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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

PART I

D. Jackson (Wallop Industries Ltd.)

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

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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

PART I

D. Jackson (Wallop Industries Ltd.)

Edited by: D. A. Dadley, RADE/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 and 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

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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 1-2 μ 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 gave an 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

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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. by 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 spherical 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:-

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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.

* Delrin is a polyacetal resin manufactured by Du Pont.

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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 | 4.5 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 $\pm 15\%$) 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

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in a closed bomb initially containing 300ccs of air at $23 \pm 3^{\circ}\text{C}$ and at atmospheric pressure. These conditions were standard for all tests and the reproducibility was better than $\pm 2\%$.

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 Hostafon (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

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particles of median particle, size 400 μ to 500 μ . 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 (5 μ) made sieving irrelevant. It has flow properties similar to those of flour.

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(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, Hostafion 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 17.6 μ)
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

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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

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- (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

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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 necessarily 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

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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 17.6 μ) | 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.

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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.

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(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 infrared 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.

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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.

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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 | | | | | |

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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 |
| | CDOO4 | 6C | DP/S | |
| | | 6 | DP/T | |
| | | 3194 | | |

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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 | | |

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TABLE 4

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

| WI No | Make and grade of PTFE | Sieve Size of PTFE | Heats of Combustion cal g ⁻¹ | Reciprocal Rate of Burning g ⁻¹ sec in ⁻¹ | Light Output kcd in ⁻² | Relative Infrared Output | |
|-------|-----------------------------------|--------------------|---|---|-----------------------------------|--------------------------|--------|
| | | | | | | Band 2 | Band 3 |
| 468 | Fluon G1 | as rec'd | | WNB | - | - | - |
| 470 | | 25-60 | | 6.0 | 8 | 63 | 66 |
| | | 60-100 | | WNB | - | - | - |
| 557 | Fluon G2F | as rec'd | 2123 | 4.6 | 21 | 79 | 74 |
| 474 | | 18-25 | | 4.2 | 24 | | |
| 473 | | 25-60 | | 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 CDO04 (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.

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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 | | |

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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 |

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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 | 27 | 108 | 111 | |
| 249 | | 18-25 | 2030 | 3.3 | | 90 | 96 | |
| 250 | | 25-60 | 2040 | 2.8 | | 100 | 103 | |
| 251 | | 60-100 | 2139 | 2.5 | | 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 C1004 (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 | | |

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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 |

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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 |
| 377 | Teflon 6H | as rec'd | | 3.1 | 50 | 114 | 120 |
| 448 | (also known | 18-25 | | 2.0 | 39 | 116 | 117 |
| 449 | as TE3200) | 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 | as rec'd | | 2.2 | 46 | 104 | 101 |
| 451 | DP/S | 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 | as rec'd | | 2.6 | | 117 | 106 |
| 519 | TF 14 | 25-60 | | 2.9 | | 130 | 101 |

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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 VP 16 | as rec'd | | 2.7 | | 111 | 110 |
| 511 | | 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 (PCTFE) | as rec'd | | 2.0 | 53 | 92 | 82 |
| 544 | | 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 |

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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 | 1908 | 2.7 | 33 | 106 | 100 | |
| 336 | | 18-25 | | 3.9 | 20 | | | |
| 337 | | 25-60 | | 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 CDOO4 (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 cal g ⁻¹ | Reciprocal Rate of Burning sec in ⁻¹ | Light Output kcd in ⁻² | Relative Infrared Output | |
|-------|------------------------|--------------------|---|--|--------------------------------------|--------------------------|--------|
| | | | | | | 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 | as rec'd | | 1.8 | 65 | | |
| 453 | (also known | 25-60 | | 2.3 | 36 | | |
| 454 | as TE3200) | 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 | as rec'd | | 1.7 | 57 | | |
| 455 | DP/S | 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 | as rec'd | | 2.5 | | 102 | 99 |
| 520 | TF 14 | 25-60 | | 2.9 | | 100 | 90 |
| 517 | Hostaflon | as rec'd | | | | 113 | 97 |
| 513 | VP 16 | 25-60 | | 3.0 | | 102 | 98 |
| 514 | | 60-100 | | 2.9 | | 115 | 96 |
| 524 | Hostaflon | as rec'd | | 8.8 | | 103 | 106 |
| | VP 17 | | | | | | |

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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 |
| 534 542 | Soreflon 502 | as rec'd 25-60 | | 2.5 | 43 | 101 | 97 |
| 537 548 549 550 551 | Kel F3 (PCTFE) | as rec'd 25-60 60-100 100-150 150-240 | | 2.2 3.8 3.0 2.5 2.1 | 43 13 22 45 37 | 72 83 77 67 56 | 72 79 74 64 53 |

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TABLE 8

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

| 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 |

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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 ₁ 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 |

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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 |

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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 | |
| 202 | Fluon G1 | 60-100 | 17.6 mean | 2.9 | 55 |
| 212 | | | 63-75 | 11.6 | |
| 213 | | | 53-63 | 3.6 | |
| 278 | | | 45-53 | 6.4 | |
| 319 | | | less than 45 | 3.6 | |
| 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 | |
| 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 |

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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 | 60-100 | 17.6 mean | 3.0 | 55 |
| 305 | | | 53-63 | WNB | - |
| 306 | | | 45-55 | 15.0 | 43 |
| 307 | | | 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 |

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TABLE 13

Thermal outputs measured in various atmospheres.

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

| Atmosphere pressure (atmos) Composition | | THERMAL OUTPUT (cal g ⁻¹) | | | | |
|--|-------|---------------------------------------|-------|----------|--------|------|
| | | air | argon | nitrogen | oxygen | air |
| | | 1 | 1 | 25 | 25 | 25 |
| 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 |

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FIG. 1

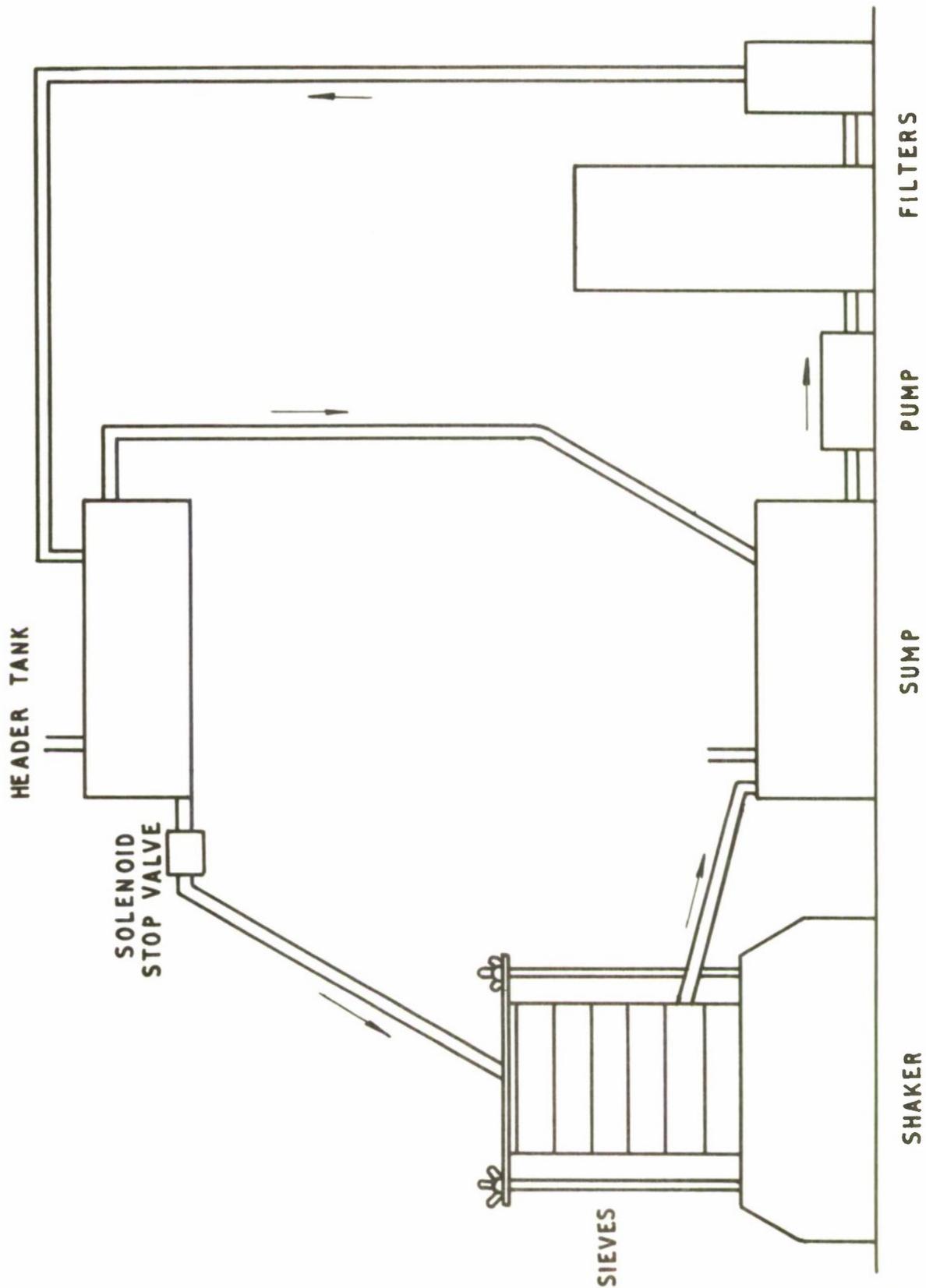


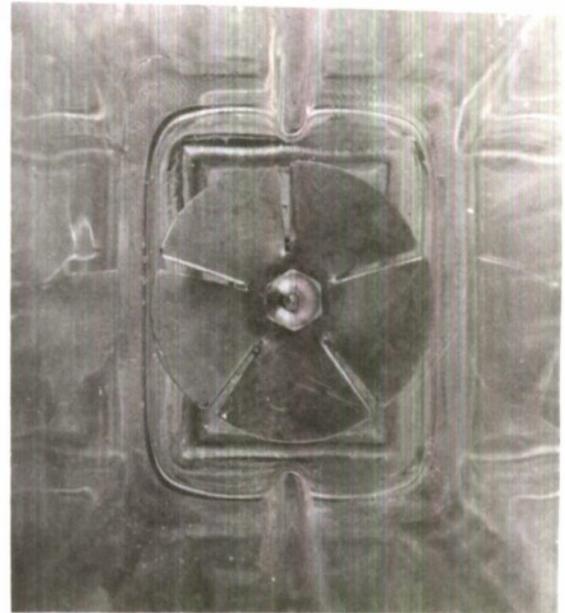
FIG. 1 SCHEMATIC LAYOUT OF P.T.F.E. SIEVING MACHINE

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

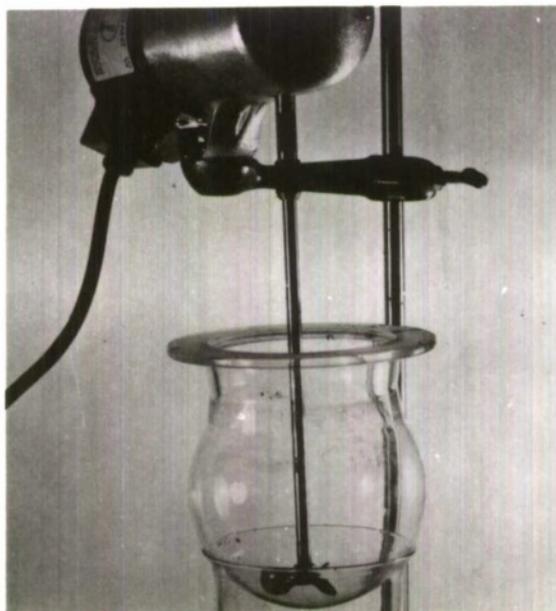
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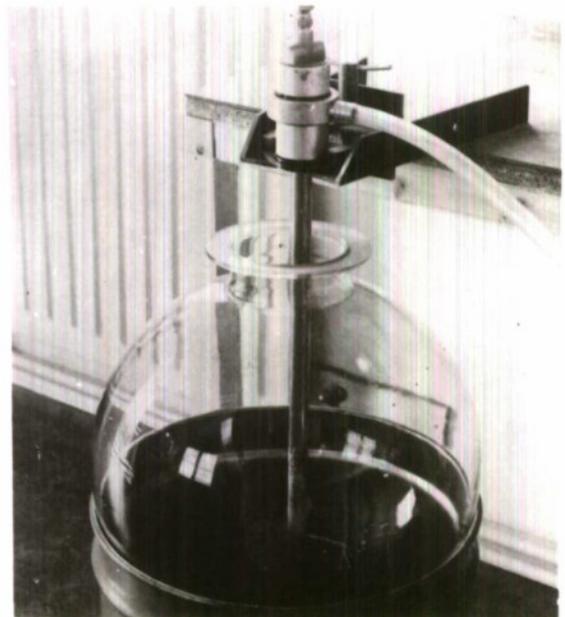
2(a) SUNBEAM MIXER.



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

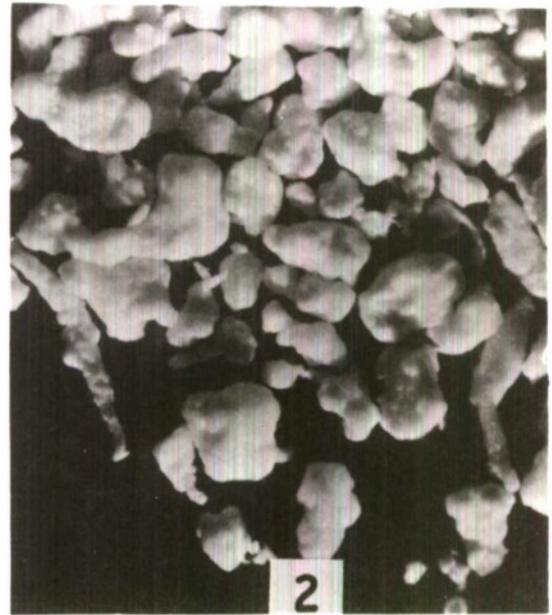


2(c) 'LIGHTNIN' MIXER WITH
SPHERICAL VESSEL.



2(d) PILOT PLANT.

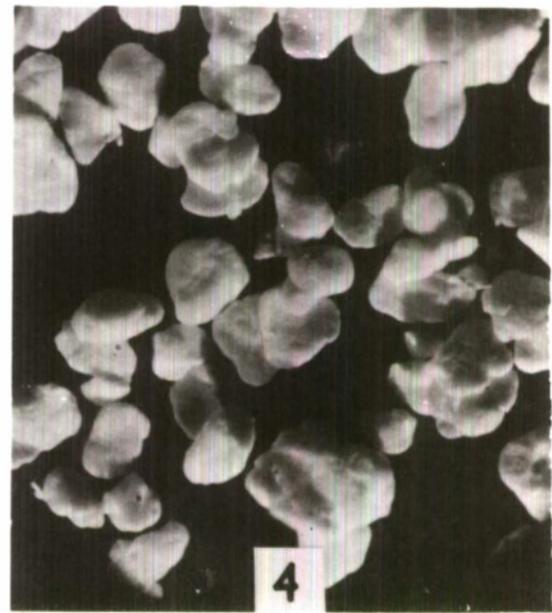
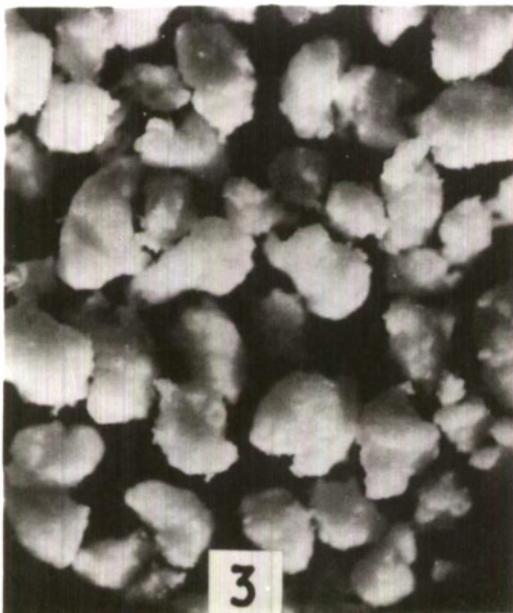
FIGS. 2(a). TO 2(d) MIXING MACHINES USED FOR THE PRODUCTION OF
VITON - CONTAINING COMPOSITIONS.



3(a) FLUON G1

3(b) FLUON G3

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



3(c) FLUON G2F

3(d) FLUON CD004

POWDER SIMILAR TO PHOTO 3:-
SOREFLON 502.

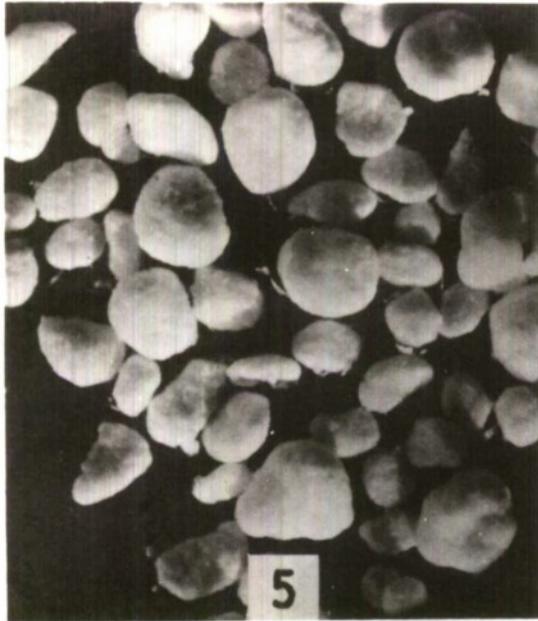
POWDERS SIMILAR TO PHOTO 4:-
FLUON CD1 TEFLON 6, 6H
ALGOFLON DP/S.

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

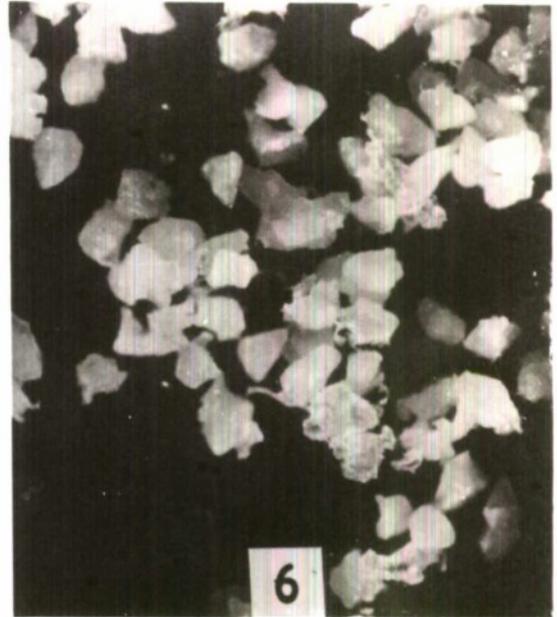
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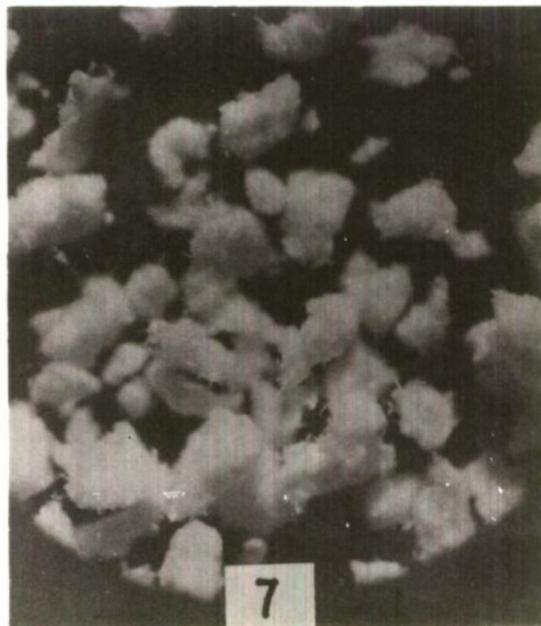
FIGS. 3.(e) to 3.(g)



3(e.) HALON G 85
POWDER SIMILAR TO PHOTO 5:-
HOSTAFLOX TFVP 16



3(f) FLUON G 162



3(g) FLUON G 4

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

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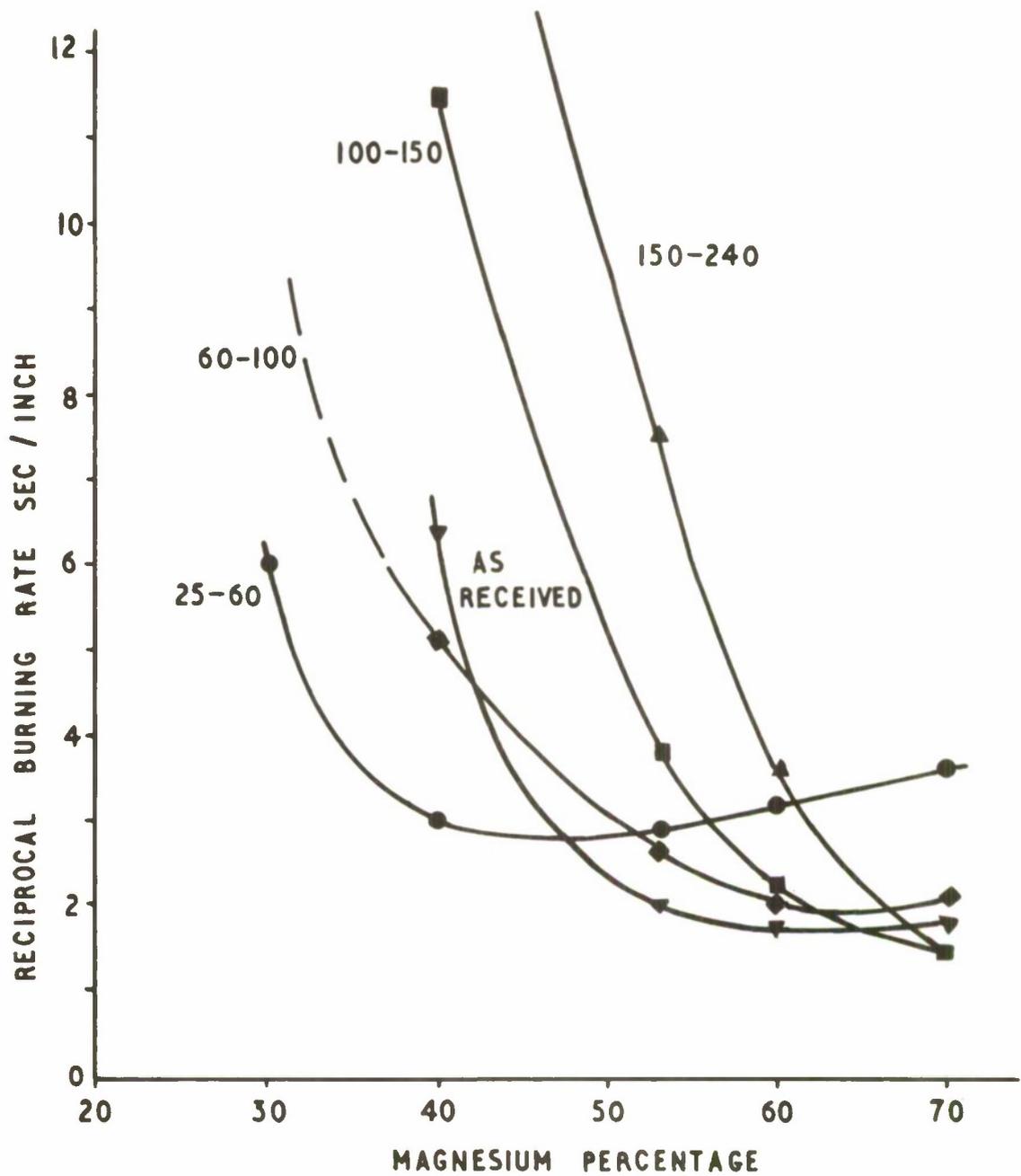


FIG. 4 VARIATION OF BURNING RATE WITH MAGNESIUM CONTENT FOR FLARES

CONTAINING: -
MAGNESIUM (M.P.S. 17.6 MICRONS)
FLUON G I (SIEVED AS STATED)
VITON

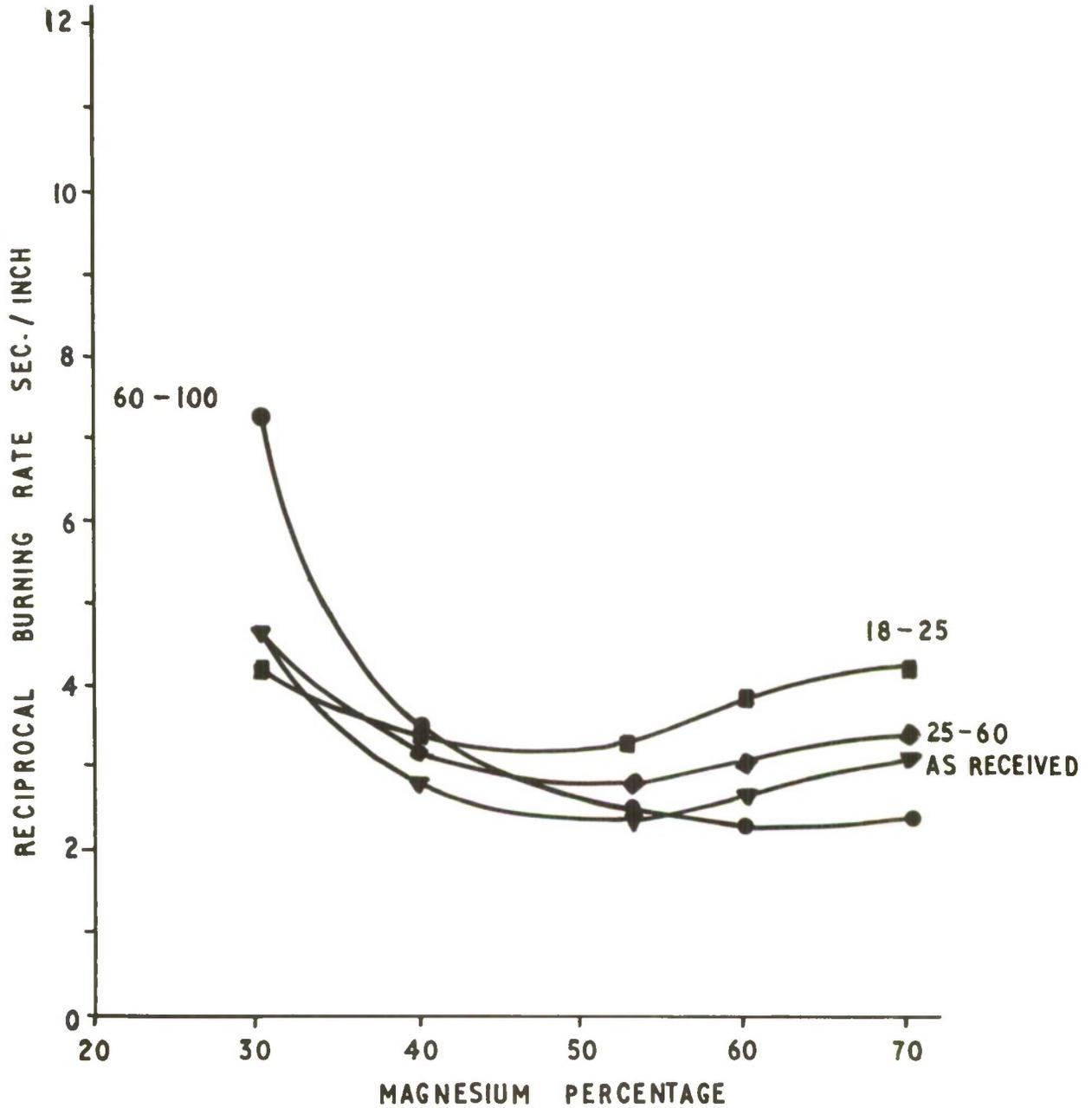


FIG. 5 VARIATION OF BURNING RATE WITH MAGNESIUM CONTENT FOR FLARES

CONTAINING:-
MAGNESIUM (M.P.S. 17.6 MICRONS)
FLUON G2F (SIEVED AS STATED)
VITON

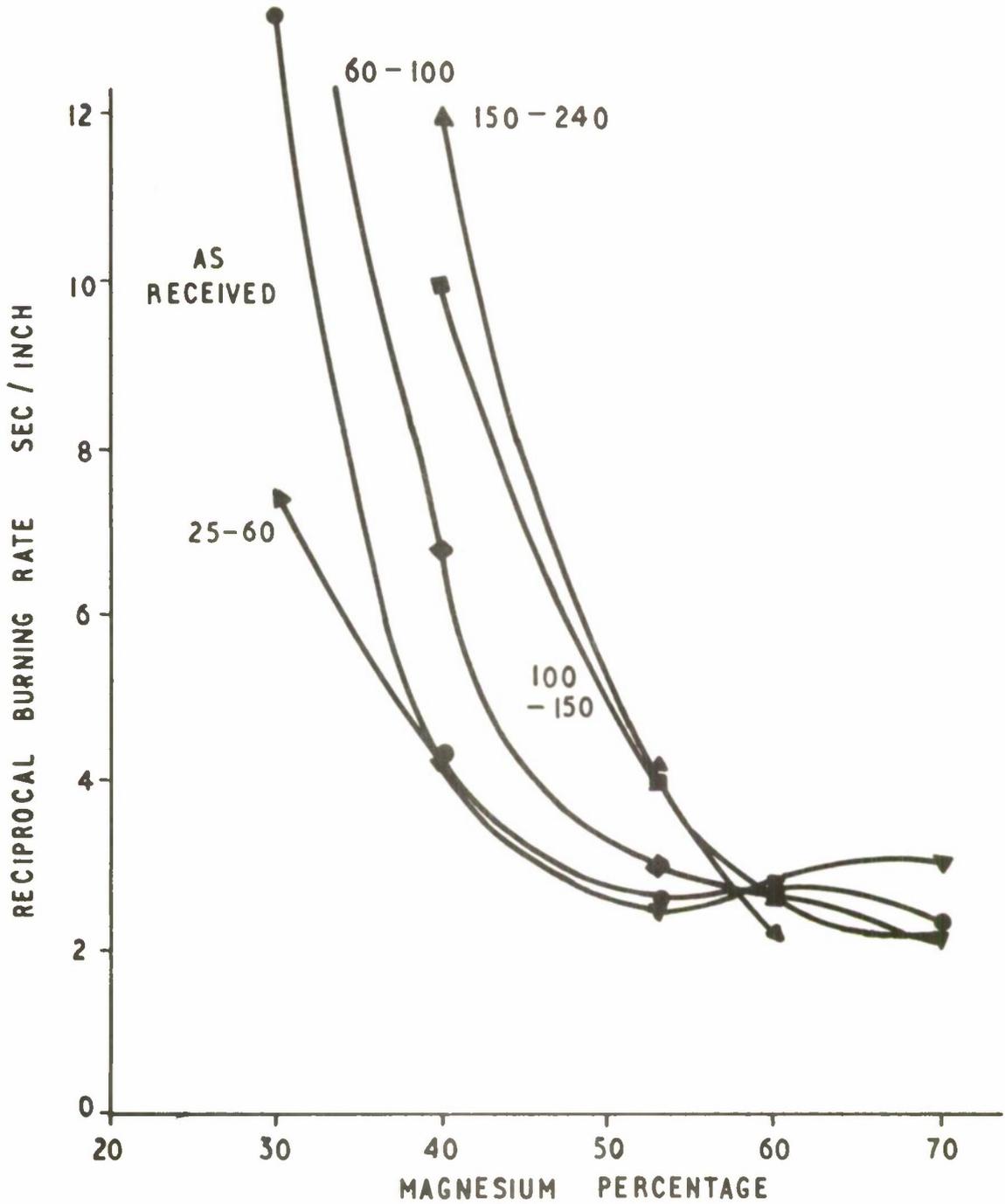


FIG. 6 VARIATION OF BURNING RATE WITH MAGNESIUM CONTENT FOR FLARES

CONTAINING: - [MAGNESIUM (M.P.S. 17.6 MICRONS)
FLUON G3 (SIEVED AS STATED)
VITON

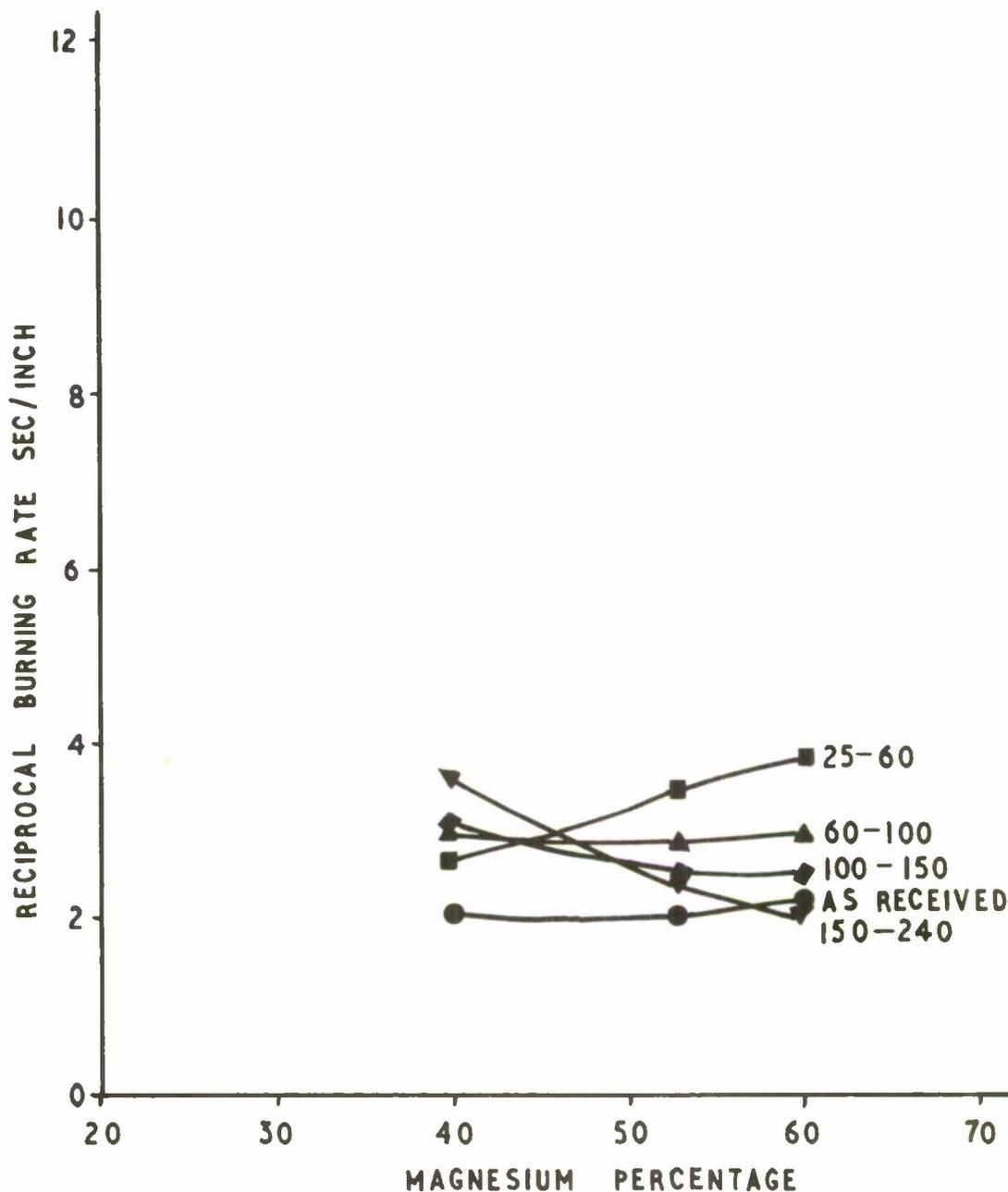


FIG. 7 VARIATION OF BURNING RATE WITH MAGNESIUM CONTENT FOR FLARES

CONTAINING:- [MAGNESIUM (M.P.S. 17.6 MICRONS)
 KEL F GRADE 3 (SIEVED AS STATED)
 VITON

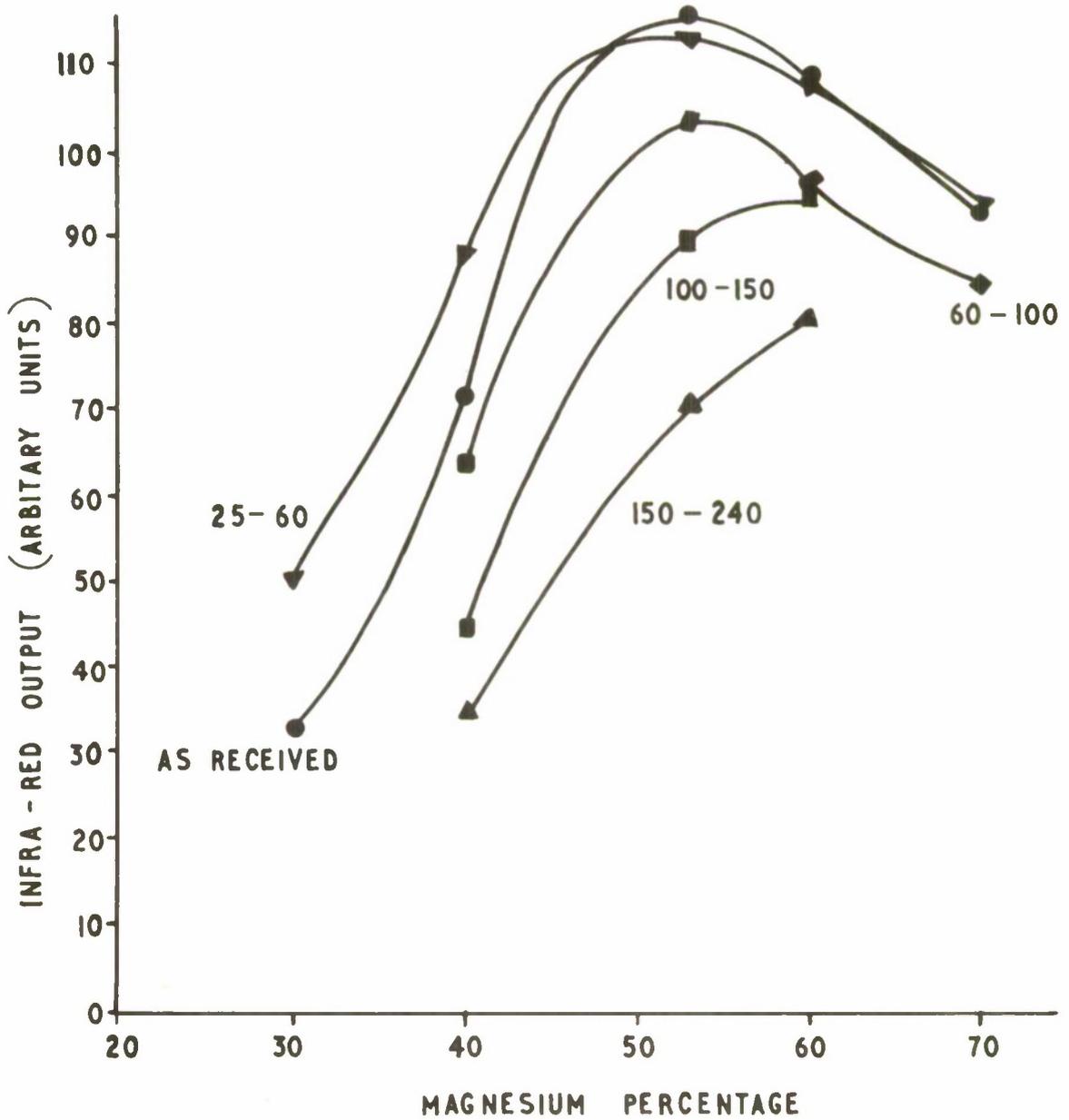


FIG. 8 VARIATION OF INFRA-RED OUTPUT BAND 2 WITH MAGNESIUM CONTENT FOR

FLARES CONTAINING:-
MAGNESIUM (M.P.S. 17.6 MICRONS)
FLUON G3 (SIEVED AS STATED)
VITON

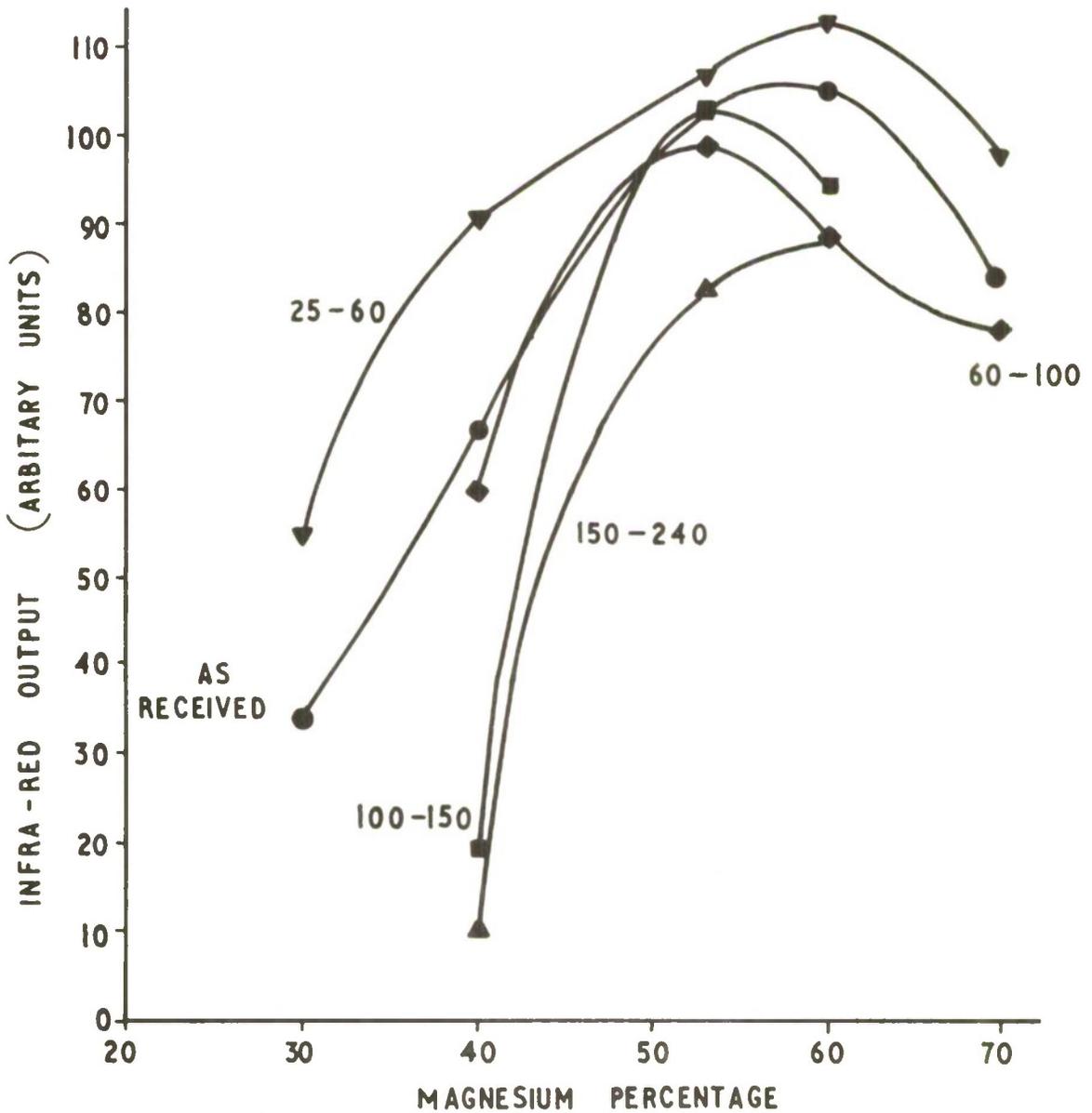


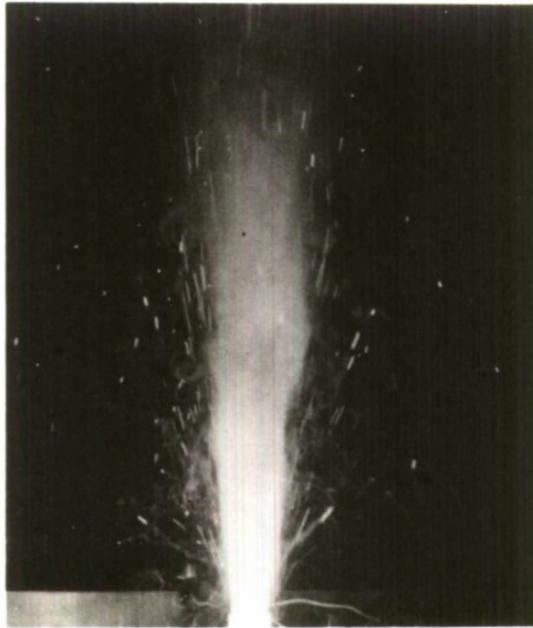
FIG. 9 VARIATION OF INFRA-RED OUTPUT BAND 3 WITH MAGNESIUM CONTENT FOR

FLARES CONTAINING:- [MAGNESIUM (M.P.S. 17.6 MICRONS)
FLUON G3 (SIEVED AS STATED)
VITON

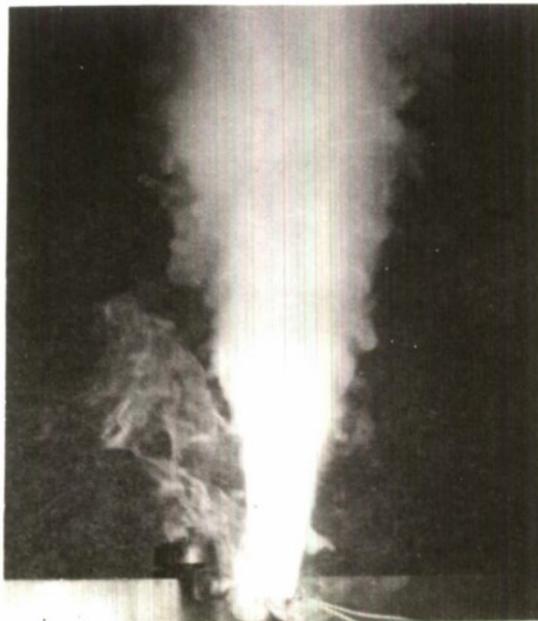
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FIGS. 10.(a) & 10.(b)



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.

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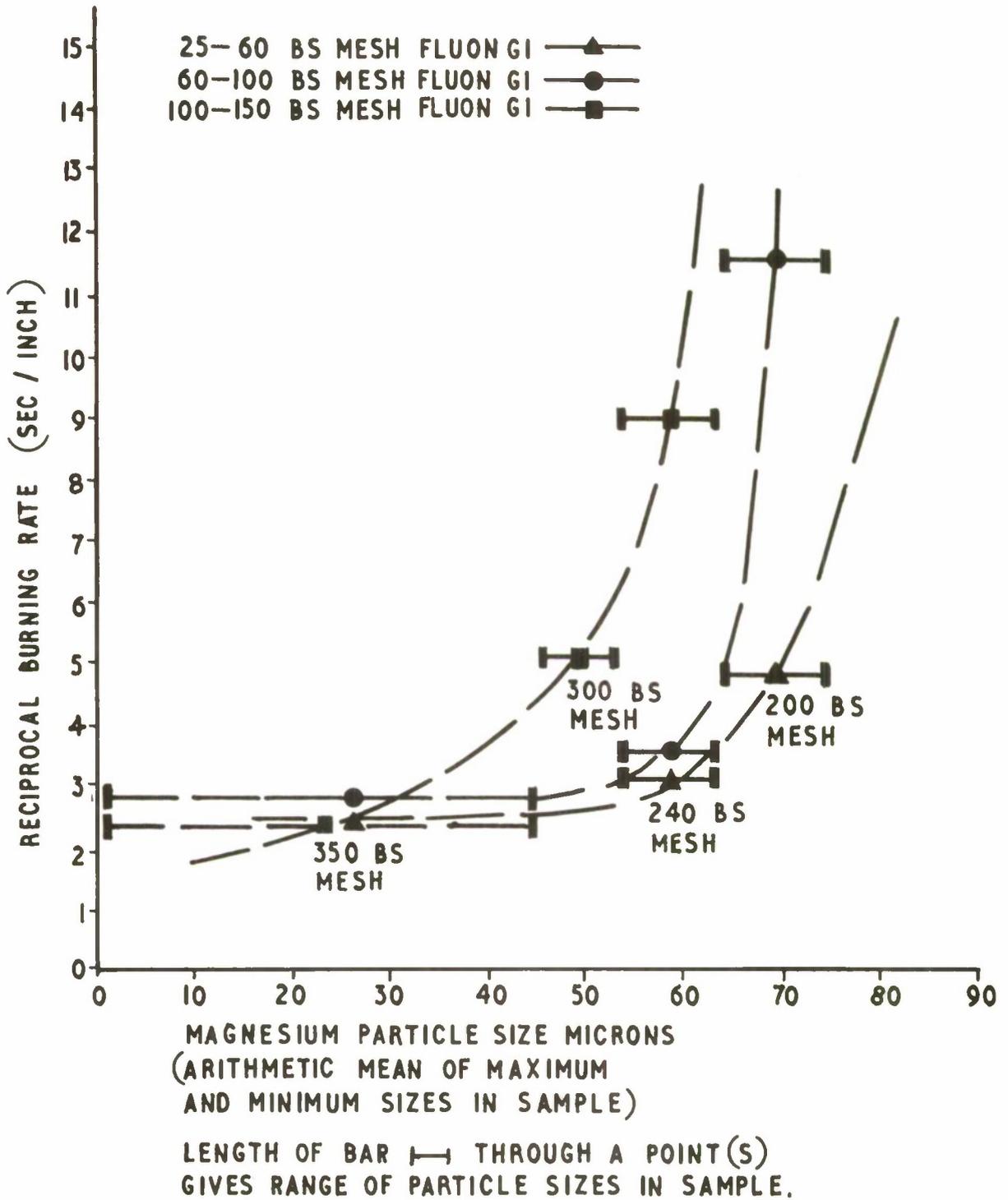


FIG. II BURNING RATES OF PYROTECHNIC MIXTURES CONTAINING

53 % MAGNESIUM
42 % FLUON GI
5 % VITON

FOR VARIOUS COMBINATIONS OF PARTICLE SIZE FRACTION OF
FLUON AND MAGNESIUM.

| | |
|---|--|
| <p style="text-align: center;">RESTRICTED</p> <p>Ministry of Defence Royal Armament Research and Development Establishment R.A.R.D.E. Memorandum 31/69</p> <p>Investigation into the manufacture and properties of magnesium/fluorocarbon compositions for pyrotechnic applications. Part I.</p> <p>D. Jackson Edited by D. A. Dadley August 1969</p> <p>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.</p> <p>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.</p> <p>34 pp. 11 figs. 13 tabs.</p> | <p style="text-align: center;">RESTRICTED</p> <p>Ministry of Defence Royal Armament Research and Development Establishment R.A.R.D.E. Memorandum 31/69</p> <p>Investigation into the manufacture and properties of magnesium/fluorocarbon compositions for pyrotechnic applications. Part I.</p> <p>D. Jackson Edited by D. A. Dadley August 1969</p> <p>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.</p> <p>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.</p> <p>34 pp. 11 figs. 13 tabs.</p> |
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