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FIELD TESTING INERT GAS AND HIGH EXPANSION FOAM

by

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FIELD TESTING INERT GAS

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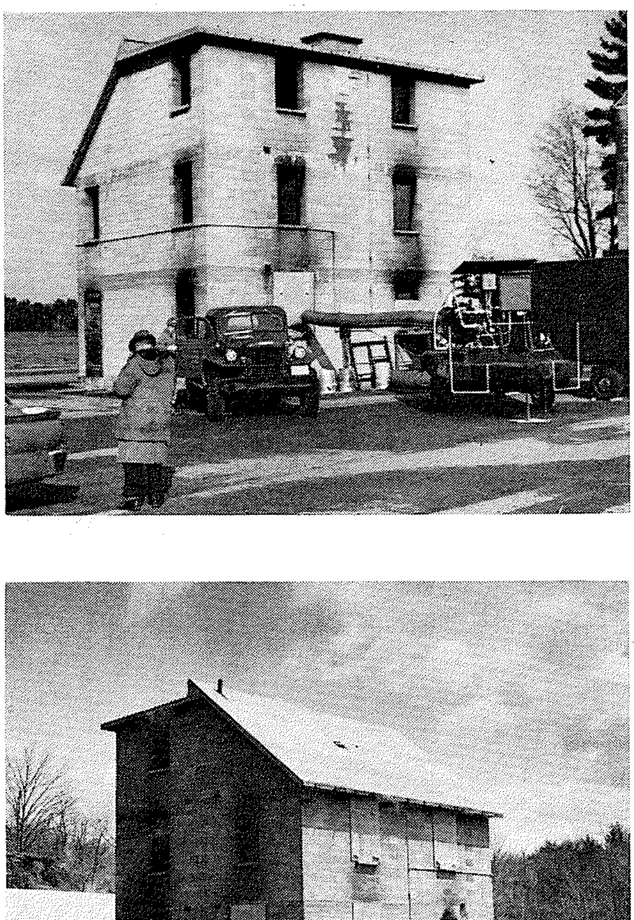

Figure 1. — Overall views of test building.

ABSTRACT

Extinguishment experiments in a three-storey test building are described. Inert gas, supplied by a high-efficiency combustion device with water injection cooling, behaved as would have been predicted theoretically. The high expansion foam was found to migrate most readily from enclosure to enclosure (a total of eight in succession) without undue breakdown. It is shown that the movement of foam, even in complex situations, is also largely predictable.

Inert gas, used on a massive scale, and high expansion foam have great potentialities as fire fighting agents. Work on both techniques originated in the United Kingdom within the last 15 years, where high expansion foam was developed by the Safety in Mines Research Establishment (U.K.)[1] for fighting mine fires. Its general potentialities were not immediately recognized in the U.K., however, and it was in the U.S.A. that it was applied to fighting building fires. A number of U.S. fire departments now possess high expansion foam units, and within a decade their popularity will almost certainly multiply manyfold. Several U.K. fire brigades, having noted the U.S. developments, have also acquired high-expansion foam units, but in Canada interest seems to be minimal at present. It is to be hoped that this agent will come into much greater use in the near future.

The massive use of inert gas for fighting building fires was made a practical possibility by D. J. Rasbash[2], of the Fire Research Station in the U.K., who suggested that it could be conveniently generated from the products of combustion of an aircraft gas turbine. Such a generator has been demonstrated to be a very effective fire-fighting tool. It will also generate high expansion foam whose gaseous phase has a lower oxygen concentration than that of air. This constitutes a most useful fire fighting medium; as it breaks down, it releases not air but a gas that will not so readily support combustion.

& HIGH EXPANSION FOAM

This paper is a contribution from the Division of Building Research, National Research Council, Canada, and is published with the approval of the Director of the Division.

A small generator based on a simple combustion device has been built at the Division of Building Research of the National Research Council, Canada, and a report on the limitations and applications of inert gas has been published.[5] More recently, Macaulay[4] of the NRC's Division of Mechanical Engineering has conceived and investigated theoretically the concept of a simple gas turbine burning a stoichiometric fuel-air mixture and having water injection between the combustion cans and the turbine. He found that such a turbine could deliver an oxygen-free gas mixture, would have the turbine's advantage of being compact, but would not involve the expense of the precision manufacture of the aircraft gas turbine.

Experimental use of inert gas and high expansion foam at NRC has so far been confined to an enclosed 40-ft cubed test area and a small wooden shed. Both media have proved most effective in extinguishing various fires, but two features have not been satisfactorily demonstrated. The first concerns the limitation to the use of inert gas, which has been shown theoretically[3] to be associated with loss of gas from high level openings. Accurate quantitative confirmation has been inhibited by the difficulty of assessing the area of the high level openings in the 40-ft cubed "burn area."

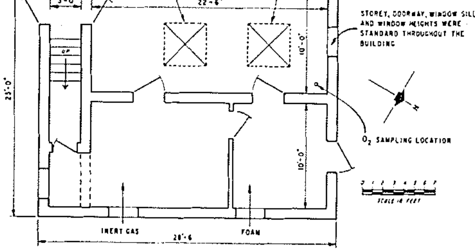

FIGURE 2 GROUND FLOOR PLAN, FIRE TEST BUILDING GRAVENHURST

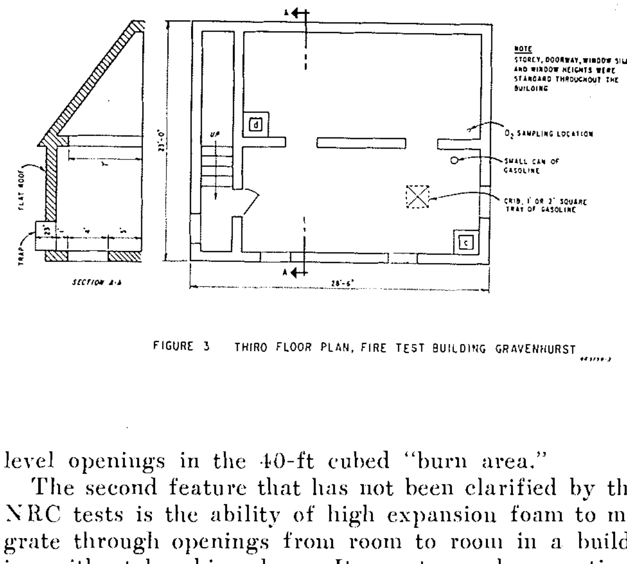

FIGURE 3 THIRD FLOOR PLAN, FIRE TEST BUILDING GRAVENHURST

The second feature that has not been clarified by the NRC tests is the ability of high expansion foam to migrate through openings from room to room in a building without breaking down. It was to resolve questions such as these that the Ontario Fire Marshal was good enough to make available to NRC the fire test building of the Ontario Fire College at Gravenhurst.

TEST FACILITIES

The NRC inert gas generator consists of a novel design of combustion chamber that burns a stoichiometric propane-air mixture, followed by a water-spray injection chamber to cool the hot products of combustion by the vaporization of water. It has an output of approximately 3300 cu ft./min at a temperature of about 90°C, with a composition of about 68 per cent water vapour, 28 per cent nitrogen, and 4 per cent carbon dioxide.

In the NRC high expansion foam generator[5] a dilute foaming agent solution is sprayed on a regular pyramid-shaped net (nylon, with base and slant dimensions of 29 in.) from a full cone nozzle. An axial flow fan is used to blow air through the wetted net to produce foam. The foaming agent solution used during the Gravenhurst tests was sodium lauryl sulphate, with an active content of 0.4 per cent plus butyl carbitol. The latter was a solvent used to reduce the problem of mixing sodium lauryl sulphate with water. This foaming agent, developed at the National Research Council[5], was used because exploratory experiments had indicated it to be very promising for the generation of high expansion foam with hot inert gas.

The Gravenhurst test building (Figure 1), is a 30-ft-high, three storey concrete block structure with concrete block partitions and reinforced concrete floors. The plans of the ground and third floors are illustrated in Figures 2 and 3, respectively. The second-storey layout is similar to that of the third storey. Independent enclosed stairways from ground to second floor and from second to third floors provide an interesting model for demonstrating the mobility of foam. Access to the third floor, for example, involves passing through five doorways and up two flights of stairs.

Heavy steel shutters were available on every window, but because some had been very badly warped by previous test fires they were closed off with ¼-in. plywood before any tests were carried out. During most of the tests the behaviour of the test fire was monitored by a chromel-alumel thermocouple a few inches above the fuel.

The east ground-floor windows were chosen as the injection points for inert gas and high expansion foam. During combined use the inert gas was fed into the duct supplying the gaseous component of the foam.

The oxygen measurements reported were made with an instrument of the magnetic susceptibility type, samples being withdrawn from the building through ⅜-in. copper and tygon tubing. The sampling rate was such that the results might include unreported errors of up to 1 minute.

INERT GAS GENERATOR TESTS

Four tests were carried out using inert gas as the extinguishing agent. In each case injection was at the location indicated in Figure 2 and the generator was operated at its maximum capacity of about 3300 cu ft/min. Two of the tests were largely demonstrative.

For the first test, fires were set on the second and third floor in small wooden cribs and in 3¼-in. diameter cans of gasoline. All exterior doors and windows were closed and all interior doors left open. Within 3 min of commencing injection the thermocouples over the crib fires indicated that they were out, but injection was continued for another 8 min to suppress smouldering by further reducing the concentration of oxygen. When the inert gas generator was turned off the oxygen concentration reading on the third storey was 10 per cent. Various doors and windows were opened and, after the atmosphere had cooled and cleared sufficiently to permit entry to the building, it was found that smouldering had been satisfactorily suppressed. From the level of gasoline in the small cans it was judged that the gasoline fires had been extinguished at about the same time as the crib fires.

For the second test a very large crib, about 4 ft cubed, was used to demonstrate that inert gas would extinguish such a fire as readily as it would a small fire. After a 3½-min pre-burn period with the main door and the roof vent open, both were closed and inert gas injection was begun. Although the generator malfunctioned for a period of about 1½ min, the fire was extinguished within 3 min. In all, the generator was left operating for 10 min, and when it became possible to re-enter the building, it was found that smouldering as well as flaming combustion had been successfully suppressed.

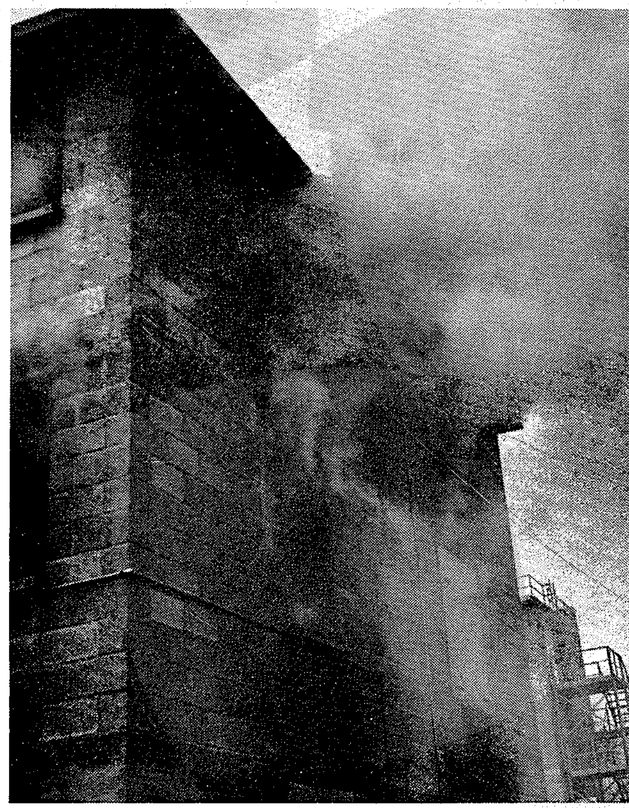

FIG. 4 — High-level loss of inert gas.

It was the object of the third test to examine the effect on oxygen concentration of having a high-level opening. One of the two shutters on each of the top windows on the east side was opened, giving an aggregate area of opening of 11 sq. ft. Small crib and gasoline fires, as for the first test, were set on the second and third storeys. Again, thermocouples were mounted over the cribs.

As will be seen from the results given in Table I, the fires were extinguished so rapidly that it became convenient to investigate the effect of further openings. The remark "low-level openings established" relates to the opening of the ground floor, south-side window (area 11 sq ft).

The thermocouple measurements have not been included in Table I because there was time for only two readings prior to the indication, 3 to 4 min after commencement of injection, that the crib fires had been extinguished. On re-entering the building, it was found that the fires had been as effectively extinguished as on previous occasions.

Comparison with theory of the results given in Table I is interesting. It was shown some years ago[3] that where air entry at a low level is unrestricted the critical area of high level opening to establish a completely inert atmosphere is given by

$$A = 3.86 \times 10^{-3} \, v/h^{\frac{1}{2}}$$

Where v = generator output, cu ft/min, and h = height, ft.

A later report[6] discusses vent areas exceeding the critical value. It shows that where an equilibrium oxygen content of 13 to 14 per cent is established, as prevailed after the low-level opening was created during the third test, the high-level openings are about four times the critical area. Using the above material (taking v = 3300 cu ft/min and h = 18 ft) gives a theoretical area of 12 sq. ft. A correction is called for, however, because the theoretical analysis relates to unrestricted low-level openings. Where the low- and high-level openings are equal in area, the neutral plane will rise to nearer the middle of the building and hence a factor of about $\sqrt{2}$ will be introduced. The final theoretical value will, therefore, be approximately 17 sq ft, which is in good agreement with the nominal measured value of 11 sq ft, bearing in mind that the latter does not include leakage around the roof vent, and various second and third floor windows, or through the concrete blocks themselves. Figure 4 shows the inert gas (which has a high water vapour content) flowing freely from two, open, third-storey windows 5 min after injection had commenced.

The object of the fourth test was to determine whether it was possible to extinguish a fire in a closed room by injection elsewhere in the building. All exterior doors and windows were closed, together with the door to the third storey, which did not fit as well as the average door in the building. The gap at floor level was almost 1 in., and elsewhere gaps of up to ¼ in. existed. Injection was, as previously, through one of the ground floor east windows.

The test fire, on this occasion, was from a 1 sq ft tray of gasoline and a thermocouple was used to register extinguishment, which occurred 15 min after the commencement of injection. A control experiment was carried out to determine whether, in fact, the fire would continue to burn indefinitely in the absence of inert gas injection. In this case, the fire burned as vigorously as ever 25 min after ignition and the oxygen concentration appeared to be approaching an equilibrium value of about 18 per cent.

Prediction of the conditions that would probably be established under the above circumstances is not practical because rate of burning in the room will be a vital but unpredictable governing variable. The rise of temperature in the room resulting from the fire will cause gas displacement and a consequent pressure differential that will constitute a back-pressure opposing flow of inert gas around the door and into the room. Such circumstances, in which rate of development of the fire will influence the extinguishing ability of an inert gas generator, will be the exception rather than the rule.

HIGH EXPANSION FOAM TESTS

Four tests were carried out using high expansion air foam. In each case foam was produced at the location indicated in Figure 2. The foaming agent solution was sprayed at a rate of about 29 U.S. gpm and the airflow through the wetted net was maintained at about 3400 cfm.

In the first test, the ability of foam to migrate up the stairways was investigated. Both exterior doors and all the windows on the ground and second floors were closed. All interior doors, the roof vent, and some third storey windows were left open. The ground floor (including the first stairway) was filled in 1 min 25 sec and the second floor in 2 min 5 sec. The ground floor was filled at a rate of about 2900 cfm, indicating the efficiency of converting air to the gaseous component of foam to be about 90 per cent. The second floor was filled at a rate of about 1900 cfm, indicating an efficiency of 60 per cent. The relatively high reduction in the rate of filling the second floor is to be expected because of the breakdown of foam as it is forced through the doorways and up stairways, and of losses of foam through gaps around exterior doors and windows.

In the second test a fire in a 2- by 2-ft tank containing 1 in. of gasoline floating on water was extinguished with foam. The tank was positioned on the third floor between the roof vent and the nearest window on the north side of the building. All exterior doors and windows were closed and all interior doors were left open so that foam would have to travel up the stairways. Fire was extinguished 4 min 40 sec after the start of foam production, as indicated by a thermocouple located just above the tank. Figure 5 shows foam coming out of the roof vent shortly after the fire was extinguished.

Figure 5. — Foam issuing from roof vent.

In the third test a fire involving two large wood cribs, each about 4 ft cubed, was extinguished with foam. Both cribs were located in the west room of the ground floor. After a 3-min pre-burn period with the exterior doors and roof vent open, the exterior door near the foam generator was closed and foam production was commenced. The fire was extinguished in about 3 min.

It was the object of the fourth test to determine whether it was possible to extinguish a small fire by means of foam passing through gaps around a door.

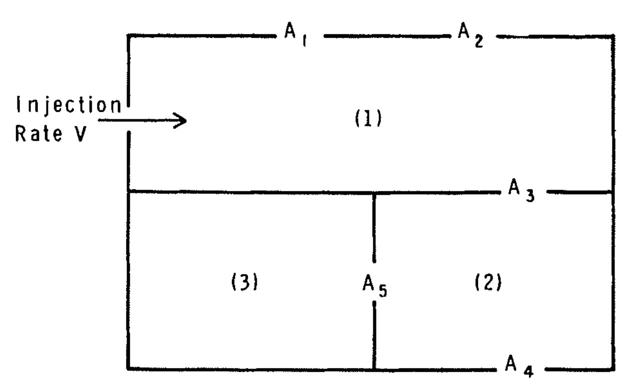

FIGURE 6 FOAM FLOW MODEL

Conditions similar to those for the fourth inert gas generator test were established. All exterior doors and windows were closed, together with the third floor door from the stairway. A 1-sq-ft tray of gasoline was used as the test fire.

Foam encountered considerable resistance at the closed door separating the stairway from the rest of the third floor. A gap at the floor level of almost 1 in. and gaps of up to ¼ in. elsewhere allowed some of the foam to enter the third floor proper and extinguish the fire in 15 min.

The test results suggest that foam flow through a building will usually follow a very simple and predictable pattern. The fact that during the tests it flowed satisfactorily through five doorways and up two flights of stairs indicates that, as a first approximation, viscous drag may be neglected. The pressure head created by a height of foam may also be neglected in most circumstances in comparison with the pressure that can be created by the foam generator.

Using the above assumptions, the flow of foam from a primary compartment to secondary compartments can immediately be predicted, because flow rates will be directly proportional to opening areas. Thus if faced with the arrangement illustrated in Figure 6, one would predict that, after compartment (1) was nearly filled, the flow rates V_2 into compartment (2) and V_{loss} out of areas A_1 and A_2 would be in the ratio

$$A_3/(A_1 + A_2) \text{ or}$$

$$V_2 = A_3V/(A_1 + A_2 + A_3)$$

$$\text{and } V_{loss} = (A_1 + A_3)\, V/(A_1 + A_2 + A_3)$$

Flow from secondary to subsequent compartments will involve greater complication than the case just discussed. Thus after compartment (2) has been filled, in the example, the flow impedance of areas A_4 and A_5 will begin to influence the flow rate through A_3. Flow velocities will no longer be the same through every opening and the problem will become non-linear. To a considerable extent, however, the non-linearity can be ignored and the influence of the flow impedance of A_4 and A_5 on the flow through A_3 can be calculated on a linear basis by analogy with electrical networks. The admittance of A_4 and A_5 in parallel is of course $(A_4 + A_5)$, and hence the admittance of A_3 and (A_4 and A_5) in series is

$$\frac{A_3\,(A_4 + A_5)}{A_3 + A_4 + A_5}$$

Thus the modified flow rate V'_2 into compartment (2) will be given by,

$$V'_2 = \frac{A_3'\,V}{A_1 + A_2 + A'_3}$$

$$\text{where } A'_3 = \frac{A_3\,(A_4 + A_5)}{A_3 + A_4 + A_5}$$

Assuming that compartment (3) has not yet filled, the division of foam between A_5 and A_4 will still follow the simple area proportioning law first enunciated.

$$\text{Therefore } V_3 = \frac{A_5\,V_2'}{A_4 + A_5}$$

A user could rapidly become familiar with the solutions to problems of this nature and hence could predict the likelihood of foam extinguishment in any given circumstance. The time, of course, could also be readily predicted.

COMBINED OPERATION

There are practical applications for high-expansion foam in which the gaseous phase has an oxygen content lower than that of air. Rasbash (7) in the U.K., has shown that foams using a gas with an oxygen content of some 16 to 17 per cent are much more effective in extinguishing flammable liquid fires than is air foam.

Another application of such foam is in fighting fires in large warehouses with high-piled stock or flammable roofing. It is not usually convenient to deliver foam from one appliance to a building at a rate exceeding about 10^5 cu ft/min, so that the complete filling of very large buildings may, on occasion, take 10 to 30 min. During this period it is desirable that flaming in the roof region be suppressed. Using an inert gas as the gaseous phase of the high-expansion foam will often achieve this. During the generation of high-expansion foam some 20 to 40 per cent of the gaseous component is usually not utilized, and where it has a low oxygen content it can be performing a useful function rather than supporting combustion as would air.

Generators of the types developed by the National Research Council and the Joint Fire Research Organization in the U.K. deliver gas at a temperature near that of boiling water. Exploratory tests conducted at Ottawa indicate that when the temperature of the gas is high the film stability of a foam is reduced and the drainage rate increased.

It was the object of the hot-gas, high-expansion foam tests to determine whether the lifetime and stability of the foam were adequate to permit filling of the Gravenhurst test building. To allow variation of the gas temperature, provision was made for mixing air with the output of the inert gas generator. The foaming agent used in the tests was one that yielded promising results in exploratory experiments, as stated earlier.

Both the exterior doors and all the windows of the test building were closed; interior doors and the roof vent were left open. In the first attempt to produce inert gas foam about 1500 cfm of air was mixed with the inert gas to give a mixture temperature of 78°C. Foam started coming out of the roof vent about 3 min 45 sec after the start of foam injection. Assuming that foam started issuing from the roof vent when the first two floors but not the third were completely filled with foam, the rate of filling of the building was estimated to be between 2200 and 3100 cfm, indicating efficiencies of 50 to 70 per cent. These values are of the same order as the efficiencies given by high expansion air foam.

The air flow rate was then reduced almost to zero, giving a gas mixture temperature of about 85°C and an oxygen concentration of less than 4 per cent. The rate of production of foam appeared to remain satisfactory, as was indicated by the continued flow of foam from the roof vent.

CONCLUSIONS

The test results indicate that in many circumstances the extinguishing abilities of inert gas and high-expansion foam will be predictable by the application of very simple theory. In this respect the techniques differ sharply from the conventional use of water for which extinguishment predictions are more of an art than a science.

Ability to predict, however, assumes knowledge of the building layout and disposition of doors, windows and other openings. At many building fires the fire fighter will not have such prior knowledge and will have to use the same "hit and miss" approach adopted in conventional fire fighting.

High-expansion foam appears to be such an effective fire-fighting medium under so many different circumstances that the applications for which the expense of an inert gas generator can be justified appear limited. Some will always exist, however, and certain classes of fire in the hold of a ship are a classic example. Similarly, in a densely packed warehouse it would be desirable to use high-expansion foam made with inert gas rather than with air, but it is debatable whether inert gas should be as readily available as high-expansion foam in the average township.

Table I

RESULTS OF THIRD TEST

Time (min.)	Oxygen Concentration (per cent)		Remarks
	Top Floor	Ground Floor	
−4			Fires lit
0			Injection commenced
3	18.5		
4	17.0		Fires extinguished
5	15.0		
6	13.5		
8	12.0		
10	11.2		
12	11.2		
14		9.5	Low-level opening established
16	12.0		
18	12.3		
20	13.5		
22	13.6		
23		12.5	
24		13.0	
25		12.8	
26		12.8	

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ESSAIS IN SITU D'EXTINCTION À L'AIDE DE MOUSSE A FORT FOISONNEMENT PAR GAZ INERTES

RESUME

Les auteurs décrivent les essais d'extinction d'incendie menés dans un immeuble expérimental de trois étages. Les gaz inertes, fournis par un appareil à combustion très efficace, se sont comportés conformément aux calculs théoriques. La mousse à fort foisonnement s'est déplacée très facilement, au travers de huit enceintes en enfilade, sans affaisement important. Les auteurs montrent que les déplacements de la mousse sont largement prévisibles, même dans les cas complexes.

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