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R.A.R.D.E. MEMORANDUM 31/69

Investigation into the manufacture and properties of magnesium/fluorocarbon compositions for pyrotechnic applications

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PART I

D. Jackson (Wallop Industries Ltd.)

Edited by: D. A. Dadley, (RARDE/E3

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ROYAL ARMAMENT RESEARCH AND DEVELOPMENT ESTABLISHMENT

R.A.R.D.E. MEMORANDUM 31/69

Investigation into the manufacture and properties of magnesium/fluorocarbon compositions for pyrotechnic applications

PART I

D. Jackson (Wallop Industries Ltd.)

Edited by: D. A. Dadley, RARDE/E3

Summary

The magnesium/fluorocarbon range of pyrotechnic compositions has been investigated to discover the control necessary to achieve a reproducible product with the desired burning characteristics.

The investigation has included the study of materials from all known sources and also the various stages of preparation between receiving the raw materials and testing the manufactured composition.

Approved for issue:
D. F. Runnicles, Principal Superintendent, 'E' Division

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1. INTRODUCTION

The postwar development of guided missiles launched against aircraft amd tanks led to a corresponding development of fuzes sensitive to heat or infrared radiation emitted by the exhaust systems of the targets. This, in turn, stimulated great interest in pyrotechnic devices capable of generating much of their energy in the same region of the spectrum in order to decoy missiles away from their objectives, to operate as practise targets for such missiles or to form essential parts of their guidance systems.

When pyrotechnic mixtures, particularly those containing magnesium powder as a fuel, burn, the energy they emit ranges from the ultraviolet to the far infrared regions of the spectrum. The distribution of energy throughout the spectrum varies for mixtures of differing ingredients and proportions, being more concentrated in the visual range for some of them and more in the infrared with others. Some of the infrared emission is absorbed by atmospheric gases leaving the following three bands of useful emission. Band 1, 0.4 to 0.7 microns (visible), band 2, 1.9 to 2.6 microns (infrared), band 3, 3.5 to 5.2 microns (infrared).

The basic ingredients of infrared compositions can be the same as those for visual ones, namely, magnesium powder and the nitrates of sodium, barium or strontium, and they can be used in either role with varying success. However, all such flares suffer from the effects of reduced pressure at altitude and their overall energy output is considerably diminished. Some years ago American investigators found that when mixtures of magnesium powder and polytetrafluoroethylene, a convenient source of fluorine, were burned, their energy output in the infrared region was superior at ground level to that of mixtures containing nitrates and was also less affected by altitude; hence they were considerably more effective as infrared emitters.

Prior to the commencement of this programme of work, these mixtures of magnesium and polytetrafluoroethylene gave extremely variable results when burned as pyrotechnic devices. This led to the present study of the pyrotechnic behaviour of mixtures of magnesium powder and all the obtainable fluorocarbons with the object of improving pyrotechnic infrared emitting devices and of determining the factors controlling the energy liberated during combustion.

2. EXPERIMENTAL TECHNIQUES

2.1 Methods of sieving powdered ingredients

Fractionation and particle size analyses were important to discover the control necessary, on the raw materials used, to ensure reproducibility and the best pyrotechnic performance from the manufactured compositions.

An Endecott test sieve shaker has been used throughout this investigation. No special precautions were necessary during the sieving of magnesium and polychlorotrifluoroethylene (PCTFE) and sieving was complete so long as the sieves were not overloaded. Polytetrafluoroethylene (PTFE) is however a difficult material to sieve due to a tendency to agglomerate and to the ease with which it becomes charged with static electricity. To overcome these problems the sieving process was modified as described below.

2.1.1 Sieving PTFE

The process developed for sieving PTFE consists of washing the powder through a nest of sieves with perchloroethylene while the sieves are continuously shaken. Since the perchloroethylene must be recycled for this process to be economically feasible, the apparatus shown diagrammatically in Fig.1 has been developed. This system ensures that no powder passing the bottom sieve will re-enter the top sieve.

Using the present apparatus, a batch of 150 to 200 grams can be sieved in 40 minutes, at the end of which time, the machine automatically stops shaking and washing. The powder is then tipped by hand from the sieves onto aluminium trays and dried in a forced air oven at 80°C-90°C under fume extraction hoods. To avoid clogging the sieves, the PTFE is removed by inverting the sieve over a tray and tapping the frame of the sieve. When changing to a different grade of PTFE, the sieve is washed in perchloroethylene and banged on a hard wooden surface to dislodge all particles adhering to the mesh. Brushing must be avoided as it merely clogs the mesh without removing any of the material.

Two filters are shown in the diagram for cleaning the perchloroethylene, the first large one being made for this purpose and including a specially treated paper element to remove all solid particles down to about 1-2µ size and activated charcoal to remove any oils and colouring. The second small filter is an automotive type and serves to trap any carbon which may be shed from the first filter. Perchloroethylene is added to the system at the sump so that it is cleaned in the filters before reaching the sieves.

2.2 Mixing procedures

As filling contractors, Wallop Industries Limited have a considerable amount of experience handling magnesium/PTFE compositions as currently made and are well aware of the shortcomings of these compositions. With this experience in mind, it was attempted from the beginning to rationalise the whole magnesium/PTFE system by limiting the number of variables, other than those being investigated, to an absolute minimum. One of the variables, as in any composition, is the degree of mixing and homogeneity of the completed mix.

The traditional methods of mixing magnesium/PTFE compositions was to place the two powders in a vessel with a suitable quantity of methylated spirit and to stir the mass until it appeared to be mixed. This gaveaan uncertain mix which tended to segregate on standing, particularly if too much methylated spirit was used. To overcome this a simple methods of mixing was developed which gave a reliable homogeneous product and incidentally allowed the handling of the finished product in a dry state.

The technique used depends on the introduction of 'Viton' into the composition. Viton is a trade name for a Du Pont product, a copolymer of hexafluoropropylene and vinylidene-fluoride. Like PTFE, it is a fluorocarbon but unlike PTFE it is soluble in ketones, although insoluble in most other solvents. Since Viton is similar in constitution to PTFE, when present in small quantities in a composition containing magnesium and PTFE, the characteristics of the compositions do not appear to be significantly altered. In use, for this purpose, the Viton is dissolved in acetone to form a solution of known strength, usually in the region of 18-22% wt. to volume. The type of mixer does not seem to matter provided that the ingredients, when suspended in acetone/Viton solution, are being thoroughly agitated without being subjected to excessive shear.

In principle the mixing of magnesium/PTFE/Viton compositions involves the mixing together of the magnesium and PTFE in an acetone solution of Viton, the precipitating, whilst mixing, of the Viton on to the other two ingredients by the addition of excess petroleum spirit, and the subsequent washing of the mix with portions of petroleum spirit to yield, on drying, a non-sticky, friable, semi-granular composition, which does not segregate on handling.

Usually all the ingredients are placed in a vessel with sufficient acetone to allow easy mixing. When using a PTFE with a tendency to clump, the PTFE, Viton and acetone are first mixed to break down the clumps and then the magnesium is added, followed by the usual precipitation process.

The mixer first used at Wallops was a Sunbeam food mixer. As manufactured this machine has a very violent mixing action and it was, therefore, modified by replacing the steel cutter blades with a brass impeller. At the same time the shaft seals were changed to PTFE in order to withstand the effect of the solvents. The mixer worked well with batches of 50 grams and 100 grams but removal of the mix was difficult, causing slight segregation of the PTFE. Despite this, reproducibility of compositions, as indicated by burning rates, was good.

The second mixer tried was of Lightnin manufacture and consisted of an electric motor driving a long shaft terminating in a $\frac{1}{2}$ in. square-pitch impeller. This was used with sperical glass vessels and gave a good mix with 100 gram batches in a 1 litre vessel. The mix was easy to remove, no segregation occurred with handling, and there was no change in burning characteristics from those of the previous method. A larger version of the Lightnin mixer has been made at Wallops using an air motor driving a home-made impeller allowing 1000 gram batches to be made in a 5 litre vessel; again no change has occurred in the burning characteristics.

A further version made at Wallops is now in use as a pilot plant. It is capable of the satisfactory production of 6 kilogram batches in a 20 litre vessel.

Photographs of the modified Sunbeam mixer and two of the Lightnin type mixers are shown as Fig.2.

Tests have been conducted at the burning grounds to see if this method of mixing introduced any danger. Batches of compositions were ignited under the three sets of conditions occurring during mixing with the following results:-

1st stage: 100 grams composition wet with 100 ml acetone.

Very quiet burning without spurts, producing extremely large quantities of soot.

2nd stage: 100 grams composition wet with 500 ml petrol.

The petrol burned first, then the composition burned very quietly without spurts, producing extremely large quantities of soot.

3rd stage: 100 grams composition damp with petrol as after filtration.

Instantaneous burning, sparky, quiet, extremely sooty.

It was considered that these results show the mixing process to be as safe as can be expected for any pyrotechnic process, and that at stages 1 and 2, normal fire fighting methods could probably be employed quite safely.

2.3 Measurements of pyrotechnic properties

All the compositions made in the course of this investigation have been tested by burning flares containing the composition and measuring their pyrotechnic properties. To identify the compositions made, each one was allocated a WI number starting at WI201.

The rate of burning and the visible light output were measured on all the flares. These parameters were of general interest and were measured in all cases to show the differences between these compositions and the more conventional compositions and, particularly, to give a measure of the reproducibility of any given mix.

Infrared output and heats of combustion were measured when the equipment became available, some time after the start of this work, to find the composition best suited for use as an infrared source.

All the burnings on which measurements were made were conducted in a fireproof cabinet in the laboratory to eliminate outside effects such as wind and sunlight. The flare used for test burnings consisted of a Delrin* tube of internal diameter 1.05 inches and wall thickness 0.070 inches (a production size) which was filled with approximately 60 grams of composition. This was pressed at 2 tons/sq.in. as three pellets, in a slightly undersize mould. Each pellet was then pressed into the tube at 4 tons/sq. in. to give a flare length of 2.5 inches. The priming used was SR182, ignited by an I.C.I. 'E' type fuzehead.

2.3.1 Visible light output and burning time

The light output was measured by a calibrated selenium photocell fitted with an 'eye-response' filter and feeding into a high speed oscillograph recorder. The effective burning time was read from the time scale of the light output trace.

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* Delrin is a polyacetal resin manufactured by Du Pont.

2.3.2 Infrared output

Measurements of infrared output in selected wavebands have been made on some two hundred compositions. Results are included in Tables 4-8. These results are of necessity related to an arbitrary standard and their magnitude in absolute terms is not known accurately. It should also be noted that comparisons can only be made within each waveband and not from one waveband to the other.

The arbitrary standard chosen was a flare manufactured at Wallops which has been shown to be particularly reproducible and steady burning. These flares were made to the following specification:

Composition WI 286 -

Magnesium <45 microns	60%
Fluon G2F 25-60 B.S.mesh	35%
Viton A	5%

A considerable number of these flares have been burned and found to give reproducible (within ±10%) infra-red outputs. The outputs of these flares have been assigned the nominal value of 100 in each waveband and all the other measurements are related to these figures.

The detection and amplifying equipment which has been built at Wallops conforms to the usual scheme of chopping the incident radiation, detecting this signal and converting it to an A.C. electrical signal which is then amplified and fed to a recorder. The various parts of the equipment are as follows:

(i) Chopper assembly consisting of a metal disc with regular castellations around its circumference, rotated by a synchronous electric motor to chop the incident radiation at 800 cycles per second.

(ii) Filters and photoconductive devices.

Band 2: Mullard 61SV cell faced with S.T.C. filters E5304F and 8LFA001WGD. Effective band width 1.06μ to 2.68μ

Band 3: Mullard ORP10 cell faced with S.T.C. filters E5231F and E5229F. Effective band width 2.56μ to 5.18μ

The detectors and filters for each channel are mounted in large heat sinks.

(iii) The amplifier is a two channel, high gain, narrow band linear amplifier with built-in meters and D.C. outputs to a separate ultra-violet recording oscillograph.

2.3.3 Heat of combustion

Measurements of heats of combustion were made using an adiabatic bomb calorimeter. 1.4 grams of composition ignited by an 'E' type fusehead in a closed bomb initially containing 300ccs of air at 23 ± 3°C and at atmospheric pressure. These conditions were standard for all tests and the reproducibility was better than ± 2%.

3. FLUOROCARBON MATERIALS

Four types of fluorocarbon have been used in this investigation:

(a) The copolymer of hexafluoropropylene with vinylidene-fluoride.

This is available from Du Pont as Viton and from Minnesota Mining and Manufacturing as Fluorel. Each manufacturer supplies two grades which differ in molecular weight. Viton A which has been used throughout this work was chosen mainly due to considerations of solution viscosity.

(b) Polytetrafluoroethylene, PTFE

The fluorocarbon most commonly used for pyrotechnic purposes, it is the most highly halogenated solid hydrocarbon.

(c) Polychlorotrifluoroethylene PCTFE

This is in effect PTFE modified by replacing one in four of the fluorine atoms with chlorine.

(d) Fluorinated ethylene propylene, FEP, is a copolymer of tetrafluoroethylene and hexafluoropropylene, the first two members of an homologous series of per fluoro hydrocarbons.

3.1 Comparisons of different grades and makes of PTFE

3.1.1 Availability

Six manufacturers of PTFE have been located and samples of various grades have been obtained from each of them.

These are twelve grades of Fluon (made by I.C.I.), six grades of Teflon (Du Pont, USA), two grades of Algoflon (Montecatini, Italy), two of Halon (Allied Chemical Corp, USA), three of Hostaflon (Hoescht Chemicals, Germany) and one of Soreflon (La Societe Plastugil, France). All these products are 100% PTFE.

There are two types of PTFE potentially suitable for pyrotechnics.

(i) Granular polymers which may be free flowing powders or fibrous particles. Different grades have median particle sizes varying from 550μ to 5μ. Sieving is more difficult with the smaller median particle sizes and fibrous powders are more difficult than free flowing ones.

(ii) Coagulated dispersion (CD) polymers which consist of soft particles of median particle, size 400µ to 500µ. CD polymers create difficulties in sieving and to be of any real use must give the desired results as obtained direct from the manufacturer. They must also be handled as little as possible, although this is no disadvantage with the mixing process now used.

All the granulated and coagulated dispersion powders at present known to be commercially available in this country are listed in Tables 1 & 2 together with their mean particle sizes as stated by the manufacturer.

3.1.2 Sieving

All the samples obtained have been subjected to sieve analysis and the results are shown as Table 3. Photographs are included as Fig. 3 to illustrate the characteristics of the different grades. All the photographs are of sieved fractions between 25 and 60 B.S. mesh and are shown at the same magnification, (x25).

The following observations were made during the sieving tests on the various grades of PTFE:-

(i) The only powder impossible to sieve was Hostaflon TFVP17 with a mean particle size of 30-50 microns.

(ii) The sieve analysis obtained for Fluon G4 was not in agreement with the figure of 30 microns for mean particle size claimed by the manufacturers (I.C.I.). Microscopic examination of the powder showed that the coarse fractions were in fact agglomerates of fine hair-like particles which could not be separated.

(iii) Halon G85 consisted of fine powder loosely held together by a patented process to form larger spheroidal particles. Unfortunately, for our purposes, it was easily broken down by handling such as occurs during the sieving process.

(iv) Hostaflon VP16 appeared similar to Halon G85 but did not crumble when sieved.

(v) Soreflon 502 and Fluon G2F are claimed to be sintered agglomerates of fine powder and the photographs show this to be so. The agglomerates are not spheroidal as with Hostaflon and Halon.

(vi) Fluon G162 was affected by the combination of perchloroethylene and heat whilst being dried after sieving. The granules appeared to sinter and assume a glassy appearance. It is believed that this is due to Fluon G162 being of low molecular weight. This is not denied by the manufacturers.

(vii) The particle size of Fluon L169 (5µ) made sieving irrelevant. It has flow properties similar to those of flour.

(viii) All the coagulated dispersion polymers handled badly, being soft and easily smeared, thereby tending to clog the sieves.

3.2 The use of fluorinated ethylene propylene (FEP) as a substitute for PTFE

The only known manufacturer of FEP is Du Pont who makes two grades in the USA. Both these grades, known as Teflon 100 and Teflon 110, are in the form of chopped extruded rod with a particle diameter of about one-eighth inch. The two grades apparently differ in molecular weight thus giving different melt viscosities.

It is known that the material can be ground to a powder and attempts have therefore been made at grinding in liquid nitrogen. To date all attempts have been fruitless. If a suitable powder can be obtained it will be used in the manufacture of compositions for comparison with magnesium/PTFE compositions.

3.3 The use of polychloretrifluoroethylene (PCTFE) as a substitute for either PTFE or Viton

Three makes of PCTFE have been traced. They are Plaskon, made by Allied Chemical Corporation, Hostaflon C, made by Hoescht Chemicals, and Kel F, made by Minnesota Mining and Manufacturing. Of these three, only Kel F is available in this country.

Kel F is available in granular and coagulated dispersion forms similar to PTFE. It is also available as a series of oils or waxes, the different polymers having molecular weights from 303 (in thin oils) through 5000 (hard waxes) to 250000 which is a hard granular powder. From this range it was decided to test the highest melting wax and one of the two powder grades.

4. RESULTS

4.1 Variations due to grade and particle size of the PTFE

In order to determine the effect of PTFE particle size on the burning of compositions, all the sieved fractions of PTFE, together with samples of the virgin materials, were used to make compositions to the following formula:-

53% magnesium (atomised, mean particle size 17.6µ)
42% PTFE
5% Viton

Flares were made using all these compositions and burned so that their burning rates and light outputs could be measured. The results are given in Table 6.

The burning rates were found to follow a definite trend with the fastest rates given by compositions made with medium size PTFE. As the size tends towards either the massive state or very fine powder the burning rate becomes slower. The burning rates have been found reproducible with the exception of those compositions containing sieved fractions of Fluon G4 and Teflon 7. This is due to the difficulty of sieving these fine powders. If sieving is incomplete with retention of fines on the sieves then the resultant composition will have erroneous burning properties. The anomalous results have been noted but are not included in this report since they have no apparent value.

Six of the Fluons tested (G097, 098, 099, 101, 102, 162) were experimental powders which it was thought would show advantages over normal moulding powders. No advantages were, however, discovered and further testing did not include these powders.

The particle size of PTFE affects not only the burning rate, but also the nature of the flame. Flares containing coarse PTFE burn with a sparky flame containing incandescent solid particles, while the finer powders give a smooth burning flame. Photographs showing this variation in flame structure are included in Fig. 10.

Following the completion of this series of 53% magnesium 47% fluorocarbon mixes, two further series were investigated. The compositions used were:-

(i) 40% Magnesium
55% PTFE
5% Viton

(ii) 60% Magnesium
35% PTFE
5% Viton

Mixes in these series were made, filled and burned under the same conditions as before. The results obtained from these tests are given in Tables 5 and 7 respectively.

The results obtained from these three series of tests for each PTFE sample were plotted to give a graph of burning rate versus magnesium content for each size fraction of PTFE. The graphs demonstrated clearly that for each grade of PTFE the rate of change of burning rate with change in magnesium content was greatest with the finest PTFE. Mixes with the coarsest PTFE changed their burning rates relatively little, those with the finest PTFE changed from slowest burning at 40% magnesium 60% fluorocarbon to fastest at 60% magnesium 40% fluorocarbon.

Several of the PTFE's have also been used in the following series of mixes:-

(iii) 30% Magnesium
65% PTFE
5% Viton

(iv) 70% Magnesium
25% PTFE
5% Viton

Results obtained from burning flares containing these mixes are given in Tables 4 and 8 respectively.

Figs 4-6 show graphs of burning rate versus magnesium content for the various size fractions of several PTFE's. These graphs not only show clearly the effect of PTFE particle size but also the variation between grades.

4.2 The use of PCTFE as a substitute for either PTFE or Viton

4.2.1 Use in compositions as a replacement for PTFE

The powder, Kel F3, was used in the same manner as PTFE. It was sieved and then made up into compositions. Sieving was easy in a dry state with no need for washing with perchloroethylene. A sieve analysis is included in Table 3. The mixing achieved was poor, with PCTFE apparently not being coated with Viton. Subsequent handling caused some separation.

A range of flares made with compositions containing PCTFE were burned and measurements made giving the results reported in Tables 5-7.

Fig. 7 shows the variation of burning rate with percentage magnesium for each sieve fraction of PCTFE. Comparison of this graph with those of PTFE compositions in Figs. 4-6 and with others not published yet shows that the burning rate of compositions containing Kel F have a lesser dependence on accuracy of mix than nearly all PTFE compositions.

4.2.2 Use in compositions as a replacement for Viton

Kel F200 hard wax has been tested with a view to its use as a replacement for Viton. To permit use in this manner it was necessary to find a pair of miscible liquids, one of which would dissolve the wax, the other to be used to precipitate the wax from solution. Both liquids must also present no undue fire hazard and have no noxious properties.

Initial attempts to find a solvent consisted of putting 30 grams of wax in 100ml solvent in a flask and shaking for three hours. The contents of the flask were then allowed to settle and a portion of the supernatant liquor removed and evaporated to dryness. Results are given as Table 10. The results pointed to the possibility of obtaining a 20% W/V solution in benzene or toluene. Attempts were therefore made at dissolving varying amounts of wax in 100ml portions of toluene. The results of this test indicated a certain fractionation of the wax with only the low molecular weight fraction dissolving. The results are shown as Table 11.

The proposition that these attempts at solution of the wax were leading to fractionation was confirmed by the appearance of the wax reclaimed from the solution. The reclaimed wax invariably had a softer consistency than the virgin material. In view of this finding, attempts to use the Kel F200 hard wax were abandoned.

4.3 The effect of magnesium particle size

Various fractions of magnesium were obtained by dry sieving grades III and V blown magnesium to give the narrowest size cuts obtainable with standard test sieves.

Mixes were made using the 53/42/5 proportions and employing known size fractions of magnesium with known size fractions of three types of Fluon - G1, G2F and G3. Table 12 shows the results obtained by burning flares and the effect of varying magnesium particle size on the pyrotechnic properties of the compositions. The results are as might be expected, the finer the magnesium the faster the composition burns. Attempts to reproduce these figures with different batches of magnesium have been successful only for the fine powders. The coarser powders, i.e. about 50 microns, give extremely variable results. The reason for these variable results is indicated by the graph in Fig. 11 referring to compositions containing Fluon G1. It will be seen that a small change in magnesium particle size above 50 microns produces a large change in burning rate.

Many batches of atomised magnesium have been tested for use as received in magnesium/fluorocarbon compositions. The burning rates have been found to be dependent on the particle size of the magnesium even when more than 80% is smaller than 45 microns.

If the magnesium is sieved and only that portion which passes a 350 B.S. sieve (45 micron aperture) is used, then predictable, reproducible results are always obtained.

4.4 Measurements of thermal output

A selection of the compositions made in this investigation have been tested for calorific output - calorific output being interpreted as the total heat released when a unit mass of the material is ignited. Under the conditions of these tests this value is necessary related not only to the composition of the surrounding atmosphere but also the available amount of that atmosphere. The basic heat producing reaction is the formation of magnesium fluoride and carbon from the elemental metal and the polyfluorocarbon. Side reactions involving the atmosphere particularly oxidation of carbon are obviously dependent on concentrations of the atmospheric gases immediately available to the hot products of the primary reaction. These in turn must depend on the availability of such gases to maintain these concentrations. Calorific output as defined here must not be confused with the 'heat of combustion' as the latter is conventionally defined.

It was hoped that these tests would provide an easy means of forecasting the burning efficiency and infrared output of new compositions.

The values obtained for any particular series of compositions varying only in the particle size of the PTFE, followed the pattern observed with burning rates and light output, i.e. a maximum value being given by compositions containing medium size PTFE. Tests of compositions containing different grades of PTFE of the same particle size have shown no relationship between calorific value and any other burning property. These results are shown in Tables 4-8 inclusive.

For any particular PTFE tested a maximum calorific value was obtained from a composition of approximately 40% magnesium/60% fluorocarbon. This does not correspond with the peak value for any other property measured, but is near the stoichiometric mixture of 36% magnesium/64% PTFE.

It was felt that the conditions of burning in the calorimeter might be introducing errors due both to the pressure generated and to the fact that a strictly limited supply of air was present in the calorimeter. To check the effects of these two conditions a series of tests has been carried out at different pressures and with different gases in the calorimeter. Results are in Table 13.

This work on calorific values has reinforced the previous information on the effect of particle size of the PTFE on the burning characteristics. It does not, however, agree with any theory that a change in magnesium/fluorocarbon ratio should affect burning rate and calorific output similarly. Nor is calorific value related to infra-red output as the magnesium/fluorocarbon ratio is altered.

4.5 Discussion of results on infrared measurements

Measurements have been made on some two hundred compositions. The method used is described in detail on page 5. The results are included in Tables 4-8 inclusive.

The first series of tests was carried out on compositions made to the standard formula of:-

Magnesium (mean particle size 17.6μ)	53%
PTFE or PCTFE	42%
Viton A	5%

The results of measurements made on test flares filled with these compositions are given in Table 6. These results show that infra-red output is related to the particle size of the PTFE in exactly the same fashion as burning rate and light output. An increase in burning rates is, however, accompanied by a proportionally smaller increase in infrared output. A study of infrared and light output figures for a wide range of compositions leads to the following general conclusion. An increase in burning rate leads to a greater proportion of the total energy being emitted as light at the expense of infrared.

Further tests with varying magnesium/fluorocarbon ratios have been carried out and are reported in Tables 4, 5, 7 and 8.

Graphs have been prepared for compositions containing various PTFE's to show the variation of infrared output as the magnesium/fluorocarbon ratio is altered. Since they are all similar only the one referring to Fluon G3 is included (Fig. 9).

As has been found previously with burning rates, the peak value is in the middle of the range with a decrease as the magnesium content varies in either direction. The peak values for burning rate and infrared output do not, however, coincide at the same magnesium content. This would seem to be an extension of the conclusion reached earlier, when it was found that any increase in burning rate brought about by varying the PTFE particle size leads to the production of light at the expense of infrared.

For comparative purposes a range of compositions has been made by the traditional method using magnesium and PTFE mixed together with methylated spirits. Results for these compositions are given in Table 9.

5. CONCLUSIONS

5.1 Mixing procedures

(i) The traditional method of mixing magnesium and PTFE in methylated spirit gives a product of uncertain homogeneity with a tendency to segregate on standing.

(ii) The mixing method based on the use of Viton as a binder has been found satisfactory for batch sizes from fifty grams to six kilograms. A good mix is obtained which does not segregate on standing or when being handled.

(iii) The use of Viton enables the compositions to be handled dry during all pelleting and pressing operations.

(iv) The mixing is as safe as can be expected for any pyrotechnic process.

5.2 Effects of variations in the fluorocarbon

(i) The burning rate of the compositions is dependent on the particle size of the PTFE. The fastest rates are given by compositions made with medium sized PTFE. As the size tends towards either the coarse powder or very fine powder, the burning rate becomes slower.

(ii) Visible light output is affected in a similar fashion to burning rate by variations in PTFE particle size.

(iii) Infrared output is affected in a similar fashion.

(iv) Thermal outputs are affected in a similar fashion though only to a slight degree.

(v) Different grades and makes of PTFE vary in their susceptibility to changes in particle size and change in magnesium/fluorocarbon ratio.

(vi) The particle size of the PTFE affects the structure of the flame produced by the burning flare. Coarse PTFE gives rise to a flame containing large incandescent solid particles. Fine PTFE gives a smooth burning flame

(vii) The use of PCTFE powder as a substitute for PTFE gives compositions with poor mixing and handling properties and with decreased infrared output.

(viii) The use of PCTFE wax as a substitute for Viton is impracticable due to solubility problems.

(ix) The use of FEP as a substitute for PTFE was not practical at this time since it is only obtainable in this country in the form of chopped rod and no means has been found of grinding it to a powder.

5.3 Effects of variations in the magnesium

(i) Rate of burning is affected by the particle size of the magnesium. The finest magnesium gives the fastest burning rates.

(ii) To obtain reproducible results with different batches of magnesium, all the magnesium in the composition must be less than 45 microns in particle size.

5.4 Effects of varying the magnesium/fluorocarbon ratio

(i) Variations in the magnesium/fluorocarbon ratio affect all the properties. The peak value for any given property never occurs at either extremity of the burning range, but somewhere within the range with a decrease in both directions.

(ii) The peak values for burning rate and visible light output are coincident.

(iii) The peak values for burning rate, thermal outputs and infraredd output are not coincident.

5.5 General

An increase in burning rate leads to a shift of the emission peak towards the shorter wavelength end of the spectrum.

6. FUTURE WORK

Work in hand and planned may be conveniently grouped under the following headings.

6.1 Additives

Various materials are being tested with the objective of modifying the spectral distribution of the emitted radiation and the burning rates.

6.2 Effects of environment

Flares are being burned under varying conditions of temperature and pressure to discover the compositions best suited to any particular environmental conditions.

TABLE 1

GRANULAR P.T.F.E. POWDERS AVAILABLE AND THEIR MEAN PARTICLE SIZES (MANUFACTURERS FIGURES)

Micron Size	Fluon I.C.I.	Teflon Du Pont	Algoflon Montecatini	Halon Allied Chemical Corporation	Hostaflon Hoechst Chemicals	Soreflon Societe Plastugal
600				G10. G85		
550		1. 1B. TE6096	G.E.			
500						
450		TE 6057				
400	G2F					
375		TE 6055			TF 14	
325	G3	5				502
300	G1		P	G50	TF VP 16	5A
270		5B				
225	L162					
50			F			
35		7			TF VP 17	
30	G4. G4B.					
20		7A		G80		
5	L169					

TABLE 2

COAGULATED DISPERSION POLYMERS OF P.T.F.E. AVAILABLE AND THEIR MEAN PARTICLE SIZES (MANUFACTURERS FIGURES)

Micron Size	Fluon	Teflon	Algoflon	Halon
400/500	CD1	6H	DP/N	None
	CD004	6C	DP/S	
		6	DP/T	
		3194		

TABLE 3

Sieve Analyses of P.T.F.E.

Sample	Percentage passing stated B.S. sieve mesh								
	16	18	25	60	100	150	240	300	350
Fluon G1			99	55.5	37.5	27.5	13		
G2F	99.5	97	65	18	6.5	2.7	0		
G3			98	44.5	17.75	7.0	1		
G4				77	54	22	14		0
G162			100	84.1	29.2	14.1	3.2		
G097			100	99	96	87	54		
G098			100	98.2	95.4	75.3	32.6		
G099			100	98.7	72.5	49.4	24		
G101			100	77.9	40	19.3	6.7		
G102			100	59.4	40	24	12.7		
CD1		93	60	0					
CD004		92	64	2	0				
Teflon 5			90	30	15.5	8.5	4		
5B			88	51	16.5	9	5		
6		100	90	6.2	0				
6H		100	85	19	3				
6055		100	94	60	25.4	12.6	6		
7						97	71	68	34
Algoflon P			100	94	40	22	8		
DP/S	89	71	19.6	0					
Halon G50	83	77	68.5	24.6	9.2	3.1	0		
G85	90	83	64	29.7		21			
Hostaflon TF14			91	21	7	2	0		
VP16			99.5	36	3	2	0		
VP17									
Soreflon 502			86	33	16	9	3		
Kel F 3 (PCTFE)			91	68	49	36	20		

TABLE 4

Pyrotechnic properties of mixture Magnesium 30% with various types
PTFE 65%
Viton 5%
of PTFE

WI No	Make and grade of PTFE	Sieve Size of PTFE	Heats of Combustion cal g^{-1}	Reciprocal Rate of Burning sec in^{-1}	Light Output kcd in^{-2}	Relative Infrared Output	
						Band 2	Band 3
	Fluon G1	as rec'd		WNB	-	-	-
468		25-60		6.0	8	63	66
470		60-100		WNB	-	-	-
557	Fluon G2F	as rec'd		4.6	21	79	74
474		18-25		4.2	24		
473		25-60	2123	4.6	20	82	85
475		60-100		7.3	15	57	57
502	Fluon G3	as rec'd	2173	13.2	3	33	34
461		25-60	2176	7.4	12	51	55
463		60-100		16.5	5		
501		100-150		WNB	-	-	-
505	Fluon CD004 (now known as CD4)	as rec'd	2208	20.0	3	22	25
556	Teflon 5	as rec'd		7.0	8		
558		25-60		11.0	5		
559		60-100		WNB	-	-	-

* WNB - would not burn.

TABLE 5

Pyrotechnic properties of mixture Magnesium 40%
PTFE 55%
Viton 5%
with various types of PTFE

WI. No.	Make and grade of PTFE	Sieve Size of PTFE	Heats of Combustion cal. g^{-1}	Reciprocal Rate of Burning sec in^{-1}	Light Output kcd in^{-2}	Relative Infrared Output	
						Band 2	Band 3
346	Fluon G1	as recd		6.5	20	78	74
353		25-60		3.0	41	97	86
354		60-100		5.1	30	79	78
355		100-150		11.5	10		
356		150-240		16.0	6		
347	Fluon G2F	as recd		2.8	29	116	112
357		18-25		3.4	22		
358		25-60	2269	3.2	29	105	99
359		60-100		3.5	29	97	92
348	Fluon G3	as recd	2378	4.3	30	72	67
360		18-25					
361		25-60	2371	4.2	31	88	91
362		60-100	2385	6.8	18	64	60
363		100-150		10.0	8	45	19
590		150-240		12.0	4	35	10
399	Fluon G4	as recd		16.0	17		
443		25-60		2.2	50		
444		60-100		15.5	5		
445		100-150		16.0	5		
446		150-240		16.0	5		
447		240-350		16.0	5		
352	Fluon CD1	as recd		4.3	32		
351	Fluon CD004 (now known as CD4)	as recd	2362	4.8	35	78	76
603	Fluon L169	as recd		14.5	9	32	30
349	Teflon 5	as recd		3.7	31	78	77
364		18-25		2.5	27		
365		25-60		4.5	27	88	86
366		60-100		6.9	18	55	59
383	Teflon 5B	as recd		4.2	32		
412		25-60		4.2	23		
413		60-100		5.7	19		
384	Teflon 6	as recd		5.6	22		
423		25-60		4.3	25		

TABLE 5 (Cont'd)

WI. No.	Make and grade of PTFE	Sieve Size of PTFE	Heats of Combustion cal. g^{-1}	Reciprocal Rate of Burning sec in^{-1}	Light Output kcd in^{-2}	Relative Infrared Output	
						Band 2	Band 3
385	Teflon 6H (also known as TE3200)	as recd		7.9	16		
457		25-60		4.4	26		
		60-100		10.0	8		
386	Teflon 6055	as recd		3.9	30		
404		25-60		3.6	39		
405		60-100		5.2	26		
350	Teflon 7	as recd		16.0	6		
417	Algoflon P	as recd		5.5	20		
429		25-60		5.3	19		
430		60-100		9.5	12		
420	Algoflon DP/S	as recd		4.1	24		
459		18-25		4.2	23		
460		25-60		4.2	30		
370	Halon G50	as recd		4.2	23		
372	Halon G85	as recd		2.3	64		
523	Hostaflon TF14	as recd		4.4		130	90
521		25-60		4.5	33	111	111
518	Hostaflon VP16	as recd		3.7		95	104
515		25-60		2.5	30	107	98
516		60-100		5.2		53	133
525	Hostaflon VP17	as recd		17.1	10	34	37
535	Soreflon 502	as recd		3.0	32	127	107
543				2.9	41	114	99
538	Kel F 3 (PCTFE)	as recd		2.0	45	105	95
552		25-60		2.6	22	94	92
553		60-100		2.9	19	88	99
554		100-150		3.0	22	89	98
555		150-240		3.6	20	79	85

TABLE 6

Pyrotechnic properties of mixture Magnesium 53% with various types of PTFE
PTFE 42%
Viton 5%

WI No	Make and grade of PTFE	Sieve Size of PTFE	Heat of Combustion cal g^{-1}	Reciprocal Rate of Burning sec in^{-1}	Light Output kcd in^{-2}	Relative Infrared Output	
						Band 2	Band 3
238	Fluon G1	as rec'd	2036	2.0	78	118	115
201		25-60	2070	2.9		102	100
202		60-100	2085	2.7		112	108
203		100-150	2071	3.8		84	82
204		150-240	2113	7.5		64	61
239	Fluon G2F	as rec'd	2120	2.4		108	111
249		18-25	2030	3.3	27	90	96
250		25-60	2040	2.8	36	100	103
251		60-100	2139	2.5	50	116	104
252		100-240	2040	2.5		104	97
240	Fluon G3	as rec'd	2056	2.6	54	110	103
288		18-25	2067	2.5	73	104	111
232		25-60	2110	2.4	61	114	107
233		60-100	2061	3.0	55	104	99
234		100-150	2067	4.0	39	90	103
589		150-240		4.2	35	71	83
397	Fluon G4	as rec'd		9.5	7	103	
433		25-60	2123	2.1	53	110	115
434		60-100		3.3	37	99	113
435		100-150		4.4	30	88	96
436		150-240		5.6	17	78	84
437		240-350		11.0	5		
315	Fluon CD1	as rec'd		2.3	75	116	103
316		18-25	2240	3.7	21	90	83
317		25-60		3.0	37	100	96
292	Fluon CD004 (now known as CD4)	as rec'd	2098	3.1	50	106	104
313		18-25	2045	3.2	35	108	103
314		25-60	2079	3.1	39	120	97
241	Fluon G162 (now known as L162)	as rec'd		2.6	37		
253		25-60		3.8	13		
254		60-100		3.2	19		
255		100-150		2.3	66		
256		150-240		2.5	46		

TABLE 6 (Cont'd)

WI No	Make and grade of PTFE	Sieve Size of PTFE	Heat of Combustion cal g^{-1}	**Reciprocal Rate of Burning** sec in^{-1}	**Light Output** kcd in^{-2}	Relative Infrared Output	
						Band 2	Band 3
242	Fluon G097	as rec'd		11.0	6		
257		100-150		5.0	26		
258		150-240		7.4	13		
243	Fluon G098	as rec'd		8.6	7		
259		100-150		3.5	49		
260		150-240		8.8	79		
244	Fluon G099	as rec'd		6.3	18		
261		60-100		3.0	50		
262		100-150		3.4	55		
263		150-240		9.5	7		
245	Fluon G101	as rec'd		4.0	28		
264		25-60		3.4	28		
265		60-100		3.1	50		
266		100-150		4.2	36		
267		150-240		8.4	12		
246	Fluon G102	as rec'd		2.3	70		
268		25-60		2.4	59		
269		60-100		2.7	49		
270		100-150		3.6	45		
271		150-240		5.2	26		
602	Fluon L169	as rec'd		10.8	8	43	47
247	Teflon 5	as rec'd		2.3		106	107
272		18-25		2.4	70	98	96
273		25-60	2033	2.4	85	100	99
274		60-100		2.7	62	112	93
375	Teflon 5B	as rec'd		2.1	60	125	103
409		18-25		3.0	30	115	113
395		25-60	2114	2.6	37	112	106
396		60-100		2.7	46	102	86
414		100-150					
376	Teflon 6	as rec'd		2.2	66	108	107
421		25-60	2151	3.0	30	110	101

TABLE 6 (Cont'd)

WI No	Make and grade of PTFE	Sieve Size of PTFE	Heat of Combustion cal g^{-1}	Reciprocal Rate of Burning sec in^{-1}	Light Output kcd in^{-2}	Relative Infrared Output Band 2	Relative Infrared Output Band 3
377	Teflon 6H (also known as TE3200)	as rec'd		3.1	50	114	120
448		18-25		2.0	39	116	117
449		25-60		2.1	37	110	101
450		60-100		2.4	28	106	103
378	Teflon 6055	as rec'd		1.9	61		
406		18-15					
400		25-60	2145	2.7	33	105	99
401		60-100		2.3	59	106	104
407		100-150		3.3	45	88	101
408		150-240		6.3	17	88	81
248	Teflon 7	as rec'd		7.0	20	93	110
275		150-240		2.8	37	100	107
276		240-300		5.1	25	88	97
277		300-350		7.9	14	67	67
415	Algoflon P	as rec'd		2.4	52	105	104
424		25-60	2135	2.3	40	108	103
425		60-100		3.2	35	102	101
428		100-150		6.8	12		
418	Algoflon DP/S	as rec'd		2.2	46	104	101
451		18-25		3.0	25	84	92
452		25-60		3.0	36	94	96
367	Halon G50	as rec'd		2.6	53	102	108
394		18-25		3.3	20	92	89
392		25-60		2.9	35	106	97
393		60-100		2.7	47	112	103
368	Halon G85	as rec'd		2.2	47	112	114
387		18-25		4.0	15	78	83
388		25-60		3.0	28	100	104
389		60-150		2.6	52		
508	Hostaflon TF 14	as rec'd		2.6		117	106
519		25-60		2.9		130	101

TABLE 6 (Cont'd)

WI No	Make and grade of PTFE	Sieve Size of PTFE	Heat of Combustion cal g^{-1}	Reciprocal Rate of Burning sec in^{-1}	Light Output kcd in^{-2}	Relative Infrared Output	
						Band 2	Band 3
509	Hostaflon	as rec'd		2.7		111	110
511	VP 16	25-60		2.9		117	105
510	Hostaflon VP 17	as rec'd		12.1	10	47	55
533	Soreflon 502	as rec'd		1.9	48	120	113
540		18-25			24	85	85
541		25-60		2.5	40	107	93
536	Kel F 3	as rec'd		2.0	53	92	82
544	(PCTFE)	25-60		3.4	16	95	99
545		60-100		2.9	35	89	84
546		100-150		2.5	41	77	74
547		150-240		2.4	43	89	95

TABLE 7

Pyrotechnic properties of mixture Magnesium 60% with various types
PTFE 35%
Viton 5%
of PTFE.

WI No	Make and grade of PTFE	Sieve Size of PTFE	Heats of Combustion cal g^{-1}	Reciprocal Rate of Burning sec in^{-1}	Light Output kcd in^{-2}	Relative Infrared Output	
						Band 2	Band 3
325	Fluon G1	as rec'd		1.8	96	109	87
332		25-60		3.2	40	102	100
333		60-100		2.1	53	105	103
334		100-150		2.2	58		
335		150-240		3.6	41		
326	Fluon G2F	as rec'd		2.7	33	106	100
336		18-25		3.9	20		
337		25-60	1908	3.1	26	98	98
338		60-100		2.3	46	107	101
327	Fluon G3	as rec'd	1916	2.7	53	109	106
339		18-25					
340		25-60	1909	2.8	46	108	113
341		60-100	1940	2.6	50	96	89
342		100-150	1890	2.6	42	95	95
591		150-240		2.2	80	81	89
398	Fluon G4	as rec'd		3.2	38		
438		25-60		2.9	31		
439		60-100		3.6	27		
440		100-150		3.9	25		
441		150-240		6.6	16		
442		240-350		6.8	9		
331	Fluon CD1	as rec'd		3.1	40		
330	Fluon CD004 (now known as CD4)	as rec'd	1851	2.8	45	106	94
604	Fluon L169	as rec'd		8.0	26	61	69
328	Teflon 5	as rec'd		2.4	24	112	110
343		18-25		2.6	24		
344		25-60		2.7	30	100	101
345		60-100		2.1	60	100	101

TABLE 7 (Cont'd)

WI No	Make and grade of PTFE	Sieve Size of PTFE	Heat of Combustion	Reciprocal Rate of Burning	Light Output	Relative Infrared Output	
			cal g^{-1}	sec in^{-1}	kcd in^{-2}	Band 2	Band 3
379	Teflon 5B	as rec'd		1.9	55		
410		25-60		2.6	40		
411		60-100		2.4	36		
380	Teflon 6	as rec'd		2.5	42		
422		25-60		2.7	33		
381	Teflon 6H (also known as TE3200)	as rec'd		1.8	65		
453		25-60		2.3	36		
454		60-100		2.0	45		
382	Teflon 6055	as rec'd		1.8	60		
402		25-60		2.8	30		
403		60-100		1.9	55		
329	Teflon 7	as rec'd		6.5	19		
416	Algoflon P	as rec'd		1.8	58		
426		25-60		2.1	42		
427		60-100		2.4	45		
419	Algoflon DP/S	as rec'd		1.7	57		
455		18-25		2.7	34		
456		25-60		2.7	42		
369	Halon G50	as rec'd		2.7	31		
371	Halon G85	as rec'd		2.6	36		
522	Hostaflon TF 14	as rec'd		2.5		102	99
520		25-60		2.9		100	90
517	Hostaflon VP 16	as rec'd				113	97
513		25-60		3.0		102	98
514		60-100		2.9		115	96
524	Hostaflon VP 17	as rec'd		8.8		103	106

TABLE 7 (Cont'd)

WI No	Make and grade of PTFE	Sieve Size of PTFE	Heat of Combustion cal g^{-1}	Reciprocal Rate of Burning sec in^{-1}	Light Output kcd in^{-2}	Relative Infrared Output	
						Band 2	Band 3
534	Soreflon 502	as rec'd					
542		25-60		2.5	43	101	97
537	Kel F3 (PCTFE)	as rec'd		2.2	43	72	72
548		25-60		3.8	13	83	79
549		60-100		3.0	22	77	74
550		100-150		2.5	45	67	64
551		150-240		2.1	37	56	53

TABLE 8

Pyrotechnic properties of mixture Magnesium 70% with various types
PTFE 25%
Viton 5%
of PTFE

WI No	Make and grade of PTFE	Sieve Size of PTFE	Heats of Combustion cal g^{-1}	Reciprocal Rate of Burning sec in^{-1}	Light Output kcd in^{-2}	Relative Infrared Output	
						Band 2	Band 3
481	Fluon G1	as rec'd		1.9	40	99	60
467		25-60		3.6	14	72	74
469		60-100	2.1	2.1	36	84	75
479		100-150		1.5	42		
480		150-240		1.5			
482	Fluon G2F	as rec'd		3.1	18	78	83
476		18-25		4.2	15		
477		25-60	1518	3.4	18	85	83
478		60-100		2.3	35	85	75
484	Fluon G3	as rec'd	1514	2.3	35	93	84
462		25-60	1527	3.0	20	94	98
464		60-100	1627	2.0	36	85	78
483		100-150	1601	2.1			
506	Fluon CD004 (now known as CD4)	as rec'd	1561	3.2	38	91	91
606	Fluon L169	as rec'd		2.4	86	77	100
562	Teflon 5	as rec'd		2.5	37	100	93
560		25-60		3.2	30	90	93
561		60-100		2.4	40	84	79

TABLE 9

Pyrotechnic properties of mixtures containing atomised magnesium and PTFE only.

WI No	Make and grade of PTFE	Magnesium Content	Reciprocal Rate of Burning sec in^{-1}	Light Output kcd in^{-2}	Relative Infrared Output	
					Band 2	Band 3
527	Teflon 7	50%	15.9	6	57	52
528	Fluon G1	55%	1.9	70	109	117
500		60%	1.3	56	104	104
531		70%	1.2	43	96	101
529	Teflon 5	55%	1.8	60	133	92
530		60%	1.4	54	109	118
532		70%	1.5	47	122	103

TABLES 10 and 11

Solubility of KEL F200 Wax

Table 10. 30 grams wax shaken with 100ml solvent.

Solvent	Concentration of solution w/v	Proportion dissolved
Toluene	23.4	78.0
Benzene	23.2	77.3
Acetone	19.2	64.0
Petroleum Spirit 60-80°C	17.5	58.3
n-Hexane	16.4	54.7
Cyclohexane	13.6	45.3
n-Butanol	1.2	4.0
Methanol	0.6	2.0

Table 11: varying amounts of wax shaken with 100ml toluene

Amount of wax added (grams)	Concentration of solution w/v	Proportion dissolved per cent
5	4.74	95
10	9.15	91.5
15	13.25	88.5
20	17.6	87.5
30	24.1	80.4
40	32.9	82.1
55	44.4	80.6
70	54.8	78.4
85	63.0	74.1
100	69.3	69.3

TABLE 12

Effect of varying magnesium particle size on pyrotechnic
properties of mixture Magnesium 53%
PTFE 42%
Viton 5%

WI No	Make and grade of PTFE	Sieve Size of PTFE	Magnesium Size. Micron	Reciprocal Rate of Burning sec in^{-1}	Light Output kcd in^{-2}
201	Fluon G1	25-60	17.6 mean	2.7	
210			75-90	WNB	-
209			63-75	5.0	
208			53-63	3.2	
229			45-53	5.4	
318			less than 45	3.0	41
202	Fluon G1	60-100	17.6 mean	2.9	
212			63-75	11.6	
213			53-63	3.6	
278			45-53	6.4	
319			less than 45	3.6	55
203	Fluon G1	100-150	17.6 mean	3.8	
215			53-63	9.0	
217			45-53	7.8	
218			less than 45	5.6	
204	Fluon G1	150-240	17.6 mean	7.5	
320			45-53	WNB	-
321			less than 45	10.3	4
249	Fluon G2F	18-25	17.6 mean	3.3	27
299			53-63	5.4	10
300			45-53	5.1	12
301			less than 45	3.8	16
250	Fluon G2F	25-60	17.6 mean	2.8	36
312			53-63	4.8	13
230			45-53	3.5	
231			less than 45	2.8	
251	Fluon G2F	60-100	17.6 mean	2.5	50
293			53-63	6.8	11
295			45-53	4.5	21
297			less than 45	2.7	58

TABLE 12 (Cont'd)

WI No	Make and grade of PTFE	Sieve Size of PTFE	Magnesium Size. Micron	Reciprocal Rate of Burning sec in^{-1}	Light Output kcd in^{-2}
252	Fluon G2F	100-240	17.6 mean	2.5	92
294			53-63	17.8	35
296			45-53	12.3	43
298			Less than 45	2.9	60
232	Fluon G3	25-60	17.6 mean	2.4	61
302			53-63	7.9	12
303			45-53	6.3	15
304			less than 45	3.6	30
233	Fluon G3				
305		60-100	17.6 mean	3.0	55
306			53-63	WNB	-
307			45-55	15.0	43
			less than 45	3.7	39
234	Fluon G3	100-150	17.6 mean	4.0	39
308			53-63	WNB	-
309			45-53	22.0	3
310			less than 45	5.1	24
589	Fluon G3	150-240	17.6 mean	4.4	38
311			less than 45	7.1	14

TABLE 13

Thermal outputs measured in various atmospheres.

Fluon G2F 25-60 B.S. with Magnesium and 5% Viton.

		THERMAL OUTPUT (cal g^{-1})				
Atmosphere		air	argon	nitrogen	oxygen	air
pressure (atmos)		1	1	25	25	25
Composition W.I. No.	% Mg.					
432	30	2123	1913	1883	3766	3202
282	40	2269	2011	2090	4118	3299
283	45	2290	1908	2087	4318	3087
284	50	2135	1795	1990	4295	3063
285	55	2003	1605	1803	4167	2713
286	60	1908	1421	1630	4255	2550
431	70	1518	1093	1163	4764	2000

FIG. 1

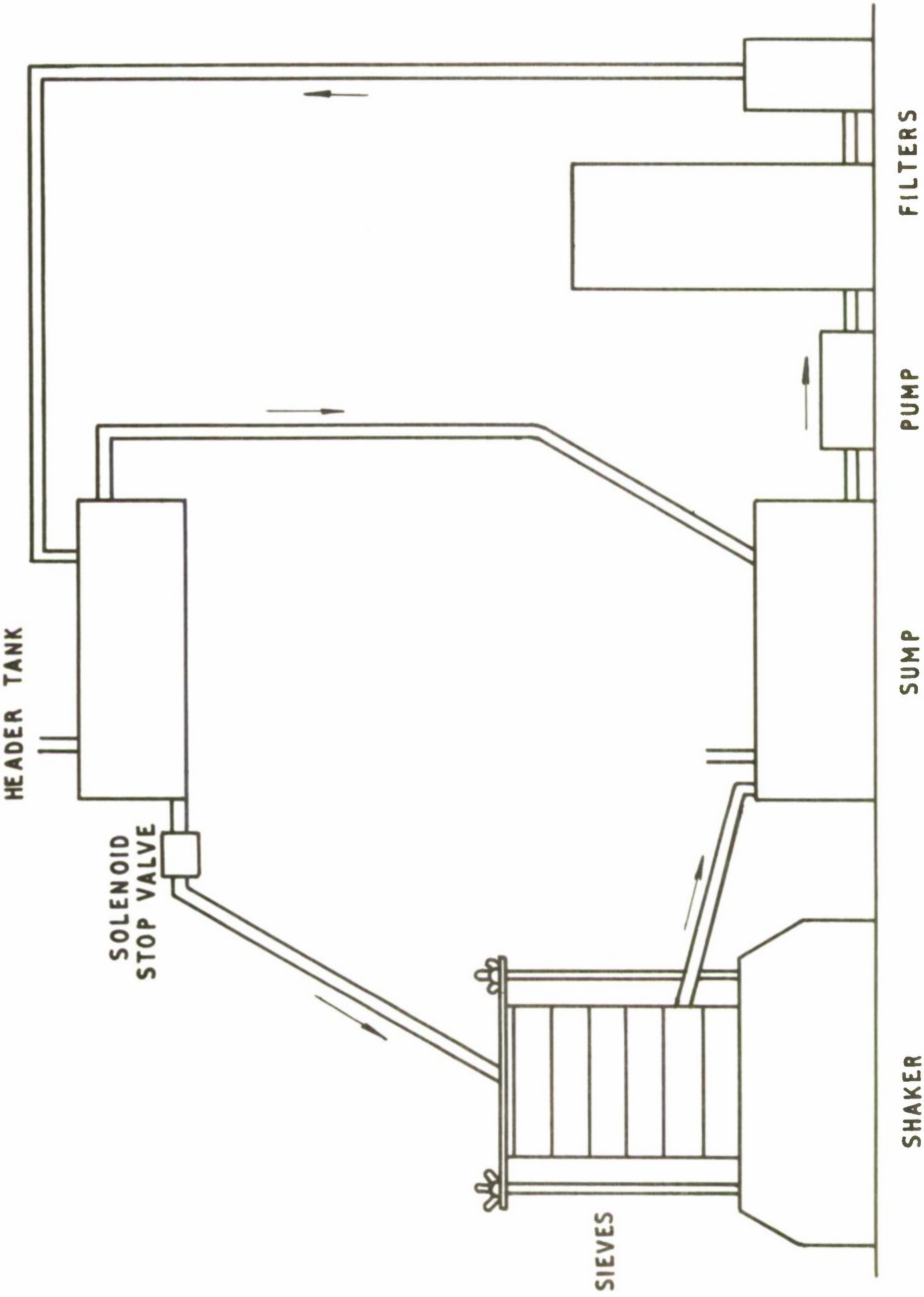
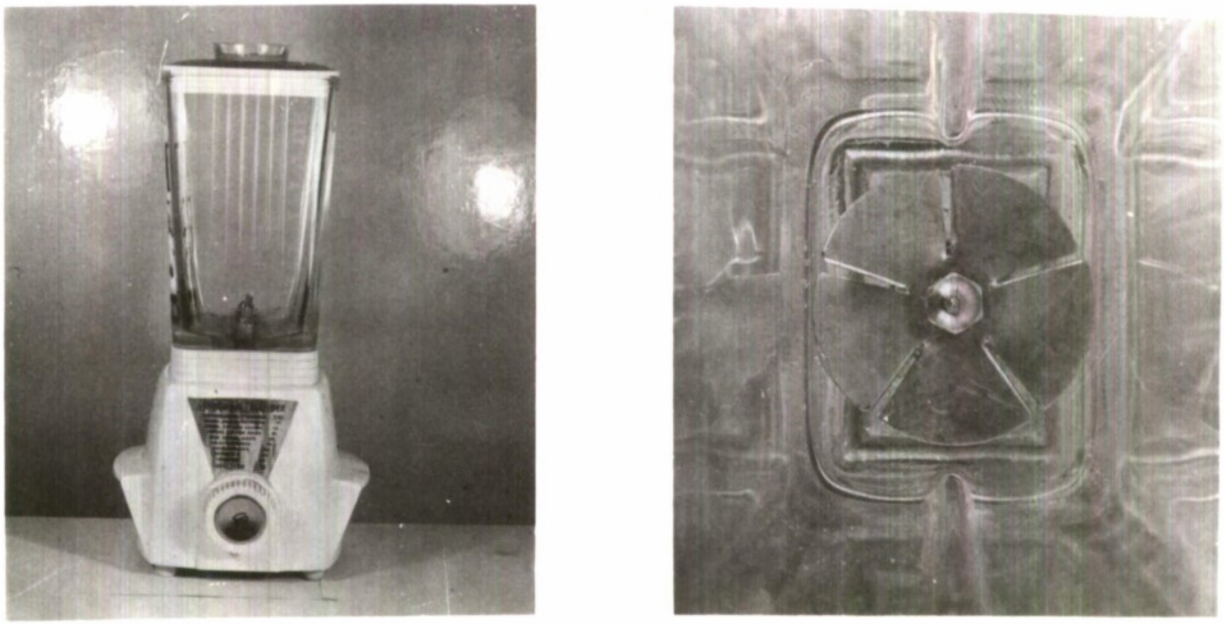


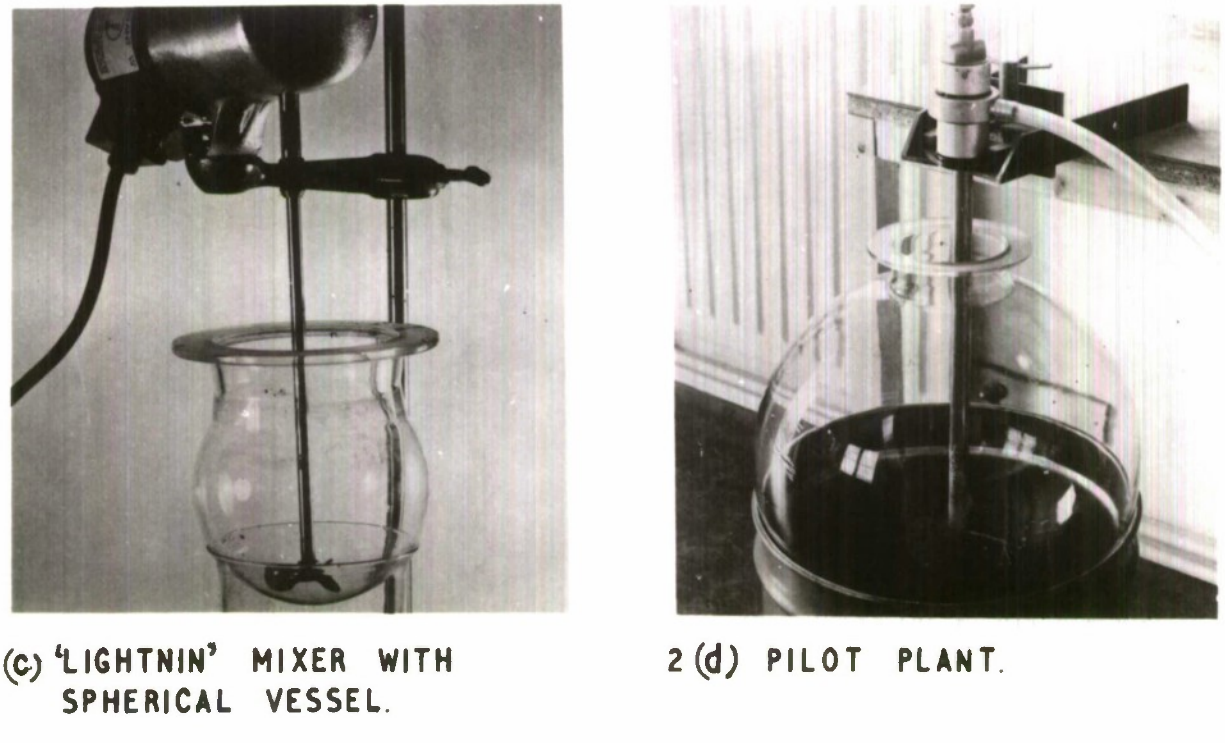
FIG. 1 SCHEMATIC LAYOUT OF P.T.F.E. SIEVING MACHINE

NOTES:-1. SHAKER SOLENOID & PUMP CONNECTED TO TIME SWITCH.
2. ARROWS INDICATE DIRECTION OF PERCHLOROETHYLENE FLOW.



2(a) SUNBEAM MIXER.

2(b) TOP VIEW OF SUNBEAM MIXER SHOWING MODIFIED IMPELLER.



2(c) 'LIGHTNIN' MIXER WITH SPHERICAL VESSEL.

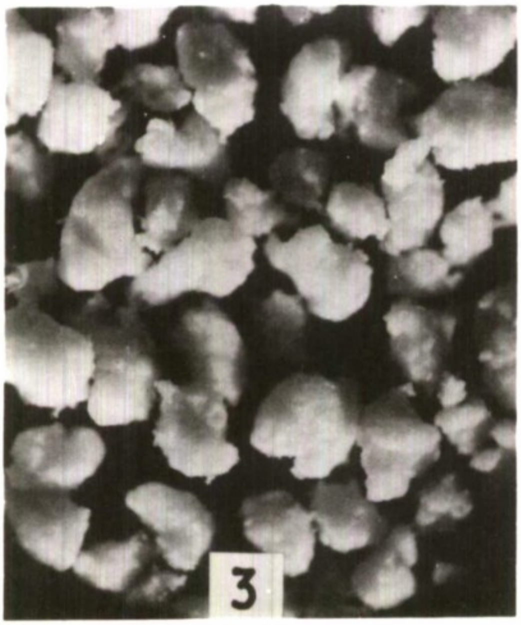
2(d) PILOT PLANT.

FIGS. 2(a). TO 2(d) MIXING MACHINES USED FOR THE PRODUCTION OF VITON - CONTAINING COMPOSITIONS.

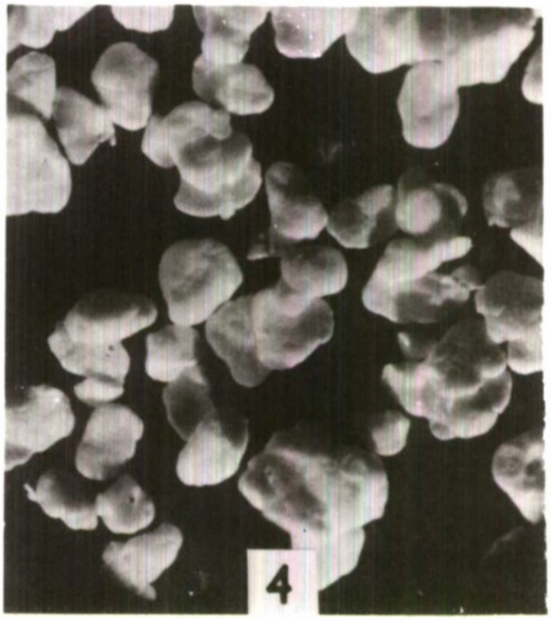
3(a) FLUON G1

3(b) FLUON G3

POWDERS SIMILAR TO PHOTOS 1 AND 2:- FLUON G102 TEFLON 5, 5B 6055 HOSTAFLON TF 14 ALGOFLON P HALON G50.



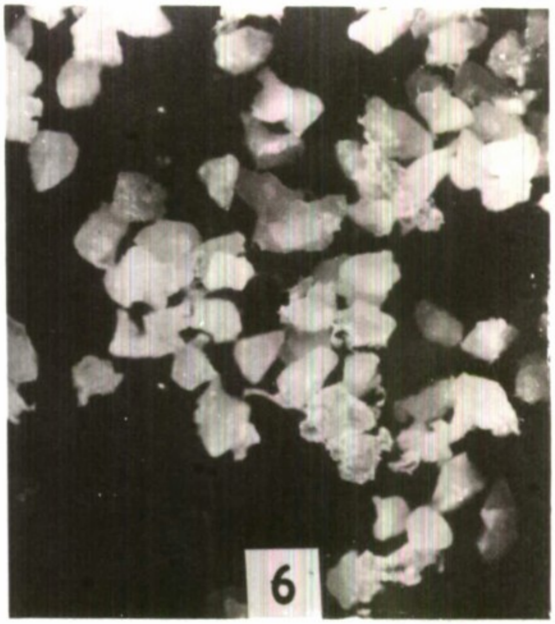
3(c) FLUON G2F
POWDER SIMILAR TO PHOTO 3:-
SOREFLON 502.



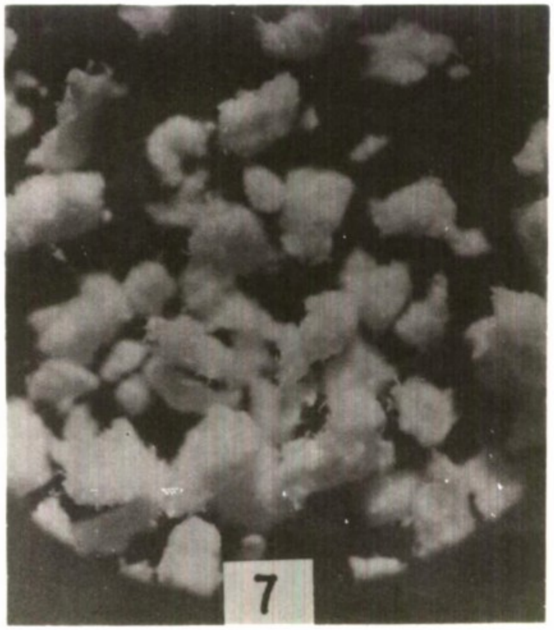
3(d) FLUON CD004
POWDERS SIMILAR TO PHOTO 4:-
FLUON CD1 TEFLON 6, 6H
ALGOFLON DP/S.

FIGS.3(a) TO 3(d) PHOTOMICROGRAPHS OF PTFE POWDERS.
MAGNIFICATION X25.

3(e.) HALON G85
POWDER SIMILAR TO PHOTO 5:-
HOSTAFLON TF VP 16



3(f) FLUON G162



3(g) FLUON G4

FIGS. 3(e.) TO 3.(g) PHOTOMICROGRAPHS OF PTFE POWDERS
MAGNIFICATION X 25

FIG. 4

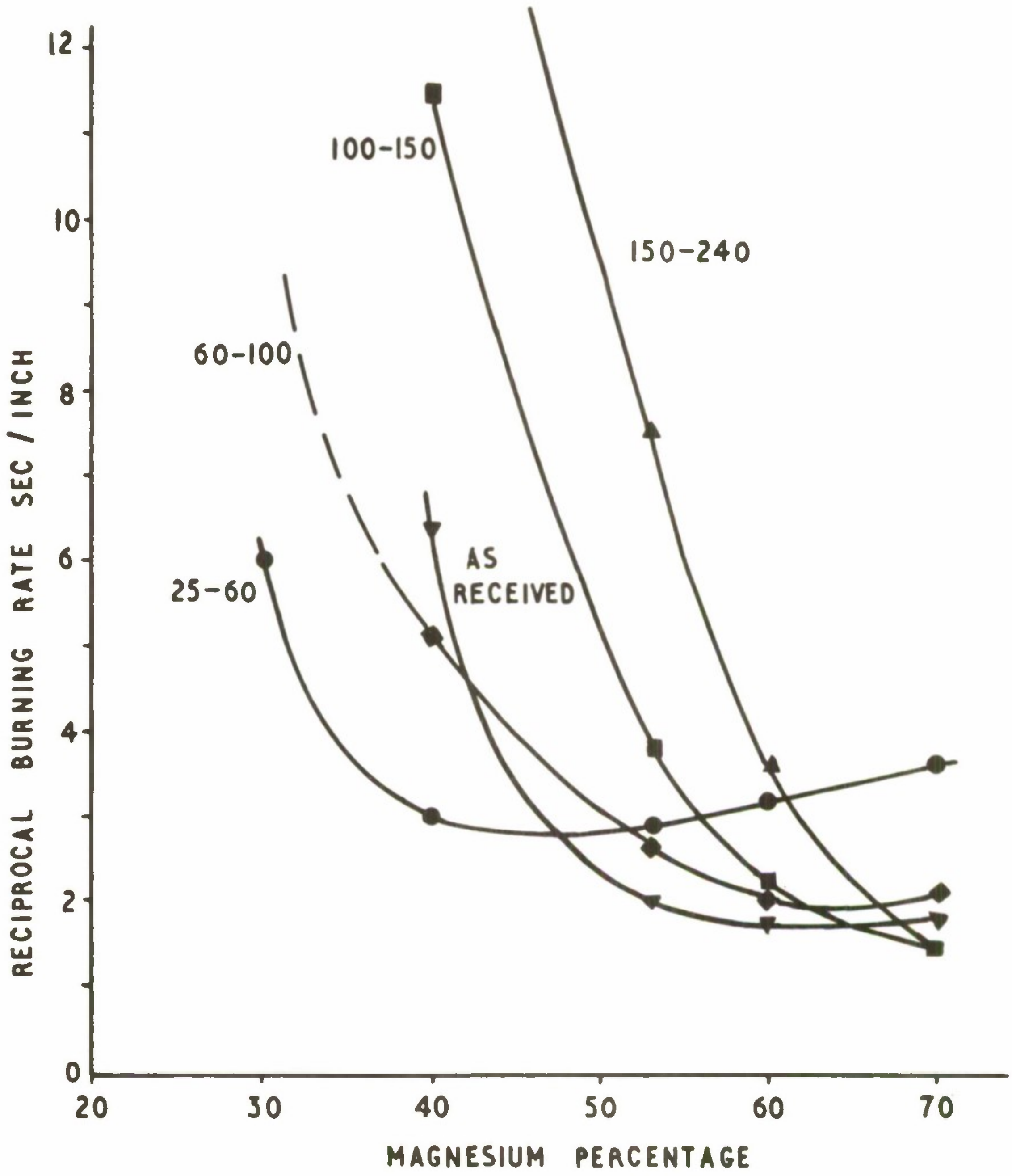


FIG. 4 VARIATION OF BURNING RATE WITH MAGNESIUM CONTENT FOR FLARES

CONTAINING:-
- MAGNESIUM (M.P.S. 17·6 MICRONS)
- FLUON G I (SIEVED AS STATED)
- VITON

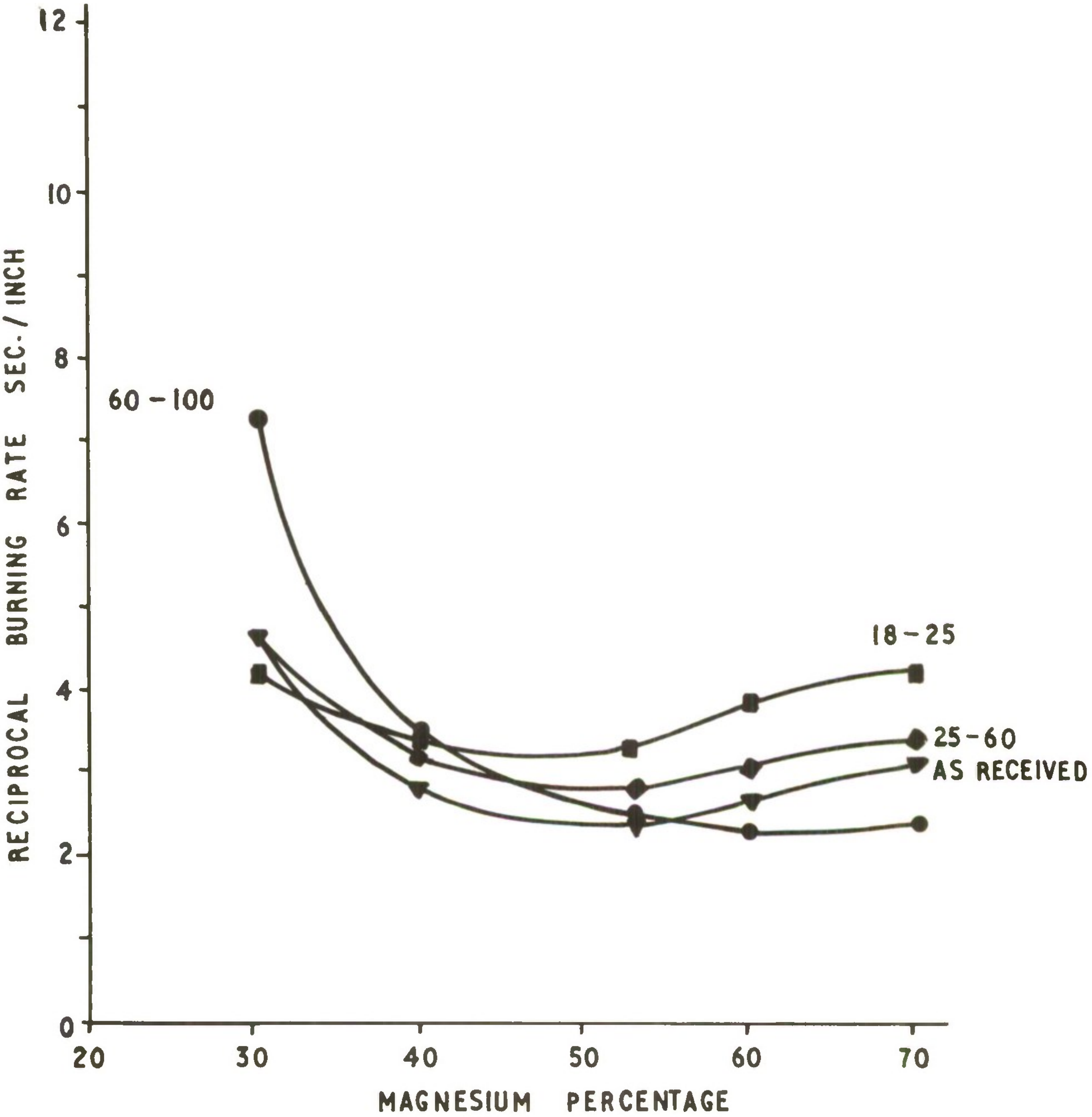


FIG. 5 VARIATION OF BURNING RATE WITH MAGNESIUM CONTENT FOR FLARES

CONTAINING:- MAGNESIUM (M.P.S. 17·6 MICRONS)
FLUON G2F (SIEVED AS STATED)
VITON

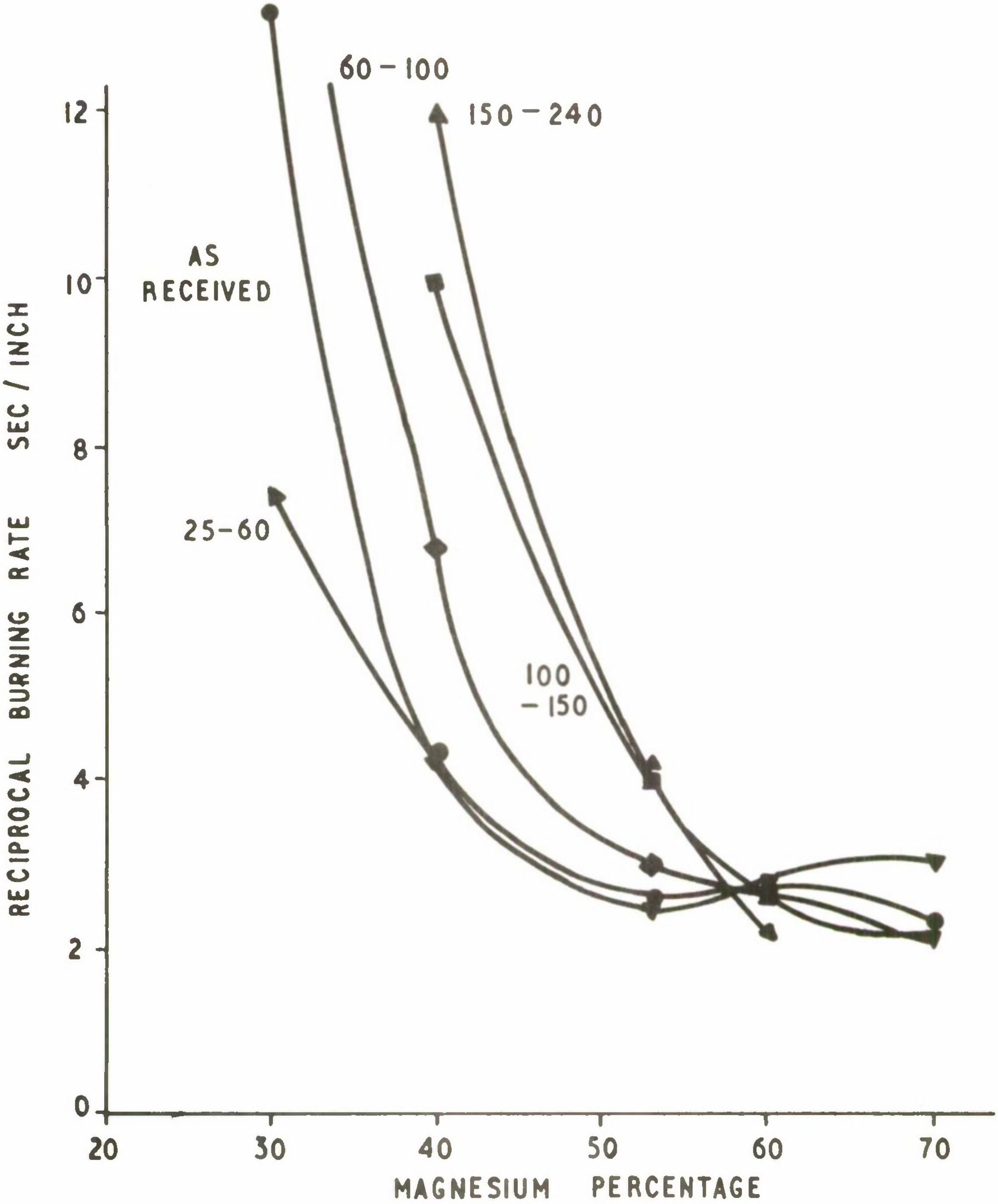


FIG. 6 VARIATION OF BURNING RATE WITH MAGNESIUM CONTENT FOR FLARES

CONTAINING:-
MAGNESIUM (M.P.S. 17·6 MICRONS)
FLUON G3 (SIEVED AS STATED)
VITON

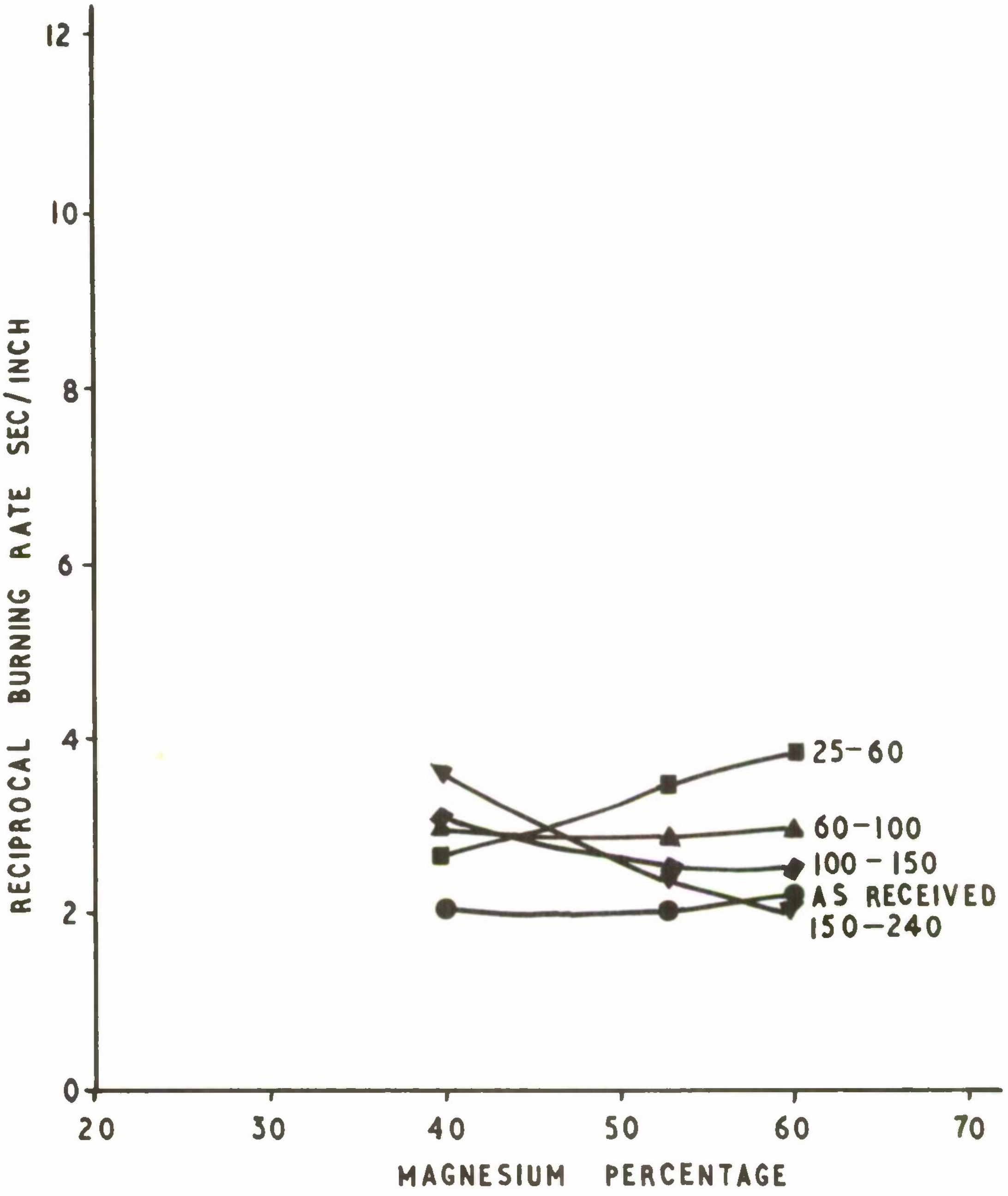


FIG. 7 VARIATION OF BURNING RATE WITH MAGNESIUM CONTENT FOR FLARES

CONTAINING:- MAGNESIUM (M.P.S. 17·6 MICRONS)
KEL F GRADE 3 (SIEVED AS STATED)
VITON

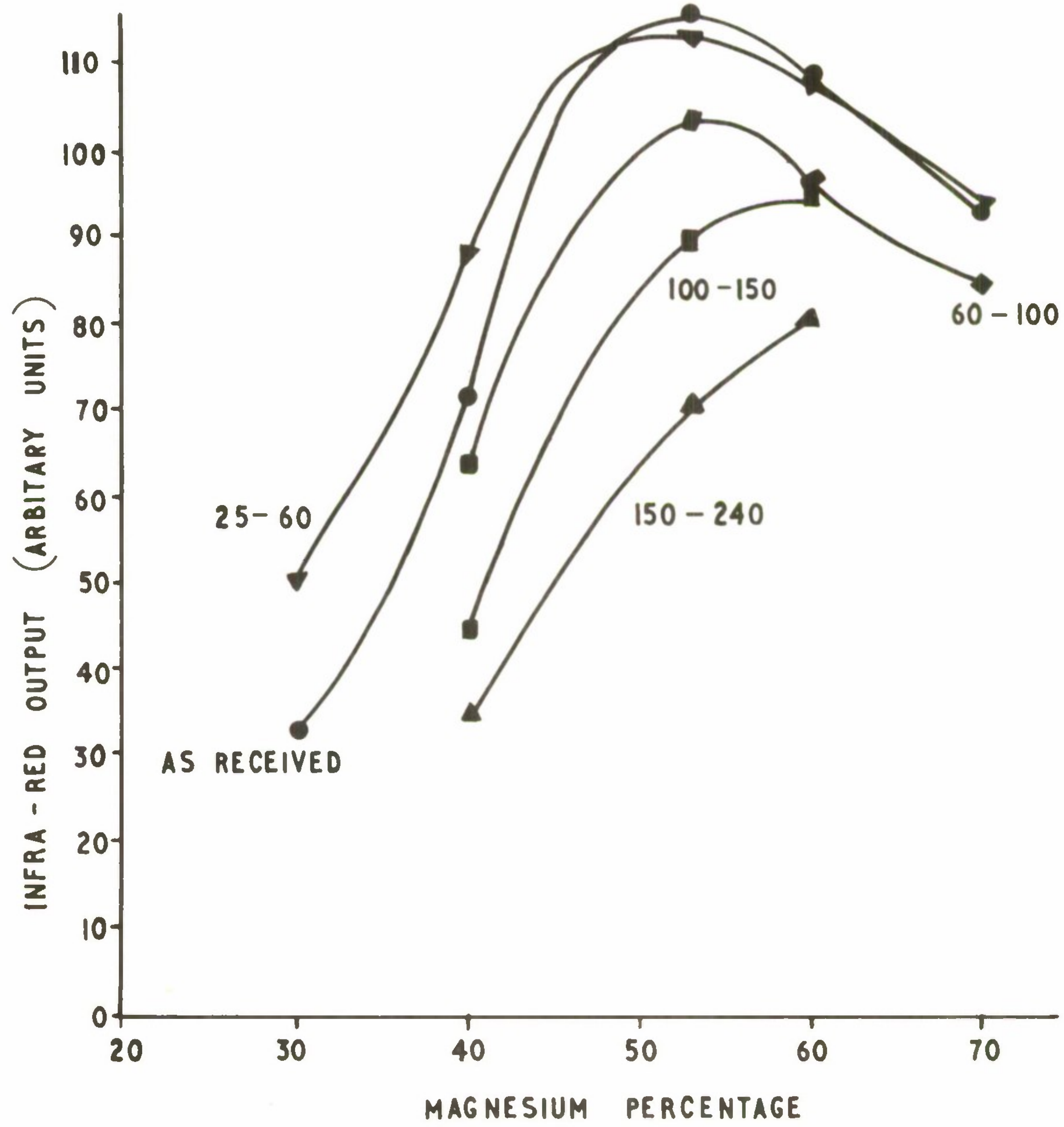


FIG. 8 VARIATION OF INFRA-RED OUTPUT BAND 2 WITH MAGNESIUM CONTENT FOR

FLARES CONTAINING:- MAGNESIUM (M.P.S. 17·6 MICRONS)
FLUON G3 (SIEVED AS STATED)
VITON

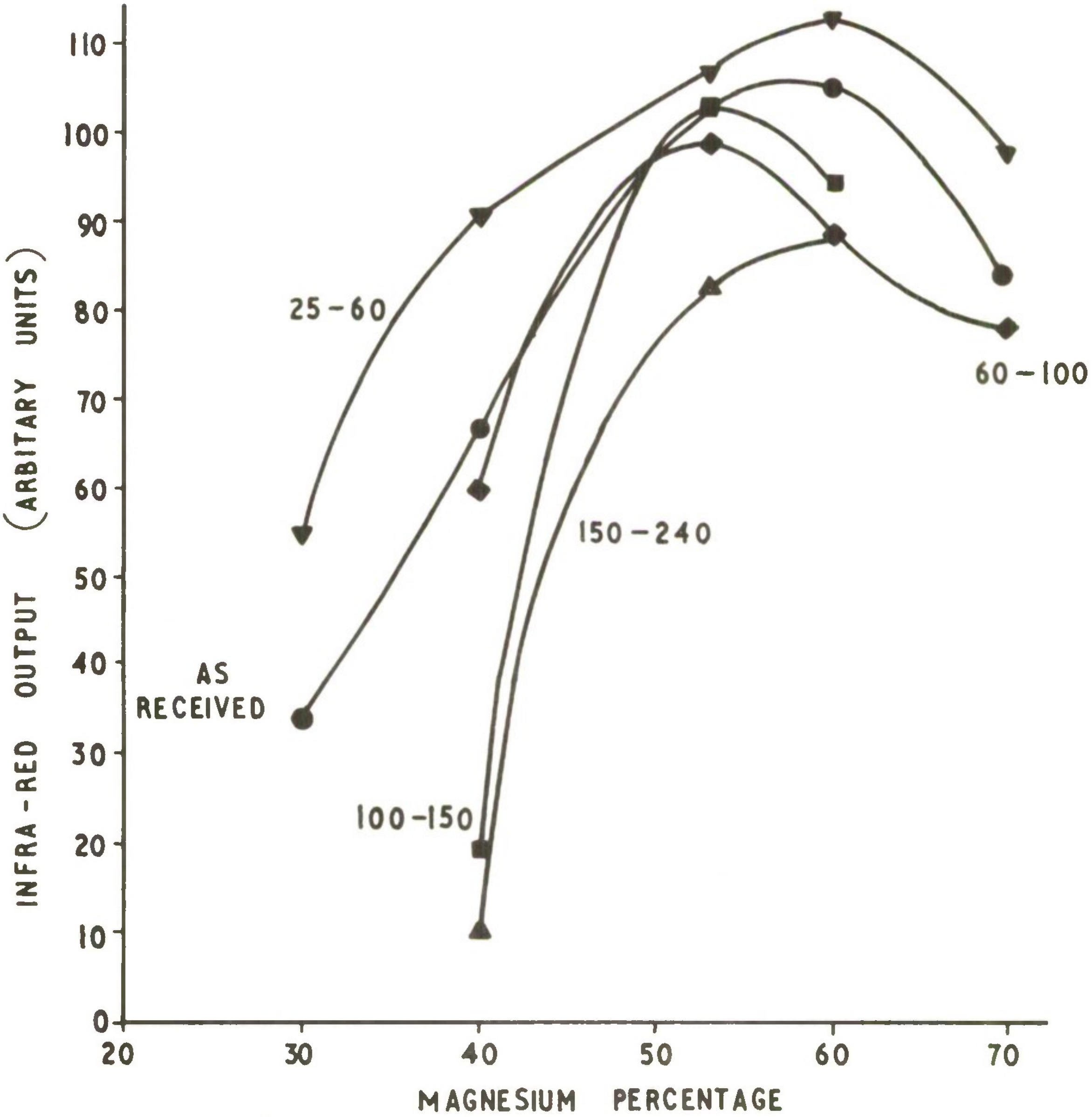


FIG. 9 VARIATION OF INFRA-RED OUTPUT BAND 3 WITH MAGNESIUM CONTENT FOR

FLARES CONTAINING:-
MAGNESIUM (M.P.S. 17·6 MICRONS)
FLUON G3 (SIEVED AS STATED)
VITON

10(a) COARSE PTFE:- SPARKY FLAME.

10(b) FINE PTFE:- SMOOTH FLAME.

FIGS. 10(a) & 10(b) FLARES SHOWING EFFECT ON FLAME OF FINE AND COARSE PTFE.

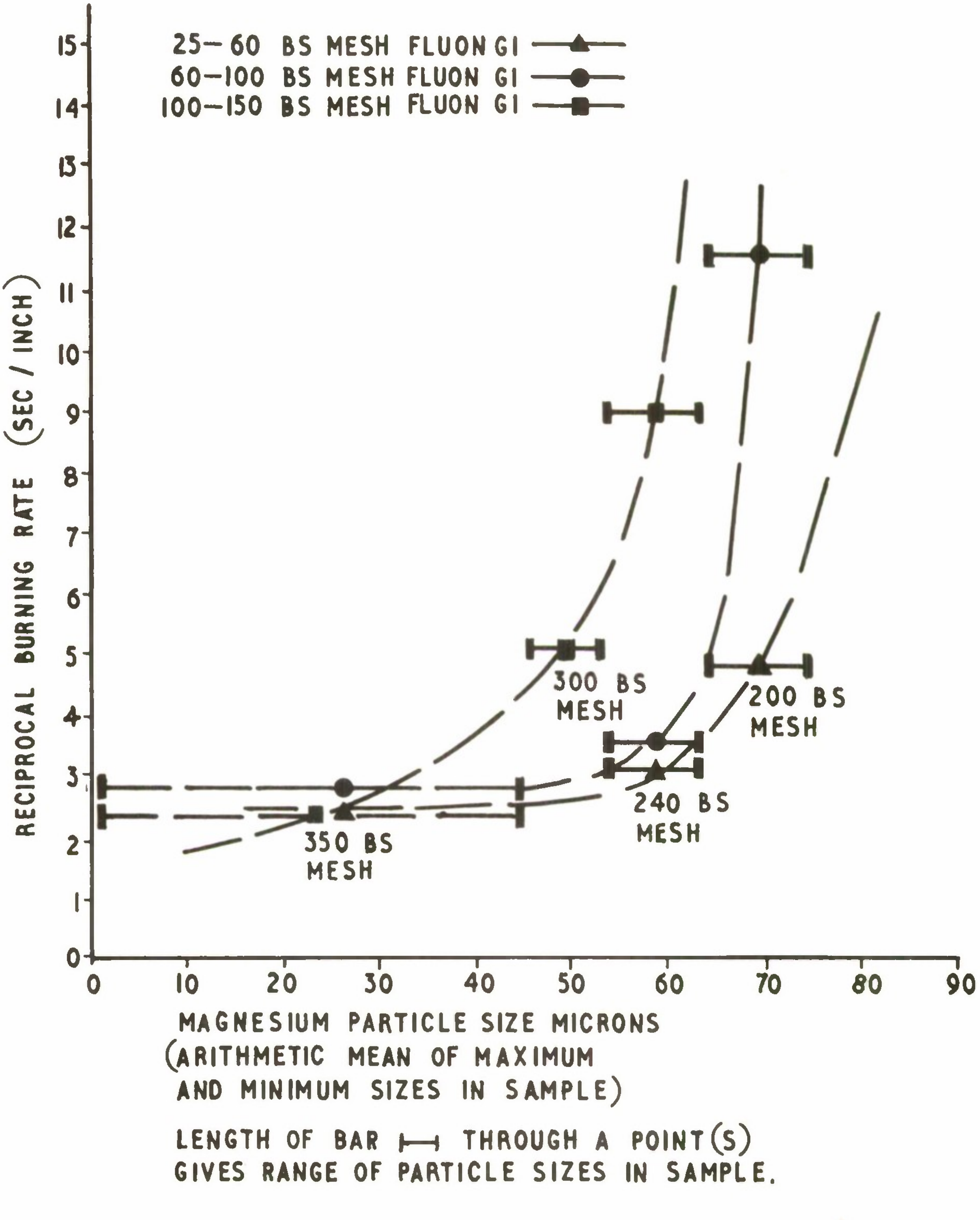


FIG. 11 BURNING RATES OF PYROTECHNIC MIXTURES CONTAINING [53 % MAGNESIUM, 42 % FLUON G1, 5 % VITON] FOR VARIOUS COMBINATIONS OF PARTICLE SIZE FRACTION OF FLUON AND MAGNESIUM.

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Investigation into the manufacture and properties of magnesium/fluorocarbon compositions for pyrotechnic applications.
Part I.
D. Jackson Edited by D. A. Dadley August 1969

The magnesium/fluorocarbon range of pyrotechnic compositions has been investigated to discover the control necessary to achieve a reproducible product with the desired burning characteristics.

The investigation has included the study of materials from all known sources and also the various stages of preparation between receiving the raw materials and testing the manufactured compositions.

34 pp. 11 figs. 13 tabs.

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