to one side of the aircraft fuse-

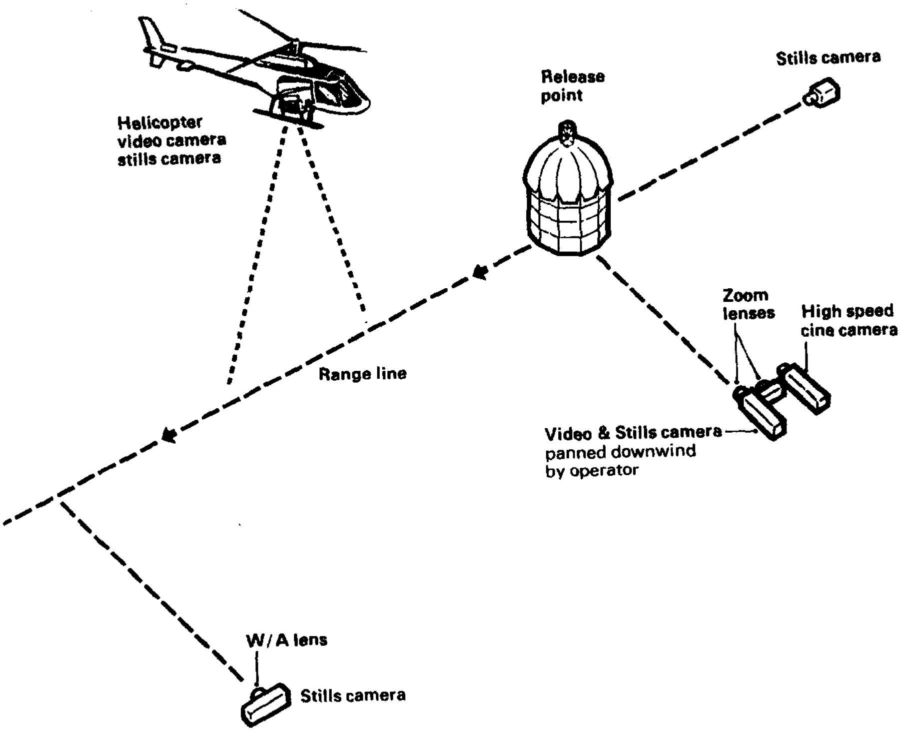

Fig.18. Visual records system.

lage, with a video monitor, recorder and power supply inside the cabin with the operator. When the helicopter arrived on site shortly before starting to fill the gas container, the simple attachment to the door and access step above the landing skid, enabled the installation of the equipment to be completed in just a few minutes.

With the container now ready to receive gas, after a further check that favourable weather conditions for a release were still expected, the gas plant could be started and the countdown programme initiated on the computer. The filling of the container normally took about one hour and during this time a running series of questions or cues would be displayed on the Visual Display Unit (VDU) in the operations room at the top of the control tower. These prompted the Trials Manager on various actions that needed to be taken at certain times during the countdown in order to be ready to release the gas with the minimum delay once the filling operation was complete. Such actions included informing local safety and security agencies of the imminent gas spill with its associated large orange cloud, checking and if need be adjusting the contents of the container with the aid of gas concentration and pressure measurements, sequential firing of smoke charges, activating gas grabbers, getting the helicopter airborne and most particularly keeping a watch on the weather, looking out especially for any local variations in wind speed and direction.

To ease this latter task, four wind vectors were continuously displayed on the VDU beside the countdown programme. These were derived from the wind speed and direction data coming in from the main meteorological mast and from the fixed mast at the downwind end of the measurement field, together with the wind vane signals from the two eddy forecasting stations, although strictly speaking the latter, not being associated with any wind speed values, produced only pseudo-vectors of a fixed length. Nevertheless, the eddy forecasting pair of vanes were sufficiently light to respond very rapidly to sudden fluctuations in direction several seconds before their influence could reach the spill point and when viewed in conjunction with the two vectors produced by the other wind sensors a very reliable picture was created of when the mean conditions were sufficiently in range and steady to allow the release to proceed. In addition to the display on the VDU, supporting evidence concerning the wind conditions on site was available from an analogue recorder also running in the operations room but independently of the main data system, which continuously indicated wind speed and direction as measured by a Porton wind vane and cup anemometer at a height of 20 m on a trailer mounted mast positioned on open grassland behind the control tower.

The continuous monitoring of the pressures and inferred quantities of gas supplied provided a frequent update of the forecast release time, generally assumed to correspond approximately with the container being full. Occasionally, due to leakages of gas or inaccurate measures of storage tank contents, it was not possible to achieve the full 2000 m^3 of gas in the container and at other times, unforseen delays towards the end of the countdown but before the gas plant was shut down led to the container being overfilled. Thus judging the right moment to stop the gas supply against the likely time to retract the container lid and initiate the gas release, relied crucially on the evolving experience of the Trials Manager.

At the end of the countdown programme, automatic collection of data from the field was initiated, running at first in a cyclic mode which always kept the most recent five minutes of incoming data stored in the disc memory while final checks were made to ensure that all pre-release actions had been completed and that no personnel were too close to the spill area. Once all was declared to be ready, the main data collection programme was set running and as soon as the wind conditions appeared reasonably steady, the Trials Manager put out a final 10 seconds count over the radio and a strident siren blast heralded the container collapse and gas release (see Figs.19 and 20).

Data collection continued typically for 20 minutes or more and video and camera systems were kept running until the smoke which marked the spreading cloud was no longer visible. After the gas had dispersed, a final set of readings from all sensors was first recorded and then the post trial activities began with the dismantling of equipment in the field and careful inspection of the container lifting and release system to identify

Fig.19. Instantaneous gas release viewed at ground level.

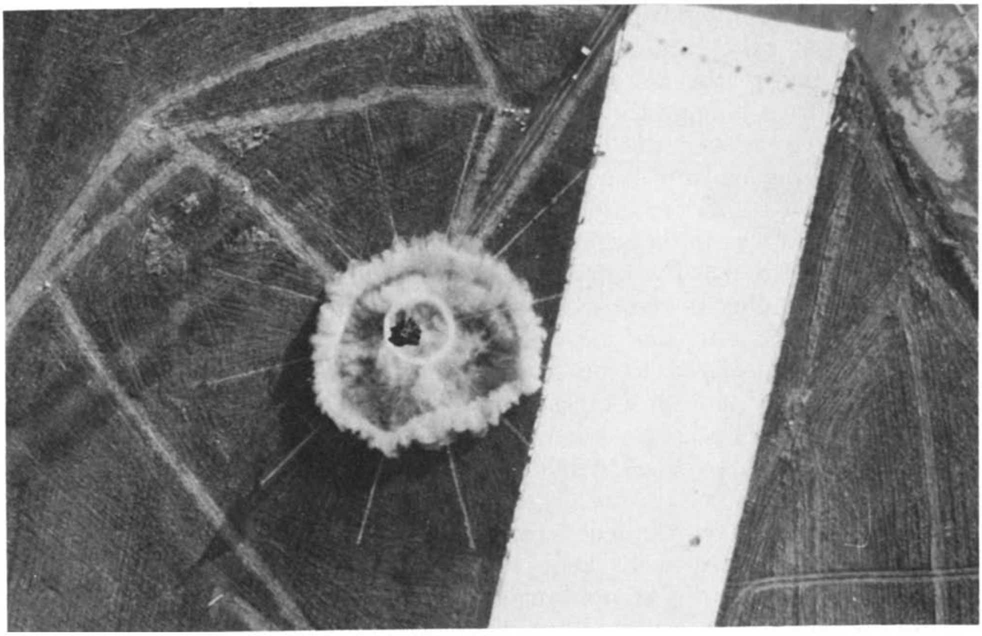

Fig.20. Instantaneous gas release viewed from overhead.

any damage that would have to be repaired before another trial could be performed. Gas grabbers were retrieved and the inflated sample bags were individually labelled and packed into purpose built transit cases for despatch to the gas analysis laboratory. Meanwhile checks were made by the Data System Manager to confirm the successful acquisition and the integrity of all the raw data which were then immediately copied from the main computer disc store to two identical magnetic tape records, a master copy for safe and secure keeping and a working copy for subsequently processing the results of the trial [9]. Preliminary estimates were made of the volume and density of gas which had finally been released, to be confirmed or refined later by examination of visual records of the container collapse and gas release, and by the results of the grab sample analyses.

6. Trials achieved

The series of trials on unobstructed instantaneous spills, leaving aside three early releases of only smoke-marked air to test equipment, had begun towards the end of June 1982 and by the time it was concluded almost 12 months later, 16 releases of gas had been made, over three times the number originally planned and with little more than 20% increase in overall costs. The first actual gas release was the required one of neutrally buoyant nitrogen only and at a later stage the release of neat Refrigerant-12, 4.2 times as heavy as air, was also accomplished. Wind speeds ranged from 1.7 to 7.5 m/s and typically up to a third of the sensors deployed in the field detected gas. On just one occasion a malfunction of the release mechanism interrupted the fall of the container for several minutes and during one other trial only, a sudden shift of wind direction at the moment of release caused the dispersing gas cloud to miss most of the measurement field. The times when, after assembling a full team and completing all preparations, the failure of forecast weather conditions to arrive led to trials being abandoned, numbered no more than three.

Increasing experience and confidence in conducting the trials made it possible towards the end of the first series to exploit two opportunities to perform a pair of gas releases on the same day within just a few hours of each other. Furthermore, the general reliability of the systems and effectiveness of the procedures developed for the Thorney Island trials had proved sufficiently satisfactory to ensure the realisation of plans for a continuation series of experiments to determine the influence of various obstructions on the dispersing gas clouds [10].

Acknowledgement

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