LIBRARY REFERENCE ONLY

F. R. S. LIBRARY

THE LIBRARY
FIRE RESEARCH STATION
BOREHAMWOOD
HERTS.
NO. A99FR.N1009

Fire Research Note
No 1009

COLLECTED SUMMARIES OF FIRE RESEARCH NOTES 1973

by

L C Fowler

April 1974

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

FIRE
RESEARCH
STATION

© BRE Trust (UK) Permission is granted for personal noncommercial research use. Citation of the work is allowed and encouraged.

50792

Fire Research Station
BOREHAMWOOD
Hertfordshire WD6 2BL

Tel: 01 953 6177

Fire Research Note No 1009
April 1974

COLLECTED SUMMARIES OF FIRE RESEARCH NOTES 1973

by

L C Fowler

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

APRIL 1974

KEY WORDS: Fire Research, review

Crown copyright

This report has not been published and should be considered advance research information. No reference should be made to it in any publication without the written consent of the Head of Fire Research

Department of the Environment and Fire Offices' Committee
Joint Fire Research Organization

Synopsis of FR Note No.822

THE DETECTION OF FIRES BY SMOKE

PART 5: DEVELOPMENT OF A SMOKE TUNNEL FOR TESTING FIRE DETECTORS

by

E F O'Sullivan, R L Sumner, B K Ghosh, P G Smith

A simple laboratory-scale apparatus for measuring the sensitivity of smoke detectors is described in the Note which also includes details of experimental work so far carried out with this equipment.

The apparatus consists of an aluminium framed rectangular box of 0.63 m^3 capacity. It is 2.3 m long, 0.38 m wide and 0.76 m high with rounded ends and with a horizontal aluminium plate along the centre line extending to within 0.38 m of each end so that there is virtually a circular tunnel around which air or gases and smoke can circulate continually when a fan, fitted in the lower half of the tunnel, is operating. The top and sides of the box are made of perspex with trap doors to enable the operations in the tunnel to be seen and for access. The top half of the tunnel contains a baffle and a lamp and photocell for measuring smoke density. In the top of the box there is a removable panel to which up to four detectors can be fitted so that they protrude into the upper half of the tunnel. On the down-stream side of the fan there is a 1 kw electrical heating element, fitted horizontally across the tunnel, on which a thin card can be clamped so that when the element is heated the card produces smoke. The tunnel is similar to that suggested by the IENT Laboratory at Aachen.

The quantity of smoke produced can be varied either by altering the area of the card or by switching off the heater when the optical density has reached the desired level and the rate of rise of smoke production can be varied by pre-setting the heater voltage. The fan can circulate the smoke at from 200 to 600 mm per sec.

Experiments were carried out on optical scattering and ionization chamber detectors with the object of determining the influence of the smoke concentration, the type and age of the smoke and its velocity on the performance of detectors. Although detectors would not be required to operate in the tunnel at the same optical density as in a real fire, it is necessary for there to be a direct correlation between the tunnel test and real fire performances. The tunnel is not at present used to assess the sensitivity of detectors to fire but it is used to check their sensitivity before and after environmental tests such as shock, impact and corrosion.

An important factor which complicates the correlation is ageing of smoke. The ageing of smoke appears to result from the gradual coagulation of smoke particles of various sizes and, whilst this action did not affect the smoke density in the tunnel or the performance of the light scattering detector, it did affect the performance of the ionization chamber detector. A similar phenomenom has been observed in full scale fire tests. Coagulation may, however, vary according to the surface under which the smoke is flowing and, also, the performance of detectors may differ for smokes produced from different materials.

Further work on the apparatus should include means for increasing the smoke concentration by adding aged instead of fresh smoke, for measuring low smoke concentrations and for improving the method of producing smoke from cellulosic materials. The application of smokes from other fuels or from artificial aerosols should be investigated and so should the measurement of detector response to conditions which simulate the extremes observed with experimental wood fires.

Synopsis of FR Note No.898

COST OF FIRE PROTECTION - TOWARDS A DEFINITION

by

D V Maskell

This Note contains a preliminary general review of the various factors which contribute to the cost of fire protection and the author expresses his views regarding the problem and suggests some definitions, of these factors, which might form the basis of future cost investigations.

Direct fire losses have risen from £12M in 1946 to about £128M in 1971 and, although inflation must account for some of the increase, it is clear that fires have become more numerous and losses larger, particularly in commercial premises. If indirect losses, costs of the fire brigades and research etc are added to the 'fire bill' then the national loss is greater still and even in 1965 the total cost was estimated at £364M of which £63M was in respect of the fire protection of buildings.

The fire protection measures can be divided into three broad categories of passive, active and indirect (and administrative). The problem can be considered from the point of view of the building owner/occupier or in the context of the national economy, the latter being of prime importance and the main concern of this report.

The crux of the matter is to decide if money spent on fire protection is justified by any consequent reduction in fire losses or what increase in fire loss would occur if the money spent was reduced. Legislation requires that certain measures be taken, mainly for life safety, but this does not necessarily mean that costs are consequently higher and it is necessary to compare the costs of a structure erected and occupied both with and without regard to fire protection. The difference in amount will give some idea of the cost of the fire protection incorporated in the building.

Requirements under the Building Regulations are passive measures and concern the fire resistance of elements of construction, doors, shafts, staircases etc and the provision of ventilation, flame retardant linings and adequate separation from adjoining buildings. The active measures consist mainly of such items as sprinklers, fire extinguishers and alarms, and hydrants. The installation of these is often encouraged by premium discounts offered by insurance companies. The indirect measures include the provision of the fire

brigades and emergency services, research and educational propaganda. The author concludes that there is difficulty in deciding what actually constitutes fire protection particularly in the case of passive and indirect measures. However, building costs for new buildings are being analysed and over a period of time it should be possible to provide a library of cost information dealing with both active and passive fire protection measures.

Information on building costs is obtained from technical journals etc and details of one example are provided in an appendix to the Note. This example concerns an office block costing £148,000. The costs of fire protection measures such as protected shafts, fire resisting doors and shutters, supplementary lighting, external escapes, treated linings, alarms, hose reels, extinguishers and warning signs are extracted. The expenditure on all these items amounts, in all, to 5.4 per cent of the total building cost.

Synopsis of FR Note No.923

FULLY-DEVELOPED FIRES IN SINGLE COMPARTMENTS
A COOPERATIVE RESEARCH PROGRAMME OF CONSEIL INTERNATIONAL DU BÂTIMENT (CIB REPORT NO.20)

by

P H Thomas and A J M Heselden

Although some pioneering work on the behaviour of full-developed fires in single compartments had been done in the US and Japan it was decided in 1958 to carry out a further full programme of experiments at eight laboratories participating in Working Party 14 of the Conseil International du Bâtiment (CIB). Over 400 experiments were done and a preliminary examination of the results was carried out and reported upon in FR Note No.877. In the present Note the full results of the programme are presented and discussed and it is pointed out that the resulting information is mainly of value to fire technologists in connection with the protection of structures and the prediction of fire-resistance requirements. The experimental fires were carried out in small scale compartments and were designed to assess the relative importance, in fully-developed fires, of compartment shape and ventilation and to study the effect of scale.

The compartments were rectangular and constructed of asbestos millboard sheet fixed to a metal framework and were $\frac{1}{2}$, 1 and $1\frac{1}{2}$ m in height. The compartment shape was designated in code form representing width, depth and height viz: 211, 121, 221 and 441. The '211' model being 2 units wide, 1 unit deep and 1 unit high. One side of the compartment had an opening for ventilation which extended from floor to ceiling and was $\frac{1}{4}$, $\frac{1}{2}$, $\frac{3}{4}$ or the full width of that side. In some experiments a wind was blown across the ventilation opening.

The fuel was a timber crib having sticks 10, 20 or 40 mm thick with stick spacing $\frac{1}{3}$, 1 or 3 stick thicknesses. The fire load densities were mainly 20, 30 and 40 kg/m^2 which represented normal fire loads except for warehouses.

Measurements were made during the experiments of the loss in weight of fuel which indicated the rate of burning, the temperatures in the compartment and the radiation in front of the ventilation opening and of the flames above the opening. The Note contains numerous tables and graphs giving detailed information on the experimental results. The data from each test were produced in a standardised form which enabled the results to be studied over different periods according to the rate of burning, eg when fuel weight was falling from 80 to 55% and from 55 to 30%, these periods representing the time of steady burning after flashover. The time the fire was growing and the later period when only charcoal was burning were excluded although the former can be important for safety of life.

The series of experiments enabled comprehensive conclusions to be reached despite laboratory variations. It was established that with appropriate corrections the effects of scale were small thus justifying the use of models and, further, the effects of fuel thickness were minor. The effects of wind were not studied in detail but it was clear that wind could be an important factor in the performance of real fires. The thermal properties of walls and ceilings in full scale risks could also be important although the differences in this respect in the models had only a small effect.

It was found that the intensity of radiation from the ventilation opening could be related to the rate of burning (R) per unit ventilation opening area and the temperature within the compartment irrespective of the opening size and was of more use than a single temperature measurement. The radiation of the flames above the opening could also be related to the burning rate, radiation at the opening and the compartment size.

It was shown that there were substantial differences between fires in compartments of different shape. The mean value of $\frac{R}{A_W\sqrt{H}}$ (A_W is ventilation area and H its height) increases as $\frac{A_T}{A_W\sqrt{H}}$ increases (A_T is area of walls and ceiling) though the effect is less with small openings. A simplified calculation of the fire resistance requirement for a particular structural member shows that the fire resistance (t_f) can be expressed as $b \frac{L}{\sqrt{A_W A_T}}$ (total fire load) where b is approximately 1.3 min m^2/kg for 1 fuel spacing and 1.1 for 3 fuel spacing in these experiments. For a wide range of large scale experimental fires b might be 0.95. This correlation largely eliminates the effect of compartment shape.

This work goes some way towards increasing knowledge of the effect of various parameters on the development of fire in buildings and this is necessary before rational control can be set up. Too much fire protection is expensive and too little is dangerous. Control based on objective assessment rather than on long-term accumulation of experience helps to permit more rapid assimilation of new and improved building methods and materials.

Synopsis of FR Note No.937

THE SAFETY OF HOT SELF-HEATING MATERIALS IN COOL SURROUNDINGS - A METHOD OF ANALYSIS

by

P H Thomas

It was mentioned in FR Note No.940 that if material which is capable of self-heating is initially hot and is then suddenly cooled it may not lose heat fast enough to prevent ignition and this problem is reviewed in more detail in the present Note. If a piece or pile of such material is heated, for instance during manufacture, and is then placed in cool surroundings it may not cool sufficiently to prevent ignition. It is already possible to assess the hazard if the surface heat loss is either very low or very high but no simple and accurate solution to the problem has previously been available when the heat loss is between the two extremes.

The conditions to which such material can be safely exposed are determined by relating the rate of heat generation to the rate of heat loss and the problems are demonstrated in considerable scientific detail in this Note with the aid of equations and graphs. Materials being stored may be in spherical or cylindrical form or in cubical or rectilinear piles. The theory now developed for determining the safety of hot self-heating materials allows safe temperatures or minimum cooling requirements to be specified in terms of the self-heating and geometrical properties of the materials at risk.

Synopsis of FR Note No.940

THE SURFACE HEATING OF A REACTIVE SOLID

by

P H Thomas

A material capable of self-heating may behave in various ways. A large mass of the material in cool surroundings may reach a constant temperature higher than the surroundings, but in hot surroundings the temperature may rise rapidly and cause spontaneous ignition. If the material is heated more quickly, ignition can occur on the surface and the interior of the material acts only as a heat sink. If material which is initially hot is suddenly cooled it may not be able to lose heat fast enough to prevent ignition and this is a matter which is particularly relevant to certain storage risks and will be considered by the author in another paper. However, the simple approximate method developed for that study is used in this Note for application to certain classes of surface ignition problems.

Scientists have recently reviewed various approximate methods for calculating the time taken for the temperature of self-heating materials to rise substantially when the surface is subjected to constant radiation. The author of this Note considers these theories in some detail and shows that the simple approximation can provide results which agree closely with other more detailed calculations. He is mainly concerned with demonstrating the wider scope of the methods of approximation already established rather than with any new approach to the surface ignition problem.

Synopsis of FR Note No.941

THE EFFECT OF ROOF CONSTRUCTION AND CONTENTS ON FIRES IN SINGLE STOREY BUILDINGS

by

C R Theobald

The work of the Fire Survey Group was briefly described in FR Note No.882 and some house fires were analysed therein. Another Note, now in preparation, examines surveys of some industrial fires and this present Note investigates data obtained from 9 fires in shed buildings (one a virtual shed on top of a 3 sto. block) with particular reference to roof venting. Twenty-four shed building fires have been surveyed but these 9 fires were chosen because the quantity of fuel burnt and the fire duration were ascertainable. An analysis of the data is made for the purpose of confirming that the parameters of earlier experimental research work were representative of actual fires and to provide information on the circumstances in which predictions of fire behaviour on an experimental or theoretical basis can be made.

Brief details (extracted from the numerous tables in the Note) of the fires investigated are given in the tabulated summary. Much of the information was obtained from the Chief Officers of the Herts and Bucks Fire Brigades in whose areas the fires occurred. Details of the experimental fires are also shown. The buildings varied in size from 170 to over 10,000 sq metres and contained fire loads ranging from less than 1 up to 1000 kg of fuel per sq metre of floor area and the table indicates the total wood load equivalent of the actual fuel present.

The table shows that corrugated asbestos sheeting and PVC rooflights were particularly effective in venting the fires; the GRP rooflights were less reliable in this respect but did eventually vent the fire (incidents 1, 2 and 3). Although in incident 8 the building had an asbestos roof, the cardboard cartons burnt rapidly and completely regardless of the roof. In incident 7, the GRP rooflights remained in position for more than 1 hour probably because the fire was generally slow burning and starved of air. Asbestos roofs protected by linings did not readily collapse to vent the fires.

In incidents where roofs vented the fire quickly, fire spread was limited to less than 20% of the building area but in all the other incidents fire spread exceeded 80% and the buildings were virtual total losses. In incident 5 the main fuel was the Belfast roof.

An analysis of incidents 4-9 confirms that unless the structural roof supports are so designed that their fire resistance exceeds that of the roof cladding, then the roof will collapse over a large area. The presence of roofing encourages flame spread and in one incident the flames under the roof were more than 50 m long. Also, lack of venting causes smoke logging with consequent escape and fire fighting problems.

The sprinkler installation in incident 9 was sub-standard but it did retard fire growth although the bottoms of the stacked goods (3.6 m high) were not wetted. However, the sprinklers would probably have confined the fire to the stack of origin if the roof had vented effectively. Twenty heads opened in rapid succession.

The time of fire duration refers to the time the fire was burning strongly and was determined from the degree of wood charring when the actual time was not known.

With regard to the comparison with earlier experimental work, only the fire involving cardboard cartons (incident 8(a)) burned at a greater rate than the largest crib fire or the 'ad hoc' cardboard experimental fire. The rates of burning quoted are the averages for the fire duration and they could have been much higher before the brigade reduced the burning rate with water.

SUMMARY

Incident No. or experiment reference	Occupation	Contents	Construction: Frame	Walls	Roof	Roof lining	Roof lights	Floor area m^2	Est'd total wood fuel equivalent kg	Fuel consumed %	Est'd burning rate per unit area of comp't kW/m^2 (fire area rate)	Fire duration min	Venting effect	Notes
1	Furniture store	Stacks of crated furniture	Concrete	Bk. & asb.	Asb. cement		PVC	171	140,000	0.3	(100) 19	30	Very effective	Roof vented early when lights failed
2	Timber store and workshop	Stacked and sawn timber, machinery	Timber	Timber	Asb. cement			171	4,500	16	(390) 21	45	Effective	Roof vented early when roof failed
3	Garage repair shop	Vehicles, petrol and cellulose	Timber	Bk. & glass	Iron		GRP	260	145	25	(260) 6	5	Effective	Building smoke logged until GRP lights failed
4	Hospital research unit	Library and research equipment	Alumin-ium	Asb.	Asb. cement	Fibre-board		460	44,000	25	(93) 85	60	Ineffective	Extensive fire spread
5	Factory	Paint spray booth Metal components	Timber	Bk.	Bit. on timber	Belfast roof		1332	40,000 (roof)	85	(210) 180	30	Ineffective	Extensive fire spread
6	Cardboard and timber store	Stacked cardboard (a) Stacked chipboard (b)	Timber	Corr. iron	Iron			390	16,500 (a) 220,000 (b)	33 1	(320) 320 (86) 86	40	Ineffective	Extensive fire spread
7	Factory and store	Electrical goods cardboard cartons	Steel	Conc. asb.	Asb. cement	Plaster board	GRP	2208	116,000	25	(310) 35*	80	Ineffective	Extensive fire spread
8	Warehouse	Stacked card'd cartons (a) Stacked card'd reels (b)	Steel	Bk. asb.	Asb. cement			4150	113,000 (a) 2,540,000 (b)	100 20	(620) 620 (210) 210	30 210	Ineffective	Rapid fire spread through cartons regardless of roof
9	Warehouse (non-standard spklrs)	Wrapped and packed consumer goods	Steel & iron	Bk.	Slate	Timber	Wired glass	10440	7,200,000	52	(540) 440	180	Ineffective	Extensive fire spread
K	Test apparatus with 11.1 m^2 window opening	Wood cribs	Brick built compartment					28.5	218	100	(290) 88	19		
D									436	100	(550) 165	20		
F									872	100	(980) 300	22		
L									1744	100	(1550) 470	28		
ad hoc	2.6 m^2 window opening	Cardboard cartons							408	100	(1550) 470	6.7		

*Fire spread rapidly in early stages and then became starved of air

Synopsis of FR Note No.942

DUST EXPLOSIONS IN A LARGE SCALE CYCLONE PLANT

by

P S Tonkin and C F J Berlemont

The fire and explosion hazards of cyclone dust separators and ancilliary plant are well known (136 fires in such plant in UK in 1968) and, although the relationship between the explosibility class (see FR Note No.639) and the explosibility of dusts in turbulent conditions has been established, it was decided to carry out a series of tests using full scale plant in order to investigate the size and type of venting necessary to reduce explosion pressures to safe levels. A study was also made of the pressures in the plant away from the cylone itself and of the effect of rotary valves in the ducting. The dusts used were cork, phenolformaldehyde resin, wheat flour and polypropylene, all classified (a) for explosibility.

The plant consisted of an inverted cone of mild steel plate 4 ft (1.22 m) in diameter at the top and 6.25 ft (1.9 m) high with a 4 ft diameter cylindrical upper part 2 ft (0.62 m) high. The total volume of the cone and cylindrical part was 43 ft^3 (1.2 m^3). The extracted dust was discharged at the bottom of the cone, via a rotary valve, into a hopper which itself discharged, also via a rotary valve, into 9 in diameter steel ducting containing a circulating fan which blew the dust and air up a vertical and then a horizontal section of ducting into the top of the cyclone where it discharged the dust and air in the normal way, ie the dust being thrown against the cyclone sides and separating out from the air which was vented through the air outlet (about 1 ft in diameter) fitted axially in the cyclone top cover.

The air vented from the cyclone through the air outlet was recirculated via ducting to a point just below the hopper where a deflector plate ensured good mixing of dust and air. The rotary valves had six blades and were constructed so that at no point in the revolution of the blades was there free passage from one side of the valve to the other, apart from the clearance gap.

Tests were begun by filling the hopper with the dust and then starting up the fan and rotary valves. The dust and air continued to circulate until the required conditions were attained at which time a propane/air flame was injected into the top part of the ducting at about 4.5 ft from the top cyclone inlet. The top cover of the cyclone was fitted with various shaped explosion vents, whole or part segmental in shape, and for some tests ducting of various lengths, with and without elbows, was fitted to one of the vents. Some explosions were vented through the air outlet in the top of the cyclone.

In all the experiments there was an initial positive pressure of 0.15 lbf/in^2 in the cyclone. The segmental vents in the cyclone top cover were either circumferential slots or radial openings and in most of the experiments brown paper covered the opening although some experiments were done with weighted hinged covers. As previously mentioned, a few experimental explosions were vented through the axial air outlet at the top of the cyclone.

The plant withstood all the experimental explosions except in one case when using phenolformaldehyde resin and a small radial vent. Severe damage was then caused to the plant. It was difficult to ignite the polypropylene dust except when the circulating fan was running slowly and, therefore, no comparison could be made between this and the other dusts.

The Note contains Tables showing details of the dusts, the explosion pressures in the various experiments and the time taken for the rotary valve at the bottom of the cyclone to stop after the explosion (about 0.5 sec). There are also drawings of the plant, photographs of the vents and graphs of the explosion pressures in relation to the vent type and area. Ciné film was taken of most of the experiments.

As a result of the experiments it was possible to establish the vent sizes and shapes necessary, for the dusts tested, to ensure relatively low explosion pressures. A linear relationship was established between the explosion pressure and the weight of the hinged explosion relief cover. Lower explosion pressures were attained when the vent in the cyclone top cover was near the ducting inlet to the cyclone rather than remote from it. Venting through the axial air outlet resulted in pressures about 2.5 times greater than when venting through the cyclone top cover. When explosions were vented through ducting it was found that pressures increased and when an elbow (up to 45° bend) was included in the duct the pressure increased by about 50% on that account alone.

The pressures in the cyclone and the other parts of the system were much the same and any part of the plant can be subjected to the maximum pressure. It was found that rotary valves could not be relied upon, in all circumstances, to act as explosion checks.

The relationship between the maximum explosion pressure and the vent area will be considered in more detail in a subsequent FR Note but it is suggested that safe venting areas would be 1 ft^2 for 20 ft^3 of cyclone for cork dust and flour and 1 ft^2 for 15 ft^3 for phenolformaldehyde resin. These venting areas should reduce explosion pressures to below 1.0 lbf/in^2 for these three dusts.

Synopsis of FR Note No.943

EXTREME VALUE THEORY AND FIRE RESISTANCE

by

G Ramachandran

Apart from the costs and benefits of providing fire safety, factors which can be evaluated later, it is clearly desirable that building elements should have the minimum fire resistance which is capable of surviving a fire of maximum severity. This is a more efficient basis of building control than one which is related only to the average fire resistance and the average fire severity.

If a building element is assessed on the average fire resistance, the probability of a specimen under test being found less than average would be about 50% and it is questionable whether it is wise to adopt this 50% level of probability for safety measures. The safest approach would be to base decisions on the expected minimum fire resistance. The probability of the actual fire resistance being less than the minimum would be much less than the corresponding probability for the expected average. The average value of the minima in repeated tests is required but in order to reduce, for economic reasons, the number of tests actually carried out, the statistical theory of extreme values can be used to obtain the minima from a small number of samples when the distribution of the results is known.

In order to demonstrate this theory it is necessary to obtain data from a small number of tests which measure the time to failure rather than the ability of the element to survive a required level of fire resistance. For the purpose of illustration in this Note, use is made of the fire resistance times obtained during a series of tests on laminated timber columns reported upon in FR Note No.671.

Fire resistance is measured in time and it is well known that a variable measured in time is likely to have an exponential or a log normal probability distribution. The fire resistance times of the laminated timber columns have been converted into log minutes and the average minimum times for the four different species of wood, irrespective of the glue, load and shape, are shown, together with the common variance, as follows:

Douglas Fir	1.6803 (47.9 minutes)	log minutes with a common variation of 0.0030
Western Hemlock	1.6218	
Red Wood	1.6668	
Western Red Cedar	1.5727 (37.4 minutes)	

If a hypothetical large number of samples is considered then, having determined the standard normal distribution, the extreme value theory can be used to show that the expected minimum, in a sample of 100, of the fire resistance time in log minutes for Douglas Fir is 1.5831 (38.3 minutes) and that the actual fire resistance will be less than this value in only one out of 100 cases.

Once the minimum fire resistance has been established the economist has to measure the expectation of cost and benefit for the acceptable degree of safety and the risk which he is prepared to tolerate.

Synopsis of FR Note No.944

THE RAPID EXTINCTION OF FIRES IN HIGH-RACKED STORAGES

by

P Nash, N W Bridge and R A Young

Warehouse fires in the UK cost about £30M per annum in direct losses only and the introduction of large high-racked warehouses involving several £M in one building alone makes the situation even more serious. In an endeavour to find a solution to the problem some experimental work was carried out by JFRO (see FR Notes Nos.814, 857, 914 and 916), by the Factory Mutual in the US and by Walther & Cie in Germany. Whilst it was found that sprinkler installations erected in accordance with the 29th Edition of the FOC Rules for Automatic Sprinkler Installations effectively controlled fires in high-racked warehouses, there was considerable fire, water and smoke damage before extinguishment and further work was therefore carried out at Cardington in order to find a quicker detection and extinction system.

The main operational requirements of any system were that there should be detection within 2 min, a supply of water to the fire within a further 1 min and extinction within a further 7 min. The system should be safe, it should keep down smoke to a minimum and it should not cost more than 10% of the building and racking expenditure.

Steel racking, having six levels, was erected at one end of the Cardington hangar. It was about 37 ft high, 56 ft long and 14 ft wide and was divided into 144 pallet spaces in two back-to-back rows, each pallet space being 9 ft wide, 7 ft deep and 6 ft high. Half the racking was fitted with sprinklers at each level as described in FR Note No.866 (in order to do experiments comparable with the earlier work) but the other half was modified so that there were 6 zones, each zone being 3 pallet cells in height and the full width of the racking, ie this half of the racking had 3 zones horizontally and 2 zones vertically with 12 pallet spaces in each zone (4 pallet spaces at each level).

A 1 in vertical sprinkler pipe was fitted down the centre of each zone fed by a 2 in horizontal pipe along the longitudinal axis of the racking at the top of the third and sixth levels, ie half way up the racking and along the top. The vertical pipe fed three open conventional sprinklers, these being in the middle of each zone at the top of each level. Valves on the horizontal pipe controlled the supply of water to each vertical group of 3 open sprinklers. Each valve had a frangible disc of nylon (0.55 in thick) with an electrically fired miniature plastic detonator fixed to it. Firing of the detonator blew the nylon disc into small pieces, thus allowing water to flow to the open heads. The nylon 'bits' were washed out with the water.

The detonator was fired by the operation of a line detector which consisted of a pair of steel wires each insulated with a cellulosic layer and twisted together. Further layers of insulation round the twisted wires gave protection against mechanical damage, moisture, etc. The line detector, operated by a 24 volt supply, was fitted around the racking itself so that it could detect any fire in its initial stages. On being heated to 68°C the inner layer of insulation melted so that the two wires sprung together and made electrical contact, thus completing the circuit and firing the detonator. This type of detector has been used, apparently reliably, in the US for about 30 years. A small electric current (insufficient to fire the detonator) can be used to monitor the system and provision can be made for a fire warning light, audible alarm, manned operation and automatic operation of adjoining zone(s).

Seven experiments were carried out using goods ranging from Category 1 to 4 of the Extra High Hazard classification list of the FOC Rules, eg wood wool bales, polyurethane foam blocks, aerosols and foamed polythene reels, in addition to the previously used steel drums in cardboard cartons. The water was supplied at 900 gal/min (4.1 m^3/min) and at 72 lbf/in^2 (5b) although this was reduced to 4b when 2 zones were operated together so as to simulate the normal sprinkler conditions.

Fires were started mainly by igniting the torn edge of a carton near the base, either on the face or in a gap, or by igniting wood wool on the floor. A record was kept of the air temperature and humidity and of the times and other details of the flaming and smoke, together with the extinguishment time. It was found that the maximum flame height was 8 ft, not more than 2 pallet loads were damaged by fire nor, except in one test, were more than 12 pallet loads wetted. Negligible amounts of smoke were produced even with plastics. The average quantity of water used was 630 gal and the maximum duration of any experiment was about 11 min.

After the experiments the maximum time taken to renew the line detector and replace the frangible disc was about 30 min.

The conclusion reached from these experiments was that the system was very effective in controlling fires quickly whatever the class of goods and that there was only a minimum amount of water and smoke damage. The system could be used to trigger off other facilities such as the opening of ventilators or the inflation of smoke stopping devices projecting down into the aisles, although the virtual absence of smoke probably makes this kind of operation unnecessary.

In addition to these main experiments other tests were carried out using 'igniter cord' which burns at 1 ft/sec (in place of the line detector) to operate either the sprinklers or the control valve. The cord would burn up to the sprinkler or valve faster than the fire and it needs no power supply. However, it is not easily monitored. The valve would need modification for operation with the igniter cord and there are humidity problems with this system. Other variations of the line detector are discussed together with a possible alternative form of frangible disc consisting of a glass disc shattered by a piston actuator having a sharppoint. This type of actuator could be removed and tested without having to drain any part of the sprinkler system. This method of valve operation is under active development.

Synopsis of FR Note No.945

FLASH BACK THROUGH CRIMPED RIBBON ARRESTERS

by

Z W Rogowski and S A Ames

Flame arresters both of crimped metal ribbon and metal foam have recently been successfully used to protect lightweight containers functioning in flammable atmospheres. The performance of the former was described in FR Notes Nos.613, 658 and 784, and the latter in FR Note No.931.

Although the arresters may operate efficiently in preventing an explosion in a container passing through to the outside flammable atmosphere, it is possible that the outside gases may be drawn into the container, after the products of combustion have cooled and contracted, where they may burn close to the arrester surface inside the container. Flaming on the surface for any length of time may be rare but it is possible that an arrester might be required to resist such flaming for a specified time. This Note describes tests for evaluating the performance of crimped ribbon arresters in resisting the flashback of this flame to the outside gases.

A commercially available crimped ribbon arrester for test was fitted to the end of a 300 mm long steel tube (35 mm internal diameter) at the other end of which was a protecting arrester and a pipe supplying the gases which were 4.2 per cent propane/air and 6.5 per cent ethylene/air fed at speeds of 24.5, 16.5 and 8.2 cm/sec. The crimp height ie gap between the alternate flat and crimped ribbons, was 1.0 or 0.5 mm.

The gases emerging from the test arrester were ignited on the outside and the combustion, like a bunsen flame, was observed for 60 mins unless flashback occurred earlier. With low flow rates there was no glow on the surface of the arrester but as the flow rate was increased the arrester matrix glowed and eventually, in some tests, there was no visible luminosity but because there was combustion in the matrix a flash back usually followed. Although there was, generally, no visible damage on the outside of the arrester even when flash back occurred there was usually extensive melting and oxidation damage on the inner or upstream side of the arrester. With propane/air mixtures there was no flash back with either crimp height. Using ethylene/air mixtures the arresters failed at the higher rates of flow and failed more quickly when the crimp height was smaller (0.5 mm), although the difference was only marginal.

Before burning in the matrix can occur it is necessary for the arrester to be heated by the outside flame. There is more heat the greater the flow of gas but, on the other hand, the faster the flow the more chance there is that the flame will lift off the outer surface of the arrester thus reducing the heat transfer to the matrix. The maximum velocity of the gas is therefore critical and the factors of scale and method of mounting the arrester may influence the performance. However, the present work gives a broad indication of the relevant tests needed for an assessment of the arrester's performance and it is clear that crimped ribbon arresters of suitable crimp height may safely hold surface flames for a considerable period without any flash back.

Synopsis of FR Note No.946

SOME STATISTICS OF FIRES IN SHOPS AND THEIR APPLICATION TO TOWN CENTRE DEVELOPMENTS

by

M A North and R Baldwin

An attempt is made to assess the fire hazard in shopping malls for which there is, as yet, little practical experience, by studying the statistics available in respect of fires in all shops. There is evidence from the United States that 78 per cent of fires in shopping malls originate within individual shops and, therefore, the UK fire brigade reports for fires in shops during 1967 have been analysed. It is estimated that the number of shops at risk was 505000 in 1967 during which year there were 5580 shop fires attended by the fire brigade and, of these, 79 were large fires (£10,000+).

The Note contains tables showing, as regards these 5580 fires, brief details of the number of large fires and the time of control at different times of the day, the type of shop and the extent of fire spread by age of building, source of ignition, material or fuel involved at inception of fire, rescues and escapes and sprinkler performance (for the 3 years 1967/8/9).

The analysis indicates that, as regards shop fires, there were more fires during the day but that the chance of a fire becoming large during the night was about 3 times as high as during shopping hours. Most of the fires were confined to the room or building of origin but 2 per cent spread beyond that building and this factor is of particular concern with shopping malls where size and difficulty of access may also encourage fire to spread more easily than with individual shops.

It is calculated that with ordinary shop risks there is a chance of one fire in each shop every 90 years and in a 200-shop mall a chance of a fire every year, with a large fire about every 30 years. However the chance of fires and, in particular large fires, is greater with departmental and similar stores and, since shopping arcades are somewhat analogous to these risks, a large fire might occur every 5 years if arcade fires follow that pattern.

The most common sources of fire inception were cooking appliances (deep fat frying), smoking, lighting and accumulation of waste. The analysis emphasises once again the importance of good housekeeping, and the need for automatic fire detection to reduce the delay in discovery.

There were 79 large fires in shops in 1967 and of these only two were said to be in sprinklered premises. Both these fires were controlled by the sprinklers and involved losses of £30,000 and £10,000. The influence of sprinklers was investigated in the light of data disclosed in FR Note No.828 and of other fires in sprinklered premises in 1968/9. It appears that the installation of sprinklers reduces the number of fires attended by the fire brigade by a factor of 2 or 3. The probability of failure of sprinkler systems in shops seems to be between 0.065 and 0.09 which is in line with the failure rate previously calculated from the UK Fire Statistics for other occupancies.

With regard to casualties it appears that, on average, a person in a shop is as safe or safer than one in his home. However, present information refers to individual shops only and when escape has to be made into an arcade or mall the life hazard may be much greater and a high level of fire protection should be demanded.

Synopsis of FR Note No.947

THE PRODUCTION OF FREE DIISOCYANATE FROM THE THERMAL AND THERMAL-OXIDATIVE DECOMPOSITION OF FLEXIBLE POLYURETHANE FOAMS

by

W D Woolley and Ann I Wadley

Both polyester and polyether flexible polyurethane foams are made from TDI (Tolylene diisocyanate) which is known to be a highly toxic material and which, at 0.5 ppm (parts per million) can be a severe irritant or worse. Laboratory experiments were therefore carried out in order to analyse the production of free TDI from the thermal and thermal oxidative decomposition of these commercially available foams at temperatures between 200 and 800°C both in an inert atmosphere (nitrogen) and in air. Although TDI is known to be released as a yellow smoke during decomposition, the experiments were designed to evaluate the production of free TDI both from the foams and from the yellow smoke.

TDI is a difficult material to monitor and it readily combines with substances containing active hydrogen atoms (alcohols, water etc). The experimental procedures were therefore complex and intricate. An all-glass system was used and this consisted of a laboratory furnace (max. temp. 1000°C). A glass tube (20 mm o.d.) which passed through the furnace contained a ceramic 'boat' on which the sample was placed and this was moved along the tube and into the furnace by an external magnet acting on a steel plug fixed to the 'boat'. Dry air or oxygen-free nitrogen was injected into the glass tube and this carried the TDI, produced during decomposition, through a heated collection tube at the far end of the furnace where it bubbled through a beaker containing 1 ml of dry toluene which absorbed the TDI. The decomposition period was about 15 min. Great care had to be exercised during the experiments and the subsequent analyses, using chromatographic and mass spectrometry apparatus, in view of the numerous difficulties in handling TDI. Some tests were done using commercial TDI for calibration in order to verify the validity of the actual experiments when using the foams and polyester yellow smoke (10 mg of foam or 2.5 mg of yellow smoke being the amount of smoke produced from 10 mg of foam). Yellow smoke is produced by heating the foam to 300°C and the release of free TDI in the furnace therefore involved a second heating cycle.

It was found that TDI was released during the decomposition, in the furnace, of both types of foam and that in an inert atmosphere the maximum yield was at about 300°C. In air the maximum yield was at about 300°C for polyester foam and at about 250°C for polyether foam. The decomposition of 1 gram of either foam in 1 m^3 of air would, under the most favourable conditions for the production of TDI, give 1.6 and 1.0 ppm respectively. It appears that high temperatures tend to destroy TDI and when TDI was injected into the furnace it was detected only at temperatures below 800°C in inert atmospheres and below 700°C in air.

It is recommended that realistic fire tests involving TDI-based flexible polyurethane foams be undertaken in order to monitor the concentration of TDI in fire gases under real fire conditions. Further information on the toxic effects of TDI may also be required for a complete appraisal of the problem.

Synopsis of FR Note No.948

THE SURVEY OF FIRES IN BUILDINGS
FIRE SURVEY GROUP 2ND REPORT - INDUSTRIAL FIRES

by

A Silcock, C R Theobald and W N Daxon

The initial work of the Fire Survey Group was described in FR Note No.882 which included brief details of 19 private house fires. The present Note provides an analysis and summary tables of 40 industrial fires all but 5 of which were in the Herts and Bucks Fire Brigade areas. Although no conclusions can be reached from such a relatively small sample of fires the information obtained is sufficient to give some indication of the possibilities of a survey programme of this nature and of the basis upon which the information should be analysed. The main objectives of the programme are to assess the value of Building Regulation requirements, the cost effectiveness of fire protection measures and the importance of various factors which influence the behaviour of fire.

Initially a fire in a building must be confined by some form of walls, floors, ceiling or roof and this confine or enclosure can be referred to as the 'fire environment' which expression includes its size, materials and form of construction, ventilation, nature of the contents and their disposition and other particular circumstances. The main purpose of each fire survey is to study the fire behaviour in the 'fire environment' and to assess the reasons for the spread beyond or containment within that area.

The long term objectives of the programme are to provide basic information for a 'data bank' and also detailed information related to a specific study or studies which might also include verification and design of laboratory experiments. The information included in the various tables is broadly as follows:

Construction and size of building
'Fire environment' size and nature and proportion involved in the fire
Factors which assisted or prevented or might have prevented fire spread
Structural damage and nature of contents, including the fire load
Cause of fire and nature of initial burning
Fire discovery details including delays and civilian fire fighting activities
Fire duration, size and spread or containment

The tables are separated for single and multi-storied buildings with a further breakdown into 'factories' and 'storage' and sprinklered risks.

At the end of the 32 analysis tables there are brief notes on each table which draw attention to the main features revealed by the analysis. A full discussion on the use of the information obtained from the fire surveys will be published in FR Note No.949 but some tentative observations are made in the present Note.

Some of these observations refer to the means of escape and the $\frac{1}{2}$ hour fire resistance requirements of the Building Regulations. Eventually it should be possible to assess the value of the $\frac{1}{2}$ hour standard and its importance in relation to the costs involved. The poor fire resistance of timber floors which allowed fire to spread upwards and downwards did not seriously affect the life hazard nor did the collapse of unprotected structural members of shed buildings. Only one person was trapped (subsequently rescued) in the fires investigated and the means of escape, with this exception, proved adequate although the margin of safety was sometimes small. Regular inspection of escape routes is important.

Both the average building size and the 'fire environment' size were only slightly greater for multi-storied buildings than for sheds; however the average fire size for the former greatly exceeded that for the latter.

The most important factor affecting the fire and smoke resistance of timber doors is the direction of air currents around the edges of the door. Some doors of very inferior construction and fit provided complete protection from very severe fires for considerable periods, eg double swing corridor doors and a 1 in ledged and braced door with 'Norfolk' latch.

Sprinklers were installed in three multi-storied and eight shed buildings and they operated successfully in all incidents except one in which the system was inadequate and inefficient.

It is emphasised that the purpose of the analysis and tables is to demonstrate the nature of the information which can be obtained from the fire surveys and not to provide comprehensive useable data at this stage although it can form the beginnings of a data bank.

Synopsis of FR Note No.949

THE SURVEY OF FIRES IN BUILDINGS - THIRD REPORT
THE USE OF INFORMATION OBTAINED FROM FIRE SURVEYS

by

A Silcock

The initial work of the Fire Research Station's Fire Survey Team was reported upon in FR Notes Nos.882 (houses) and 948 (industrial buildings) and in this present Note the role of these fire surveys in fire research is reviewed in considerable detail, particularly as regards its relevance to national fire problems and its practical application for specific purposes. Although the fire brigade report forms K433 provide basic facts about the general nature and distribution of fires, detailed surveys of as many fires as possible are necessary if the statistics provided by the brigades and other organisations are to be put to practical use.

In addition to the technical information and assessments indicated in the earlier Notes, data is beginning to accumulate in respect of such factors as the behaviour of modern forms of construction, the effect of bad workmanship, smoke movement, the early stages and growth of fire and its spread, the nature of the fire environment, the influence of air currents and the smoke resistance of doors, and the fire resistance of actual structures to fires of varying severity.

Modernization has resulted in many changes in building construction and occupation and it is important to rationalize the fire protection systems to meet these developments. This rationalization calls for the total integration of the major fire protection aspects of means of escape provisions, structural fire protection as controlled by the Building Regulations, and active and passive protection measures. In addition, complete integration should take into account the cost effectiveness. Full consultation at the initial planning stage of any project is essential.

All the information obtained so far from the fire surveys will be recorded on a punched card index and on magnetic tape and this, together with the findings of future surveys, will form a data-bank for later programmes, and further analyses. Reports will be issued as the work proceeds.

Synopsis of FR Note No.950

A METHOD OF EVALUATING HUMAN LIFE FOR ECONOMIC PURPOSES

by

S J Melinek

It is suggested that it is possible to value human life by estimating the risks that an individual is willing to take as well as by taking the economic value to society of an individual's life. Values taken hitherto range from £5,000 to £30,000 and result mainly from work done by the Road Research Laboratory. Methods of assessment can depend on the replacement cost, the loss of gross productivity or the productivity less consumption, or the effect on the gross national product of the reduction in population as a result of deaths. These methods of assessment often give small or even negative values since the community as a whole consumes most of what it produces.

It is, however, relevant to consider the value which an individual attaches to his own life. People probably estimate risks by their own assessment of the dangers, by their knowledge of accidents and by personal experience. Misjudgments of the hazards may, of course, affect their behaviour as will their concern for the safety of others and their acceptance of some risks for pleasure.

The method of life valuation described in this Note aims to measure what the average person is willing to spend on safety measures designed to avoid deaths and to make people feel safer, and the whole problem is discussed in considerable detail. Much of the data necessary is not available but even so examples are tentatively analysed.

Two examples deal with road safety. It is suggested that a motorist is willing to increase the risk of a fatal accident by 3% in order to obtain a 1% saving of time by driving faster. Also it is suggested that pedestrians would be willing to spend 16.5s additional time to use a subway. Assuming that the value put on a unit of time saved is one third of the average wage rate of £1,360 pa the value of life calculated for these two examples is £73,500 and £86,500 respectively but allowing for losses (uncompensated by insurance) due to injury and material damage these values are reduced to £66,000 as the life value from driving speed and £84,000 from the use of subways.

Another example concerns the extra amount which people would be prepared to pay for cigarettes which are safe and this analysis produces a life value of only £26,000 (taking a discount rate of 6%) but this is probably the result of an underestimate of the hazards.

The payment of danger money is also investigated and after allowances have been made for non-fatal accidents the value put on life is calculated at around £65,000.

Future risks can be discounted for various reasons eg future costs can be met by investing a smaller sum beforehand. The Note contains a table showing the discounted earnings and value of life for different age groups assuming a discount rate of 6% and an average value of life of £50,000 which corresponds to an annual value of £3,880. It has been suggested in the US that the value of life is six times the discounted earnings which, in this Note, are estimated as £10,450 so that the total life value would be £62,700 which is in good agreement with the previously mentioned estimates. The tables also show the deaths per annum, in the various age groups, from road accidents and from fires. Deaths from fire occur mainly in the young and the old age groups and fire casualties tend to be poorer than average especially in relation to the motoring casualties. About 7319 people are killed in road accidents each year and 819 die in fires. Taking the average life value for the two classes the total loss per annum as a result of road accident deaths is £332M and deaths from fire £34M.

The results obtained depend very much on the assumptions made, and to obtain more accurate estimates refinement and fuller analysis of the available data would be required.

Synopsis of FR Note No.951

STUDIES OF THE THERMAL DECOMPOSITION OF FLEXIBLE POLYURETHANE FOAMS IN AIR

by

W D Woolley, Ann I Wadley and P Field

Previous work on the thermal decomposition, in an inert atmosphere, of flexible polyurethane foams prepared from TDI (tolylene diisocyanate) indicated that the TDI unit was released, at between 200 and 300°C, as a volatile yellow smoke leaving a polyol residue (see FR Notes 880, 881 and 913). The present report deals with the basic decomposition processes in air atmospheres, particularly those leading to the formation of nitrogen-containing materials such as hydrogen cyanide, acetonitrile, acrylonitrile, pyridine and benzonitrile. These processes were found to be similar to those observed when using nitrogen as the inert atmosphere. A later report will deal with the formation of oxides of carbon and nitrogen during the decomposition of the foams and polyols both in air and inert atmospheres.

The samples used were from typical polyester and polyether foams, both with and without flame retardants, and the yellow smoke samples were prepared from the thermal decomposition of the foams at around 300°C in a stream of nitrogen.

The tube furnace described in the earlier reports was used and the analyses, both qualitative and quantitative, were done by gas chromatography. The foam samples weighed 10 mg and the yellow smoke samples, which were prepared from such samples, weighed 2.5 or 2.4 mg. The samples were placed in the ceramic boat inside the tube before being moved into the furnace which operated at a maximum temperature of 1000°C. During the 15 min decomposition period a stream of air (BOC medical grade) was introduced into the tube of the furnace and this stream carried the products of decomposition to the outlet where they were trapped from the air stream by rapid freezing. The collected products were then quickly heated and fed to the chromatograph for analysis.

The experimental results suggested that the nitrogen-rich material was the same yellow smoke which was observed during the experiments using inert atmospheres. However, the presence of oxygen markedly reduced the stability of the polyether polyol residue although it had little effect on the polyester polyol. The decomposition products, at 300 to 600°C, of the polyols were different from those using inert atmospheres. The yellow smoke decomposed at temperatures above about 600°C to give hydrogen cyanide and small quantities of the other previously mentioned substances.

There appeared to be two distinct decomposition regions above 600°C. Firstly, at 600 to 800°C it was largely oxidative but between 800 and 1000°C it was affected by the vitiation of the atmosphere. The yields of hydrogen cyanide tended to be lower than when an inert atmosphere was used but at around 700°C about 20% of the theoretical maximum nitrogen content was released. Although there was a decrease at about 800°C the production of hydrogen cyanide increased rapidly to about 50% at 1000°C. Above 1000°C the production of this substance may be even higher.

It was apparent that the yellow smoke, whether injected directly into the furnace or formed indirectly from the decomposition of the foams 'in situ' in the furnace, decomposed in air at temperatures above about 600°C.

Synopsis of FR Note No.952

A PRELIMINARY INVESTIGATION INTO THE VISUALIZATION OF GAS LAYERS

by

M Senior

Research into gas explosions involving the use of gases in layers requires information regarding the position and concentration of the gas layers both during the formation of the layers and at the time of the explosion. At present the layer formation is monitored by analysing gas samples obtained from various parts of the gas container but this system does not provide sufficient information regarding the conditions throughout the container since the number of sampling points has to be limited. An alternative method would be to provide a visual means of monitoring the layers and, in this Note, various systems are considered.

If a beam of light is passed through the gases in a gas container there will be various optical effects when the beam passes through the interface between the different gases. Variations will occur in the refractive index when the light beam travels from one gas to another or through the interface area. The resultant effect on the light beam can be viewed or analysed and, consequently, the gas distribution in the container can be ascertained. Not only does a change in the refractive index deflect the light beam but it also alters its velocity and, therefore, any optical system which can measure small time differences or view, by focussing or projecting the light beam on a screen, can be adapted for the purpose required.

In the experimental work described in this Note the test area or gas container consisted of a wooden box 1.28 m long x 0.30 x 0.58 m with perspex windows at each end. Gas inlets were provided in the top and bottom of the box and provision was made for a removeable horizontal false floor to be inserted, when required, so as to divide the box into two sections and thus provide, for a time, a physical separation of the gases. When used, helium was injected into the top and carbon dioxide into the bottom of the box and the displaced air was allowed to leak out at the same rate as the injected gas. The light came from a high intensity mercury discharge point source or a laser and was directed by means of lenses and mirrors through the test area and onto a screen. In some experiments the beam was split into two, one beam going direct to the screen and the other through the test area and this enabled the time differences to be measured.

A comparison of the split beams is known as the interference method and although this is a flexible and sensitive system there are several disadvantages which made it unsuitable for this application. The 'schlieren' method observes the refractive index gradient at the interface and, although less sensitive, is relatively simple and suitable for this investigation. The effect on the light beam is viewed on a screen where the image is focussed. Other optical systems include the shadowgram, deflection through a grid and the holographic method which employs a photosensitive material as a recording medium. Further work on the holographic method is being undertaken. Although the schlieren system was best and produced good results it is not entirely suitable for use in the vicinity of large scale gas explosion rigs. However, the experimental work proved extremely useful in assessing the relative sensitivities of the various methods which were tried.

The Note contains diagrams of the different optical systems together with photographs of the images produced in some of the experiments.

Synopsis of FR Note No.953

THE BEHAVIOUR OF PEOPLE IN FIRES

by

P G Wood

This Note contains a full report on the study made at Loughborough University of Technology of the behaviour of people in fires; this was carried out under a contract from the Fire Research Station. Although all aspects of people's behaviour were considered, particular attention was given to the evacuation of buildings and movement through smoke.

It was decided to study actual fires which occurred during the course of the research and, initially, interview and questionnaire techniques were evaluated. As a result of this evaluation arrangements were made for a questionnaire to be completed by or handled by Fire Brigade Officers at the scene of the fire. The data produced formed the basis of the main study and detailed information was obtained at nearly 1000 fire incidents and from more than 2000 people involved in the fires.

The reactions to a fire mainly concerned evacuation, fire fighting and raising the alarm and, in general terms, most people appeared to behave in an appropriate manner, although some 5% of them reacted in a way which might have increased the risk. There was, however, little evidence of real panic.

People's reactions depended largely on whether they were men or women, whether they had previously been in a fire and whether they were familiar with the building. The older the person the more likely he was to fight the fire and frequent training appeared to improve the chance that the first action would be to raise the alarm. Other reactions regarding evacuation and movement through smoke were very varied and were dependent mainly on the factors mentioned above and on the extent of any smoke. They are all enumerated in detail in the Note.

In addition to the main points of the study comments are also made on other aspects revealed as a result of the questionnaires; for instance, many people considered a fire in the home more serious than one elsewhere. Also, most men first became aware of fire through sight or sound whereas most women also smelt the smoke but did not hear anything. Men were more likely to fight the fire, and women more likely to raise the alarm and evacuate the building.

The Note contains a copy of the questionnaires together with tables and comments, in considerable detail, on the data obtained. Many of the results of the study were to be anticipated but some were unexpected, for instance, it was revealed that some people prefer to return to a burning building to investigate rather than stand around in safety doing nothing. This is an aspect which appears to require urgent investigation. It is also suggested that more intensive studies are called for on why people do one thing rather than another and what are their attitudes, knowledge and beliefs concerning fire.

Synopsis of FR Note 954

FIRE PROBLEMS OF PEDESTRIAN PRECINCTS. PART 2
LARGE-SCALE EXPERIMENTS WITH A SHAFT VENT

by

A J M Heselden, H G H Wraight and P R Watts

The fire and smoke problems of pedestrian precincts were initially discussed in FR Notes Nos.806, 807, 832 and 875 and a description of the experimental arcade built at the Fire Research Station was provided in FR Note No.856. Since then further experimental fire tests have been carried out in order to investigate the smoke venting problems and in the present Note the results of 14 tests with natural venting are shown together with the conclusions to be drawn from these.

Experimental fires were lit at the rear of the fire chamber, a brick built ground level compartment to one side of the closed end of the arcade (representing a shop) with an opening onto the mall 3 m wide and 2.2 m high. The fires were of 0.6, 1.1 and 3.2 MW and consisted of kerosene in trays 0.58 m^2 or 1.65 m^2 or a wood crib 0.6 x 1.8 m^2.

A vertical venting shaft having a cross section area of 2.4 m x 0.6 m was fitted in the ceiling of the arcade about a fourth of the way from the compartment opening to the open end of the arcade and to the side of the arcade away from the compartment (ie about one width of the arcade from the fire chamber opening). The shaft extended upwards for 4.8 m and could be opened or closed. For most of the tests a vertical hardboard screen or curtain extending across the full width of the arcade was erected 3.2 m from the open end of the arcade (ie about two-thirds of the distance from the vent to the open end). This screen extended 0.9 m down from the ceiling. In addition to these constructions a 'fascia board' was erected across the upper part of the fire compartment opening for two tests and this consisted of a 3 m wide asbestos wood sheet 0.9 m deep.

Various thermocouples, heat flux meters, radiometers, smoke meters and anemometers were installed for recording, via data-logging equipment, all the numerous measurements required and readings were also taken of the CO_2 concentrations which, in practice, provided a reliable means for measuring the gas flow and air mixing. The Note contains drawings of the experimental building, and tables and graphs of the test results together with two photographs of the arcade.

It was found that the most serious problem concerned the entrainment of air into the smoke layer and, therefore, the mixing and cooling of the gas and smoke layers. The mixing occurred mainly as the gases passed into the mall from the fire compartment and this was particularly noticeable when there was a deep fascia board. The mixing continued as the gases passed along the mall and at their entry into the venting shaft where about one-third of the gas flowing up the shaft was air. The mixing along the mall probably only persisted for a distance equal to 2 or 3 widths of the mall. The mixing at the entry to the vent could probably be cured by better design of the vent inlet or by replacing the one large vent by a number of smaller vents. This problem will be explored further, in particular with a small scale model. A distributed vent system might produce a calmer smoke layer and less entrainment of air. The temperature of the smoke-laden gases fell as they flowed along the mall partly because of the mixing with cool air and partly because of heat losses and, clearly, larger vent areas are needed than when dealing with fires in simple single-storeyed buildings. In fact they may have to be 4 to 5 times as large, ie 3.75 m^2 compared with 0.8 m^2.

The action of the vent was much improved by the presence of the screen beyond the vent but the screen alone, without the vent, did not prevent smoke travel beyond the screen. The results of the experiments clearly showed that the presence of a screen would make a vent very much more effective in arresting or retarding smoke flow along a long mall. A screen without a vent depressed the bottom of the smoke layer by an amount as large as the depth of the screen itself.

The fascia board to the fire compartment opening did not slow down the passage of smoke into the mall but, clearly, it would help to prevent entry of smoke from a mall into other compartments or shops.

Synopsis of FR Note No.955

FIRE TESTS ON AN AIR-SUPPORTED STRUCTURE

by

J S Hopkinson

Air inflated structures, invented in 1917, were used to protect radar antennae during the 1950s but, more recently, have been developed as coverings for sporting activities, exhibitions, and for temporary warehouses. As a result of this development there has been some concern regarding the life hazard and the safety of property within the structure.

A series of tests was therefore arranged at the Fire Research Station to investigate the fire and smoke problems. For this purpose a Swedish structure made of nylon (matrix) fabric coated on both sides with PVC and 19 m long, 9 m wide, and 4 m high (at apex) was erected on a layer of sand on open ground. The structure, which was specially made this size for the tests, had a volume of about 480 m^3 and was erected with its major axis approximately east-west and with an air-lock having two 1.9 m high doors opening outwards at the east end. Air was pumped into the structure by a 0.75 kw electric fan blowing air along a 3 m long sleeve (0.53 m in diameter) of the same material. In practice a diesel operated fan would be needed as a 'standby'. The fabric was anchored around the perimeter by placing water bags and sand in the fabric trough provided around the edge of the structure. A more permanent structure would be secured to concrete foundations. The internal pressure was in the range 12–15 mm wg above atmospheric pressure.

Laboratory tests were carried out on the fabric and these showed it to be 'not easily ignitable' and 'inherently flameproof', and the Fire Propagation Index was 17.83 with an initial i_I of 11.01 indicating that the heat content was released in the early stages.

Removeable panels, 1 m square, were provided, one at the apex and the other 0.5 m off the ground, in order to study the effect of high and low openings. Both hot and cool smoke tests were carried out using smouldering wood and fibreboard for the cool smoke and a tray of petrol for the hot smoke. There were also three fire tests, one using a wood crib of 27 kg near a side wall, another, a crib of 48 kg placed centrally 1.2 m off the ground and, the last, a crib of 630 kg with 25 car tyres at each end of the crib, in addition, placed along the major axis and on the ground.

Numerous readings were taken of the internal pressures, smoke densities, air temperatures and times of collapse and these are shown in table and graph form in the Note. There is also a drawing showing the position of the instruments and an appendix giving detailed observations of each of the 7 smoke and 3 fire tests.

It was found that cool smoke diffused over the whole volume without being influenced by the inflow of air from the fan but hot smoke rose and formed a stratified layer which eventually dropped, thus causing a serious reduction in visibility. Any vent allowed air and with it, smoke, to escape and the quantity depended on the opening area. Escape of air through small apertures, up to a limited size, could be counter-balanced by air pumped in by the fan. Opening the air-lock doors caused smoke to escape that way and there was reduced visibility at the doors down to eye level. The smoke level was, of course, lowered as the structure collapsed. The supporting structure of the air-lock allowed the exit to remain usable for longer than would have been possible if it had collapsed with the main structure.

Once there was a large opening the structure collapsed quickly although the buoyancy from hot gases of a fire appeared to treble the collapse time, unless the aperture was excessively large.

There was no tendency for flames to spread along the underside of the fabric during the fire tests. However, once a hole formed as a result of heat from the flames it increased in area but flames passing through the hole drew cool air with them past the edges of the hole which then set hard and did not tear.

Small fires might be extinguished from inside the structure but any openings necessary for access would help to deflate the structure as would a large fire, and then the fire fighting could best be done from outside. Once the fabric has collapsed onto the ground, with the burning contents protruding, the fire is easily fought but it might be more difficult if unburnt fabric remained over any of the contents.

Escape times depend on the size of any aperture but if collapse is slow, occupants can move around freely even if there is a small fire. However, escape time can be very short if the fire is large and it may be necessary to provide some additional means for supporting the fabric structure.

It is suggested that similar tests should be carried out on a larger structure because size may be an important factor, and the design of any supplementary support should be investigated. Further, the use of escape doors with air curtains needs to be investigated.

Synopsis of FR Note No.956

LARGE FIRES DURING 1971

by

G Ramachandran, Cristine Eveleigh and Eileen Hudson

Reference should be made to the Synopsis of FR Note No.891 for the corresponding information regarding the 1970 large fires.

During 1971 there were 1252 large fires (£10,000 or more) in the UK causing direct damage amounting to £81.9M (63.6 per cent of the total fire wastage of £128.7M). The average loss per large fire was £65,400.

Out of the 1252 large fires, 51 started in outdoor hazards and although there was a reduction in the average loss for these fires the losses were, on average, higher than those for fires which started in buildings. There were 4 oil refinery losses costing in all, £1¾M.

The Note contains tables showing the occupancy or hazard involved, the source of ignition and place of origin, extent of spread and number of jets used, date of construction, time of call, control time and the month and day of week. Brief details are also shown of the 278 non-fatal and 37 fatal casualties in the large fires.

A table, similar to that included for previous years, showing the behaviour of the protection devices may be of interest and is shown below:

BEHAVIOUR OF FIRE PROTECTION DEVICES IN LARGE FIRES

Fire protection devices installed		No. of fires	Total direct loss (£000)	Average direct loss per fire (£000)
	TOTAL	1252	81921	65.4
Detectors	(operated (did not operate	11 6	550 366	50.0 61.0
CO_2, steam	(operated (did not operate	7 -	291 -	41.6 -
Roof vents	(operated (did not operate	1 -	13 -	13.0 -
Fire doors	(operated (did not operate	3 2	711 45	237.0 22.5
Others	(operated (did not operate	5 2	547 121	109.4 60.5
Any combination of above	(operated (did not operate	3 -	1097 -	365.7 -
Dry and/or wet riser	(operated (did not operate	52 15	5196 1744	99.9 116.3
Dry and/or wet riser with other devices (except sprinklers)	(operated (did not operate	7 1	4901 350	700.1 350.0
Sprinklers	(operated (did not operate	64 21	7499 5550	117.2 264.3
Not installed, unknown or not applicable (including 3 sprinkler systems - action not stated)		1052	52940	50.3

With regard to the behaviour of the 85 sprinklered risks, 21 did not operate mainly because the system was shut down (12 cases) and the average loss per fire was £264,300. Out of the 64 cases where the sprinklers operated 10 failed to control the fire for various reasons and the average loss was £519,500, but of the 54 cases where the sprinklers either controlled or extinguished the fire the average loss was only £42,700. In two cases where the sprinklers failed to control the fire the total loss was £4M as a result of insufficient water pressure.

Synopsis of FR Note No.957

THE PERFORMANCE OF SOME PORTABLE GAS DETECTORS WITH AVIATION FUEL VAPOURS AT ELEVATED TEMPERATURES
PART 2 TESTS WITH 'AVCAT', 'KERO B' AND 'AVTUR' VAPOURS

by

P J Fardell

Tests on five portable gas detectors or 'explosimeters' using 'Avtag', 'Civgas' and n-hexane vapours in air, were described in FR Note No.938 and in the present Note there is a description of further similar tests, with four of the detectors, whilst using 'Avcat', 'Avtur', (aviation turbine fuels) and 'Kero B' (kerozine). In the earlier tests there was only moderate humidity and, at the lower explosion limit (LEL), there was no evidence of the vapour condensing out, but with the later tests, still with only moderate humidity, some of the vapour condensed out at 65°C and allowance was made for this condensate which was collected in a glass tube and measured. Apart from the modification required to collect the condensed vapour, the apparatus used was similar to that described in the earlier Note.

The results of the recent tests showed, as did those found earlier, a response markedly lower than the true value. However, it should be possible to find a particular vapour which, when used to calibrate the detectors, will ensure a correct or even a high reading (to be on the safe side) and this matter is being investigated.

The LEL concentrations determined for the fuels so far tested are as follows:

Fuel	LEL at 65°C (% by mass)
n-hexane	3.56 (at 25°C)
Civgas	3.41
Avtag	3.49
Avcat	4.01
Avtur	3.74
Kero B	3.75

Synopsis of FR Note No.958

PRESSURISATION OF ESCAPE ROUTES IN BUILDINGS

by

P J Hobson and L J Stewart

This Note contains a detailed and comprehensive report made, under a research contract, by the Heating and Ventilating Research Association under the supervision of the Fire Research Station on the problems of and the design requirements for a mechanical air distribution system for keeping escape routes in buildings clear of smoke and toxic gases. Such mechanical ventilation is known as a 'pressurisation system' since higher pressures are required in the escape routes than in the surrounding areas so that any smoke and gas flow is away from the escape routes. The need for such a system has been brought about mainly by the rapid increase in the number of high rise buildings.

The problems investigated and reported upon include the air pressures acting on and in buildings, the influence of normal mechanised ventilation plant, air leakage characteristics of buildings, and the requirements for and reliability of a pressurisation system. A computer program was used for the study of the wind, stack, fire and ventilation (or air conditioning) effects. Available data on air flow around doors and windows, and through masonry were studied in relation to the leakage effect.

The stack or chimney effect is caused by the column of air in a building being at a different temperature from that of the outside air at the same level. A fire in a building can also affect the air movement and so can the wind which may produce a suction on all external areas except the windward face of the building.

All the information on the problems of pressurisation and smoke control available from the United Kingdom, USA, Canada, Australia, Japan and France is summarised in the Note. Existing buildings containing pressurisation systems such as the Pearl Assurance House, Cardiff and Royal Courts of Justice, London were examined and commented upon. A number of tests were carried out on sites and these are critically described.

It is suggested that a pressure of 25–50 N/m^2 (0.1–0.2 in wg) is necessary to keep an escape staircase clear of smoke under all conditions and to override the effects of a fire and weather conditions. The higher pressure would be required for buildings of 50 m or more in height or on exposed sites.

During the course of this investigation it was found that some problems were more complex than envisaged and new problems arose. Pressure systems require 'barriers' or closed doors but these must be opened for escape, especially the doors at ground level, and the influence of such openings on the wind and stack effect and pressurisation needs further research. A well-sealed building might be adequately pressurised by the normal air conditioning or ventilating system if this was properly protected and reliable. However, sufficient and suitable venting would be required for the removal of smoke and gases and this matter needs detailed consideration. Further, this report deals basically with the wind and stack effects on buildings of simple shape and further research would be necessary when dealing with unusually shaped buildings.

The Note contains a number of photographs, together with building plans, diagrams and illustrations.

Synopsis of FR Note No.959

PRELIMINARY EXPERIMENTS ON THE USE OF WATER ADDITIVES FOR FRICTION REDUCTION IN FIRE HOSE

by

P F Thorne and K Jordan

Frictional drag during the flow of water through a fire hose reduces efficiency and in this Note the authors investigate the problem, a solution to which was first suggested in 1948 by B A Toms who discovered that soluble long chain high molecular weight polymers such as polyethylene oxide (PEO) added to the water flow did reduce the friction and produced what has been called 'slippery water'.

A thorough investigation is made of the available technical literature having a bearing on the problem. Pressure losses in pipes, both smooth and rough due to friction and the boundary layer structure of the fluid in contact with the internal surface of the pipes are considered in some detail, including the 'form drag' which results from eddy currents caused by the impact of the fluid on protrusions on the pipe's internal surface. The salient features of drag reduction resulting from the introduction of additives are outlined.

Experiments were carried out using a 75.3 m (247 ft) length of 70 mm non-percolating fire hose and a 16.5 m (54 ft) length of 19 mm hose from a hose reel. A solution of PEO (trade name Polyox WSR 301) was added to the water flow at a collecting breech (Y junction) near the hydrant valve. The solution was fed into the water flow through a perforated copper tube of $\frac{1}{4}$ in dia fitted concentrically in the fire hose at the Y junction.

Numerous tests with different concentrations of PEO were carried out and the pressure drops (from one end to the other of the test length of hose) and the flow rates (Reynolds number) were recorded. The average concentration of PEO in water was 23 ppm for the 70 mm hose and 33 ppm for the 19 mm hose. Results are shown in table and graph form in the Note. Some experiments were made using a transportable fire pump, instead of the hydrant, to pump a premixed solution of PEO in water through the 70 mm hose. The PEO was, therefore, passed through the pump and not into the hose after the pump.

As a result of these experiments it was found that the friction factors were reduced by about 50 per cent by the addition of PEO to the water but that if the dilute solution (ie including PEO) was passed through the fire pump the friction-reducing phenomenon was destroyed. It was also noticed that the presence of PEO in the water enhanced the coherence of the water jet possibly contributing to an increased 'throw'.

It is suggested that further investigation is required in regard to the friction factors beyond the range of flow conditions so far encountered. Further tests with 19 mm hose and with other types of hose are required, together with more research on the method of introducing the PEO into the hose both in experiments and on the fire ground. The effect of PEO on jets, sprays and fogs from hoses and on the flow through longer lengths of hose also needs further investigation together with the possible use of alternative friction reducing additives.

Synopsis of FR Note No.961

DUST EXPLOSION VENTING - CONSIDERATION OF FURTHER DATA

by

K N Palmer

In the previous FR Note No.830 two scientific equations were derived for the purpose of relating the explosion pressure to the vent ratio (ie area of vent/volume of vessel) and the maximum explosion pressure and maximum rate of pressure rise of a dust explosion in a standard apparatus. One equation dealt with relatively low and the other with relatively high pressures. The former is more applicable to most dust handling plants of sheet metal construction where pressures should not normally exceed 2 lb/in^2 (15 kN/m^2). Certain assumptions had to be made at that time since there was insufficient experimental data available but now further data has come to hand and the problem is again reviewed in the light of the additional evidence. In FR Note No.942 dust explosions in a large scale cyclone plant were described and it was then stated that the relationship between the maximum explosion pressures and the vent area would be considered later in more detail.

In this report the equations (1) and (2) are considered in relation to explosion pressures in ducting attached to relief vents, in cyclone plants and to the pressures resulting from tests in large compact vessels of 1 m^3 and 30 m^3 which were strong enough to withstand the full explosion pressure without relief venting. These latter pressures could reach 100 lb/in^2 (700 kN/m^2).

The force of an explosion depends mainly on whether there is simultaneous burning of the dust throughout the whole volume of the vessel involved or whether, due to the size of the vessel or the dispersal of the dust, the burning is limited or restricted in any way. For instance, if a venting duct from a vessel is much smaller in volume than the vessel the explosive pressure in the duct could be severe since there might be sufficient burning suspension in the vessel to fill the ducting. On the other hand the dispersal of dust in a cyclone can be such that the dust is mainly concentrated around the wall of the cyclone and not throughout its whole volume so that a relatively small explosive force would result. In a large vessel the burning of the dust may be restricted to a smaller proportion of the whole volume than in a smaller vessel but the presence of a vent in either vessel could affect the nature of the burning.

The whole problem is discussed in some detail in the Note and the experimental data are compared with the theoretical answers provided by equations (1) and (2) and any differences or variations are explained or the reasons for them suggested. There are a number of graphs showing the comparison between the practical and the theoretical results.

The explosion pressures in vent ducting have been related to the dust parameters, or characteristics, and they are shown to vary as the square of the ducting length ie extending a duct, venting a cork dust explosion in a vessel, by 10 ft could increase the explosive pressure in the vessel being vented by about 1 lb/in^2 whereas a 20 ft length would increase it by about 4 lb/in^2. The design of a duct is very important.

Data from the cyclone experiments showed that the explosion pressures were considerably lower than they would have been had the whole cyclone been filled with a homogeneous suspension and an approximate method of calculating the reduction from the equation (1) situation has been derived. When the cyclone explosion was vented through the air outlet and not through a vent in the cyclone top cover the pressure was higher since there was more dispersal of dust in the cyclone before it could be relieved through the centrally placed vortex pipe.

Explosion pressures in relatively large vessels with small vents were calculated from the original equation (2) with modifications to cover the observed reduced rate of pressure rise in these vessels. The maximum rate of pressure rise is inversely proportional to the cube root of the vessel's volume. Further, a method of extrapolation was proposed for relating the maximum rate of pressure rise in the small scale standard closed vessel test apparatus and in much larger vessels.

There is still a serious shortage of experimental data for dust explosion venting and this must be remedied if confirmation is to be obtained of the assumptions which still have to be made.

Synopsis of FR Note No.962

ANALYSIS OF A QUESTIONNAIRE ON ATTITUDES

by

S J Melinek, Sara K D Woolley and R Baldwin

A questionnaire regarding 'attitudes to risk' and designed to help in establishing a rational basis for expenditure on safety measures was distributed during Open Days at the Fire Research Station in 1972 and was completed by 873 people out of a total attendance of about 6000. The form contained seven questions, with some sub-sections, and asked for the person's impressions, rather than his knowledge of any statistics. He was asked the proportion of fires caused by carelessness as against unforeseeable accident, whether more frequent fatal fires or more deaths in one fire were more shocking and how many fatal fires resulted in more than one death. Further, was being in a house on fire more risky than a car drive, a scheduled flight or crossing the road and which of these activities was more likely to be fatal. Also, he was asked to say how much he would spend on safety measures in the home and how much extra he would pay for a cigarette which was safe to health.

The results of the questionnaire's analysis showed that this type of survey is feasible although great care is necessary in drafting the questions if they are not to be misunderstood. The following tentative conclusions were drawn from the answers given by this fairly small and biased sample of the population.

More people think fires are caused by carelessness than by unforeseeable accident and, therefore, increased expenditure on fire safety might be acceptable. A high level of concern is caused both by infrequent fires causing many deaths and frequent fires resulting in only one death. The risk of injury appears to be more important than the chance of death except, perhaps, in the case of crossing the road. People cannot accurately estimate risks in numerical terms although they can rank them reasonably accurately in most cases. The fire hazard in a home on fire, for instance, is underestimated by many people.

Taking the calculated value of the risks and the perceived value of reducing or eliminating the risk it was found that the average implied values of life were £17000 for cigarette smoking and £55000 for expenditure in the home.

Synopsis of FR Note No. 963

PASSIVE AND ACTIVE PROTECTION - THE OPTIMUM COMBINATION

by

R Baldwin and P H Thomas

This Note contains formulae and graphical indications of the principles of and the methods which can be used to determine the cost effectiveness of active and passive fire protection measures. Active fire protection such as sprinklers and alarm systems can fail and so can passive structural measures taken to protect a building and prevent fire spread. Extra costs can be incurred to duplicate or improve active fire protection systems or strengthen passive measures and if these are less expensive than the losses which are saved thereby then the additional expenditure may be justified. It is assumed, for this investigation, that if active measures operate successfully then it is possible that no structural damage will be suffered, in which event any passive measures of fire resistance will be of no value in that instance. On the other hand, in some cases the saving in losses as a result of taking passive measures may be sufficiently substantial to make active measures unnecessary. In other cases, however, both active and passive measures will be required.

For the purposes of the formulae, the various probabilities are defined as follows:

- P is taken as the probability of a fire occurring per building per year and the other probabilities are:
- P_0 of a fire becoming large enough to damage the structure when active protection is either not installed or fails
- P_1 similar to P_0 but active protection is installed and operates (this is taken as zero ie no structural damage)
- P_2 of failure of active protection given that a fire occurs
- P_3 of failure of passive protection given that a fire becomes sufficiently large to damage the structure.

The estimated damage or loss of usefulness is shown as D_1, D_2, D_3 and D_4 according to whether the active measures operate and the passive measures also operate or fail, or the active measures fail and the passive measures again operate or fail.

The expected losses, E, can be reduced if the probabilities of failure ie P_2 and P_3 are reduced by, for example, increasing the fire resistance or duplicating the active systems at an additional cost of C_A for active systems or C_P for passive measures where $C_A = - C_2 \log P_2$ and $C_P = - C_3 \log P_3$ (C_2 and C_3 being constants).

As an indication of the solutions proposed it is suggested that for active systems the optimum occurs when -

$$P_2 = \frac{C_2}{P(D_3 - D_1) + PP_0(D_4 - D_3)}$$

and for passive systems when -

$$P_3 = \frac{C_3}{PP_0 (D_4 - D_3)}$$

It should be noted that if a particular system cannot be justified in isolation then it cannot be used in combination with the other and if neither system can be justified in isolation then neither can any combination. Where both systems can be justified it does not follow automatically that a combination is best in all cases.

Before these criteria can be put to practical use in assessing the 'trade-off' of fire resistance as against sprinklers or detectors it will be necessary to undertake further analysis of the costs of sprinklers and detectors and of fire resistance. The important factor, however, is the cost of reducing the probability of failure and although some work has been done on this problem in relation to structural protection there is little information yet regarding active protection.

Synopsis of FR Note No.965

ON THE RATE OF BURNING OF CRIBS

by

P H Thomas

Wood cribs provide a convenient source of heat in experimental and standard test fires although, if the sticks are too close together, they may not accurately represent any other kind of fire. The rate of burning of crib fires is an important factor when comparing experimental fires with real fires and, in this Note, the problem is reviewed and discussed in some detail as a result of a major advance in the understanding of the theory of crib fires propounded by J A Block at a Symposium in the USA during 1971.

One of the main points of Block's theory is the consideration and estimation of the burning up the vertical passages or shafts of a crib. These passages form vertical parallel ducts where there is buoyancy and friction or drag.

However, previous statistical correlations of data for cribs not in enclosures obtained at the Fire Research Station show discrepancies from Block's theory. These discrepancies are removed to some extent by this further detailed study and on the basis of this latest work it is hoped to understand better certain aspects of the behaviour of cribs in enclosures.

Synopsis of FR Note No.966

THE PRODUCTION OF OXIDES OF CARBON FROM THE THERMAL AND THERMAL-OXIDATIVE DECOMPOSITION OF FLEXIBLE POLYURETHANE FOAMS

by

W D Woolley and Ann I Wadley

As predicted in FR Note No.951 further experiments were carried out using the laboratory tube furnace and gas chromatograph, in order to investigate the production of oxides of carbon from the thermal and thermal-oxidative decomposition of TDI based polyester and polyether flexible polyurethane foam, the parent polyol and the yellow smoke at temperatures between 200 and 1000°C. Once again the experiments were conducted both in a flow of nitrogen (inert atmosphere for the thermal decomposition) and in air (for the thermal-oxidative decomposition) for 15 minute intervals.

The decomposition gases were collected over the 15 minute period in an evacuated plastic bag from which samples were removed by syringe for analysis. In each experiment the samples, as before, weighed 10 mg or the equivalent weight of polyol and yellow smoke, the latter being prepared from the decomposition of polyester foam in nitrogen which was found to be similar to that produced from polyether foam.

The Note contains tables showing the maximum yields of CO and CO_2 at 1000°C, both in the inert atmosphere and in air, and the proportion of the original constituents of the material which were recovered as carbon and oxygen. The yields in relation to temperature are also shown in graph form.

It was found that CO was an important product of the decomposition in an inert atmosphere of both foams at temperatures above 500°C. At 1000°C 1 gram of the polyester foam released 260 mg of CO and 145 mg of CO_2 and 1 gram of the polyether foam released 404 mg of CO and 42 mg of CO_2. At this temperature virtually the entire oxygen content of each foam was released as oxides of carbon.

As a result of the decomposition in air the maximum release of CO occurred at 600°C when 1 gram of polyester foam released 295 mg of CO and 1 gram of polyether foam released 440 mg. At 1000°C the yields of CO_2 were 960 and 715 mg respectively for the two foams. It was found that the main oxidation occurred at between 600 and 700°C and that at higher temperatures the atmosphere was vitiated as a result of the rapid release of volatiles from the foams which restricted the access of air to the material and this, coupled with a rapid uptake of oxygen by the sample, caused some reversion to pyrolytic decomposition.

In the light of the data from the present work it now appears that the decomposition of the yellow smoke to produce hydrogen cyanide is 'catalysed' by oxygen and this is the reason for the reduced yields of cyanide over about 700°C although the cyanide yields rise again over 900°C when 'inert' conditions have an influence.

Synopsis of FR Note No.967

PRELIMINARY ANALYSIS OF FIRE REPORTS FROM FIRE BRIGADES IN THE UNITED KINGDOM 1972

by

S E Chandler

A first analysis of the fire brigades' K 433 (and K 433H) report forms indicates that the brigades attended 290 343 fires in the UK during 1972 (253 535 in 1971) and estimates supplied by the British Insurance Association show the total direct monetary loss at £141.2M (£128.7M in 1971) which includes damage caused by civil disturbances in Northern Ireland.

Fatal casualties number 952 (782 in 1971) and non-fatal casualties 5963 (4883 in 1971). The deaths were the highest ever recorded. The most serious incident was at a mental hospital in which 30 male patients died and 12 firemen were killed during the year (7 in one fire).

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 26 February 1973 and is subject to revision when outstanding reports are received.

Synopsis of FR Note No.968

A NEW RADIOMETER FOR MONITORING FIRE EXTINCTION EXPERIMENTS

by

D M Tucker

The flame radiation from liquid fuel fire tests eg under Defence Standard 42-3, 1969, is normally monitored by four conventional thermocouple type radiometers which are not simple to manufacture, have to be placed close to the fire and involve the use of extensive wiring which can affect the readings. The radiometers are used mainly to determine the time to 'control' the fire and this is assumed to be when the heat radiation is one tenth of the mean radiation during the last 5 seconds of the free burning period before extinction is attempted.

A new improved type of radiometer is described in this Note which also includes test results of a prototype and a comparison with the conventional radiometer when monitoring 3 ft^2 (0.28 m^2) and 875 ft^2 (81 m^2) kerosine fires extinguished with foam. The new radiometer monitors the radiation by means of a photocell which gives an amplified output proportional to the radiant intensity. The photocell, amplifier and batteries are contained in a metal box about $4\frac{1}{2}$" x $2\frac{1}{2}$" x $1\frac{1}{2}$". Although batteries are provided an external power supply can be used. The other main features of the radiometer are that it is sensitive enough to be placed at a distance from the fire, it is also sensitive only to radiation typical of hydrocarbon diffusion flames, it has a fast response and is simple to produce and use.

The basic design of the radiometer allows great flexibility in performance and the field of view can be altered by using suitable shielding. It is more reliable in use than the conventional radiometer. Although it was designed to give relative measurements only it can be used for absolute measurements if it is calibrated, and it can certainly be used advantageously in place of the conventional system to measure the control times on both small and large fires.

Synopsis of FR Note No.970

FOAM BRANCHPIPE DESIGN

by

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

The quality of fire fighting foam liquid is assessed on the Defence Standard 42-3 test which has involved the use of a No.2 branchpipe (227 l/min or 50 gal/min) for the foam production. This branchpipe is no longer made and, in any case, it is difficult to manufacture precisely and this and other features of its use have led to poor reproducibility in tests. A replacement branchpipe is required and this should be simple to produce accurately and it should produce good foam both for the Standard test and for use on laboratory size fires.

A very thorough investigation has been carried out into the whole problem of branchpipe production of foam and this has involved a large number of experiments using models, mainly of perspex so that the foam formation could be observed, which have gradually progressed from the simplest form to the latest acceptable pattern, there being about seven variations in basic form in all, each involving tests with various types of foam liquid. Approximately 750 measurements were made but, even so, corners had to be cut since there would be thousands of variable combinations. The only practical approach was to endeavour to establish the principles of branchpipe behaviour. The gradual evolution of the model branchpipe is fully described in the Note with drawings and with tables and graphs of the numerous tests carried out. These tests involved expansion, shear stress and drainage time measurements for the different foam liquids (protein, fluoroprotein, synthetic and light water) at each stage of the development. The design of a branchpipe is very complicated because a slight change in one part of it can have repercussions on other parts and the effects can vary according to the foam liquid used.

The models were attached horizontally to the top of a 9 l (2 gal) extinguisher containing the premixed solution (usually 4%) and pressurised to 100 lb/in^2 (690 kPa) for most of the tests. A brass model made to the final design is fully described, with engineering drawings, in FR Note No.971.

Briefly, the model finally decided upon consists of a brass tube about 400 mm long and mainly 19 mm in diameter. The first part, about 20 mm long, is the turbulence chamber having an upstream orifice plate 3.2 mm thick with a central hole of 3.0 mm dia and a downstream orifice plate (also 3.2 mm thick) with a central hole of 2.2 mm dia. The next part, also about 20 mm long, is the air induction chamber having four air inlet holes of 6 mm dia at right angles to each other. After this part the internal diameter of the tube is gradually reduced to 6.35 mm dia to form a venturi tube at the end of which the tube immediately opens out to the full diameter again to form the foam making chamber which is about 200 mm long containing two semi-circular baffle plates, fixed at 180° to each other, near the downstream end. The tube is then reduced to 12.7 mm internal diameter to form an outlet restriction about 70 mm long.

The main principles of the branchpipe are that the foam making chamber should be full (or flooded) and that no back pressure should develop. The minimum outlet restriction is required, consistent with a good throw and stability of the foam jet. The model branchpipe produces a good coherent rope of foam with acceptable expansion, shear stress and drainage time except for one liquid (Protein C) which does not foam readily. The remedy for such a foam is to increase the concentration from the 4% mixture to, say, 6%. The best foam is produced in this branchpipe when the flow rate is 5 l/min (1.1 gal/min) at 100 lb/in^2 (690 kPa) pressure.

It is concluded that this model branchpipe is suitable for use at laboratories for the Standard test. Matters which may merit further study include the design of the converging section of the venturi and the construction of larger branchpipes based on the principles established.

Synopsis of FR Note No.971

A 5 LITRE PER MINUTE STANDARD FOAM BRANCHPIPE

by

S P Benson, D J Griffiths and J G Corrie

Fire fighting protein foam properties are determined in a laboratory test which involves measuring the foam expansion, the shear stress (N/m^2) and the 25% drainage time (min) and some of the problems of reproducibility encountered and the possible solutions are discussed in FR Note No.972 which, however, is mainly concerned with the method of calculating the 25% drainage time.

The production of the foam itself is also important and in this Note there are detailed engineering drawings and photographs of a new type branchpipe the use of which should enable standard foam to be produced in any laboratory. The branchpipe can be fitted to a 10 litre stainless steel container pressurised from an air supply line to 100 lb/in^2 (690 kPa) and containing the correct premixed foam solution. The discharge rate should be 5 l/min and there must be the necessary valves and cocks for controlling the operation.

A straight outlet from the branchpipe can be used for fire testing but a swan-neck outlet is required for filling the sample pan without splashing.

The shear stress is measured by using a torsional vane viscometer on a sample pot of foam.

The Note contains appendices giving full details of the test procedures and a typical test record. The expansion, drainage rate, and shear stress are all dependent upon the temperature and this is a matter which is being investigated in some detail and will be reported upon in a subsequent FR Note.

Synopsis of FR Note No.972

AN IMPROVED METHOD FOR MEASURING THE DRAINAGE RATE OF FIRE-FIGHTING FOAMS

by

Miss S P Benson, K Morris and J G Corrie

In assessing the performance of fire extinguishing foam it is necessary, under the UK Defence Standard 42-3 Issue 1 24 Jan 1969, to measure the 25% drainage time, ie the time taken for 25% of a foam sample to drain away as a liquid. When carrying out the full Standard test it is essential to reduce, as far as possible, the variabilities which can arise, especially as between one laboratory and another. Trouble can be caused by the non-uniformity of the branch-pipe used to produce the foam, inaccuracies in the expansion measurement and the size of the sample, water quality, temperature, premix time and other unspecified factors.

Five new type branch-pipes, constructed as described in FR Notes Nos.970 and 971 and produced for the purpose of reducing the branch-pipe variable, were used at the Fire Research Station and four other laboratories for a series of Standard test experiments designed to explore the reproducibility problems which have arisen. The Note contains full details of the results of these experiments and these are shown in tabular and graph form, and there is a full description of the various problems involved.

The experiments were carried out using a 4% solution of foam liquid at 100 lb/in^2 (690 kPa) discharge pressure with delivery from the new branch-pipe at 5 l/min (1.1 gal/min) and also from the laboratory generator which delivered foam at 0.75 l/m (0.1 gal/min).

The particular problem dealt with in this Note is the type and size of pan used to collect the foam sample for the drainage test. The pan previously used was of 1400 ml capacity with sides 5 cm high and this resulted in poor reproducibility. The foam content of the pan is calculated from its volume and the foam expansion, the latter being obtained by weighing another sample of known volume and dividing this into the weight of the sample container when full of water.

It was discovered that greater uniformity in the measurement of the drainage time could be achieved if the pan had sides 20 cm high so that the sample, which must fill the open-topped pan, was also 20 cm deep. For use with the branch-pipe the pan was 20 cm in diameter with a total volume of 6320 ml and when used to collect the laboratory generator foam the pan was 10 cm in diameter with a volume of 1630 ml. The circular pans had a stout base sloping to a centrally placed drain hole consisting of a 25 mm length of 12.7 mm dia perspex tube and a drain cock of 1.6 mm bore (large enough to prevent a meniscus forming). The liquid draining away was collected in a glass measuring cylinder. The pan must be free of grease.

When filled with the same type of foam it was found that both these drainage pans gave average 25% drainage times differing by less than 1.5% and so, provided the temperature is kept around 20°C it should be possible to obtain comparable test results from the various laboratories since the main cause of the variability has now been removed.

Synopsis of FR Note No.975

A LABORATORY BURN-BACK TEST FOR FIRE-FIGHTING FOAMS

by

D J Griffiths

When fire-fighting foams are used for the extinction of liquid hydrocarbon fires, eg aircraft crash, there is always the risk of reignition or burnback after the initial control. The burn-back resistance of the foam is only measured indirectly in the UK by noting the 25% drainage time under the Defence Standard 42-3 test and it was suggested in FR Note No.925 that a standard burn-back test should be developed.

A laboratory-scale burn-back test has now been evolved and in this Note there is a full description of the experimental work which involved over 200 tests using protein, fluoroprotein, fluorochemical and synthetic foams on petroleum spirit, Avgas, Avtag and Avtur fuels. The test results are shown in tabular and graph form.

The apparatus used consists of a steel (preferably stainless) tray (on legs) 23.6 in (60 cm) long, 9.8 in (25 cm) wide and 3.9 in (10 cm) deep. A sparge pipe with 2 mm holes is fixed across the bottom of the tray at one end and this is fed, when required for reignition, with hydrogen.

The suggested test procedure is as follows. Six litres of the chosen fuel (with primer if necessary) is poured into the tray, lit and allowed to burn for 3 min when it is extinguished by smothering with an asbestos board. After 1 min the chosen foam is gently applied, with a spreader, for 30 secs to form an even blanket over the hot fuel. One minute after the foam application the hydrogen is turned on and ignited. The burn-back time is that recorded from the ignition of the gas jets to the point when the tray is full of flame.

The test can be used to determine the effect of forceful foam application from the model 5 l/min branchpipe (see FR Note No.971). There seems to be little advantage in applying foam to the standard fire at a greater rate and there is, apparently, no advantage in building up a deep layer of foam. Forceful application will stir up the liquid thus cooling the surface through the mixing with the cooler lower layers but it may not be effective if the fuel is highly volatile and becomes entrained in the foam.

It is established that the burn-back resistance is affected by shear stress, drainage rate, weight and age of foam, type of fuel and its temperature, and the mixing of two different foams. It may be necessary to carry out some large scale tests in order to establish the relevance of these differences in practical situations. As an example, in an aircraft fire it may be preferable to use a free flowing foam for initial quick control and then follow up with a good burn-back resistant foam. On the other hand, for a large tank fire, without life risk, a high shear and drainage time foam would probably provide a better burn-back resistance although control might be slower.

AUTHOR INDEX

(The numbers in the index refer to the numbers of the FR Notes)

SUBJECT INDEX

(The numbers in the index refer to the numbers of the FR Notes)

Printed for Her Majesty's Stationery Office by Studio Trade Plates Ltd., Watford, WD1 8SA 6/74