Fire Research Note No.960

COLLECTED SUMMARIES OF FIRE RESEARCH NOTES 1972

by

L C FOWLER

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

February 1973

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FR Note No. 960
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KEY WORDS: Fire Research, review

DEPARTMENT OF THE ENVIRONMENT AND FIRE OFFICES COMMITTEE
JOINT FIRE RESEARCH ORGANIZATION

Synopsis of FR Note No 866

SOME EXPERIMENTAL STUDIES OF THE CONTROL OF DEVELOPING FIRES IN HIGH-RACKED STORAGES BY A SPRINKLER SYSTEM

by

P. Nash, N.W. Bridge and R.A. Young

Initial experiments, carried out in the Models Laboratory at the Fire Research Station, on high-racked storage were described in FR Note No 814. In view of the development in high-racked storage involving areas of up to one million square feet and, say, 120 ft in height, a further series of six experiments, on a larger scale than was possible in the Models Laboratory, was carried out in one of the huge ex-airship hangers of the R.A.F. at Cardington. The 37 ft high experimental steel racking was erected near one end of the 165 ft high hanger which was otherwise virtually empty. There were two racks, each six pallet-cell levels in height. One rack was six cells in length (55.5 ft) and the other two cells long (18.5 ft). The shorter rack was parallel to and facing the two centre cells of the longer one with an aisle about 4 ft wide between them. Each cell contained four wooden pallets on each of which were loaded nine corrugated cardboard cartons each containing three empty steel drums with wood wool packing. There were, therefore, 144 pallet loads in the longer rack and 48 in the shorter one and the cartons were tested for moisture content.

Sprinklers were installed at each level along the longitudinal centre line of the racking with heads over each vertical gap between the pallet loads and with a small metal plate 6 in above each head to prevent water from above cooling the head. The sprinklers were of the glass bulb type (155°F). In the first four experiments conventional $\frac{1}{2}$ in bore heads were used and in the last two tests spray pattern $\frac{3}{8}$ in bore heads were installed. The number, the levels and the positions of the 'operative' heads were varied from test to test and the 'non-operative' heads were blanked-off.

Measurements were taken of the temperatures, radiation, water flow and pressures. Several alarm detectors were tested and observations were made of the smoke. A detailed photographic record was produced of each test.

The fires were lit with a match at a tear in the side of a carton in the bottom layer and midway along the larger rack and a few inches in from the aisle.

The flames from the fires tended to move up the vertical gaps between the pallet loads, at first in the transverse gaps and then in the gaps between the back-to-back pallet loads but not up the central longitudinal flue. This was contrary to the experiments in the Models Laboratory and was probably due to the pallet loads being only $\frac{2}{3}$rds full in those tests and, completely filled at Cardington. The initial growth of the fire was slow (the source of ignition was small) but then the flames developed rapidly. The flame height took the same time to grow from 5 ft to 30 ft as it did from 0 to 5 ft. Any moisture content of the cartons was, therefore, relatively unimportant in the second rapid growth stage. Sideways spread of fire was very limited but since there was no ceiling over the racking fire spread at this level could not be judged and further research is required on this problem. Fire, if allowed to grow, could spread to the adjoining rack either by radiation or by falling debris.

The sprinkler installation was operated on the basis that the last four heads to operate in a full size system would give a density of 7.5 mm/min but the actual pressures used were those which would apply to the first heads to operate in such a system. Consequently, the densities were about 20 mm/min for experiments 1 to 4 and about 15 mm/min for experiments 5 and 6. When it was judged that the sprinklers had effectively controlled the fire, the final damping down was done manually. At least 2 but not more than 6 heads operated in each experiment.

Water from the sprinklers, both $\frac{1}{2}$ in and $\frac{3}{8}$ in, adequately controlled all the experimental fires and no damage was done to the racking. The heads (with one exception) operated only after the flame tips had passed them and a sprinkler system cannot therefore prevent a fire moving upwards.

During the tests some alarms, fitted to an expanded metal screen which was temporarily lowered over the top of the main racking, were tested and so were infra-red and the laser-beam fire detectors. In general, the detectors operated about 2 minutes before the first sprinkler head opened.

Various layers of smoke were formed, depending on the smoke temperature and buoyancy, but clearly extensive smoke would result in a high-racked warehouse unless the fire is quickly extinguished. A really effective fire detection/control system is needed so that a fire can be extinguished in the initial stages. It is the intention to follow up several promising lines of enquiry in future work by J.F.R.O.

Synopsis of FR Note No 880

A PRELIMINARY STUDY OF THE THERMAL DECOMPOSITION OF POLYURETHANE FOAMS BY ELEMENTAL ULTRA MICRO ANALYSIS

by

W.D. Woolley and P. Field

A series of experiments was carried out using the small tube furnace described in FR Notes No 769 and 851 in order to investigate the thermal decomposition of polyurethane foams, which are now widely used in buildings.

In these experiments samples of polyurethane foam were decomposed at temperatures between 200°C and 500°C for 15 minute periods. The residues were weighed and analysed for nitrogen content by elemental ultramicro-analysis in order to determine the decomposition conditions which promote loss of the nitrogen content. This is important since loss of nitrogen from the foams can indicate the formation of toxic nitrogenous products such as hydrogen cyanide.

The materials examined were:-

(1) Rigid polyether foam based on diphenyl methane di-isocyanate and a polyether polyol (known as M.D.I.)

(2) Rigid isocyanurate foam similar to (1) but without the polyol

(3) Rigid polyester foam similar to (1) but with a polyester polyol (known as M.D.I.)

(4) Flexible polyester foam based on tolylene di-isocyanate and a polyester polyol (known as T.D.I)

(5) Flexible polyether foam similar to (4) but with a polyether polyol (known as T.D.I)

It was found that the rigid foams (1) (2) and (3) liberated the nitrogen gradually as the foam decomposed and the temperature rose to 500°C. However, with the flexible foams (4) and (5) the nitrogen was lost much more rapidly so that at 300°C there was an almost complete loss of nitrogen although the weight loss of the sample was only about 35% and this meant that those flexible T.D.I. foams could present a serious toxic hazard in fires. In view of this, further work was undertaken on flexible foams and this is described in FR Note No. 881.

Synopsis of FR Note No 881

THE FORMATION OF NITROGEN-CONTAINING PRODUCTS FROM THE THERMAL DECOMPOSITION OF FLEXIBLE POLYURETHANE FOAMS

by

W.D. Woolley, Ann I. Wadley, and P. Field

Numerous experiments have been carried out to investigate, more fully than had so far been done, the release of toxic pyrolysis products containing nitrogen, such as hydrogen and organic cyanides and ammonia, in fires involving polyurethane foams. A preliminary study (see FR Note No 880) indicated that, as between flexible and rigid polyurethane foams, the former released almost all the available nitrogen at temperatures as low as $300^{\circ}C$ and, therefore, the new series of experiments dealt with two common types of flexible foams, (namely a polyester and a polyether type) as being the more hazardous.

In general, flexible foams are used in furnishings and rigid foams in building structures but both are formed, basically, by the interaction between an isocyanate and alcohol, the latter being not simple alcohols but polymers which are termed polyols and are based on either polyester or polyether units. The rigid or flexible nature of the foam is determined mainly by the degree of cross-linking of the polyols (or polymer chains). The cellular structure is normally formed by the addition of water which reacts with the isocyanate to give CO_2 as the 'blowing up' agent.

In present day foams two di-isocyanates are commonly used viz: tolylene (known as T.D.I.) and diphenyl methane (known as M.D.I.), the former being mainly used for flexible foams and the latter for rigid foams.

As in previous similar experiments (see FR Notes Nos 769 and 851) a small tube furnace was used. Small samples (10 mg) of the foams were placed on a ceramic boat and were introduced into the furnace which was heated to a controlled temperature and the decomposition was carried out in a measured stream of dry nitrogen. The products of decomposition were collected and analysed.

The decomposition of both foams was similar and at low temperatures ($200^{\circ}C$ to $300^{\circ}C$) a volatile yellow smoke, apparently containing all the nitrogen (T.D.I. unit) from the foams, was given off leaving the polyol residue. At $800^{\circ}C$ the yellow smoke began to decompose giving off hydrogen cyanide, acetonitrile, acrylonitrile, pyridine and benzonitrile as the main nitrogen-containing products. At $1000^{\circ}C$ about 80% of the nitrogen was recovered with hydrogen cyanide as the main product and it is suggested that above this temperature virtually all the nitrogen may be released as hydrogen cyanide. At these high temperatures (about $1000^{\circ}C$) the decomposition products of the polyols were mainly hydrocarbons.

Although this analysis work, using the gas chromatography - mass spectrometry apparatus, showed that the T.D.I. unit was released as polymeric material this does not preclude the possibility of the release of some free T.D.I. which is known to be highly toxic and further work is in progress on this problem. Further work, including studies of the composition of the yellow smokes, and studies of the thermal-oxidative decomposition of the foams will be recorded in future reports.

Synopsis of FR Note No 882

THE SURVEY OF FIRES IN BUILDINGS
FIRE SURVEY GROUP: FIRST REPORT SEPTEMBER 1971

by

A. Silcock

This Note describes the setting up in April 1970 and the initial work of the Fire Survey Group at the Fire Research Station. This team, consisting of an architect and an assistant (with some additional help) has so far visited about 100 fires, mainly in Buckinghamshire and Hertfordshire, and with the assistance of the Fire Brigade Officers, reports have been prepared showing, in considerable detail, much relevant information regarding the inception, discovery, spread and behaviour of these fires and their effect on the building and the contents. The author has included in this Note numerous tables, with comments, giving detailed information on 19 private house fires in order to provide some indication of the practical use to which this exercise could be put in comparing the effects of actual fires and the effects estimated in experiments and laboratory assessments, and the bearing they have on the Building Regulations.

Apart from the house fires, 23 factory fires were visited together with those in a number of shops, offices, farms, schools etc., and, consequently, similar detailed information is available on those fires and will be provided for all those visited in the future. The results will be published as a series of Fire Research Notes. A report file is prepared for each fire visited and this contains a summary, small scale plan, a self-coding form and colour photographs together with a copy of the K433 form.

As an indication of the kind of information likely to result from these "fire" visits the following is a summary of the conclusions arising from the 19 private house fires previously mentioned:-

(1) the average time from inception to discovery was about $1\frac{1}{4}$ hours

(2) only in one case was civilian effort at extinguishment of any use and then only partially

(3) no fires were discovered by smell

(4) most fires began with smouldering and were oxygen starved

(5) in eight fires the windows broke during the growth period but only in one case did this radically accelerate the growth.

(6) the advantage of the door to the room of origin being closed was clearly established at least in regard to the fire and smoke area involved.

(7) no door was attacked for as long as 30 min and six doors failed in 5 min

(8) when fires spread it was mainly to the roof space due to the poor fire resistance of the first floor ceilings. However, fire spread could have been greater had the ceilings not failed and vented the fire to the roof space.

(9) fibreboard linings resulted in rapid fire growth but a skim of plaster prevented rapid spread.

(10) several fires in the roof space spread to adjoining property, mainly as a result of weaknesses in the party wall between the top of the wall and the roof cladding i.e. poor workmanship.

When all the present reports have been analysed it will be necessary to assess the overall results and consider the range of information to be collected in the future.

Synopsis of FR Note No 888

AUTO DIALLERS IN THE UNITED KINGDOM

by

C.M. Jessop and E.D. Chambers

As a result of telephone enquiries to Fire Brigades covering about half the total population of Great Britain it is estimated that there are at present in the whole of the U.K. about 1400 auto diallers extending automatic fire detection systems to fire brigade control rooms.

The auto diallers normally pass recorded messages to the brigades via a manned G.P.O. telephone exchange. The unofficial estimate for Greater London is 200.

Synopsis of FR Note No.889

SMOKE TESTS IN NEW LAW COURTS BUILDING

by

E.G. Butcher (F.R.S) and Maurice Hall (D.O.E.)

This new building, 75 ft square and 12 floors high, has a centre core, about 30 ft square, containing 2 staircases and 3 lifts surrounded by a 5 ft wide corridor, with office accommodation, opening off this corridor, all around the outside walls of the building. Double swing doors are used to form lobbies where the staircases open on to the corridor on each floor. A restaurant and the plant room are on the top two floors, Ducts are used to provide air to the centre core staircases and to extract air from the centre core corridor (and toilets), The offices etc. are heated or cooled by a high velocity system with small diameter duct work, and this system produces a slight excess pressure in the offices, etc.

Smoke tests were carried out to determine the effectiveness of the pressurization system which normally produces an excess pressure of 0.75 mm (water gauge) in the staircase enclosure but in an emergency, by using extra fans, can produce a pressure in that area of at least the 'design' pressure of 2.55 mm (water gauge).

Smoke was produced in an office on the third floor and for most of the time this office door to the corridor was open. Three tests were carried out, one with no fans operating, one with normal ventilation working and the third with the emergency fans in operation. The Note contains tables showing the pressure differentials throughout the building during the tests and the observations made during the half-hour experiments. Conditions during each experiment varied slightly in that, for instance, some doors were opened and shut and fans put on and off for short periods in order to assess the effects of such actions. Further, prevailing weather conditions may have affected the results. However, the results of the smoke experiments showed that the

emergency pressurization system not only prevented smoke penetrating to the staircases but also acted to clear smoke which had been allowed to penetrate into the lobbies.

The authors conclude that, with fire conditions to be expected in an office building, smoke would not interfere with the escape of occupants from a building having a system of pressurization such as that contained in this New Law Courts building.

Synopsis of FR Note No.890

AN INSTRUMENT FOR CONTINUOUS WEIGHING OF FIRES

by

M.J. O'Dogherty

The author describes in this Note a laboratory instrument which will continuously measure the weight of a timber crib or tray of petrol etc. on fire so that, with the necessary instrumentation, the rate of weight loss during an experimental fire can be obtained. This continuous recording of the burning rate can be used as a measure of the size of the fire at any time and if this size is recorded at the time of detection it may be used to compare the performance of different types of fire detection equipment.

The instrument is constructed of mild steel with a central platform supported by four beams (like a stretcher), the beams being fixed to the inside face of a rectangular supporting frame. The fire is placed on an asbestos board on the central platform. There are no moving parts but the weight on the central platform is measured by bonding electrical resistance strain gauges to the four beams near to the point where they are fixed to the supporting frame e.g. where there is the largest, although extremely small, bending moment.

Although the instrument which was made had a central platform only 5" square and was designed to carry a total weight of only 50 lb, any weight of fire could be accommodated by suitably designing the supporting beams.

Synopsis of FR Note No.891

LARGE FIRES DURING 1970

by

G. Ramachandran, Patricia Kirsop and
Christine Eveleigh

Reference should be made to the synopsis of FR Note No 829 for the corresponding information regarding the 1969 large fires.

During 1970 there were 1115 large fires (£10,000 or more) in the UK causing direct damage amounting to £69.9 M (63 per cent of the total fire wastage of £110.9 M). The average loss per large fire was £62,700.

Out of the 1115 large fires, 75 started in outdoor hazards and 42 of these fires spread to buildings. There were only 30 large fires starting in outdoor hazards in 1965 and therefore the frequency of such fires has more than doubled in six years. The 1971 "outdoor" fires included the following:-

Menai railway bridge	£2 M loss
1 Oil distributors' jetty	£1 M + loss
7 Chemical plant fires	£1 M, £$\frac{1}{2}$ M, and less losses
1 Fire spreading to Paper Manufacturers building	£1 M loss

The average loss in these "outdoor" fires was twice the average in the 1040 fires that started in buildings.

The Note contains tables showing:-

(1) Occupancy or hazard involved.

(2) Source of ignition and place of origin.

(3) Extent of the spread and number of jets used.

(4) Date of construction.

(5) Time of call, control time, month and day of week.

The table relating to the behaviour of fire protection devices may be of interest and is shown in the following:-

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		1115	69944	62.7
Sprinklers and drenchers	(operated (did not operate	29 3	1560 1345	53.8 448.3
CO_2, foam, steam and nitrogen system	(operated (did not operate	113 1	7300 11	64.6 11.0
Automatic detectors	(operated (did not operate	5 2	273 165	54.6 82.5
Fire doors	(operated (did not operate	2 3	225 171	112.5 57.0
Others	(operated (did not operate	66 12	8071 945	122.3 78.7
Combination of above	(operated (did not operate	73 3	8516 111	116.7 37.0
Roof vents	(operated (did not operate	- -	- -	- -
Not installed, unknown or not applicable		803	41251	51.4

Synopsis of FR Note No 892

INTUMESCENT COATED HONEYCOMBS AS FIRE RESISTANT MATERIALS

by

D.I. Lawson and E.G. Butcher

Experiments were carried out, mainly on the 1 m square pilot furnace, to investigate the fire resistant qualities of a paper honeycomb matrix, coated with a commercially available intumescent paint, when used either as a fire damper in a ventilation duct or as a core for a lightweight partition or a door. The matrix could also be used for suspended ceilings or as a preformed protection for steelwork but these constructions have not yet been tested.

When heated the untumescent paint expands to form a thick insulating coating and the paper honeycomb holds this in place and is itself protected thereby.

The coated honeycomb forms a cheap, non-corrosive and easily replaceable fire damper when inserted vertically in ventilation ducts. The obstruction to the air flow is small since the structure only occupies about $^1/10$ of the total duct area. When tested for this purpose the honeycomb had a cell size of 9 mm and was 38 mm thick, and the specimens were squares 0.23 m x 0.23 m.

For tests as a core to doors and partitions a honeycomb cell size of 25 mm was used with thicknesses from 13 mm to 51 mm, and 4 mm thick hardboard facings were stuck, with the intumescent paint as the adhesive, on each side of the honeycomb. The specimens varied from 0.23 m x 0.23 m up to about 1 m x 1 m squares. They weighed only $\frac{1}{3}$ of the weight of traditional constructions giving the same fire resistance.

The BS 476 time temperature curve was followed in the furnace tests but results would have to be confirmed on larger specimens in the standard Fire Resistance Test using the larger furnace. It was found that the fire resistance time could be related to the weight, or thickness, of the paint application. When used as a fire damper the honeycomb was completely sealed in 1 min and in all three applications it was possible to achieve a Fire Resistance of up to one hour.

Synopsis of FR Note No 893

AN ASSOCIATION BETWEEN FIRE SPREAD AND CASUALTIES IN FIRE

by

M. A. North and R. Baldwin

Legislation for the control of fire safety in buildings is mainly effective in preventing loss of life and casualties by restricting fire spread by means of compartmentation and the control of linings and by providing means of escape. Dwellings normally form one fire compartment but it is still of interest to know what saving in life loss would result if fire spread within that compartment was reduced.

Fire Brigade reports, during 1967, on fires in multi-storied dwellings were examined for any association between casualties and fire spread. Fires starting in roof spaces etc. or which spread beyond the building of origin or in which clothing on a person was the item first ignited were excluded since these were not relevant to this investigation.

The information extracted is analysed as regards fatal and non-fatal casualty fires, time of call and spread of fire.

It appears that the probability of a fatal fire is higher by a factor of about three in fires which do spread than in those which do not, whether day or night fires are considered. The association between spread and fatalities does not mean that there is any casual relationship between them and it is impossible to say, at the moment, whether fire spread causes fatalities or whether fatalities lead to fire spread by, for example, killing a person who would otherwise have dealt with the fire.

Synopsis of FR Note No. 894

EXTINCTION OF LABORATORY HYDROCARBON FIRES
WITH A SYNTHETIC FOAM

by

J. G. Corrie and D.J. Griffiths

Experiments were carried out, in a laboratory, in order to investigate the effectiveness of a modern synthetic high-expansion foam liquid, when used at a low expansion of about 10, on a petrol fire. A proprietary liquid designated "Synthetic Foam Liquid A" was used and this apparently consisted of a lauryl ether sulphate/lauryl alcohol mixture with anti-freeze and other additives. The test fire was the standard 3 ft^2 (0.28 m^2) petrol fire specified in UK Defence Standard 42-3/issue 1 and comparisons were made with protein, fluorochemical and fluoroprotein foams. The standard application rate of 0.05 $gal/ft^2/min$ (0.04 $1/m^2/s$) was normally employed in the experiments.

It was found that a 2 per cent concentration of the Synthetic A liquid was sufficient to produce foams up to an expansion of 20 and a shear stress of 30 N/m^2, and all the fire tests with the synthetic foam were made using this concentration. The stirred jar described in FR Note No. 863 was used in the investigations and for the production of the laboratory foam. Tests were also done using a No. 2 branchpipe and, although the expansion was a little high, the production of foam in this way may not be impractical.

The Note contains tables and figures showing the expansions, shear stresses (i.e. flow properties), drainage times and fire control times for the various foams. In addition to having the minimum control time the synthetic A liquid also had a fire drainage time significantly lower than that for the other foams and this must favour post control protection against reignition. It is interesting to note that the control times of all the different solutions were generally related to shear stress, indicating that this was the major factor influencing control time.

The laboratory experiments showed that the Synthetic A liquid produced the best results at an expansion of 12 and a shear stress of about 10 N/m^2 and in these conditions it was as good as fluorochemical foam and better than all the other types which have been tested. The 2 per cent concentration necessary means that it costs about the same as protein foam which requires a concentration of 4-6 per cent and it is considerably cheaper than the fluorochemical and fluoroprotein liquids. Further, the small quantity required means less transport costs and facilitates the carriage to a fire. Protein foam is largely dependent on imported ingredients but synthetic foams would probably be manufactured as a side stream product of a detergent industry with consequent flexible and economic production.

There would be a great advantage if only one type of foam liquid could be used for both high and low expansions. Before the synthetic foams could be accepted as replacements for protein foams, however, further studies would be required on a larger scale, including the measurement of the critical application rate, the effects of forceful application and their use on various fuels.

Synopsis of FR Note No 895

NEWS VALUE OF FIRES : MATERIAL DAMAGE AND DEATHS

by

Elizabeth Hagger

An attempt was made to assess the monetary value of press reports of fires and to see if this value bore any relationship to the material damage or the number of deaths, since the public get most of their knowledge of fires from the press.

Reports of large fires in the London area appearing in the National press (including Evening papers) for July 1970 and January 1971 were examined and an assessment was made of the value of each report based on the newspaper's "classified advertising" single column charge. Although not always mentioned in the press reports, the amount of the material damage loss was available from other sources. Fourteen fires of £10,000 or over were reported upon but twenty-one such "large" fires were not and the "space value" of the latter was taken as £0.

Fires in the London area involving deaths were all reported in the press and there were 16 such incidents during the two months involved.

It was found that the average value of newspaper space devoted to this news was about £140 per fire death and about £100 per £100,000 of material damage.

Synopsis of FR Note No. 896

NOTES ON CHARRING RATES IN WOOD

by

C.P. Butler

In this Note the author reviews much of the existing technical information on the charring of wood and the use of wood blocks as radiometers. He finds that there is correlation between the data regarding the charring of wood blocks obtained at two laboratories viz: the Fire Research Station and the Naval Radiological Defence Laboratory in San Francisco (where the author has worked).

Comments are made on earlier furnace tests carried out on timber beams, floors and columns and use is made of the information on charring that was then obtained, but the author is mainly concerned with the value of layers of char on a partially burned piece of timber as a permanent record of the intensity and duration of a fire. In the laboratory work on wood block radiometers the wood never burns by itself because the heat fed back into the surface from the flames of combustion is never sufficient to sustain the charring rate and charring always ceases as soon as the source of radiation is removed.

In regard to the furnace tests previously mentioned the "rule of thumb" charring rate usually accepted is $^1/40$ inch per minute. As the char builds up the rate of heat flow from the furnace to the base of the char layer decreases but this decrease is compensated for by the heat of combustion of the wood so that the actual charring rate remains constant although the furnace temperature continues to rise. In view of the constant charring rate it is concluded that the BS476 time-temperature curve is equivalent to a thermal energy of about 3 $W_{cm}{}^{-2}$ at the surface of the wood.

As a result of the laboratory work it is concluded that the depth of char produced in wood by intense thermal radiation is directly proportional to the irradiance level with little dependence on the species of wood, the type of radiation or the method used for measuring the char depths ie cutting the specimen in half or scraping off the char and comparing the remainder with the original thickness of the specimen. The Note contains a graph showing the char depth in cm per sec resulting from an irradiance in watts per square cm on the surface of the wood. The equivalent heat input to sustain the charring rates shown by the furnace tests is about 1300 calories per gramme of wood and this is about one third of the heat of combustion of the wood.

Synopsis of FR Note No.899

CONSIDERATIONS OF THE FIRE SIZE TO OPERATE AND THE WATER DISTRIBUTION FROM AUTOMATIC SPRINKLERS

by

M.J. O'Dogherty and P. Nash

Information obtained by the National Fire Protection Association from details of 67,500 fires during the period 1925–1959 involving sprinkler operation indicates that 70 per cent of fires involve 4 sprinklers or less, 91 per cent involve 16 or less and 96 per cent involve 36 sprinklers or less. The purpose of this Note is to indicate the largest size of fire which can be tolerated if the maximum number of sprinklers to be operated is specified and it is assumed that in normal risks 16 sprinklers may open without the risk of the installation being overwhelmed provided there is adequate water coverage over the whole 16 sprinkler area.

The point of origin of the fire is taken as the centre of a 4 sprinkler array since this is the region in which the water application is normally at a minimum. It is accepted therefore that the fire may develop so that the next larger size of 'square' of sprinklers, ie a total of 16 heads, is in operation with a minimum water application all over, but not the next larger square of 36 heads. The calculations are on the basis that the fire will develop with uniform radial growth and that all heads will operate at the same temperature. Much of the research work on which the calculations are based was described in Fire Research Technical Paper No.17 and the 'fire' is taken to be the Crib B as detailed in that paper.

The factors involved include the fire load, the rate of fire development, the ceiling height, the horizontal distance of the heads from the fire, the sprinkler rating and the depth of the heads below the ceiling or roof (taken as 8 in (203 cm) for this investigation). The 'fire' is the wood crib and to simplify the work it is assumed that if the fire load is doubled the crib will be twice the height and for a given fire area the rate of burning will be proportional to the crib height. There is also extrapolation of the earlier research results.

All parts of the area under the 16 sprinklers must be covered by a certain minimum water distribution if the fire is not to spread beyond the central area required to cause the operation of the 16 sprinklers. It is assumed that this minimum distribution is not less than 50 per cent of the average rate of water flow required to control a fire of a certain size and that this minimum distribution is restricted to not more than a specified percentage of the area of sprinkler coverage, ie the area covered by 16 sprinklers adjacent to the point of origin of the fire.

The higher the fire load the smaller the proportion of the covered area which can be permitted to receive less than the minimum water distribution. However, although the reverse will apply to light fire loads there must be a maximum to the permitted minimum water distribution area in order to avoid the possible conjunction of low water distribution areas, and this is taken as 20%. Similar considerations apply to the wider spaced sprinkler installations on low ceilings since relatively small fires can operate large numbers of sprinklers on low ceilings and criteria more severe than normal are required in these circumstances. Limitations must, similarly, be imposed with high rated sprinklers in order to avoid spread between sprinklers, and again, 20% is suggested as the maximum low water distribution area.

All the various factors are discussed in detail in the note and there are various tables and graphs. The maximum area of low water distribution is, in effect, the maximum area of fire which will operate and be controlled by 16 sprinklers and the following table summarises the main conclusions (details for ceiling heights of 6.1 and 8.55 m (20 and 28 ft) are also available).

Area of fire as a percentage of coverage at operation of 16 sprinklers

Fire load (k cal/m^2) (Btu/ft^2)	Sprinkler rating (°C) [°F]	Ceiling height (m)					
		11.0 (36 ft)			3.66 (12 ft)		
		coverage (M^2)			coverage (M^2)		
		9.29 (100 ft^2)	12.08 (130 ft^2)	20.90 (225 ft^2)	9.29 (100 ft^2)	12.08 (130 ft^2)	20.90 (225 ft^2)
271,000 (100,000)	68 [155] 93 [200] 141 [286]	20^x 20^x 20^x	20^x 20^x 20^x	13.8 19.8 20^x	9.0 12.6 19.8	7.0 10.4 16.4	4.6 6.8 10.8
542,000 (200,000)	68 [155] 93 [200] 141 [286]	12.0 17.2 20^x	10.0^{+} 14.3 20^x	6.9 9.9 15.4	4.5 6.3 9.9	3.5 5.2 8.2	2.3 3.4 5.4
1,084,000 (400,000)	68 [155] 93 [200] 141 [286]	6.0 8.6 13.4	5.0 7.2 11.0	3.5 5.0 7.7	2.3 3.2 5.0	1.8 2.6 4.1	1.2 1.7 2.7

x maximum permitted area.

+ The Crib B fire had a fire load of 550,000 k cal/M^2 (205,000 Btu/ft^2). As an example from the above table it will be seen that for a fire of this size with 68°C rated sprinklers on a 11.0 m ceiling with a coverage of 12.08 m^2, not more than 10 per cent of the coverage should receive less than 2.5 mm per min of water ie 50 per cent of the 5 mm per min design discharge for an ordinary hazard system under the 29th edition of the Sprinkler Rules.

Synopsis of FR Note No.900

A STATISTICAL APPROACH TO THE SPREAD OF FIRE IN BUILDINGS

by

R. Baldwin

Statistics of fires attended by the fire brigades and reports made by the JFRO visiting team have been and will be examined for the purpose of investigating the effects of fire protection and building controls so that ultimately building regulations may be based on real fire experience. It is hoped that this work will eventually provide a new approach to the fire grading of buildings.

The role of the building structure in inhibiting fire spread is largely revealed by comparing the features of small and large fires and by estimating the influence of various factors on fire spread. Although, numerically, large fires (£10,000+) constitute only about 1 per cent of all fires, they account for about 60 per cent of the annual fire wastage. It was suggested in FR Note No.833 (see Synopsis) that the chance of all fires spreading beyond the room of origin (P_S) and the chance of the fires becoming large (P_L) were approximately related in the proportion $P_L = P_S^3$ and the present investigation supports this theory. This cube law means that if the chance of fires spreading is reduced there will be a considerably larger chance of fires not being large.

The basic concept for the grading of buildings that they should be able to survive a burn-out of the contents can be modified in certain circumstances as is indicated in the Building Regulations eg relaxations for sprinklers or impositions for high-rise buildings. Examination of the fire statistics can provide information on the effectiveness of various factors eg early discovery, fire fighting, walls, floors and linings, age and height, and sprinklers, and some of these factors have been discussed in FR Notes Nos.729, 735, 789 and 848 (see Synopses).

Although this analysis is not yet complete, the study of spread beyond the room or origin is clearly a valuable technique for investigating the spread of fire in buildings and some interesting results have already emerged.

The chance of a fire becoming large is about four times as great at night than during the day but the average size of large night fires (time of call 18–05 hours) is £63,000 as against £60,000 for day fires (time of call 06–17 hours) implying that once a fire has exceeded a critical stage its ultimate size is determined not by the time of call but probably by the size of the building or compartment. It was suggested in FR Note No.839 that the expected loss was proportional to the square root of the building or compartment area. It is now suggested that the critical area is about 400 ft^2 and that the critical control time, which is related to the size of the fire on arrival of the brigade (see FR Note No.694), is about 20 mins after which time the fire may be uncontrollable.

≠ Although the brigade attendance time (time of call to arrival) has little effect on the spread of fire since the time is relatively small when compared with the time from ignition to detection, the time to detection is important. The arrival time is influenced by the Fire Brigade risk classification and tends to be shorter for the more hazardous risks involving more rapid fire spread. A detection system to detect fires as early at night as during the day would reduce the incidence of large fires to about a third (but not the maximum size) and hence losses due to large fires at night would be cut to about a third.

It is hoped that more national and international data will become available so that the work on this problem can expand and incorporate a study of the hazards to life.

≠ (Note – the effects of attendance times have been subject to further review and are discussed more fully in FR Note No.912 to be issued).

Synopsis of FR Note No.901

THE FIRE RESISTANCE REQUIRED TO SURVIVE A BURNOUT

by

P.H. Thomas

The requirements regarding fire resistance in most building regulations can be traced back to the work of Ingberg in the late 1920s and to a similar work viz: Post War Building Studies 20, published in the UK in 1946. Both these works related the fire resistance time (t_f) to the time to resist a complete burnout in a compartment having adequate walls, floor and ceiling and specified fire load (or amount of fuel) per unit of floor area ie $\frac{L \text{ (fire load)}}{A_F \text{ (floor area)}}$.

Although the UK Building Regulations do not specify fire load densities they do refer to buildings of particular occupation and size and in arriving at the fire resistance times required consideration is given to the brigade attendance (making a 'burnout' unlikely) and to tall buildings which may require increased standards in view of the life risk and to other factors such as sprinklers etc.

In this Note the author considers in some detail the latest available research information regarding the requirements for predicting the fire resistance to withstand a 'burnout' in a compartment. Life safety problems and the resistance of a given element of construction or structure are not considered. Experience from actual fires is being investigated separately on a statistical basis from the fire brigade reports.

The pioneering work on fully developed fires mentioned above was followed by detailed studies in Japan by Fujita and Kawagoe and later, at the instigation of the JFRO, by a co-operative programme under a CIB Working Party to investigate the influence of various factors on the development of fire such as the shape of the compartment and the size of window openings. Various laboratories were involved in the programme and in view of this and the numerous other variables small scale tests were utilised and compartments of $\frac{1}{2}$, 1 and $1\frac{1}{2}$ m in height were employed. The four compartment shapes examined were 211, 121, 221 and 441, the units being width, depth and height respectively. The ventilation was in the front of the compartment and extended the full height and either $\frac{1}{4}$, $\frac{1}{2}$ or the full width of the front. The compartments were made of 10 mm asbestos board and wood cribs extending over 5/6 of the floor area were used. Crib sticks, 1, 2 and 4 cm thick, were placed with horizontal spacings of $\frac{1}{3}$, 1 or 3 stick thicknesses. Fire load densities of 20, 30 and 40 kg/m^2 were used and these represented normal occupancies other than warehouses.

In all the experiments measurements were made of the rate of burning (loss in weight of fuel), (R), temperatures (θ) and radiation in front of the ventilation opening (I_o) and a full report of the work will be published by CIB. It was found that the fire resistance (t_f) required to survive the fires was closely proportional to $\frac{L}{\sqrt{A_W A_T}}$ where L is the amount of fuel, A_W is the window area and A_T is the area of the internal surfaces over which heat is lost (excluding the floor area for preference) or, in other words $\frac{L}{A_F}\left(\frac{A_F}{\sqrt{A_W A_T}}\right)$. Therefore regulations designed on this basis would recognize the role of windows and compartment shape in a "design factor" $\frac{A_F}{\sqrt{A_W A_T}}$, additional to the conventional fire load density, $\frac{L}{A_F}$.

As previously mentioned current building regulations implicitly follow Inberg's basis ie t_f varies proportionally as $\frac{L}{A_F}$ but the CIB experiments indicate that this basis would overestimate the fire resistance when $\frac{A_W A_T}{{A_F}^2} > \frac{1}{3}$ and underestimate it when this ratio is $< \frac{1}{3}$ and some regulations do demand higher values of t_f for large area compartments. The CIB experiments emphasized the need to recognize the role of windows and compartment shape if only to convince the engineer or architects that the basis of the regulations is scientific.

As a result of these findings the author of FR Note No.877 was able to calculate the relationship between t_f and $\frac{L}{\sqrt{A_W A_T}}$ for many other experimental fires reported in technical literature. The same kind of relationship holds good for these too and, since these data have more realistic and practical compartment constructions and sizes, the results are more general than the CIB experimental conditions. It is argued that Inberg's experimental results are a special case of this more general relationship.

It appears from the experiments described above that the radiation (I_o) may be as good or better as a measure of temperature (θ) than the thermocouple measurement itself.

A study of actual fire incidents involving structural damage might correlate the severity of such damage with values of $\frac{A_W A_T}{A_F^2}$ as well as $\frac{L}{A_F}$. If so there might be practical grounds for raising the standards in these situations, and for relaxing them when $\frac{A_W A_T}{A_F^2}$ is large (ie small area compartment). If no such correlation is found then it would seem that either there is now considerable 'over-design' or these scientific studies are not sufficiently refined to justify much change.

Synopsis of FR Note No.903

FREQUENCIES AND CAUSES OF FIRES IN LAUNDRIES, LAUNDERETTES AND SIMILAR OCCUPANCIES

by

S.E. Chandler

Reports on fires in laundry premises, including launderettes, attended by the fire brigade during the three years 1967-8-9 have been analysed by using a sampling basis. There were 1702 such fires but, so far as risks other than launderettes are concerned, there were no unusual features and no material increase in the number of fires over the three year period.

With regard to launderettes, both the shop and the ancillary sections of the premises, there were 260 fires in 1967, 300 in 1968 and 480 in 1969 but, no doubt, the rise can be attributed, at least in part, to an increase in the number of launderettes. Out of the total of 1040 fires 271 (26.1%) were caused by electric washing machines, 202 (19.4%) by gas drying apparatus and 105 (10%) by electric drying apparatus. Unknown causes and common hazards were responsible for the remainder, apart from water heating and boiler apparatus which was responsible for 67 fires and dry cleaning machines for 35 fires.

In laundries within schools, hospitals, prisons etc., drying apparatus accounted for 41 fires (20%) and washing machines for 24 fires.

Synopsis of FR Note No.904

FIRE EXTINGUISHERS IN PRIVATE DWELLINGS

by

E.D. Chambers and Carolyn M. Jessop

A Fire Prevention Campaign in the Tyne-Tees area, carried out for the Home Office, included a question about fire extinguishers in private dwellings and the somewhat vague responses to the survey have been analysed.

It appears that about 6 per cent of the 2904 houses visited had extinguishers of some type and about 50 per cent of these were in the garage or car and about 40 per cent in the house (the balance was elsewhere). Of the known types, 46 per cent were dry powder and, somewhat strangely, 22 per cent were said to be foam.

Synopsis of FR Note No 905

A COST STUDY OF CONCRETE AND STEEL FRAMEWORKS

by

D.V. Maskell

In a building where a fire resisting framed structure is suitable this may be either of steel or of reinforced concrete and it is important to compare the costs. Although it is proposed eventually to make economic comparisons of complete frameworks, the initial work described in some detail in this Note deals only with one element, viz. a column which if it is to have at least $\frac{1}{2}$ hour fire resistance, must be either an encased steel stanchion or a reinforced concrete column of the requisite load bearing dimensions.

The methods of construction which are analysed as regards costs have been taken from the "deemed to satisfy" provisions of Regulation E6 of the 1965 Building Regulations and the Note contains tables showing the costs of the two types of construction for $\frac{1}{2}$, 1, $1\frac{1}{2}$, 2 and 4 hours fire resistance, and they indicate the nature of the encasement or protection which would be most economic. There would be, in practice, many variations depending on the load bearing requirements but for the main comparisons in the tables an 8 in x 8 in (200 mm x 200 mm) 32 lb/ft steel stanchion has been used for comparison with a 10 in x 10 in (250 mm square) reinforced concrete column with 4 per cent (cross sectional area) steel reinforcement.

As examples, a 10 in square reinforced concrete column (without any plaster cover) would be the equivalent of the 8 in x 8 in steel stanchion encased in $\frac{5}{8}$ in sprayed asbestos, both getting a $1\frac{1}{2}$ hour grading. Also, for 2 hours the concrete column would need a $\frac{1}{2}$ in vermiculite gypsum plaster cover and the steel stanchion $\frac{3}{4}$ in of sprayed asbestos. For 4 hours the concrete column would have to be 18 in x 18 in or 12 in x 12 in with the $\frac{1}{2}$ in plaster cover, and the steel stanchion would need $1\frac{3}{4}$ in of sprayed asbestos.

The Note also contains tables showing the cheapest form of column for the period of fire resistance required for various types of buildings and the economic solution according to the size of column involved. Generally speaking, as the fire resistance requirement increases so does the margin in favour of concrete but as the size of the steel stanchion increases, the margin in favour of concrete diminishes. For only $\frac{1}{2}$ hour fire resistance the cost difference is negligible.

Besides the need for fire resistance there are other considerations which may affect the choice of material, such as the flexibility, finish, weathering, handling and erection, repairability and weight etc. but these have been assumed to be compensating as regards comparative costs and have been omitted at this stage in order not to confuse an already complex problem. The main disadvantage of steel appears to be in the additional cost of protection, and present day conditions seem to favour concrete but the steel industry is improving its techniques and the supply situation so that future comparisons may well be different when full framework systems are evaluated. Concrete technology is, of course, also advancing.

The next stage is to investigate the relative costs of a bay of a framework system. Eventually all the other factors will be evaluated so that comparisons can be made as regards complex frameworks and the fire resistance aspect assessed in relation to all these various factors. This research work might also be used as a basis for a thorough cost-benefit analysis of the Building Regulations at a later date. Some of the present permitted methods of construction are either outdated or uneconomic and a greater sense of urgency is required in the future both in assessing the relative merits of the available and practical constructions and in drafting and amending the Regulations, based on the principles established in this Note.

Synopsis of FR Note No.906

NATIONAL EXPENDITURE ON SPRINKLER INSTALLATIONS

by

G. Ramachandran

An earlier estimate by the Fire Research Station of the cost of fire protection to buildings was £30 M in 1962 and an attempt has now been made to assess the 1970 cost of this fire protection including a separate estimate for sprinkler protection.

Most of the relevant information is obtained from Board of Trade publications and reference is also made to earlier investigations into this problem, including FR Notes Nos.828 and 839 for which synopses were issued. In 1967 the average size of sprinklered buildings involved in fires attended by the fire brigade was 168,000 sq ft and for non-sprinklered buildings it was 14,000 sq ft. Since it would be the larger (1967) non-sprinklered buildings which were newly sprinklered in 1970 it is assumed that a reasonable estimate for the average size of these buildings first sprinklered in 1970 is 49,000 sq ft.

It is estimated that the current initial cost of installing sprinklers is about 15 (new) pence per sq ft and that the annual maintenance cost is about 2 per cent of the capital cost.

Based on the available information it is estimated that there were 45,000 sprinklered premises (one or more buildings) in 1970 of which 3,300 were newly sprinklered in that year as follows:

	Manufacturing Industries	Retail Distributive	Wholesale Distributive
Total sprinklered in 1970	15,000	21,000	9,000
Newly " " "	1,200	1,500	600

About £25 M was spent on installing sprinklers in the 3,300 premises and £9 M on maintenance costs in the 45,000 premises, so that the National expenditure on sprinkler protection in 1970 was of the order of £34 M out of a total estimated cost of £80 M on all forms on fire protection to buildings.

This is the National cost. The building user derives benefits from tax rebates and reduced insurance premiums although additional rates may be charged. These are not matters considered in this paper.

Synopsis of FR Note No.907

COMPARATIVE FIRE AND EXPLOSION HAZARDS OF DOMESTIC FUELS

by

Winifred N. Daxon and J.F. Fry

An appraisal has been made of the changing domestic fuel situation over the period 1960–69 as regards fires and explosions. Fuel consumption figures have been converted to a 'common denominator' of therms and a sample analysis has been made of incidents in dwellings, caravans, ships and rivercraft.

The following table summarises the results:

	Town Gas	L.P.G.	Burning Oil
Annual Consumption in therms (millions)	1950	29	647
Fires per 10^8 therms	56.0(1)	583.7(10)	274.0(5)
Explosions per 10^8 therms	4.8(2.5)	64.9(34)	1.9(1)
Fatalities in the 10 years	24	5	1

(Approximate ratios are shown in brackets)

Therefore, when the consumption is taken into account L.P.G. is shown to be the most hazardous fuel as regards both fire and explosion. Over the ten year period the rates of incidence of fires decreased with oil and gas but increased with L.P.G. The explosion incidence rates fluctuated.

Synopsis of FR Note No.909

SOME NOTES ON THE MATHEMATICAL ANALYSIS OF SAFETY

by

R. Baldwin

The relationship between fire grading and building design and contents was reviewed in FR Note No 877 in so far as any predicted fire resistance is related to the compartment shape and the ventilation but clearly there are many other variables both practical and theoretical which can also have an influence on fire resistance requirements. It is, for instance, not necessarily essential to construct all buildings to resist a 'burn-out' if some degree of failure is acceptable and the cost of complete security from destruction is uneconomic. A factor of safety which implies the acceptance of a degree of risk, has been adopted in other engineering fields such as aircraft and earthquake resistance design and may well be appropriate and inevitable in regard to fire safety as regards both structure and the life hazard.

In this paper the main developments in other fields of engineering as regards reliabilities and probabilities of failure are reviewed in considerable technical detail but it is realized that there are peculiar features of the fire hazard such as the chance of discovery, the fire brigade action and the operation of sprinklers which must be borne in mind.

Any reliability analysis must acknowledge that the probability of failure will depend on such factors as the variability of building materials, the uncertainty of fire resistance testing and fire severity and the uncertainty of statistical and mathematical data. There may be subsequent variations from the original design, deterioration due to age and damage as the result of excessive loading or vibration.

At this stage it may not be profitable to analyse the life hazards except, possibly, for tall buildings where evacuation is impracticable. Some degree of life risk must be accepted although the cost-benefit of fire protection may justify investigation as a result, for instance, of public disquiet about the incidence of deaths in hotel fires.

It is suggested that the most acceptable future approach for engineers is to define the characteristic values of fire severity and resistance on a statistical basis in conjunction with a factor of safety related to the design uncertainties which may be numerous and inter-related. Engineers endeavour to design and build structures which are both safe and economic and this philosophy should be applied to fire engineering. The definition of safety and the specification of acceptable risks are briefly discussed in this paper with the object of introducing the subject and indicating some of the methods available for the study of safety on an analytical basis. One practical approach to the problem might be to accept existing practice as representing the best practical solution, particularly where traditional buildings are concerned, and to assess safety factors and probabilities of failure etc so that new designs may be appropriately varied, thus ensuring some uniformity in the future.

Synopsis of FR Note No.910

EXTREME VALUE THEORY AND FIRE LOSSES - FURTHER RESULTS

by

G. Ramachandran

The theory of extreme values was introduced in some detail in FR Note No.837 as a means of estimating loss trends and the influence of various factors on the whole pattern of fire losses, both large and small ($\pm$ £10,000) when only details of the large losses (£10,000+) are known. This statistical method could be used both to assess the total losses in one or more groups of occupancies or for estimating the expected loss in a particular building of known value.

In this paper the theory is developed and is applied to the textile industry over the 21 years 1947 to 1967 for which the highest 17 losses in each year are used to explain and demonstrate the operation of the theory. Although the statistical assessment of fire characteristics could be related to the extent of spread or duration of burning, the present investigation is restricted to the financial loss. The relationships between financial loss and physical damage or time could be studied later.

Tables in the note give details of the 17 annual large textile industry losses for the 21 years adjusted to 1947 values together with the logarithm of these amounts since, as explained in the earlier note, the $\log_e$ of the loss (called Z) follows a probability law of the exponential type.

The various parameters are examined and discussed in considerable detail together with the concept for predicting future loss trends and for estimating the expected losses in smaller fires. Many fires never develop and die at an early stage and so are disregarded as of no economic consequence. After this early stage a fire has an increasing tendency to spread and this will then remain constant for a time until, eventually, the probability of extinction h(u) will increase and in the end the fire will become extinct. This probability of extinction follows a 'U' shaped curve but, ignoring the initial failures to develop, the remaining long range variables of h(u) will increase exponentially since the larger the fire becomes the greater will be its chance of extinction. When a fire has been burning for some time fire fighting will have started and the probability of extinction h(u) will increase at a higher rate than the probability of spread so that h(u) would increase for large value risks. As an example, the loss ratio (loss over value at risk) could be 0.320 for risks of value £1,000 but only 0.013 for risks of value £1M. The proportion destroyed in a small building would, therefore, be expected to be greater than the proportion destroyed in a large building; the proportionate damage decreases, perhaps exponentially, with increasing value at risk.

Ignoring the smallest losses and assuming the minimum loss (1967 values) to be £55 the techniques of the extreme value theory have been applied to the textile industry, and correlation between observed and theoretical values are good.

In 1967 there were 65 large fires costing £10,000 or more and it is calculated, therefore, that there were about 170 fires costing £55 or more of which 105 were smaller fires (less than £10,000). According to F.P.A. data there were 59 smaller fires in sprinklered buildings and, since about 50 per cent of the textile industry is sprinklered, an equal number of 'non-sprinklered' fires. Also in 1967 there were 982 fires (465 in 1947) attended by fire brigades of which only 194 spread beyond the room of origin. The frequency of fires increased at a rate of 3.8 per cent per annum and, therefore, about 1310 fires are likely to occur in 1975.

The average of the 17 top losses over the 21 years was £54,100 (± £1,500) at 1947 prices. During 1967 it is estimated that the average loss in the range £55–10,000 was about £2,200 and the known average on sprinklered buildings was £1,600. These figures indicate an average loss of £2,800 in non-sprinklered buildings and there is, therefore, a saving of £1,200 per fire due to sprinklers.

Further, it appears that the total loss in all smaller fires in 1967 was not more than £300,000 and since the large losses totalled £4.55M they accounted for 94 per cent of the total losses in the industry during 1967.

The extreme value theory appears to have practical applications in the field of fire losses but needs further refinement. It is not suggested, however, that at this stage the studies would help insurers in deciding on the maximum number of policies to accept in a particular range of sums insured nor in tackling reinsurance problems. However, the values of the various parameters could serve as indices of fire risks and a statistical assessment of financial damage could play a vital role in the economics of fire protection measures. The error of ± £1500 mentioned above is a "standard" error and this, together with the other studies which could be of value to insurers, will be investigated further.

Synopsis of FR Note No.911

SOME ELECTRICAL PROPERTIES OF HIGH EXPANSION FOAM

by

P.F. Thorne and D.M. Tucker

The electrical hazards arising from the use of plain water jets were reviewed in FR Technical Paper No. 13. In the present Note the electrical hazards arising from the use of low expansion foam from a jet (eg portable extinguisher) and from the use of medium and high expansion foam to fill a compartment are investigated. An electrical current of 1 mA is just perceptible, a "safe" current might be up to 5 mA but 50 mA could be fatal and an operator could receive a shock if he is holding a branch which ejects a low expansion foam onto live electrical equipment or if he is standing in a medium or high expansion foam which is covering live electrical equipment.

In order to assess the hazards it is necessary to know the conductivity of the foam and earlier research work gave some indication of the electrical resistance of various water supplies and foam liquids. These data are tabulated in the Note.

The present investigation was designed to correlate the earlier work and to measure the conductivity of foam samples up to expansions of over 1000. Three conductivity cells were used, one proprietary type having small platinum electrodes spaced 11 mm apart, another larger cell which was constructed at F.R.S. having 500 cm^2 square copper plates or electrodes 25 cm apart and the other similar to this but with aluminium plates. A conductivity "bridge" was used to measure the electrical current flowing through the foams from one electrode to the other and hence the resistance of a foam of a particular solution and expansion. Conversely, the conductivity cell could be used to determine the expansion of a sample of foam.

The results of these preliminary experiments were not sufficiently precise for accurate calibration but the conductivity cells could be modified and it is clear that the technique of foam expansion measurement by electrical means could be used with foams of expansions up to 1000.

Although the specific resistance of a foam may, therefore, be known, this does not mean that the life hazard can be reliably assessed. The area of the foam in contact with electrical equipment or an operator is not easy to determine; foam will gradually drain and will form water on the floor with a layer of lower expansion foam just above (hence a lower electrical resistance than the main foam) and unearthed metal objects in the foam between the equipment and the operator may reduce the effective resistance of the foam. Further, electrical equipment may be hidden from view and therefore, unlike the situation with jets or sprays of plain water, unknown and unpredictable circumstances may arise and it is essential that, before personnel enter a foam-filled compartment, all electrical equipment in contact with the foam should be isolated.

Synopsis of FR Note No.912

FIRE FIGHTING AND EXTENT OF SPREAD

by

S.J. Melinek

The extent of fire spread is dependent upon the type of building, its occupancy and other factors such as the effectiveness of the fire brigade action and other fire fighting activity. In this Note the data for 1967 regarding fires attended by the brigade and still burning at the time of arrival are examined in order to isolate and estimate the effect of any time delay from ignition to discovery, from discovery to time of arrival of the brigade, and the effect of fire fighting before the brigade's arrival. Reference is made to previous papers dealing with this problem viz: Fire Research Technical Paper No 19 and Fire Research Notes Nos 694, 789, 792, 884 and 915.

The Note contains tables and graphs showing the effect of delay time (t_{DA}) in arrival of the brigade after discovery on the probability of fire spreading beyond the room of origin (P_S) and of it becoming large (£10,000+) (P_L) and on the time taken to control the fire (t_c). Brief details are also given of the methods of fire fighting before the brigade's arrival and the material first ignited.

Conclusions reached as a result of this examination are summarised as follows:

(1) the longer the delay time (t_{DA}) the greater is P_S and t_c

(2) P_L is independent of t_{DA} but increases with time from discovery to call (t_{DC}). The independence on t_{DA} is possibly due to most fire stations being sited near to the high risks.

(3) about 50% of the fires are fought before the brigade arrives and for these fires the mean time between ignition and discovery is about 3 min. For fires not fought before the brigade's arrival the mean time is about 18 min. The mean time taken to commence fire fighting after discovery is about 2 min.

(4) about one quarter of fires fought before the brigade's arrival are out on its arrival. Fires which are small on discovery are more likely to be fought before the brigade's arrival.

(5) the mean rate of increase of P_s with t_{DA} is little altered by fire fighting before the brigade's arrival.

(6) fires which are large on discovery or which cannot be extinguished within a few minutes tend to be much more difficult for the brigade to extinguish.

Synopsis of FR Note No.913

THE THERMAL DECOMPOSITION BEHAVIOUR OF SOME COMMERCIALLY AVAILABLE FLEXIBLE POLYURETHANE FOAMS

by

W.D. Woolley, Ann I. Wadley and P. Field

Earlier reports on experiments with flexible polyurethane foams (known as T.D.I.) indicated that at about 200°C to 300°C there was a rapid release of the T.D.I. unit as a volatile yellow smoke leaving the polyol residue to decompose up to 800°C after which the yellow smoke decomposed. This work was described in FR Notes No 880 and 881, and it indicated that at around 1000°C about 70 per cent of the available nitrogen was released as hydrogen cyanide.

In order to verify the earlier work and to study the problems further in relation to commercially available foams, a series of experiments was carried out using the same tube furnace, other apparatus and techniques as before (see FR Notes 769, 851, 870, 880 and 881). As in the earlier tests a basic "reference" polyether foam was also tested for comparative purposes and the test temperatures chosen were 600°C and 900°C since the former was suitable for the examination of the polyol residue and the latter was sufficiently high to decompose the yellow smoke.

Brief details of the flexible TDI foams are as follows:-

Type	Main qualities	Density (kg/m3)	Flame retardant	Composition		
				C%	H%	N%
"Reference"			No	61.3	9.0	4.1
D	Typical foam for furnishings	30	No	60.6	8.7	3.9
H	Special high resilience	50 - 100	No	60.3	8.2	5.1
F	Similar to D	30	Yes	57.6	8.1	4.3

The experiments demonstrated that the decomposition of the three commercial foams was similar and comparable to that of the reference foam. Any slight difference in the behaviour of the Type H foam was attributable to the relatively high nitrogen content which could make it similar to the rigid foams which contain up to 8.9 per cent nitrogen.

The flame retardant may have altered slightly the decomposition products of the polyol but the effect is not clear and may be investigated later.

The analyses carried out clearly showed that the foams can be identified by these means. All the three commercial foams behaved as expected and, in particular, the nitrogen containing products (mainly hydrogen cyanide, acetonitrile, acrylonitrile, pyridine and benzonitrile) were released at temperatures above about 800°C. At above 1000°C all available nitrogen may be released as hydrogen cyanide.

Synopsis of FR Note No.914

EXPERIMENTS WITH SPRINKLERS IN HIGH RACKED STORAGES
(2) EXTINCTION WITH FACE-MOUNTED SPRINKLERS

by

P. Nash, N.W. Bridge and R.A. Young

A series of 8 experiments was carried out at Cardington using the racking and 32 pallet loads of cartons described in FR Notes No.814 and 916 but with the sprinklers installed on both faces of the racking instead of centrally as in all the other experiments. Closed sprinklers were fitted everywhere except for the central (vertical) positions which were fitted with open or closed sprinklers as required for each experiment and, as described in FR Note 916, the water was turned on by hand when the flames had reached a predetermined height. There was a pressure of about 6 bars in all the experiments. The centrally mounted sprinklers were left in place as a second line of defence.

Some fires were lit at a tear in a carton on the face of the stack and some in the centre, in both cases near the bottom middle of the racking. Some temperature, radiation and smoke obscuration measurements were recorded and so was the moisture content of the cardboard.

Conventional, spray and sidewall sprinklers were tried, some perpendicular, some at right angles to the face and some sidewall heads angled at 20° to the perpendicular. In the first three experiments extinction was eventually achieved only with the central sprinklers and therefore angled sidewall sprinklers were used in the remaining experiments so that the water bounced off the pallet above towards the central flue and also ran down the face of the cartons.

The remaining experiments using the angled sidewall sprinklers established the success of this arrangement provided the water was turned on in time to a sufficient number of heads. Neither the temperature nor the radiation reached dangerous levels.

It was concluded that sprinklers of the angled sidewall type (in the absence of a special design) could be reasonably effective if positioned on the face of the racking but that this system was less satisfactory than one employing centrally mounted sprinklers, in both cases having open heads operated in a zone or group by a line detection system.

Other disadvantages of the face mounted system are the additional pipework required, the damageable situation of the heads and the difficulty of fitting heat shields to prevent cooling by water from above (this would apply to closed heads only).

Synopsis of FR Note No.915

THE USE OF FIRE EXTINGUISHERS IN DWELLINGS

by

G. Ramachandran, P. Nash and Miss S.P. Benson

Fires in dwellings attended by the fire brigades in 1969 were reviewed for the purpose of determining what effect, if any, fire fighting action by the occupants before the arrival of the brigade had on the fire severity. Although fires not attended by the brigade are not included in the review it is considered that the 45,876 incidents analysed are representative of the general experience and give a fair indication of the effectiveness of the various first aid methods.

In FR Note No.904 it was suggested that about 6 per cent of households owned fire extinguishers of which about 50 per cent were actually in the dwelling. Apart from extinguishers, of which dry powder and water were the most common, the other first aid methods considered in this review were buckets, hose, sand, smothering, beating, removal, etc. etc. and the Note contains tables and graphs showing the number of fires attacked by each method, the proportion successful and the approximate time taken to control the fires.

The proportion of fires extinguished by the occupants during 1969 was approximately the same whether in dwellings or in other buildings and it seems therefore that in the early stages of fire growth a fire is no less severe in a dwelling than in industrial premises although, of course, the fire risk in the latter could be quite different. The results of this review could have general application, bearing in mind that occupants of dwellings probably have less training and experience in fire fighting methods than those in industrial buildings.

About 47.4 per cent of all dwelling fires were attacked by the occupants (52.6 per cent were not attacked) and of these about 42 per cent were extinguished before the brigade arrived. The 47.4 per cent of fires attacked were divided as follows:- 44.3 by 'Sundry means' 2.9 by extinguishers and 0.2 by various other means such as hose reels, jets, etc. The occupants were successful in extinguishing 43 per cent of fires tackled with 'Sundry means' but only 27.5 per cent of those attacked with extinguishers.

Any initial attack by the occupant, although unsuccessful, was an advantage in that the subsequent duration of the fires was reduced. About one fifth of all the fires were effectively extinguished by the occupants.

Although 'sundry means' were more effective than extinguishers in dealing with the fires, the relatively poor performance of the latter was probably due to lack of training, distance of the extinguisher from the fire, and the inadequate size of some appliances. However, CO_2 and dry powder extinguishers were almost as effective as 'sundry means'. The most common method of attack was by buckets (8000 fires out of 21,724 attacked) and this action was successful in 34 per cent of the fires so attacked. 'Removal' in about 5000 fires was 50 per cent successful. Although 'beating' was seldom used this was effective in 68 per cent of the fires dealt with in this way and the least effective means of initial attack were garden hose and hose reels.

The number of fires analysed was not sufficient however to enable definite conclusions to be drawn regarding the effectiveness of individual extinguishers nor of other specific means of extinguishment.

Synopsis of FR Note No.916

EXPERIMENTS WITH SPRINKLERS IN HIGH RACKED STORAGES
(1) EXTINCTION WITH CENTRALLY MOUNTED SPRINKLERS

by

P. Nash, N.W. Bridge and R.A. Young

Initial experiments on high racked storage were carried out in the Models Laboratory at the Fire Research Station (see FR Note No.814) and these were followed by larger scale experiments at Cardington (see FR Note No.866) when it was found that the sprinklers which were installed along the longitudinal centre line of the racking with heads over each vertical gap between the pallet loads adequately controlled the fires but did not stop the flames reaching the top of the racking. Horizontal spread was prevented but the flame tips passed the sprinkler heads before they opened.

A further series of experiments was therefore carried out at Cardington using the original Models Laboratory racking which was 16 ft long, 8 ft 2 in deep and 18 ft 6 in high containing 32 pallet loads (full except for the last experiment when they were only two-thirds full) consisting of cardboard cartons with empty steel drums and wood wool packing inside. There were eleven experiments in all. The sprinkler heads in the vertical centre line of sprinklers could be left open and the water was turned on by hand, at a valve 2 m from the bottom of the rising main, when the flames had reached a predetermined height. Each experiment was an advance on the previous one in that the flames were allowed to progress further before the water was turned on and different levels of the sprinkler heads were left open. In the final experiment closed heads were used throughout, operating automatically, with the pallets only two-thirds full. The water pressure was, generally, kept to 7 bars (100 lbf/in^2).

Each fire was lit with a match at a tear in the side of a carton on the bottom layer between the two centre pallets, near the face. With the pallets full the flame spread from the ignition point was mainly up the face of the stack, the flaming gradually moving into the centre as the flame height increased. However, in the final experiment the flame spread was up the centre of the stack probably because the pallets were only partially filled but, even so, the flames still reached the top of the racking.

It was found that, in general, a single sprinkler head had to operate at least one full racking level in advance of the flames in order to be effective. A single head should be sufficient to arrest a fire if it could be made to operate soon enough and was in a suitable position to do so. A vertical zone or group of several heads operating together would be a more certain way of controlling a fire and the size of the zone would depend on the combustibility of the goods, and between 2 and 6 heads would probably be needed. In order to operate these heads considerably sooner than the present individual thermal heads it would be necessary to devise a reliable line detector system to bring a head or a group of heads into operation in advance of the flames.

During the experiments measurements were made of temperatures, radiation and optical densities at various positions in and around the racking. The maximum radiation recorded at a distance of 1 m in these tests was 0.65 watts/sq cm which is less than one-tenth of the intensity to ignite cardboard. In no case, when the fire spread was arrested, did the temperature in the centre of the racking increase by more than 20°C.

Smoke measurements taken at the top of the centre of the racking indicated that a smoke detector set to operate at, say, 5 per cent obscuration would enable a fire to be detected before the flames spread beyond the pallet level of fire origin. The cardboard moisture content was recorded but any influence this had on the fires was masked by other factors.

Synopsis of FR Note No.917

SURFACE TEMPERATURES OF A DIESEL ENGINE AND ITS EXHAUST SYSTEM

by

P.S. Tonkin and C.F.J. Berlemont

Diesel engines without electrical starting mechanisms may be used on fork lift trucks etc., in areas where flammable gases or vapours are present and in those circumstances hazards can arise from high surface temperatures, the emission of sparks from the exhaust, and flashback from gases being drawn into the engine through the air intake, and ignited by the engine itself.

In order to investigate these problems experiments were carried out on a $7\frac{3}{4}$ BHP single cylinder air cooled diesel engine with exhaust manifold and silencer outside the engine cowling inside which cooling air was circulated by a fan. The engine was arranged to drive a centrifugal water pump at various gearing ratios in order to provide a variable load on the engine. In some experiments the cowling was modified so that cooling air flowed over the exhaust system. Two types of spark and flame arrester silencers were used. The air intake cleaner was either the paper or the oil bath type but only the former was used in the engine tests and separate experiments were carried out on an oil bath air intake cleaner using propane/air gas mixture to determine the flame arresting properties.

It was tentatively accepted that 200°C was a safe maximum surface temperature but this temperature could only be achieved at full power with the engine under no load. Under full load one silencer reached 468°C but by diverting the cooling air over the silencer the temperature there was considerably reduced and with suitable design this method might be effective in keeping the silencer temperatures to a safe level without reducing the effectiveness of the main engine cooling. Alternatively and ideally the engine and exhaust system should be fully water cooled. By "derating" or reducing the engine power, temperatures were reduced but not sufficiently to be safe nor were they reduced to a safe level by alternately running the engine at full and idling speed.

The silencers which were of the centrifugal type were effective as spark arresters. The air intake oil bath filter was not effective as a flame arrester and crimped ribbon type arresters and cut off valves would be required to prevent flashbacks. It was found that 'temperature indicating' stickers which change colour when certain temperatures are reached were effective and reliable in operation as warning devices.

Synopsis of FR Note No.918

THE EFFECT OF THE VELOCITY OF FOAM JETS ON THE CONTROL AND EXTINCTION OF LABORATORY FIRES

by

D.M. Tucker, D.J. Griffiths and J.G. Corrie

A programme of 130 tests was carried out for the purpose of investigating the performance of different types of foam liquid at different expansions and sheer stress and at various rates of application to the surface of petrol and AVTUR fuel fires in a 0.28 m^2 (3 ft^2) inverted cone apparatus. Performance was judged by the 90% control and the complete extinction times and consideration was given to the implication of these results to the design of laboratory test equipment and methods.

Attention had been drawn to the difficulty of extinguishing petrol (N.B.P. fuel) fires when the foam was applied to the fuel surface as a jet, as opposed to gentle surface application, and this caused considerable concern. Tests in accordance with Defence Standard 42-3 (1969) had previously proved of value in controlling the quality of protein foam compounds but recent experience indicated that the test might not reflect the comparative performance of the newer foam liquids on larger fires of AVTUR fuel. The various foam liquids involved were - protein, fluoro-protein A & B, fluoro-chemical and synthetic A. The test apparatus was as described in Defence Standard 42-3 although the method of foam application varied during this recent series of tests. The preburn time was 30 s for petrol and 1 min for AVTUR, the latter taking longer to reach full intensity.

The Note contains tables and graphs showing full details of all the tests ie type of fuel expansion, drainage time, sheer stress, velocity of application and size of jet, control and extinction time. Details are also given of the ignition tests on some foams containing fuel since the mixing of foam and fuel during the foam application is often the cause of prolonged extinction times because flames continue to flicker around the contaminated foam. One result of the tests was to emphasise the wide variety of extinction "patterns". These patterns are dependent on many variables such as the type of foam liquid and even its batch number, the relationship between expansion and sheer-stress and the readiness of fuel to mix with the foam etc and it was impossible to cover all the eventualities and variables. Why proteins differ to the extent shown in the tests is a subject which obviously merits some study and uniformity in performance would be desirable.

At high sheer stress and high expansions foam tends to pile up at the point of impact but, on the other hand, foam of low sheer stress may disintegrate on striking the fuel liquid. Mixing of foam and fuel may make extinction impossible. Any 'general purpose' foam liquids should be tested for both gentle and forceful application. Forceful application can sometimes control a fire quickly but be ineffective in extinguishing it and there are wide variations in the performances of the various foam liquids on petrol and AVTUR fires and even in the quality of one type of foam.

These experiments illustrate the complex nature of the control and extinction of hydrocarbon fires by foam. Study is still required to define the process in detail and to develop valid laboratory fire tests. Both large and small scale tests should take account of the following principal factors:-

(a) the character of the foam liquid and the fuel at risk
(b) the expansion and sheer stress of the foam produced
(c) the method and conditions of application of the foam and any restrictions as regards its use.

The type of fuel has a major effect on the difficulty of extinction when forceful application is used. In aircraft crash fires the fuel may well be aviation gasoline or a wide cut fuel (JP4/AVTAG) and not a narrow cut kerosine (Jet A, JP5, AVTUR) and this factor must be taken into account when approving a foam liquid. The mutual emulsification properties of fuel and foam are important and even with motor spirit different fuel additives may influence the performance. Simple laboratory tests may be possible for assessing this compatability of foam and fuel.

Synopsis of FR Note No.920

FIRES IN OIL REFINERIES AND OUTDOOR CHEMICAL PLANT IN 1969

by

S.E. Chandler

Fires attended by the fire brigade (local authority) at oil refineries and outdoor chemical plants during 1967, 1968 and 1969 numbered 171, 204 and 242 respectively and of the latter figure 52 fires were in refineries and 190 in chemical plants (the 1967 and 1968 fires are not analysed).

In 1969 there were four large fires (£10,000+) in outdoor chemical plants but none in oil refineries.

The major causes of fires were spontaneous combustion, fixed equipment or machinery, steam or hot pipes, welding or cutting equipment, and kilns or furnaces.

Forty per cent of the refinery fires and over fifty per cent of the chemical plant fires were tackled before the arrival of the brigade but most of the other fires required the use of hose reel jets or jets from pumps or hydrants. Foam was used in 14 refinery fires and in 20 chemical plant fires during 1969 but there was no report of high expansion foam being used. Of the 128 fires extinguished before the arrival of the brigade, 32 were extinguished by fixed installations, 36 by extinguishers and 46 by hoses of various kinds.

Synopsis of FR Note No 921

THE PROJECTION OF FLAMES FROM BURNING BUILDINGS

by

P.H. Thomas and Margaret Law

In view of the growing interest in the use of external structural steel it was decided to re-examine in detail the earlier research work concerned with the emergence of flames from window openings. An attempt has been made to compare, correlate and summarize the scientific information which has been made available mainly as a result of work by Webster, Seigel and Yokoi, so that the resultant data can be augmented by information from the other sources.

The size and shape of the window openings affect the flame trajectory and with wide windows flames tend to emerge only a short distance and then cling to the wall above whereas with narrow windows air can get between the facade and the flames which therefore tend not to cling to the wall. There may, of course, be no wall above the windows, but on the other hand, projections and balconies may influence the flame behaviour.

Apart from the geometry of the windows, the type of fire, the rate of burning or heat release, and differences in defining the flame tip (visual or where there is a temperature of $540^{\circ}C$) added to the complications of comparing the existing research information but reasonable agreement was reached.

Although the comparisons are complex the authors come to the conclusion that it is possible to assess the length of a flame which does not lie against the wall whether or not the flame is considered as a driven jet or a buoyant plume even allowing for the uncertainties regarding the conditions of burning. The length and trajectory of flames could be affected by flammable linings, chimney effect from a fire below, and wind.

Even so, it is not possible to make a complete assessment of the hazard from projecting flames since heat transfer from radiation around the flames must also be considered but this can be calculated once the position and temperature of the flames have been estimated. However, the heat transfer by radiation is so critically dependent on flame temperature that direct measurements of radiation are preferable when these are available.

Synopsis of FR Note No 924

FIRE RESEARCH IN EUROPE

by

D.I. Lawson

As a result of an approach to 42 European laboratories 17 of them answered a questionnaire regarding their basic research interests and resources and the information is tabulated in this Note. The main fields of activity and the staff involved on research and testing are indicated and brief details are shown of the experimental facilities and aids available at each laboratory.

Synopsis of FR Note No.925

COMPATIBILITY OF FLUOROCHEMICAL AND PROTEIN FIRE-FIGHTING FOAMS

by

T.B. Chitty, D.J. Griffiths and J.G. Corrie

A series of experiments was carried out in accordance with the Defence Standard 42-3 test, using the inverted cone apparatus of 0.28 m^2 (3 ft^2) surface area and a gentle foam application rate of 0.04 l/m^2s (0.05 gal/ft^2 min) and a 30 s preburn time, on a special grade of petrol (NBP fuel). Commercially available fluoro-chemical foam (now superseded by an improved grade) and a standard protein foam were used in the experiments both separately and mixed in various proportions either as a liquid or applied as separate foams both during and after extinction. Re-ignition and burnback tests were also carried out.

There were 9 extinction tests and all were successful. However, in the re-ignition experiments when the two foams were used together, either as a mixture or as separate foams, re-ignition occurred in every case and the mixing of the foams resulted in a substantial deterioration in burnback resistance. It was clear that the presence of a proportion of fluoro-chemical had an adverse effect on the protein foam, causing it to lose water by drainage at a very high rate and, also, when protein foam was applied after fluorochemical foam had extinguished the fire, the protection from re-ignition and repropagation was very much less than when either foam was used alone.

In an emergency, both foams could be used for extinguishment but their joint use should be avoided if possible in view of the considerable deterioration in post control protection.

The tests revealed the desirability of developing standard test procedures for re-ignition and burnback properties of foams which will take account of the age of the foam, the type of fuel and the fuel temperature etc. It is also necessary to develop a test method specifically designed to study the phenomenon of compatibility of foams.

Synopsis of FR Note No.926

VEHICLE FIRES ON MOTORWAYS IN 1969

by

S.E. Chandler

During 1969 there were 570 vehicle fires on the 1000 km of motorways in Great Britain producing a frequency of 0.57 fires per km as compared with 0.35 fires per km on other major roads. Included in the 570 fires were 182 car and 282 lorry fires, these being 32 and 49 per cent of the total respectively as compared with 49 and 23 per cent respectively for all road vehicle fires and therefore lorries have a comparatively bad record on motorways. The general accident rate per km on motorways compares favourably with that for other roads.

The Note contains tables giving details of the time of call, sources of ignition, method of attack before brigade arrival and method of extinction.

Regarding lorry fires, these were most frequent between 0800 and 1200 hours and tyre and frictional heat was the most common cause (about 40 per cent of the lorry fires). The most frequent sources of ignition of all motorway vehicle fires were - engine (27 per cent), mechanical heat and sparks (26 per cent) wire and cable (18 per cent) and exhaust pipe (13 per cent). Only 24 fires were attributed to collisions.

Almost 30 per cent of the fires were extinguished before the arrival of the fire brigade and of those tackled early but unsuccessfully only 6 per cent required the brigade's jets (other than hose reels) as compared with 20 per cent of those not tackled before the brigade's arrival. CTC extinguishers were successful on 62 per cent of the occasions on which they were used but only 30 per cent of the dry powder extinguishers were effective. It is expected that other vaporizing liquid extinguishers would be as effective as CTC but they were not often used.

There were only four deaths due to fire injuries on motorways out of a total of 185 fatal casualties which compares favourably with the casualty rate for other roads.

Synopsis of FR Note No.927

EXPLOSION PRESSURE ABSORPTION WITH A METAL FOAM

by

S.A. Ames

An investigation was carried out into the use of the new metal foam material "Retimet", (see FR Note No.809) as an absorbent and cooling material inside a sealed vessel so as to reduce the explosion pressures inside, for instance, enclosures containing electrical equipment installed in flammable atmospheres. This arrangement might be a valuable alternative to flame arresters if there was a possibility of arrester blockage as a result of pollution.

A cubical steel vessel of $^1/10$ cu ft (2.8 litres) capacity with walls $\frac{1}{2}$ in thick was used in the experiments and this was fitted with inlet and outlet pipes with valves and a pressure sensitive transducer to measure pressure changes. Various grades of "Retimet" were used from 10 to 80 pores per inch. This material was $\frac{1}{2}$ in thick and was cut to the same cross sectional area as the vessel. One piece was placed against the inside of the vessel wall containing the inlet pipe and another against the wall with the outlet pipe. In some experiments a piece was also placed on the floor of the vessel and additional wall pieces were used.

The vessel was filled with an explosive mixture of gas. Propane, ethylene and hydrogen/air mixtures were used in such proportions as to produce the highest explosion pressure and the mixtures were ignited by an electric spark in the centre of the vessel.

It was found that the presence of the metal foam inside the vessel substantially reduced the explosion pressure but that the degree of reduction depended on the grade of Retimet and the proportion, by volume, of the vessel occupied by the foam. The presence of 50 per cent of 45 grade foam (45 pores per inch) reduced the pressure from 90 p.s.i. (620 kN/m^2) to about 12 p.s.i. (83 kN/m^2). Grade 10 Retimet was not so effective but grades 30, 45, 60 and 80 all produced similar good results.

The theory is that when the gas mixture in the free volume is ignited and expands, it compresses the unburnt gas in front of it until the flame reaches the metal foam whereupon the reaction stops and the remainder of the mixture is unheated and compressed inside the foam. The theoretical calculations were in close agreement with the practical results for all the finer grades (above 30) of the metal foam and it was evident from this theoretical work that there was no cooling of the hot gases by the foam before the maximum pressure developed, a factor which would not have been apparent from the tests alone.

Synopsis of FR Note No 928

THE DETERMINATION OF MAXIMUM PERMISSIBLE OXYGEN CONCENTRATIONS IN A SMALL SCALE VERTICAL TUBE DUST EXPLOSION APPARATUS

by

P.S. Tonkin and P.J. Fardell

The oxygen concentration in dust laden atmospheres can be reduced by dilution with inert gases such as nitrogen, CO_2 or argon so that explosions are prevented and this is often a more economic safety method than venting or constructing pressure enclosures. At present, dusts are classified as (a) or (b), the former igniting and propagating flame but the latter not doing so, and the test procedure is described in Fire Research Technical Paper No. 21, the apparatus concerned being a modified furnace operating at a relatively high temperature with a large source of ignition.

It has, however, been shown that the maximum permissible oxygen concentrations as determined in the furnace test are unnecessarily low when considered for application to many industrial situations in which large sources of ignition are absent. Explosibility results using a small scale vertical tube have indicated that this apparatus might be suitable for determining the maximum permissible oxygen concentration when there is no severe source of ignition. This apparatus, which consists of a vertical explosion tube 12 in long and $2\frac{1}{2}$ in in diameter with ancilliary equipment, was therefore modified and numerous experiments were carried out on group (a) dusts of phenol-formaldehyde resin, diphenylol propane, caprolactum, protein, wood, aluminium and magnesium, using nitrogen as the inert gas.

The Note contains a table and graphs of the experimental results and compares them with those obtained using a large scale vertical explosion tube of industrial proportions and the furnace test. In the small scale vertical tube experiments the dust was either suddenly dispersed or there was a continuous dust dispersion, and the ignition source was either an electric spark or an electrically heated coil. In respect of those tests where there was no propagating flame beyond the vicinity of the ignition source, the results were in reasonable agreement with the values obtained using the large scale vertical explosion tube. It was concluded, therefore, that the small scale apparatus could be used as a basis for determining oxygen levels in industrial plant that will ensure safe and economic working. Further, it was found that the method used in these experiments for obtaining oxygen/inert gas mixtures could be used successfully with the Standard test apparatus (FR Technical Paper No. 21) for measuring maximum pressure and rate of pressure rise with explosible dusts in reduced oxygen atmospheres.

Synopsis of FR Note No.929

AN APPLICATION OF THE THEORY OF EXTREME VALUES FOR ESTIMATING THE DELAY IN THE DISCOVERY OF A FIRE

by

G. Ramachandran

The statistical theory of extreme values has previously been referred to in FR Notes Nos. 837 and 910. In brief, it means that if the "probability distribution" or general pattern of the problem is established then any "extremes" data, either maximum or minimum, can be used to complete the whole picture. In order to demonstrate one possible application of the theory, information was provided by the Fire Visiting Team of the Fire Research Station regarding the maximum delay in calling the fire brigade to 14 industrial fires where there were no automatic detectors. These were one or more jet fires, ie in that sense "large", and the maximum delay time was taken as the time from when there was definitely no fire, such as when the premises closed for the day, to the actual time of discovery, and these delay times varied from 13 to 361 min. The actual time of ignition is, of course rarely known.

It is assumed that, as a first approximation, the probability distribution of the delay time is of simple exponential form. Once a fire starts there is a probability of discovery and this probability increases with time although some fires may never be discovered. Using the appropriate mathematical expressions of the theory it is estimated that for the sample of 14 fires considered, the most probable maximum delay was 68 min and on this basis it is estimated that the average delay in discovering all "large" fires in industrial buildings without automatic detectors is about 110 min. The median or 50 per cent point is 77 minutes. The estimated delay times for the 14 fires considered ranged from 6 to 97 min. The precise nature of the probability distribution of delay time could, of course, be established if data were available for actual delays instead of maximum delays.

Assuming that it is possible to determine the time taken from ignition for a detector to operate, the reduction in delay brought about by a detection system could be estimated and its economic value assessed.

It is considered that the application of the extreme value theory and of certain realistic assumptions can be a valuable research tool in determining the influence of various factors causing delays, although larger samples of fires and other refinements in the methods of estimation would be desirable.

Synopsis of FR Note No.930

GEOGRAPHICAL DISTRIBUTION OF LARGE FIRES DURING THE PERIOD 1966-1970

by

G. Ramachandran

This Note contains tables giving brief information on the number and values of large losses (£10,000+) in each fire brigade area during each of the years 1966-1970 and the total data for the five years. The basic information was supplied by the British Insurance Association and for each year and each brigade (with more than about 2 losses per year) the information shown is the number of large fires and the total loss in £'000 which has not been adjusted for inflation.

There is considerable geographical variation in the frequency of large fires and the total loss in these fires. The following is a summary of the main totals for the five year period 1966-70 inclusive:-

Brigades	Number of large fires	Total loss (£'000)	Loss per large fire (£'000)
County	2711	74896	64.5
County Borough	1605	99944	62.2
Scottish	579	30568	57.2
Northern Ireland	149	8033	53.9
	(Unknown 12)		
United Kingdom	5056	313798	62.0

The yearly breakdown for the United Kingdom is as follows:-

United Kingdom

	1966	1967	1968	1969	1970
Number of large fires	890	928	1005	1118	1115
Total loss (£'000)	48370	55708	61564	78212	69944

Most of the frequency increase can be attributed to inflation.

The average number of large fires in Northern Ireland during the four years 1966-69 was about 22 but in 1970 the total was 58 and this increase was due to factors other than inflation.

Synopsis of FR Note No.931

PERFORMANCE OF METAL FOAM AS A FLAME ARRESTER
WHEN FITTED TO GAS EXPLOSION RELIEF VENTS

by

Z.W. Rogowski and S.A. Ames

A series of experiments was carried out to examine the effectiveness of the new metal foam material "Retimet" (see FR Note No.809) as a flame arrester when fitted to industrial equipment for use in areas where flammable gases or vapours may occur. "Retimet" is made with various pores per square inch eg 10, 20, 30, 45 etc but only grade 45 was used, although samples representing the coarsest and the finest in the 45 grade were tested, the former causing less pressure drop in the standard permeability test.

Strong cubical steel explosion vessels of $^1/10$, $^1/3$ or 1 ft^3 (2.8, 9 and 28 litres respectively) were provided with circular vents of 2.5 or 4.3 inch diameter in the top flanged cover to which the, approximately, $\frac{1}{2}$ inch thick metal foam was fitted and held in place by a circular steel collar bolted to the top cover. The vessel was placed in a 14 ft^3 test chamber having one side of polyethylene sheet. There were three pairs of ignition electrodes in the vessel placed along the central vertical axis at different distances from the vent and there was a pair of electrodes close to the polyethylene sheet in the test chamber. Flammable gas mixtures of 4.2% propane/air or 6.5% ethylene/air were fed into the steel vessel and the mixture passed through the metal foam arrester into the test chamber also.

The gas mixture in the explosion vessel was exploded by using one of the three electrodes and if the mixture in the test chamber did not also explode at the same time it was finally disposed of by using the separate electrodes near the polyethylene sheet. The Note contains tables and graphs showing the venting factor K ie the ratio of the cross sectional area of the vessel over the total area of the vent, and the maximum explosion pressures obtained under the various venting and ignition conditions for the grade of metal foam involved, together with the equivalent performance of a crimped ribbon arrester. The result of each test regarding the effectiveness of the metal foam arrester in preventing the transmission of the explosion is also indicated.

After the initial explosion in the vessel fresh flammable gas was drawn into the vessel from the test chamber due to the cooling and contraction of the combustion products in the vessel. This fresh gas mixture can be ignited and burn close to the inner surface of the flame arrester, this process usually being audible. In order to examine the effects of gas burning on the surface of the metal foam a further series of "flash-back" tests was carried out. For this purpose a sample of the foam 1.4 in. in diameter was fitted at the end of a metal tube through which gas mixtures similar to those used in the main tests were fed at various speeds. As the gas emerged through the metal foam it was ignited with a match in order to see if the flame penetrated the foam and ignited the up-stream gas, or, if not, to what extent combustion occurred within the matrix of the metal foam. Temperatures were recorded and a note was taken of any damage to the metal foam.

It was found that certain simple modifications to the surface of the metal foam caused the flame to lift off the arrester surface thus reducing the heating of the metal foam matrix. This would be desirable since excessive heating and oxidation which occurred after repeated tests resulted in loss of plasticity and in cracking of the material. This trouble only arose when very small vent areas were used.

It is concluded that metal foam, particularly the finer grade when the pressure drop across the matrix is unimportant, can be an efficient flame quenching material and an effective arrester if the venting area is of sufficient size. In practice the arrester areas required to secure reasonable pressure reductions would be considerably in excess of the areas which could give flash-back of flames. The particular advantages of metal foam are lightness, corrosion resistance, and ease of installation. The foam arresters were found to be no worse than crimped ribbon arresters (see FR Note No.784) with crimp height similar to the pore diameter of the foam.

Synopsis of FR Note No.932

FAILURE RATES OF AUTOMATIC FIRE DETECTION AND ALARM SYSTEMS

by

E.D. Chambers

Special report forms provided by the fire brigades during 1968 in respect of fire calls to premises protected with an automatic detection system were analysed as regards false alarms in FR Note No.810. Out of 6218 calls to premises so equipped only 489 were genuine alarm calls.

A further analysis of the reports has now been carried out in respect of calls to actual fires in protected premises in order to find the reasons for alarm system failures. After scrutinising the reports and subjectively interpreting the limited information available it was concluded that there were about 460 fires in premises protected solely by an automatic fire alarm system.

It was found that in 8 fires (1.7%) there was a complete failure of the system and in a further 8 fires there was a failure in the brigade connection only. In many other instances the alarm did not work or was late in operation mainly due to the presence of a person or persons who detected the fire at an early stage and, consequently, it could not be said that the system failed since it was not, in fact, put to the complete test. The balance of 442 fires has been classified as "Sensitivity Non-operations, Late operations and Systems discoveries" and includes 2 fires where there were only minor faults.

The reasons for the 16 failures mentioned above were varied and were as much human as technical. The brigade connection failures were probably not too serious since the local alarm may have caused someone to call the brigade earlier than would otherwise have been the case.

It is emphasised that since much of the information in the reports was inadequate in some measure the statistics produced are only approximate.

Synopsis of FR Note No.933

STORAGE PROPERTIES OF FOUR FOAM LIQUIDS
(Interim report)

by

T.B. Chitty, D.J. Griffiths, D.M. Tucker, and J.G. Corrie

The storage characteristics of some newer types of foam liquids used for the control of hydrocarbon fires is being investigated at the request of the Defence Materials Standardisation Committee and, in this interim report, the results of tests after the first year of the proposed 2 year storage period are discussed. Samples of commercially available protein, fluoroprotein (A & B) and fluorochemical foam liquids in diluted or concentrated form (as recommended by the manufacturers) have been stored at $38^{\circ}C$, at room temperature (about $15^{\circ}C$) and subject to a number of freezing cycles ($-18^{\circ}C$ to room temperature).

Samples were withdrawn from storage and allowed to reach room temperature before being subjected to the U.K. Defence Standard 42-3 Issue I test using the 3 ft^2 circular inverted cone apparatus containing petrol as the fuel. The laboratory apparatus produced foams, from various concentrations of the foam liquids, with expansions of from about 8 to 12 and with a shear stress similar to that obtained from a No. 2 branchpipe when using the new liquids in the earlier tests. The preburn time was 30 s and foam was fed gently on to the fuel surface at the perimeter of the fuel tray for a period of 4 min. Radiation was measured, and drainage of the foam was recorded at 5 min because some of the foams were fast draining and at the standard 10 min the measuring tube would have been overfilled.

The Note contains tables showing some details of tests viz: storage time, expansion, shear stress, 25% drainage time, 75 and 90% control times, extinction time, and the 5 min fire drainage percentage, together with the minimum concentration of the foam liquid necessary for maximum effectiveness. This information is also indicated in graph form for each type of foam liquid and a table summarises the changes in each foam liquid arising from the storage.

It was found that, in general, the time to control the test fire did not increase when using the foam liquids at the recommended concentrations of 4 or 6 per cent but it was apparent that changes in the properties of the liquids were occurring during storage. There was often a decrease in the 25 per cent drainage time, ie the cold foam was draining faster, and an increase in the 5 min fire drainage percentage indicating that after application the foam was being lost at a faster rate and these changes were associated with a fall in shear stress. Storage at 38°C did not appear to accelerate the deterioration in every case as compared with storage at room temperature but in some instances freezing caused a marked deterioration.

There were some marked differences between manufacturers' products and even in the different drums of the same batch. In some cases there was appreciable deterioration in performance when the foam was used at concentrations lower than those recommended. Deterioration did not follow a simple pattern and, as stated, this is only an interim report.

Synopsis of FR Note No.934

A RELATIONSHIP BETWEEN THE FIRE RESISTANCE OF COLUMNS AND THE COST OF CONSTRUCTION

by

D.V. Maskell and R. Baldwin

The Fire Research Station has a current research programme under which all available statistics and experimental data are analysed in order to assess the costs and benefits of fire protection and in this Note the construction costs of a simple fire protection system, ie the provision of fire resistance to columns, both reinforced concrete and steel, are studied.

The various degrees of fire resistance required under Part E of the Building Regulations 1965 depend on the occupation, the height and the internal area and cubic capacity of the building, the degrees of resistance recognised are $\frac{1}{2}$, 1, $1\frac{1}{2}$, 2 and 4 hours. The "deemed to satisfy" provisions under Schedule 8 of the Regulations have been priced, as indicated in FR Note No.905, for a steel column 8 in x 8 in and a 6 in square reinforced concrete column. Although the costs of treatments considered in this Note have been attributed to fire protection, some treatments may be required on aesthetic grounds or solely for load bearing etc and in that event the function having the highest priority would, in practice, be allocated the costs involved.

Costs of protection of the two types of column have been plotted on graphs in the Note as a function of the fire resistance. It can be seen that the relationship between that cost and the fire resistance is approximately linear, the straight line being in the form cost = A + BR where A and B are constants and R is the fire resistance in hours. The straight line is gradual for steel but steeper for concrete. In the case of the former the main cost factor is the application of the treatment, any increase in thickness etc being relatively small. In the case of concrete columns, it may be found in practice that the load bearing requirements are more onerous than the fire resistance requirements, the additional fire resistance being, therefore, a bonus.

From the data considered it was found that the formula A + BR produced costs within a maximum error of 5% for protected steel and within 10% for concrete columns which would seem to be an acceptable margin and the formula will be used in subsequent cost-benefit analyses.

Synopsis of FR Note No. 935

PRELIMINARY ANALYSIS OF FIRE REPORTS FROM FIRE BRIGADES IN THE UNITED KINGDOM, 1971

by

S.E. Chandler

A first analysis of the fire brigades' K433 report forms indicates that the brigades attended 253535 fires in the U.K. during 1971 and estimates supplied by the British Insurance Association show the total direct monetary loss at £128.7 M which includes damage caused by civil disturbances in Northern Ireland.

Fatal casualties numbered 782 and non-fatal casualties 4883 and, for the first time, this annual summary of the reports includes brief details regarding casualties viz:- nature of injuries, sex and age of fatal and non-fatal casualties, the month and type of risk involved and the source of ignition. Numbers are also provided of the persons rescued or escaping by emergency means. All the information regarding casualties is subject to revision when outstanding reports are received.

Synopsis of FR Note No.936

FIRES IN BUSES, COACHES AND MINI-BUSES

by

I.B. O'Hara and Shelagh Lewis

The number of fires reported by the fire brigades in the U.K. in buses, coaches and mini-buses rose from 190 in 1964 to 562 in 1969 although the number of these vehicles and the millions of miles travelled declined slightly; in fact the number of fires per million miles travelled trebled in this period and the number of fires per 1000 such vehicles rose from 2.5 in 1964 to 7.1 in 1969.

The initial theory that mini-buses were responsible for the deterioration was not substantiated since only 10 per cent of the reports examined related to these vehicles, although the actual number of mini-buses at risk was not known.

An examination of a 1 in 2 sample of the 1969 fire brigade reports was carried out and the Note contains tables showing the supposed cause of fire, the location of the fire in the vehicle and the location of the vehicle itself, the month and time of day, the vehicle's age, and the method of fire fighting both before and after arrival of the fire brigade.

In general, the fires occurred at the times when the particular type of vehicle was in greatest use, as would be expected, and mostly when the vehicle was on the road.

The majority of fires (58 per cent) started in the engine compartment mainly through overheating causing the ignition of oil and grease and to a lesser extent through electrical faults. Fifteen per cent of the fires started inside the vehicle itself and a number of fires resulted from overheating of brakes, and friction caused by deflated tyres.

About 60 per cent of the fires were tackled before the fire brigade arrived and of these about 20 per cent were extinguished by that time. The most common method of fire fighting was the C.T.C. extinguisher but this was only successful in 52 cases out of 216. Other methods, eg foam, water, dry powder, disconnection of fuel supply etc were used less often but were proportionately more effective. In 55 per cent of the fires fought by the brigade only one hose reel jet was required and only in 6 per cent of the fires was it necessary to use jets fed from pumps and hydrants.

The overall rate of fire casualties (fatal and non-fatal) was 16 per thousand fires in 1968 as compared with 34.1 in tanker fires.

Synopsis of FR Note No.938

THE PERFORMANCE OF SOME PORTABLE GAS DETECTORS WITH AVIATION FUEL VAPOURS AT ELEVATED TEMPERATURES

PART I - TESTS WITH N-HEXANE, 'AVTAG' AND 'CIVGAS' VAPOURS

by

P.J. Fardell

Portable gas detectors or "explosimeters" are now used to give an indication of the explosive nature of a mixture of flammable gas or vapour and air, and they work by passing the mixture over a heated catalytic filament where oxidation takes place. The heat evolved by the oxidation raises the temperature and hence the resistance of the filament which forms one arm of a Wheatstone bridge circuit thus enabling the out of balance electric current to be registered on a galvanometer. When properly designed and calibrated these instruments can be used to detect the lower explosion limits (L.E.L.) of flammable gases or vapours. They may either give an alarm when dangerous conditions are reached or they may give quantitative readings over the range 0 - 100% L.E.L.

There was some uncertainty regarding the efficiency of the commercially available explosimeters under all conditions and a method was devised for testing these portable gas detectors under high or tropical ambient temperatures and low humidity using various fuels. Five proprietary instruments were tested using n-hexane, 'Avtag' and 'Civgas' vapours at 65°C and n-hexane vapour at 25°C.

The laboratory apparatus is fully described in this Note. The vapour is fed into an explosion tube contained, together with the explosimeter to be tested, in an oven enclosure maintained at the required temperature. The ancilliary equipment and the test procedures are also described in detail.

It was found that the detectors tested did not give accurate indications of the concentration of 'Avtag' and 'Civgas' (4 star petrol) vapours in air and care is thus needed if the instruments are to be used for quantitative measurements (a purpose possibly not intended by the manufacturers). Also, a significant change in response was observed with an increase in temperature from 25°C to 65°C when testing n-hexane vapour in air. It is suggested that the calibration gas used by the manufacturer should be stamped on the face of the meter.

It is proposed to study further the effects of increased humidity and the detector performance in the 0 - 10% L.E.L. range. Also tests will be carried out using other aviation fuels. Reports on these further studies will be issued later.

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