



HSE CONTRACT RESEARCH REPORT No. 62/1994

**DEVELOPMENT AND TESTING OF A PROCEDURE
TO EVALUATE THE DUSTINESS OF POWDERS
AND DUSTS IN INDUSTRIAL USE**

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This report concerns the development and testing of a practical new method for determining the propensity of a material to produce airborne dust when handled (known as *dustiness*). The new method enables the dustiness of a material to be determined for three health-related fractions of airborne dust - the inhalable fraction, the thoracic fraction and the respirable fraction. This is achieved using a system based on the original Warren Spring Laboratory rolling drum dustiness tester, modified to maximise the dust dispersed and incorporating a new three-stage dust sampling system. The sampling system consists of two particle size selective stages in series, followed by a back-up filter. The size selectors are cylindrical plugs of porous polyurethane foam, chosen to select the thoracic and respirable dust fractions, and the inhalable fraction is obtained by empirical choice of the conical passage between the end of the drum and the first foam size selector. The performance of the size selective foams was calibrated using two different aerosols - sodium fluorescein and fused alumina (aloxite), and good agreement with the requirements of the ISO/CEN sampling conventions was found. Determination of the dustiness values is by weighing the foams and filter before and after the test. However, due to instabilities in the weights of the foams, an identical set are positioned at the inlet to the drum to serve as controls.

The performance and practicalities of the prototype design were evaluated by determining the dustiness of 23 different materials supplied from a range of industries. These tests demonstrated that the new device is capable of providing meaningful, reproducible results for materials of a wide range of dustiness values (5 orders of magnitude). A complete set of engineering drawings for the new tester is supplied in the report, as is a draft MDHS describing the method.

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1 BACKGROUND

1.1 Introduction

The control of dust emission during the handling and transportation of materials is an important consideration in the design and operation of many industrial processes. Excessive airborne dust levels in workplaces are undesirable for a number of reasons: a) they can cause long-term adverse health effects to the workforce; b) they can be costly in terms of lost material; c) they can be responsible for the contamination of machinery and other products, and d) their control can involve the use of costly ventilation and filtration systems. It is advantageous, therefore, for process engineers to have information about the propensity of materials to produce airborne dust (the '*dustiness*' of the material) so that such problems can be minimised.

A wide variety of methods have been used to assess the dustiness of materials. A preliminary assessment of some of these methods has been carried out by the British Occupational Hygiene Society (BOHS) Technology Working Party on Dustiness Estimation, and published as BOHS Technical Guide No 4 (1985). Subsequent work by this group has involved a round-robin exercise in which samples of ten different powders have been analyzed for their dustiness by (ten) laboratories using a variety of methods. This data has been analyzed and will be reported soon. Warren Spring Laboratory (WSL) has played a major role in this work, both from the viewpoint of materials handling and of evaluating the performance of a number of different types of dustiness tester.

From this work, three main methods of determining the dustiness of materials have emerged as the most suitable in terms of validity and reproducibility. These are the impact, or single drop method, the fluidised bed method, and the rotating drum method.

The impact, or single drop, methods involve dropping the test material in an enclosed chamber onto a metal surface. Dust is generated both during the flight and on impact with the surface, and is usually sampled on to a simple filter mounted on the ceiling, or in the sides of the chamber. It is thought that these methods may represent a falling stream of material reasonably well.

Fluidised-bed methods involve passing a current of air through a bed of coarse particles mixed with the test material at a velocity sufficient to overcome the inter-particle forces in the bed and to cause dust to be dispersed. Sampling takes place isokinetically in the particle laden airflow emerging from the bed. This method is thought to simulate the effects of pneumatic conveyancing.

In rotating drum methods a series of blades fixed to the inside of a cylindrical drum repeatedly lift and let fall the test material as the drum rotates. This tumbling action is thought to be representative of many material handling processes, including the action of mixers, conveyors and similar machines. The airborne dust generated is sampled onto a filter or cascade impactor system.

Of these three types of test the rotating drum methods are the most versatile having the advantage that fine, lumpy, dry or damp materials can be tested easily. The effects of particle attrition and the breakup of aggregated particles, found in practical materials-handling situations, are also simulated more realistically. Furthermore, work carried out in the USA by Heitbrink et al (1989) has shown that dustiness results generated from a

rotating drum method correlated better with personal exposure measurements than those generated from a single drop method. The correlation however, was not consistent between industries, and further work is needed to relate dustiness measurements to the dust emitted from real material handling processes, and to the resultant exposures of the workers involved in the processes.

In most of the work that has been carried out so far, the specification of the dust sampling system has not been explicitly stated. Generally, it is assumed that a simple filter holder collects (with 100% efficiency) a representative sample of all of the dust particles made airborne in the test. Clearly this will not be the case, because the larger particles, with significant settling velocities, may either suffer vertical elutriation before reaching the filter holders in the roof of the chamber (for single drop tests), or may deposit on bends or horizontal surfaces between the exit plane of the drum and the collection surface (for rotating drum methods). The quantitative results that are currently obtained from dustiness testing methods are therefore difficult to interpret in terms of the prediction of dust levels in practice.

If the dustiness measurement is to be used to aid the design of equipment to minimise worker exposure, it is important that the results are expressed in terms of the relevant health-related size fractions of the dust. These have recently been specified by working groups of both the International Standards Organisation (ISO), and the Comité Européen de Normalisation (CEN) (1992), but unfortunately no dustiness method is currently capable of providing this information.

The Health and Safety Executive (HSE) is seeking to specify a standard method (as part of their Methods for the Determination of Hazardous Substances (MDHS) series) which is simple, reproducible, can be used to test a wide range of types of material and gives meaningful results. It is hoped that the test will provide results that design engineers can use to predict and minimise the impact of airborne dust, from materials handling, on both worker's health and on machinery. Other uses of the test are in measuring the effectiveness of dust suppressing additives to a dusty material and for quality control purposes. The aim of this project is to carry out the development work required to produce the standard method.

1.2 Review of WSL Rotating Drum Method

1.2.1 Description

The current design of the WSL rotating drum method is given in Figure 1, and was developed by Higman et al (1984). It consists of a large cylindrical drum (300 mm diameter, 460 mm long) with conical ends. Inside the drum are eight vanes attached to the walls to lift and tumble a sample of material placed inside the drum as it rotates at 30 rpm. Air is drawn through the drum at 28.3 l/min (1 cfm), and the airborne dust generated passes through a modified Andersen cascade impactor sampler, comprising three stages only. The pre-separator stage, which has 50% penetration (d_{50}) at 10 μm aerodynamic diameter, is used to minimise overloading of the greased impaction stage, which has a d_{50} of 9 μm . The backup filter collects those small particles which penetrate the impactor. A pipe with a 90° bend connects the sampler to the drum, and a rotating seal on the exit of the drum allows the sampler to be stationary, whilst the drum rotates. The flowrate through the drum and sampler is initially set to 28.3 lpm before the test using a rotameter,

which is also used to ensure that this flowrate is maintained during the test. This measurement is supplemented by a dry gas meter which is used to obtain an accurate measure of the actual volume of air sampled in the test.

All the size separating stages are weighed before assembly and 100 g of sample material is then spread evenly over the bottom of the drum. An automatic timing system controls the operation of the system. A simple push button starts the drum rotating, and after 5 s the pump starts and dust laden air is drawn through to the sampler for a period of 1 minute, after which the system automatically switches off. At the end of the test, the sampler is dismantled, the size selecting stages are weighed and the amounts of dust greater and less than $9\text{ }\mu\text{m}$ are calculated. The drum and size selecting stages are then cleaned and prepared for the next sample. Three repeat measurements are usually made on a material to give an idea of the consistency of the result. Three measures of dustiness are obtained; fine (particles $<9\text{ }\mu\text{m}$), coarse (particles $>9\text{ }\mu\text{m}$), and all particles sampled.

1.2.2 Critical appraisal

The WSL dustiness tester was developed during the early 1980's during a large programme to investigate all aspects of dust production from materials handling processes. At that time they were not specifically interested in using the dustiness measurements for assessing the risk to worker health from materials handling processes, and so the sampling/particle collection system employed was not required to give to health-related dustiness values. For this application therefore, the current sampling system is unsuitable.

The main feature of the device is its large (300 mm diameter x 460 mm long) rotating drum. This means that a wide variety of materials can be tested, including pellets, lumps of material, damp materials, as well as powders. In addition, the tumbling action involved in this test is thought to be representative of many material handling processes, including the action of mixers, conveyors and similar machines. It is especially relevant for processes where dust is thought to be produced by particle attrition and the breakup of aggregated particles. For these two reasons it is the most versatile of the dustiness testers currently available, and has been used on a great many materials giving a large body of data for reference (Higman et al 1984).

Despite these advantages the current design has a number of operational problems that need resolving before it can be recommended for widespread use.

These are:

- 1) Cleaning the drum can be a laborious and time-consuming task. Some materials can adhere quite strongly to the walls of the drum and require a major effort to remove them.
- 2) Particles deposit on the walls of the pipe that carries the dust laden air from the drum to the sampler. Although these are added to the dust collected in the pre-separator, the losses have not been characterised with respect to particle-size and errors from subsequent misclassification of fine particles may be large but are in any case unknown.
- 3) A more critical source of error comes when very dusty materials are tested. The impaction plate can become completely coated with particles and further particles may bounce from the surface to be collected on the filter. This can happen despite

greasing the impaction plate. The amount of material needed to overload the plate is variable depending on the density of the material and the shape of the particles. In addition, with extremely dusty materials (for example fine grades of carbon black) the pre-separator also becomes overloaded. Both of these effects will tend to produce errors in the classification of particles between the two size fractions due to particle bounce and re-entrainment.

4) The narrow inlet and outlet pipe was thought to give rise to a jet through the centre of the drum. This reduces the effective volume from which air was sampled and might affect the results obtained.

From this review, it can be seen that although the WSL rolling drum dustiness tester suffers from both design and operational problems, it is the most versatile method, and has therefore been chosen as the starting point for the development described in this report.

1.3 Health-related Sampling Conventions

Dusts emitted from the handling of powders and materials contain particles of a wide range of sizes. The likely hazard to health from the inhalation of a specific particle is dependent upon the nature and aerodynamic diameter of the particle, which govern its deposition to various parts of the respiratory tract. The International Standards Organisation (ISO, 1992), and the Comité Européen de Normalisation (CEN, 1992) have proposed new conventions for health-related sampling of airborne particles. Three main size fractions are proposed for industrial hygiene use; inhalable, thoracic and respirable, and they are shown in Figure 2.

Inhalable fraction, E_I : is defined as the mass fraction of total airborne particles which is inhaled into the nose and mouth. For industrial workplaces it is given by:

$$E_I = 50(1 + \exp[-0.06D])$$

where D is the particle aerodynamic diameter.

Thoracic fraction, E_T : is defined as the mass fraction of inhaled particles penetrating beyond the larynx. It is given by a cumulative lognormal curve, with a median aerodynamic diameter of $11.64 \mu\text{m}$ and geometric standard deviation of 1.5.

Respirable fraction, E_R : is defined as the mass fraction of the inhaled particles which penetrates to the unciliated airways. It is given by a cumulative lognormal curve with a median aerodynamic diameter of $4.25 \mu\text{m}$ and a geometric standard deviation of 1.5.

It is these sampling conventions that comprise the target specification for the design of the size selective sampling system of the new dustiness tester.

2 AIMS OF THE PROJECT

The aims of the proposed work are to:-

- 1) establish a quantitative test to assess the relative dustiness of materials in powder, granular or related forms;
- 2) determine the most relevant and appropriate techniques for measurement of dustiness for both nuisance and health-related size fractions;
- 3) design a test apparatus which incorporates the above requirements, whilst minimising the construction costs;
- 4) test the apparatus with a number of dusts and products to be specified by the HSE;
- 5) verify the performance of the apparatus in terms of the validity and reproducibility of the results, and the practical 'usability' (e.g. ease of use, portability, etc.) of the apparatus; and
- 6) produce a draft document for inclusion in the 'Methods for the Determination of Hazardous Substances' (MDHS) series on the proven method.

3 DESIGN STRATEGY

The decision was made, in the revised proposal, to base the development of the new dustiness tester on the original WSL rolling drum tester. This decision was not taken arbitrarily, but is based upon a number of advantages that the WSL design of tester has over other rolling drum methods such as the Heubach tester. They include; a) large drum size, which is easier to work with, and allows the use of large powder samples and samples comprising large particles and pellets; b) the construction of the WSL drum, with detachable end cones, is very amenable to design changes, including the incorporation of an improved sampling system; and c) the WSL tester has been widely used by a number of different laboratories such as HSE themselves (O'Farrell and Vaughan, 1986), Janhunan et al (1988), and Goodfellow and Smith (1988).

The design approach adopted for this development was to consider the dustiness tester as comprising three main components: a) a dust generation/dispersion system, b) a dust sampling system, and c) a pump, airflow measurement and control system. Although all three components are obviously interdependent, we were able, in the main body of the design work, to consider each component separately. The development traced the logical path given below.

- 1) Preliminary work:** to choose the most suitable method of providing the health-related size fractions, and to investigate the parameters of dust dispersion in the rolling drum to provide the dust necessary for the chosen size selective sampling system.
- 2) Prototype test rig:** a test or "bread-board" system designed to be versatile enough to enable the performance of the dust dispersion system to be optimised and the size-selective sampling system to be calibrated.
- 3) Tests with industrial materials:** to highlight any problems with the chosen design and provide information on the range of dustiness values obtainable with industrial materials currently in common use.
- 4) Design of production version:** design to incorporate essential features of prototype, whilst producing a system that is both easy to use and not too expensive.

These four stages of the development are described in the following chapters of this report.

4 PRELIMINARY WORK

4.1 Choice of Size Selective Sampling System

4.1.1 Introduction

The sampling system for the dustiness tester must meet a number of requirements.

- 1) It must be capable of selecting the thoracic and respirable fractions of those airborne particles that leave the dust dispersion drum.
- 2) It must be easy to dismantle and reassemble so that particle losses in handling are minimised.
- 3) It must use collecting media that are relatively light so that a balance with sufficient resolution to determine the mass loadings can be used.

Biologically-relevant dust fractions may be obtained in two ways; a) by the use of a cascade impactor to provide a full particle size distribution, from which the fractions can be derived, or b) by the use of specially designed stages. The cascade impactor option, whilst offering the advantage of a device with the size selection stages already-calibrated, must be operated vertically to minimise inter-stage wall losses. However, this means that a 90° bend is required and the inevitable wall losses in this must be calibrated. Although a slow bend will reduce these wall losses it will not eliminate them completely. An important drawback of cascade impactors is the overloading of the stages which lead to errors as particles are misclassified. Also the entry characteristics are unknown when it is used in this mode. We therefore propose to develop a three-stage sampling system to give measurements of the total dust emitted from the drum and the corresponding thoracic and respirable subfractions (as defined by the ISO/CEN conventions). This may be achieved by the use of either two stages of porous polyester foam or a double cyclone arrangement, and a backup filter.

The size selecting performance of the cyclones (like that of impactors) can be theoretically predicted and so form an attractive option. In addition, cyclones can cope with large dust masses as the particles separated at each stage are collected in grit pots (which can, in principle, be of any size) at the bottom of each cyclone. One double cyclone system considered was the TBF50 (Stuke and Emmerichs, 1973). It samples at 50 l min⁻¹, and uses two cyclones and a filter to give coarse and fine dust fractions. However, these fractions do not necessarily comply with the ISO/CEN sampling conventions and would require extensive calibration and possibly some redesign to achieve compliance. Also, despite the use of internal plastic liners to collect particles deposited on the cyclone walls, there are still considerable particle losses between the two cyclone stages. A problem common to both impactors and cyclones is particle bounce. Hard particles can be misclassified by bouncing off hard surfaces and being re-entrained into the air flow. These considerations guided our decision to use porous foams as size selectors for this application.

4.1.2 Porous polyurethane foams

The particle size selecting performance of porous polyurethane foams has been reported by a number of workers (Roessler (1966), Brown (1980), Gibson and Vincent (1981)). A semi-empirical theoretical treatment has recently been reported by Vincent et al, 1993, in which they attempt to piece together the various experimental work to produce a predictive model. From all these studies it became evident that the predominant modes of particle collection are inertial and gravitational deposition. This combination of inertial and gravitational forces is similar to the particle capture mechanisms that occur in the human respiratory system, and therefore by careful choice of parameters should lead to suitable size selecting stages. The structure of the foams is characterised by the following parameters:

- nominal porosity (in pores per inch, ppi);
- volume (packing) fraction, σ ;
- the effective filament thickness, df ;
- the thickness of the foam in the direction of airflow, t .

The particle penetration (P) was shown by Gibson and Vincent (1982) to be governed by the following parameters;

$$P = f(St, Ng, df, t)$$

where St is the Stokes number defining the inertial behaviour of the particle in the foam, and Ng defines the effect of gravitational forces.

The use of porous foams as particle size selectors for health-related aerosol fractions is not new. They are used in the French CIP10 personal sampler to both select and collect the alveolar fraction (Courbon et al, 1983). They have also been used in a sampler for the thoracic fraction for the ambient atmosphere (Mark et al, 1990), and in a personal sampler for both thoracic and respirable fractions (Mark et al, 1988). The development of the personal sampler is currently continuing under the auspices of the Nickel Environmental Producers Research Association (NiPERA) (Aitken et al, 1993). It was shown in the early work (Mark et al, 1988) that if aerosol is drawn through a 25 mm thick plug of foam of porosity 30 ppi with a velocity of 4 cm s^{-1} , particles comprising the thoracic fraction will penetrate. Subsequent unpublished work (Mark, 1989) showed that the respirable fraction will penetrate a plug of the same thickness of 90 ppi foam if aerosol is drawn through at the same velocity. To maintain the same size selection characteristics at higher flowrate it is simply necessary to increase the cross sectional area of the foam plug. In the NiPERA-funded project one of the main question marks concerning the use of foams was addressed - that of the consistency and quality control of the foam itself. For other size-selective devices such as impactors, cyclones and elutriators it is possible to ensure reproducibility of size selection from one specimen to the next by specifying adequate tolerances for manufacture. For foams, despite the manufacturers' assurances of adequate quality control, wide acceptance for the technique has been prevented by worries about reproducibility. This question was resolved by the extensive work reported by Aitken et al (1993). They showed that for both 30 and 90 ppi foams, particle penetration was unaffected by choosing plugs either from the same sheet or from sheets manufactured at different times with different batch numbers.

There is therefore, growing confidence in the use of foams as aerosol size selectors for health-related purposes. However, one main problem remains with the use polyurethane foams. Their mass varies with changes in the ambient environment. This is not important if the particles collected in the foams are not weighed, for instance where a single aerosol fraction is required, or where the particles are analyzed chemically (as in the case of the personal sampler for the nickel industry). For a sampling system for the dustiness tester, it is essential to determine the precision with which the mass of these foams can be measured, as this will affect the accuracy of the measurement of the collected dust. It is also important to determine which factors affect weight stability so that these can be controlled. This information was thought to be essential before the final decision to develop foam size selectors could be made.

Weight stability of foams: This was assessed by making repeat measurements of the masses of ten 5 cm diameter, 25 mm thick plugs of 90 and 30 ppi foam. The temperature and relative humidity at each set of repeat measurements were noted. As controls on the stability of the balance, 5 and 10 g standard masses were also weighed, these being of similar weight to the test foams. A Sartorius five figure balance (model 2004) was used. Although these foams were smaller than the ones used in the final version, they were assumed to respond in the same way to changes in the ambient environment and gave us a background set of data from which the minimum precautions needed to condition the foams was deduced. This assumption was later tested.

The weights of the foams were found to be sensitive to small changes in the ambient environment. Results in Appendix A show that, for the ten foam plugs with a mean weight of 5.5 g, day-to-day variations in that mean could be as much as 20 mg. Corresponding variations in the weights of the test mass, weighed simultaneously, were of the order of 0.05 mg. Analysis by Student's t-test showed these day-to-day variations in the measured foam weights were statistically significant at the 5% level whilst those for the test masses were not. This variation was worrying, as the total amount of dust measured in the old WSL dustiness tester was often less than 20 mg. However, as all the ten plugs of each foam were found to change weight consistently, the use of control foams was considered. This was found to eliminate a large amount of the variation in the measured weights, reducing the effective variation to 0.5 mg. This figure enables us to specify a minimum requirement for accurate measurement of collected dust. Vaughan et al (1989) in their paper on filter weights, suggested that masses of dust at least three times the background variation of the mass of blank filters are required for accurate measurements. This means that at least 1.5 mg of dust must be generated and collected in each dust fraction. The effects of weight changes in the test materials themselves would increase the variation as the test material may lose weight through drying or gain weight through absorption.

The work described so far has considered the effects on the weight stability of the foams, of day-to-day changes in temperature and humidity. However, as these effects were quite large, it was thought necessary to investigate the effects of drawing air through the foam to simulate its treatment in the dustiness tester. Filtered air was drawn through five plugs of each foam type at 40 lpm for 1 min to give a blank or null test, representing the background noise on the measurement of the weight of the foams. All of the foams were weighed before and after "exposure" with two groups of five control foams, one for each porosity. The test foams and the control foams were then weighed half an hour later, and then subsequently at intervals of one hour. The results of this work are shown in Figure 3 with the raw data given in Appendix B. It is clear that the process of passing air through the foams reduced their weights considerably. Their weights did not recover until at least

two hours conditioning in the weighing room atmosphere had passed. At this time the differences in weights between the test and control foams had returned to within ± 0.5 g of what they were before the test foams were exposed.

4.2 Improvements in Dust Dispersion

4.2.1 Introduction

From the weight stability problems of the foams, reported above, it became clear that the amount of dust dispersed in the rolling drum had to be increased for an accurate and sensitive method. A series of tests were carried out therefore to investigate the parameters that affected the amount of dust dispersed. Batches of near-monodisperse powders of fused alumina were used. This material, marketed under the name of Aloxite, has been used widely (Mark et al, 1985) in tests on the performance of aerosol samplers, and is readily available in large quantities and in a range of graded sizes from 9 to 120 μm aerodynamic diameter. Three main operating parameters were investigated. They were:

- 1) the flowrate through the drum;
- 2) the dust dispersion time; and
- 3) the mass of test material.

A preliminary investigation of the dustiness of a range of grades of Aloxite showed that F360 gave the largest dust yield. With this material it was hoped that small effects due to changes in the parameters mentioned above would show up more clearly and nearly all of the subsequent measurements described below, were made with this grade. In order to minimise possible errors due to batch to batch variation in the mean particle size of the Aloxite, all test samples were taken from a single batch.

At the outset it was not clear how the dust output from the drum varied with the parameters above. If the dust yield varied linearly with these quantities then the test parameters could be changed to suit unusual materials. For instance, if a material gave out a small quantity of dust then either the sampling time or the sample mass could be increased to give a dust yield that could be measured more accurately. Correction could then be made after the test confident that the effect of the changes has been to increase the yield linearly. Conversely, if the sampling stage became overloaded by a very dusty material either the sampling mass or the time could be reduced and correction made afterwards. This procedure is used for materials that overload the Heubach dustiness tester. If, however, the dust yield did not vary linearly then the parameters would have to be fixed. The values would be chosen to give the widest range of accurately measurable dust yields without overloading the sampling foams or filter. In any case, the flowrate, once set will have to remain constant as the calibration for any size selecting stages will only be valid for that flowrate.

4.2.2 The flowrate through the drum

Flowrates of 20, 28.3, 35 and 40 l min^{-1} were drawn in turn through the old WSL dustiness tester, with 100 g of Aloxite F360 used as the test material in each test. The results, which are given in Figure 4, show that the dust yield increases linearly with

flowrate. The error bars represent one standard deviation from the mean of three replicate tests. The results represent the total dust yields as the size calibration for the impactor stages used is only valid for the normal flowrate through the Andersen impactor of 28.3 l min^{-1} . In order to maximise the dust yield for the new tester therefore, the flowrate of 40 l min^{-1} was chosen. Higher flowrates were not tried as they were not within the capabilities of the pump. A higher flowrate would also have meant that the open area of foam required for a face velocity of 4 cm s^{-1} would be too large to be practical.

4.2.3 The dust dispersion time

The dust dispersion time was initially doubled from 1 minute to 2 minutes, with the expectation that a doubling of the time would result in twice as much dust being emitted. Surprisingly, doubling the sampling time had no effect on the dust yield and therefore caused an apparent reduction in the dustiness of the Aloxite F360, as the dimensions of dustiness are mass per unit volume of air sampled. Furthermore, when the dust dispersion time was reduced to 30 s, no change in the dust yield was recorded. Even with a dust dispersion time of just 5 s only a small fall in the dust yield was measured. These results can be seen in Figure 5. To observe what was happening, a transparent window was fixed to the non-sampling end of the drum. As the drum rotated a dust cloud was produced, as expected, but after just a few seconds the walls of the drum became coated with a thin layer of Aloxite particles. On further rotation of the drum the remaining airborne Aloxite particles (which have a tendency to agglomerate readily) stuck to those already deposited on the walls and no further dust was dispersed. This did not happen when a coarser grade of Aloxite (F230) was used, as the weight of the particles was sufficiently large to overcome the adhering forces. Additional tests with a finer grade of Aloxite (F1200) showed a much greater tendency to agglomerate.

All of these results are material specific. Although Aloxite tends to agglomerate in the test drum, other materials may continue to produce more dust with time, as agglomerates can be broken up by the tumbling action in the drum. This observation demonstrates the arbitrary nature of the choice of dust dispersion time and the need to define a standard, fixed time. This may give an underestimate of the likely dust emission in practice for some materials, but may also give overestimates for other materials. We decided therefore, to stay with the existing dust dispersion time of one minute as the data required for a more rigorous study would need work that was beyond the scope of this project.

4.2.4 The mass of test material

Masses of test material from 25 to 400 g were investigated. Tests were carried out using the old WSL dustiness tester, operated at the flowrate of 40 l min^{-1} and dust dispersion time of 1 minute, as recommended from the tests reported above. The results of these experiments are shown in Figure 6, where it can be seen that increasing the mass of material increases the dust emitted from the drum. The line represents a second order polynomial fit to the data. A further series of tests were carried out for the larger masses of test material, where the dust dispersed was investigated as a function dust dispersion time. These tests were similar to those reported above in section 4.2.3. The results, which are displayed in Figure 7, showed that when a larger mass of material is tested, dust is given off for a longer period of time. From Figure 7, it is apparent that for a 200 g mass of material, dust is emitted for about 60 s. When the mass of material is increased to 400 g, dust is emitted for 100 s. Again these results are only applicable to this material and also the grade of Aloxite used, but we may conclude that in order to increase the weight

of dust dispersed for subsequent collection in the sampling system we can increase the mass of material tested.

4.3 Recommendations from the Preliminary Tests

4.3.1 The Sampling System

- 1) The work described above showed that the most suitable method of particle size selection for giving both the thoracic and respirable fractions of the dust dispersed in a new design of dustiness tester is porous polyurethane foams.
- 2) However, due to the variability of the foam weights with environmental conditions, foams can only be used if at least 5 mg of dust is collected on each of the foam stages.
- 3) This conclusion provides the necessary specifications for the improvements in the quantity of dust dispersed in the dust dispersion section of the test apparatus.
- 4) The sensitivity of the foams to small changes in the environment meant that some care had to be taken with the handling and storage of the foams.

4.3.2 The Dust Dispersion System

From the work described above the following operating parameters were recommended in order to maximise the mass of dust dispersed:

- 1) As the dust yield was linearly proportional to the flowrate, a compromise value of 40 l min^{-1} was chosen.
- 2) The dust dispersion time was kept at 1 min, this seeming to be a fair compromise for the range of different materials likely to be tested in the new dustiness tester.
- 3) The mass of test material was fixed at 200 g, this again being a compromise for the range of materials likely to be tested in the new dustiness tester.

4.3.3 The Design of the New Foam Stages

With a recommended flowrate of 40 l min^{-1} , a circular open area of about 130 mm would be required to give the 4 cms^{-1} velocity through the foam necessary for selecting the thoracic and respirable fractions using 25 mm thick plugs of 30 and 90 ppi foams respectively.

5 THE PROTOTYPE TEST RIG

5.1 Description

The new prototype test rig (shown in Figure 8) was designed to enable us to carry out the necessary optimisation and calibration procedures prior to the design of a production version. Consequently, it was designed to be a versatile system, easy to dismantle so that changes could be made to some of the essential details, such as the distance between the foams and the end of the drum. It also enabled us to provide the exact face velocity through the foams (for correct particle size selection), by using thin annular disks with different internal diameters to change the open area of foam and the sampling flowrate. The prototype device consists of the rolling drum from the original WSL tester fitted with a new sampling system. The pumping and control system are also from the original WSL tester.

The prototype sampling system comprises a new end cone, a spacer piece to vary the distance between the first foam and the cone, two foam holders, and a filter holder. The new end cone bolts onto the end of the drum and the other components slide in series onto three long threaded rods, fastened to the end of the cone. Gaskets between each stage provide adequate sealing when the three nuts are tightened on the rods. A teflon shaft seal was used to connect the sampling system to the pump and the flow control. In this prototype version, the sampling system rotates with the drum.

Each foam measures 150 mm diameter by 25 mm thick and is held in an solid aluminium frame. The open area of the foam plug (nominally 130 mm) is defined by the thin annular aluminium disks on either side of the foam plug shown in Figure 8. A number of disks, of different internal diameters, were made so that the face velocity through the foam could be changed, to optimise the agreement of the particle penetration performance of the foams with the ISO/CEN sampling conventions. Assembly is as follows: the spacer is first fitted against the cone of the drum on the threaded rods, then the frame containing the 30 ppi foam is put into place followed by the 90 ppi foam frame. Finally, the filter holder is located on the rods behind the 90 ppi foam , and the nuts tightened on the rods to compress the gaskets between each stage so that the system is leak-proof. The pump and flow control are then connected to the back of the sampling system via the rotating seal. After a dustiness test has been completed, the sampling system is dismantled and the foam frames laid down horizontally on the bench for removal of the aluminium disk. The foam plug is then carefully lifted out of the frame with tweezers and prepared for what ever conditioning or analysis procedure is required.

5.2 Weight Stability of the Foams

As the diameters of the foam plugs specified for the new prototype were increased from 50 mm to 150 mm, it was considered essential to assess the effects on the weight stability of the larger foams. Tests similar to those described in section 4.1.2 were carried out to determine the effects of drawing air through the foams and the variable ambient conditions. The results are shown in Figure 9 and are given in detail in Appendix C. As expected, larger foams show greater variations in weight when stressed and take longer to recover than the smaller foams. The amount of dust that must be collected on each

foam is therefore greater and was calculated to be 6 mg for the error to be the same as that permitted in the paper by Vaughan et al (1989). In addition, the recovery time before results can be obtained with the larger foams was increased to 4 hrs.

5.3 Optimisation of Dust Dispersion

In order to finalise on the choice of parameters required to maximise the dust dispersion from the drum, a comprehensive set of tests were carried out with the new prototype tester. The parameters that were considered to have a possible effect on the concentration of dust reaching the first measurement stage of the sampling system (the 30 ppi foam plug) are described below.

1) **Drum length.** From observations of the distribution of dust within the drum, it became clear that most of the dust that reached the sampling section was generated in just the downwind half of the drum. It was thought therefore, that if the length of the drum was halved, more of the airborne dust generated would be collected on the foams. Tests were proposed with the standard 460 mm length and 250 mm length drums.

2) **Distance between the drum and the first foam.** The spacer piece was introduced into the prototype because we were concerned about large lumps of material impacting on the surface of the first foam. Tests were proposed with, and without, the 10 cm long spacer piece.

3) **Mass of test material.** Results from the preliminary study have shown that increasing the mass of test material does increase the mass of dust dispersed. However this can introduce problems for valuable materials, and those that are harmful to health. Consequently the choice of the mass of test material must be a compromise. Tests were therefore proposed to investigate the minimum mass of material that would give reliable results. Masses of 100 and 200 g were investigated.

4) **Type of material.** In order to gain maximum benefit from the tests, two of the least dusty materials available were used as the test materials. The rationale for this choice was that if we could accurately measure the health-related dustiness of those materials, then the dustiness of other, more dusty materials, could be measured accurately. Aloxite F1200 grade and granular fertiliser (Growmore) were chosen, these having been shown earlier, and by Higman et al (1984), to have very low dustiness values.

The experimental design, in the form of a randomised block, is shown in Table 3. Each entry represents a three repeat measurements of dustiness. Therefore the data set represents a balanced block design. The open area of the foams in the sampling system was set at 130 mm and was not changed during these tests.

Foam weights were measured using a system of five control foams for each foam type. These were weighed with the test foams before each test. After the test was carried out the foams were left overnight in the balance room to condition before weighing in the morning. Changes in the weights of the control foams were used to correct for the variation in the test foams due to changes in ambient conditions. The weight of dust

collected on the foam, W_d was therefore calculated from:

$$W_d = W_t - W_c$$

where W_t is the change in weight of the test foam, and W_c is the mean change in weight of the control foams.

The length of the drum was adjusted by using a sliding conical insert which sealed against the inside walls of the drum, see Figure 8a. This enabled the same drum to be used throughout the tests, thereby avoiding problems of differences in the internal geometry of the drum, including the blades. All the samples used in these tests were riffled into 100 and 200 g lots from the original bulk material to ensure representative samples. These samples were stored in a drying cabinet at 60°C to ensure consistency of moisture content between replicates of the same material.

The results of all these tests are summarised in Tables 1 and given in detail in Appendix D. They show, as expected that, increasing the sample mass and reducing the drum length increases the amount of dust collected on the foams. The tests also showed that the two materials differed significantly in their dustiness values. This was not revealed when the same materials were tested in the old dustiness tester.

Surprisingly, the presence of the spacing piece between the drum and the 30 ppi foam had no significant effect on the dust collected by either of the foams or the filter. The 30 ppi foam is the most likely to have been affected as it was considered possible that extraneous lumps of material could be thrown on to the foam. However, the variability on the measurements with the 30 ppi foam, are larger than those with either the 90 ppi foam or the filter, so that any small effect may have been masked. This variability could arise from agglomerated particles hitting the surface of the foam, and then either breaking up to penetrate, or being collected by the foam. This could appreciably increase the variance in the data for the 30 ppi foam.

The most encouraging conclusion to come out of this series of tests was that the dust masses collected on both of the foams was significantly above the measurement limit of 6 mg, set by the stability of the foam weight, for all but one of the test conditions. In addition, it is worth repeating at this stage that, the new prototype tester appeared to be more sensitive than the old WSL tester, because the differences in the values of dustiness for the two materials tested were significant in this series of tests, whilst they were not significant with the old tester.

Finally, from the results of these tests, it appeared that a four-figure balance could be used to measure the foam weights with the necessary precision, thereby reducing the overall cost of the method. All these factors gave us confidence to proceed further with the development, and on to calibration.

5.4 Calibration of Sampling System

5.4.1 Introduction

With most of the parameters of the test method assigned fixed values, from the tests described above, a complete calibration of the sampling system was the next step.

We decided at the outset to consider the sampling system (two foam size selectors and filter) as a unit that could be separated from the dust dispersion system (drum and means of rotation). This meant that we had to decide, for the purposes of the calibration of the size selective stages, where the dispersion finished and the sampling began, and then which particles constituted the health-related fractions. For this purpose, we defined a "sampling plane", which is shown in Figure 8b. This plane at the entry to the inlet cone, defines those particles that are available for sampling. The mass of particles penetrating this plane is defined as the true total 100% reference, and is determined by adding the mass of particles deposited on the inlet cone to those collected on the other sampling stages. A second sampling plane can be set at the surface of the 30 ppi foam, and it is only particles that reach this plane that will be included in the routine dustiness test. Other planes at the surfaces of the 90 ppi foam and the filter respectively can also be defined. In practice therefore, the following parameters can be measured. The total weight of dust entering the sampler, W_T is given by:

$$W_T = W_C + W_{30} + W_{90} + W_F$$

where

W_C is the weight of dust deposited on the cone,

W_{30} is the weight of dust collected on the 30 ppi foam,

W_{90} is the weight of dust collected on the 90 ppi foam,

and

W_F is the weight of dust collected on the filter.

The particle penetrations, P_C , P_{30} , and P_{90} through the three stages of the sampler are then given by:

$$P_C = \frac{W_{30} + W_{90} + W_F}{W_T}$$

$$P_{30} = \frac{W_{90} + W_F}{W_T}$$

$$P_{90} = \frac{W_F}{W_T}$$

where

P_C is the particle penetration of the inlet cone to reach the surface of the 30 ppi foam,

P_{30} is the particle penetration of the 30 ppi foam to reach the surface of the 90 ppi foam,

P_{90} is the particle penetration of the 90 ppi foam to reach the surface of the filter.

The first task with the calibration procedure was to ensure, in a preliminary set of tests, that at the flowrate chosen from the work described above, the particle penetrations of the two foam size selective stages were in good agreement with the ISO/CEN thoracic and respirable conventions. This was carried out using two test particles of aerodynamic diameters of 5 and 10 μm -close to the d_{50} 's of the respirable and thoracic conventions respectively. Once this was confirmed, the calibration curves were completed using about eight other test aerosols of different sizes. Each penetration curve was then compared with the respective health related size fraction. The penetrations through the cone and the

30 and 90 ppi foams were compared with, respectively, the inhalable, thoracic and respirable size fractions.

Two types of aerosol were used for the calibration to highlight any effects due to particle bounce from the wide range of material types that may be used in the test method. Sodium fluorescein aerosol was used as the main aerosol for the calibration. The particles consisted of monodisperse spheres which are soft and have a tendency to stick to any surfaces they come in contact with, whilst fused alumina (Aloxite) on the other hand is made up of irregularly shaped particles which are hard and will probably bounce off any hard surfaces they come in contact with.

5.4.2 Calibration with Sodium Fluorescein

Calibration using monodisperse aerosols of sodium fluorescein was carried out using the experimental layout shown in Figure 10. The test aerosol was generated using a spinning top aerosol generator with the particle size being controlled by a combination of the speed of the disc and the concentration of the sodium fluorescein in a solution of water and ethanol. Measurements of the aerodynamic diameters of the particles were made using microthreads and optical microscopy for particles greater than 5 μm (May and Druett 1968, Barrett et al, 1988) and a Palas sedimentation cell for smaller particles. In all of the tests reported here the geometric standard deviation σ_g was always less than 1.1. Unfortunately due to excessive losses of the larger particles within the aerosol generating system, the maximum size of sodium fluorescein particles tested was 25 μm . The Aloxite particles provided information on the penetration of the larger sizes. After generation particles were blown past the inlet to the dustiness apparatus which drew in aerosol laden air at a rate of 38 lpm through the drum and the prototype sampling system. The preliminary work with 5 and 10 μm particles showed this flowrate gave closest agreement to the curves. As described above, the foam size selectors were held in rings of internal diameters of 130 mm, which defined the open area of foam exposed to the aerosol. In the prototype version, for convenience, a 70 mm diameter filter was used. The dustiness apparatus was rotated at 30 rpm as it would in an ordinary test. Tests lasted for about 1 to 10 mins depending on the particle size. To remove possible biases the order in which each particle size was used for the calibration measurement was randomised.

After the test, the dustiness apparatus was carefully dismantled and each of the foams washed thoroughly in 500 ml of deionised water. The walls of the cone were washed down with 250 ml of deionised water. In addition, the filter and the walls between the 90 ppi foam and the filter were washed with 100 ml of deionised water. All of the deionised water was buffered to pH 7, and 3.5 ml samples were taken from the wash volumes for fluorometric analysis. A Perkin Elmer 1000M model fluorometer was used for all of these analyses.

The results of this work are shown in Figure 11 along with the ISO/CEN definitions of the health related size fractions for inhalable, thoracic and respirable dusts. Close agreement can be seen between the experimental points and the sampling conventions for both the thoracic and respirable fractions. Although the data seem to give an underestimate of the thoracic fraction the error is small. Later experiments in which the open area of the foam was increased (and therefore the face velocity of the air was reduced) did not affect the fit greatly. The only practical changes that could be made to the thickness had too great an effect and resulted in considerable departures from the curves. The most surprising

result is the good agreement between the results of the cone penetration P_c and the inhalable convention. This is purely fortuitous and was not designed to happen. Nevertheless, for particles of aerodynamic diameters up to $25\ \mu\text{m}$ we can conclude that we have produced a device that provides values of the dustiness of materials in the three main health-related fractions.

5.4.3 Calibration with Aloxite

As sodium fluorescein is a soft solid material it does not behave in the same way as a harder, more bouncy materials in a sampling system. For this reason it was thought essential that a second calibration was done using a much harder material, Aloxite. It is supplied in a wide range of graded sizes that are nearly monodisperse ($\sigma_g = 1.3$) and was readily available. The other advantage of Aloxite was that it would allow us to extend the calibration up to $50\ \mu\text{m}$ aerodynamic diameter.

Figure 12 shows the system used for this calibration. Samples of 100 g of aloxite of all the grades between F1200 and F360 (ie, a range from 6 to $46\ \mu\text{m}$ mean aerodynamic diameter) were riffled from bulk supplies and dried in an oven at 60°C . In a single measurement 25-50 g of the chosen Aloxite grade was poured into the hopper on the dispensing system. The drum was set rotating and the pump started before the dispenser was started. Air was blown through the tube under the hopper at between 10 and 20 lmin, depending on the grade of Aloxite being used. A rotating scraper arm was used to ensure smooth, continuous feed of the dust from the hopper. Dust dispensed from the system was then drawn, with air from outside, into the drum and through the foams and the filter at 40 lmin. Both of the foams and the filter had been weighed before the test. The open area of foam presented to the air flow was a 130 mm circle, as used in the previous fluorescein calibration. Sampling continued until the dispenser ran out of dust which usually took about 20 mins. After each test the disperser and the drum were thoroughly cleaned.

After the test the foams and the filter were weighed. No controls were used as the dust loadings on the foams were such that any variations in the foam weight were swamped by the amount of dust on the foam. Typically between 5 and 15 g of dust were collected on the foams, whereas the variation in the weight of the foam due to stressing would be, at the most, 20 mg. Any dust collected on the cone was washed on to a pre-weighed glass fibre filter which was then dried overnight before weighing. Again no controls were used as the amount of dust collected swamped any variation in the weight of the filter. As in the previous calibration the order in which the particle sizes were selected was randomised to eliminate any potential biases. A few sizes were repeated to get a crude estimate of the reproducibility of the measurements.

A few grams of each grade of Aloxite were saved for size measurement in a Micromeritics Sedigraph. This instrument measures the changes in x-ray transmittance of a system of particles as they sediment through a viscous fluid. From this the distribution of the sedimentation diameters of particles in the fluid is calculated. These need only be multiplied by the square root of the material density to get the aerodynamic diameter. Any shape effects are accounted for in the original measurement.

The results of this series of measurements are shown in Figure 13. Again good agreement between the ISO/CEN size fractions and the data can be seen. Also the agreement between this data and the fluorescein data is very good considering the differences

between the two test aerosol materials and in the test methods. This suggests that the sampling characteristics are unaffected by the nature of the particles being sampled. Also, the foams are able to hold about 20 g of dust without the sampling flowrate being affected. This is much more than could be held in an impactor, and demonstrates the versatility of the foam size selectors. The micrographs in Figure 14 show slices through the foams. Most of the dust is held on the first few millimetres from the face of the foam. However, this highly concentrated particle loading does not appear to affect the particle size selection characteristics of the foams, as the aloxite calibration is in good agreement with the sodium fluorescein calibration method, where mass loadings were much lower.

5.4.4 Agreement with ISO/CEN Sampling Conventions

As required in the original project specification, the results of the two calibrations show good agreement with the ISO/CEN thoracic and respirable sampling conventions. This agreement is especially encouraging when it is supported by calibrations using two entirely different types of test aerosol. It is also informative here to discuss the criteria for deciding whether the performances of the two size selective stages are close enough to the requirements of the ISO/CEN sampling conventions. The methods of assessing the acceptability of aerosol samplers are still under discussion by working groups of ISO and CEN. Essentially, they follow a two-stage approach that firstly prescribes tolerance bands on the respective selection curves and then classifies samplers according to the inaccuracy with which they estimate the mass concentration of the particular aerosol fraction. For this application it is clear that most of the calibration points for each size selector lie well within $\pm 10\%$ of the specified curves, and so no further analysis of the data will be carried out at this time.

As mentioned above, the agreement between the penetration curve for the cone, P_c and the inhalable fraction (shown in Figures 11 and 13) is purely fortuitous. We did not design the cone to select the inhalable fraction. Nevertheless, the agreement is good for both particle types for aerodynamic diameters of up to 30 μm . Above this particle size, the penetration appears to tail off and is considerably lower than the inhalable fraction. It must be remembered that the sampling situation within the dustiness apparatus is entirely different from that experienced by real aerosol samplers. In the dustiness apparatus, we have **defined** a sampling plane where the dust concentration is **defined** as being true total. All subsequent penetration efficiencies are referred to this value. In aerosol samplers, performance is dependent upon a number of uncontrollable parameters such as windspeed. Much more work is required to relate the size fractions in our sampling apparatus to worker's exposure to airborne dust. This would require controlled simulations of material handling processes, as well as field work. However, if the dust given off in the dustiness test is separated into these fractions it will be easier to compare the results of the test with dust exposure measurements.

6 LABORATORY TESTS WITH THE NEW PROTOTYPE METHOD

6.1 Method

All of the previous work showed that we could use the ISO/CEN health related size fractions in a dustiness test and make measurements with sufficient accuracy to measure the least dusty materials we had to hand. The next stage was to check that the test was suitable for the real materials that are currently handled in industry. The project sponsor (The Health and Safety Executive), through its network of National Industry Groups (NIGs), supplied samples of 23 materials from a wide range of industries, including agriculture, potteries and paints and dyes. These materials were selected to give as wide a range of dustiness values as possible and are listed in Table 2.

For these tests two methods of correcting for the variability in the weights of the foams was evaluated. A second method was considered necessary because although the method of using five control foams gave reliable results, it had a number of disadvantages. It involved a large number of weighings and considerable space in the balance room to lay out the controls. In addition, the operator of the test method had to wait for at least four hours before the results became available. These disadvantages were clearly unacceptable.

The second method involved putting two clean foams on the inlet of the drum, in an arrangement identical to that used for the sampling system (Figure 15). These inlet control foams were protected on both sides by the use of filters to prevent contamination of the control foams from dust from the ambient air drawn into the drum and from any non-airborne test material thrown on to them during the test. The four foams to be used in each test - the two test foams and the two control foams - were weighed on a four-figure balance (Sartorius 3708) to 0.1 mg, after first being allowed to condition in the laboratory atmosphere for at least one hour.

After the test, the four foams were removed from the dustiness tester and reweighed immediately. As the foams were changing weight rapidly at this stage, a protocol was used that required the weight to be taken 30 seconds after the foam plug was placed on the balance pan. The weight of dust collected on the two sampler foams was calculated. The two sampler foams were then taken into the balance room where they were left to condition with the five control foams with which they had been previously weighed. After four hours of conditioning, all foams were reweighed on a five-figure balance (Mettler AT201). Comparisons between the two methods of control weighings were made as the results became available.

The dustiness test for each material consisted of three measurements, each with a 200 g charge of material. These 200 g charges were riffled from the bulk material to ensure that they were representative of the original material and our results would not be affected by differences in the particle size distribution between samples. Nearly all of the materials were tested in the same state as they were supplied. The exceptions to this were the samples of Nepheline syenite, goonyean bone and ground flint from the pottery NIG. These were supplied with a large amount of a wetting agent. Dust from the use of material is produced when spillages dry and the resulting deposits of dust are disturbed when the surfaces are knocked. For this reason these samples were drained and dried before they

were riffled into reproducible samples for testing. After riffling the samples were stored in air tight Kilner jars until they were required for the test.

After each measurement the internal walls of the drum were thoroughly cleaned. Generally, this was done using a combination of brushing and vacuum cleaning, but for some very stubborn materials like calcium stearate, the walls were washed with a suitable solvent and allowed to dry. Repeat dustiness tests were carried out for some of the materials for a range of reasons: in one case we were not happy with the reproducibility of the three individual measurements and wanted to try different cleaning methods; in other cases to get a crude measure of the reproducibility of the test; and for some of the low dustiness materials, to try to improve the precision of the measurement by replacing either the 90 ppi foam or both foams with a filter. This, however reduced the information obtained.

6.2 Results

The results are presented in Figure 16, where the masses of dust collected for each material on the 30 and 90 ppi test foams and the filter are represented by histograms. All of the data in the tests is given in Appendix E. It must be stated here that all the data in this chapter is presented in terms of dust collected by a given stage, so that the sensitivity of the method can be clearly seen. To convert to dustiness values, one just has to multiply by a fixed conversion factor. In Figure 16, it can be seen that the values for the materials tested extend over five orders of magnitude and therefore the log scale on the y-axis was necessary. The error bars on the top of the columns indicate one standard deviation of the three replicates of the dustiness measurement. For nearly all of these materials the 30 ppi foam caught more material. The exception to this was the granular fertiliser for which equally low masses of dust were captured.

Each measurement gives a rough estimate of the size distribution of the material tested. This size distribution depends on the agglomeration and attrition properties of the material tested. The results for the two grades of carbon black illustrate this. For the fine grade of carbon black there was far more dust caught on all three stages of the sampling system than for the coarse grade. This is surprising since the individual particles were generally sub-micron. However, they tend to agglomerate and break up readily and so can have a whole range of particle sizes dependent upon the conditions of treatment. The coarse grade however, is made up of particles which are far less likely to agglomerate or break up. The results for graphite, being a friable material, are similar to those of the fine grade of carbon black. The results for the coarse and fine grades of centrimex show a similar, but not so large, effect.

The results for the three animal feeds show interesting differences. All of these materials were supplied in pellet form and so the differences in the amount of dust caught on the filter give an indication of the friability of the pellets. The ammonium nitrate granular fertiliser was the least dusty material tested.

This data set also provides a good evaluation of the quicker foam control method. The first point to note is the good agreement between the two control foam methods. For both the 30 ppi and the 90 ppi foams, linear relationships between the two methods are obtained when the weight of dust collected is more than 80 mg (Figure 17). For lower weights of dust collected on the foams, the single foam method generally underestimated the weight

of dust collected when compared with the more precise five control foam method.

The only low dustiness material for which the single control method gave a larger weight was for garden peat (Figure 18 and 19). This was because the peat dried out as the test foams conditioned overnight with the controls. A sample of the peat was dried and found to have a water content of about 60%. The single control method therefore avoids any problems of the test material drying as it conditions. Any errors due to any extra water vapour affecting the weight of the test foams is likely to be small in comparison to that due to the test material drying out over the conditioning time.

"Interpon" was marked as potentially explosive. Although the risk was slight it was thought best to leave the end that was covered with the control foams open. This would allow any powder explosions to dissipate through the open end. The five control method was used to measure the dust given off from this material. Two control methods increase the versatility of the test. Although no explosions occurred in the test, the ability to remove one end of the test rig represents a safety feature.

The underestimates of the dust caught on the foams for the other low dustiness materials was checked in one of two ways, depending on the weight of dust. When there was only a small amount of dust caught on the 90 ppi but enough for good measurements on the 30 ppi, the 90 ppi foam was replaced with a filter to get the thoracic fraction in a single measurement. With the granular fertiliser less than 10 mg of dust was caught on both foams and so they were removed leaving the filter to obtain a direct measure of the inhalable fraction. The filters were treated in the same way as the foams, the only difference being that three controls were used instead of the five used for the foams. By reweighing the filters the following day any effect due to the test material conditioning to the balance room should show up. From the results of the repeat weighings (Appendix E) it appears that the discrepancy between the two methods is due to the different control methods. The single foam method seems to underestimate slightly the weight of dust collected. This error was most significant for low dustiness materials for which less than 100 mg might be collected. It is interesting to note how filters can be used to improve the precision of the measurement for low dustiness materials.

As the new test apparatus uses a smaller drum the surface area to be cleaned is greatly reduced. This meant the test took less than half the time for the old test. For most materials cleaning took about 10 mins. An interesting exception to this is calcium stearate. This is a waxy white powder which when tested gave a high dust yield for the first reading but the subsequent readings were around 30% lower. Repeat measurements confirmed this finding. It was only when the drum was washed out with absolute ethanol between the three replicate measurements that good reproducibility was obtained. The fine grade of carbon black also required this treatment to clean the drum between runs. From this it is clear that the cleaning procedures will have to be adapted to suit some materials tested and that the cleaning must be extremely thorough to ensure repeatable results.

The large holding capacity of the foams meant that we could get weight measurements over six orders of magnitude without the flow through the foams being affected. For most of this range the dust is held securely on the foam. Unfortunately when there is between 0.5 and 1 g on the foam some dust is liable to fall from the face of the foam if the foam is not handled very carefully. This leads to large variances for some of the dustier materials.

7 DESIGN OF PRODUCTION VERSION

7.1 Introduction

The prototype tester, described above, served its purpose well in allowing us to optimise the design of the system and its operating parameters. However, it was intended to be a "breadboard" version upon which changes could be easily made - it was not designed for manufacture and general use. The prototype tester was put together mainly from components of the old WSL tester, but with a modified drum and sampling system. A new design was therefore required that would be suitable for manufacture and subsequent general use. The following areas were identified for improvement in the new design.

- 1) The foams and filters must be held in robust carrying frames that both define the open areas exposed to the dust and ensure ease of handling during weighing and dismantling. It was considered to be essential that the exposed surfaces of the foams and filters should not be touched.
- 2) The sampling system must be quickly and easily removed from the drum, and must be designed to enable either both, one or no foams are used for particle selection in front of the filter.
- 3) The rotating parts of the apparatus must be housed inside a protective guard to prevent accidents from entrapment in the rollers/gears etc.
- 4) The components of the apparatus must be designed so as to minimise the utilisation of laboratory bench space.

As the expert skills for product design and engineering were not available in-house, the services of Mr John Fish from J S Holdings of Stevenage were employed to provide the new design together with a complete set of engineering drawings, which are presented in Appendix F.

7.2 The New Design

The general arrangement of the design of the production version of the new dustiness tester is given in Figure 20. It shows the various components of the apparatus built into a self-contained unit, with the rotating drum and sampling system at bench top level, and the pump and flow control system situated below. The improvements to the design of the individual components of the apparatus are described below.

7.2.1 The dust dispersion system

As recommended from the results of the investigations described above, the drum is half the length of that of the old WSL tester. The additional improvements suggested are as follows.

- * The drum is now to be constructed by first welding the lifting vanes in place on a flat sheet of stainless steel, then rolling it to form a 30 cm diameter cylinder and welding the join. Two identical cones are then welded to either end, so as to

minimise the number of flanged joints. The welding of the lifting vanes to a flat surface produces a smooth joint, thereby reducing the problems of cleaning.

- * The method of rotating the drum, a system of two rollers forming a drive bed, is to be retained. This has advantages over other methods in that it allows the drum to be easily removed for cleaning and is not subject problems associated extraneous dust particles.

7.2.2 The sampling system

- * The foam carriers (shown in Figure 21) are to be made from rolled aluminium channel, joined to form a ring, so that the edges of the foam are totally enclosed. This prevents air leakages, and also helps to minimise contact with the foam surface.

- * The filter is to be of diameter 142 mm this being a standard stock size for most manufacturers. It is to be held in a filter carrier comprising two interlocking stainless steel rings between which the filter is sandwiched. Again this has the benefit of minimising contact with the filter surface itself.

- * The foams and filters are fitted into a protective housing designed to enable two, one, or no foams stages to be installed between the cone and the filter, dependent upon the dust fraction required and the level of dustiness expected.

- * An identical sampling system is fitted to the inlet of the drum, carrying the control foams and filter, and protected from extraneous dust by the use of filters on either side. The inlet therefore comprises the following components; protection filter 1, 30 ppi and 90ppi control foams, control filter, protection filter 2.

7.2.3 Other design improvements

- * The timing and flow control systems are to be essentially the same as that used in the old WSL tester. However, they have been modernised using an up-to-date timer and a simpler, easier to use flow control system.

- * The apparatus is to be built around a main chassis which is covered steel panels. Access to the rotating drum and sampling systems is via a safety lid which automatically switches off the electrical power when opened.

8 DISCUSSION

The aim of this project was to develop a practical dustiness test method, that gave dustiness values that are based on health-related definitions of airborne dust. The development was funded by the Health and Safety Executive, with the intention that the new method should be recommended by HSE in their "Methods for the Determination of Hazardous Substances" series.

The original WSL rolling drum tester was chosen to form the basis of the development due to its versatility, in terms of range of materials capable of being tested and the handling operations simulated. In addition, as the sampling system is separated from the dust dispersion drum, the installation of a new sampling system was relatively simple. Several other workers had suggested improvements to the design (O'Farrell and Vaughan, 1986, and Janhunan et al, 1988), and these were taken into account in our development. The special feature of this development is the use of porous polyurethane foam plugs as the particle size selectors for the thoracic and respirable dust fractions in a specially designed sampling system that rotates with the drum. By careful choice of the porosity and dimensions of the foams, and the flowrate, we were able to produce size selective stages whose performance agreed closely with the requirements of the CEN/ISO sampling conventions for the thoracic and respirable fractions. The main drawback with the use of foam as particle size selectors was found to be the instability of their weight, and much time and effort was expended to develop a suitable weighing procedure, including the use of controls. Due to the weight problems with foam plugs, the dust dispersion system was modified in order to maximise the weight of dust collected.

A bread-board prototype tester was used to determine the dustiness values of a 23 different materials from a range of industries. The results demonstrated that the new device operated satisfactorily, being able to discriminate between two materials whose dustiness values showed no difference when using the old WSL method. These materials were chosen to cover the range of materials used in various industries. Some would give off very little dust when handled but give an indication of the resolution of the test method and its versatility. This work has also shown that when increased resolution is required for low dustiness materials then one or both of the foams can be removed leaving the filter to give precise measures of the thoracic or inhalable fractions.

Despite providing for the first time, dustiness values in health-related dust fractions, it must be remembered that any connection between the measurements made in these tests and those made to estimate a worker's exposure to handling a dusty material can only be tentative at this stage. Much more work needs to be done to relate dustiness values to the emissions from processes and then to workers' exposures. Only when this is done will the full benefit from these measurements, in terms of either assessing the risk from the handling of a particular material or designing a suitable control strategy, be realised.

9 DRAFT MDHS**Methods for the Determination of Hazardous Substances (MDHS)****DUSTINESS OF POWDERS AND MATERIALS IN INDUSTRIAL USE****INTRODUCTION**

1 The control of dust emission during the handling and transportation of powders and materials is an important consideration in the design and operation of many industrial processes.

2 Excessive airborne dust levels in workplaces are undesirable for a number of reasons; a) they can cause long-term adverse health effects in the workforce, b) they can be costly in terms of lost product, c) they can be responsible for the contamination of machinery and other products, and d) their control can involve the use of costly ventilation and filtration systems.

3 The dustiness of a material is defined as the propensity of that material to produce airborne dust when handled. This information is essential to those involved in both assessing the likely health hazard from materials and to dust control engineers. This publication describes a method of determining the dustiness of materials in three health-related fractions.

DEFINITIONS

4 Dusts emitted from the handling of powders and materials contain particles of a wide range of sizes. The likely health hazard from inhalation of a specific particle is dependent upon the nature and size of the particle. The International Standards Organisation (ISO) and the Comité Européen de Normalisation (CEN) has proposed new conventions for health-related sampling^{1,2}. Three main size fractions are proposed for industrial hygiene use; inhalable, thoracic and respirable.

Inhalable fraction

5 The Inhalable fraction E_i is the mass fraction of total airborne particles which are inhaled through the nose and mouth. For industrial workplaces it is given by

$$E_i = 50(1 + \exp[-0.06D])$$

where D is the particle aerodynamic diameter.

Thoracic fraction

6 The thoracic fraction E_T is the mass fraction of inhaled particles penetrating beyond the larynx. It is given by a cumulative lognormal curve with a median of diameter $11.64 \mu\text{m}$ and a geometric standard deviation of 1.5.

Respirable fraction

7 The respirable fraction E_R is the mass fraction of inhaled particles which penetrates to the unciliated airways. It is given by a cumulative lognormal curve with a median diameter of $4.25 \mu\text{m}$ and a geometric standard deviation of 1.5.

SCOPE OF THE METHOD

8 The method described is suitable for the determination of the health-related dustiness of powders and materials currently in use in industrial processes, including powders, pelletized material, loosely-packed fibrous material, etc. For some particularly hazardous materials the apparatus must be housed in a suitable ventilated enclosure.

9 The lower limit of detection for each health-related fraction is governed mainly by the size distribution of the emitted dust cloud and the quality of the handling and weighing procedures. If emitted dust levels are too low to allow reliable measurements of the three fractions, the particle size selective stages can be removed and results for one combined fraction - the inhalable fraction - can be obtained.

PRINCIPLE

10 A measured mass of material is tumbled in a rotating drum, through which air is passed at a known flowrate for a fixed time. The resulting dust cloud is passed through a three-stage dust sampling system, comprising two size-selective foams and a filter. The masses of dust collected are determined by weighing the foams and filter before and after the test runs, and values for the dustiness of the material in terms of the inhalable, thoracic and respirable fractions are calculated.

APPARATUS

Dustiness test apparatus

11 The apparatus required to determine the dustiness of materials is shown in Figure 1, with sets of engineering drawings of the apparatus given in the Appendix together with a list of potential suppliers. It comprises a 300 mm diameter drum rotating at 30 rpm, equipped with longitudinal vanes to lift and let fall 200 g of the material under test, and a three-stage dust sampling system through which the emitted dust cloud is drawn by a vacuum pump at a flowrate of 38 l min^{-1} for 1 minute. The sampling system comprises two particle size-selective stages in series followed by a back up filter. The size selectors are cylindrical plugs of 30 ppi and 90 ppi porous polyester foam chosen to select the thoracic and the respirable fractions respectively. The inhalable fraction is obtained by

empirical choice of the conical passage between the end of the drum and the thoracic fraction size selector (the 30 ppi foam). The foams and a back up filter are weighed before and after the test to provide the dustiness estimates. An identical set of foams and filter are positioned at the inlet to the drum to take account of weight changes due the passage of air through the foams and filter. Extra filters are positioned either side of the inlet foams/filter combination to prevent dust contamination. The flowrate through the device is monitored using an in-line rotameter and the volume of air sampled measured with a calibrated gasmeter. The operation of the apparatus is automatically controlled by a simple timing control circuit.

Size selective foams

12 Porous polyurethane foam size selectors with a reticulated open-cell structure should be used to select the thoracic and respirable dust fractions. These are manufactured by Recticel PRB in Belgium, and are available in the UK from Foam Engineers Ltd. Both size selectors comprise 140 mm diameter plugs, 25 mm thick, and they are housed in carrying frames to facilitate both handling and weighing.

Filters

13 Glass fibre filters are used to collect the fine respirable particles that penetrate the 90 ppi size selective stage. GF/A filters made by Whatman and Gelman are suitable, as are similar filter types from different manufacturers. 140 mm diameter filters are required, which are held and weighed in carrying frames.

Ancillary equipment

14 The balance room or chamber where the weighings are carried out should have its temperature and humidity either controlled or stable. A balance capable of weighing 50 g with a reproducibility better than ± 0.1 mg, and able to accommodate the size of foams and filter being used, should be employed.

A weighing frame to position the foams and filters upright on the balance pan should be used.

15 A small riffler should be used to select the samples of material for test from the bulk material to ensure that errors in the method are not exacerbated by unrepresentative powder samples. A balance capable of weighing 250 g with a reproducibility of ± 0.1 g should be available for weighing the samples of test material.

PROCEDURE

Preparation of apparatus

16 Prior to the tests being carried out, the rotating drum is cleaned thoroughly using a combination of compressed air and vacuum cleaner. For material that sticks to the internal surfaces it may be necessary to wash the surfaces with a suitable solvent, and allow the apparatus to dry.

17 Select three samples, each of 200 (± 0.1) g, of the test material by means of a sampling riffler. Spread one of the samples evenly along the bottom of the drum. Fix two

sets of the foams and filter combination to either end of the drum, with an extra filter on the inlet to prevent contamination of the control foams.

Running the test

18 Before commencing the test cycle the pump is switched on and the flowrate set to 38 lpm. The timing circuit is then switched on and the test programme allowed to proceed. At the end of the test, carefully remove the foam size selectors and the filters from either end of the drum and place them in the balance room, taking care not to disturb the collected dust.

Weighing the foams and filters

19 The weight of dust collected is determined by weighing the foams and filters before and after the test. Before the tests, sufficient foams and filters for three complete tests should be assembled in their respective holders and left in the balance room atmosphere for at least 2 hours to stabilise. They should then be weighed in their holders following a sequence where similar materials are weighed in batches for each of the three runs. After the tests the foams and filters are reweighed in the same sequence. For each weighing it is essential that a protocol be followed as to when the weight indicated by the balance should be recorded. It is recommended that the weight be taken 30 seconds after the specimen is placed on the balance pan and the balance door closed.

20 The masses of dust collected on each foam and filter are calculated by subtracting the post-test weight from the pre-test weight. This is also performed for the foams and filter on the inlet end of the drum and the resultant figures used to correct the masses of dust collected for weight changes in the foam and filter materials themselves due to the passage of air through them.

21 For greater accuracy, a procedure involving the use of five controls for each foam and filter may be employed. However, this also involves much longer times for conditioning and sufficient space in the balance area to lay out the foams and filters.

Determination of the dustiness values

22 The dustiness values for each fraction are calculated by dividing the mass of dust collected (mg) in that fraction by the mass of powder under test (kg). For the inhalable fraction, the masses of dust collected on both foams and the backup filter are added together. For the thoracic fraction, the masses of dust collected on the 90 ppi foam and the filter are added together, whilst the dust collected on the filter represents the respirable fraction. The mean values from the three replicate tests of a given material are then calculated for each fraction, together with the standard deviation.

23 If the masses of dust collected on the foams are too low for meaningful results to be obtained, a second set of tests may be carried out in which both foams are omitted and all the dust collected on the filter to give the inhalable fraction dustiness value only. The filters are subject to much smaller changes in weight and can therefore be used to detect smaller dust masses.

REQUIREMENTS OF COSHH REGULATIONS

24 In order to comply with the requirements of the COSHH Regulations certain precautions must be carried out to prevent the exposure of the operator to hazardous dust.

25 The dustiness test apparatus, the riffler and the balance for weighing the material should be placed inside a fume cupboard or extraction booth. Care should be taken when handling the dust-laden foams and filters to prevent collected dust from being dispersed into the air. Before commencing a test programme it is essential that the hazard data sheet accompanying the material should be consulted to see if further, more stringent precautions need to be taken.

26 When the method is first applied, and periodically through its use, personal dust exposure measurements should be taken (following MDHS 14³) to ensure that the procedures do not lead to excessive exposures of the operators.

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- 2 Comité Européen de Normalisation. Size fraction definitions for the measurement of airborne particles in the workplace. prEN 481 - 1992.
- 3 Health and Safety Executive. General methods for the gravimetric determination of respirable and total inhalable dust. MDHS 14 (HSE 1989).

10 ACKNOWLEDGEMENTS

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Table 1. Summary of the Analysis of variance

Source of variance	Significant at the 5% level			
	Total dust	Dust on the 30 ppi foam	Dust on the 30 ppi foam	Dust on the filter
Material	No	Yes	No	Yes
Spacer	No	No	No	No
Length	Yes	No	Yes	Yes
Mass	Yes	No	Yes	Yes

Table 2. List of the materials used in the tests.

Code Number	Material	
1	Animal feed (type 1)	
2	Animal feed (type 2)	
3	Animal feed (type 3)	
4	Granular fertiliser	
5	Garden peat	
6	Calcined alumina	
7	Silica flour	
8	Graphite	
9	Nepheiline syenite, sample 1	
10	Talc	
11	Plaster	
12	Flowers of sulphur	
13	Centrimex, fine grade	
14	Centrimex, coarse grade	
15	Calcium stearate	
16	Carbon black, coarse	
17	DC34527,1830/810, sample 1	Label gave no indication of the composition of this white powder.
18	DC34527,1830/810, sample 2	
19	Interpon	
20	Carbon black, fine	
21	Goonyean bone	
22	Nepheiline syenite, sample 2	
23	Ground flint	

Table 3. Results of repeat measurements made on some of the materials used in this series of tests.

Material	Mass of dust captured on the sampling stage (mg)					
	30 ppi foam	Standard deviation on the 30 ppi dust mass	90 ppi foam	Standard deviation on the 90 ppi dust mass	Filter	Standard deviation on the filter dust mass
2	413	34	92	5	6.79	0.72
	225	30	67	14	4.65	0.77
4	-5	1	-5	6	0.02	0.01
	0.11	0.08	Filter used in place of the 90 ppi, 30 ppi and filter stages			
9	344	105	61	6	26.25	2.7
	445	143	113	4	Filter used in place of the 90 ppi foam and filter stages	
22 (same composition as material 9)	181	16	73	8	31.27	2.49
10	7655	282	515	15	23.52	0.11
	7561	429	649	166	22.99	0.21
11	114	11	28	5	11.19	0.94
	161	24	62	2	Filter used to in place of the 90 ppi foam and filter	
14	14678	652	1581	150	110.68	3.7
	12720	266	1206	60	82.86	15.6
15	2823	870	208	51	14.47	1.8
	1607	902	151	23	11.93	1.1
	1712	456	147	33	11.36	3.44
	1718	268	193	22	10.97	0.53
16	221	108	8	3	0.92	0.28
	275	49	24	4	Filter used to in place of the 90 ppi foam and filter	

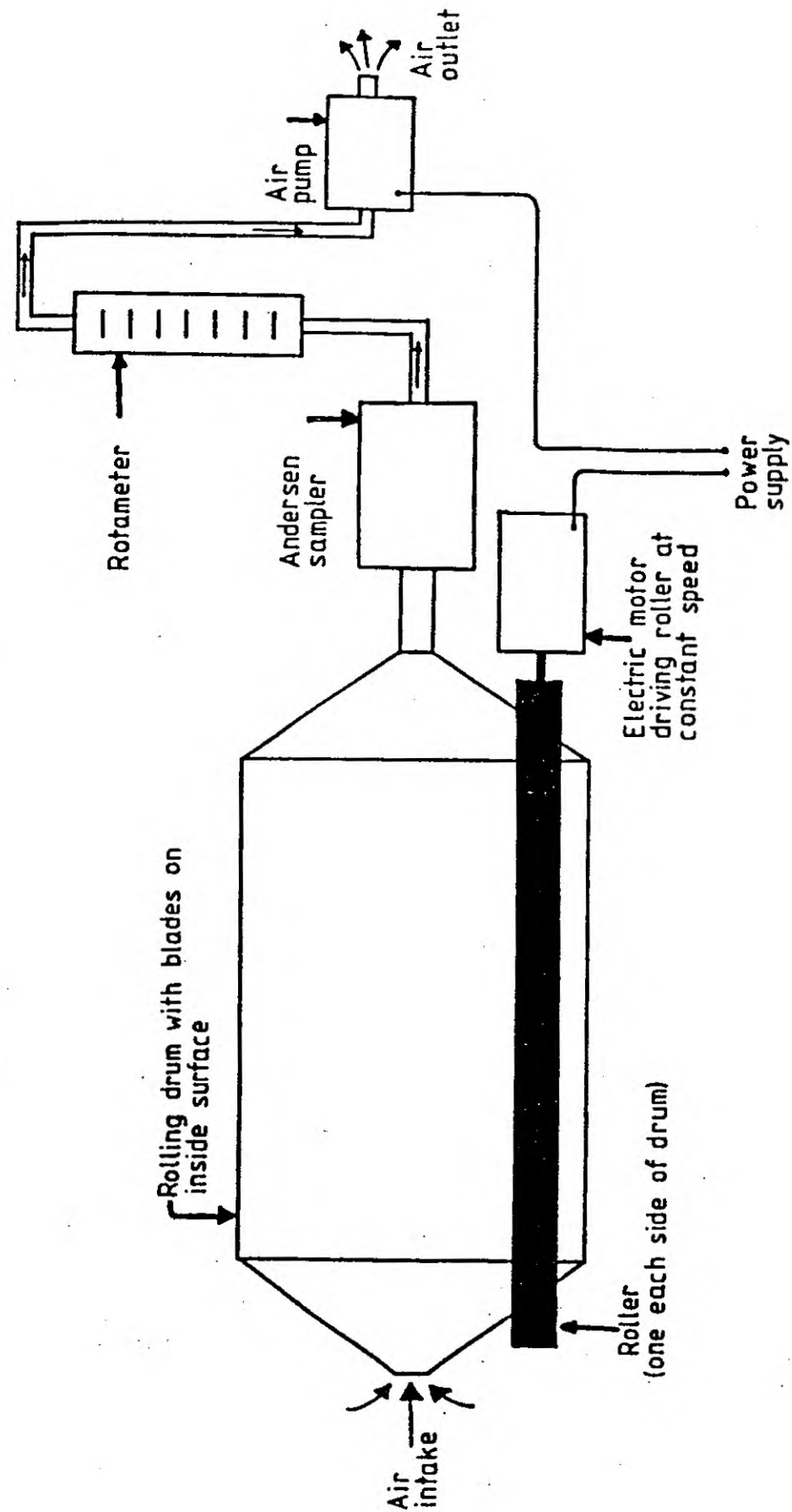


FIGURE 1. - The Original Rolling Drum Apparatus

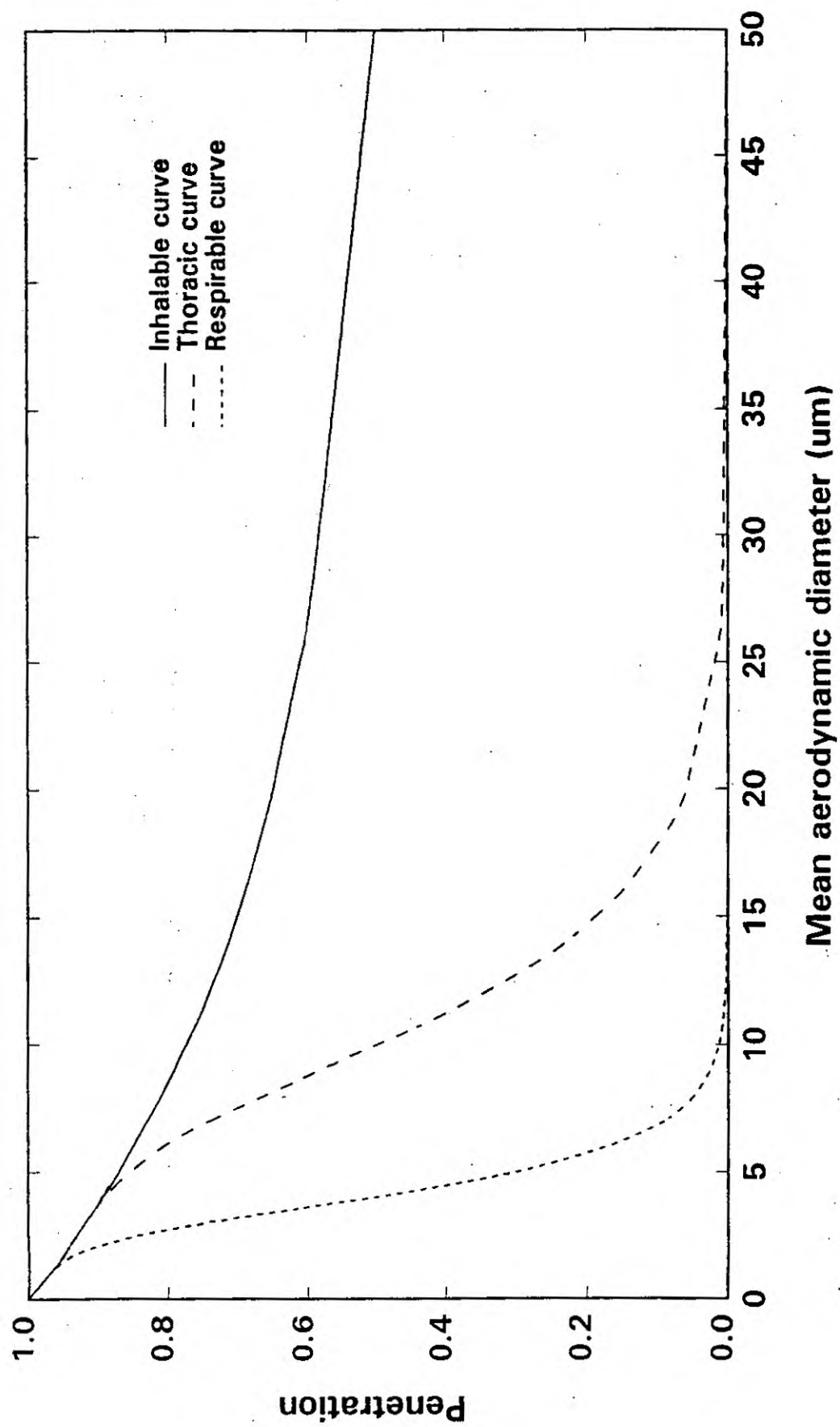


FIGURE 2. - The ISO/CEN Particle Size Conventions for Respirable, Thoracic and Inhalable Dust.

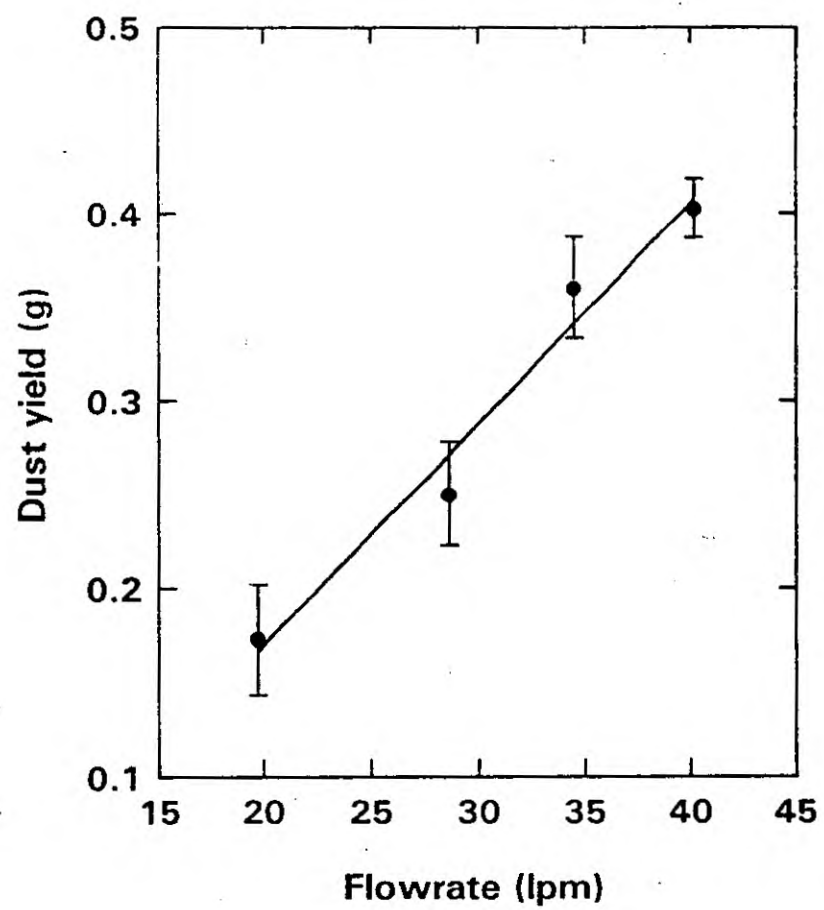


FIGURE 4. - Dust Yield Against Flowrate for Samples of Aloxite F360 Grade.

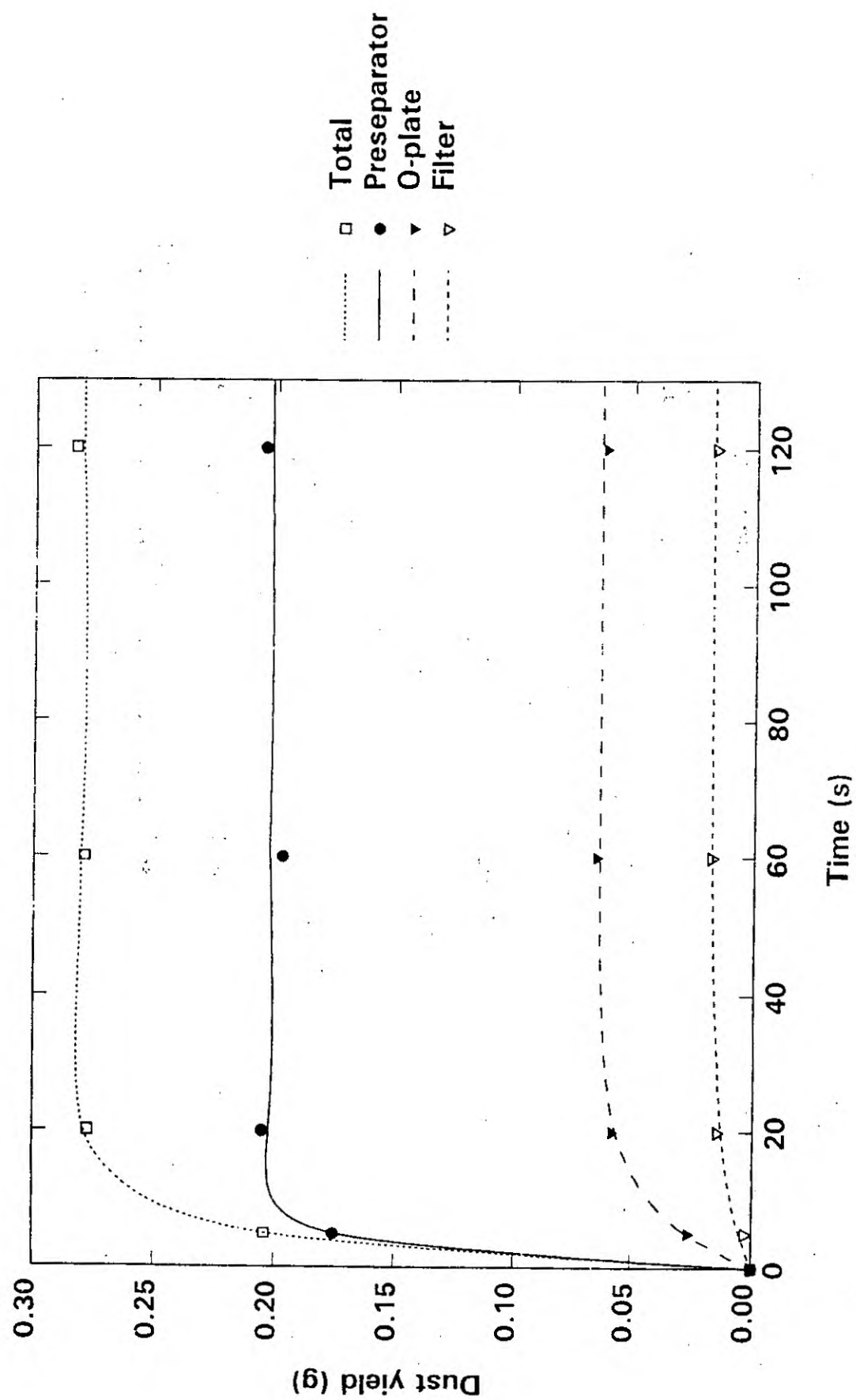


FIGURE 5. - Variation in the Dust Yield With Sampling Time for a Sample Mass of 100 g (Aloxite F360)

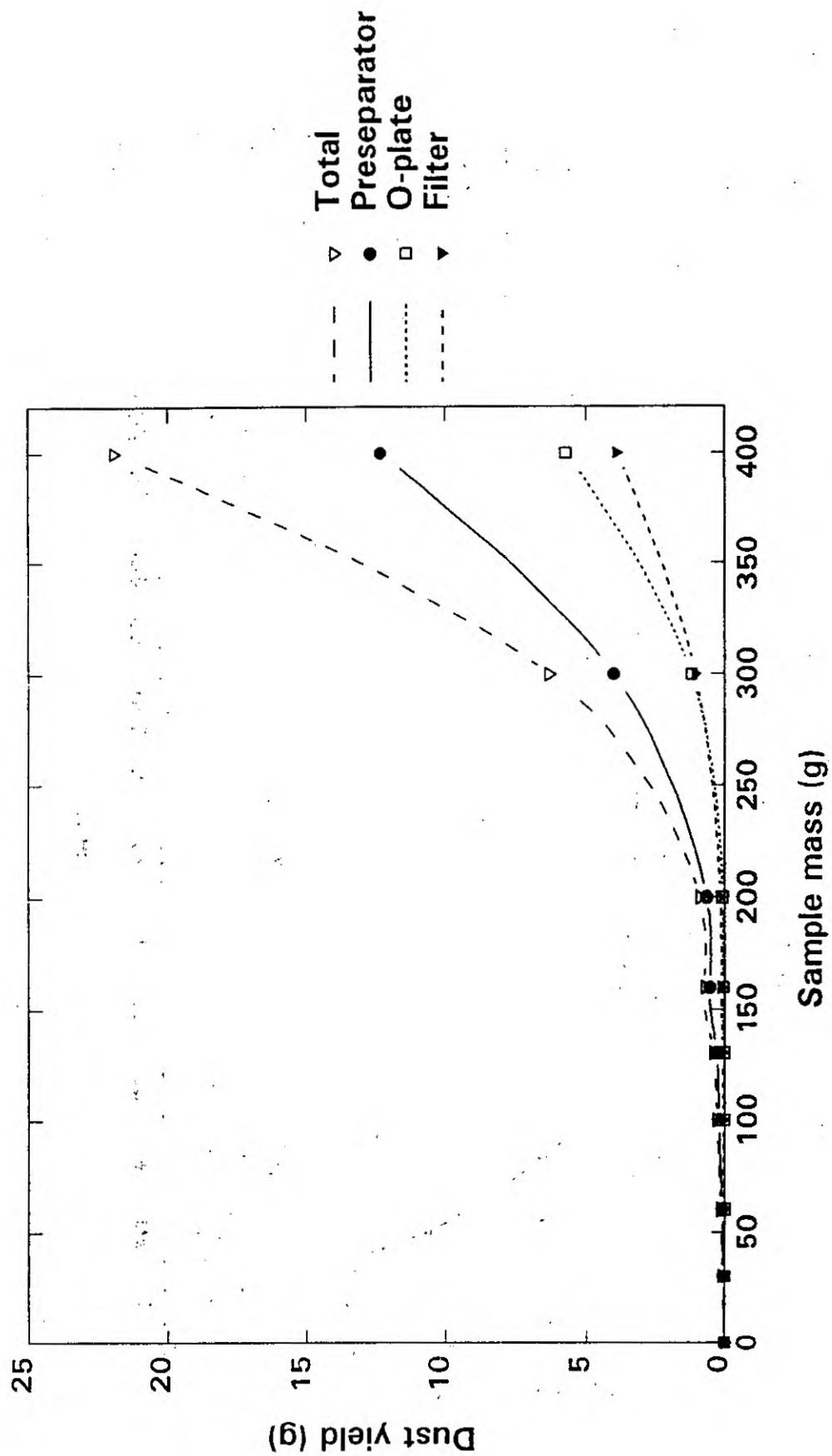


FIGURE 6. - Variation in Dust Yield With Sample Mass (Aloxite F360)

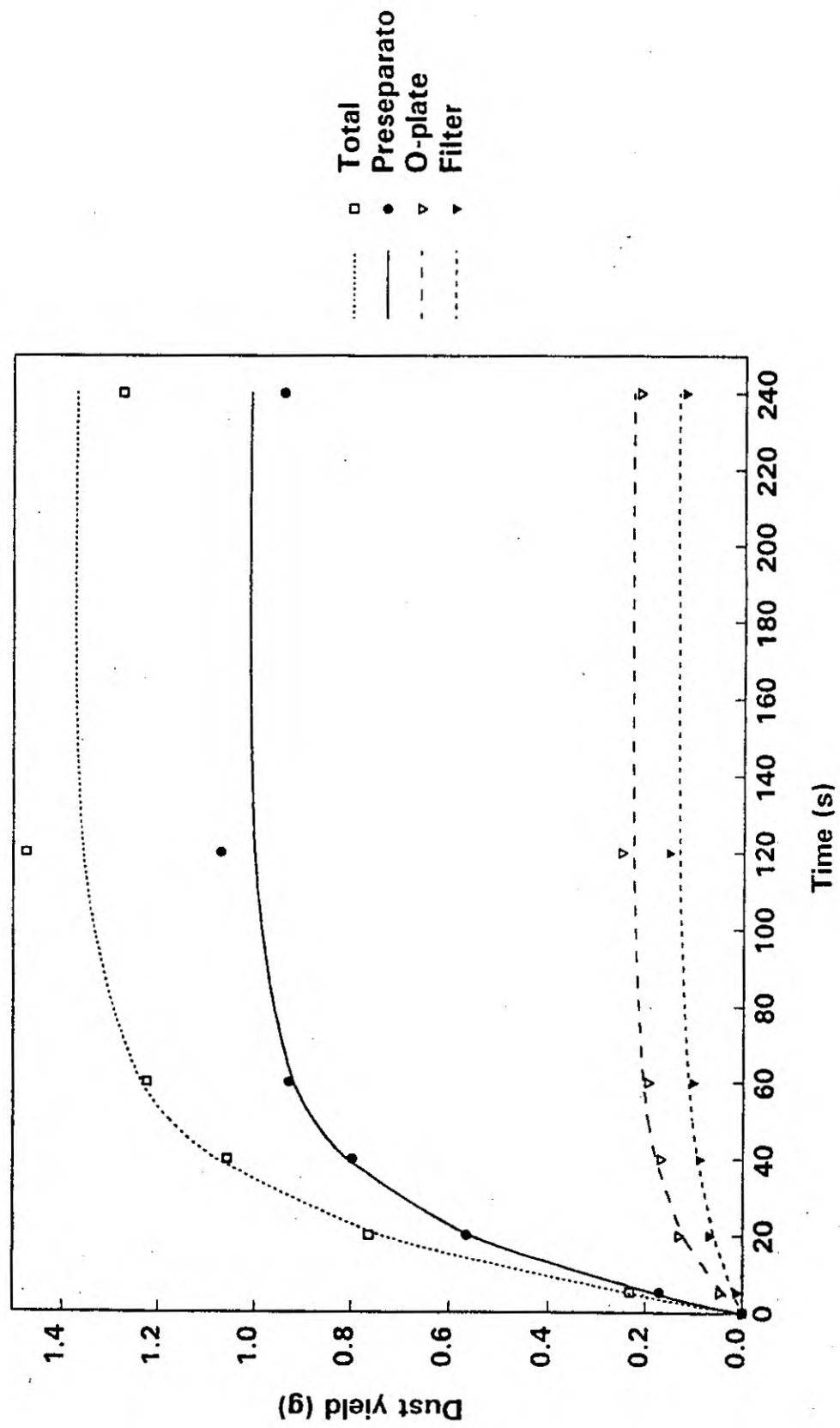


FIGURE 7. - Effect of Different Sampling Times for a Sample Mass of 200 g (Aloxite F360)

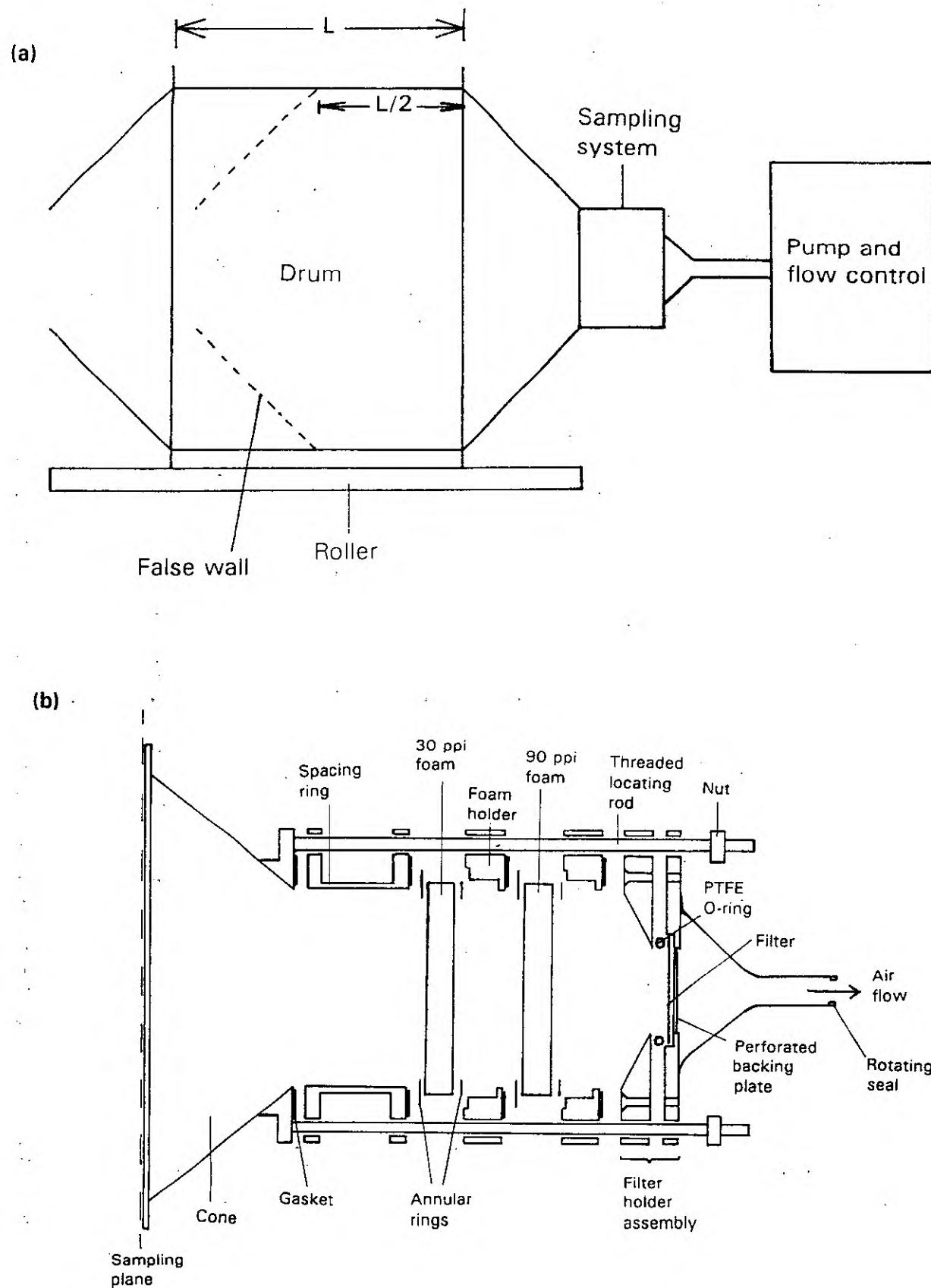


Figure 8. Schematic diagrams of the prototype test rig: (a) shows the whole apparatus with the false wall used in the first series of tests indicated with the broken line; (b) gives a cross-section through the apparatus for holding the foams.

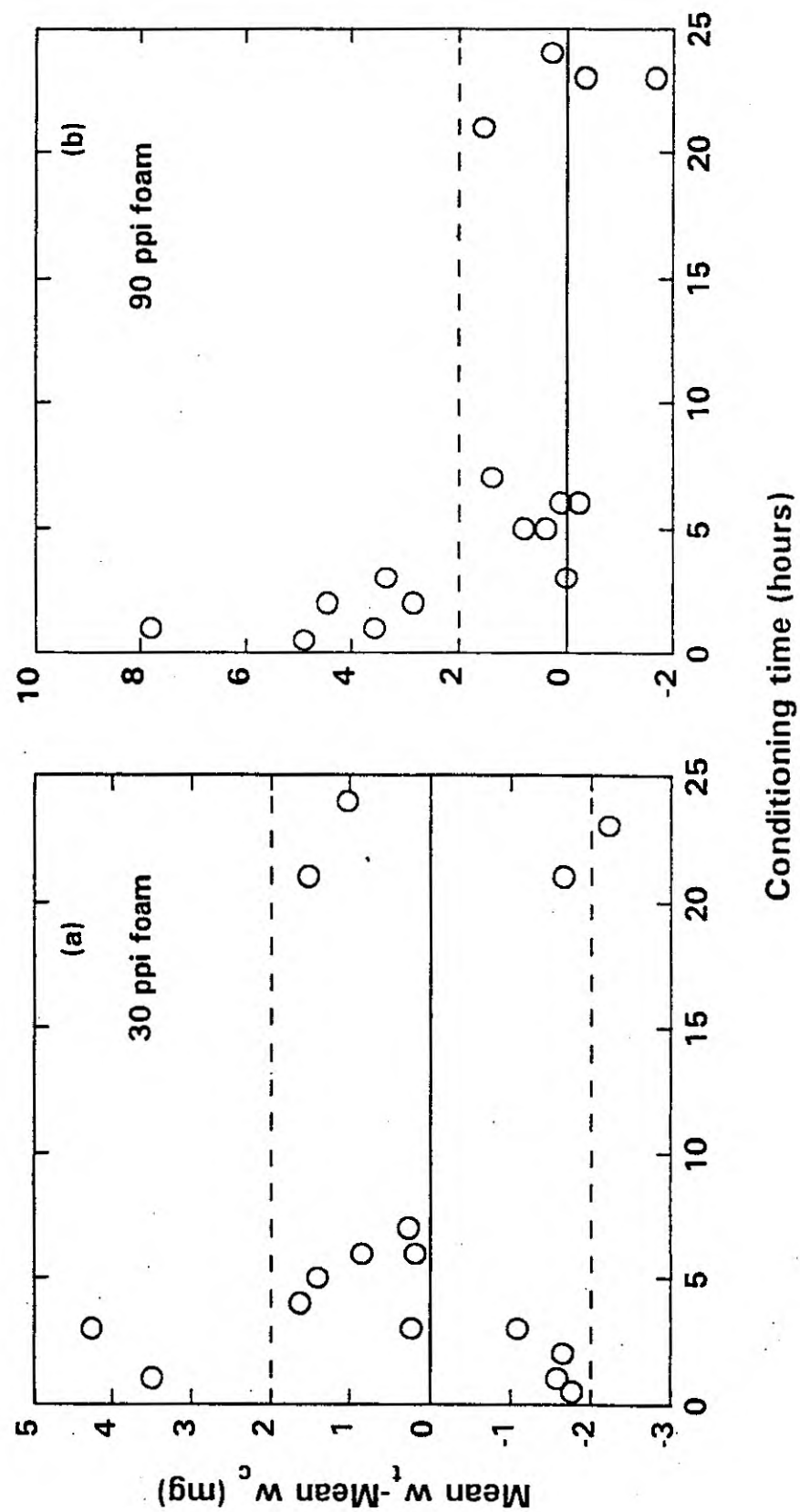


FIGURE 9. - Change in Weight Difference Between the Control (w_c) and Test (w_t) Foams With Time

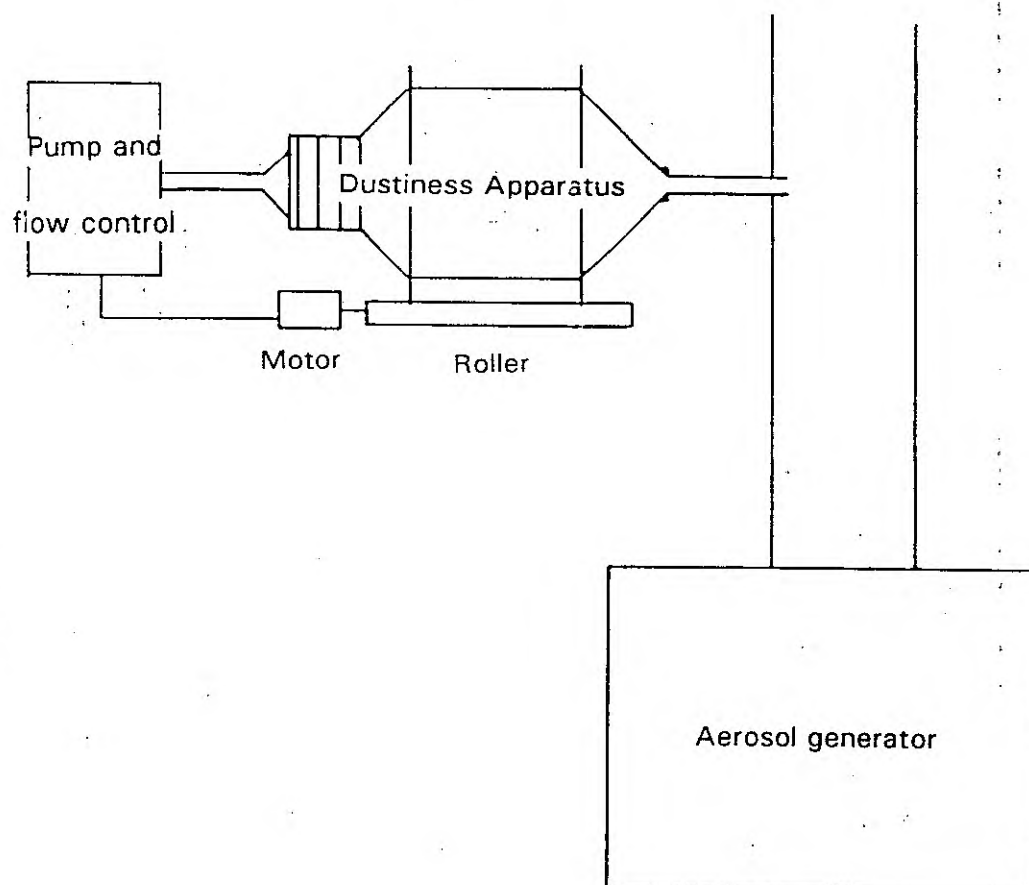


FIGURE 10. - Experimental Set-Up Used for the Calibration of the Foams With Fluorescein

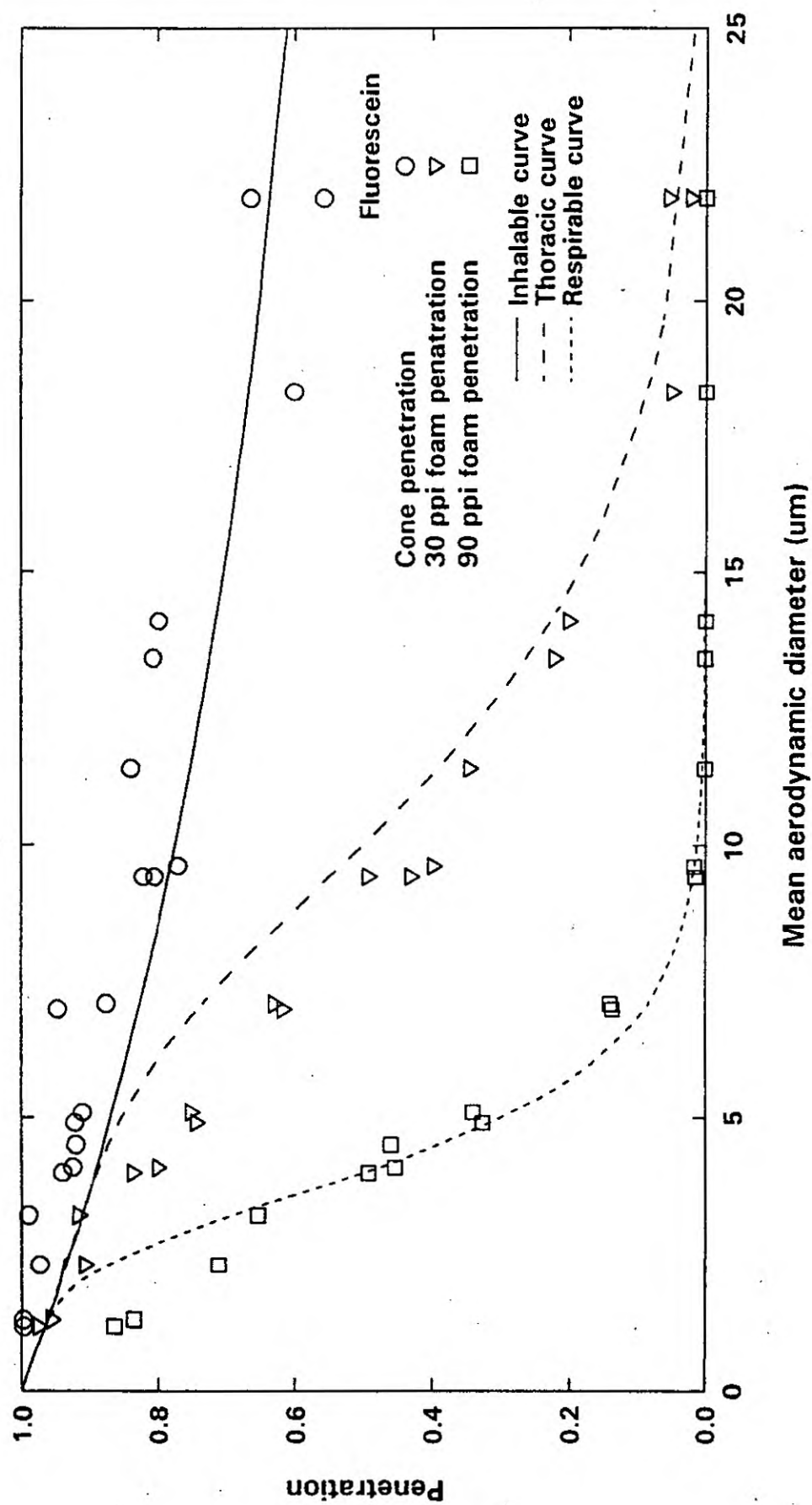


FIGURE 11. - Results of the Calibration Measurements Made with Fluorescein

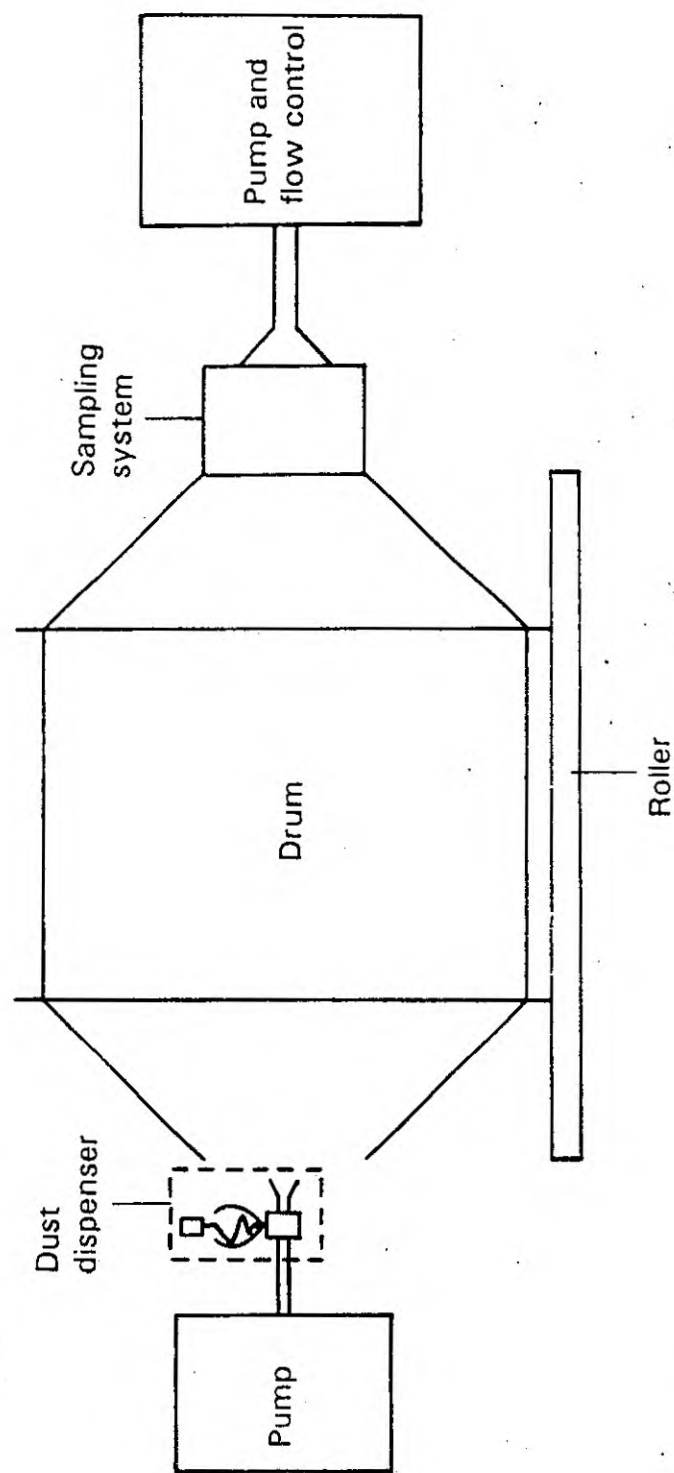


FIGURE 12. - Experimental Set-Up Used for the Aloxite Calibration

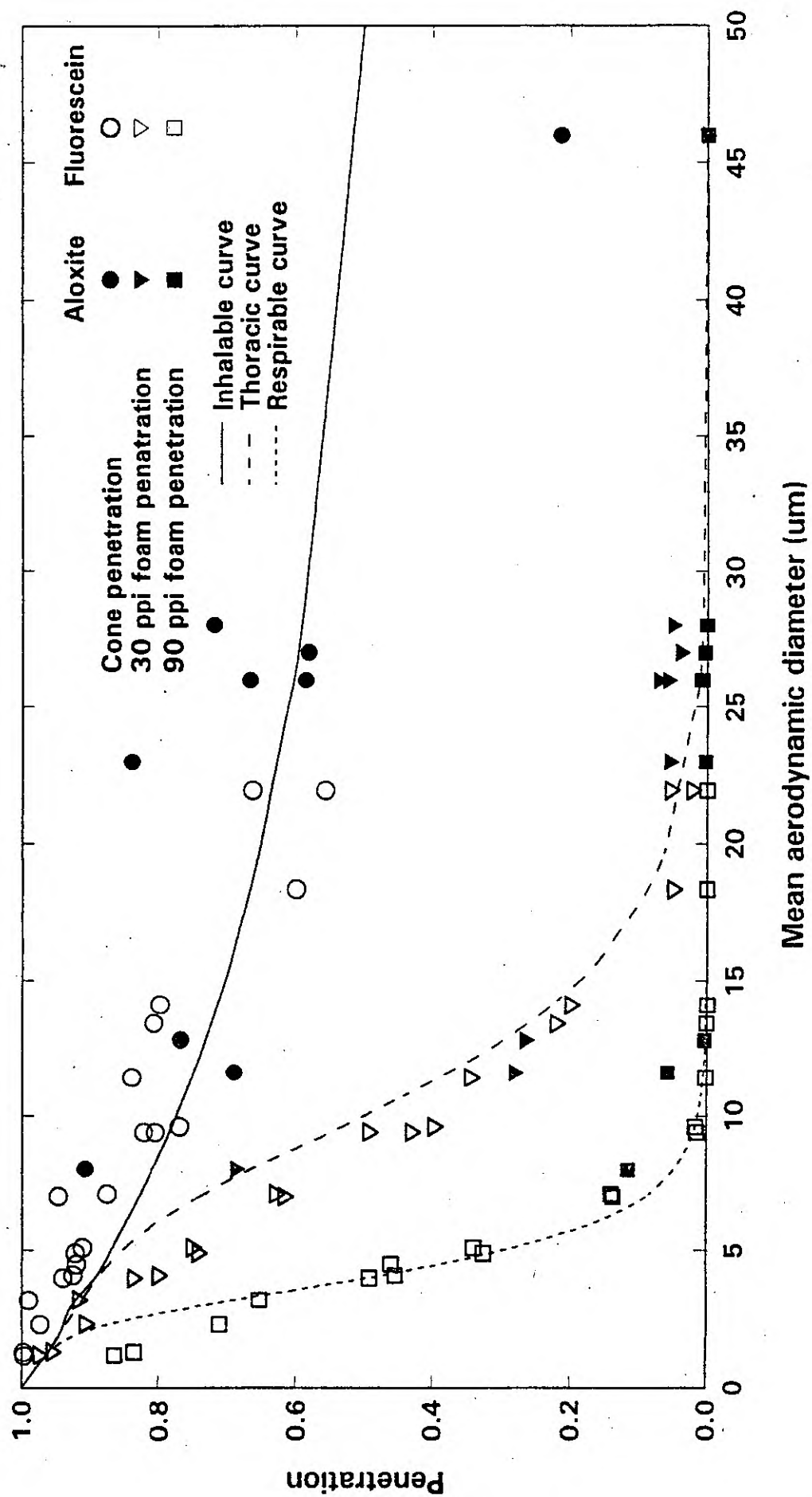


FIGURE 13. - Results of the Calibration Measurements made with Sodium Fluorescein and Aloxite

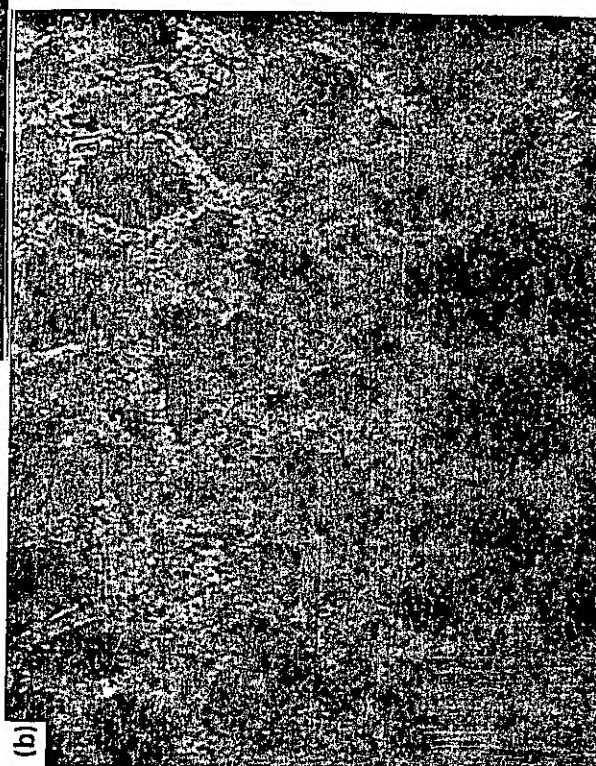
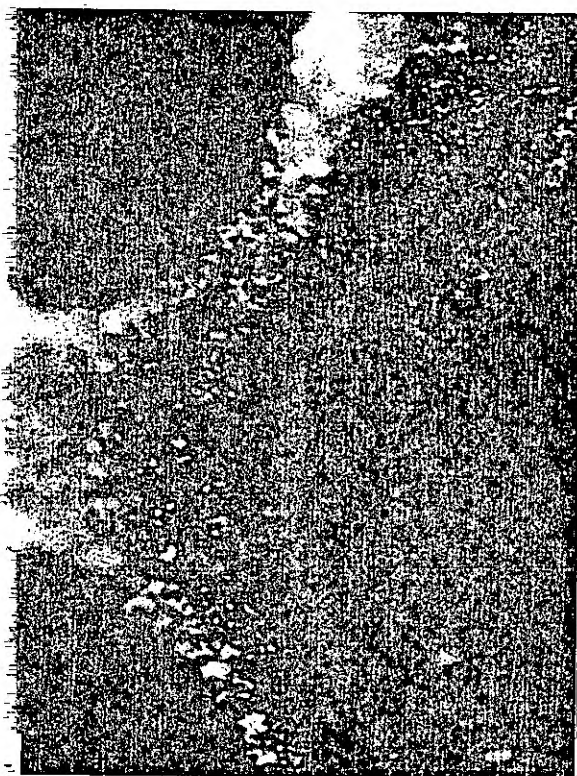


Figure 14. Micrographs of sections through the foams used in an Aloxite calibration measurement with F1000 grade: (a) 90ppi foam; (b) Close to the windward edge of the 30 ppi foam; (c) The 30 ppi foam 15 mm behind (b). All micrographs are 1000x magnification.

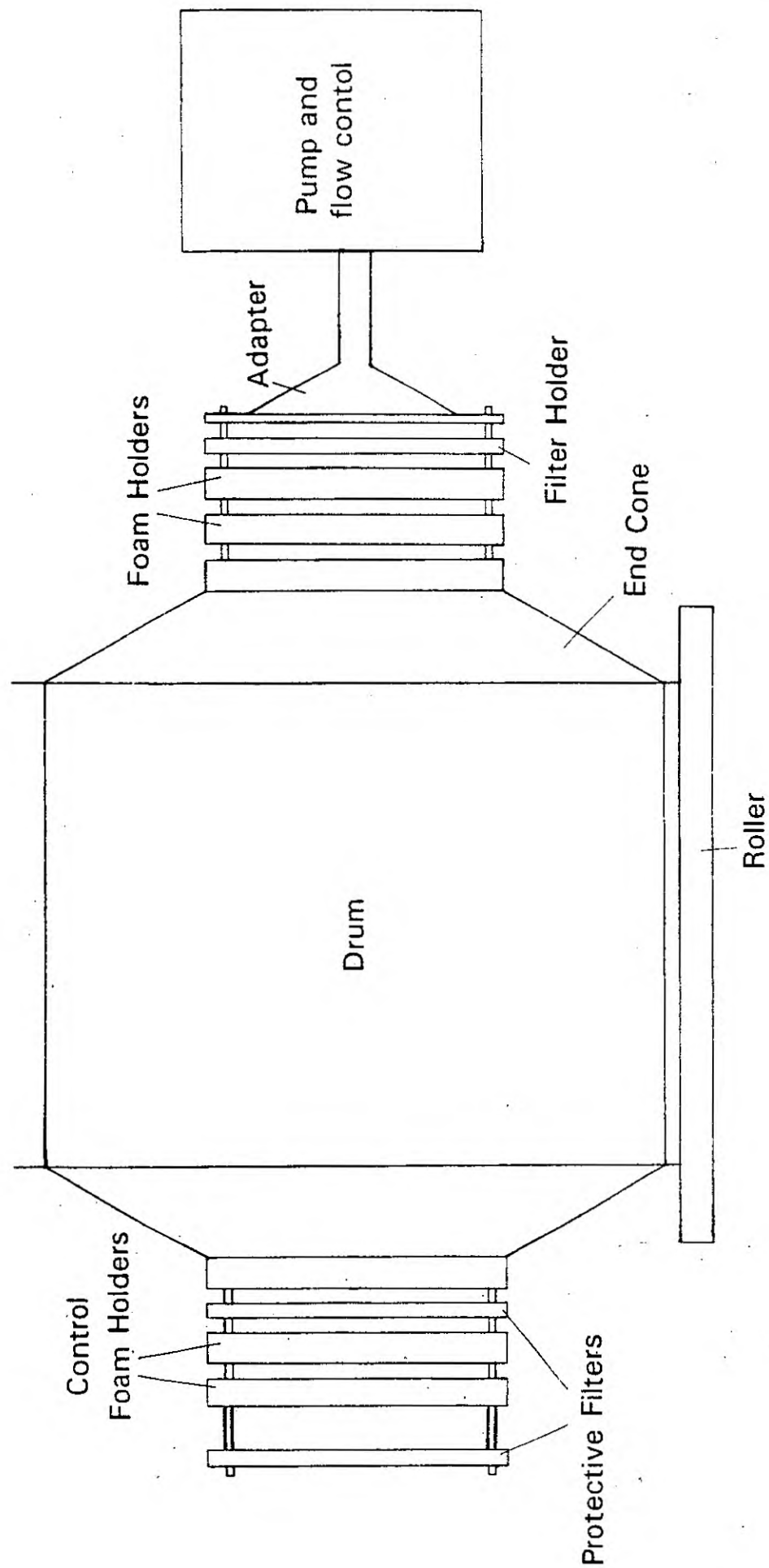


FIGURE 15. - Schematic Diagram of the Test Apparatus Used in the Test on the Materials Supplied by HSE

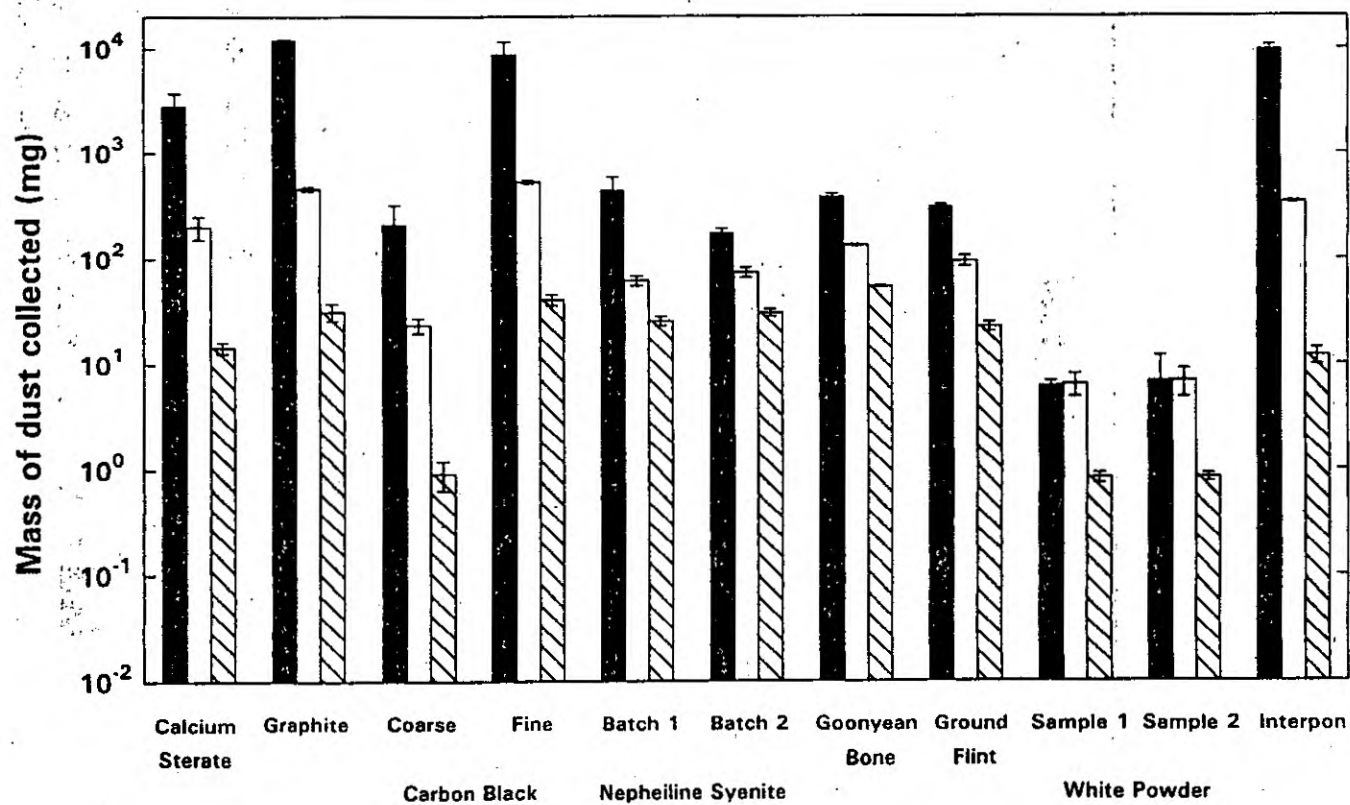
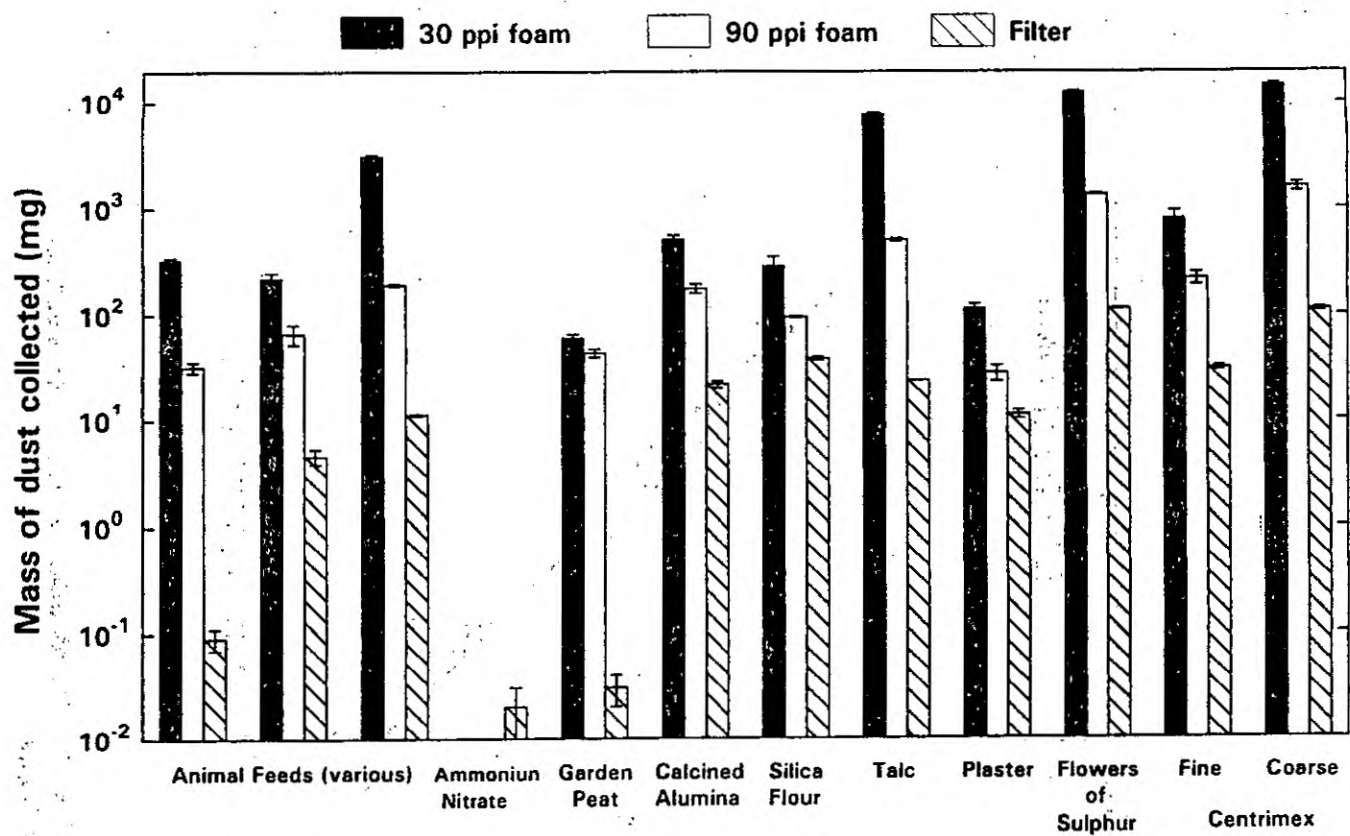


FIGURE 16. - Results of the Tests on the Materials Supplied by the NIGs

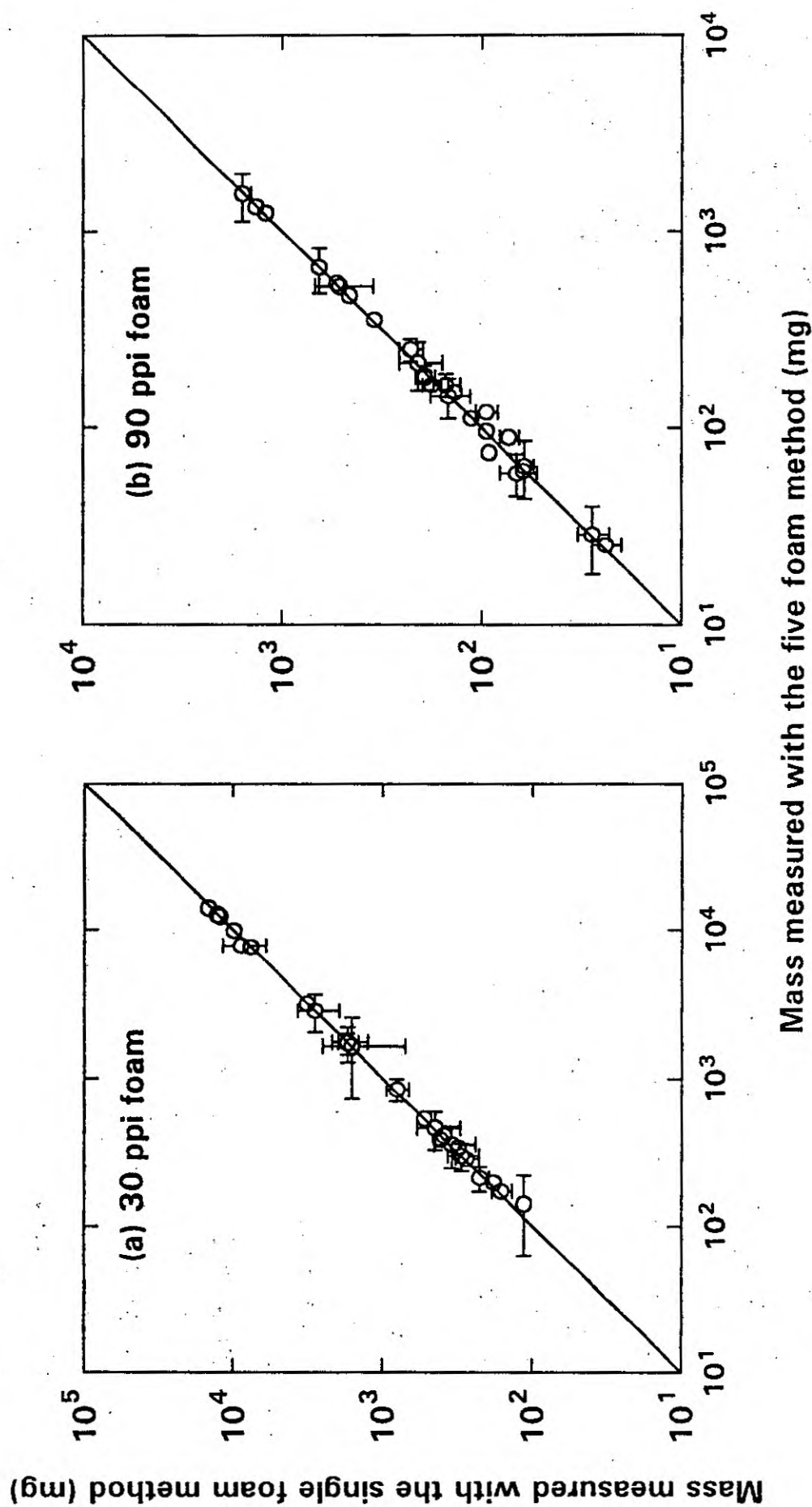


FIGURE 17. - Graphs Showing the Correlations Between the Two Control Methods Used in these Tests for Both the 30 and 90 ppi Foams

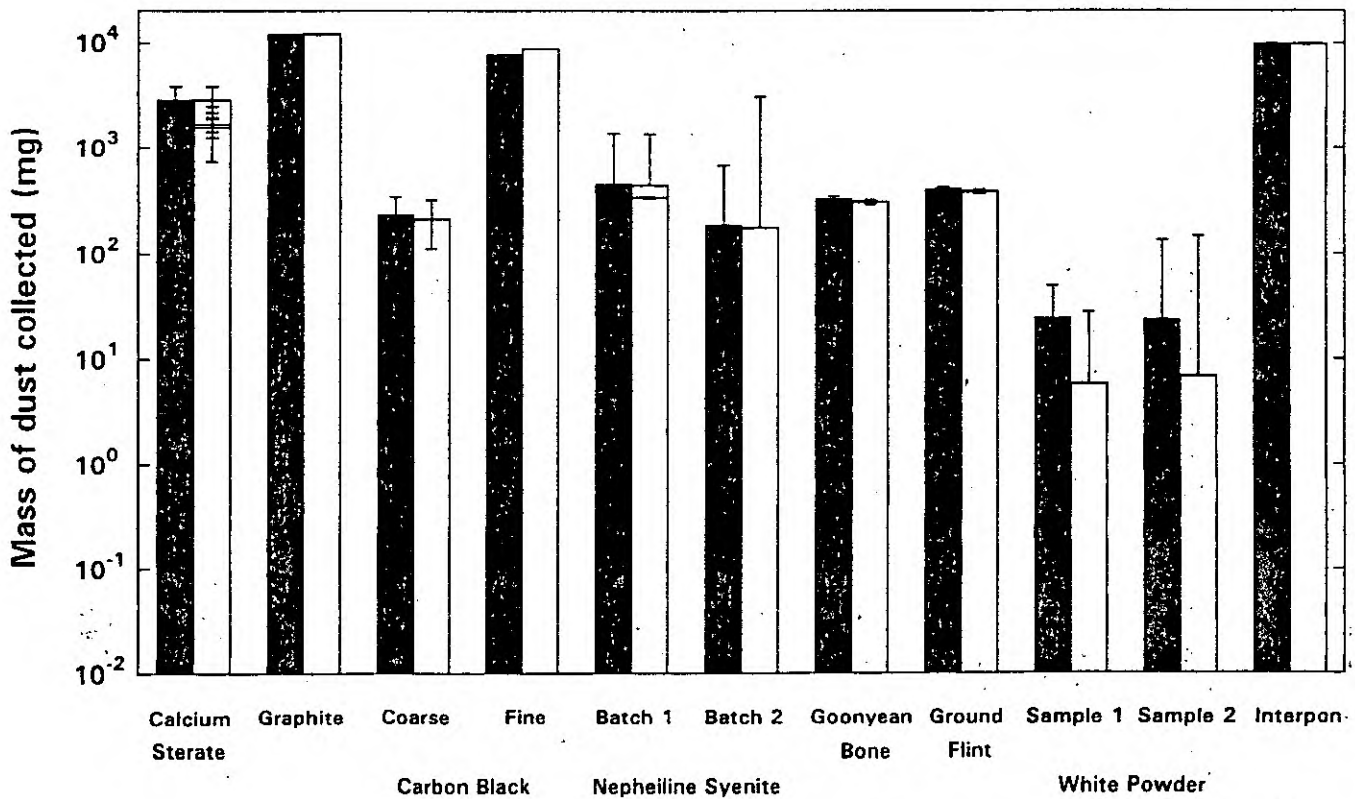
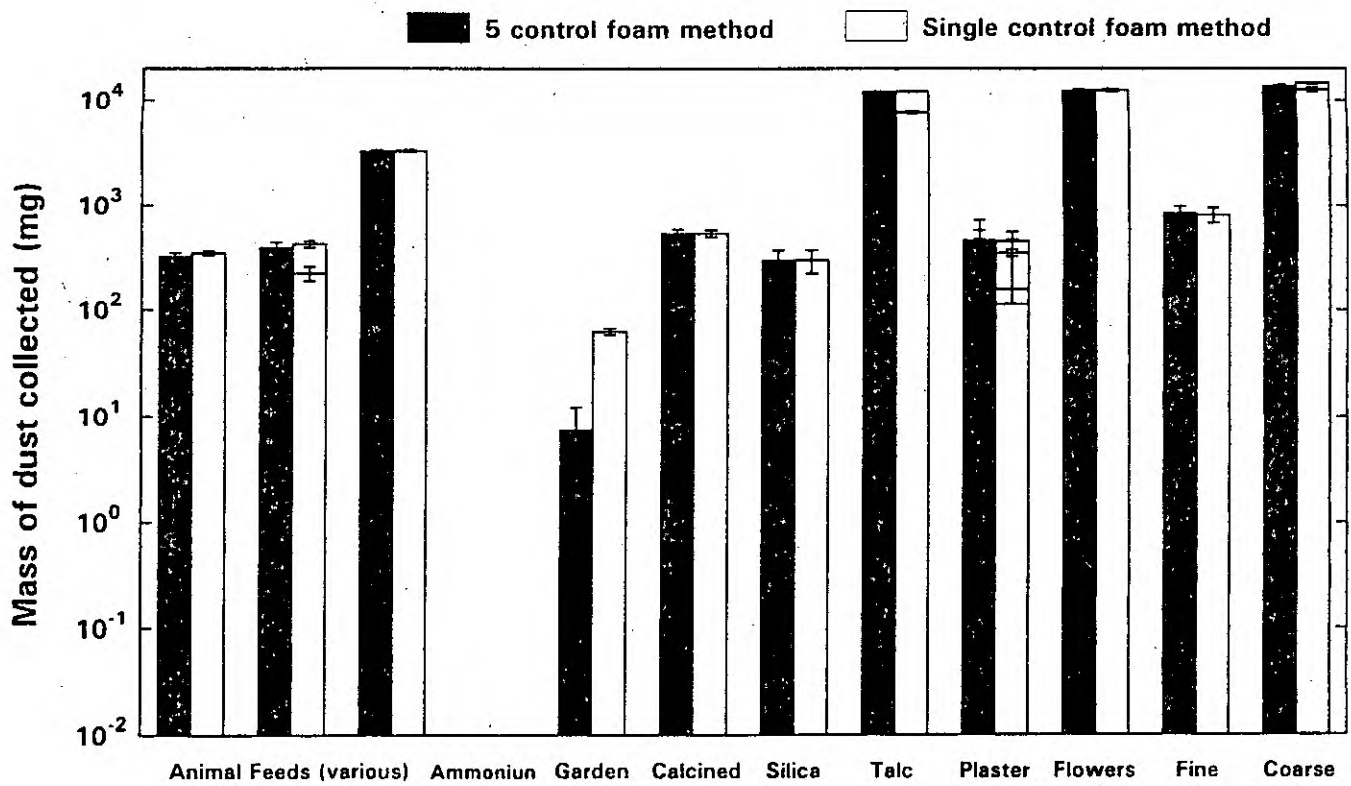


FIGURE 18: - Mass of Dust Collected on the 30 ppi Foam for Each Material

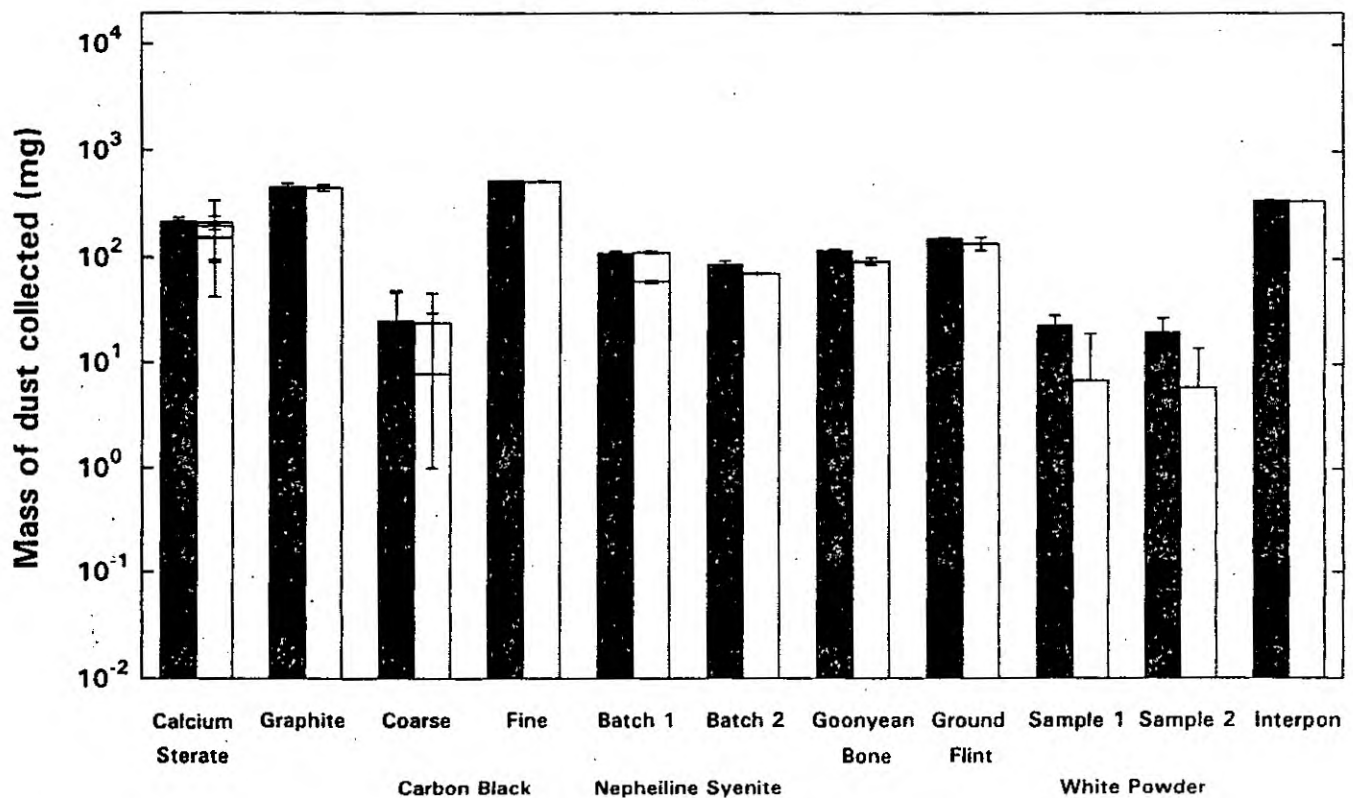
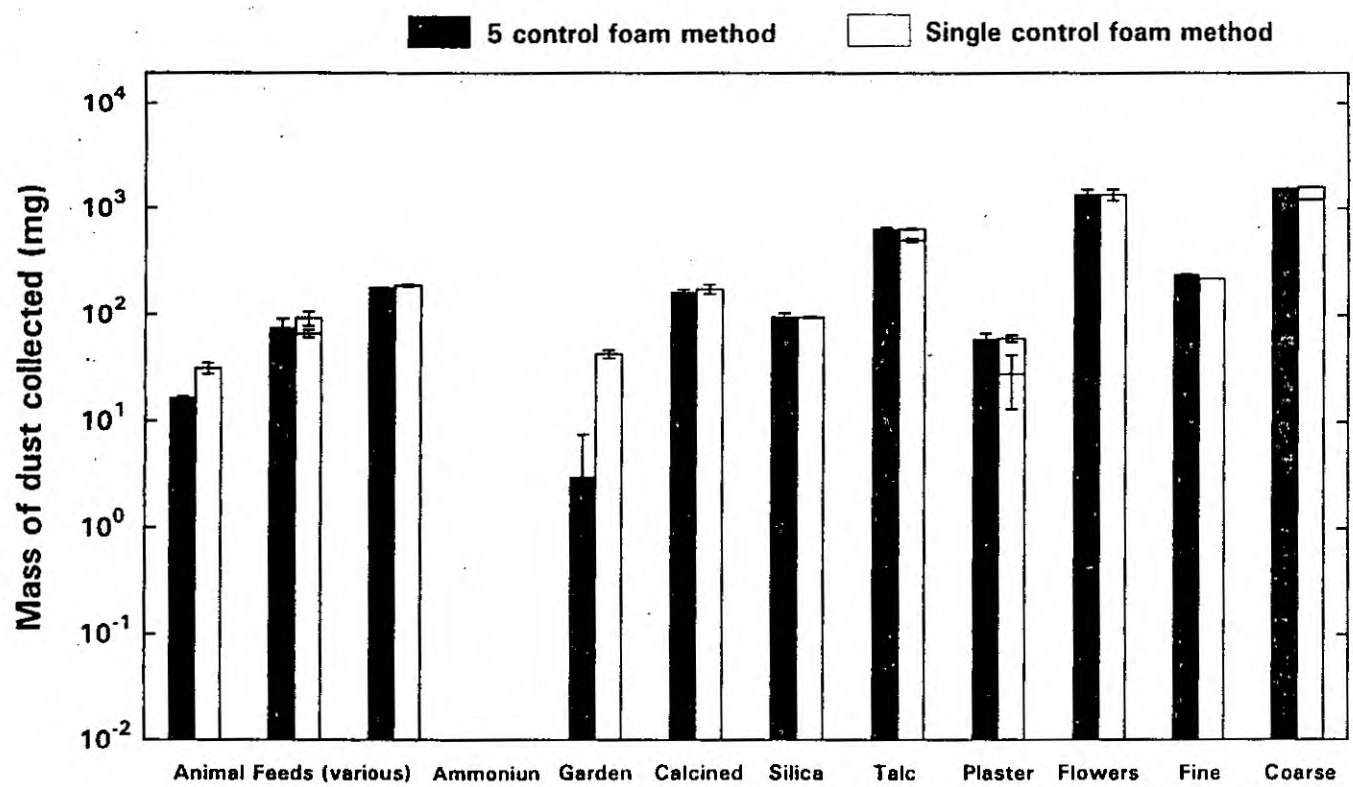


FIGURE 19. - Mass of Dust Collected on the 90 ppi Foam for Each Material

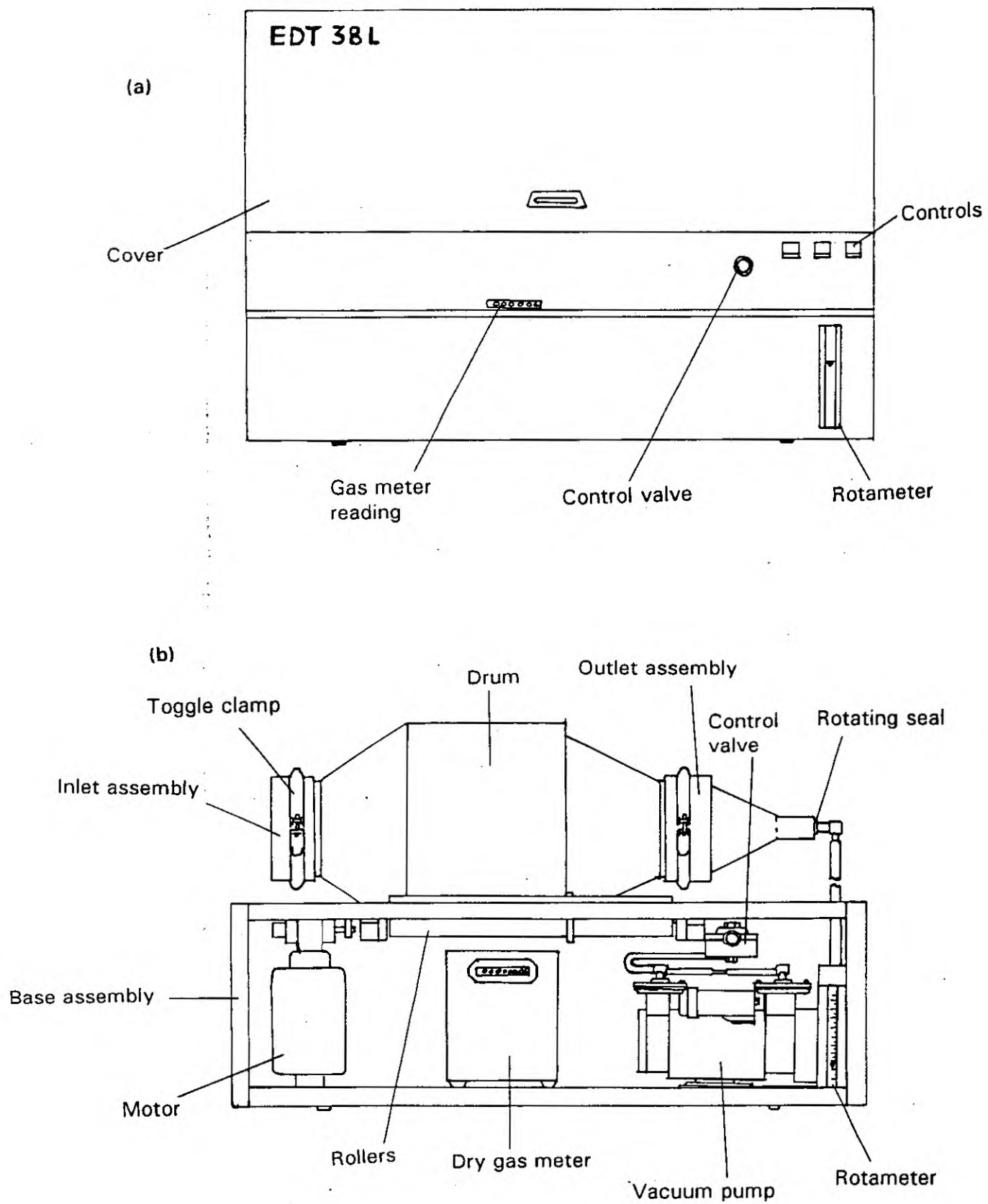


FIGURE 20. - Final Design: (a) shows the test apparatus with its cover for use; (b) shows the apparatus with the cover and side panel removed

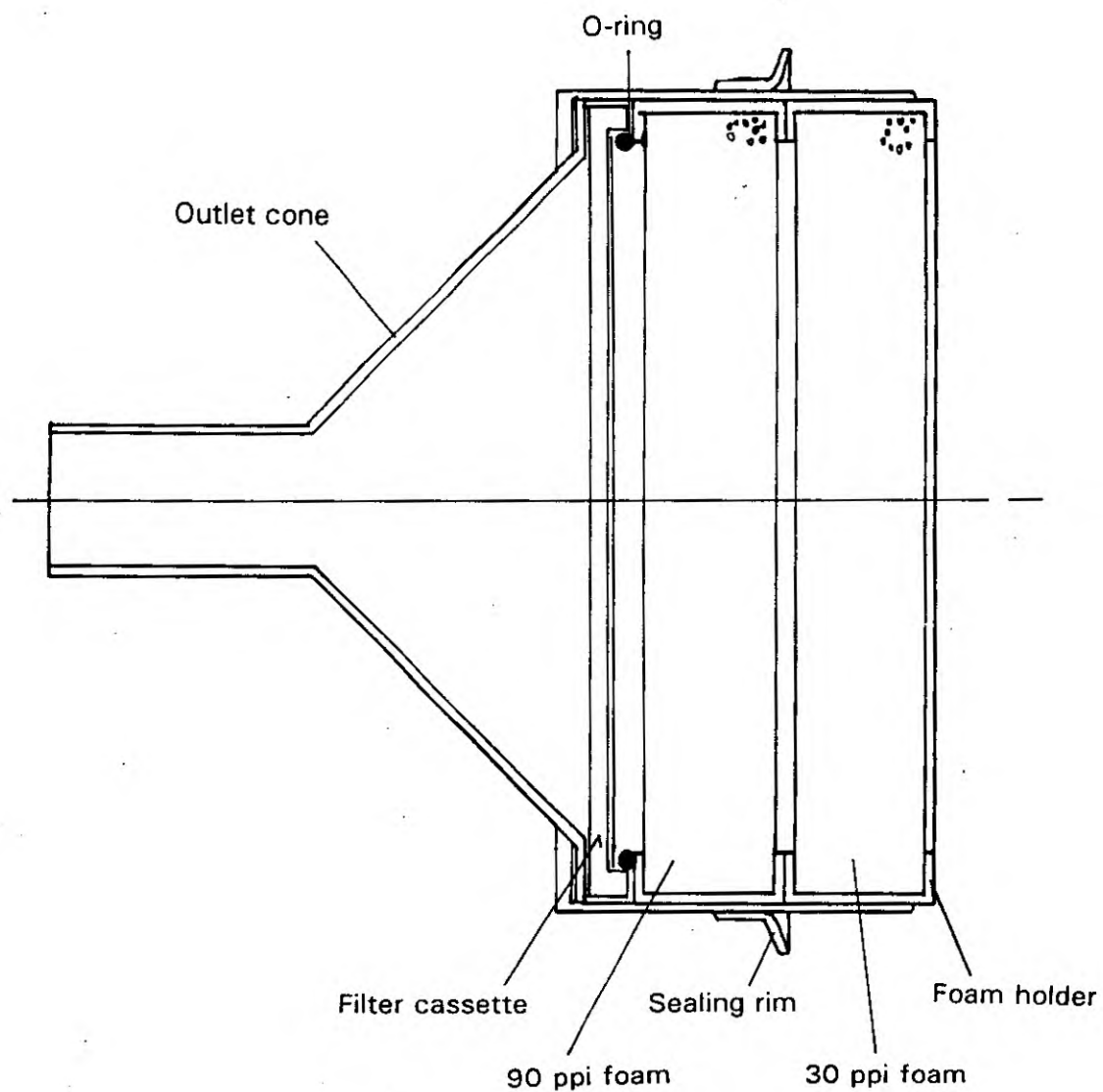


FIGURE 21. - Section Through the Outlet Foam Carrier Assembly. A Similar System is Used on the Inlet

Appendix A
FOAM MASS STABILITY DATA

Test 1

Foam No.	Small 30 ppi foam	Small 90 ppi foam	Large 30 ppi foam	Large 90 ppi foam	5 g test weight	10 g test weight
1	2.43860	3.20936	15.89805	17.96271	5.00043	10.00091
2	2.43908	3.20982	15.89750	17.96001	5.00037	10.00078
3	2.43914	3.20982	15.89994	17.95846	5.00041	10.00088
4	2.43904	3.20960	15.89928	17.95881	5.00054	10.00082
5	2.43903	3.20943	15.89697	17.95936	5.00038	10.00087
6	2.43887	3.20965	15.89718	17.95999	5.00040	10.00089
7	2.43912	3.20978	15.89796	17.96043	5.00044	10.00085
8	2.43911	3.20962	15.89832	17.95982	5.00044	10.00088
9	2.43897	3.20956	15.89842	17.95954	5.00045	10.00084
10	2.43900	3.20980	15.89824	17.95872	5.00047	10.00094

Test 2

Foam No.	Small 30 ppi foam	Small 90 ppi foam	Large 30 ppi foam	Large 90 ppi foam	5 g test weight	10 g test weight
1	2.43922	3.21024	15.8999	17.96103	5.00039	10.00087
2	2.43926	3.21046	15.89762	17.96178	5.00042	10.00082
3	2.43958	3.21067	15.89718	17.96268	5.00038	10.00080
4	2.43949	3.21022	15.89658	17.96248	5.00039	10.00083
5	2.43943	3.21005	15.8965	17.96239	5.00039	10.00085
6	2.43959	3.21047	15.89546	17.96165	5.00045	10.00086
7	2.43969	3.21023	15.89534	17.96196	5.00035	10.00083
8	2.43932	3.20986	15.89546	17.96239	5.00045	10.00095
9	2.43938	3.21012	15.89594	17.96303	5.00045	10.00086
10	2.43857	3.20989	15.89619	17.96368	5.00046	10.00085

Test 3

Foam No.	Small 30 ppi foam	Small 90 ppi foam	Large 30 ppi foam	Large 90 ppi foam	5 g test weight	10 g test weight
1	2.43940	3.21061	15.92841	18.00761	5.00044	10.00084
2	2.43924	3.21025	15.92926	18.00636	5.00041	10.00085
3	2.43925	3.21034	15.93083	18.00646	5.00045	10.00087
4	2.43942	3.21068	15.93289	18.00666	5.00044	10.00093
5	2.43947	3.21050	15.93354	18.00633	5.00042	10.00086
6	2.43924	3.21028	15.93271	18.0052	5.00041	10.00087
7	2.43946	3.21052	15.9325	18.00606	5.00045	10.00087
8	2.43964	3.21028	15.93378	18.00673	5.00043	10.00091
9	2.43937	3.21058	15.93492	18.00737	5.00043	10.00083
10	2.43936	3.21045	15.93467	18.00689	5.00044	10.00084

Appendix B
BLANK TESTS WITH SMALL FOAM DISKS

Test 1: 30 ppi foams.

Test foams

Foam No.	(1) Initial Weight (g)	(2) Weight after test (g)	(3) Weight 0.5 hr later (g)	(4) Weight 2 hr later (g)	(2)-(1)	(3)-(1)	(4)-(1)
1	2.8349	2.8318	2.8359	2.8351	-0.0031	0.0010	0.0002
2	2.7566	2.7534	2.7572	2.7570	-0.0033	0.0006	0.0004
3	2.9143	2.9104	2.9147	2.9141	-0.0039	0.0004	-0.0002
4	2.9448	2.9410	2.9454	2.9448	-0.0038	0.0006	0.0001
5	2.6387	2.6347	2.6388	2.6384	-0.0040	0.0001	-0.0003
6	2.9449	2.9391	2.9448	2.9443	-0.0058	-0.0001	-0.0006
7	3.1478	3.1413	3.1471	3.1468	-0.0064	-0.0007	-0.0010
8	2.4847	2.4792	2.4842	2.4840	-0.0055	-0.0005	-0.0007
9	2.8973	2.8907	2.8966	2.8964	-0.0066	-0.0007	-0.0009
10	2.7237	2.7179	2.7232	2.7228	-0.0058	-0.0006	-0.0009

Control foams

Foam No.	(1) Initial Weight (g)	(2) Weight after test (g)	(3) Weight 0.5 hr later (g)	(4) Weight 2 hr later (g)	(2)-(1)	(3)-(1)	(4)-(1)
1	3.2067	3.2077	3.2076	3.2073	0.0010	0.0010	0.0006
2	3.4778	3.4789	3.4787	3.4782	0.0011	0.0010	0.0004
3	3.2658	3.2669	3.2667	3.2659	0.0011	0.0009	0.0001
4	3.2403	3.2414	3.2408	3.2400	0.0012	0.0005	-0.0003
5	2.8079	2.8087	2.8080	2.8074	0.0008	0.0001	-0.0004
6	3.3458	3.3463	3.3455	3.3451	0.0005	-0.0003	-0.0008
7	2.3998	2.4000	2.3994	2.3990	0.0002	-0.0004	-0.0009
8	2.4749	2.4752	2.4748	2.4743	0.0003	-0.0001	-0.0007
9	2.7522	2.7521	2.7516	2.7512	-0.0001	-0.0006	-0.0010
10	2.5925	2.5926	2.5922	2.5916	0.0001	-0.0003	-0.0009

Test 2. 30 ppi foams

Test foams

Foam No.	(1) Initial Weight (g)	(2) Weight after test (g)	(3) Weight 0.5 hr later (g)	(4) Weight 2 hr later (g)	(2)-(1)	(3)-(1)	(4)-(1)
1	2.8343	2.8300	2.8340	2.8315	-0.0043	-0.0003	-0.0028
2	2.7556	2.7512	2.7552	2.7511	-0.0044	-0.0004	-0.0045
3	2.9127	2.9082	2.9125	2.9115	-0.0045	-0.0002	-0.0012
4	2.9433	2.9388	2.9433	2.9434	-0.0045	0.0000	0.0001
5	2.6371	2.6331	2.6371	2.6371	-0.0040	0.0000	0.0000
6	2.9430	2.9389	2.9431	2.9431	-0.0041	0.0001	0.0001
7	3.1455	3.1403	3.1455	3.1453	-0.0052	0.0000	-0.0002
8	2.4830	2.4790	2.4822	2.4820	-0.0040	-0.0008	-0.0010
9	2.8951	2.8910	2.8953	2.8948	-0.0041	0.0002	-0.0003
10	2.7214	2.7172	2.7219	2.7214	-0.0042	0.0005	0.0000

Control foams

Foam No.	(1) Initial Weight (g)	(2) Weight after test (g)	(3) Weight 0.5 hr later (g)	(4) Weight 2 hr later (g)	(2)-(1)	(3)-(1)	(4)-(1)
1	3.2057	3.2053	3.2056	3.2029	-0.0004	-0.0001	-0.0028
2	3.4762	3.4761	3.4762	3.4733	-0.0001	0.0000	-0.0029
3	3.2639	3.2644	3.2644	3.2648	0.0005	0.0005	0.0009
4	3.2383	3.2384	3.2386	3.2391	0.0001	0.0003	0.0008
5	2.8062	2.8063	2.8066	2.8067	0.0001	0.0004	0.0005
6	3.3437	3.3438	3.3442	3.3440	0.0001	0.0005	0.0003
7	2.3981	2.3982	2.3985	2.3981	0.0001	0.0004	0.0000
8	2.4732	2.4734	2.4736	2.4732	0.0002	0.0004	0.0000
9	2.7499	2.7499	2.7504	2.7500	0.0000	0.0005	0.0001
10	2.5902	2.5902	2.5909	2.5905	0.0000	0.0007	0.0003

Test 3. 30 ppi foams

Test foams

Foam No.	(1) Initial Weight (g)	(2) Weight after test (g)	(3) Weight 0.5 hr later (g)	(4) Weight 2 hr later (g)	(2)-(1)	(3)-(1)	(4)-(1)
1	2.8331	2.8297	2.8323	2.8311	-0.0034	-0.0008	-0.0020
2	2.7545	2.7511	2.7535	2.7522	-0.0034	-0.0010	-0.0023
3	2.9116	2.9080	2.9106	2.9095	-0.0036	-0.0010	-0.0021
4	2.9444	2.9377	2.9412	2.9405	-0.0067	-0.0032	-0.0039
5	2.6364	2.6307	2.6352	2.6347	-0.0057	-0.0012	-0.0017
6	2.9422	2.9360	2.9409	2.9401	-0.0062	-0.0013	-0.0021
7	3.1445	3.1389	3.1430	3.1424	-0.0056	-0.0015	-0.0021
8	2.4813	2.4770	2.4802	2.4796	-0.0043	-0.0011	-0.0016
9	2.8938	2.8894	2.8927	2.8920	-0.0044	-0.0012	-0.0018
10	2.7204	2.7165	2.7197	2.7192	-0.0039	-0.0007	-0.0012

Control foams

Foam number	(1) Initial Weight (g)	(2) Weight after test (g)	(3) Weight 0.5 hr later (g)	(4) Weight 2 hr later (g)	(2)-(1)	(3)-(1)	(4)-(1)
1	3.2046	3.2045	3.2035	3.2022	0.0000	-0.0010	-0.0024
2	3.4751	3.4755	3.4740	3.4724	0.0004	-0.0012	-0.0028
3	3.2632	3.2636	3.2621	3.2611	0.0004	-0.0011	-0.0021
4	3.2375	3.2378	3.2364	3.2358	0.0003	-0.0011	-0.0018
5	2.8045	2.8052	2.8043	2.8037	0.0007	-0.0003	-0.0009
6	3.3428	3.3423	3.3412	3.3404	-0.0006	-0.0016	-0.0024
7	2.3973	2.3972	2.3964	2.3959	-0.0001	-0.0009	-0.0014
8	2.4722	2.4790	2.4714	2.4708	0.0068	-0.0008	-0.0013
9	2.7489	2.7487	2.7479	2.7473	-0.0002	-0.0010	-0.0016
10	2.5895	2.5898	2.5886	2.5885	0.0002	-0.0009	-0.0011

Test 4. 90 ppi foams

Test foams

Foam number	(1) Initial Weight (g)	(2) Weight after test (g)	(3) Weight 0.5 hr later (g)	(4) Weight 2 hr later (g)	(2)-(1)	(3)-(1)	(4)-(1)
1	2.4370	2.4322	2.4380	2.4366	-0.0049	0.0009	-0.0004
2	2.5608	2.5552	2.5619	2.5604	-0.0056	0.0011	-0.0004
3	2.5697	2.5641	2.5703	2.5689	-0.0056	0.0006	-0.0008
4	2.4828	2.4780	2.4835	2.4822	-0.0048	0.0007	-0.0006
5	2.3930	2.3882	2.3931	2.3920	-0.0048	0.0001	-0.0010
6	2.3671	2.3629	2.3676	2.3665	-0.0043	0.0005	-0.0006
7	2.4393	2.4356	2.4396	2.4387	-0.0037	0.0003	-0.0006
8	2.4261	2.4209	2.4260	2.4253	-0.0052	-0.0001	-0.0009
9	2.4371	2.4321	2.4373	2.4363	-0.0050	0.0002	-0.0008
10	2.4306	2.4248	2.4300	2.4289	-0.0058	-0.0006	-0.0017

Control foams

Foam number	(1) Initial Weight (g)	(2) Weight after test (g)	(3) Weight 0.5 hr later (g)	(4) Weight 2 hr later (g)	(2)-(1)	(3)-(1)	(4)-(1)
1	2.9685	2.9679	2.9688	2.9669	-0.0006	0.0003	-0.0016
2	2.3037	2.3035	2.3041	2.3027	-0.0002	0.0004	-0.0010
3	2.9362	2.9351	2.9356	2.9339	-0.0011	-0.0006	-0.0023
4	2.4934	2.4928	2.4932	2.4918	-0.0006	-0.0002	-0.0015
5	2.5404	2.5392	2.5395	2.5383	-0.0012	-0.0009	-0.0021
6	2.3387	2.3383	2.3383	2.3373	-0.0004	-0.0004	-0.0014
7	2.8574	2.8564	2.8566	2.8554	-0.0010	-0.0008	-0.0020
8	2.3716	2.3708	2.3709	2.3701	-0.0008	-0.0007	-0.0015
9	2.6117	2.6119	2.6121	2.6108	0.0002	0.0004	-0.0009
10	2.5924	2.5927	2.5927	2.5913	0.0004	0.0004	-0.0011

Test 5. 90 ppi foams

Test foams

Foam No.	(1) Initial Weight (g)	(2) Weight after test (g)	(3) Weight 0.5 hr later (g)	(4) Weight 2 hr later (g)	(2)-(1)	(3)-(1)	(4)-(1)
1	2.4370	2.4321	2.4367	2.4369	-0.0049	-0.0003	-0.0001
2	2.5610	2.5554	2.5607	2.5692	-0.0056	-0.0003	0.0082
3	2.5693	2.5641	2.5691	2.5692	-0.0052	-0.0002	-0.0001
4	2.4825	2.4775	2.4825	2.4828	-0.0050	0.0000	0.0003
5	2.3923	2.3875	2.3922	2.3923	-0.0048	-0.0001	0.0000
6	2.3668	2.3620	2.3669	2.3669	-0.0048	0.0001	0.0001
7	2.4389	2.4346	2.4389	2.4389	-0.0043	0.0000	0.0000
8	2.4253	2.4206	2.4256	2.4254	-0.0047	0.0003	0.0001
9	2.4363	2.4321	2.4368	2.4365	-0.0042	0.0005	0.0002
10	2.4288	2.4246	2.4295	2.4293	-0.0042	0.0007	0.0005

Control foams

Foam No.	(1) Initial Weight (g)	(2) Weight after test (g)	(3) Weight 0.5 hr later (g)	(4) Weight 2 hr later (g)	(2)-(1)	(3)-(1)	(4)-(1)
1	2.9674	2.9671	2.9673	2.9674	-0.0003	-0.0001	0.0000
2	2.3032	2.3030	2.3031	2.3033	-0.0002	-0.0001	0.0001
3	2.9344	2.9343	2.9343	2.9345	-0.0001	-0.0001	0.0001
4	2.4923	2.4922	2.4920	2.4921	-0.0001	-0.0003	-0.0002
5	2.5386	2.5386	2.5385	2.5386	0.0000	-0.0001	0.0000
6	2.3375	2.3375	2.3375	2.3374	0.0000	0.0000	-0.0001
7	2.8555	2.8558	2.8559	2.8557	0.0003	0.0004	0.0002
8	2.3700	2.3703	2.3705	2.3702	0.0003	0.0005	0.0002
9	2.6108	2.6112	2.6116	2.6113	0.0004	0.0008	0.0005
10	2.5914	2.5919	2.5922	2.5920	0.0005	0.0008	0.0006

Test 6. 90 ppi foams

Test foams

Foam No.	(1) Initial Weight (g)	(2) Weight after test (g)	(3) Weight 0.5 hr later (g)	(4) Weight 2 hr later (g)	(2)-(1)	(3)-(1)	(4)-(1)
1	2.4380	2.4376	2.4379	2.4379	-0.0440	-0.0059	-0.0101
2	2.5630	2.5625	2.5629	2.5629	-0.0471	-0.0087	-0.0116
3	2.5692	2.5687	2.5691	2.5691	-0.0474	-0.0072	-0.0085
4	2.4823	2.4817	2.4822	2.4822	-0.0615	-0.0065	-0.0107
5	2.3924	2.3917	2.3923	2.3923	-0.0691	-0.0058	-0.0123
6	2.3666	2.3658	2.3665	2.3665	-0.0762	-0.0066	-0.0098
7	2.4391	2.4384	2.4390	2.4390	-0.0725	-0.0057	-0.0093
8	2.4255	2.4248	2.4254	2.4254	-0.0664	-0.0076	-0.0107
9	2.4362	2.4355	2.4361	2.4361	-0.0739	-0.0126	-0.0147
10	2.4286	2.4279	2.4285	2.4285	-0.0680	-0.0108	-0.0113

Control foams

Foam No.	(1) Initial Weight (g)	(2) Weight after test (g)	(3) Weight 0.5 hr later (g)	(4) Weight 2 hr later (g)	(2)-(1)	(3)-(1)	(4)-(1)
1	2.9672	2.9672	2.9671	2.9671	0.0018	-0.0066	-0.0109
2	2.3034	2.3034	2.3033	2.3033	0.0002	-0.0071	-0.0115
3	2.9341	2.9341	2.9340	2.9340	0.0017	-0.0079	-0.0127
4	2.4927	2.4927	2.4927	2.4926	0.0032	-0.0048	-0.0109
5	2.5384	2.5384	2.5384	2.5383	0.0042	-0.0023	-0.0090
6	2.3373	2.3373	2.3373	2.3372	0.0019	-0.0041	-0.0098
7	2.8558	2.8558	2.8557	2.8557	-0.0008	-0.0069	-0.0132
8	2.3703	2.3703	2.3702	2.3702	-0.0009	-0.0066	-0.0103
9	2.6106	2.6106	2.6105	2.6105	-0.0013	-0.0103	-0.0135
10	2.5911	2.5911	2.5910	2.5910	0.0001	-0.0099	-0.0120

Appendix C
BLANK TESTS WITH LARGE FOAM DISKS

Test 1.

30 ppi foams

(1) Foam weights before the test (g)	(2) Foam weights 0.5 hours after the test (g)	(3) Foam weights 2 hours after the test (g)	(4) Foam weights 4 hours after the test (g)	(2)-(1)	(3)-(1)	(4)-(1)
Control foams						
14.55297	14.56005	14.56500	14.56790	-0.00708	-0.01203	-0.01493
13.16771	13.17880	13.18350	13.18602	-0.01109	-0.01579	-0.01831
14.49637	14.50288	14.50866	14.51102	-0.00651	-0.01229	-0.01465
13.16640	13.12864	13.13440	13.13696	Outlier		
14.68681	14.69384	14.70091	14.70561	-0.00703	-0.01410	-0.01880
Test foams						
14.61232	14.61467	14.62191	14.62326	-0.00235	-0.00959	-0.01094
14.65556	14.65813	14.66704	14.66931	-0.00257	-0.01148	-0.01375
14.61032	14.61447	14.61922	14.62225	-0.00415	-0.00890	-0.01193

90 ppi foams

(1) Foam weights before the test (g)	(2) Foam weights 0.5 hours after the test (g)	(3) Foam weights 1 hour after the test (g)	(4) Foam weights 2 hours after the test (g)	(2)-(1)	(3)-(1)	(4)-(1)
15.73481	15.73808	15.74838	15.75236	-0.00327	-0.01357	-0.01755
15.94623	15.95112	15.96198	15.96630	-0.00489	-0.01575	-0.02007
16.82074	16.82827	16.84125	16.84764	-0.00753	-0.02051	-0.02690
16.28678	16.29339	16.30283	16.30715	-0.00661	-0.01605	-0.02037
15.84300	15.85292	15.86007	15.86334	-0.00992	-0.01707	-0.02034
16.88542	16.88091	16.89902	16.90509	0.00451	-0.01360	-0.01967
16.32218	16.33609	16.34364	16.34826	-0.01391	-0.02146	-0.02608
16.07680	16.09201	16.09623	16.09913	-0.01521	-0.01943	-0.02233

Test 2

30 ppi foams

(1) Foam weights before the test (g)	(2) Foam weights 1 hour after the test (g)	(3) Foam weights 3 hours after the test (g)	(4) Foam weights 6 hours after the test (g)	(5) Foam weights 24 hours after the test (g)	(2)-(1)	(3)-(1)	(4)-(1)	(5)-(1)
13.50625	13.50248	13.50454	13.50230	13.50336	0.00377	0.00171	0.00395	0.00289
14.40881	14.40520	14.40530	14.40447	14.40496	0.00361	0.00351	0.00434	0.00385
14.44923	14.44610	14.44660	14.44538	14.44499	0.00313	0.00263	0.00385	0.00424
14.00610	14.00320	14.00315	14.00192	14.00363	0.00290	0.00295	0.00418	0.00247
14.48683	14.48325	14.48300	14.48253	14.48327	0.00358	0.00383	0.00430	0.00356
13.35219	13.34036	13.34941	13.34910	13.34936	0.01183	0.00278	0.00309	0.00283
14.73546	14.72489	14.73238	14.73075	14.73092	0.01057	0.00308	0.00471	0.00454
14.64400	14.67716	14.68557	14.68475	14.68526	Foam damaged			

90 ppi foams

(1) Foam weights before the test (g)	(2) Foam weights 1 hour after the test (g)	(3) Foam weights 3 hours after the test (g)	(4) Foam weights 6 hours after the test (g)	(5) Foam weights 24 hours after the test (g)	(2)-(1)	(3)-(1)	(4)-(1)	(5)-(1)
Control foams								
15.8895	15.87968	15.88	15.88445	15.87837	0.00982	0.0095	0.00505	0.01113
16.38058	16.37331	16.37911	16.37577	16.37104	0.00727	0.00147	0.00481	0.00954
13.62667	13.62148	13.62676	13.62407	13.6197	0.00519	-0.00009	0.0026	0.00697
15.83992	15.83256	15.83875	15.83506	15.82873	0.00736	0.00117	0.00486	0.01119
16.28089	16.27458	16.27995	16.27688	16.27117	0.00631	0.00094	0.00401	0.00972
Test foams								
16.62212	16.60995	16.62001	16.61781	16.60987	0.01217	0.00211	0.00431	0.01225
16.59447	16.58523	16.5931	16.58956	16.58488	0.00924	0.00137	0.00491	0.00959
16.05709	16.04642	16.05603	16.05296	16.04671	0.01067	0.00106	0.00413	0.01038

Test 3

30 ppi foams

(1) Foam weights before the test (g)	(2) Foam weights 3 hours after the test (g)	(3) Foam weights 21 hours after the test (g)	(2)-(1)	(3)-(1)
Control foams				
14.45183	14.44885	14.44449	0.00298	0.00734
14.48874	14.48644	14.48251	0.00230	0.00623
13.67343	13.66996	13.66899	0.00347	0.00444
14.67879	14.67668	14.67516	0.00211	0.00363
13.50972	13.50624	13.49986	0.00348	0.00986
Test foams				
14.19849	14.18875	14.18852	0.00974	0.00997
14.65960	14.65338	14.65449	0.00622	0.00511
13.83905	13.83632	13.83061	0.00273	0.00844

90 ppi foams

(1) Foam weights before the test (g)	(2) Foam weights 3 hours after the test (g)	(3) Foam weights 21 hours after the test (g)	(2)-(1)	(3)-(1)
Control foams				
16.42357	16.42932	16.41707	-0.00575	0.00650
16.39461	16.39993	16.39139	-0.00532	0.00322
16.67332	16.67822	16.66672	-0.00490	0.00660
15.93606	15.94105	15.93336	-0.00499	0.00270
15.88531	15.89140	15.88025	-0.00609	0.00506
Test foams				
15.84676	15.85052	15.83941	-0.00376	0.00735
16.56592	16.56615	16.56394	-0.00023	0.00198
16.32455	16.32398	16.32439	0.00057	0.00016

Test 4

30 ppi foams

(1) Foam weights before the test (g)	(2) Foam weights 2 hours after the test (g)	(3) Foam weights 5 hours after the test (g)	(4) Foam weights 6 hours after the test (g)	(5) Foam weights 23 hours after the test (g)	(2)-(1)	(3)-(1)	(4)-(1)	(5)-(1)
Control foams								
13.51326	13.51236	13.50891	13.50376	0.00000	0.00090	0.00435	0.00950	0.00000
14.45556	14.45407	14.45168	14.44802	14.44593	0.00149	0.00388	0.00754	0.00963
13.67771	13.67472	13.67315	13.66843	13.66777	0.00299	0.00456	0.00928	0.00994
14.41113	14.40899	14.40694	14.40167	14.40137	0.00214	0.00419	0.00946	0.00976
13.65065	13.64812	13.64655	13.64138	13.64264	0.00253	0.00410	0.00927	0.00801
Test foams								
14.87545	14.86961	14.86876	14.86603	14.86521	0.00584	0.00669	0.00942	0.01024
14.61319	14.60844	14.60926	14.60409	14.60563	0.00475	0.00393	0.00910	0.00756
14.66473	14.66072	14.66154	14.65588	14.65553	0.00401	0.00319	0.00885	0.00920

90 ppi foams

(1) Foam weights before the test (g)	(2) Foam weights 2 hours after the test (g)	(3) Foam weights 5 hours after the test (g)	(4) Foam weights 6 hours after the test (g)	(5) Foam weights 23 hours after the test (g)	(2)-(1)	(3)-(1)	(4)-(1)	(5)-(1)
Control foams								
15.87273	15.86847	15.87243	15.86867	15.86711	0.00426	0.00030	0.00406	0.00562
15.94033	15.94003	15.94070	15.93786	15.93612	0.00030	-0.00037	0.00247	0.00421
15.72685	15.72345	15.72583	15.72534	15.72429	0.00340	0.00102	0.00151	0.00256
16.81615	16.81435	16.81821	16.81414	16.81057	0.00180	-0.00206	0.00201	0.00558
15.84028	15.83937	15.83855	15.83851	15.83349	0.00091	0.00173	0.00177	0.00679
Test foams								
16.61246	16.60820	16.60974	16.60620	16.60291	0.00426	0.00272	0.00626	0.00955
16.32460	16.32282	16.32305	16.32256	16.32030	0.00178	0.00155	0.00204	0.00430
16.59507	16.59401	16.59406	16.59374	16.58948	0.00106	0.00101	0.00133	0.00559

Test 5

30 ppi foams

(1) Foam weights before the test (g)	(2) Foam weights 5 hours after the test (g)	(3) Foam weights 7 hours after the test (g)	(4) Foam weights 23 hours after the test (g)	(2)-(1)	(3)-(1)	(4)-(1)
Control foams						
14.45791	14.42942	14.42770	14.44574	0.02849	0.03021	0.01217
14.01337	13.98502	13.98305	14.00032	0.02835	0.03032	0.01305
13.16883	13.14237	13.14019	13.15461	0.02646	0.02864	0.01422
14.42460	14.39734	14.39405	14.40891	0.02726	0.03055	0.01569
13.51571	13.48679	13.48278	13.50555	0.02892	0.03293	0.01016
Test foams						
14.60807	14.57671	14.57591	14.59805	0.03136	0.03216	0.01002
13.87035	13.84059	13.83740	13.85638	0.02976	0.03295	0.01397
13.84420	13.81923	13.81357	13.83399	0.02497	0.03063	0.01021

90 ppi foams

(1) Foam weights before the test (g)	(2) Foam weights 5 hours after the test (g)	(3) Foam weights 7 hours after the test (g)	(4) Foam weights 23 hours after the test (g)	(2)-(1)	(3)-(1)	(4)-(1)
Control foams						
15.87604	15.85556	15.85683	15.87087	0.02048	0.01921	0.00517
15.84583	15.82330	15.82212	15.83748	0.02253	0.02371	0.00835
13.63134	13.61257	13.61095	13.62417	0.01877	0.02039	0.00717
16.38826	16.36159	16.36399	16.38145	0.02667	0.02427	0.00681
16.67917	16.65809	16.65500	16.66958	0.02108	0.02417	0.00959
Test foams						
16.59898	16.56708	16.57380	16.59465	0.03190	0.02518	0.00433
16.14273	16.11855	16.11887	16.13374	0.02418	0.02386	0.00899
16.07798	16.06411	16.05915	16.07568	0.01387	0.01883	0.00230

Appendix D

ANALYSIS OF VARIANCE DATA FROM THE OPTIMISATION EXPERIMENTS

ANOVA of the total dust data		AIO F1200						Granular Fertiliser						Totals
		100g			200g			100g			200g			
		No Spacer	Spacer		No Spacer	Spacer		No Spacer	Spacer		No Spacer	Spacer		
Full length	Mean value	61	52		47	65		38	19		36	46		
	Sum of values	186	154		139	196		115	57		108	138		1093
	Sum of squares	17930	11414		6642	13098		4338	1115		3888	7274		
Half length	Mean value	98	29		127	109		16	59		56	59		
	Sum of values	295	71		381	333		46	200		168	178		1672
	Sum of squares	33326	1878		48806	39561		1154	13843		9795	10835		
Σ sum of values		481	225		520	529		161	257		276	316		2765

ANOVA of the 30ppi foam data		AIO F1200						Granular Fertiliser						Totals
		100g			200g			100g			200g			
		No Spacer	Spacer		No Spacer	Spacer		No Spacer	Spacer		No Spacer	Spacer		
Full length	Mean value	52	39		21	34		16	12		17	18		
	Sum of values	158	117		61	103		48	37		51	54		629
	Sum of squares	15366	7667		1419	3545		782	457		869	1220		
Half length	Mean value	80	12		57	56		7	26		36	27		
	Sum of values	240	26		172	172		19	79		108	82		898
	Sum of squares	24422	300		9954	12002		141	2091		3920	2284		
Σ sum of values		398	143		233	275		67	116		159	136		1527

ANOVA of the 90ppi foam data		AIO F1200						Granular Fertiliser						Totals
		100g		200g		100g		200g						
		No Spacer	Spacer	No Spacer	Spacer	No Spacer	Spacer	No Spacer	Spacer					
Full length	Mean value	7	9	19	23	19	7	18	24					
	Sum of values	22	25	57	69	58	20	54	72		377			
	Sum of squares	174	213	1097	1805	1132	158	974	1952					
Half length	Mean value	12	15	52	37	8	26	19	28					
	Sum of values	37	39	155	113	24	100	57	84		609			
	Sum of squares	501	545	8021	4501	470	3702	1229	2474					
Σ sum of values		59	64	212	182	82	120	111	156		986			

ANOVA of the filter data		AIO F1200						Granular Fertiliser						Totals
		100g		200g		100g			200g					
		No Spacer	Spacer	No Spacer	Spacer	No Spacer	Spacer	No Spacer	Spacer					
Full length	Mean value	2	4	7	8			3	0	1	4			
	Sum of values	6	12	21	24			9	0	3	12		87	
	Sum of squares	14	50	138	218			22	0	3	50			
Half length	Mean value	6	2	18	16			1	7	1	4			
	Sum of values	18	6	54	48			3	21	3	12		165	
	Sum of squares	125	24	1009	833			3	142	4	49			
Σ sum of values		24	18	75	72			12	21	6	24		252	

ANOVA table for the total masses				
Source	Degrees of freedom	Sum of squares	Mean square	F statistic
1/Material	1	11563	11563	9.2
2/Spacer	1	257	257	0.2
3/Length	1	6984	6984	5.6
4/Mass	1	5569	5569	4.4
1&2	1	3056	3056	2.4
1&3	1	1112	1112	0.9
1&4	1	595	595	0.5
2&3	1	230	230	0.2
2&4	1	910	910	0.7
3&4	1	2993	2993	2.4
1,2&3	1	4982	4982	4.0
1,2&4	1	2147	2147	1.7
1,3&4	1	2228	2228	1.8
2,3&4	1	438	438	0.3
Error	18	22560	1253	
Total	32	65621	2051	

F > 4.45 for significant effect.

ANOVA table for the 90 ppi foams				
Source	Degrees of freedom	Sum of squares	Mean square	F statistic
1/Material	1	48	48	0.5
2/Spacer	1	70	70	0.7
3/Length	1	1121	1121	11.1
4/Mass	1	2352	2352	23.3
1&2	1	243	243	2.4
1&3	1	252	252	2.5
1&4	1	884	884	8.8
2&3	1	96	96	1.0
2&4	1	16	16	0.2
3&4	1	140	140	1.4
1,2&3	1	660	660	6.5
1,2&4	1	37	37	0.4
1,3&4	1	432	432	4.3
2,3&4	1	520	520	5.1
Error	18	1822	101	
Total	32	8694	272	

F > 4.45 for significant effect.

ANOVA table for the 30 ppi foams				
Source	Degrees of freedom	Sum of squares	Mean square	F statistic
1/Material	1	6793	6793	6.3
2/Spacer	1	729	729	0.7
3/Length	1	1508	1508	1.4
4/Mass	1	130	130	0.1
1&2	1	1190	1190	1.1
1&3	1	111	111	0.1
1&4	1	438	438	0.4
2&3	1	624	624	0.6
2&4	1	1055	1055	1.0
3&4	1	1419	1419	1.3
1,2&3	1	1376	1376	1.3
1,2&4	1	2837	2837	2.6
1,3&4	1	285	285	0.2
2,3&4	1	20	20	0.0
Error	18	19348	1075	
Total	32	37861	1183	

$F > 4.45$ for significant effect.

ANOVA table for the filter data				
Source	Degrees of freedom	Sum of squares	Mean square	F statistic
1/Material	1	331	331	33.1
2/Spacer	1	7	7	0.7
3/Length	1	127	127	12.7
4/Mass	1	217	217	21.7
1&2	1	27	27	2.7
1&3	1	48	48	4.8
1&4	1	243	243	24.3
2&3	1	0	0	0.0
2&4	1	3	3	0.3
3&4	1	27	27	2.7
1,2&3	1	61	61	6.1
1,2&4	1	1	1	0.1
1,3&4	1	91	91	9.1
2,3&4	1	7	7	0.7
Error	18	173	10	
Total	32	1361	43	

F > 4.45 for significant effect.

Appendix E

**RESULTS OF TESTS WITH THE NEW PROTOTYPE TESTER USING
A RANGE OF INDUSTRIAL MATERIALS**

Dustiness test No. 1

Material: 1 Animal Feed

Temp: 19°C: Humidity: 41%

All masses in g.		Run 1		Run 2		Run 3		Mean value of three runs ± standard deviation
		Test	Control	Test	Control	Test	Control	
30 ppi Foam	After	16.687	12.970	15.938	15.843	16.542	14.643	0.342 ± 0.017
	Before	16.322	12.966	15.601	15.843	16.213	14.642	
	Difference	.365	.004	.337	0	.329	.001	
	Mass of dust	0.361		0.337		0.328		
90 ppi Foam	After	12.812	12.340	12.990	12.684	12.984	13.266	0.032 ± 0.004
	Before	12.783	12.341	12.960	12.684	12.954	13.273	
	Difference	.029	-.001	.030	0	.030	-.007	
	Mass of dust	0.030		0.030		0.037		
Filter	After	.32971		.32694		.32866		.00009 ± 0.0002
	Before	.32964		.32686		.32854		
	Mass of dust	.00007		0.00008		0.00012		

ANIMAL FEED										
MATERIAL 2	Control foam mass (mg)			Test foam mass (mg)			Dust mass (mg)			
Foam porosity (ppi)	Before	After	Difference	Before	After	Difference	Mass collected	Mean mass	Standard deviation	
30	16322.9	16325.89	2.99	16141.27	16313.15	171.88	169.38	209.53	40.71	
30	15544.42	15545.61	1.19	14445.27	14656.19	210.92	208.42			
30	15504.26	15504.94	0.68	15857.53	16110.81	253.28	250.78			
30	14419.36	14423.23	3.87							
30	16162.83	16166.6	3.77							
90	12724.6	12730.13	5.53	12334.86	12381.8	46.94	43.438	59.55	14.68	
90	12298.71	12302.67	3.96	12486.14	12552.71	66.57	63.068			
90	12433.84	12437.04	3.2	13644.19	13719.85	75.66	72.158			
90	12775.68	12779.28	3.6							
90	14117.49	14118.71	1.22							
Date	22 Jan 1993	23 Jan 1993								
Temperature (deg C)	17.2	12.3								
Rh (%)	62	62								
Filter										
				327.04	330.91	3.87		4.65	0.77	
				330.37	335.04	4.67				
				328.66	334.06	5.40				

Dustiness test No. 2

Material: 2 Animal Feed

Temp: 19.4°C: Humidity: 41%

All masses in g		Run 1		Run 2		Run 3		Mean value of three runs ± standard deviation
		Test	Control	Test	Control	Test	Control	
30 ppi Foam	After	16.288	15.844	14.619	14.644	16.071	15.844	0.225 ±0.003
	Before	16.080	15.837	14.406	14.646	15.812	15.843	
	Difference	.208	.007	.213	-.002	.259	.001	
	Mass of dust	0.201		0.215		0.258		
90 ppi Foam	After	12.349	12.680	12.518	12.332	13.627	13.266	0.067 ±0.014
	Before	12.295	12.678	12.447	12.340	13.566	13.273	
	Difference	.054	.002	.071	-.008	.061	-.007	
	Mass of dust	0.052		0.079		0.068		
Filter	After	.33021		.33504		.33406		0.00465 ±0.00077
	Before	.32704		.33037		.32866		
	Mass of dust	.00387		.00467		.00540		

REPEAT OF TEST 2 ANIMAL FEED										
MATERIAL 2	Control foam mass (mg)			Test foam mass (mg)			Dust mass (mg)			
Foam porosity (ppi)	Before	After	Difference	Before	After	Difference	Mass collected	Mean mass	Standard deviation	
30.00	16280.09	16303.57	23.48	16068.61	16521.86	453.25	428.10	387.49	38.14	
30.00	15499.01	15523.67	24.66	16262.31	16669.39	407.08	381.93			
30.00	15455.89	15480.22	24.33	16179.95	16557.52	377.57	352.42			
30.00	14379.05	14403.39	24.34							
30.00	16113.57	16142.50	28.93							
90.00	12686.25	12710.57	24.32	11925.79	12030.28	104.49	79.21	75.37	6.04	
90.00	12261.89	12283.46	21.57	13208.78	13312.55	103.77	78.49			
90.00	12395.79	12416.57	20.78	12778.68	12872.37	93.69	68.41			
90.00	12736.01	12759.89	23.88							
90.00	14047.29	14083.12	35.83							
Date	5 Feb 1993	6 Feb 1993								
Temperature (deg C)	16.7	11.5								
Rh (%)	51	57								
Filter										
				332.41	338.41	6.00		6.79	0.72	
				332.49	339.89	7.40				
				326.94	333.90	6.96				

Dustiness test No. 25

Material: Animal Feed (Repeat of Test 2

Temp: 19.2°C: Humidity: 38%

All masses in g		Run 1		Run 2		Run 3		Mean value of three runs ± standard deviation
		Test	Control	Test	Control	Test	Control	
30 ppi Foam	After	16.505	15.590	16.652	15.319	16.546	15.145	0.413 ±0.034
	Before	16.054	15.588	16.246	15.320	16.161	15.142	
	Difference	.451	+.002	.406	-.001	.385	.003	
	Mass of dust	0.449		.407		.382		
90 ppi Foam	After	12.004	12.327	13.282	11.856	12.849	12.724	0.092 ±0.005
	Before	11.915	12.329	13.192	11.863	12.764	12.726	
	Difference	.089	-0.002	.090	-0.007	.085	-0.002	
	Mass of dust	0.091		0.097		0.087		
Filter	After	.33841		.33989		.33390		0.00679 ±0.00072
	Before	.33241		.33249		.32694		
	Mass of dust	.00600		.00740		.00696		

ANIMAL FEED										
MATERIAL 3	Control foams mass (mg)					Test foams mass (mg)			Dust mass (mg)	
Foam porosity (ppi)	Before	After	Difference	Before	After	Difference	Mass collected	Mean mass	Standard deviation	
30	16322.9	16325.89	2.99	16402.46	19641.27	3238.81	3236.31	3173.99	77.55	
30	15544.42	15545.61	1.19	15837.01	19038.04	3201.03	3198.53			
30	15504.26	15504.94	0.68	16719.83	19809.47	3089.64	3087.14			
30	14419.36	14423.23	3.87							
30	16162.83	16166.6	3.77							
90	12724.6	12730.13	5.53	12938.2	13126.99	188.79	185.29	184.06	1.86	
90	12298.71	12302.67	3.96	12927.52	13112.94	185.42	181.92			
90	12433.84	12437.04	3.2	12335.83	12524.3	188.47	184.97			
90	12775.68	12779.28	3.6							
90	14117.49	14118.71	1.22							
Date	22 Jan 1993	23 Jan 1993								
Temperature (deg C)	17.2	12.3								
Rh (%)	62	62								
			Filter			326.68	337.73	11.05	11.19	0.21
						330.28	341.36	11.08		
						326.71	338.14	11.43		

Dustiness test No. 3

Material: 3 Animal Feed

Temp: 19°C: Humidity: 42%

All masses in g		Run 1		Run 2		Run 3		Mean value of three runs ± standard deviation
		Test	Control	Test	Control	Test	Control	
30 ppi Foam	After	19.582	12.969	18.983	14.643	19.757	15.842	3.184 ±0.074
	Before	16.338	12.978	15.772	14.641	16.654	15.840	
	Difference	3.244	.001	3.211	.002	3.103	.002	
	Mass of dust	3.243		3.209		3.101		
90 ppi Foam	After	13.080	12.334	13.064	12.681	12.479	13.263	0.193 ±0.006
	Before	12.892	12.334	12.873	12.681	12.287	13.270	
	Difference	.188	0	.191	0	.192	-.007	
	Mass of dust	0.188		0.191		0.199		
Filter	After	.33773		.34136		.33814		0.01119 ±0.00021
	Before	.32668		.33028		.32671		
	Mass of dust	.01105		.01108		.01143		

GRANULES											
MATERIAL 4	Control foams mass (mg)					Test foams (mg)			Dust mass (mg)		
Foam porosity (ppi)	Before	After	Difference	Before	After	Difference	Mass collected	Mean mass	Standard deviation		
30.00	16322.90	16325.89	2.99	15750.56	15744.47	-6.09	-8.59	-0.16	8.26		
30.00	15544.42	15545.61	1.19	16009.70	16020.12	10.42	7.92				
30.00	15504.26	15504.94	0.68	15886.24	15888.93	2.69	0.19				
30.00	14419.36	14423.23	3.87								
30.00	16162.83	16166.60	3.77								
90.00	12724.60	12730.13	5.53	12686.48	12701.10	14.62	11.12	6.93	3.64		
90.00	12298.71	12302.67	3.96	12599.21	12607.81	8.60	5.10				
90.00	12433.84	12437.04	3.20	13185.19	13193.26	8.07	4.57				
90.00	12775.68	12779.28	3.60								
90.00	14117.49	14118.71	1.22								
Date	22 Jan 1993	23 Jan 1993									
Temperature (deg C)	17.2	12.3									
Rh (%)	62	62									
			Filter								
			327.44					327.46	0.02	0.02	0.0
			328.13					328.15	0.02	0.02	
			325.03					325.06	0.02	0.02	

Dustiness test No. 4

Material: 4 Hard Granular Beads

Temp: 19.4°C: Humidity: 42%

All masses in g		Run 1		Run 2		Run 3		Mean value of three runs ± standard deviation
		Test	Control	Test	Control	Test	Control	
30 ppi Foam	After	15.671	12.966	15.937	14.634	15.809	15.834	-0.005 ± 0.001
	Before	15.677	12.966	15.951	14.643	15.817	15.837	
	Difference	-.006	0	-.014	-.009	-.008	-.003	
	Mass of dust	-0.006		-0.005		-0.005		
90 ppi Foam	After	12.635	13.264	12.539	13.256	13.127	12.326	-0.005 ± 0.006
	Before	12.646	13.264	12.551	13.267	13.133	12.334	
	Difference	-.011	0	-.012	-.011	-.010	-.008	
	Mass of dust	-0.011		-0.001		-0.002		
Filter	After	.32746		.32815		.32506		0.00002 ± 0.00001
	Before	.32744		.32813		.32503		
	Mass of dust	+ 0.00002		+.00002		+.00003		

YELLOW BEADS WEIGHINGS ARE FOR GLASS FIBRE FILTERS									
MATERIAL 4	Control foam mass (mg)			Test foam mass (mg)			Dust mass (mg)		
Foam porosity (ppi)	Before	After	Difference	Before	After	Difference	Mass collected	Mean mass	Standard deviation
	Filter 1	327.08	327.20	0.12	328.37	328.79	0.42	0.35	0.27
	Filter 2	326.80	326.86	0.06	325.40	325.69	0.29	0.22	
	Filter 3	330.61	330.64	0.03	327.29	327.60	0.31	0.24	
Date	8 Feb 1993	8 Feb 1993							
Temperature (deg C)	17.7	15.3							
Rh (%)	65	62							

Dustiness test No. 30

Material: Yellow Beads

Temp: 19.7°C: Humidity: 53%

All masses in g		Run 1		Run 2		Run 3		Mean value of three runs ± standard deviation
		Test	Control	Test	Control	Test	Control	
Filter	After	.32868	.32713	.32560	.32682	.32741	.33059	0.00011 ± 0.00008
	Before	.32866	.32715	.32540	.32682	.32732	.33058	
	Difference	.00002	-.00002	.00020	0	.00009	.00001	
	Mass of dust	.00004		.00020		.00008		

MOIST PEAT											
MATERIAL 5	Control foam mass (mg)						Test foam (mg)			Dust mass (mg)	
Foam porosity (ppi)	Before	After	Difference	Before	After	Difference	Mass collected	Mean mass	Standard deviation		
30.00	16278.10	16326.97	48.87	15581.99	15633.75	51.76	5.30	7.50	4.94		
30.00	15498.20	15543.94	45.74	15850.21	15909.83	59.62	13.16				
30.00	15457.38	15503.04	45.66	14654.21	14704.73	50.52	4.06				
30.00	14377.00	14419.75	42.75								
30.00	16114.85	16164.15	49.30								
90.00	12684.44	12724.76	40.32	12696.46	12748.01	51.55	6.51	3.00	4.61		
90.00	12262.25	12301.53	39.28	13281.06	13330.81	49.75	4.71				
90.00	12396.24	12438.26	42.02	11450.61	11493.43	42.82	-2.22				
90.00	12734.83	12775.12	40.29								
90.00	14050.05	14113.32	63.27								
Date	226 Jan 1993	27 Jan 1993									
Temperature (deg C)	14.3	15.6									
Rh (%)	52	63									
Filter											
					330.11	330.14	0.03	0.03	0.01		
					330.58	330.61	0.03				
					329.08	329.12	0.04				

Dustiness test No. 5

Material: 5 Moist Peat

Temp: 17.8°C Humidity: 34%

All masses in g		Run 1		Run 2		Run 3		Mean value of three runs ± standard deviation
		Test	Control	Test	Control	Test	Control	
30 ppi Foam	After	15.616	16.204	15.887	16.062	14.689	15.309	0.062 ±0.004
	Before	15.546	16.192	15.817	16.058	14.618	15.300	
	Difference	.070	.012	.070	.004	.071	.009	
	Mass of dust	0.058		0.066		0.062		
90 ppi Foam	After	12.706	12.655	13.280	13.020	11.455	12.651	0.044 ±0.004
	Before	12.664	12.654	13.244	13.027	11.417	12.661	
	Difference	.042	.001	.036	-.007	.038	-.010	
	Mass of dust	0.041		0.043		0.048		
Filter	After	.33014		.33061		.32912		0.00003 ±0.00001
	Before	.33011		.33058		.32908		
	Mass of dust	.00003		.00003		.00004		

CALCINED ALUMINA FINE WHITE POWDER										
MATERIAL 6	Control foam mass (mg)				Test foam mass (mg)			Dust mass (mg)		
Foam porosity (ppi)	Before	After	Difference		Before	After	Difference	Mass collected	Mean mass	Standard deviation
30.00	16278.10	16326.97	48.87		12977.13	13496.90	519.77	473.31	528.17	47.72
30.00	15498.20	15543.94	45.74		15429.51	16027.11	597.60	551.14		
30.00	15457.38	15503.04	45.66		15403.80	16010.33	606.53	560.07		
30.00	14377.00	14419.75	42.75							
30.00	16114.85	16164.15	49.30							
90.00	12684.44	12724.76	40.32		12708.46	12907.88	199.42	154.38	165.68	9.85
90.00	12262.25	12301.53	39.28		11836.17	12053.66	217.49	172.45		
90.00	12396.24	12438.26	42.02		12809.02	13024.25	215.23	170.19		
90.00	12734.83	12775.12	40.29							
90.00	14050.05	14113.32	63.27							
Date	226 Jan 1993	27 Jan 1993								
Temperature (deg C)	14.3	15.6								
Rh (%)	52	63								
Filter										
					326.03	346.01	19.98		21.55	1.70
					328.62	349.93	21.31			
					327.44	350.79	23.35			

Dustiness test No. 6

Material: 6 Calcined Alumina, Fine White Powder

Temp: 18°C: Humidity: 35%

All masses in g		Run 1		Run 2		Run 3		Mean value of three runs ± standard deviation
		Test	Control	Test	Control	Test	Control	
30 ppi Foam	After	13.425	16.196	15.933	16.055	15.919	15.303	0.523 ±0.040
	Before	12.948	16.196	15.398	16.062	15.369	15.303	
	Difference	.477	0	.535	-.007	.550	0	
	Mass of dust	0.477		0.542		0.550		
90 ppi Foam	After	12.829	12.700	11.980	13.023	12.952	12.654	0.178 ±0.019
	Before	12.676	12.703	11.800	13.030	12.765	12.659	
	Difference	.153	-.003	.180	-.007	.187	-.005	
	Mass of dust	0.156		0.187		0.192		
Filter	After	.34601		.34993		.35079		0.02155 ±0.0017
	Before	.32603		.32862		.32744		
	Mass of dust	.01998		.02131		.02335		

MATERIAL 7 SILICA FLOUR FINE FAWN COLOURED POWDER										
Foam porosity (ppi)	Control foam mass (mg)			Test foam mass (mg)			Dust mass (mg)		Standard deviation	
	Before	After	Difference	Before	After	Difference	Mass collected	Mean mass		
30.00	16278.10	16326.97	48.87	16000.93	16286.86	285.93	239.47	298.62	64.97	
30.00	15498.20	15543.94	45.74	15198.07	15532.78	334.71	288.25			
30.00	15457.38	15503.04	45.66	14209.33	14623.95	414.62	368.16			
30.00	14377.00	14419.75	42.75							
30.00	16114.85	16164.15	49.30							
90.00	12684.44	12724.76	40.32	12470.26	12603.38	133.12	88.08	96.12	7.37	
90.00	12262.25	12301.53	39.28	12831.30	12974.05	142.75	97.71			
90.00	12396.24	12438.26	42.02	13184.09	13331.70	147.61	102.57			
90.00	12734.83	12775.12	40.29							
90.00	14050.05	14113.32	63.27							
Date	26 Jan 1993	27 Jan 1993								
Temperature (deg C)	14.3	15.6								
Rh (%)	52	63								
Filter										
				329.48	369.75	40.27		38.63	1.54	
				327.05	364.26	37.21				
				328.26	366.66	38.40				

Dustiness test No. 7

Material: 7 Silica Flour

Temp: 18.1°C: Humidity: 37%

All masses in g		Run 1		Run 2		Run 3		Mean value of three runs ± standard deviation
		Test	Control	Test	Control	Test	Control	
30 ppi Foam	After	16.201	16.203	15.448	16.061	14.551	15.308	0.296 ±0.07
	Before	15.965	16.203	15.161	16.060	14.187	15.311	
	Difference	.236	0	.287	.001	.364	-.003	
	Mass of dust	0.236		0.286		0.367		
90 ppi Foam	After	12.539	12.707	12.901	13.031	13.262	12.664	0.095 ±0.002
	Before	12.446	12.710	12.807	13.030	13.165	12.666	
	Difference	.093	-.003	.094	.001	.097	-.002	
	Mass of dust	0.096		0.093		0.099		
Filter	After	.36975		.36426		.36666		0.03863 ±0.00154
	Before	.32948		.32705		.32826		
	Mass of dust	.04027		.03721		.03840		

GRAPHITE FINE BLACK POWDER										
MATERIAL 8	Control foam mass (mg)			Test foam mass (mg)			Dust mass (mg)			
Foam porosity (ppi)	Before	After	Difference	Before	After	Difference	Mass collected	Mean mass	Standard deviation	
30.00	16278.10	16326.97	48.87	14979.26	27181.99	12202.73	12156.27	12247.13	103.60	
30.00	15498.20	15543.94	45.74	16016.18	28287.81	12271.63	12225.17			
30.00	15457.38	15503.04	45.66	16200.77	28607.18	12406.41	12359.95			
30.00	14377.00	14419.75	42.75							
30.00	16114.85	16164.15	49.30							
90.00	12684.44	12724.76	40.32	12781.08	13285.64	504.56	459.52	471.96	28.47	
90.00	12262.25	12301.53	39.28	12757.43	13306.99	549.56	504.52			
90.00	12396.24	12438.26	42.02	12457.90	12954.76	496.86	451.82			
90.00	12734.83	12775.12	40.29							
90.00	14050.05	14113.32	63.27							
Date	26 Jan 1993	27 Jan 1993								
Temperature (deg C)	14.3	15.6								
Rh (%)	52	63								
Filter								32.59	5.95	

Dustiness test No. 8

Material: 8 Graphite

Temp: 18.8°C: Humidity: 40%

All masses in g		Run 1		Run 2		Run 3		Mean value of three runs ± standard deviation
		Test	Control	Test	Control	Test	Control	
30 ppi Foam	After	27.100	16.209	28.206	16.075	28.531	15.315	12.271 ±0.17
	Before	14.955	16.214	16.010	16.079	16.195	15.323	
	Difference	12.145	-.005	12.199	-.005	12.452	-.008	
	Mass of dust	12.150		12.203		12.460		
90 ppi Foam	After	13.217	12.710	13.210	12.714	12.894	12.718	0.460 ±0.018
	Before	12.761	12.716	12.741	12.721	12.459	12.724	
	Difference	.456	-.006	.469	-.007	.435	-.006	
	Mass of dust	0.462		0.476		0.441		
Filter	After	.35789		.35750		.36704*		0.03259 ±0.00595
	Before	.32914		.32792		.32760		
	Mass of dust	.02875		0.02958		0.03944		

NEPHELINE SYENITE WHITE POWDER											
MATERIAL 9	Control foam mass (mg)				Test foam mass (mg)			Dust mass (mg)			
Foam porosity (ppi)	Before	After	Difference		Before	After	Difference	Mass collected	Mean mass	Standard deviation	
30	16328.49	16331.72	3.23		16121.44	16554.34	432.9	432.50	356.94	112.08	
30	15545.17	15545.12	-0.05		16157.94	16568.49	410.55	410.15			
30	15503.8	15504.42	0.62		15757.78	15986.34	228.56	228.16			
30	14421.52	14419.2	-2.32								
30	16164.08	16164.58	0.5								
90	12726.82	12727.39	0.57		11511.39	11579.77	68.38	66.27	64.70	21.26	
90	12302.51	12302.4	-0.11		13061.08	13148.33	87.25	85.14			
90	12436.12	12439.81	3.69		12869.08	12913.89	44.81	42.7			
90	12776.49	12777.38	0.89								
90	14113.45	14118.96	5.51								
Date	28 Jan 1993	29 Jan 1993									
Temperature (deg C)	16.9	16.7									
Rh (%)	63	62									
Filter											
					331.71	361.18	29.37		26.25	2.70	
					332.79	357.38	24.59				
					330.06	354.85	24.79				

Dustiness test No. 9

Material: 9 Nepheiline Syenite White Powder

Temp: 19.4°C: Humidity: 48%

All masses in g		Run 1		Run 2		Run 3		Mean value of three runs ± standard deviation
		Test	Control	Test	Control	Test	Control	
30 ppi Foam	After	26.504	15.172	16.520	15.619	15.941	15.347	0.344 ±.105
	Before	16.091	15.176	16.125	15.619	15.721	15.350	
	Difference	0.413	-.004	0.395	0	0.220	-0.003	
	Mass of dust	0.415		0.393		0.223		
90 ppi Foam	After	11.539	12.356	13.113	12.752	12.877	11.890	0.061 ±0.006
	Before	11.471	12.356	13.055	12.752	12.822	11.892	
	Difference	0.068	0	0.058	0	0.055	-0.002	
	Mass of dust	0.068		0.058		0.057		
Filter	After	.36118		.35738		.35485		0.02625 ±0.0027
	Before	.33171		.33279		.33006		
	Mass of dust	0.02937		0.02459		0.02479		

NEPHELINE SYENITE: GLASS FIBRE FILTER IN FRONT OF 90 PPI FOAM											
MATERIAL 9	Control foam mass (mg)						Test foam mass (mg)			Dust mass (mg)	
Foam porosity (ppi)	Before	After	Difference	Before	After	Difference	Mass collected	Mean mass	Standard deviation		
30.00	16320.87	16284.41	-36.46	15788.07	16063.87	275.80	309.84	478.73	147.61		
30.00	15536.80	15502.07	-34.73	15276.90	15786.08	509.18	543.22				
30.00	15493.60	15459.67	-33.93	16315.77	16864.84	549.07	583.11				
30.00	14414.91	14384.56	-30.35								
30.00	16155.13	16120.38	-34.75								
Date	9 Feb 1993	11 Feb 1993									
Temperature (deg C)	16.6	15.0									
Rh (%)	61	54									
Filter 1	1358.58	1358.55	-0.03	1340.81	1447.81	107.00	106.91	111.96	7.24		
Filter 2	1354.60	1354.81	0.21	1345.67	1454.47	108.80	108.71				
Filter 3	1361.15	1361.24	0.09	1357.16	1477.51	120.35	120.26				

Dustiness test No. 31

Material: Nepheline Syenite

Temp: 19.6°C: Humidity: 39%

All masses in g		Run 1		Run 2		Run 3		Mean value of three runs ± standard deviation
		Test	Control	Test	Control	Test	Control	
30 ppi Foam	After	16.035	15.331	15.759	15.552	16.842	15.596	0.445 ±0.143
	Before	15.752	15.330	15.252	15.550	16.295	15.597	
	Difference	.283	.001	.507	0.002	.547	-0.001	
	Mass of dust	0.282		0.505		0.548		
Filter	After	1.441	1.352	1.450	1.352	1.471	1.352	0.113 ±0.004
	Before	1.332	1.352	1.340	1.355	1.353	1.351	
	Difference	.109	0	.110	-0.003	.118	0.001	
	Mass of dust	0.109		0.113		0.117		

TALC WHITE POWDER										
MATERIAL 10	Control foam mass (mg)			Test foam mass (mg)			Dust mass (mg)			
Foam porosity (ppi)	Before	After	Difference	Before	After	Difference	Mass collected	Mean mass	Standard deviation	
30.00	16328.49	16331.72	3.23	15182.81	--	--	--	7602.30	385.09	
30.00	15545.17	15545.12	-0.05	15278.79	22609.19	7330.40	7330.00			
30.00	15503.80	15504.42	0.62	15797.43	23672.43	7875.00	7874.60			
30.00	14421.52	14419.20	-2.32							
30.00	16164.08	16164.58	0.50							
90.00	12726.82	12727.39	0.57	12424.05	12947.36	523.31	521.20	522.05	15.20	
90.00	12302.51	12302.40	-0.11	12698.47	13238.24	539.77	537.66			
90.00	12436.12	12439.81	3.69	12727.15	13236.56	509.41	507.30			
90.00	12776.49	12777.38	0.89							
90.00	14113.45	14118.96	5.51							
Date	28 Jan 1993	29 Jan 1993								
Temperature (deg C)	16.9	16.7								
Rh (%)	63	62								
			Filter					23.52	0.11	

Dustiness test No. 10

Material: 10 Talc White Powder

Temp: 20°C: Humidity: 50%

All masses in g		Run 1		Run 2		Run 3		Mean value of three runs ± standard deviation
		Test	Control	Test	Control	Test	Control	
30 ppi Foam	After	22.813*	15.173	22.561	15.614	23.625	15.342	7.655 ±0.282
	Before	15.148	15.175	15.222	15.618	15.763	15.344	
	Difference	7.765	-0.002	7.339	0.004	7.862	-0.002	
	Mass of dust	7.767		7.335		7.864		
90 ppi Foam	After	12.904	12.355	13.206	12.748	13.202	11.891	0.515 ±0.015
	Before	12.391	12.355	12.676	12.750	12.700	11.891	
	Difference	0.513	0	0.530	-0.002	0.502	0	
	Mass of dust	0.513		0.532		0.502		
Filter	After	.35320		.35490		.35582		0.02352 ±0.00011
	Before	.33034		.33219		.33230		
	Mass of dust	0.02286		0.02271		0.02352		

* 30 ppi foam test 1 sample lost

TALC FINE WHITE POWDER REPEAT OF TEST 10										
MATERIAL 10	Control foam mass (mg)				Test foam mass (mg)			Dust mass (mg)		
Foam porosity (ppi)	Before	After	Difference	Before	After	Difference	Mass collected	Mean mass	Standard deviation	
30	16299.74	16277.17	-22.57	15629.26	23619.56	7990.3	8010.05	7565.12	423.32	
30	15516.2	15497.13	-19.07	15176.84	22324.46	7147.62	7167.37			
30	15472.68	15451.92	-20.76	14640.24	22138.42	7498.18	7517.93			
30	14394.41	14377.6	-16.81							
30	16132.66	16113.1	-19.56							
90	12701.15	12683.63	-17.52	12577.28	13101.24	523.96	544.03	650.26	169.18	
90	12276.86	12259.34	-17.52	13094.66	13635.98	541.32	561.39			
90	12411.44	12392.83	-18.61	12721.46	13546.75	825.29	845.36			
90	12751.88	12733.2	-18.68							
90	14073.28	14045.25	-28.03							
Date	4 Feb 1993	5 Feb 1993								
Temperature (deg C)	15.6	15.1								
Rh (%)	57	52								
			Filter			333.32	356.44	23.12	22.99	0.21
						328.42	351.52	23.10		
						331.12	353.86	22.74		

Dustiness test No. 24

Material: Talc - Repeat of Test 10

Temp: 19.5°C: Humidity: 39%

All masses in g		Run 1		Run 2		Run 3		Mean value of three runs ± standard deviation
		Test	Control	Test	Control	Test	Control	
30 ppi Foam	After	23.597	15.315	22.298	15.142	22.119	15.593	7.561 ±0.429
	Before	15.588	15.319	15.140	15.144	14.609	15.593	
	Difference	8.009	-0.004	7.158	-0.002	7.510	0.000	
	Mass of dust	8.013		7.150		7.510		
90 ppi Foam	After	13.085	11.857	13.612	12.724	13.528	12.333	0.649 ±0.166
	Before	12.541	11.859	13.056	12.729	12.689	12.334	
	Difference	0.544	-0.002	0.556	-0.005	0.839	-0.001	
	Mass of dust	0.546		0.561		0.840		
Filter	After	.35644		.35152		.35386		0.02299 ±0.00021
	Before	.33332		.32842		.33112		
	Mass of dust	0.02312		0.02310		0.02274		

PLASTER WHITE POWDER										
MATERIAL 11	Control foam mass (mg)				Test foam mass (mg)				Dust mass (mg)	
Foam porosity (ppi)	Before	After	Difference	Before	After	Difference	Mass collected	Mean mass	Standard deviation	
	30.00	16328.49	16331.72	3.23	16331.63	16477.58	145.95	139.92	6.77	
	30.00	15545.17	15545.12	-0.05	16041.89	16174.70	132.81			
	30.00	15503.80	15504.42	0.62	15591.82	15734.02	141.80			
	30.00	14421.52	14419.20	-2.32						
30.00	16164.08	16164.58	0.50							
90.00	12726.82	12727.39	0.57	13213.80	13249.40	35.60	33.49	28.80	10.92	
90.00	12302.51	12302.40	-0.11	12515.12	12553.82	38.70	36.59			
90.00	12436.12	12439.81	3.69	12852.66	12871.09	18.43	16.32			
90.00	12776.49	12777.38	0.89							
90.00	14113.45	14118.96	5.51							
Date	28 Jan 1993	29 Jan 1993								
Temperature (deg C)	16.9	16.7								
Rh (%)	63	62								
Filter			329.09	340.05	10.96	11.19		0.94		
			329.70	340.09	10.39					
			329.84	342.07	12.23					

Dustiness test No. 11

Material: 11 Plaster White Powder

Temp: °C: Humidity:

All masses in g		Run 1		Run 2		Run 3		Mean value of three runs ± standard deviation
		Test	Control	Test	Control	Test	Control	
30 ppi Foam	After	16.416	15.174	16.110	15.618	15.670	15.346	0.114 ±0.011
	Before	16.296	15.180	16.009	15.621	15.561	15.350	
	Difference	0.120	-0.006	0.101	-0.003	0.109	-0.004	
	Mass of dust	0.126		-0.104		0.113		
90 ppi Foam	After	13.203	12.352	12.503	12.749	12.830	12.749	0.028 ±0.005
	Before	13.187	12.358	12.488	12.754	12.812	12.752	
	Difference	0.016	-0.006	0.025	-0.005	0.028	-0.003	
	Mass of dust	0.022		0.030		0.031		
Filter	After	.34005		.34009		.34207		0.01119 ±0.00094
	Before	.32909		.32970		.32984		
	Mass of dust	.01096		0.01039		0.01223		

PLASTER: GLASS FIBRE FILTER IN FRON OF 90 PPI FOAM										
MATERIAL 11	Control foam mass (mg)			Test foam mass (mg)			Dust mass (mg)			
Foam porosity (ppi)	Before	After	Difference	Before	After	Difference	Mass collected	Mean mass	Standard deviation	
30.00	16320.87	16284.41	-36.46	16011.48	16151.53	140.05	174.09	192.21	25.51	
30.00	15536.80	15502.07	-34.73	15604.80	15792.14	187.34	221.38			
30.00	15493.60	15459.67	-33.93	15582.26	15729.38	147.12	181.16			
30.00	14414.91	14384.56	-30.35							
30.00	16155.13	16120.38	-34.75							
Date	9 Feb 1993	11 Feb 1993								
Temperature (deg C)	16.6	15.0								
Rh (%)	61	54								
Filter 1	1358.58	1358.55	-0.03	1350.26	1410.91	60.65	59.63	60.66	1.92	
Filter 2	1354.60	1354.81	0.21	1355.29	1415.78	60.49	59.47			
Filter 3	1361.15	1361.24	0.09	1356.09	1419.98	63.89	62.87			

MATERIAL 13		CENTRIMEX COARSE WHITE POWDER									
Foam porosity (ppi)	Control foam mass (mg)			Test foam mass (mg)			Dust mass (mg)				
	Before	After	Difference	Before	After	Difference	Mass collected	Mean mass	Standard deviation		
30.00	16324.16	16314.53	-9.63	15211.54	16208.76	997.22	1007.03	844.93	145.05		
30.00	15543.62	15533.95	-9.67	15960.85	16751.45	790.60	800.41				
30.00	15503.86	15492.57	-11.29	15656.08	16373.63	717.55	727.36				
30.00	14419.64	14412.22	-7.42								
30.00	16164.55	16153.51	-11.04								
90.00	12724.41	12719.48	-4.93	12755.74	13033.44	277.70	285.46	248.96	31.97		
90.00	12297.95	12291.45	-6.50	12868.97	13096.68	227.71	235.47				
90.00	12433.44	12425.96	-7.48	12959.32	13177.49	218.17	225.93				
90.00	12777.11	12768.99	-8.12								
90.00	14110.83	14099.04	-11.79								
Date	29 Jan 1993	30 Jan 1993									
Temperature (deg C)	18.4	12.9									
Rh (%)	60	60									
Filter											
				327.61	360.79	33.17	31.27		1.70		
				328.15	358.85	30.71					
				328.97	358.99	29.92					

Dustiness test No. 12

Material: 12 Yellow Powder (100 g Sample) Sulphur

Temp: 19.3°C Humidity: 50%

All masses in g		Run 1		Run 2		Run 3		Mean value of three runs ± standard deviation
		Test	Control	Test	Control	Test	Control	
30 ppi Foam	After	28.662	15.342	28.632	15.174	28.476	15.622	12.630 ±0.316
	Before	16.329	15.347	15.667	15.174	15.688	15.622	
	Difference	12.333	-0.005	12.965	0	12.588	0	
	Mass of dust	12.338		12.965		12.588		
90 ppi Foam	After	13.741	12.747	14.248	11.894	13.983	12.754	1.352 ±0.05
	Before	12.432	12.752	12.839	11.894	12.651	12.755	
	Difference	1.309	-0.005	1.409	0	1.332	-0.001	
	Mass of dust	1.319		1.409		1.332		
Filter	After	.44369		.43814		.44211		0.11301 ±0.00121
	Before	.33013		.32651		.32826		
	Mass of dust	0.11356		0.11163		0.11385		

MATERIAL 12		YELLOW POWDER									
Foam porosity (ppi)	Control foam mass (mg)			Test foam mass (mg)			Dust mass (mg)				
	Before	After	Difference	Before	After	Difference	Mass collected	Mean mass	Standard deviation		
30.00	16328.49	16332.59	4.10	16366.26	28674.16	12307.90	12305.05	12667.25	320.77		
30.00	15545.17	15547.08	1.91	15704.69	28622.97	12918.28	12915.43				
30.00	15503.80	15506.28	2.48	15723.80	28507.94	12784.14	12781.29				
30.00	14421.52	14424.24	2.72								
30.00	16164.08	16167.14	3.06								
90.00	12726.82	12729.50	2.68	12469.45	13768.82	1299.37	1296.47	1341.27	53.80		
90.00	12302.51	12303.61	1.10	12874.65	14278.49	1403.84	1400.94				
90.00	12436.12	12439.17	3.05	12686.36	14015.67	1329.31	1326.41				
90.00	12776.49	12780.23	3.74								
90.00	14113.45	14117.38	3.93								
Date	28 Jan 1993	29 Jan 1993									
Temperature (deg C)	16.7	17.4									
Rh (%)	62	63									
Filter											
				330.13	443.69	113.56		113.01	1.21		
				326.51	438.17	111.63					
				328.26	442.11	113.85					

Dustiness test No. 32

Material: Plaster

Temp: 19.8°C: Humidity: 38%

All masses in g		Run 1		Run 2		Run 3		Mean value of three runs ± standard deviation
		Test	Control	Test	Control	Test	Control	
30 ppi Foam	After	16.118	15.328	15.751	15.552	15.686	15.588	0.161 ±0.024
	Before	15.967	15.333	15.566	15.551	15.546	15.590	
	Difference	.151	-0.005	.185	0.001	.137	-0.002	
	Mass of dust	0.157		0.186		0.139		
Filter	After	1.405	1.352	1.411	1.353	1.416	1.356	0.062 ±0.002
	Before	1.343	1.352	1.351	1.353	1.352	1.355	
	Difference	.062	0	.060	0	.064	0.001	
	Mass of dust	0.062		0.060		0.063		

Dustiness test No. 13

Material: 13 Centrimex Coarse White Powder

Temp: 19.7°C: Humidity: 52%

All masses in g		Run 1		Run 2		Run 3		Mean value of three runs ± standard deviation
		Test	Control	Test	Control	Test	Control	
30 ppi Foam	After	16.158	15.356	16.703	15.181	16.322	15.622	0.809 ±0.139
	Before	15.204	15.362	15.948	15.189	15.635	15.626	
	Difference	.954	-0.006	.755	-0.007	.687	-0.004	
	Mass of dust	0.960		0.762		0.691		
90 ppi Foam	After	13.000	12.364	13.060	11.896	13.140	12.754	0.227 ±0.031
	Before	12.744	12.370	12.851	11.898	12.936	12.757	
	Difference	.256	-0.006	.209	-0.002	.204	-0.003	
	Mass of dust	0.262		0.211		0.207		
Filter	After	.36079		.35886		.35899		0.03127 ±0.00170
	Before	.32761		.32815		.32897		
	Mass of dust	.03317		0.03071		0.02992		

100g used										
MATERIAL 14		Control foam mass (mg)			Test foam mass (mg)			Dust mass (mg)		
Foam porosity (ppi)		Before	After	Difference	Before	After	Difference	Mass collected	Mean mass	Standard deviation
30.00		16317.70	16309.32	-8.38	15385.90	29338.89	13952.99	13961.77	14649.67	645.27
30.00		15536.30	15527.88	-8.42	14990.20	30222.97	15232.77	15241.55		
30.00		15495.29	15486.33	-8.96	14503.04	29239.95	14736.91	14745.69		
30.00		14414.92	14406.00	-8.92						
30.00		16156.51	16147.29	-9.22						
90.00		12722.08	12711.06	-11.02	12783.08	14250.43	1467.35	1477.08	1585.51	148.82
90.00		12294.22	12286.29	-7.93	12128.08	13873.53	1745.45	1755.18		
90.00		12428.02	12419.54	-8.48	12569.47	14084.02	1514.55	1524.28		
90.00		12771.90	12761.99	-9.91						
90.00		14102.09	14090.80	-11.29						
Date		30 Jan 1993	1 Feb 1993							
Temperature (deg C)		12.9	14.7							
Rh (%)		60	61							
		Filter				333.31	439.23	105.92	110.68	3.47
						334.08	445.34	111.26		
						333.03	446.79	113.76		

Dustiness test No. 14

100 g in Drum

Material: 14 Centrimex Fine White Powder

Temp: 19.6°C: Humidity: 48%

All masses in g		Run 1		Run 2		Run 3		Mean value of three runs ± standard deviation
		Test	Control	Test	Control	Test	Control	
30 ppi Foam	After	29.320	15.605	30.234	15.341	29.236	15.168	14.678 ±0.652
	Before	15.354	15.615	14.961	15.349	14.471	15.171	
	Difference	13.976	-0.010	15.273	-0.008	14.765	-0.003	
	Mass of dust	13.986		15.281		14.768		
90 ppi Foam	After	14.227	11.883	13.848	12.743	14.055	12.350	1.581 ±0.150
	Before	12.755	11.890	12.102	12.750	12.543	12.358	
	Difference	1.472	-0.007	1.746	0.007	1.512	-0.008	
	Mass of dust	1.479		1.753		1.520		
Filter	After	43923		.44534		.44679		0.11068 ±0.0037
	Before	33331		.33408		.33303		
	Mass of dust	0.10592		0.11126		0.11376		

100 g IN DRUM REPEAT OF TEST 14 CENTRIMEX FINE WHITE POWDER										
MATERIAL 14	Control foam mass (mg)			Test foam mass (mg)			Dust mass (mg)			
Foam porosity (ppi)	Before	After	Difference	Before	After	Difference	Mass collected	Mean mass	Standard deviation	
30.00	16280.09	16303.57	23.48	15903.85	28821.56	12917.71	12892.56	12717.30	271.51	
30.00	15499.01	15523.67	24.66	15747.09	28627.02	12879.93	12854.78			
30.00	15455.89	15480.22	24.33	15765.09	28194.78	12429.69	12404.54			
30.00	14379.05	14403.39	24.34							
30.00	16113.57	16142.50	28.93							
90.00	12686.25	12710.57	24.32	12513.55	13833.76	1320.21	1294.93	1242.14	66.27	
90.00	12261.89	12283.46	21.57	12787.49	14076.49	1289.00	1263.72			
90.00	12395.79	12416.57	20.78	12789.06	13982.11	1193.05	1167.77			
90.00	12736.01	12759.89	23.88							
90.00	14047.29	14083.12	35.83							
Date	5 Feb 1993	6 Feb 1993								
Temperature (deg C)	16.7	11.5								
Rh (%)	51	57								
Filter					328.65	394.95	66.30	82.86	15.60	
					329.26	416.31	97.05			
					333.64	418.87	85.23			

CALCIUM STERATE WHITE SOFT STICKY POWDER										
MATERIAL 15										
Foam porosity (ppi)	Control foam mass (mg)			Test foam mass (mg)			Dust mass (mg)		Standard deviation	
	Before	After	Difference	Before	After	Difference	Mass collected	Mean mass		
30.00	16317.70	16309.32	-8.38	15966.04	19777.92	3811.88	3820.66	2832.57	861.56	
30.00	15536.30	15527.88	-8.42	15395.97	17625.50	2229.53	2238.31			
30.00	15495.29	15486.33	-8.96	16507.56	18937.52	2429.96	2438.74			
30.00	14414.92	14406.00	-8.92							
30.00	16156.51	16147.29	-9.22							
90.00	12722.08	12711.06	-11.02	12561.24	12832.08	270.84	280.57	213.61	58.00	
90.00	12294.22	12286.29	-7.93	12692.31	12861.39	169.08	178.81			
90.00	12428.02	12419.54	-8.48	12754.94	12926.68	171.74	181.47			
90.00	12771.90	12761.99	-9.91							
90.00	14102.09	14090.80	-11.29							
Date	30 Jan 1993	1 Feb 1993								
Temperature (deg C)	12.9	14.7								
Rh (%)	60	61								
Filter										
				335.27	351.80	16.53	14.47	1.80		
				329.99	343.64	13.65				
				330.74	343.96	13.22				

Dustiness test No. 15

Material: 15 Calcium Sterate, Soft White Sticky Powder

Temp: 19.5°C: Humidity: 46%

All masses in g		Run 1		Run 2		Run 3		Mean value of three runs ± standard deviation
		Test	Control	Test	Control	Test	Control	
30 ppi Foam	After	19.738	15.605	17.577	15.333	18.888	15.158	2.823 ±0.870
	Before	15.926	15.613	15.359	15.334	16.464	15.163	
	Difference	3.812	-0.008	2.218	-0.001	2.424	-0.005	
	Mass of dust	3.820		2.219		2.429		
90 ppi Foam	After	12.795	11.882	12.831	12.740	12.895	12.344	0.208 ±0.051
	Before	12.530	11.884	12.657	12.743	12.720	12.349	
	Difference	0.265	-0.002	0.174	-0.003	0.175	-0.005	
	Mass of dust	0.267		0.177		0.180		
Filter	After	.35180		.34364		.34396		0.01447 ±0.00180
	Before	.33527		.32999		.33074		
	Mass of dust	0.01653		0.01365		0.01322		

CALCIUM STERATE REPEAT OF TEST 15 AND 28										
MATERIAL 15	Control foam mass (mg)					Test foam mass (mg)			Dust mass (mg)	
Foam porosity (ppi)	Before	After	Difference	Before	After	Difference	Mass collected	Mean mass	Standard deviation	
30.00	16303.57	16363.01	59.44	15902.76	17925.74	2022.98	1969.05	1725.74	454.81	
30.00	15523.67	15577.41	53.74	15642.53	16897.50	1254.97	1201.04			
30.00	15480.22	15534.24	54.02	16320.89	18381.96	2061.07	2007.14			
30.00	14403.39	14451.83	48.44							
30.00	16142.50	16196.51	54.01							
90.00	12710.57	12753.18	42.61	12769.50	12998.87	229.37	174.25	144.83	33.94	
90.00	12283.46	12329.76	46.30	12868.56	13031.37	162.81	107.69			
90.00	12416.57	12464.38	47.81	12483.76	12691.43	207.67	152.55			
90.00	12759.89	12806.38	46.49							
90.00	14083.12	14175.51	92.39							
Date	6 Feb 1993	8 Feb 1993								
Temperature (deg C)	11.5	15.4								
Rh (%)	57	69								
Filter										
			332.13	346.99	14.86	11.36	3.44			
			330.88	338.86	7.98					
			330.10	341.34	11.24					

Dustiness test No. 26

Material: Calcium Sterate (Repeat of Tests 15 and 28)

Temp: 18.6°C: Humidity: 38%

All masses in g		Run 1		Run 2		Run 3		Mean value of three runs ± standard deviation
		Test	Control	Test	Control	Test	Control	
30 ppi Foam	After	17.820	15.549	16.784	15.610	18.273	15.350	1.712 ±0.456
	Before	15.852	15.547	15.607	15.618	16.303	15.365	
	Difference	1.968	+0.002	1.177	-0.008	1.970	-0.015	
	Mass of dust	1.966		1.185		1.985		
90 ppi Foam	After	12.899	12.330	12.954	11.886	12.627	12.764	0.197 ±0.033
	Before	12.727	12.332	12.844	11.887	12.473	12.761	
	Difference	.172	-0.002	.110	-0.001	.154	+0.003	
	Mass of dust	0.174		0.111		0.157		
Filter	After	.34699		.33886		.34134		0.01136 ±0.00344
	Before	.33213		.33088		.33010		
	Mass of dust	.01486		.00798		.01124		

CALCIUM STERATE (REPEAT OF TEST 15) SOFT STICKY POWDER												
MATERIAL 15	Control foam mass (mg)			Test foam mass (mg)			Dust mass (mg)					
Foam porosity (ppi)	Before	After	Difference	Before	After	Difference	Mass collected	Mean mass	Standard deviation			
30.00	16280.09	16303.57	23.48	16058.92	18747.92	2689.00	2663.85	1625.09	899.81			
30.00	15499.01	15523.67	24.66	15826.58	16938.01	1111.43	1086.28					
30.00	15455.89	15480.22	24.33	15801.84	16952.11	1150.27	1125.12					
30.00	14379.05	14403.39	24.34									
30.00	16113.57	16142.50	28.93									
90.00	12686.25	12710.57	24.32	12883.53	13100.74	217.21	191.93	166.05	22.62			
90.00	12261.89	12283.46	21.57	13118.88	13300.30	181.42	156.14					
90.00	12395.79	12416.57	20.78	12609.17	12784.53	175.36	150.08					
90.00	12736.01	12759.89	23.88									
90.00	14047.29	14083.12	35.83									
Date	5 Feb 1993	6 Feb 1993										
Temperature (deg C)	16.7	11.5										
Rh (%)	51	57										
			Filter		332.25	345.44	13.19	11.93	0.11			
					331.44	342.64	11.20					
					327.11	338.51	11.40					

Dustiness test No. 28

Material: Calcium Sterate Soft White Sticky Powder (Repeat of Test 15)

Temp: 19.3°C: Humidity: 39%

All masses in g		Run 1		Run 2		Run 3		Mean value of three runs ± standard deviation
		Test	Control	Test	Control	Test	Control	
30 ppi Foam	After	18.683	15.587	16.875	15.322	16.884	15.541	1.607 ±0.902
	Before	16.037	15.591	15.811	15.327	15.781	15.543	
	Difference	2.646	-0.002	1.064	-0.005	1.103	-0.002	
	Mass of dust	2.648		1.069		1.104		
90 ppi Foam	After	13.046	11.862	13.244	12.725	12.727	12.331	0.151 ±0.023
	Before	12.872	11.864	13.106	12.730	12.598	12.335	
	Difference	.174	-0.002	.138	-0.005	.129	-0.004	
	Mass of dust	0.176		0.143		0.133		
Filter	After	.34544		.34264		.33851		0.01193 ±0.0011
	Before	.33225		.33144		.32711		
	Mass of dust	.01319		.01120		.01140		

CALCIUM STERATE (REPEAT OF TEST 15) SOFT STICKY POWDER										
MATERIAL 15		Control foam mass (mg)			Test foam mass (mg)			Dust mass (mg)		
Foam porosity (ppi)		Before	After	Difference	Before	After	Difference	Mass collected	Mean mass	Standard deviation
30.00		16303.57	16.36301	59.44	15171.79	17187.07	2016.28	1962.35	1704.64	277.20
30.00		15523.67	15577.41	53.74	15043.36	16839.14	1796.78	1742.85		
30.00		15480.22	15534.24	54.02	14435.82	15900.46	1464.64	1410.71		
30.00		14403.39	14451.83	48.44						
30.00		16142.50	16196.51	54.01						
90.00		12710.57	12753.18	42.61	12889.09	13139.61	250.53	195.40	181.32	25.47
90.00		12283.46	12329.76	46.30	13036.33	13243.37	217.04	161.92		
90.00		12416.57	12464.38	47.81	13306.54	13558.30	251.76	196.64		
90.00		12759.89	12808.38	46.49						
90.00		14083.12	14175.51	92.39						
Date		6 Feb 1993	8 Feb 1993							
Temperature (deg C)		11.5	15.4							
Rh (%)		57	69							
Filter				333.17	344.48	11.31	10.97		0.53	
				331.54	342.77	11.23				
				329.28	339.64	10.36				

Dustiness test No. 29

Material: Calcium Sterate

Temp: 19°C: Humidity: 54%

All masses in g		Run 1		Run 2		Run 3		Mean value of three runs ± standard deviation
		Test	Control	Test	Control	Test	Control	
30 ppi Foam	After	17.111	15.591	16.831	15.637	15.837	15.370	1.718 ±0.268
	Before	15.159	15.594	15.061	15.640	14.416	15.376	
	Difference	1.952	-0.003	1.770	-0.003	1.421	-0.006	
	Mass of dust	1.955		1.773		1.427		
90 ppi Foam	After	13.075	12.369	13.191	11.902	13.500	12.769	0.193 ±0.022
	Before	12.877	12.371	13.024	11.904	13.295	12.775	
	Difference	.198	-0.002	.167	-0.002	.205	-0.006	
	Mass of dust	0.200		0.169		0.211		
Filter	After	.34448		.34277		.33964		0.01097 ±0.00053
	Before	.33317		.33154		.32928		
	Mass of dust	.01131		.01123		0.1036		

CARBON BLACK										
MATERIAL 16	Control foam mass (mg)				Test foam mass (mg)			Dust mass (mg)		
Foam porosity (ppi)	Before	After	Difference	Before	After	Difference	Mass collected	Mean mass	Standard deviation	
30.00	16324.16	16314.53	-9.63	14833.47	15190.47	357.00	366.81	241.36	110.40	
30.00	15543.62	15533.95	-9.67	16131.51	16319.93	188.42	198.23			
30.00	15503.86	15492.57	-11.29	16049.69	16198.91	149.22	159.03			
30.00	14419.64	14412.22	-7.42							
30.00	16164.55	16153.51	-11.04							
90.00	12724.41	12719.48	-4.93	12436.09	12456.91	20.82	28.58	24.04	3.94	
90.00	12297.95	12291.45	-6.50	12814.78	12828.92	14.14	21.90			
90.00	12433.44	12425.96	-7.48	12319.14	12333.01	13.87	21.63			
90.00	12777.11	12768.99	-8.12							
90.00	14110.83	14099.04	-11.79							
Date	29 Jan 1993	30 Jan 1993								
Temperature (deg C)	18.4	12.9								
Rh (%)	60	60								
Filter								0.92	0.28	
								0.75		
								0.77		

Dustiness test No. 16

Material: 16 Carbon Black

Temp: 19.5°C: Humidity: 52%

All masses in g		Run 1		Run 2		Run 3		Mean value of three runs ± standard deviation
		Test	Control	Test	Control	Test	Control	
30 ppi Foam	After	15.153	15.350	16.286	15.177	16.163	15.626	0.221 ±0.108
	Before	14.809	15.350	16.107	15.176	16.024	15.626	
	Difference	.344	0	.179	.001	.139	0	
	Mass of dust	0.344		0.180		0.139		
90 ppi Foam	After	12.424	12.362	12.794	12.358	12.301	11.894	0.008 ±0.003
	Before	12.414	12.362	12.792	12.361	12.294	11.896	
	Difference	.010	0	.002	-.003	.007	-.002	
	Mass of dust	0.010		0.005		0.009		
Filter	After	.32965		.33228		.33318		0.00092 ±0.00028
	Before	.32841		.33153		.33241		
	Mass of dust	.00124		.00075		.00077		

Dustiness test No. 27

Material: Centrimex Fine White Powder (Repeat of Test 14)

Temp: 19.3°C: Humidity: 38%

All masses in g		Run 1		Run 2		Run 3		Mean value of three runs ± standard deviation
		Test	Control	Test	Control	Test	Control	
30 ppi Foam	After	28.771	15.584	28.583	15.321	28.159	15.545	12.720 ±0.266
	Before	15.879	15.583	15.726	15.320	15.750	15.550	
	Difference	12.892	+0.001	12.857	+0.001	12.409	-0.005	
	Mass of dust	12.891		12.856		12.414		
90 ppi Foam	After	13.772	11.857	14.025	12.728	13.927	12.332	1.206 ±0.06
	Before	12.491	11.864	12.777	12.728	12.766	12.334	
	Difference	1.281	-0.007	1.248	0.000	1.161	-0.002	
	Mass of dust	1.288		1.248		1.163		
Filter	After	.39495		.41631		.41887		0.08286 ±0.0156
	Before	.32865		.32926		.33364		
	Mass of dust	.06630		.09705		.08523		

CARBON BLACK: GLASS FIBRE FILTER IN FRON OF 90 PPI FOAM											
MATERIAL 16	Control foam mass (mg)						Test foam mass (mg)			Dust mass (mg)	
Foam porosity (ppi)	Before	After	Difference	Before	After	Difference	Mass collected	Mean mass	Standard deviation		
	16320.87	16284.41	-36.46	15633.92	15855.50	221.58	255.62	308.76	51.37		
	15536.80	15502.07	-34.73	15030.99	15355.11	324.12	358.16				
	15493.60	15459.67	-33.93	16236.76	16515.20	278.44	312.48				
	30.00	14414.91	14384.56	-30.35							
30.00	16155.13	16120.38	-34.75								
Date	9 Feb 1993	11 Feb 1993									
Temperature (deg C)	16.6	15.0									
Rh (%)	61	54									
Filter 1	1358.58	1358.55	-0.03	1344.84	1370.80	25.96	24.94	24.68	0.33		
Filter 2	1354.60	1354.81	0.21	1350.80	1376.60	25.80	24.78				
Filter 3	1361.15	1361.24	0.09	1355.85	1381.17	25.32	24.30				

Dustiness test No. 33

Material: Carbon Black

Temp: 19.5°C: Humidity: 38%

All masses in g		Run 1		Run 2		Run 3		Mean value of three runs ± standard deviation
		Test	Control	Test	Control	Test	Control	
30 ppi Foam	After	15.817	15.322	15.314	15.551	16.472	15.593	0.275 ±0.048
	Before	15.598	15.329	14.990	15.551	16.200	15.596	
	Difference	.219	-0.007	.324	0	.272	-0.003	
	Mass of dust	0.226		0.324		0.275		
Filter	After	1.366	1.353	1.376	1.351	1.377	1.352	0.024 ±0.004
	Before	1.345	1.352	1.350	1.353	1.353	1.352	
	Difference	.021	0.001	.026	0.002	.024	0	
	Mass of dust	0.020		0.028		0.024		

Dustiness test No. 17

Material: DC 34527 1830/810 (3)

Temp: 19.2°C: Humidity: 39%

All masses in g		Run 1		Run 2		Run 3		Mean value of three runs ± standard deviation
		Test	Control	Test	Control	Test	Control	
30 ppi Foam	After	15.674	15.588	16.026	15.322	15.599	15.145	0.0063 ± 0.0006
	Before	15.670	15.590	16.023	15.325	15.596	15.149	
	Difference	0.004	-0.002	0.003	-0.003	0.003	-0.004	
	Mass of dust	0.006		0.006		0.007		
90 ppi Foam	After	12.545	12.337	12.861	11.860	12.818	12.725	0.0065 ± 0.0015
	Before	12.544	12.340	12.860	11.867	12.815	12.730	
	Difference	0.001	-0.003	0.001	-0.007	0.003	-0.005	
	Mass of dust	0.004		0.008		0.008		
Filter	After	.33089		.33561		.33357		0.00084 ± 0.00009
	Before	.33010		.33483		.33263		
	Mass of dust	.00079		.00078		.00094		

DC 34527 1830/810 (4) YELLOWISH LIKE FINE GRIT										
MATERIAL 18	Control foam mass (mg)			Test foam mass (mg)			Dust mass (mg)			
Foam porosity (ppi)	Before	After	Difference	Before	After	Difference	Mass collected	Mean mass	Standard deviation	
30.00	16295.19	16307.76	12.57	15671.32	15707.50	36.18	24.03	24.40	0.42	
30.00	15512.94	15525.45	12.51	15717.11	15754.12	37.01	24.86			
30.00	15470.08	15481.57	11.49	15296.38	15332.82	36.44	24.29			
30.00	14389.72	14403.68	13.96							
30.00	16131.92	16142.12	10.20							
90.00	12700.54	12709.41	8.87	12957.94	12993.32	35.38	25.66	19.85	5.39	
90.00	12276.84	12284.86	8.02	12921.55	12950.17	28.62	18.90			
90.00	12410.22	12418.96	8.74	11511.08	11535.81	24.73	15.01			
90.00	12750.00	12758.67	8.67							
90.00	14069.29	14083.60	14.31							
Date	2 Feb 1993	3 Feb 1993								
Temperature (deg C)	15.2	15.8								
Rh (%)	55	59								
Filter										
				333.28	334.10	0.82		0.85	0.07	
				329.55	330.48	0.93				
				327.79	328.60	0.81				

Dustiness test No. 18

Material: DC 34527 1830/810 (4)

Temp: 19.3°C: Humidity: 43%

All masses in g		Run 1		Run 2		Run 3		Mean value of three runs ± standard deviation
		Test	Control	Test	Control	Test	Control	
30 ppi Foam	After	15.653	15.597	15.694	15.328	15.276	15.150	0.007 ±0.005
	Before	15.651	15.601	15.693	15.330	15.267	15.154	
	Difference	0.002	-0.004	0.001	-0.002	0.009	-0.004	
	Mass of dust	0.006		0.003		0.013		
90 ppi Foam	After	12.940	12.339	12.906	11.864	11.499	12.731	0.006 ±0.001
	Before	12.942	12.346	12.905	11.869	11.500	12.737	
	Difference	-0.002	-0.007	0.001	-0.005	0.001	-0.006	
	Mass of dust	0.005		0.006		0.007		
Filter	After	.33410		.33048		.32860		0.00085 ±0.00007
	Before	.33328		.32955		.32779		
	Mass of dust	.00082		.00093		.00081		

INTERPON TESTED WITHOUT CONTROL FOAMS ON DRUM POSS EXPLOSIVE										
MATERIAL 19	Control foam mass (mg)			Test foam mass (mg)			Dust mass (mg)			
Foam porosity (ppi)	Before	After	Difference	Before	After	Difference	Mass collected	Mean mass	Standard deviation	
30.00	16295.19	16307.76	12.57	15882.56	26686.80	10804.24	10792.09	9887.82	940.25	
30.00	15512.94	15525.45	12.51	15203.87	25172.07	9968.20	9956.05			
30.00	15470.08	15481.57	11.49	16122.50	25049.96	8927.46	8915.31			
30.00	14389.72	14403.68	13.96							
30.00	16131.92	16142.12	10.20							
90.00	12700.54	12709.41	8.87	12783.32	13128.46	345.14	335.42	354.20	17.94	
90.00	12276.84	12284.86	8.02	12702.55	13083.43	380.88	371.16			
90.00	12410.22	12418.96	8.74	12492.62	12858.38	365.76	356.04			
90.00	12750.00	12758.67	8.67							
90.00	14069.29	14083.60	14.31							
Date	2 Feb 1993	3 Feb 1993								
Temperature (deg C)	15.2	15.8								
Rh (%)	55	59								
Filter										
				330.79	343.24	12.45		12.05	2.21	
				331.53	345.56	14.03				
				333.89	343.56	9.67				

Dustiness test No. 19

Material: Interpon

Temp: 19.1°C: Humidity: 44%

All masses in g		Run 1		Run 2		Run 3		Mean value of three runs ± standard deviation
		Test	Control	Test	Control	Test	Control	
30 ppi Foam	After	26.631	15.595	25.109	15.329	24.992	15.157	9.871 ± 0.942
	Before	15.860	15.603	15.183	15.338	16.102	15.158	
	Difference	10.771	-0.008	9.926	-0.009	8.890	-0.0009	
	Mass of dust	10.779		9.935		8.899		
90 ppi Foam	After	13.097	12.337	13.043	11.869	12.821	12.733	0.344 ± 0.007
	Before	12.763	12.341	12.693	11.870	12.483	12.738	
	Difference	0.334	-0.004	0.350	-0.001	0.338	-0.005	
	Mass of dust	0.338		0.351		0.343		
Filter	After	.34324		.34556		0.34356		0.01205 ± 0.00221
	Before	.33079		.33153		.33389		
	Mass of dust	.01245		.01403		0.00967		

CARBON BLACK (FINER???)										
MATERIAL 20	Control foam mass (mg)					Test foam mass (mg)			Dust mass (mg)	
Foam porosity (ppi)	Before	After	Difference	Before	After	Difference	Mass collected	Mean mass	Standard deviation	
30.00	16295.19	16307.76	12.57	15996.35	24123.48	8127.13	8114.98	7754.13	484.85	
30.00	15512.94	15525.45	12.51	15874.53	23089.68	7215.15	7203.00			
30.00	15470.08	15481.57	11.49	16266.52	24223.08	7956.56	7944.41			
30.00	14389.72	14403.68	13.96							
30.00	16131.92	16142.12	10.20							
90.00	12700.54	12709.41	8.87	13948.14	14512.41	564.27	554.55	540.27	14.72	
90.00	12276.84	12284.86	8.02	13011.30	13546.16	534.86	525.14			
90.00	12410.22	12418.96	8.74	12739.51	13290.37	550.86	541.14			
90.00	12750.00	12758.67	8.67							
90.00	14069.29	14083.60	14.31							
Date	2 Feb 1993	3 Feb 1993								
Temperature (deg C)	15.2	15.8								
Rh (%)	55	59								
Filter										
				328.29	361.00	42.71	41.39	4.49		
				328.02	363.07	45.05				
				331.56	367.93	36.37				

Dustiness test No. 20

Material: Carbon Black (Finer)

Temp: 19.6°C: Humidity: 44%

All masses in g		Run 1		Run 2		Run 3		Mean value of three runs ± standard deviation
		Test	Control	Test	Control	Test	Control	
30 ppi Foam	After	28.070	15.605	23.036	15.334	24.172	15.165	8.824 ± 2.827
	Before	15.983	15.604	15.857	15.343	16.260	15.169'	
	Difference	12.087	-0.001	7.179	-0.009	7.912	-0.004	
	Mass of dust	12.088		7.188		7.916		
90 ppi Foam	After	14.485	12.345	13.517	11.876	13.258	12.741	0.531 ± 0.018
	Before	13.931	12.343	12.994	11.876	12.730	12.752	
	Difference	0.554	+0- .002	0.523	0.000	0.528	0.009	
	Mass of dust	0.532		0.523		0.519		
Filter	After	.36100		.36307		.36793		0.04138 ± 0.00449
	Before	.32829		.32802		.33156		
	Mass of dust	0.04271		0.04505		0.03637		

GOONYEAN BONE MATERIAL DRIED AND BROKEN UP										
MATERIAL 21	Control foam mass (mg)				Test foam mass (mg)			Dust mass (mg)		
Foam porosity (ppi)	Before	After	Difference	Before	After	Difference	Mass collected	Mean mass	Standard deviation	
30	16298.98	16286.66	-12.32	15306.4	15652.41	346.01	357.09	339.90	15.01	
30	15515.37	15505.05	-10.32	15733.31	16051.61	318.3	329.38			
30	15472.41	15461.27	-11.14	15693.44	16015.61	322.17	333.25			
30	14394.33	14384.95	-9.38							
30	16134.67	16122.44	-12.23							
90	12700.71	12691.83	-8.88	12936.09	13048.94	112.85	123.60	119.94	5.55	
90	12276.34	12266.48	-9.86	11521.59	11633.5	111.91	122.66			
90	12411.21	12400.99	-10.22	12973.82	13076.63	102.81	113.56			
90	12751.42	12742.22	-9.2							
90	14072.59	14056.98	-15.61							
Date	3 Feb 1993	4 Feb 1993								
Temperature (deg C)	16.9	16.9								
Rh (%)	56	54								
Filter					327.10	352.23	25.13	23.20	2.50	
					331.00	355.09	24.09			
					331.78	352.15	20.37			

Dustiness test No. 21

Material: Goon Yean Bone (supplied wet)

Temp: 18.8°C: Humidity: 47%

All masses in g		Run 1		Run 2		Run 3		Mean value of three runs ± standard deviation
		Test	Control	Test	Control	Test	Control	
30 ppi Foam	After	15.611	15.158	16.012	15.603	15.972	15.337	0.312 ±0.015
	Before	15295	15.171	15.716	15.613	15.676	15.343	
	Difference	.316	-0.013	.296	0.010	.296	-0.006	
	Mass of dust	0.329		0.306		0.302		
90 ppi Foam	After	13.011	12.736	11.603	12.341	13.043	11.875	
	Before	12.923	12.749	11.510	12.351	12.967	11.880	
	Difference	.088	-0.013	.093	-0.010	.076	-0.005	
	Mass of dust	0.101		0.103		0.081		
Filter	After	.35223		.35509		.35215		0.02520 ±0.00250
	Before	.32710		.33100		.33178		
	Mass of dust	.02513		.02409		.02037		

NEPH. SYENITE DRIED AND BROKEN UP										
MATERIAL 22	Control foam mass (mg)			Test foam mass (mg)			Dust mass (mg)			Standard deviation
Foam porosity (ppi)	Before	After	Difference	Before	After	Difference	Mass collected	Mean mass		
30	16298.98	16286.66	-12.32	15844.29	15806.3	162.01	173.09	194.31	18.39	
30	15515.37	15505.05	-10.32	15722.69	15915.89	193.2	204.28			
30	15472.41	15461.27	-11.14	16078.9	16273.4	194.5	205.58			
30	14394.33	14384.95	-9.38							
30	16134.67	16122.44	-12.23							
90	12700.71	12691.83	-8.88	12904.43	12977.65	73.22	83.97	89.64	7.47	
90	12276.34	12266.48	-9.86	12587.41	12663.51	76.1	86.85			
90	12411.21	12400.99	-10.22	12851.66	12939.01	87.35	98.10			
90	12751.42	12742.22	-9.2							
90	14072.59	14056.98	-15.61							
Date	3 Feb 1993	4 Feb 1993								
Temperature (deg C)	16.9	16.9								
Rh (%)	56	54								
Filter					327.53	356.24	28.71	31.27	2.49	
					332.52	363.94	31.42			
					329.31	362.99	33.68			

Dustiness test No. 22

Material: Neph Syenite (supplied wet)

Temp: 18.9°C: Humidity: 48%

All masses in g		Run 1		Run 2		Run 3		Mean value of three runs ± standard deviation
		Test	Control	Test	Control	Test	Control	
30 ppi Foam	After	15.783	15.162	15.889	15.612	16.248	15.340	0.181 ±0.016
	Before	15.630	15.172	15.706	15.618	16.060	15.345	
	Difference	0.153	-0.010	0.183	-0.006	0.188	-0.005	
	Mass of dust	0.163		0.189		0.193		
90 ppi Foam	After	12.950	12.742	12.646	12.350	12.928	11.880	0.073 ±0.008
	Before	12.893	12.750	12.577	12.356	12.843	11.875	
	Difference	0.057	-0.008	0.069	-0.006	0.085	+0.005	
	Mass of dust	0.065		0.075		0.080		
Filter	After	.35624		.36394		.36299		0.03127 ±0.00249
	Before	.32753		.33252		.32931		
	Mass of dust	.02871		.03142		.03368		

GROUND FLINT IN WATER MATERIAL DRIED AND BROKEN UP									
MATERIAL 23	Control foam mass (mg)			Test foam mass (mg)			Dust mass (mg)		
Foam porosity (ppi)	Before	After	Difference	Before	After	Difference	Mass collected	Mean mass	Standard deviation
30	16299.74	16277.17	-22.57	15935.14	16333.37	398.23	417.98	408.62	25.05
30	15516.2	15497.13	-19.07	15738.01	16098.49	360.48	380.234		
30	15472.68	15451.92	-20.76	16114.13	16522.02	407.89	427.644		
30	14394.41	14377.6	-16.81						
30	16132.66	16113.1	-19.56						
90	12701.15	12683.63	-17.52	12997.25	13130.27	133.02	153.092	152.04	1.87
90	12276.86	12259.34	-17.52	12996.5	13129.58	133.08	153.152		
90	12411.44	12392.83	-18.61	13136.91	13266.72	129.81	149.88		
90	12751.88	12733.2	-18.68						
90	14073.28	14045.25	-28.03						
Date	4 Feb 1993	5 Feb 1993							
Temperature (deg C)	15.6	15.1							
Rh (%)	57	52							
Filter					330.40	384.52	54.12	53.77	0.69
					330.37	383.35	52.98		
					332.34	386.56	54.22		

Dustiness test No. 23

Material: Ground Flint in Water (supplied wet)

Temp: 19.3°C: Humidity: 38%

All masses in g		Run 1		Run 2		Run 3		Mean value of three runs ± standard deviation
		Test	Control	Test	Control	Test	Control	
30 ppi Foam	After	16.295	15.320	16.061	15.143	16.481	15.585	0.388 ± 0.023
	Before	15.900	15.322	15.700	15.141	16.075	15.585	
	Difference	0.395	-0.002	0.361	+0.001	.406	0	
	Mass of dust	0.397		0.362		0.406		
90 ppi Foam	After	13.111	11.863	13.102	12.730	13.237	12.328	0.137 ± 0.003
	Before	12.975	11.867	12.965	12.729	13.104	12.330	
	Difference	0.136	-0.004	0.137	+0.001	.133	-0.002	
	Mass of dust	0.140		0.136		0.135		
Filter	After	.38452		.38335		.38656		0.05377 ± 0.00069
	Before	.33040		.33037		.33234		
	Mass of dust	0.05412		0.05298		0.05422		

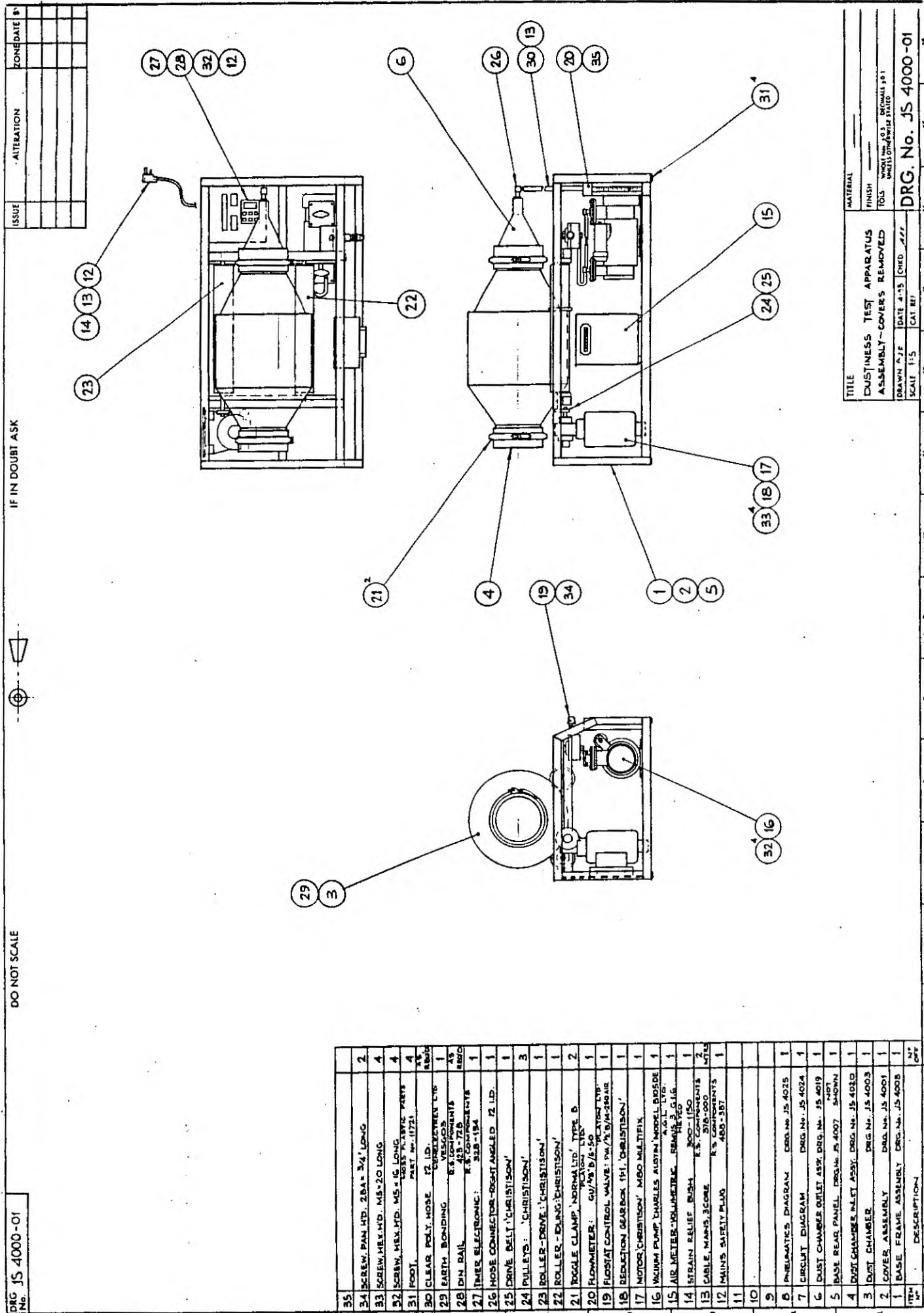
Appendix F

**FINAL DETAILED DESIGN DRAWINGS FOR THE PRODUCTION VERSION OF THE NEW
DUSTINESS TESTER**

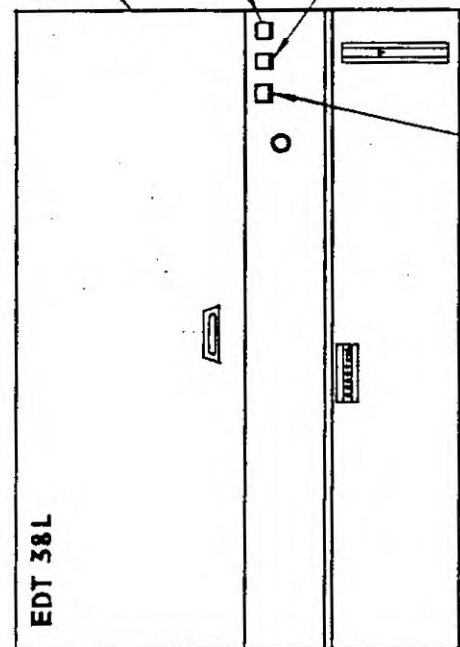
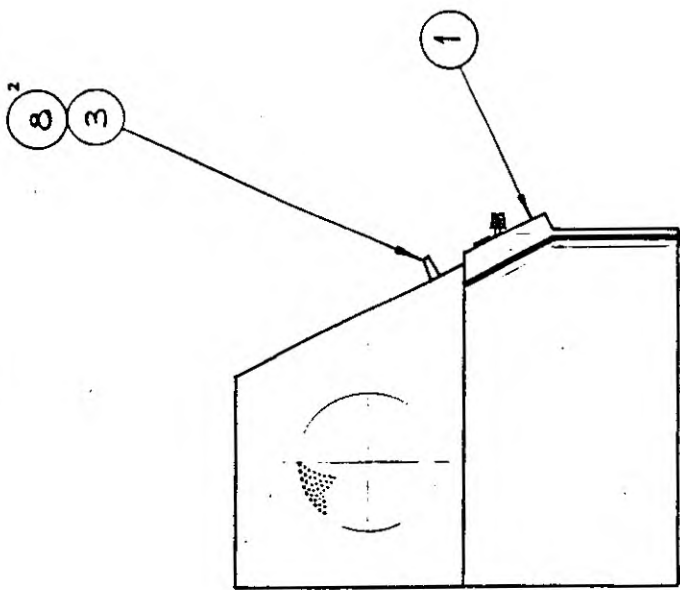
PARTS LIST

DUSTINESS TEST APPARATUS ASSEMBLY

DRG.No.	DESCRIPTION
JS 4000-01	DUSTINESS TEST APPARATUS ASSY.-COVERS REMOVED
4001-01	COVER ASSEMBLY
4002-01	BASE FRAME
4003-01	DUST CHAMBER
4004-01	FILTER HOLDER ASSEMBLY-INLET
4005-01	FOAM HOLDER ASSEMBLY-OUTLET
4006-01	OUTLET CONE ASSEMBLY
4007-01	BASE REAR PANEL
4008-01	BASE FRAME ASSEMBLY
4009-01	FOAM HOLDER
4010-01	BASE SIDE PANEL
4011-01	
4012-01	TOP COVER
4013-01	FRONT COVER
4014-01	TOP COVER ASSEMBLY
4015-01	'O' RING HOUSING
4016-01	OUTLET CONE
4017-01	FOAM DISC-1st STAGE
4018-01	FOAM DISC-2nd STAGE
4019-01	DUST CHAMBER OUTLET ASSEMBLY
4020-01	DUST CHAMBER INLET ASSEMBLY
4021-01	FILTER CASSETTE ASSEMBLY
4022-01	RETAINING RING
4023-01	UNION HOUSING
4024-01	CIRCUIT DIAGRAM
4025-01	PNEUMATICS DIAGRAM



DRG JS 4001-01		DO NOT SCALE		IF IN DOUBT ASK		ISSUE		ALTERATION		ZONE		DATE		BY	



ITEM	DESCRIPTION	QTY
8	SCREW PAN HD. MG X 10 LONG	2
7	LIMIT SWITCH	1
6	SWITCH-STOP (RED)	1
5	SWITCH-START (GREEN)	1
4	SWITCH-POWER ON (YELLOW)	1
3	LIFTING HANDLE	1
2	TOP COVER ASSY. DRG. No. JS 4014	1
1	FRONT COVER DRG. No. JS 4013	1

TITLE		COVER ASSEMBLY		MATERIAL		FINISH		TOLS:		WHOLE No. 1 0 3 DECIMALS 1 0 1	
DRAWN A J F		DATE 4-93		CHKD. A F F		SCALE 1:15		CAT. REF.		DRG. No. JS 4001-01	

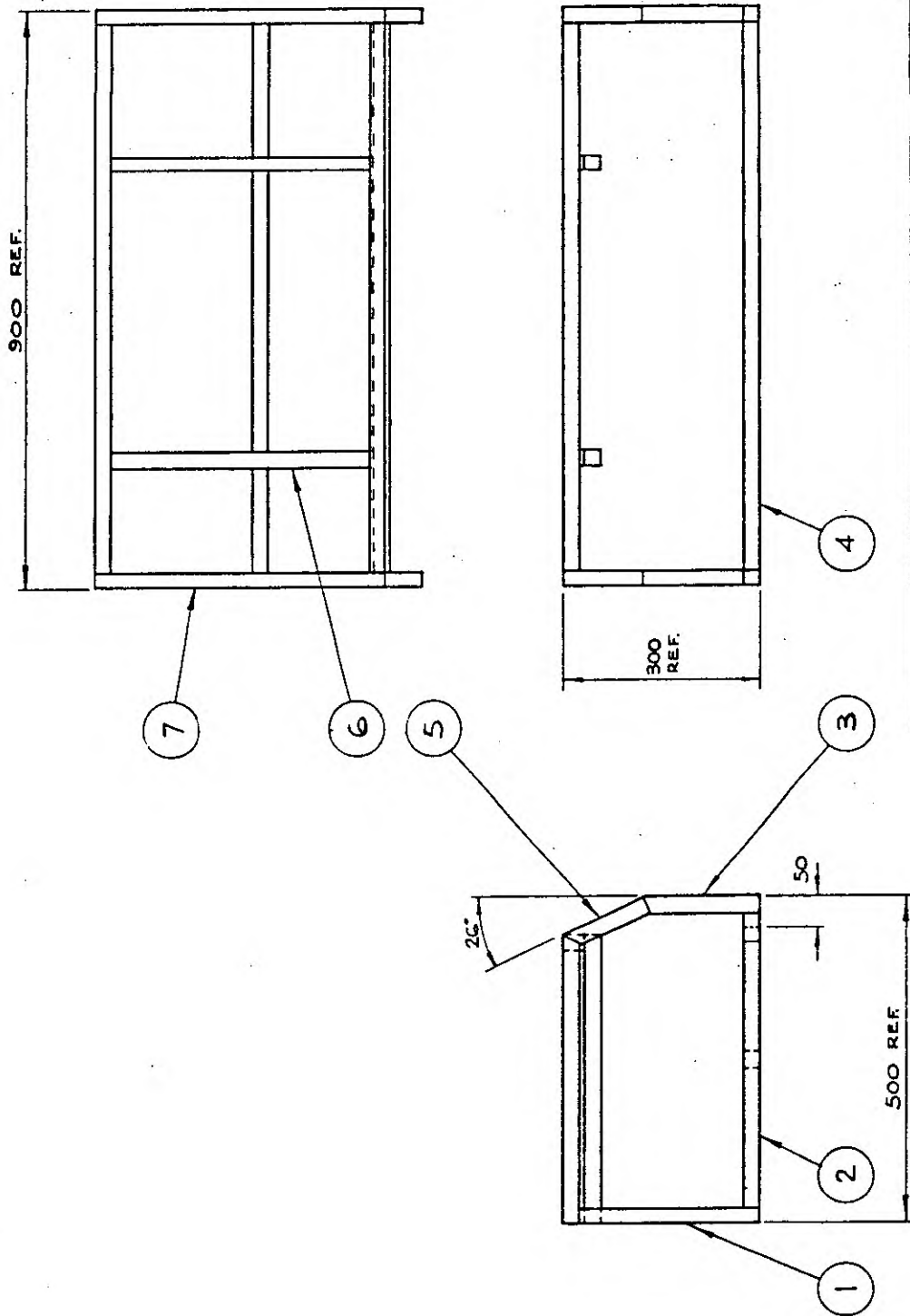
DRG
No. JS 4002-01

DO NOT SCALE



IF IN DOUBT ASK

ISSUE	ALTERATION	ZONE	DATE	BY



ITEM	DESCRIPTION	LENGTH	OFF
7	STEEL TUBE 25*25*16	445	2
6	"	445	2
5	"	132	2
4	"	850	5
3	"	180	2
2	"	450	2
1	"	275	2

TITLE		MATERIAL SEE SCHEDULE		WELDED STRUCTURE	
BASE FRAME		FINISH PRIMER			
		TOL:		WHOLE NO. 0.3 DECIMALS 0.1	
DRAWN A/JF		DATE 4-93		CHKD. A/JF	
SCALE 1"=5'		CAT. REF.			

DRG. No. JS 4002-01

DRG No. JS 4004-01

DO NOT SCALE



IF IN DOUBT ASK

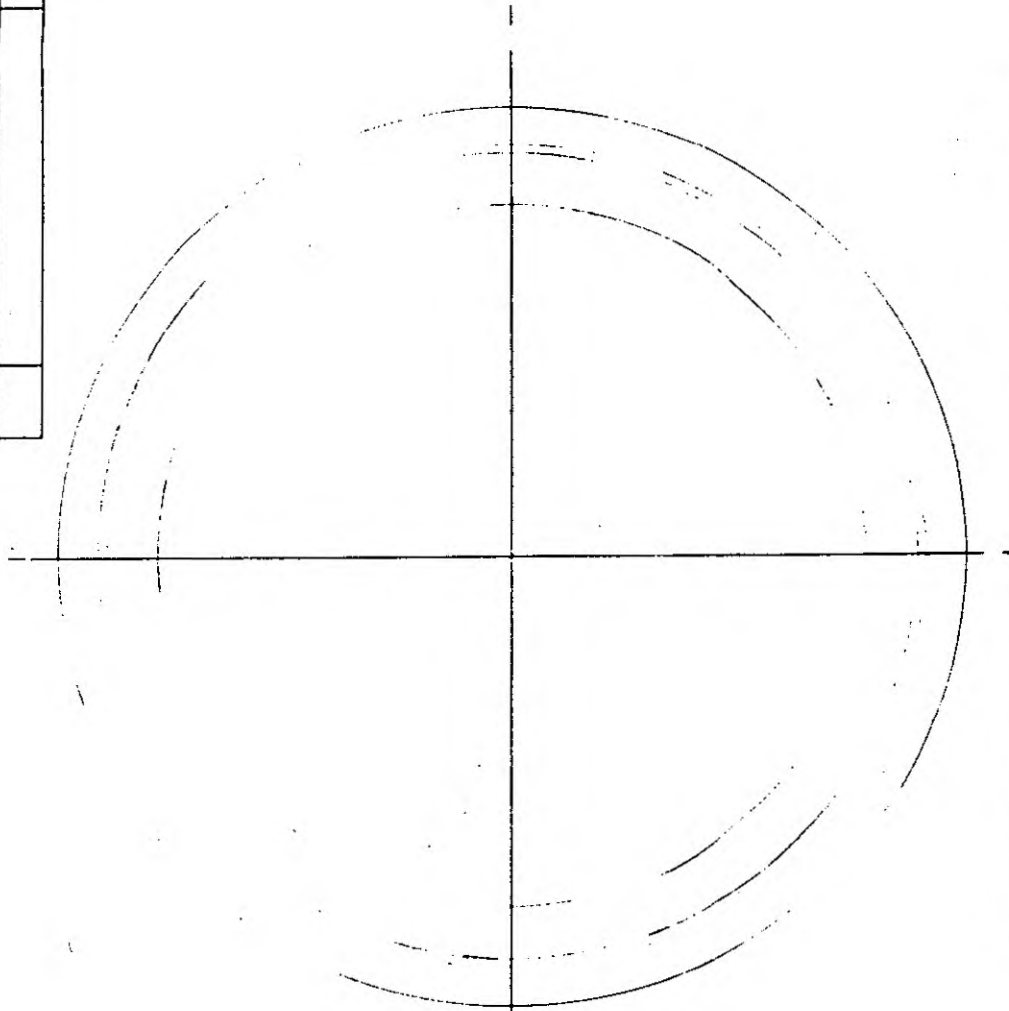
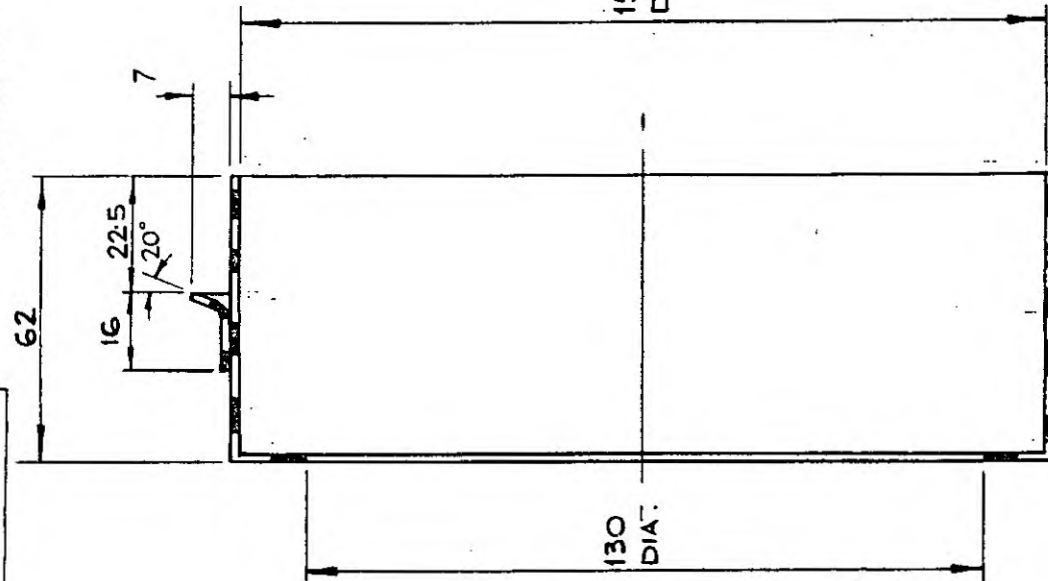
ISSUE

ALTERATION

ZONE

DATE

BY



SPOT WELD
IN POSITION

TITLE

FILTER HOLDER ASSEMBLY
~ INLET

MATERIAL STAINLESS STEEL 304
16 SWG (1/8) THK.

FINISH NATURAL

TOLS: WHOLE NOS. : 0.5 DECIMALS : 0.1
UNLESS OTHERWISE STATED

DRAWN A J F

DATE 4-93

CHKD. ARZ

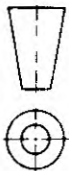
SCALE 1:1

CAT. REF.

DRG. No. JS 4004-01

DRG JS 4005-01

DO NOT SCALE

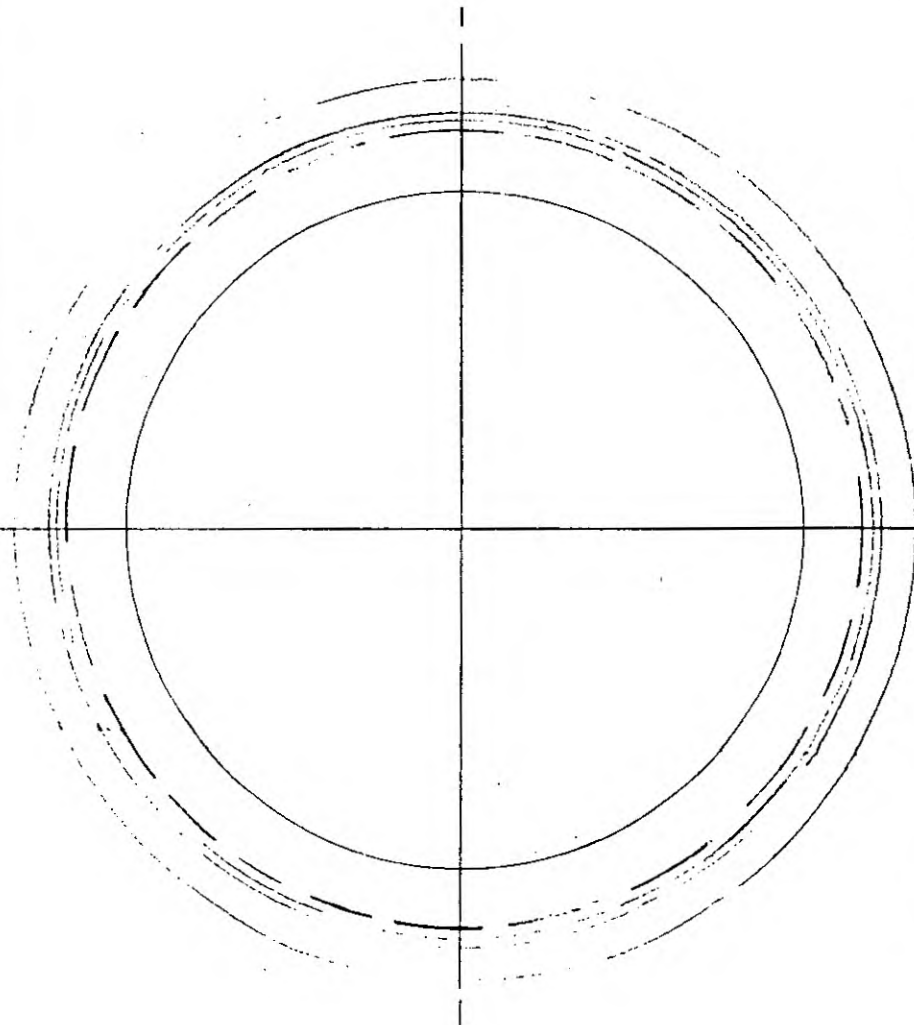
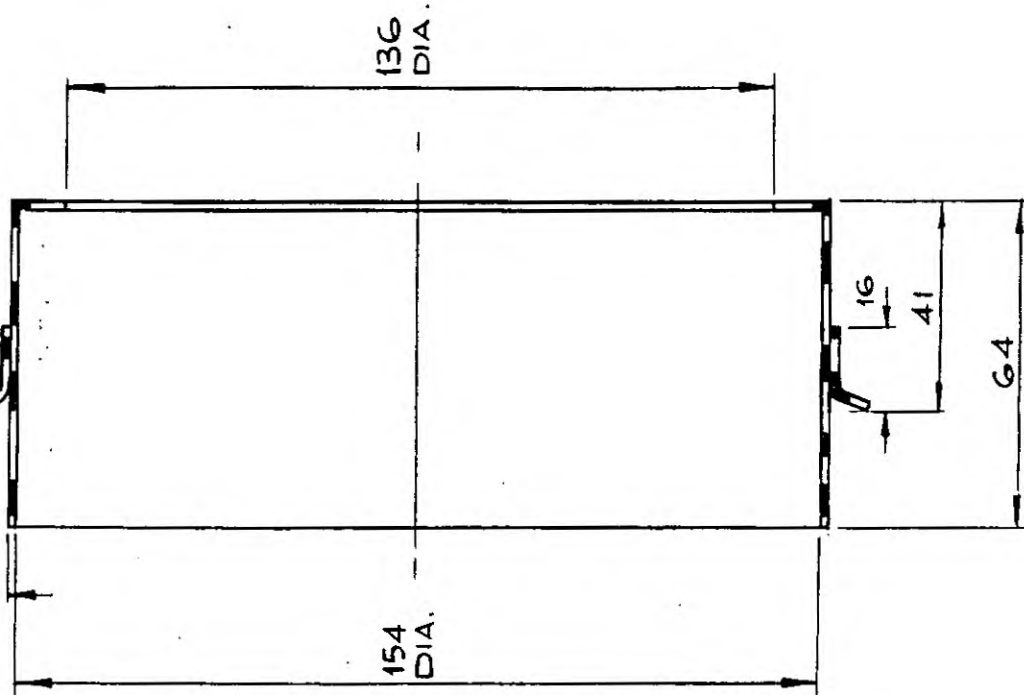


IF IN DOUBT ASK

ISSUE	ALTERATION	ZONE	DATE	BY

20°
SPOT WELD
IN POSITION

7



TITLE

FOAM HOLDER ASSEMBLY

~ OUTLET

MATERIAL STAINLESS STEEL 304
16 SWG (16) THK.

FINISH NATURAL

TOLS: WHOLE NOS. 0.5 DECIMALS 0.1
UNLESS OTHERWISE STATED

DRAWN AJF

DATE 4-93

CHKD. AJF

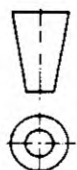
SCALE 1:1

CAT. REF.

DRG. No. JS 4005-01

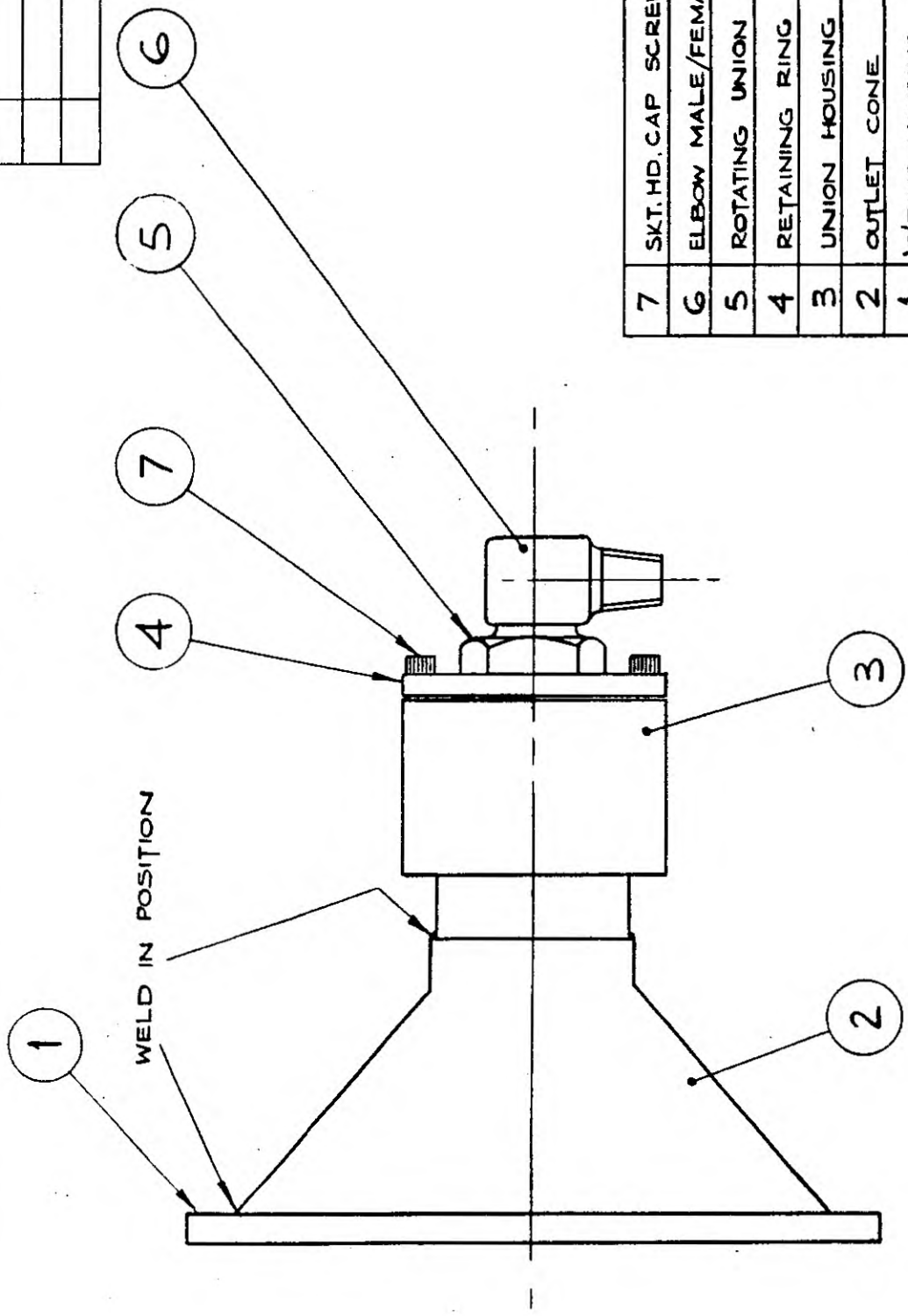
DRG No. JS 4006-01

DO NOT SCALE



IF IN DOUBT ASK

ISSUE	ALTERATION	ZONE	DATE	BY



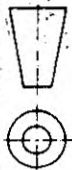
ITEM No.	DESCRIPTION	DRG. No.	JS	No. OFF
7	SKT. HD. CAP SCREW	M4x12 LONG		4
6	ELBOW MALE/FEMALE	1/4" BSP		1
5	ROTATING UNION	MODEL 1102-025-081		1
4	RETAINING RING	DRG. No. JS 4022		1
3	UNION HOUSING	DRG. No. JS 4023		1
2	OUTLET CONE	DRG. No. JS 4016		1
1	O-RING HOUSING	DRG. No. JS 4015		1

TITLE	
OUTLET CONE	ASSEMBLY
MATERIAL	
FINISH	
TOLS: WHOLE No. : 0.5 DECIMALS : 0.1 UNLESS OTHERWISE STATED	
DRAWN A J F	DATE 4-93
SCALE 1:1	CAT. REF.

DRG. No. JS 4006-01

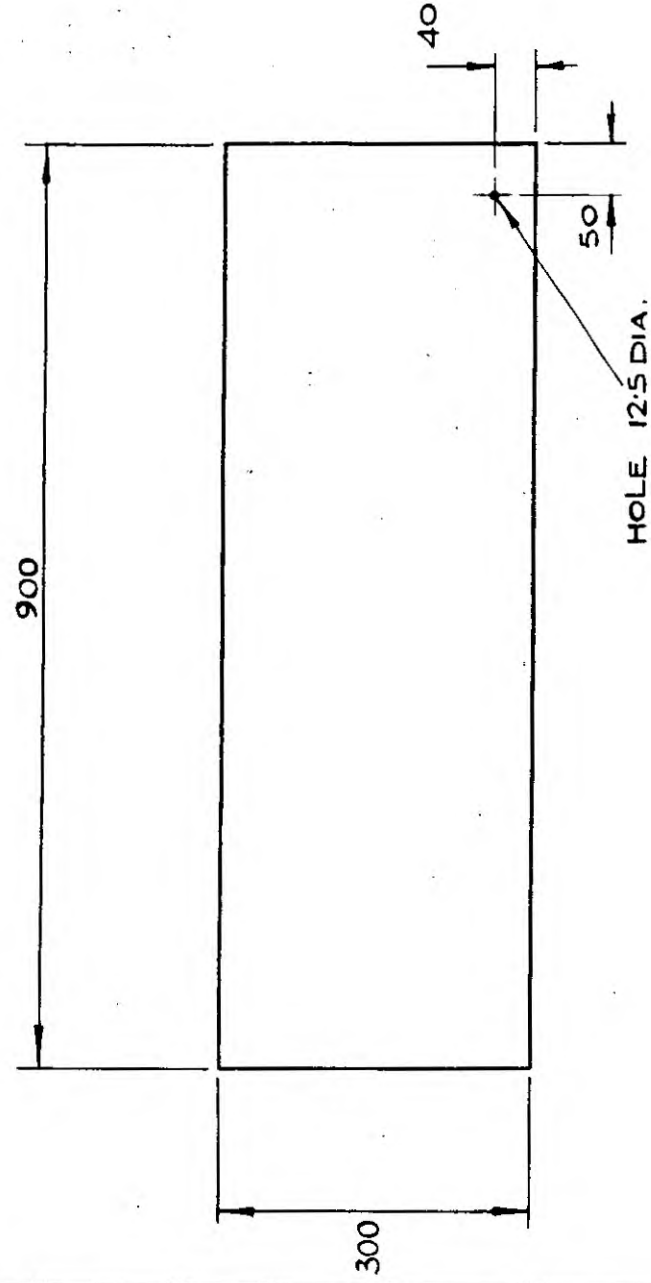
DRG JS 4007-01

DO NOT SCALE



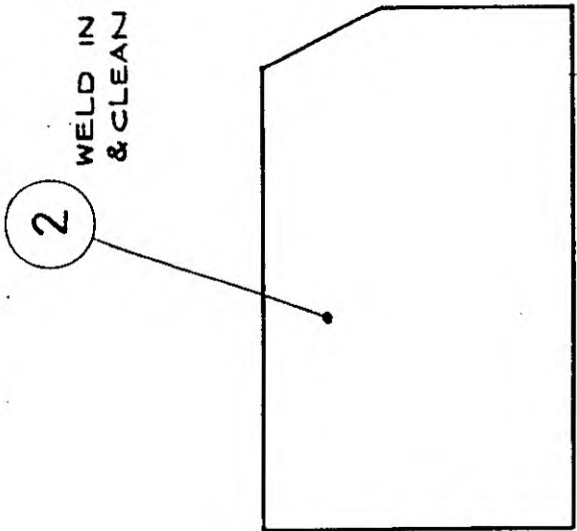
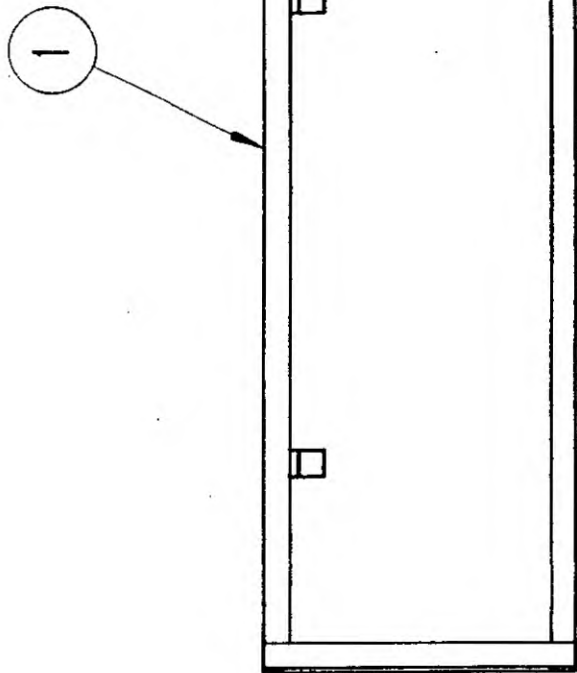
IF IN DOUBT ASK

ISSUE	ALTERATION	ZONE	DATE	BY



TITLE		MATERIAL	
BASE REAR PANEL		MILD STEEL SHEET 16 SWG (1.6) THK.	
		FINISH	PAINT
		TOLS: WHOLE NOS. : 0.5 DECIMALS : 0.1 UNLESS OTHERWISE STATED	
DRAWN A J F	DATE 5.93	CHKD. A K E	DRG. No. JS 4007-01
SCALE 1:5	CAT. REF.		

DRG No. JS 4008-01	DO NOT SCALE			IF IN DOUBT ASK	ISSUE	ALTERATION	ZONE	DATE	BY



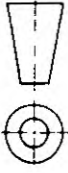
WELD IN POSITION
& CLEAN FLUSH

ITEM N°.	DESCRIPTION	N°.	OFF
2	BASE SIDE PANEL DRG.No. JS 4010	2	
1	BASE FRAME DRG.No. JS 4002	1	

TITLE		MATERIAL	
BASE FRAME ASSEMBLY		FINISH PAINT	
DRAWN A/JF		TOLS: WHOLE Nos. · 0.5 DECIMALS · 0.1 UNLESS OTHERWISE STATED	
DATE 5-93		CHKD. A/E	
SCALE 1:5		CAT. REF.	
DRG. No. JS 4008-01			

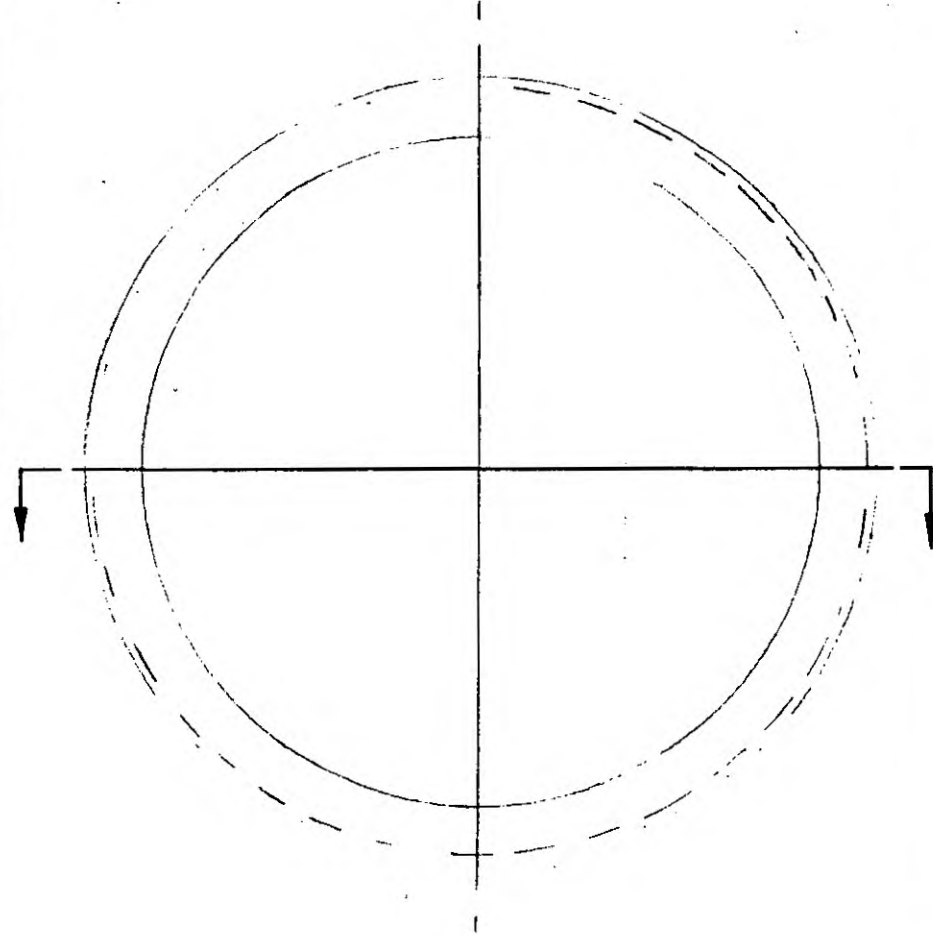
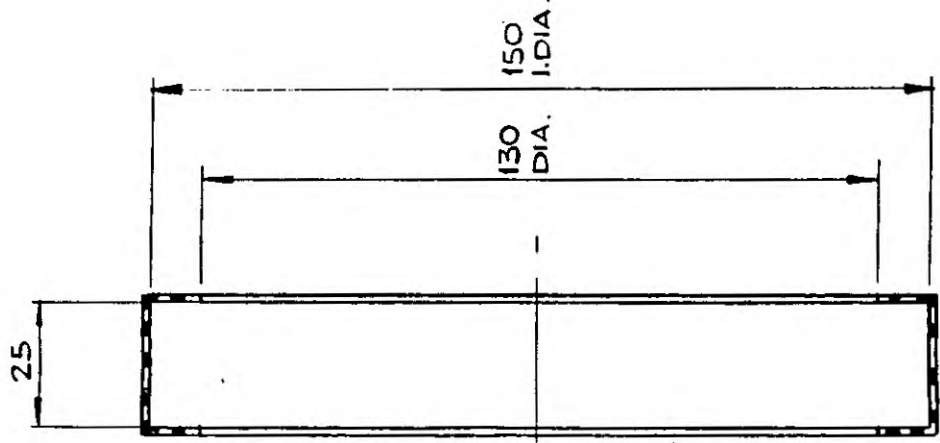
DRG No. JS 4009-01

DO NOT SCALE



IF IN DOUBT ASK

ISSUE	ALTERATION	ZONE	DATE	BY



TITLE

FOAM HOLDER

MATERIAL STN. STEEL 304
16 SWG (16) THK.

FINISH

TOLS: WHOLE Nos. 0.5 DECIMALS 0.1
UNLESS OTHERWISE STATED

DRAWN AJF

DATE 4-93

CHKD. *AKF*

SCALE 1:1

CAT. REF.

DRG. No. JS 4009-01

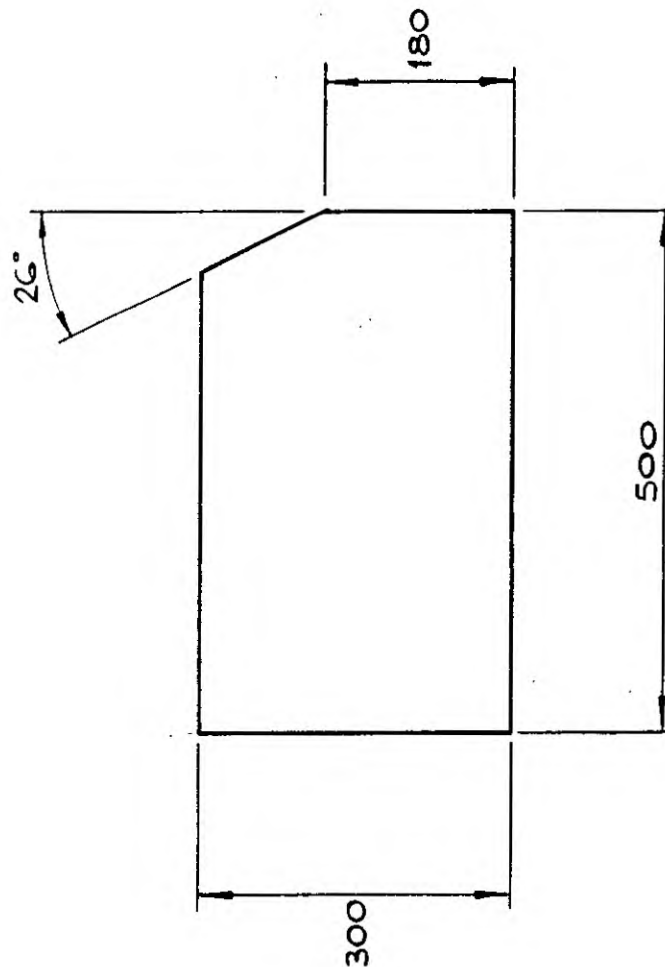
DRG No. JS4010-01

DO NOT SCALE



IF IN DOUBT ASK

ISSUE	ALTERATION	ZONE	DATE	BY



TITLE

BASE SIDE PANEL

MATERIAL MILD STEEL SHEET
1/2 SWG (1/8) THK.

FINISH

TOLS: WHOLE NOS. : 0.5 DECIMALS : 0.1
UNLESS OTHERWISE STATED

DRAWN AJF DATE 5-93 CHKD. ARE

SCALE 1:5 CAT. REF.

DRG. No. JS 4010-01

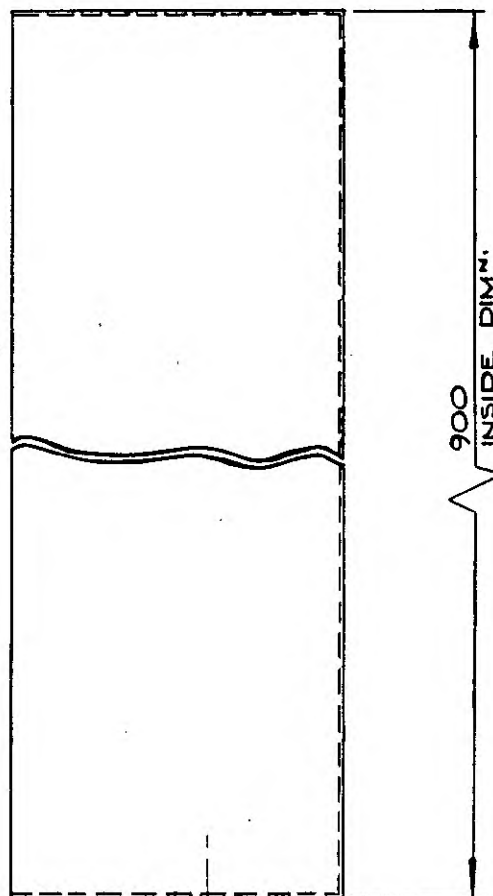
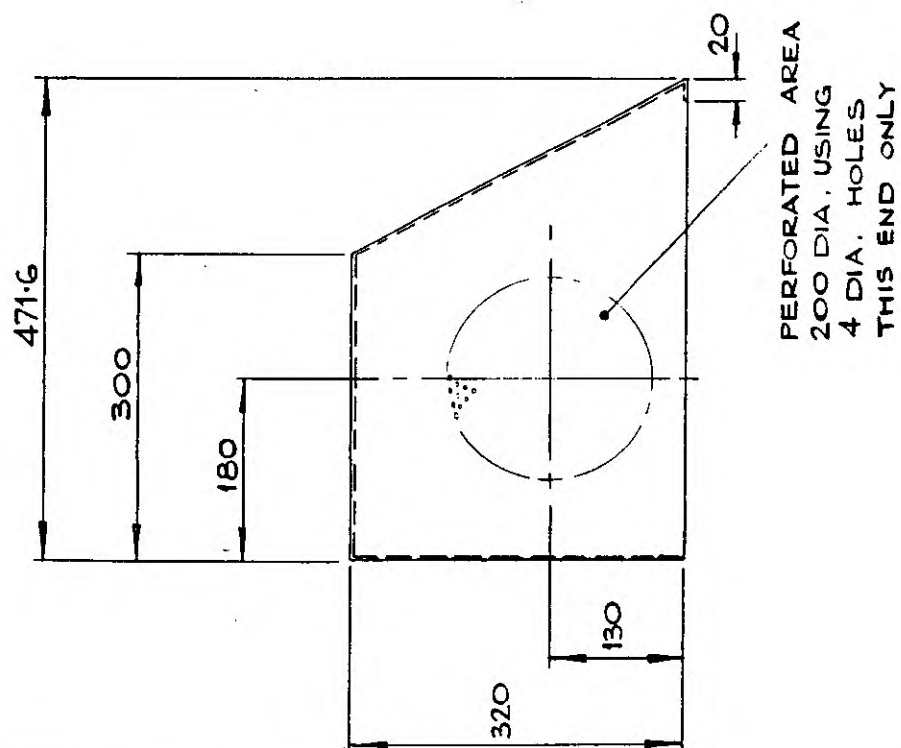
DRG No. JS 4012-01

DO NOT SCALE



IF IN DOUBT ASK

ISSUE	ALTERATION	ZONE	DATE	BY



TITLE

TOP COVER

MATERIAL 16 SWG (1.6) M.S. SHEET

FINISH POWDER COAT

TOLS: WHOLE Nos. 0.5 DECIMALS 0.1 UNLESS OTHERWISE STATED

DRAWN A J F

DATE 4-93

CHKD. A R F

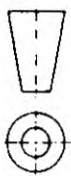
SCALE 1:5

CAT. REF.

DRG. No. JS 4012-01

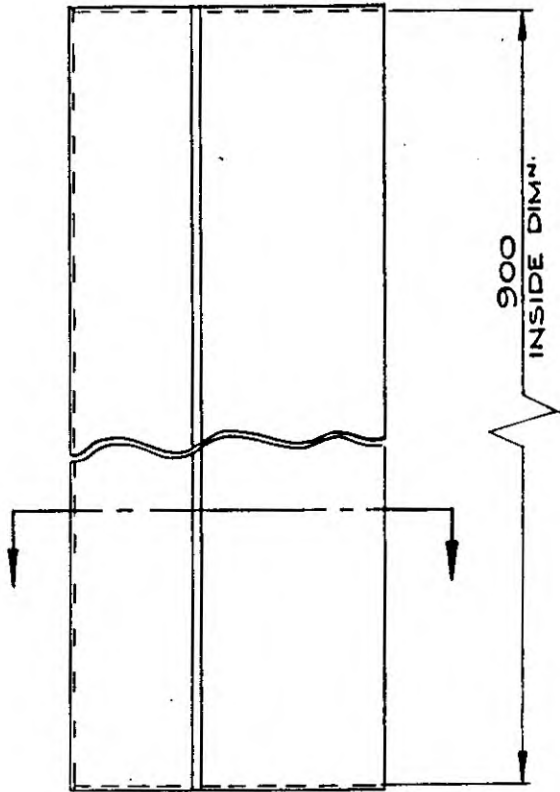
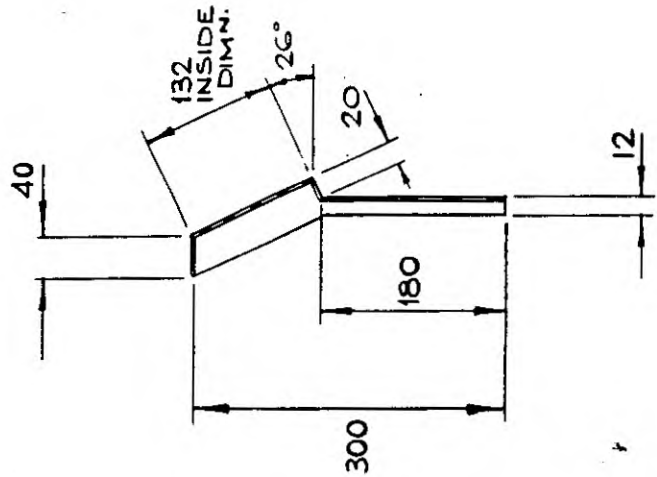
DRG No. JS 4013-01

DO NOT SCALE



IF IN DOUBT ASK

ISSUE	ALTERATION	ZONE	DATE	BY



TITLE

FRONT COVER

MATERIAL 16 SWG (1.6) M.S. SHEET

FINISH POWDER COAT

TOLS: WHOLE NOS. 0.5 DECIMALS 0.1
UNLESS OTHERWISE STATED

DRAWN AJF DATE 4-93 CHKD. ARF

SCALE 1:5 CAT. REF.

DRG. No. JS 4013-01

ICANGRAM REPORT 4/15/83/11

DRG JS 4014 -01

DO NOT SCALE

IF IN DOUBT ASK

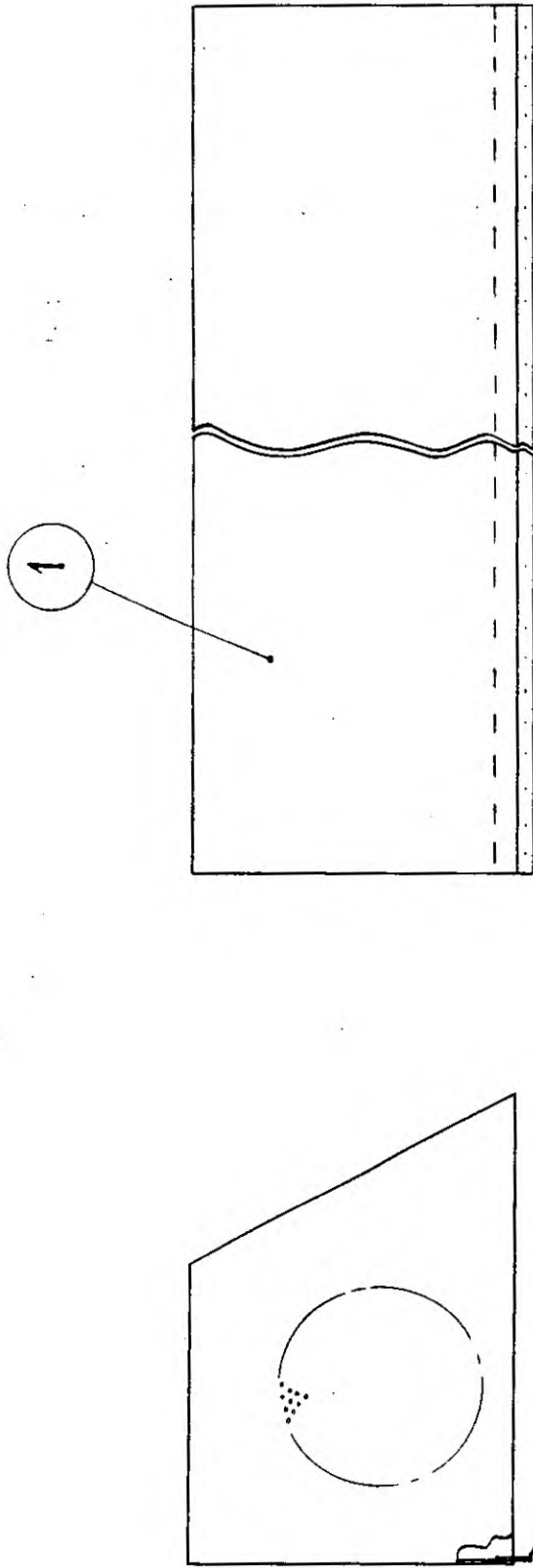
ISSUE

ALTERATION

ZONE

DATE

BY



2	PIANO HINGE	-	1
1	TOP COVER	JS 4012	1
ITEM N°.	DESCRIPTION	DRG. N°.	OFF

TITLE

TOP COVER ASSEMBLY

MATERIAL

FINISH

TOIS:

WHOLE Nos. : 0.5 DECIMALS : 0.1

UNLESS OTHERWISE STATED

DRAWN A J F

DATE 4-93

CHKD. A F F

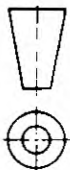
SCALE 1:5

CAT. REF.

DRG. No. JS 4014 -01

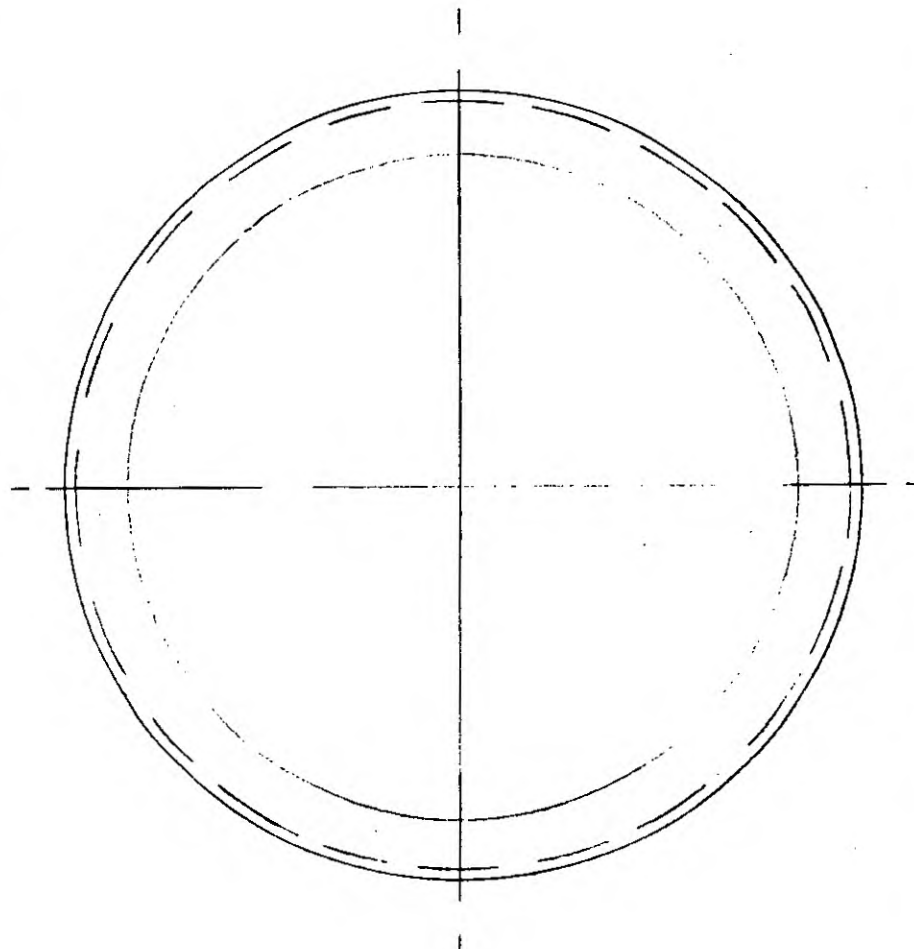
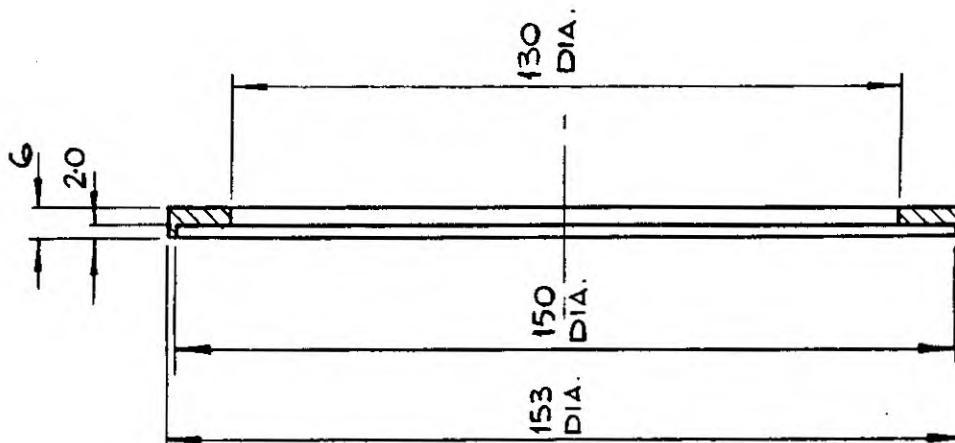
DRG JS 4015-01

DO NOT SCALE



IF IN DOUBT ASK

ISSUE	ALTERATION	ZONE	DATE	BY



TITLE

'O' RING HOUSING

MATERIAL ALUMINIUM ALLOY HE 30

FINISH NATURAL

TOLS: WHOLE Nos. : 0.5 DECIMALS : 0.1
UNLESS OTHERWISE STATED

DRAWN A J F

DATE 4.93

CHKD. A J F

SCALE 1:1

CAT. REF.

DRG. No. JS 4015-01

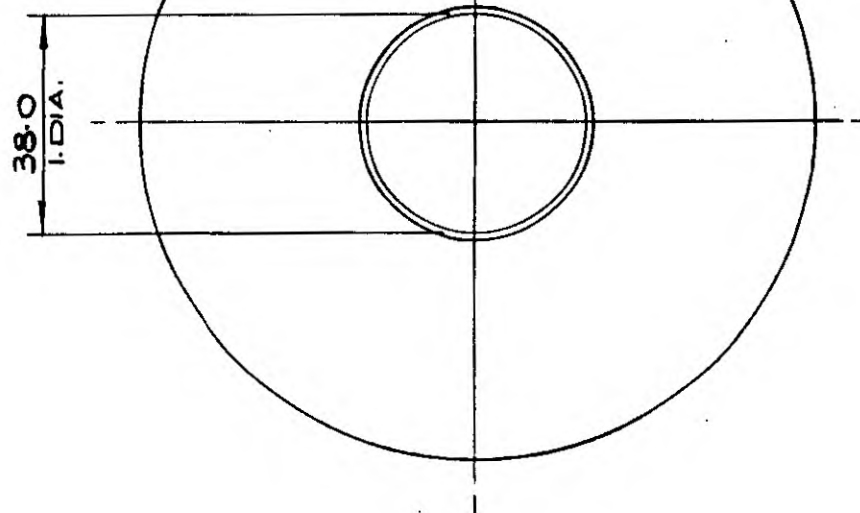
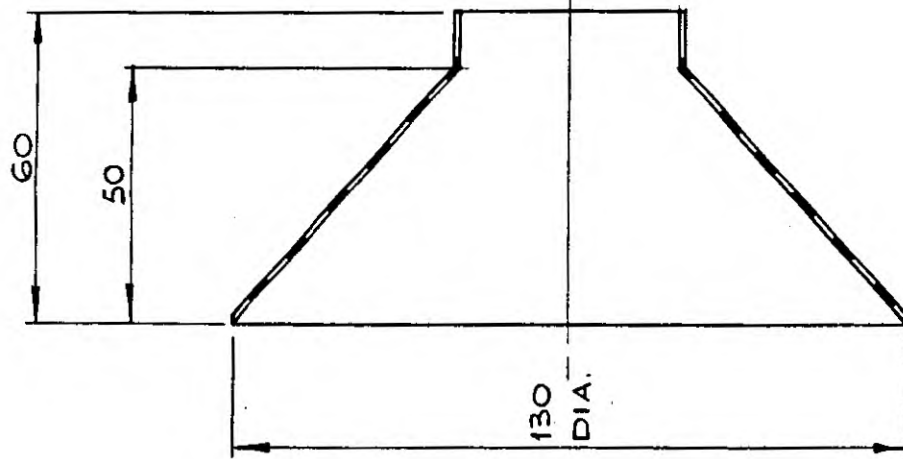
DRG No. JS 4016-01

DO NOT SCALE



IF IN DOUBT ASK

ISSUE	ALTERATION	ZONE	DATE	BY



TITLE

OUTLET CONE

MATERIAL ALUMINIUM ALLOY HE 30

FINISH

TOLS: WHOLE NOS. : 0.5 DECIMALS : 0.1
UNLESS OTHERWISE STATED

DRAWN A J F

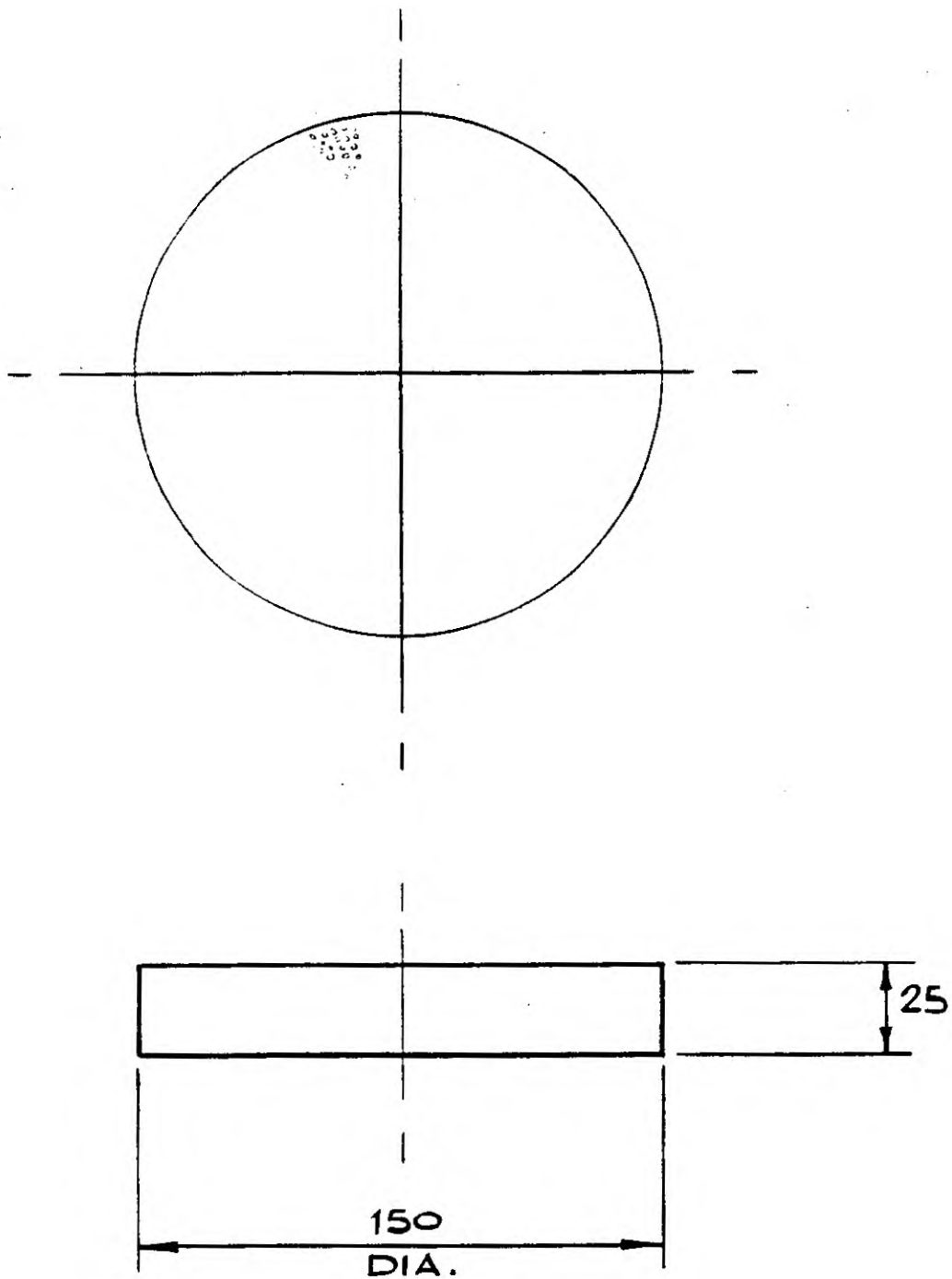
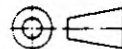
DATE 4-93

CHKD. ARE

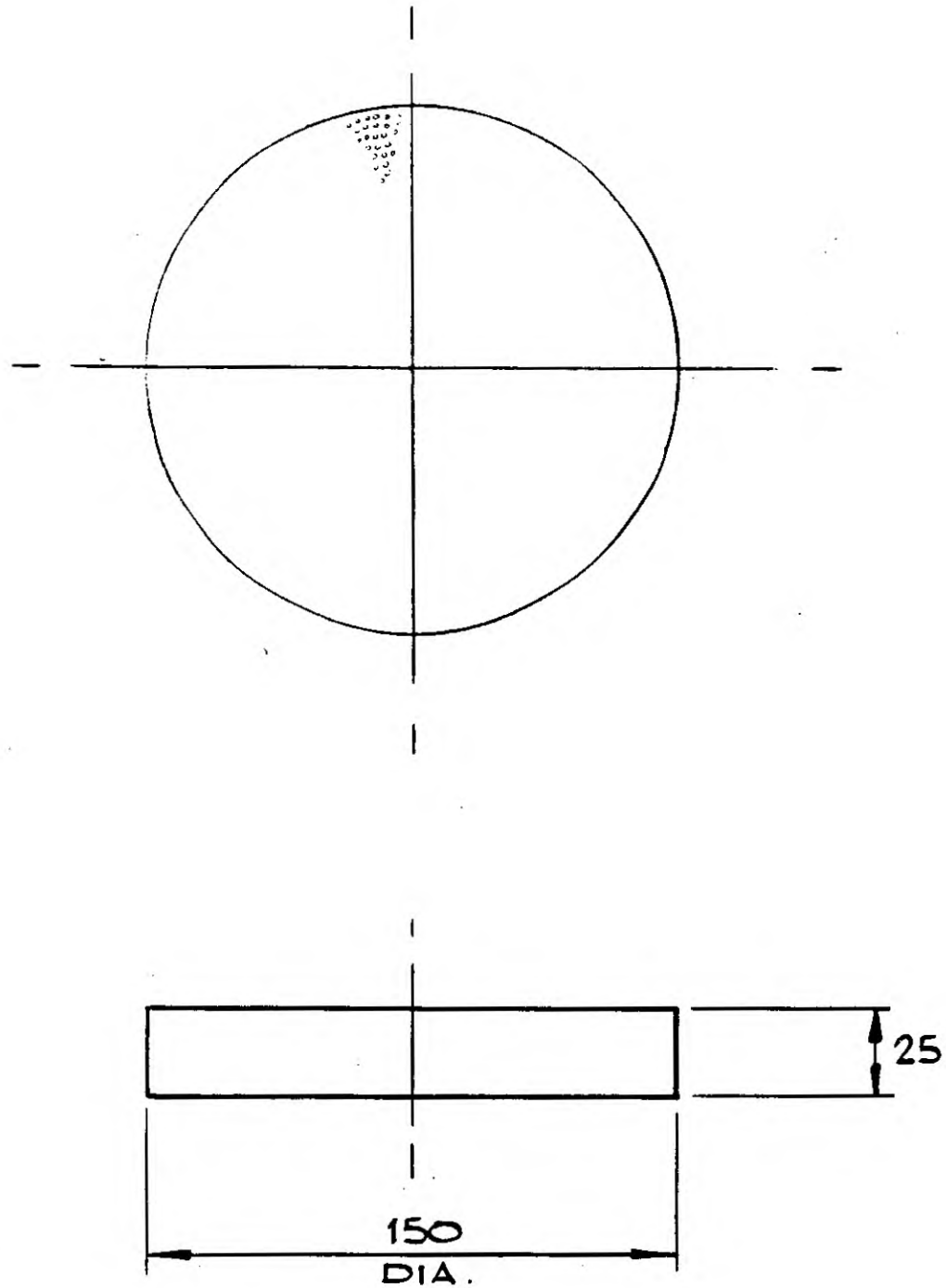
SCALE 1:1

CAT. REF.

DRG. No. JS 4016-01



ISSUE	ALTERATION	DATE	BY
TITLE FOAM DISC 1ST STAGE		MATERIAL POLYESTER SRF 30/30 BA (30 PPI) FINISH COLOUR - BLACK	
TOLS: WHOLE NUM. ± 0.3 DECIMALS ± 0.1 UNLESS OTHERWISE STATED		DRAWN AJF DATE 5-93 CHKD ARE	DRG. No. JS 4017-01
		SCALE 1:1 CAT. REF.	



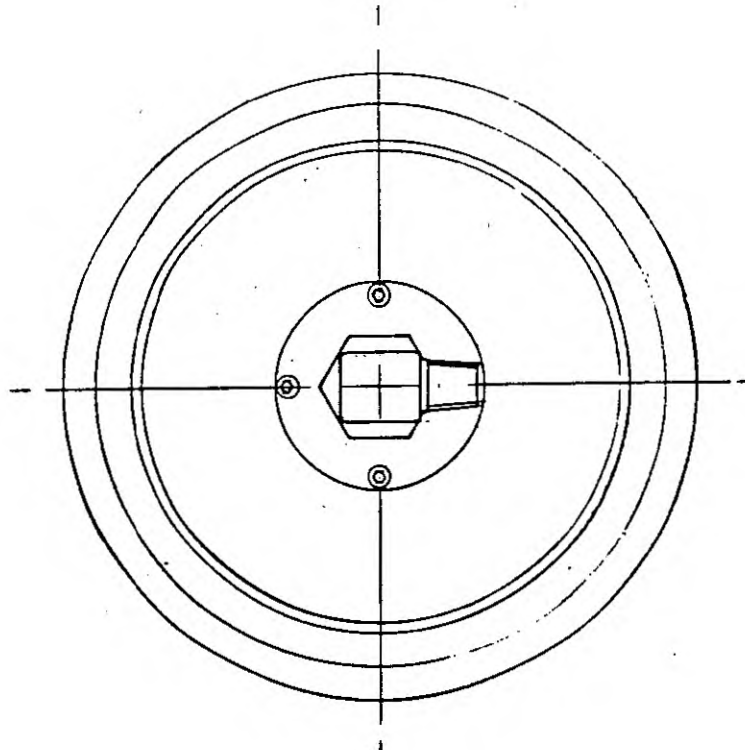
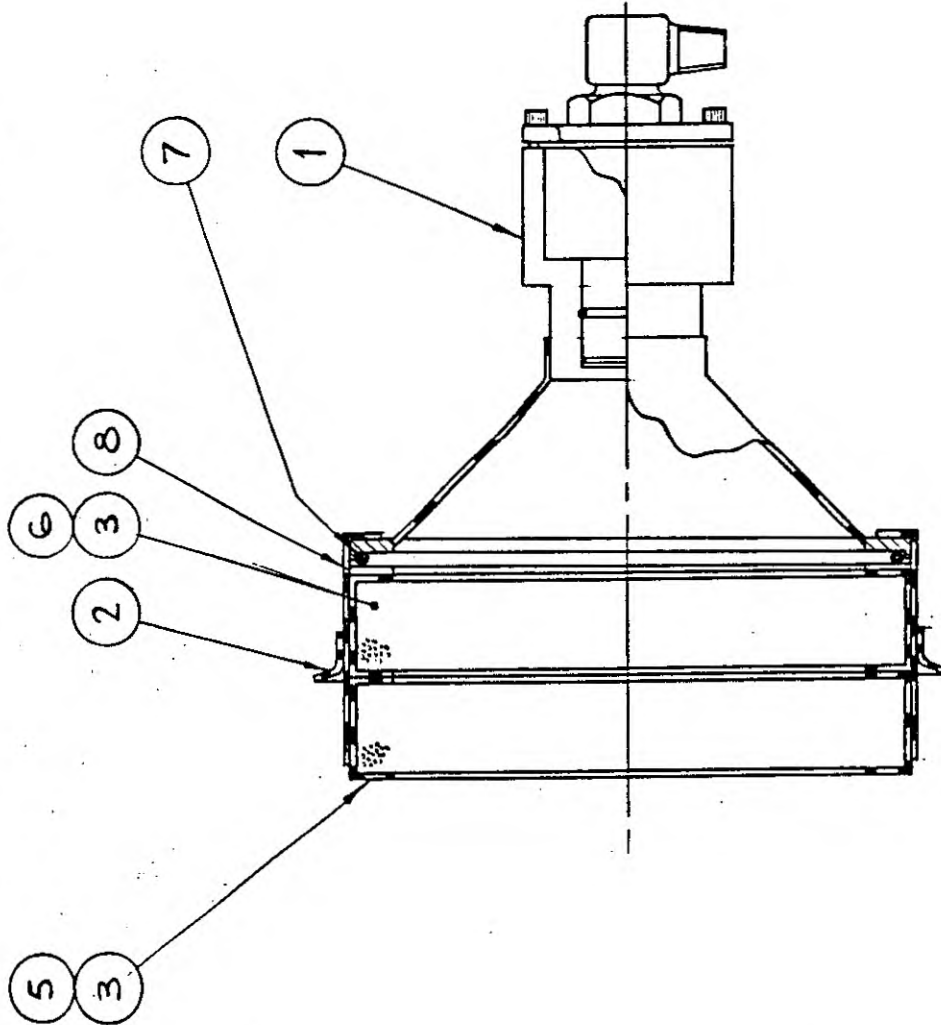
ISSUE	ALTERATION	DATE	BY
TITLE FOAM DISC 2ND. STAGE		MATERIAL POLYESTER SRF 30/90BG (90PP1) FINISH COLOUR - BEIGE	
TOLS: WHOLE Nos. ± 0.3 DECIMALS ± 0.1 UNLESS OTHERWISE STATED		DRAWN AJF	DATE 5.93 CHKD ARE
		SCALE 1:2	CAT. REF.
		DRG. No. JS 4018-01	

DRG JS 4019-01

DO NOT SCALE

IF IN DOUBT ASK

ISSUE	ALTERATION	ZONE	DATE	BY



ITEM	N°	DESCRIPTION	N°	OFF
8		FILTER CASSETTE DRG.No. JS 4021	1	
7		O'RING, PTFE 1 SIZE REF. 265	1	
6		FOAM DISC DRG.No. JS 4018	1	
5		FOAM DISC DRG.No. JS 4017	1	
4				
3		FOAM HOLDER DRG.No. JS 4009	2	
2		FOAM HOLDER ASSY.-OUTLET DRG.No. JS 4005	1	
1		OUTLET CONE ASSY. DRG.No. JS 4006	1	

TITLE

DUST CHAMBER
OUTLET ASSEMBLY

MATERIAL

FINISH

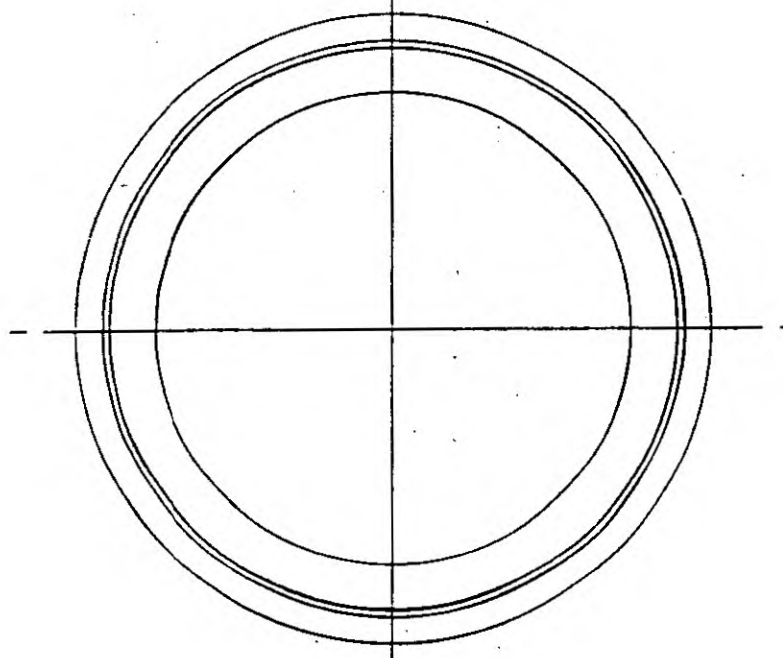
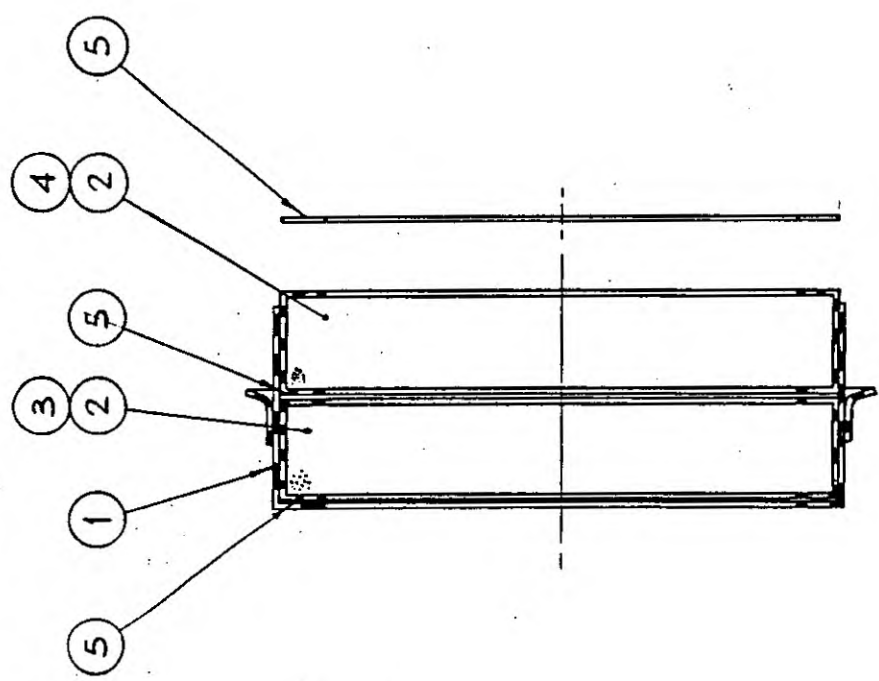
TOLS: WHOLE Nbr. 1 0 3 DECIMALS ± 0.1
UNLESS OTHERWISE STATED

DRAWN A J F DATE 5-93 CHKD. A K F

SCALE 1:1 CAT. REF.

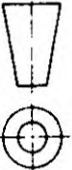
DRG. No. JS 4019-01

DRG JS 4020-01		DO NOT SCALE		IF IN DOUBT ASK		ISSUE		ALTERATION		ZONE		DATE		BY	
1	2	3	4	5	6	7	8	9	10	11					

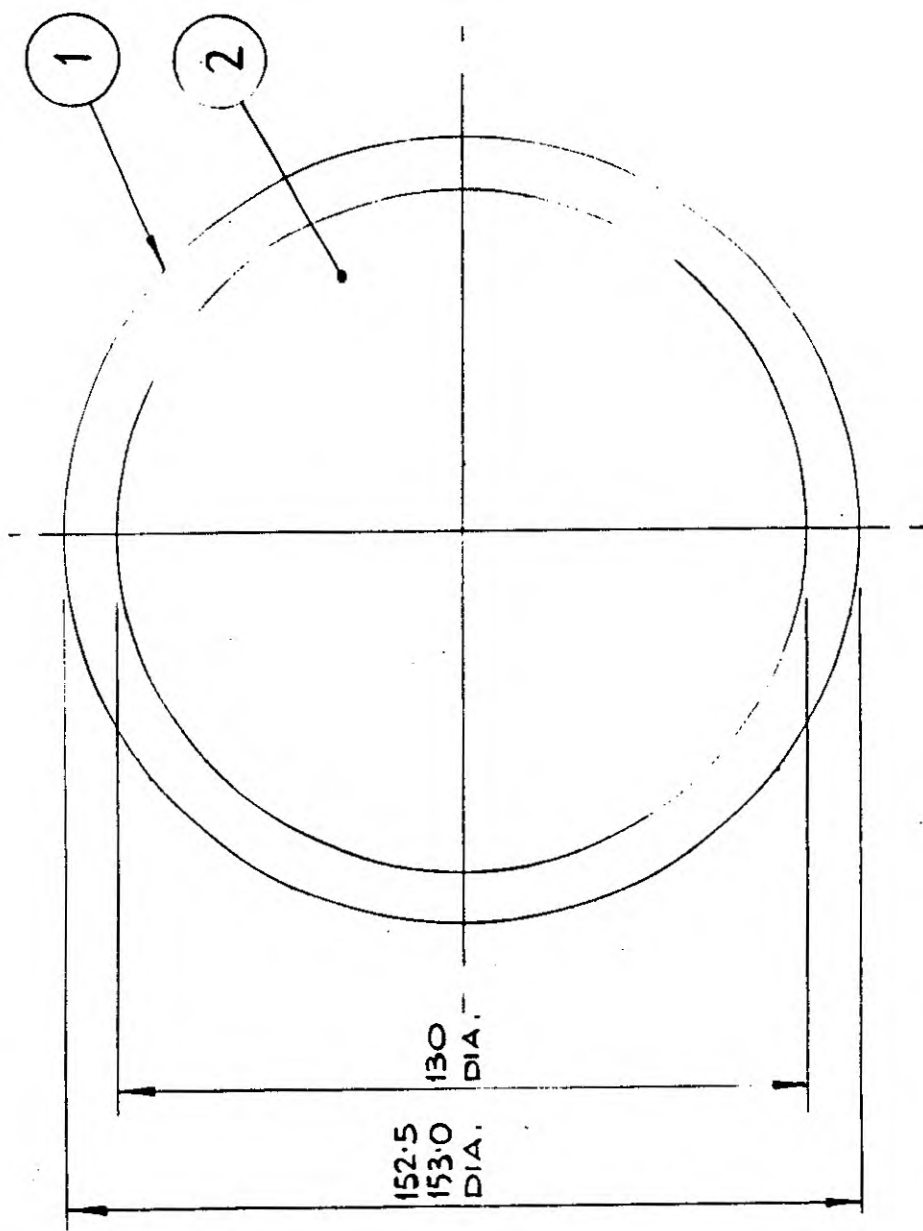


ITEM No.	DESCRIPTION	No. OFF
6		
5	FILTER CASSETTE DRG. No. JS 4021	3
4	FOAM DISC DRG. No. JS 4018	1
3	FOAM DISC DRG. No. JS 4017	1
2	FOAM HOLDER DRG. No. JS 4009	2
1	FILTER HOLDER ASSY.-INLET DRG. No. JS 4004	1

TITLE		DUST CHAMBER INLET ASSEMBLY		MATERIAL			
DRAWN A/JF		DATE 5-93		CHKD. A/F			
SCALE 1:1		CAT. REF.		FINISH			
				TOLS:		WHOLE Nos. 1 0 3 DECIMALS ± 0.1 UNLESS OTHERWISE STATED	
DRG. No. JS 4020-01							

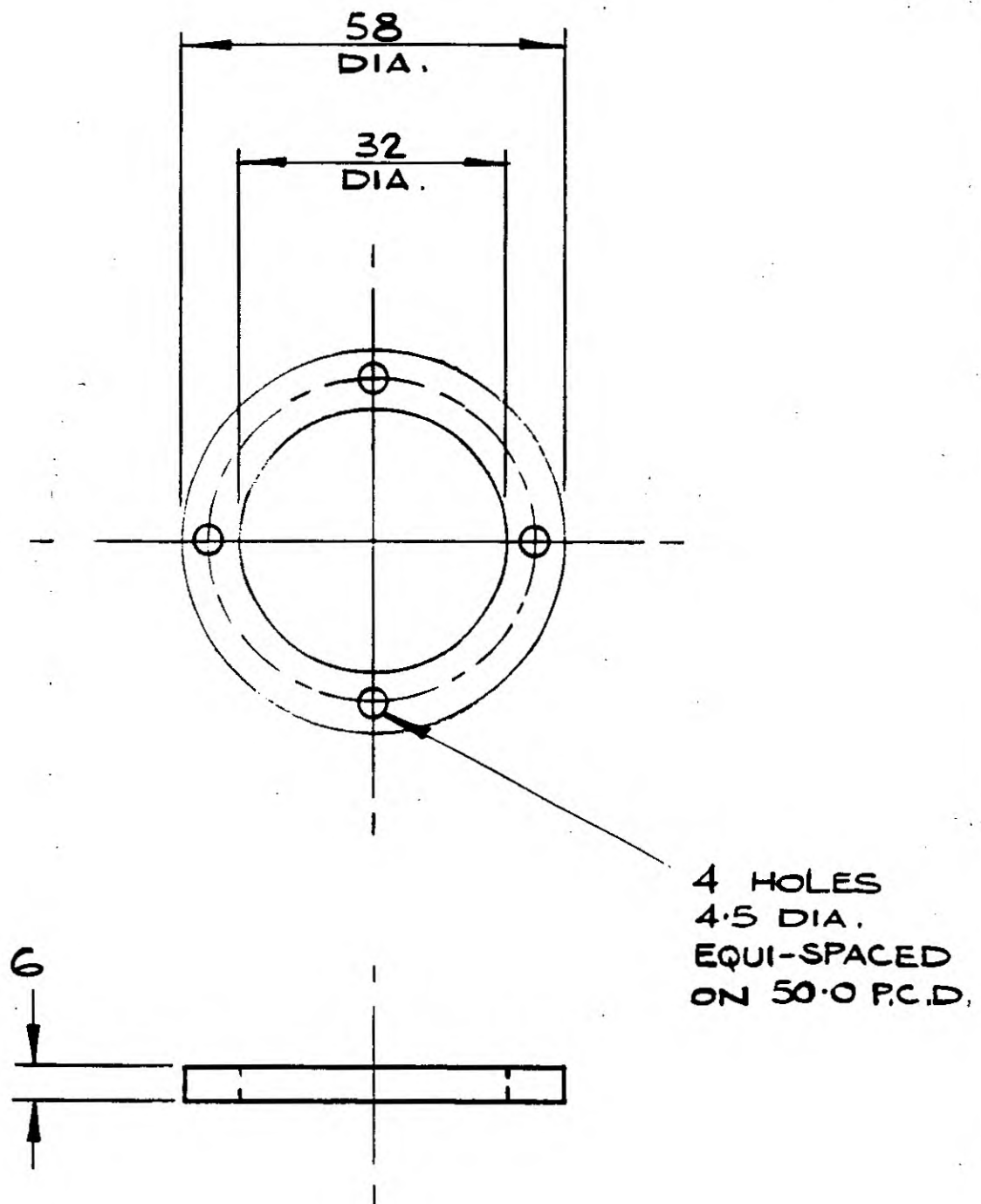
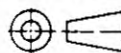
DRG No. JS 4021-01	DO NOT SCALE		IF IN DOUBT ASK	ISSUE	ALTERATION	ZONE	DATE	BY

2.5
2.0



TITLE		MATERIAL	
FILTER CASSETTE ASSY.		FINISH	
TOLS: WHOLE NOS. 0.5 DECIMALS 0.1 UNLESS OTHERWISE STATED		TOLS: WHOLE NOS. 0.5 DECIMALS 0.1 UNLESS OTHERWISE STATED	
DRAWN A/JF	DATE 5.93	CHKD. A/JF	DRG. No. JS 4021-01
SCALE 1:1	CAT. REF.		

2	WHATMAN GF/A FILTER ~ SCRM LAMINATED	1
1	PLASTIC MOULDING	1
ITEM No.	DESCRIPTION	No. OFF



ISSUE	ALTERATION	DATE	BY
TITLE RETAINING RING		MATERIAL ALUMINIUM ALLOY HE 30	
TOLS.: WHOLE Nos. ± 0.5 DECIMALS ± 0.1 UNLESS OTHERWISE STATED		FINISH	
DRAWN AJF		DATE 5.93 CHKD. ARF	
SCALE 1:1		CAT. REF.	
DRG. No. JS 4022-01			

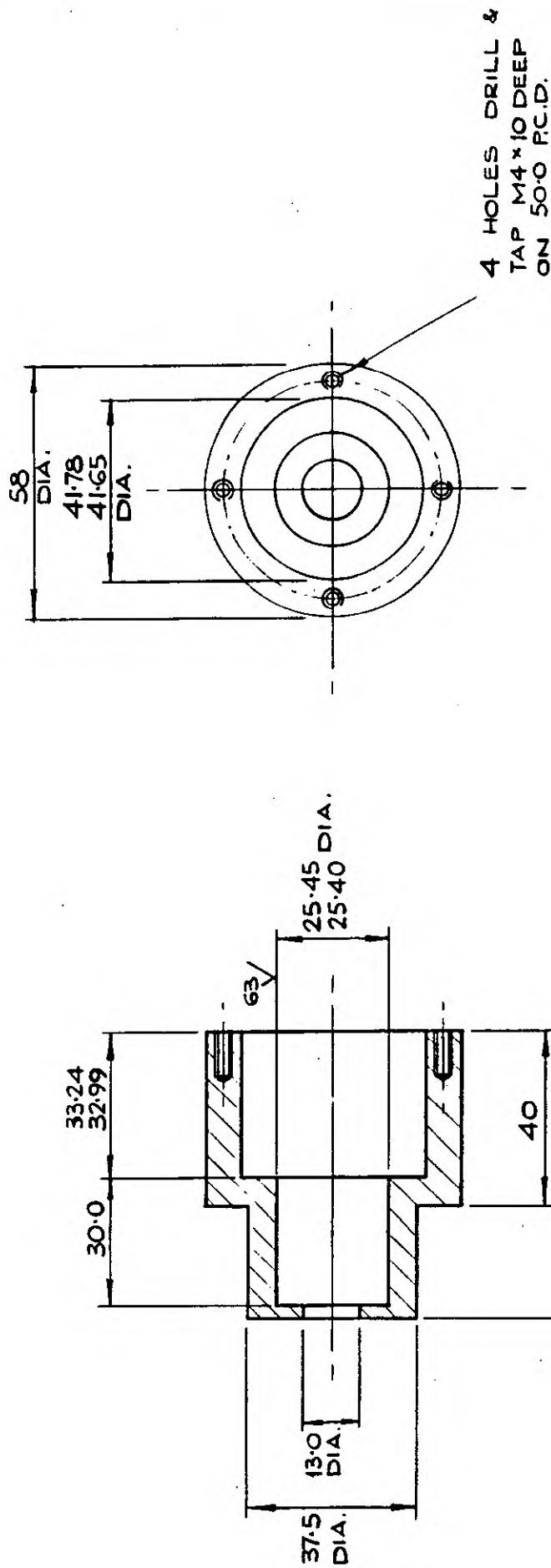
DRG No. JS 4023 01

DO NOT SCALE

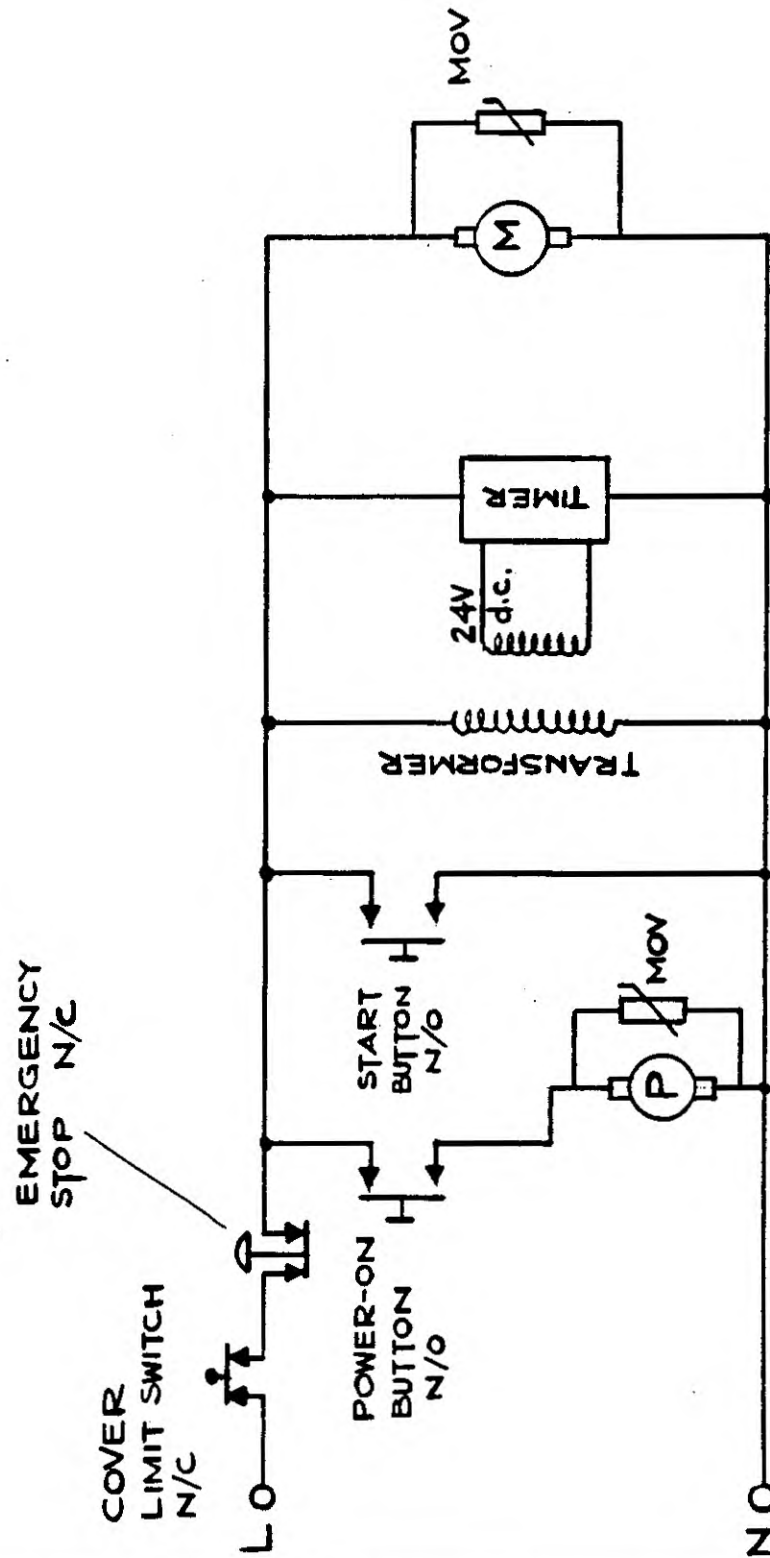
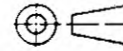


IF IN DOUBT ASK

ISSUE	ALTERATION	ZONE	DATE	BY



TITLE		MATERIAL		ALUMINIUM ALLOY	HE 30
UNION HOUSING		FINISH		_____	
		TOLS.		WHOLE NOS. ± 0.5 DECIMALS ± 0.1 UNLESS OTHERWISE STATED	
DRAWN AJF	DATE 5-93	CHKD. ARE	DRG. No. JS 4023-01		
SCALE 1:1	CAT. REF.				



ISSUE	ALTERATION	DATE	BY
TOLS: WHOLE Nos. ± 0.5 DECIMALS ± 0.1 UNLESS OTHERWISE STATED		TITLE CIRCUIT DIAGRAM	
		MATERIAL _____ FINISH _____	
DRAWN AJF DATE 5-93 CHKD ARE		DRG. No. JS 4024-01	
SCALE - CAT. REF.			

DRG No. JS 4025 - 01

DO NOT SCALE

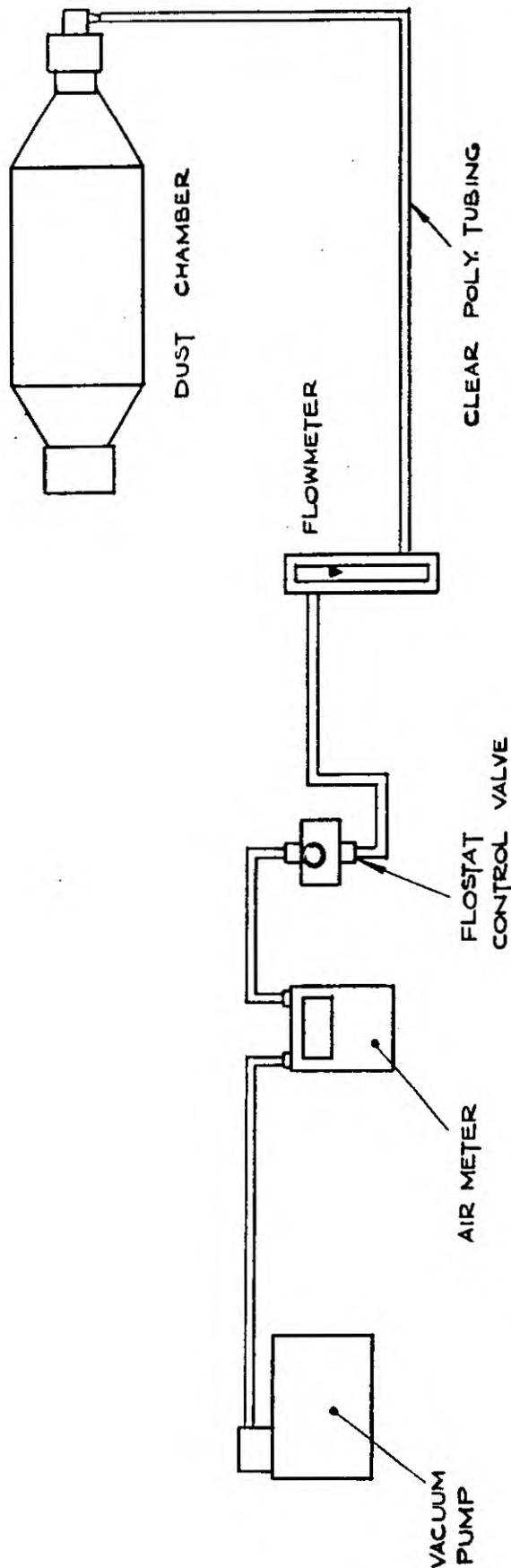


IF IN DOUBT ASK

ALTERATION

ISSUE

ZONE DATE BY



TITLE

PNEUMATICS DIAGRAM

MATERIAL

FINISH

TOLS: WHOLE NOS. ± 0.5 DECIMALS ± 0.1 UNLESS OTHERWISE STATED

DRAWN A J F

DATE 5-93

CHKD. JAF

SCALE -

CAT. REF.

DRG. No. JS 4025-01

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