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Fire Research Note No 1034

COLLECTED SUMMARIES OF FIRE RESEARCH NOTES 1974

by

L C Fowler

April 1975

FIRE RESEARCH STATION

52600

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COLLECTED SUMMARIES OF FIRE RESEARCH NOTES 1974

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(These summaries were prepared for the Fire Offices' Committee
but it is thought that they may have general interest)

EVALUATION OF ROAD TANKER DIP TUBES AS FLAME BARRIERS

by

Z W Rogowski and C P Finch

Road tankers carrying flammable liquids are fitted with devices for measuring the liquid level by means of a dip stick. Holes in the top of the tank allow a perforated dip tube, about $3\frac{1}{2}$ in in diameter and about 6 to 7 ft long, to be inserted until a flange at the top of the tube rests on the sides of the hole in the tank top to which it is bolted. A graduated dip stick is inserted in the tube so that the liquid level can be read when the stick is withdrawn. The perforations are required in the dip tube so that the liquid level is the same inside as outside the tube and the experiments described in this Note were designed to evaluate the performance of flame arresters fitted over the tube perforations for the purpose of preventing accidental explosion flames in the tube passing through to the contents of the tank.

For these experiments the tank was represented by a vertical 1 ft diameter open ended flanged steel duct, or tube, in which the dip tube was inserted from the top and bolted on. The whole apparatus was filled with a 4.5 per cent propane-air mixture. The flammable gas mixture was ignited by a spark in the dip tube, near the top, and the purpose of the experiments was to see if that explosion ignited the flammable mixture in the duct outside the dip tube. A plastic bag was fitted over the bottom of the duct to relieve the explosion if the dip tube flame arresters failed. The top of the dip tube was either open or partially restricted, the latter representing the condition with the dip stick inserted.

Three types of dip tube were tested. Tube A, of drawn aluminium, had four sections perforated with 1 in diameter holes, these sections being covered with perforated sheet metal and 28 mesh stainless steel gauze, held in place with jubilee clips, as a flame arrester. Tube B was also of drawn aluminium but had a $\frac{5}{8}$ in wide slot along its whole length, this slot being covered with similar gauze and perforated metal. The whole of tube C was made of perforated metal covered with the 28 mesh gauze. All three tubes were closed at the bottom.

It was found that only tube A performed satisfactorily. In some or all of the experiments with tubes B and C the explosion passed through the tube. In all the 20 tests with tube A the explosion was contained within the dip tube and the average explosion pressures were 0.06 lbf/in^2 (0.4 kN/m^2) and 0.09 lbf/in^2 (0.6 kN/m^2) for the open end and restricted end respectively.

Synopsis of FR Note No. 969

FIRE PROBLEMS OF PEDESTRIAN PRECINCTS

PART 3. THE SMOKE PRODUCTION OF SPRINKLERED FIRES (LOW WATER PRESSURES)

by

A J M Heselden and H G H Wraight

The general problem of town centre development and pedestrian precincts, arcades and malls was described in FR Note No. 875 and the movement of smoke and the venting requirements were assessed in FR Note Nos 856 and 954, the former Note containing a description of the full scale mock-up arcade building used at the Fire Research Station for these experiments.

The effect of sprinklers operating on a fire in the fire compartment of the arcade has now been investigated and 11 experiments were carried out, some without sprinklers and others with sprinklers rated at 79°C, discharging water at a low pressure of 18 lb/in² (1.24 bar). The various fire loads, which were representative of different shop occupancies, consisted of a wood crib (100 kg), motor tyres (64 kg), display racking containing miscellaneous cellulosic materials and foamed plastics (100 kg), or a tray of kerosene (about 30 litres). In some tests a canopy was placed between the fire and the sprinkler head and a sparge pipe was used for one kerosene test. The kerosene tests were carried out mainly to investigate the cooling effect of sprinkler sprays and one test was done with high pressure sprinklers. The arcade ventilation shaft was open for some tests and closed for others. The fascia board at the fire compartment opening and the hardboard screen or curtain across the mall were in position for all these tests.

Tables and graphs of the results are included in the Note and the test results and observations are described in some detail. The temperature readings and optical density measurements showed that the great bulk of the smoke production from the fires, both sprinklered and unsprinklered, was in a hot or warm gas layer flowing under the ceiling of the mall. This means that a ceiling extraction system of suitable capacity, together with ceiling screens, could arrest smoke travel along a mall.

The sprinklers were effective in reducing the peak burning rate and the temperature and flow of the smoky gases along the mall. The wood crib and display racking fires were quickly controlled and extinguished except for the racking fire with a canopy when the control was slower. The motor tyre fire

was not extinguished. Rough estimates of the reduction in the peak burning rate brought about by the sprinklers were: to about $\frac{1}{3}$ (motor tyres), to $\frac{1}{2}$ to $\frac{1}{3}$ (display racking with canopy) and to $\frac{1}{10}$ th for the display racking fire without the canopy. The sprinklers just about halved the sensible heat in the gases flowing along the mall. High pressure sprinklers would have reduced this heat even more.

The mall in this mock-up building is, of course, fairly short and, therefore, crosswinds at the open end can affect the smoke mixing and cooling. However, it was evident that, although there were less smoky gases produced in the sprinklered fires these were at a lower temperature and, therefore, not so easily vented. Even so, a ventilation system capable of extracting smoke from an unsprinklered fire should be able to deal with a sprinklered fire. The smoke from sprinklered fires was particularly acrid and the sprinkler spray did not appear to 'wash out' smoke particles. On the whole, the depth of the hot gas and dense smoke layer was slightly smaller for the sprinklered fires and, of course, a fire quickly controlled by sprinklers will produce much less total smoke than an uncontrolled fire so that, even if the hot smoky gases cannot be vented efficiently, the length of mall which might be drastically smoke logged will be less. In addition to this benefit sprinklers should reduce or eliminate fire spread.

THE EFFECT OF EXPLOSION PRESSURE RELIEF ON THE MAXIMUM
EXPERIMENTAL SAFE GAPS OF PROPANE-AIR AND ETHYLENE-AIR MIXTURES

by

Z W Rogowski and S A Ames

Casings containing equipment which may spark and which is being used in flammable atmospheres should be designed so that an explosion within the container or vessel will not ignite any flammable atmosphere outside. Work done at the Fire Research Station on the use of flame arresters fitted to such vessels is described in FR Note No. 658 (see synopsis). The use of these arresters enables casings to be of lighter construction than would be necessary if there was no such relief. That earlier research work did not, however, take account of the effect of vents on the size of gaps which may exist, especially at the flanges which are required at joins in the casings. The gaps usually arise as a result of inaccuracies in machining surfaces and also at bolt and spindle holes, etc.

Previous experimental work has determined the maximum experimental safe gaps at flanges (MESG) for vessels not fitted with flame arresters (see BS 229 and 4683) and the present research work investigates the effect on these measurements of the presence of a flame arrester.

Tests were carried out using a vertical stainless steel cylinder with 25 mm (1 in) thick walls and of 8 litre capacity. End plates of the same thickness closed the ends of the cylinder over which two end caps, also 25 mm thick, were placed, the whole assembly being held in an hydraulic press exerting about $7\frac{1}{2}$ ton pressure, thus holding the assembly together during the explosion tests. The flange gap being tested was between the cylinder wall and the top plate and this was 25 mm (1 in) in breadth except when adaptor rings were fitted to reduce the flange breadth to 1.6 mm ($\frac{1}{16}$ in), 3.2 mm ($\frac{1}{8}$ in), 6.4 mm ($\frac{1}{4}$ in) or 12.7 mm ($\frac{1}{2}$ in). The flange seatings were kept apart, in order to provide the gap, by six sets of small rectangular silver foil shims which could vary the gap from about 0.36 mm (14 thou. of an inch) to about 1.93 mm (76 thou. in).

The top end plate could be fitted with a flame arrester (29 mm, 57.5 mm or 110 mm in diameter) of the usual crimped ribbon type and the flammable gas mixture and ignition wires were fed in through the bottom end plate. Gas mixtures of 4.2 per cent propane/air and 6.5 per cent ethylene/air were used and electrodes for spark ignition were placed in the vessel near the inner lip of the flange gap, for most of the tests, but also just below the flame arrester or in the centre of the

vessel. The whole assembly was enclosed in a polyethylene sleeve before the flammable mixture was introduced and allowed to fill the vessel and the sleeve. This sleeve was sealed before ignition. An explosion in the vessel ignited the mixture in the sleeve if it was transmitted through the flange gap. For some tests obstacles in the form of orifice plates, providing 50 per cent and 90 per cent blockages of cross-sectional area, were fitted inside the cylinder. A piezo transducer was used to measure the explosion pressure.

In general, the broader the flange seating the wider the permissible gap (MESG). When the apparent MESG was found for a particular set of circumstances at least 20 tests were carried out in order to check that there was no ignition of the outer gas mixture in the polyethylene sleeve. The results of all the tests are shown in tabular and graphical form in the Note which also contains photographs of the apparatus.

The test results suggest that the presence of the flame arrester relief venting may allow slightly wider MESG and that the presence of obstacles in the vessel has virtually no effect on the MESG, although the explosion pressure is increased. The conditions of these tests simulated practical conditions envisaged in industrial equipment where the arrester would be mounted in the lid of the enclosing vessel and it has been shown that with such an arrangement no decrease in the MESG is to be expected, in fact, continuing work indicates that explosion reliefs may allow increases in MESG.

The MESG obtained with narrow breadth flanges are substantial enough to be used with equipment fitted with large area reliefs. However, conditions involving an ignition source near the arrester may need further investigation especially with large area vents and flanges of small breadth. The most critical conditions with unvented vessels are created by low rates of pressure rise and subsequent low velocity of emerging combustion products which facilitate ignition of the outer flammable atmosphere. Similar severe conditions may result from large area vents and ignition near the gap or near the arrester.

Synopsis of FR Note No. 974

EXPLOSION PROTECTION OF EQUIPMENT WITH FLAME ARRESTERS - SPECIFICATION OF METHODS OF TEST AND CONSTRUCTION

This Note contains a specification for the construction and for the testing in laboratories, of casings, fitted with flame arresters, designed to contain equipment which is to be used in areas, not underground, where flammable gases or vapours can occur. This form of protection would be required whether the source of any ignition inside the casing could be due to normal working or malfunction. The specification is based on work done at the Fire Research Station (see FR Notes Nos 613, 658, 756/7, 784, 786, 931, 945 and 973).

The manufacturers shall submit the equipment for test together with all relevant drawings and other details and fittings etc as required by the laboratory for the test procedures and the test results shall be recorded in a test report. The purpose of the test is to check that any explosion inside the casing is relieved without causing damage and without igniting any gas mixture outside the casing.

The equipment shall be tested inside a chamber, which is at least ten times greater in volume, having one relief wall of, say, polyethylene film. Provision shall be made for filling the equipment and chamber with, normally, a gas mixture of 4.2 per cent (by volume) propane/air or 6.5 per cent ethylene/air and for spark ignition in the equipment near or remote from the flame arrester or in the centre of the casing and also outside the equipment near the relief panel of the chamber. A small fan is required to circulate the gas mixture in the chamber. Tests should be carried out on the equipment as it is normally used and at least ten tests shall be done for each arrangement of the equipment.

Details are provided in the Note of the casing materials and any windows, the gaps at joints and other inlets, and clearances at holes for rods, bolts, spindles, shafts etc. A safety switch is required to cut off any electric supply when the casing lid is opened.

Usually crimped ribbon arresters are used but appropriate metal foam arresters may be acceptable. Arresters should be protected by shields against accidental damage or paint. No arrester shall show any sign of structural damage after completion of the tests. Safety margins may be established by repeating tests with part of the arrester relief area blocked off or with other adjustments made and a similar procedure can be adopted for establishing the safety margins for the equipment casings.

The Note contains a drawing of the test apparatus together with graphs of the maximum permissible clearances and the relationship between the maximum explosion pressure and the vent area for the gas mixtures used. In general, the maximum explosion pressure should not exceed 15 lbf/in^2 (100 kN/m^2), and the clearances are one half of the maximum experimental safe gap (MESG).

Synopsis of FR Note No. 976

PART 1. THE EFFECT OF TEMPERATURE ON THE PHYSICAL PROPERTIES
OF FOAM PRODUCED IN THE STIRRED JAR

PART 2. THE EFFECT OF TEMPERATURE ON THE PHYSICAL PROPERTIES
OF FOAM PRODUCED IN THE 5 l/min BRANCHPIPE

by

S P Benson

Laboratory tests on fire-fighting foams are carried out to assess the physical properties of the foams and they involve the calculation of the expansion, shear stress and 25 per cent drainage time. The foam samples are produced either in the "stirred jar" as described in FR Note No. 863 or by using the 5 l/min branchpipe described in FR Note No. 971. It was found recently that test results produced by various laboratories differed and it was established that this was due either to the water quality or the temperature and, by carrying out a number of tests at different temperatures but with the same water supply, the temperature was found to be mainly responsible for the variations.

Tests have now been carried out using foam produced in the stirred jar (about 30 samples each for the shear stress and drainage time tests) at temperatures ranging from about 4°C to 32°C and also with the branchpipe foam (about 20 tests in all) at temperatures ranging from about 12°C to 30°C. The temperatures were controlled mainly by varying the premix temperature and, although this was not a very accurate system, it was sufficient for this assessment.

Graphs, which are included in this Note, were produced for all the test results and these clearly indicate that there is a linear (straight line) relationship between the temperature and the shear stress and drainage time. The expansion is, however, little affected under these conditions. Air temperature changes might affect the expansion but this was not assessed in this study. The shear stress is reduced substantially by an increase in foam temperature and the 25 per cent drainage time is also reduced but to a smaller degree at the higher foam temperatures.

In laboratory tests, temperatures may well range from 16°C to 24°C and it is recommended, therefore, that test results for shear stress and drainage time should always be recorded as those appropriate for a temperature of 20°C. If the temperature of the laboratory foam is different from this a graph can be drawn based on the results of this study so that the 20°C temperature figures can be determined. Although fluoroprotein foam was used to obtain the present graphs it is thought reasonable to assume that similar graphs could be drawn for other types of foam.

FIRE PROBLEMS IN PEDESTRIAN PRECINCTS. PART 4.
EXPERIMENTS WITH A GLAZED SHOP FRONT

by

H G H Wraight

A series of 5 experiments was carried out to investigate the behaviour of glazing in a shop front opening on to a covered shopping mall. The large scale arcade building at the Fire Research Station was used for the tests; this building was described in FR Note No. 856 (see synopsis) and there have been numerous other FR Notes dealing with the arcade problems and, in particular, FR Note No. 969 refers to the effects of sprinklers in a shop.

As in earlier experiments the brick built fire chamber at the side and rear of the arcade was used and the opening to the arcade, about 10 ft x 8 ft (3 m x 2.5 m) was fitted with a typical shop front consisting of a main window, the glass being held in wooden beading and free to expand, a fully glazed wooden door and a fanlight over. The glazing was of 6 mm plate glass. The fire chamber was fitted with two sprinklers as previously described and, in addition, there was a horizontal sparge pipe installed inside the shop and about 195 mm from and parallel to the top of the glass. The 2.4 mm dia. holes in the sparge pipe at 75 mm centres were aligned so that the jets of water wetted the top of the glass and then ran down, covering the glass completely. Water was discharged at 0.5 litres/s per metre run with a water pressure of 1.24 bar (18 lb/in²). It had been shown previously that the sprinkler alone would not wet the upper part of the glass.

The fire load consisted of open racking containing about 70 kg of wood, 6 kg of polyurethane foam and 6 kg of polystyrene, and the nearest part of the rack was about 0.7 m from the glass. In all the tests the arcade vent and shop door were shut but a 1 m wide opening was left at the rear of the shop to allow air to reach the fire. It was found that the fire load used gave a fairly repeatable fire from test to test as regards rate of growth and heat output. The front sprinkler was almost directly over the racking. In one test a hardboard canopy was used over the racking in order to reduce the sprinkler effect, and the water pressure was the same as for the sparge pipe.

It was found that sprinklers alone will not usually reduce the fire at an early enough stage or quickly enough to prevent the glass cracking and, although the glass may not fall out, it cannot be relied upon to stay in position. Further, although the sparge pipe alone will wet the glass at the beginning, radiation from an unsprinklered fire will interfere with the streams of water and the resultant flow

may be insufficient to prevent damage to the glass. The glass damage is, therefore, only delayed. When both sprinkler and sparge pipe operate, the glass is undamaged provided, of course, that the sparge pipe water is not obstructed by articles etc close to the window.

Synopsis of FR Note No. 978

LOSS OF LIFE EXPECTANCY DUE TO FIRE

by

S J Melinek

The most commonly used measures of the risk of accidental death are the annual number of deaths and the deaths per million, and in respect of accidental fire deaths, in Great Britain, these figures are about 800 and 15 per million. It is thought that these figures may not be very meaningful and that the proportion of such deaths, the years of life lost and the reduction in life expectancy may also be relevant for publicity purposes and for the elucidation of attitudes towards risk.

A statistical analysis has been made based mainly on the fire fatalities in GB for 1969 together with the Registrar General's figures and the mortality tables for England and Wales, bearing in mind that the annual death rate is higher for the very young and the old.

It is concluded that the annual loss of life expectancy due to fire is about 25000 years for the whole population and that there is a 1000 to 1 chance that any one individual will die by fire. The reduction of life expectancy due to fire is about 10 days at birth and 5 days for the average member of the population.

FULLY DEVELOPED COMPARTMENT FIRES:
NEW CORRELATIONS OF BURNING RATES

by

P H Thomas and L Nilsson

Wooden cribs provide the main source of 'Fire' in all experimental research work concerned with predicting the behaviour of fully developed fires in compartments, and, in this Note, the whole problem is reviewed in considerable scientific detail in the light of the recent C.I.B. International programme (see FR Note No. 923) and the latest available information from Mr L Nilsson of Sweden. The investigation concerns mainly the theory regarding the rate of burning (R) of the cribs and the possible application to fires involving plastics.

The effects from burning a wooden crib are dependent not only on the size of the crib (fire load) but also on the size of the sticks and, consequently, on their surface area (A_s), the spacing between the sticks and the consequent fuel porosity (A_v) including the height of the crib above the floor. Model fires in compartments usually involve a window opening for ventilation and the area of the window (A_w) and its height (H_w) are also important factors. Three main regimes of fire behaviour can be identified according to the variables involved and the fire regime can be controlled by the crib porosity, the fuel surface area or the amount of window ventilation ($A_w \sqrt{H_w}$). In addition to these variables the size and shape of the compartment and its internal surface area (A_T) are also factors which have an influence on the effects of the fire. Further, some of the gases from a crib fire may burn outside the window instead of actually inside the compartment. The inter-relationship between the various factors is studied in depth.

The main conclusions reached are briefly as follows:

- (1) The fraction $\frac{R}{A_w \sqrt{H_w}}$ is not constant in the window controlled fire nor is $\frac{R}{A_s}$ strictly constant in the fuel surface controlled regime, though they are nearly so for a given stick size.
- (2) $\frac{A_w \sqrt{H_w}}{A_T}$ is the main factor in window controlled fires but there are several other factors such as heat transfer and radiation to be taken into account.
- (3) Some estimates have been made of the relationship between fires in the three regimes (porosity, fuel surface and window controlled) and although these may need revision after consideration of data for other fire loads and fuel thicknesses, they indicate for the first time the type of crib to

be avoided if experimental fires are not to be determined by crib porosity.

- (4) It is suggested that some of the discrepancies noted recently by T Z Harmathy (Fire Technology) may be explained by the role of these secondary factors.
- (5) The stick spacing used in the C.I.B. experiments was large enough for porosity not to be a limiting factor when the sticks were 20 mm square or more but 10 mm sticks probably made the fires porosity controlled. This allows one to eliminate some of the data in extrapolating to conditions of 'real' fuels.
- (6) In order to help in extending existing quantitative knowledge (largely based on wood) to plastics, the theory of ventilation controlled fires is explored. For these fires it is not the actual calorific value of the fuel that matters but the calorific value per unit mass of oxygen (or air) that controls the rate of burning and the temperature rise. This implies that fire resistance requirements are not necessarily determined by the total calorific contents.
- (7) There are some noticeable effects of scale. This paper allows one better to understand where these are important and where trivial.

STORAGE PROPERTIES OF FOUR FOAM LIQUIDS (FINAL REPORT)

by

S P Benson, D J Griffiths, D M Tucker and J G Corrie

An interim report was made in FR Note No. 933 (see synopsis) on the tests carried out on four foam liquids which had been stored at various temperatures for one year. The standard 3 ft² circular inverted cone apparatus was used for the tests which are briefly described in the above-mentioned synopsis. The present series of tests was carried out on samples of the same foam liquids after a 2 year storage period and also on an improved grade of fluorochemical foam (Type 196) after storage for 11 months. The results of the tests are shown in tabular and graphical form in this Note.

Changes occurred in the performance of most of the samples tested but there was no consistent pattern. Further, doubts are expressed regarding the method of foam generation and application both as regards consistency and simulation of practical conditions.

In most cases when the foam liquid was used at the recommended concentration the time to control the test fire had not increased after 2 year storage. However, tests on a single batch of each of four foam liquids stored for 2 years provide only a meagre amount of information and it is considered that tests on a substantial number of batches should be made over a longer period, say four years.

It is suggested that a routine be established for the continuing storage trials of foam liquids. Each of these liquids might be kept, as concentrate only, in 4 x 10 litre containers in an unheated, slightly ventilated opaque sheeted building in the open and therefore subject to a temperature range of 0°C to 25°C. After initial tests, retests to be done at 1, 2 and 4 yearly intervals. The standard 5 l/min branchpipe (see FR Note No. 971) to be used to determine the foam properties at each retest by finding the control and extinguishing time of a 2 m² fire using the foam liquid at its recommended concentration. The laboratory generator to simulate the 5 l/min branchpipe foam which would then be used to find the burnback time on a 0.15 m² laboratory fire. A single fuel would have to be selected for the two fire tests, i.e. control and burnback, and this is a difficult but important decision to make.

If there were, say, 10 foam liquids in general use and it was decided to test two batches of each, each year, then a building of 10 m² would be required to store the 240 x 10 litre samples. There would thus be 80 tests per year requiring . 2,500 gal of fuel per annum. The tests done so far indicate that future tests on this scale are necessary and development work on the problem is proceeding.

THE RISK OF DYING BY FIRE

by

M A North

If measures are to be taken to reduce the risk of fire fatalities it is necessary to know the size of the risk and the way in which it varies with age and other factors. A statistical analysis has therefore been made of the Registrar General's figures for 1969 and reference has also been made to the UK Fire and Loss Statistics for that year. The measure of risk is the fire fatality rate (FFR) which is the number of deaths per unit exposed time and this will depend on the number of deaths, the population at risk and the number of hours for which it is exposed. For a region, e.g. Scotland, or a particular industry, e.g. chemical, the FFR would be related to the total number at risk, and for a region this would be the population with an exposure of 24 hours per day.

The conclusions reached are briefly as follows:

- (1) The FFR mainly varies with age and below the age of 5 years it is double the average and above 84 years it is ten times the average.
- (2) Between ages 70-80 females are more at risk but over 80 males are more at risk. At other ages there is little difference between the sexes.
- (3) The average risk in Scotland is 70 per cent higher than in England and Wales and the number of fires and the deaths per fire are also higher.
- (4) Fire deaths account, overall, for 5 per cent of all accidental deaths and for children aged 1-4 years it is 15 per cent.

THE ECONOMICS OF ACCIDENT PREVENTION - EXPLOSIONS

by

Sara K D Coward

Three examples of accidental explosions are studied in order to deduce the amount of money worth spending in order to prevent such accidents in the future. Accident prevention is economically justified if the expected losses due to an accident exceed the cost of preventing it and the examples have been selected solely for the purpose of demonstrating the technique. Account is taken of actual damage, future loss of income, and loss of life which is assumed could be £50,000 per life (see FR Note No. 950). The risks considered are - fixed roof hydrocarbon storage tanks, the progressive collapse of high rise flats (e.g. Ronan Point) and gas explosions in dwellings.

Although many of the factors and the values involved have had to be arbitrarily assessed, a large amount of relevant research work on the subject has been studied in order to provide as accurate an assessment of the problems as possible.

In the case of the storage tanks the main issues concern the fatal accident frequency rate (FAFR) and the costs of blanketing the contents with nitrogen. Although the FAFR is sufficiently high to warrant the consideration of special protection, an examination of the costs, losses and risks involved reveals that the material damage would rarely justify protection and neither would loss of life unless this was assumed to be around £2 $\frac{1}{2}$ M per life.

With regard to blocks of flats which are liable to progressive collapse, the extra cost of protection would probably be justified if the protection was incorporated at the design stage. However, the cost of converting and strengthening existing blocks could be as high as £1000 per flat and to justify this expenditure the value of a life would have to be around £3 M. Such a high value on life might be justified in the particular circumstances of high rise flats since the risk from explosion to the flat occupier is about 1 $\frac{1}{2}$ times as great as the risk of death by fire.

The problem of gas explosions in dwellings is related mainly to the education of the occupiers since about 40 per cent of the explosions are the result of mishandling and not of faulty installations. Assuming an average material damage loss of £600 and a life value of £50,000 and discounting these figures for the future it is calculated that the total expected damage per dwelling over the next five years would be 11p. Assuming a safety campaign was fully effective it

would not be worth spending more than this amount on each dwelling unless other considerations such as public alarm intervened. A publicity campaign would only be partially effective, however, and, bearing in mind that there are about 18 M dwellings at risk, it is assessed that an annual expenditure on such a campaign of £80,000 might be justified. More information on the effects of publicity is required and it is likely that the figures quoted in this Note are over-estimated.

FIRE RISKS IN HOSPITALS

by

M A North and R Baldwin

This Note contains the results of a statistical investigation into fires in hospitals for the purpose of assisting the assessment of the fire and life hazards in existing and new buildings and for assessing the value of remedial measures. The examination involves the analysis of all hospital fires in the UK during 1967 together with some of the fires occurring in 1968 to 1970. The risks involved are broadly defined and, virtually, include all hospitals and similar institutions and ancillary laboratories but Service Department institutions are excluded.

The Note contains 30 tables showing, mainly, probabilities or numbers in respect of fire spread, ignition (both material and area), casualties, escapes and rescues. In addition to the tables the results of the analysis are examined in considerable detail and the conclusions reached are briefly summarised as follows:

1. Most hospital fire deaths are confined to mental and old patients and, in general, there is no greater death risk from fire than in the home.
2. If fires to bedding, clothing and upholstery could be eliminated, the number of deaths would be reduced by 90 per cent.
3. Injuries occurred mainly to staff and were largely due to ignition of solvents.
4. Only 0.6 per cent of hospital fires necessitated rescue or evacuation although the numbers involved may be large in any one fire.
5. The number of fires per person at risk is similar in all types of hospital and in the home.
6. Calls to the Brigade increased, probably due to greater willingness to call the Brigade.
7. 77 per cent of fires were fought before the Brigade's arrival and 70 per cent of these were out on their arrival.
8. The chance of a hospital fire is greater in the catering and storage areas than in wards, offices and laboratories.
9. There is little difference in the fire risk as between new and old buildings.

GAS EXPLOSIONS IN BUILDINGS
PART 1. EXPERIMENTAL EXPLOSION CHAMBER

by

P S Tonkin and C F J Berlemont

The Fire Research Station has undertaken the study of gas explosions in large compartments and brief details including, in particular, the methods of measuring the gas explosion pressures, are given in the synopsis for FR Note No. 985.

The present Note provides a general introduction to the work involved and a detailed description of the apparatus and ancillary equipment and of the operating procedures. The Note includes two appendices, one gives full details of the construction of the explosion chamber and the other sets out the safety warning systems together with details of the safe operating and igniting procedures.

The explosion chamber, which has a volume of 1000 ft^3 (28 m^3) is cubical and is constructed with three sides and top of $3/16$ in (4.8 mm) thick steel plates and one open side, the area of which can be varied by inserting steel plates, covered for the experiments with a burstable panel. To ensure rigidity the chamber is strengthened with two steel 6 in x 6 in (25 lb/ft) universal section frames and the whole is bolted to a concrete floor. The chamber is situated at one end of an ex-airship shed at Cardington, Beds.

Experiments which have and will be carried out lay particular emphasis, in the light of the Ronan Point disaster, on layered gas/air mixtures and the effects of layer depth, composition and point of ignition. The gas used is Natural Gas, grade NSEG (about 93 per cent methane) and is lighter than air, and is supplied from steel cylinders. The air is supplied by centrifugal fan. Although, so far, explosions have been carried out in one compartment, the study is to be extended to gas explosions in multiple compartments communicating by door openings and corridors and particular attention will be paid to the effects of turbulence at openings, bends and obstacles and the possibility of pressures increasing as the explosion propagates from one compartment to another.

The principal measurements consist of high-resolution pressure-time records at points both inside and outside the compartment and photographic records are made of the experiments. A closed circuit television unit has also been used.

Later Notes in this series will cover pressure measurements, automatic gas sampling and analysis, strain measurements and the formation of layered gas/air mixtures in the chamber but no experimental results are included in this Note which is intended only as a foreword to subsequent reports.

GAS EXPLOSIONS IN BUILDINGS

PART 2. THE MEASUREMENT OF GAS EXPLOSION PRESSURES

by

S A Ames

Following the Ronan Point disaster the Fire Research Station has undertaken to study the whole problem of gas explosions in buildings and a report on the first stage of the experiments using a 28 m^3 (1000 ft^3) steel compartment with one variable sized opening closed with a burstable panel is contained in FR Note No. 984. The research mainly concerns layered gas (natural)/air mixtures and the effects of layer depth, composition and point of ignition and is required to provide a guide for safe structural design and for a re-appraisal of the Building Regulations.

During the first 3 months of the experimental work the measurement of the explosion pressures was investigated and the present Note is concerned mainly with the problems arising from the use of quartz piezo electric transducers, with appropriate charge amplifiers, since in this particular application the transducers are subjected to high levels of heat radiation and vibration which can distort the pressure readings obtained. The transducers have a very high frequency response (80 kHz) and are therefore affected by wall vibration with the transducers acting as an accelerometer. The system can also be affected by electric mains frequency pick-up of 50 Hz so careful earthing is required. Both negative and positive pressures have to be recorded.

With regard to vibration it was found that the effects were minimised if the transducer, instead of being fixed flush over a hole in the steel compartment wall, was fitted in a steel block at the end of a 4 in long (2 in dia) convoluted rubber tube fixed over the hole with the steel block resting on a polyurethane foam block. The rubber tube mounting also shaded the transducer from some of the explosion radiation (about 4 kW/m^2) which has the effect of expanding the diaphragm and other parts of the transducer and so giving rise to false readings.

In order to reduce the radiation effects still further a 3 mm thick silicone grease coating was spread over the diaphragm of the transducer and the most effective material was found to be a commercial silastomer.

The special mounting and the coating substantially suppressed both radiation and vibration interference and a portable calibration apparatus was devised for 'on site' testing and can be used to examine the effects of interference on the sensitivity of the pressure measuring system. It may be possible to take further action to reduce interference and, in future, if acceleration compensated transducers are used, it may eliminate the need for an anti-vibration mounting.

Synopsis of FR Note No. 987

GAS EXPLOSIONS IN BUILDINGS PART IV
STRAIN MEASUREMENTS ON THE GAS EXPLOSION CHAMBER

by

M Senior

Brief details regarding the preliminary arrangements for a series of gas explosion experiments at Cardington were given in the synopsis for FR Note No 984. Natural gas is used and the explosions take place in a 1000 ft³ (28 m³) steel tank having one side with a burstable panel. The tank is bolted to the concrete floor of the ex-airship hangar.

In the present Note the problem of measuring the dynamic strains and vibrations occurring in the explosion test chamber are discussed in some detail and reference is made to the choice of electrical resistance foil gauges suitable for recording both the low dynamic strains resulting from the explosion of non-stoichiometric gas mixtures and the much larger values obtained for near stoichiometric gas mixtures. After due consideration of all the factors it was decided to use the constantan (copper/nickel) foil gauge EA 06 500 BA 120. These gauges are bonded to the sides and top of the chamber and to the concrete base at the interface with the steel stanchions, and special adhesives and surface preparation are required for efficient bonding. Protective coatings have to be applied over the gauges, against the risk of mechanical damage. Electric cables from the gauges go to a junction box at the rear of the chamber and from there special screened cable connects the gauges to the amplifiers and recording instruments placed at a safe distance. Great care has to be taken over the connections and the earthing in order to prevent interference.

Even for the same gas concentrations there was great variation of explosion pressure, and the resulting strains, due to the use of multiple ignition sources. Further, irregular strain measurements occurred after the explosions; for instance, after the initial 1.5 s of vibration there was an interval of 7 s and then a further series of 2.5 s vibrations followed by a pause and another series of vibrations. These pulses may be related to the acoustic properties of the hangar and further work is required on this problem. It may also be desirable to use more sensitive foil gauges and instruments to measure small strains caused by low explosion pressures. Modifications to the strain gauge equipment are in hand.

Synopsis of FR Note No. 989

THE ESTIMATED FIRE RISK OF VARIOUS OCCUPANCIES

by

M A North

The economic level of expenditure on fire prevention is dependent on the fire hazard and this can be assessed, for a particular occupancy, from the fire losses and the number of establishments at risk. Data and other information available from some thirty different sources, such as the UK Fire and Loss Statistics, Central Statistical Office, Fire Research Notes etc have been extracted and studied in order to estimate the risk of a fire occurring and of a fire death or injury in a number of building occupancies.

The information extracted is based mainly on the data for 1967 but some details for 1968/9/70 are also used. Details of fire losses are only available for those of £10,000 or more and the total fire losses have been calculated by applying a factor of 100/65 to the large loss figure. All the data extracted and the various estimates are comprehensively shown in the Note in tabular form. The attached table summarises the main details which are of interest to fire insurers.

The number of fires per risk per year is an indication of the probability of an outbreak of fire and the last column shows the estimated fire loss per risk per year and this varies from about £100 to £1500.

High life risks appear to be mainly in the chemical and petro-chemical industries, forestry, fishing, hotels and motels occupancies. The risk in hospitals is generally rather higher than in homes but that in the manufacturing industries is much the same as in the home. Single freak fires can, however, distort the casualty figures as happened in the timber and furniture trade in 1968.

Estimations are based on the statistical data for 1967 or 1968 or, where available, for the average of the years 1967-70.
A 'risk' is equivalent to an 'establishment' and the large losses are those of £10,000 or more

Occupancy	DATA				ESTIMATES	
	Fires per year	Large loss fires per year	Losses in large fires per year	Number of risks	Number of fires per risk per year	Loss per risk per year
	(Number)	(Number)	(£ million)		(Number)	£
Houses	43009	30.5	0.74	18 million	0.0024	-
Food, drink and tobacco	639	34.3	2.50	6,810	0.094	580
Chemicals and petroleum	948	51.3	3.50	3,426	0.280	1,600
Metal manufacture	979	30.5	1.80	3,120	0.310	870
Mechanical engineering	448	22.0	1.00	12,988	0.034	120
Instrument engineering	52	7.0	0.51	2,270	0.023	350
Electrical engineering	316	29.0	5.20	4,017	0.079	2,000
General engineering	862	58.3	6.10	20,604	0.042	460
Shipbuilding and marine	113	4.8	0.19	1,363	0.083	210
Vehicles	601	23.8	2.70	2,779	0.220	1,500
Metal goods	654	22.8	2.30	12,254	0.053	280
Textiles	1095	66.3	5.60	6,333	0.170	1,400
Clothing, footwear and leather	294	36.5	1.90	9,557	0.031	310
Bricks, pottery, glass etc	439	17.0	0.76	5,296	0.083	220
Timber, furniture etc	832	48.8	2.20	9,784	0.085	350
Paper, printing etc	564	41.8	4.20	11,204	0.050	580
Other manfg. industries	616	49.0	7.10	4,574	0.120	1,400
All manfg industries	8924	492.5	30.90	97,409	0.092	610
Agriculture forestry and fishing	3601	35.5	0.59	-	-	-
Mining and quarrying	129	0.5	0.05	-	-	-
Construction	2034	15.5	0.47	-	-	-
Gas, electricity and water	412	11.3	0.68	-	-	-
Financial and scientific services	3703	61.8	2.20	-	-	-
Public Admin. and Defence	1575	8.8	0.68	-	-	-

Table cont'd

Occupancy	DATA				ESTIMATES	
	Fires per year (Number)	Large loss fires per year (Number)	Losses in large fires per year (& million)	Number of risks	Number of fires per risk per year (Number)	Loss per risk per year £
<u>Sub-Groups</u>						
Industry	8355	417.0	32.20	180,000	0.059	350
Storage	2435	112.0	6.90	200,000	0.012	53
Offices	942	11.0	0.37	150,000	0.0058	3
Shops	5580	79.0	5.90	510,000	0.011	17
Assembly - entertainment	1447	35.0	1.60	13,000	0.120	190
Assembly - non-residential	2809	46.0	1.30	140,000	0.020	14
Residential, clubs etc	1352	28.0	0.82	37,000	0.037	35
Hotels and motels	689	15.0	0.53	-	-	-
Hospitals (GB) 1967	638	3.0	0.075	3,116	0.300	-
Hospitals (GB) 1968	856	4.0	0.13	3,121	-	-
Schools (England & Wales) 1967	1048	20.0	0.53	33,390	0.031	25
Schools (England & Wales) 1968	1072	21.0	0.80	33,183	-	-

EFFECT OF PRESSURE RELIEF ON MAXIMUM EXPERIMENTAL
SAFE GAPS OF HYDROGEN/AIR MIXTURES

by

Z W Rogowski and C P Finch

Casings containing electrical apparatus which may be used in flammable atmospheres must be designed so that the gaps at flanges are insufficient to permit an explosion inside the casing being transmitted to the gases outside. A series of experiments to determine the maximum experimental safe gaps (MESG) was previously conducted using an 8 litre vertical steel cylinder of 8.5 in (216 mm) height and diameter and propane/air and ethylene/air gas mixtures. The apparatus and experimental details are described in the synopsis for FR Note No. 973. The present series of experiments was carried out in a similar way but a 28 per cent hydrogen/air mixture was used and the flame arrester, when installed, was of 80 grade Retimet metal foam $\frac{1}{2}$ in (13 mm) thick (see synopsis for FR Note No. 931) and not of crimped ribbon. In all other respects the test apparatus and experimental methods were similar to the earlier tests. In the majority of tests the spark ignition was at 10 mm from the inner lip of the gap but, in some, in the centre of the vessel.

It was found that with a vented vessel having a 4.3 in (110 mm) diameter metal foam arrester fitted to the top plate there was a substantial increase in the MESG for flange breadths of $\frac{1}{2}$ in (12.7 mm) and $\frac{1}{4}$ in (6.4 mm) although at 1 in (25.4 mm) the gap was much the same. The increases were, however, much smaller for flange breadths of 3.2 and 1.6 mm and this suggests that a different mechanism of explosion transmission operates when the flange breadth is small. The maximum explosion pressures were, however, substantially reduced in all the vented tests. The Note contains tables of the results and some photographs including one of an arrester element which suffered small cracks and discoloration after, at least, 20 tests. The metal foam arrester can, however, cope adequately with hydrogen/air mixtures and the foam is light, easily shaped and corrosion resistant.

Some more work is needed to evaluate the safety margins and provide an adequate range of mountings for the arresters. The MESG values for vented explosions in casings having flange breadths of 6 mm or more are large enough to accommodate the tolerances required in manufacture and usage for apparatus of limited volume. The effect of surface finish of flanges should, however, be further investigated. Burrs or protruding pieces of metal on the flange face can encourage transmission of the explosion through the gaps.

As a result of the latest experimental work it might now be possible to institute a standard for the manufacture of flameproof apparatus based on flange gaps of appropriate size for use in hydrogen/air atmospheres as has been done successfully for gases in groups 11a and 11b (B.S. 4683).

Synopsis of FR Note No. 991

FACTORS AFFECTING FIRE LOSS - MULTIPLE REGRESSION MODEL WITH EXTREME VALUES

by

G Ramachandran

The broad principles of the extreme value theory were briefly described in the synopses for FR Notes No. 837 and 910 when its application to the textile industry, in particular, was examined. Basically it is a question of making use of the large (extreme) losses, for which there is detailed information, to predict the behaviour of all the losses both large and small by the use of regression parameters in a mathematical regression model. Fires in certain categories can be examined and analysed if there is a sufficient number in each category and in this paper four categories have been investigated, viz. sprinklered and non-sprinklered, single storey and more than one storey, in the textile industry for which detailed information is available for 1965 to 1970. The top two losses in each group have been extracted and the losses corrected for inflation with 1965 as the base year. The top two losses in each group ($M = 1$ and $M = 2$) are shown in tables 1 and 2.

Every year the UK Fire Brigades attend about 1100 fires in the textile industry and about 45 per cent if these are in sprinklered buildings. However, an earlier study indicated that one third of the sprinklered losses are not attended or reported and, consequently, there must be about 750 fires in sprinklered buildings as against 600 fires in non-sprinklered buildings. Further, an earlier study indicated that about 43 per cent of industrial buildings are single storied and also that, if the size of a building is doubled the frequency of fires will probably increase by a factor of $\sqrt{2}$. If these factors are taken into account the 750 fires in sprinklered buildings will be divided 250/500 as between shed and storied buildings and the 600 non-sprinklered fires will be apportioned 200/400. It is assumed that during the short period of six years there will be no appreciable increase in the numbers of fires although the frequency varies from one sub-group to another.

For a given floor area the expected loss in a shed building does not appear to differ materially from the expected loss in a storied building although in the latter type a fire may spread more vertically than sideways.

In this Note the mathematical model is developed and the parameters are assessed. The relationship between the four sub-groups is depicted in logarithmic form in Figures 1 and 2, the first being based on the largest loss ($M = 1$) and the second on the next largest ($M = 2$). The straight lines on the graphs relate the

expected loss to the total floor area. Reading off from the graphs (as examples) Fig. 1 ($M = 1$) shows an expected loss of £20,000 for a non-sprinklered building of 100,000 ft² (both shed and storied) and £4,000 for a sprinklered building of the same size. The second largest loss ($M = 2$) gives comparable figures of £20,000 and £3,000 so that there is a saving, as a result of the installation of sprinklers, of about £16,000+ and, as already mentioned, there does not appear to be any significant difference between the expected loss in a shed or a storied building (whether sprinklered or not).

These conclusions are based on the top two extreme losses in each year only and it is hoped to improve the estimates by performing a comprehensive regression analysis combining the information on a number of extremes (losses).

Synopsis of FR Note No. 992

DUST EXPLOSION HAZARDS IN PNEUMATIC TRANSPORT

by

K N Palmer

This Note contains a concise exposition (prepared especially for a lecture) of the general characteristics of dust explosions and their effects together with the principal methods of protection, test methods and their application, with particular reference to the pneumatic transport of dusts. The following is a resumé of the paper.

All explosible dusts must be combustible and can consist of sugar, flour, cocoa, plastics, chemicals, aluminium, magnesium or coal etc etc, and to be explosible the dust must be dispersed in air. Ignition can be caused by a spark or a hot surface which may be the result of static electricity or friction etc and can be of quite low intensity. The quantity of dust in the air must be neither too little nor too much for it to be explosible and it is the lower explosibility limit which is of more importance since this is the minimum concentration of dust in a cloud which is necessary for sustained flame propagation. The upper limit is, however, relevant to the pneumatic conveying systems. Dust explosions of this type under industrial conditions are termed deflagrations and the flame speed is less than the velocity of sound and even as low as 1 m/s. Ultrasonic flame speeds may be about 1000 m/s and explosions of this nature are termed detonations, although they usually start as deflagrations. Detonations are not thought to be applicable to industrial plant. The paper contains general comments on dust particle size, concentrations and flame speed.

Primary and secondary explosions are discussed and indications are given of the pressures involved. Secondary explosions are usually caused as a result of the disturbance of dust, in a building, by the primary explosion. Maximum pressures obtained with dusts in closed vessels may be as high as 150 lb/in^2 (1000 kN/m^2) and the pressure rise $15000 \text{ lb/in}^2 \text{ s}$ ($100 \text{ MN/m}^2 \text{ s}$). Apart from casualties caused by the flame and pressure effects, toxic gases resulting from the combustion can also be lethal.

It is not practical to build dust handling plant strong enough to resist any internal explosion especially since all parts of the system would have to be of similar strength. If dust clouds and sources of ignition cannot be prevented, means have to be found to suppress the explosion flame or allow the explosion to take place safely. These problems are discussed with particular reference to venting and the introduction of inert gas.

Explosible dusts are classified as Group (a) or Group (b), the latter being considered safe and there is a description of the tests involved and the application of the tests. The apparatus used and the test procedures have been described in FR Technical Paper No. 21.

The hazards of pneumatic dust conveying systems, in particular of low volume and high pressure, are described together with the various ways in which protection can be provided. High volume/low pressure pneumatic systems are mainly concerned with waste extraction and not with conveying dusts as for transfer between road tanker and silo which is the main subject of this paper. A typical low volume/high pressure system would have a 4 in (10 cm) pipe and an operating pressure of 7 lb/in² (50 kN/m²) and the dust/air ratio would normally be well above the upper explosibility limit. These systems and their problems are broadly discussed in the paper. They are certainly superior to mechanical means for transporting dusts and the experience with them has been satisfactory.

Although generally satisfactory there have been a few losses and reference is made to two explosions inside a 4500 ft³ silo. An investigation into these losses resulted in no positive conclusions as to the cause but it was thought that static electricity was responsible. The cause of such explosions, especially when small sparks are involved, is not easy to determine but valuable lessons were learnt from these two explosions. It may be that a vacuum system involving a lower rate of transfer may be preferable to a pressure system and could result in a reduction in the static electricity hazard for which special precautions should, in any case, be taken. The use of inert gas might be feasible but its use in the pipe could be expensive. The costs should be lower if the inert gas is injected only into the silo and this might provide a sufficient safeguard.

Synopsis of FR Note No. 993

THE COMPATIBILITY OF FLUOROCHEMICAL AND FLUOROPROTEIN FOAMS

by

S P Benson, D J Griffiths and J G Corrie

The compatibility of fluorochemical and fluoroprotein foams is important since both may be used on one fire such as an aircraft when one crash vehicle carries one type and a follow-up vehicle the other foam.

Possible incompatibility was discussed in FR Note No. 925 and in FR Note No. 975 the difference in burn-back times was revealed as was the advantage of using the burn-back time as a better criterion than the 25 per cent drainage time which had previously been used to measure the 'persistence' quality of the foam.

In the present series of experiments a tray fire of 1 m x 2 m (larger than in earlier tests) containing 45 litres of Avtur was used in the open and this tray was fitted at one end with a sparge pipe supplied with hydrogen for the re-ignition source as described in FR Note No. 975. Foam was applied from the 5 l/min branchpipe as described in FR Note No. 971.

The pre-burn time was 1 min and then foam was applied to extinguish the fire. After a further minute the fuel was re-ignited by means of the hydrogen jets and the time for the flames to fill the tray completely was recorded as the burn-back time.

Numerous tests were done using one or other of the foams separately or following one another at different intervals either with the fire extinguished or only partly extinguished by the first foam.

It was found that the fluorochemical foam gave a burn-back time of 72 per cent of that for the fluoroprotein foam and when the two foams were used together on a test the burn-back time varied between 67 per cent and 81 per cent of the time for the fluoroprotein foam alone. It is considered that this decrease in the burn-back time is insufficient to warrant a strict avoidance in the use of the two foams together in practice.

Synopsis of FR Note No. 994

FIRE DAMAGE TO BUILDINGS - SOME STATISTICS

by

M A North

A statistical analysis has been made of about 5000 fires reported by the Fire Brigades during 1967 in which the fire was confined to the room of origin. The object of the investigation was to try to throw some light on the problem of passive fire protection and the Building Regulations and other building controls. The building elements considered were the walls, floors, ceilings and roofs, and the fire and heat damage sustained by these elements was divided into five main categories, viz: none, surface, slight, severe and destruction, the extent of the damage being based mainly on the Fire Brigade's original estimate. The number of fires in each category was, also, sub-divided into occupancy groups which were broadly: houses, hotels, offices, assembly, industrial, storage and others. The Note contains tables giving brief numerical and proportional details of the severity and extent of any damage and the analysis is discussed in some detail.

It was found that in 70 per cent of the cases investigated no damage was sustained to the building fabric and of the remainder (30 per cent), 40 per cent involved only slight damage, 10 per cent caused destruction of some part, and otherwise the damage was partial. In about 12 per cent of the fires the floor was damaged, while the walls, ceiling or roof were affected in only 5 per cent of the cases. When damage was caused, the mean area of damage was about 2 ft^2 (0.2 m^2) for floors, walls and ceilings, and 6 ft^2 (0.6 m^2) for roofs, although there were fairly wide variations as between one occupancy group and another. Further, one fire can distort the results, e.g. an office fire which damaged more than 1000 ft^2 of building fabric, and had this been excluded the damage area for offices would have been average.

EFFECTS OF DECOMPOSITION PRODUCTS OF PVC IN FIRE
ON STRUCTURAL CONCRETE

by

W A Morris and J S Hopkinson

Shortly after a report issued in Germany in 1968 regarding possible damage resulting from the burning of plastics, in particular PVC, a meeting was held at the Fire Research Station at which representatives from ICI, FOC, JFRO and RAPRA (Rubber and Plastics Research Association) decided on a programme of full scale and laboratory tests designed to investigate the problems arising from the combustion of PVC with the resultant exposure to hydrogen chloride (HCl). The initial laboratory tests were only partially finished in 1969 when the full scale experiments were begun. The results of the laboratory work were published in RAPRA Research Report No.9642 - June 1969.

The full scale experiments were carried out at the Fire Research Station in a building 30 ft x 15 ft (9 m x 4.6 m) and 8 ft (2.4 m) high, mainly constructed of lightweight concrete block walls and divided into half with each half sub-divided into three compartments having openings between each compartment. The roof consisted of hollow prestressed concrete floor units supplied by Concrete Ltd with a superimposed load of 60 lb/ft² (413 kN/m²) made up of layers of bricks. Apart from a few specimens of electrical equipment placed in the compartments, the floor units provided the main structural material for the tests although reinforced concrete lintels over the openings between the compartments were also examined together with concrete fence posts and concrete cube and cylindrical samples with embedded steel bars.

In each half of the building the centre compartment contained a wooden crib weighing 250 lb (113 kg), the inner compartment was dry and the outer one contained a water spray to provide humid conditions. One half of the building provided the control fire and the other also contained PVC material so as to produce the HCl. In the first PVC fire the plastic material was placed in the crib and this prevented proper combustion and therefore a second PVC fire test was carried out in which PVC sheets (130 lb or 59 kg) were fixed to the walls of the fire compartment and not placed on the crib. Windows, doors and shutters were provided to control the ventilation or flow of gases from outside and between compartments.

The fire in the 'control' end of the building burnt for 30 min and the maximum fire chamber temperature was nearly 650°C. The second PVC fire was allowed to burn for 47 min at which time 50 kg of PVC had been consumed. The PVC fire chamber temperature was higher than for the control fire but the side chamber temperatures

were comparable to those in the control test. There was no major structural damage after the fires apart from some cracking along the soffit of the floor units above the fire chamber in the second PVC fire. There were three floor units above each of the six chambers and most of these were removed for examination at intervals of up to 13 months after the fire tests. The units were loaded to destruction and samples of the concrete and reinforcement were sent to RAPRA for analysis. The lintels were examined by the Cement & Concrete Asscn and the electrical equipment was also inspected.

As a result of this ad hoc and limited investigation the following conclusions were drawn:

1. The prestressed concrete units exposed to fire for 60 min and air temperature not exceeding 600°C showed no significant reduction in strength but in fire temperatures exceeding 800°C there was about a 20 per cent reduction in flexural strength just after the fire but no further reduction for a year.
2. No floor unit exposed to temperatures between 200 and 600°C and to HCl concentrations of 12000 ppm showed any significant reduction in strength for at least 13 months and visual examination using an indicator showed no chloride penetration to depths greater than 2 mm.
3. Chemical analysis of the concrete from units exposed to the PVC fires showed a surface concentration of chloride ions up to a maximum of 2.3 per cent w/w expressed as CaCl_2 by weight of cement just after the fire, decreasing to 1.5 per cent w/w of cement at 12 months. The concentration in the vicinity of the reinforcement was less than 0.4 per cent of cement and this did not increase after 12 months storage. When exposed to the non-PVC fire the concentration on the surface was not more than 0.2 w/w of cement. The chloride ions did not penetrate significantly deeper into the lower strength concrete of the fence posts but this might have been due to the high cement content of the posts.
4. Where steel bars projected from the concrete surface corrosion of steel under the surface occurred but the damage did not extend beyond 10 mm.
5. Electrical equipment could suffer serious corrosion damage but this would be minimised by washing with a mild detergent solution immediately after the fire.

The main conclusions drawn from these somewhat limited tests are, therefore, that although, in fires involving PVC, chloride deposition can occur on concrete surfaces under both dry and humid conditions, building elements should not suffer structurally from the effects of the chloride, and corrosion would be unlikely to be a problem in normal dense concrete, whether reinforced or prestressed, provided the relevant B.S. Codes of Practice are complied with.

The Note contains full details of the tests, particulars of the chemical analyses, photographs, drawings and various graphs of the results.

INVESTIGATION ON SAFE OPERATION OF RADIANT PORTABLE LPG HEATERS

by

Z W Rogowski and A I Pitt

Portable LPG heaters are of two main types, one has a catalytic bed with no visible flames and a catalytic bed temperature of about 450°C and the other has a radiant panel with flames playing on perforated ceramic burners and this type gives both radiant and convective heat. There is, at present, no British Standard for the former type of heater but the other type appears to be covered to some extent by British Standards viz. BS 2773 : 1965 dealing with domestic single room heaters and BS 1945 : 1971 which concerns fireguards.

A number of these radiant heaters have recently been imported into the UK and two such heaters have been examined for compliance with the Standards and, further, consideration was given to the possible amendment of the Standards.

One heater has a maximum heat output of 12970 Btu/h (3.8 kW/h) and the other heater 8530 Btu/h (2.5 kW/h) and they have various devices designed for ignition and for cutting off the fuel supply in the event of flame failure or increase in the CO_2 concentration. The experiments on the heaters involved the measurement of surface temperatures at numerous points on the heater body and on the floor and wall temperature apparatus as described in BS 3300 : 1963. Tests were also carried out in accordance with BS 1945 using the specified cotton flannelette and with the heaters placed in draughts of various strength. Combustion products were also analysed and a test was carried out on the second heater to examine the possibility of explosion following the extinction of the burners but not the pilot jets.

BS 2773 sets a maximum heat output of 6000 Btu/h (1.76 kW/h) and so requires revision if it is to embrace heaters such as those tested or else a new Standard should be formulated. The design, construction and performance of the two heaters was not entirely satisfactory and it is concluded that, as a result of the examination, further attention should be paid to the fail safe features of the flame failure devices, and the floor and wall temperature requirements of the Standards. Work is being carried out by JFRO on the performance of the heaters in vitiated atmospheres and on the operation of shut down devices when CO_2 concentrations exceed an acceptable level.

Synopsis of FR Note No. 998

A FIRE TEST ON A STEEL SOLVENTS CUPBOARD

by

G W Stark and P J Fardell

Highly flammable liquids and solvents which are stored in industrial laboratories and stores should be kept in cupboards for which a Certificate of Approval could be issued under the Highly Flammable Liquids and Liquefied Petroleum Gases Regulations operative in 1972 under the Factories Act 1961. Such a cupboard should provide reasonable protection against a surrounding spillage fire igniting the contents of the cupboard and, possibly, causing an explosion.

A cupboard of this type consisting of a modified office type 18 SWG mild steel sheet cupboard was tested at the Fire Research Station by standing it in a steel tray 1 m x 2 m containing 12.5 gallons of kerosine which was ignited. The double doors of the cupboard had plastic foam sealing strips around the edges and the handle and general fixing rivets were of light alloy. Gauze vents were fitted with rivets in the cupboard side panels and, for the test, four bottles of high boiling point flammable liquids were placed on two internal shelves. There was a liquid-tight base of sufficient size to contain the entire contents of the bottles. The liquids heated up in a similar way to more volatile flammable liquids but with less of an explosion risk.

The steel cupboard and the contents were virtually completely destroyed within $5\frac{1}{2}$ min and there were dangerous conditions well before that time. After the fire had been burning for 8 min, a 2 gal fluorinated chemical foam extinguisher was used and this controlled the fire within 10 s and extinguished it within about 40 s. In a previous similar test water spray was used and this took 5 min to extinguish the fire so the value of the foam extinguisher for this type of fire was proved.

A previous similar test had been carried out at the Fire Research Station on a well designed wooden cupboard and even after 7 min the temperature of the stored liquids had not reached the boiling point of ether and none of the four bottles failed in any way. Although this cupboard was combustible its behaviour in this type of test was far superior to that of the steel cupboard which, to protect its contents, would require supports and fastenings which meet the requirements of BS 476 (Part 4 - non-combustibility) in place of the light alloy rivets etc. which have a relatively low melting point.

The wooden cupboard does not, however, meet the BS 476 : Part 8, $\frac{1}{2}$ -hour fire resistance requirements as stipulated in the Regulations which apply to premises covered by the Factories Act. For other premises not covered by the Factories Act the wooden cupboard would provide protection from a surrounding spillage fire for more than 5 min and this should be sufficient time for first aid fire-fighting operations or escape.

Synopsis of FR Note No. 999

THE EFFECT OF CRIB POROSITY IN RECENT CIB EXPERIMENTS

by

P H Thomas

In FR Note No. 979 three regimes of fire behaviour when using wooden cribs in experimental 'compartment' fires were identified according to the crib porosity, the fuel surface area and the window ventilation. It was then suggested that, after further consideration of the data, it would be possible to indicate the type of experimental fires controlled by porosity or fuel spacing so that these could be excluded. Useful experimental fires could then be restricted to those controlled by the more practical considerations of fuel surface area and compartment window ventilation.

The present Note refers to the further study of recent CIB experimental data and it is shown that the correlation of the data for the widest stick spacing may be taken as independent of spacing and representative, therefore, of a total wood surface area.

STUDIES OF THE COMBUSTION PRODUCTS OF CYANIDES
IN A HYDROGEN DIFFUSION FLAME

by

W D Woolley and P J Fardell

This Note contains a detailed scientific report on laboratory work designed to provide basic information about the production of oxides of nitrogen from the decomposition of flexible polyurethane foams (4 to 4.5 per cent by weight of nitrogen), both polyester and polyether types. The decomposition of these foams produces yellow smoke which subsequently decomposes, at high temperature, to give nitrogen-containing substances, particularly acetonitrile and hydrogen cyanide. These cyanides are present in unburnt fire gases but when burnt may produce oxides of nitrogen and these, particularly nitrogen dioxide, are just as toxic as hydrogen cyanide. Combustion of the cyanides in fires does not, therefore, necessarily remove the toxic risk.

The laboratory apparatus consists basically of a 80 mm high glass 'burner' enclosure, heated to 120°C with external electrical tape, in which there is a hydrogen flame burning in the centre of the enclosure in an atmosphere of oxygen (21 per cent) and argon. Materials (liquid or gas) which are to be investigated and burnt in the hydrogen flame are introduced into the tube supplying the hydrogen at a point just below the glass enclosure. The introduction is made by using a syringe injecting through the centre of a silicone rubber septum covering the injection port on the above-mentioned tube. The plunger of the syringe is accurately operated by means of a small electric motor and drive rod so that there is a uniform feed of the cyanides or other 'calibrating' materials in the syringe. After combustion in the glass enclosure, samples of the gases are taken from the top of the enclosure, via unheated tubing, to undergo analysis by gas chromatography and mass spectrometry. A hydrogen flame is used for the combustion because water is the only product of combustion and this does not interfere with the subsequent analysis.

Extensive calibration work was undertaken and a number of experiments were carried out using hydrocarbon fuels. This work confirmed that the general combustion conditions of the flame were satisfactory for the acetonitrile and hydrogen cyanide experiments which were then carried out. Some experiments were done with the flame in a vitiated atmosphere and this was achieved by reducing the oxygen concentration in the burner enclosure to about 10 per cent. The general combustion of the cyanides to oxides of nitrogen were quite similar under both flame conditions and temperatures.

The formation of oxides of nitrogen from atmospheric nitrogen is often referred to as 'fixation' but it is clear that the quantities of oxides of nitrogen formed during the combustion of the cyanide fuels are much in excess of the quantities expected from normal 'fixation'. The hydrogen flame is not completely typical of full scale fires but it is realistic in that it ensures complete combustion of the cyanides and the process is similar for both hydrogen cyanide and acetonitrile. It is clear that there are significant yields of oxides of nitrogen during the combustion of the nitrogen content of cyanide fuels.

As a result of this work it is recommended that the concentration of oxides of nitrogen should be monitored in real fire tests involving the combustion of polyurethane foams and other fuels which release cyanides because high concentrations of these gases may be generated.

Synopsis of FR Note No. 1001

EFFICIENT EXTRACTION OF SMOKE FROM A THIN LAYER UNDER A CEILING

by

D Spratt and A J M Heselden

The general smoke problem in covered shopping centres or arcades and the pedestrian malls was discussed in FR Note No. 875 and it was then established that the basic principle of smoke control in the malls was the provision of smoke reservoirs beneath the ceiling by fitting screens extending from the ceiling towards the floor. The present Note is concerned with the extraction of the smoke from these reservoirs through vents in the ceiling and the report describes work done on this venting problem in a model about $1/7$ th full size and in three supporting experiments carried out in the large-scale building at the Fire Research Station.

In both the model and the large-scale experiments the 'fire' consisted of trays of methylated spirit which produce no smoke. A small amount of slightly warm smoke was introduced so as to form a visible layer between the hot gases and the cool air below. This smoke layer enabled the inverted funnel-shaped flow at the base of the vent shaft to be observed thus indicating at what stage cool air was being drawn into the hot gases as they rose up the shaft as a result of their buoyancy or by mechanical extraction.

The vent in the model could be varied in area and in position, i.e. near the walls or in the centre of the mall and in the large-scale building the vent position was fixed but the top of the vent shaft could be partially covered with asbestos sheets so as to alter its area. The depth of the screen on the far side of the vent from the fire could be altered in the model but not in the large-scale building.

It was found that when the rate of extraction of 'smoky' hot gases from the layer under the ceiling exceeded a critical value at any point then cool air from below the layer was drawn up and this resulted in inefficient extraction. The maximum amount of such gases which can be extracted before air is drawn in is not sensitive to the area or shape of the opening over the range of areas of practical importance but it does depend to some extent on the temperature of the gases and also the maximum extraction rate increases markedly as the depth of the gas layer is increased.

With natural ventilation it was found that if, for instance, the vents were square the most efficient size would be if the side length of the vent was not more than 50 per cent larger than the screen depth. Large vents entrain too much

cool air and more smaller vents are better than fewer large ones but their relative positions are important and no vent should be near a wall. Extraction by mechanical means could be made through even smaller openings but it would still be necessary to extract from a number of separated points unless the openings were made very small indeed when other pressure loss problems might arise.

The results obtained from the model experiments were confirmed by the few large-scale experiments. Further study is, however, required to determine the spacing necessary between extract vents in order to avoid undue mutual interference.

THE IGNITION OF CORRUGATED FIBREBOARD ('CARDBOARD')
BY THERMAL RADIATION

by

H Wraight

A series of laboratory tests was carried out to investigate the ignition hazard by thermal radiation of double and triple wall composite cardboard (corrugated fibreboard) which is used for packing goods stored in warehouses and for high stack storage. Samples 100 mm square were placed vertically in front of a 300 mm square gas fire radiant panel and there was provision for a horizontal gas jet or pilot flame placed 15 mm above and at right angles to the top edge of the sample so that it was in the rising stream of gaseous decomposition products. This flame was required for the pilot ignition tests and it was not used for the spontaneous ignition tests. The interior corrugations of the cardboard were either vertical or horizontal and they were held between the flat outer layers (and centre layer in the triple wall type) by a small quantity of adhesive. The double wall cardboard was either 2.8 or 4.6 mm thick and the triple wall board was 7.5 mm thick. In all the samples the front layer at the top was folded over backwards so as to avoid exposing the interior corrugations to radiation, and the sides were protected by the steel holder in which the sample was slotted.

It was found that the minimum irradiance for pilot ignition was marginally below the level of 1.6 W/cm^2 quoted for common softwood and that the level required for spontaneous ignition (about 1.7 W/cm^2) was about one third of that for the softwood. The cardboard thickness and the orientation of the corrugations did not appear to affect the ignition times which were appreciably shorter for pilot ignition as compared with spontaneous ignition. The exact position of the pilot flame was not critical provided it intercepted the gaseous decomposition products.

EXPERIMENTAL APPRAISAL OF AN AMERICAN SPRINKLER SYSTEM FOR
THE PROTECTION OF GOODS IN HIGH-RACKED STORAGEES

by

N W Bridge and R A Young

One half of the main block of 37 ft (11.4 m) high, six level, experimental racking in the ex-airship hangar at Cardington, described in FR Note No. 866, was used for six experimental high-racked storage fires designed to assess the effectiveness of a system derived from the American NFPA Standard 231C-1972 for Rack Storage of Materials and to compare it with results obtained using the JFRO system (see FR Note No. 944) which involves a line detector, and with the wet pipe intermediate-level system recommended in the 29th Edition of the FOC Rules for Automatic Sprinkler Installations.

The main features of the type of NFPA installation tested are the use of a barrier, in these tests of thick plywood, at the fourth racking level and extending the full width and length of the racking, and of sprinklers installed on the face of the racking and centrally just below the barrier. In two fires the bottom rack level was left empty so that the barrier was, in effect, at the third level. The experimental racking represents the lower part of what, in practice, could be very high storage and, being in a large hangar, there is no ceiling effect nor any restriction on the movement of smoke and hot gases.

Storage was on wooden pallets and consisted of cardboard cartons (moisture content 13-15 per cent) containing, for four experiments, empty metal drums and wood wool (equivalent to Class 11/111 goods of the NFPA classification) but for two experiments some plastics material was inserted to simulate Class IV goods. Sprinklers to the FOC Rules (but dry), two types of detector wire (rated 105°C), smoke detector, radiometers, and thermocouples were installed or left in place from previous tests and, although they were not used operationally in these experiments, they enabled measurements of temperatures, radiation and anticipated time of operation to be monitored and recorded.

Ignition was made to a tear in a carton in the centre of the lowest storage level about half-way between the face and the central flue of the rack and immediately below the face sprinkler under the barrier. Further experiments will be done so that no sprinkler is immediately above the ignition point; this sprinkler was the first to operate in each test. Water pressure to the sprinklers, which were either $\frac{1}{2}$ in conventional or spray, was maintained at about 2bar on the gauges.

In the first two experimental fires (designated Arrangement E) there was no barrier in place but there were sprinklers installed at the fourth level (face and central) and the sixth level (central only). These sprinklers did control the fire but not before it reached the top of the racking because, normally, with full storage, the flames go above a sprinkler before it opens. A fire in a partially filled rack might be more readily controlled but such conditions are not likely to be met in practice. This arrangement appeared no better than that provided by the FOC intermediate sprinkler system.

In the other four fires (designated G-4 levels and J-3 levels) there was a barrier in place and there were face sprinklers below the barrier at every alternate vertical pallet spacing. Although the fire did not spread above the barrier there was charring of cartons at the fifth and sixth levels. Ignition of these top cartons was probably just prevented by water spray carried upwards from lower sprinklers by thermal updraughts. Fire spread to the back of the racking and operated the face sprinklers on that side. This spread to the other side of the racking did not occur in any of the tests using the FOC arrangement nor with the JFRO system.

Radiation levels appeared to be sufficient to ignite any adjacent rack and, therefore, the chance of fire spread by this means is doubled if the fire spreads to the back of the racking. Water from face sprinklers appears insufficient to prevent ignition of adjacent racks by radiation. Flying brands could also spread fire.

The quantity of water used was within about 10 per cent of that used with the FOC arrangement but about three times the amount required for the JFRO system. The line detector in the latter system operated before any sprinkler in every test and, also, the smoke detector provided, generally, an earlier warning than the sprinklers.

Considerable quantities of smoke were produced, especially in the last two tests, and roof venting would be necessary to clear smoke; a task made more difficult when the smoke is cooled by sprinkler water. Temperatures were sufficient to damage racking steelwork if of lighter construction than that used in the experiments.

It was necessary to allow the sprinklers to operate for some time before the fires were considered under control, at which time the fire brigade was called on to extinguish them. By that time most of the fuel had been burnt but in practice, with full storage, the burn-out of fuel would, probably, not take place so soon. Full load fires were burning for from 20 to 40 min.

The Note contains a photographs of the racking together with tables showing details of the experiments and the results. There are also drawings of the sprinkler arrangements and graphs showing the relationship between flame height and the time of the sprinkler and detector operation in the six experiments.

A CALORIMETER FOR MEASURING THE HEAT FLUX FROM EXPERIMENTAL FIRES

by

S P Benson and J G Corrie

Measurement of the heat from flammable liquid fires is required for the purpose of designing test equipment and for assessing the exposure hazards from storage tank fires and the extinction properties of foam liquids. Existing equipment for measuring this heat flux, both radiant and convective, has had severe limitations and in this Note the design and development of a new type of calorimeter for this heat flux measurement is described in considerable detail.

The apparatus consists of a disc of pure aluminium 1 in (25 mm) thick and 6 in (150 mm) in diameter. One face is coated with lamp black to make it an efficient absorber of radiant heat, while the other face and the edge of the disc is highly polished to minimise heat loss by radiation. The disc is mounted in a metal case from which it is carefully insulated and it is fitted so that only the blackened face is exposed. The case has a lid which can be opened and closed, and this permits the blackened face of the disc to be exposed for a fixed period - usually several minutes. The temperature rise of the disc is recorded by a maximum reading thermometer or a thermocouple which are inserted into pockets drilled into the side of the disc.

The apparatus can stand vertically or lie horizontally on its back and it has a 'field of view' of 180° . The disc increases in temperature when the lid is opened and it is exposed to a fire. The maximum reading thermometer shows the maximum temperature achieved as a result of the total heat pick-up and this enables the radiation received to be calculated. Being a substantial disc the temperature rise is limited and the heat loss by re-radiation is, therefore, small. Because of the way it operates the apparatus is a calorimeter and not a radiometer and it provides an absolute measure of the net heat retention during the exposure period and, therefore, a calibration against a standard radiation source is not necessary and its characteristics remain constant.

This calorimeter is robust and inexpensive and operates without wires or water cooling and so is readily positioned as required. It can measure the heat flux over a period of several minutes and has been used successfully with liquid fires up to 457 m^2 in area which were extinguished with foam. It responds to both radiant and convective heat and can be used down wind in the smoke of a fire. Experience with liquid fire tests indicates that the radiation close to a fire is in the range $3\text{--}4 \text{ W/cm}^2$ and the new calorimeter can measure the heat flux within the range $0.1\text{--}10 \text{ W/cm}^2$.

A calorimeter 'twin-set' can be used to measure mixed heat fluxes in their components of radiation and convection. This apparatus consists of two discs mounted in the same case. One is the standard disc and the other is of half thickness and, therefore, half the thermal capacity. The latter has only part of the face covered with lamp black so that, taking account of its half thermal capacity, radiant heat will increase the temperature of both discs at the same rate. With convective heat, however, the thinner disc will increase in temperature at twice the rate of the standard disc since it has the same surface area and only half the thermal capacity, and convective heat transfer is independent of the disc surface covering.

An improvement to the apparatus might be to replace the lamp black with a more permanent black paint or electro-deposit. However, the apparatus, as it is, is reliable although it is not quick to respond nor highly accurate but these features are not essential for this type of work.

SPECIFICATION FOR TESTING OF PORTABLE DOMESTIC
BUTANE CATALYTIC SPACE HEATERS

The operation and safety of portable domestic butane catalytic space heaters was thoroughly investigated by Joint Fire Research Organisation and a report on the work was contained in FR Note No. 996. Although the hazards are similar in many ways to those applicable to portable gas and paraffin heaters there are other specific hazards arising from the use of butane and its catalytic combustion. No British Standard applies to such catalytic heaters at present, and, consequently, this Note contains a specification of tests for these heaters as regards their fire hazard and construction, and this is based on the above-mentioned work.

Heaters shall not exceed an output of 12000 Btu/h (3.5 kW) and must be adequately marked and labelled. The specification deals in detail with the construction of the catalytic bed, piping, taps, rigidity, stability and gas soundness. The regulator and combustion failure device shall comply with BS 3016 : Part 1 : 1958 and BS 2773 : 1965 respectively. Commercial butane to BS 4250 shall be used for all tests and details are provided for the performance requirements regarding the catalytic bed, ignition, pilot flame, surface temperatures and catalytic bed temperatures together with the temperature rise on the floor or walls adjacent to the base, back and sides of the heater.

Combustion gases shall be sampled and analysed and the heater shall undergo a draught and endurance test. The guard shall be subjected to the flannelette test in line with BS 1945 Appendix B.

Tests regarding operation in vitiated atmosphere should be carried out when the relevant information is available and further research work is required regarding the operating life of the catalyst.

A LABORATORY FIRE TEST FOR FOAM LIQUIDS

by

S P Benson, P R Bevan and J G Corrie

Fire fighting foam liquids are now tested under the Defence Standard 42-3 Issue I 24/1/69 and this involves a lengthy procedure using 35 litres of petrol fuel in a 0.28 m^2 test tray and a matching of laboratory-made foam with the foam produced in the standard 225 l/min branchpipe which is no longer obtainable. Although rather laborious, the test has served well whilst only protein foam liquid has been available. With the introduction of new foam liquids such as fluoroprotein and fluorochemical and with the need for specialised use on particular fuels, a new simpler and more economical test has become essential and such a test is described in this Note. Under the proposed arrangement a thorough examination of a foam liquid could be carried out in about a day as compared with, perhaps, a week under the Defence Standard test and, further, it is less dependent on operator skill and laboratory variations.

Reports on some of the problems and equipment involved have recently been issued and reference should be made to the synopses for FR Notes 918, 971, 972, 975 and 976. In particular, the newly designed 5 l/min standard foam branchpipe is used for the test with a modified nozzle and bypass jets to enable only $3.0 \text{ l/m}^2/\text{min}$ to be delivered as a jet on the centre of the test fire tray of 56.5 cm dia. containing only 9 litres of fuel. A burnback resistance test is incorporated in the procedure and the fire drainage measurement has been abandoned.

The Note includes the test results for numerous experiments carried out using 17 samples of foam liquid of all types and age on the aviation fuels Avtur, Avtag and Avgas. The fluoroprotein foams were generally much superior to the proteins in the control and extinction of the fires.

The brass fire tray, which stands on legs, is almost flat bottomed and has an area of 0.25 m^2 and sides 15 cm high. The foam liquid premix (mainly 4 per cent) is prepared in a pressurised stainless steel container and the temperature, expansion, shear stress and 25 per cent drainage time determined. For the fire test the foam jet is projected from the branchpipe's 7 mm dia nozzle at 750 g/min with the branchpipe fixed in a horizontal position so that the unwanted foam discharged through the bypass holes is projected downwards outside the tray. The preburn time, before the foam application, is 1 min (30 s for the Defence Standard) and

the foam is then projected on to the centre of the flaming fuel until the fire is $\frac{9}{10}$ ths controlled and then extinguished but at least for a total time of 3 min. Most fires were extinguished in about 1 min.

The burnback test involves a brass pot 12 cm in diameter, containing 1 litre of Avgas, which is carefully lowered into the centre of the test tray when the foam application has finished. After another minute the fuel in the pot is ignited. Care must be taken to ensure that no foam enters the pot. After some minutes the fuel in the test tray ignites again and the time when the tray is once more full of flames is recorded as the burnback time and this is, on average, about 25 min.

The new test was designed in the light of the principles applying to large fires although precise correlation between laboratory tests and real fires would involve a difficult and expensive test programme. It may, however, be worthwhile conducting a series of large fire tests of, say, 100 m² area in order to establish a correlation, and further studies on the branchpipe application of foam are desirable. Even so, the test, as it stands, does provide a very practical laboratory method for assessing the control, extinction and burnback properties of foams and the rate of foam application is representative of the maximum rate required in real fires.

Real fire situations can involve structures and plant which complicate the fire scene and much further work would be required before any laboratory tests could be used to predict with confidence the quantity of foam required to extinguish large fires.

Postscript by the Authors:

Following the completion of this work a new Defence Standard test based upon it is now under consideration and the International Standards Organisation is also examining it as a test method for foam liquids.

Synopsis of FR Note No. 1008

PRELIMINARY ANALYSIS OF FIRE REPORTS
FROM FIRE BRIGADES IN THE UNITED KINGDOM 1973

by

S E Chandler

A first analysis of the fire brigades' K 433 and K 433H report forms indicates that the brigades attended 322,037 fires in the UK during 1973 (290,343 in 1972) and estimates supplied by the British Insurance Association show the total direct monetary loss at £193.9M (£141.2M in 1972) which includes damage caused by civil disturbances in Northern Ireland (£179.3M without the N.I. losses).

Fatal casualties number 944 (952 in 1972) and non-fatal casualties 6377 (5963 in 1972). The final figure for the deaths may approach the final 1972 figure of 1078. The most serious incidents were at the Summerland fire (50 deaths) in the Isle of Man and at an hotel in Oban (10 deaths). 3 firemen were killed during the year (12 in 1972).

The Note contains tables showing the numbers of fires attended by the various brigades, the sex and age of fatal and non-fatal casualties, the nature of injuries to casualties, the month of occurrence of fatal injuries and the hazard in which the fire started and the source of ignition. Brief details are also given of the people rescued or who escaped by emergency means. A table shows the monthly direct fire damage.

All the information regarding the number of fires and casualties is based on reports received up to 8 March 1974 and is subject to revision when outstanding reports are received.

SMOKE EXTRACTION BY ENTRAINMENT INTO A DUCTED WATER SPRAY

by

H P Morgan and M L Bullen

A series of experiments, primarily designed to investigate the extraction of hot gases through an intumescent-coated honeycomb fire damper, led to a fuller study of the use of a water spray from a nozzle placed centrally in a duct as a possible general method of removing hot gases and smoke from, for instance, a shopping complex. The system is simple, cheap and has no moving parts. It is unaffected by heat and, in fact, cools the gases which can then be further extracted by fans or other conventional means which might be damaged by high temperatures.

The tests were carried out using a 1 ft dia circular metal duct sloping downwards from the fire compartment, in order to drain away the water, having a proprietary type swirl spray nozzle placed centrally near the middle of the ducts length so that the spray cone played water away from the fire. The water impinged on the sides of the duct but some tests were carried out with the end of the duct cone-shaped with a divergence only just less than the cone angle of the spray so that the amount of water splashing on the duct sides was reduced. The portable pump supplying the water could produce a pressure of 200 psi (13.5 bar) at the nozzle. Air pressures and velocities were measured and the size of the inlet opening to the duct at the fire compartment end was varied in order to produce different frictional loads or resistance.

A theory was developed for the system, which was borne out by the test results, in which the friction between the liquid drops in the spray and the surrounding air produces a drag which results in the water spray pulling the air and gases along the duct. The technical details of the principles involved and the test results are provided in the Note and it is concluded that the system provides an effective means of extracting high temperature gases. Even large quantities of gas and smoke could be removed if there is not a large adverse pressure head or resistance between the inlet and outlet of the duct. The cone shaped outlet was only marginally better when there was a low resistance and in other cases there was little difference between the two outlets.

Full scale installations are discussed and, as an example, one such installation might require a water flow of 160 gal/min (12 l/s) and a pressure of 160 psi (11 bar) in a 1.125 m^2 duct and such water flows and pressures are easily obtainable in practice.

SOME STATISTICS OF FIRE IN ROAD VEHICLES

by

M A North

The risk of fire in road vehicles is only a small part of the total road transport problem but it is of importance and the following FR Notes have already been published on this topic, viz: FR Notes No.836 (1968 statistics), No.926 (Motorways in 1969) and No.936 (buses, coaches and minibuses). The present Note deals with the statistics mainly for 1971 and it includes statistical tables in respect of the types of vehicles, age, location, month and time of call, source of ignition and material first ignited, fire spread, casualties by vehicle types, and nature of injuries and age of casualties, and source of ignition in respect of fatalities.

It is shown that the frequency of fire in road vehicles is largely dependent on the number of vehicle-miles travelled and this varies according to the class of vehicle involved. As an example, the statistics for 1970-71 indicate that the fire rates for each thousand million vehicle-miles in respect of the main classes of road vehicle are as follows:

all road vehicles	-	95 (including classes in addition to the aftermentioned)
cars and taxis	-	130
light vans	-	210
motor cycles etc	-	445
buses and coaches	-	450

The effect of the vehicle's age is not clear but there is some indication that the fire risk is greater for older cars and motor cycles. The most common sources of ignition are wire, cable and exhaust systems but mechanical heat and sparks are important for heavy vehicles. Electrical installations and fuel are the materials most commonly ignited first.

With regard to car fires, most of these start in the engine compartment (65 per cent) and most car fires are confined to the compartment of origin (75 per cent). However, about 20 per cent of these fires cause severe damage to most or all of the car. Most malicious car fires cause severe damage but there is only minor damage in about 35 per cent of car fires and this proportion rises to about 55 per cent for fires starting in wire and cable and from smoker's materials.

The risk of death or injury by fire must be related to the exposure time and on this basis the risk is greater than in most buildings. For instance, in the

manufacturing industries, the fire fatality risk is about 0.1 to 0.2 per 10^8 person-hours exposure while for fires in road vehicles the equivalent figure is 0.7 to 0.8. The risk of death or injury by fire is much higher for motor cycles than for cars, buses or lorries. The road risk is, however, relatively less important than the risk in buildings but, on the other hand, the bulk of the road fire fatalities are young adults.

THE FIRE PROBLEMS OF PEDESTRIAN PRECINCTS - PART 5
A REVIEW OF FIRES IN ENCLOSED SHOPPING COMPLEXES

by

H G H Wraight

A survey has been undertaken of fires which have occurred in enclosed shopping complexes and similar risks during the period 1949 to 1971 in order to study the hazards involved and make suggestions for future improvements. The available information, mainly from the NFPA journals and publications, has been studied and of 128 fires listed 67 were fairly fully described and of these 18 were considered of special interest and information on each has been summarised and tabulated in this Note. Of these 18 fires, 11 occurred in the USA, 5 in the UK and 1 each in Canada and Mexico. Seven of the risks had partial sprinkler protection but otherwise the 18 risks were unsprinklered. The summary of each fire includes a brief description of the building, a note of the cause, point of origin and fire spread, casualties and escape problems, and special hazards, together with any conclusions to be drawn from the incident.

The examination reveals that the following factors are common to many of the risks:

- (1) fires are easily started in rubbish and other inflammable materials such as cardboard, textiles and plastics especially if near a source of heat, and flimsy decorations are particularly hazardous.
- (2) fire spread is mainly caused by combustibile linings and ceiling and wall cavities. A glazed showcase is an ideal place for a fire to develop.
- (3) congested sites, restricted approaches and venting problems make the fire brigade's task difficult.
- (4) smoke logging and lighting failure make escape difficult.

The following recommendations are listed:

- (1) the design should permit easy escape and equally easy access for the fire brigade.
- (2) sprinkler protection should be provided in individual shops and storage areas.
- (3) smoke extraction system is required particularly for basements.
- (4) cavities and concealed spaces should be avoided or else fire breaks should be provided.
- (5) provision required for water removal.
- (6) strict control of rubbish and decorations essential.

In the UK, requirements for shopping centres involve horizontal compartmentation on all floors, acceptable building materials, sprinkler protection in shops and storage areas and adequate smoke venting of malls. These requirements should prevent incidents as described in the Note.

Synopsis of FR Note No. 1014

INVESTIGATION OF SAFE OPERATION OF A RADIANT PORTABLE LPG HEATER

by

A I Pitt

Two radiant portable heaters, fired by bottled liquid petroleum gas contained on the appliances, were previously tested, at the request of the Home Office, for safe operation, and the investigation was reported in FR Note No. 996. These heaters, which were both imported, were found to be not entirely satisfactory especially as regards the flame failure device, and the floor and wall temperature requirements of BS 3300 : 1963. Further, the heat output of both heaters was in excess of 1.76 kW/h (6000 Btu/h) which is the limit imposed by BS 2773 : 1965.

A further similar heater of different make now on the market has been examined and the present Note records details of the investigation. This heater has a single row of gas jets under a heavy mesh gauze, backed by a curved reflector plate. Its output can be varied from 0.6 to 3.0 kW/h (2 - 10,000 Btu/h) so it is also outside the performance limit imposed by BS 2773 which, consequently, may have to be revised in order to deal with modern heating demands. With regard to the other relevant clauses of BS 2773 the heater met the stability and flame failure requirements but not the resistance to draught stipulation although, as the fuel supply was shut down when the flame failed, the heater should be safe in practice. It also met the CO/CO₂ ratio and heater surface temperature requirements of the Standard but failed the side wall temperature limit set by BS 3300. A revision of this Standard, BS 3300, may also be desirable.

The heater complied with BS 1945 as regards the guard, and the flannelette test was also satisfactory.

A test was carried out in a vitiated atmosphere and the flame failure device cut off the fuel supply after 39 minutes when the CO₂ concentration in the room reached 2.0 per cent.

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