Publication 37/84

HOME OFFICE

The Use of Smoke Extracting Equipment in Fire Brigade Operations

Fiona E Smith

SCIENTIFIC RESEARCH & DEVELOPMENT BRANCH

Publication 37/84 : Use of Smoke Extracting Equipment in Fire Brigade Operations

Home Office Scientific Research and Development Branch.
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May 1984

SC/82 138/144/1

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SUMMARY

The Report considers the use of portable smoke extraction equipment in fire brigade operations.

Previous work on this topic is mentioned, and a brief account given of the production and movement of smoke in general. The current use of extractors in Overseas Brigades and in U.K. Brigades and Salvage Corps is described . Commercially available extractors are reviewed. Smoke clearance tests using both 'cold smoke' and 'hot smoke' in 'Industrial B' building of the Fire Service College are described. Comment is made on the handling and electrical characteristics of the extractors.

It is concluded that smoke extraction equipment of a size practicable for carrying on fire appliances can have a significant effect in clearing smoke logged buildings where natural ventilation is poor for structural reasons, or wind speeds are low.

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1. INTRODUCTION.

The Fire Experimental Unit (FEU) of SRDB undertook this work as part of the Home Office Fire Research Programme. The Project Definition, prepared in 1975, is reproduced as Appendix A. This was reviewed in 1981 to take account of new techniques.

For the firefighter the major problems of entering smoke are the reduction in visibility and the potential irritant and toxic effects. Working in smoke necessitates the wearing of breathing apparatus (BA). Movement and communication are hampered and fatigue is accelerated.

The fire service is required to minimise damage to property in a fire situation. Smoke is a major cause of damage during and after a fire.

To alleviate these problems the task of ventilation can be carried out by brigades to clear smoke. Reference 1 gives guidelines for the timing and methods of ventilation at fires. The advice given is to ventilate as early as is practicable but warnings are given that fire spread and flashovers can occur as a consequence.

Depending on the circumstances, satisfactory smoke clearance can be achieved by the use of natural ventilation through suitable openings in the building. In difficult situations, such as fires in basements and ships, natural ventilation may be too limited, and forced ventilation may be used.

The most common method of forced ventilation by brigades is the use of portable fans ('smoke extractors'), and this is the major area of work described in this report.

Smoke extractors are not in general use in the U.K. Fire Service but they were found in use by the U.K. Salvage Corps and by some overseas brigades.

2. METHOD OF APPROACH.

A study of scientific literature on the production and movement of smoke was first made. Information on operational use of smoke extractors was obtained through visits to U.K. Fire Brigades and London and Liverpool Salvage Corps (Section 5.3). Reports on the use of extractors by overseas brigades were also consulted. Following this the programme of work was planned.

The types of smoke extractor currently available to the Fire Service either directly from manufacturers or through agents in the U.K., were identified. Examples of the main types were purchased for test purposes. Each extractor was assessed for physical characteristics, ease of use, maintenance problems and any other factors which might have a bearing on operational use. Simple measurements of air movement patterns of fan-type extractors were performed by FEU, and more comprehensive measurements were made by a contractor[1]. These adopted the measurement methods of a British Standard (Reference 2).

Smoke clearance tests were performed on the 'Industrial B' building at the Fire Service College, Moreton-in-Marsh. Two different rooms were used for the tests; a large first floor room with windows and doors on two opposite sides to enable lateral ventilation, and a smaller basement room with only one vent. These rooms were thought to be representative of the type of situation that might be met on the fireground, the first floor room enabling considerable flexibility in types of ventilation procedure, and the basement simulating a volume from which removal of smoke by natural means is difficult. Both 'hot' and 'cold' smoke were used in the tests. Two identical electrically powered fans were used to compare different ventilation procedures. A second series of smoke tests was used to compare the range of extraction equipment available.

A correlation of smoke tests and fan performance will be possible when the SWIRL Report[1] is available.

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1. South Western Industrial Research Ltd. (SWIRL), University of Bath, Claverton Down, Bath BA2 7AY. This report is not yet available (May 1984).

3. PREVIOUS WORK ON THE PRODUCTION AND MOVEMENT OF SMOKE.

Many references to smoke production and movement can be found in the literature but these refer to pre-determined situations in buildings using either natural convection or fixed systems for forced ventilation.

3.1 Fixed systems for forced ventilation.

The use of fixed ventilation systems to clear smoke is well documented by manufacturers and in other literature (References 3 - 5).

3.2 Work of the Fire Research Station (FRS) of the Department of the Environment.

Major areas of FRS research relevant to this project are:

a) Smoke production and movement in corridors, tunnels and shopping malls. Experimental work involving model studies, computer simulation and full-scale tests.
b) Criteria for ventilation for smoke control.
c) Methods of identifying and fighting oxygen-starved fires.
d) Methods of smoke extraction by fixed systems.

Further details of this work (a-d) are given in Appendix B.

e) Use of portable smoke extractors in firefighting.
Following a request in 1969 from the CFBAC Joint Committee on Design and Development of Appliances and Equipment, FRS produced a brief review on ways portable smoke extractors may be used in operations (Reference 6). The report explores the necessity of maintaining smoke stratification and non-turbulent flow to prevent smoke entering clear layers. The utilization of extractors to direct smoke flow and to dilute smoke is discussed. The report concludes that smoke extractors may be of some use to the fire service both during and after fires.

3.3 Model studies on smoke movement at Leeds Polytechnic School of Architecture.

A report published in 1981 assessed the validity of using small-scale architectural models to indicate smoke flow (Reference 7).

Case studies of recent fires were selected which represented different types of buildings, and for which information was available from fire brigade, press or eye witness accounts. The only case study which used scientific data involved the 'Industrial A' building at the Fire Service College, Moreton-in-Marsh. This utilised data from a previous FRS test on smoke movement (Reference 8).

Scale models were constructed from drawings or other records.

The results indicated that a general guide to the movement of smoke through a building could be obtained from such studies of models. Problems were encountered when trying to scale the effects of wind.

3.4 University of Edinburgh MSc Dissertation.

This dissertation, produced in 1981[1], (Reference 9) aims to give a critical assessment of available information on portable smoke extraction equipment and methods for firefighting. The report deals with both the theoretical aspects of smoke behaviour and the practical means by which ventilation may be effected. Mathematical formulae are included in the sections on generation and movement of smoke. The dissertation acts well as a quick reference guide to these theories.

The treatment given of the practical use of smoke extractors is based on manufacturers' recommendations.

The dissertation concludes that forced ventilation might be of use to the U.K. Fire Brigades but that, before it is adopted as practice further large scale experimental work must be undertaken.

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1. The author of this dissertation spent three weeks at FEU during his study. He was also a Local Authority fireman and therefore aware of the fire service requirement.

4. INTRODUCTION TO THE PRODUCTION AND MOVEMENT OF SMOKE.

4.1 Volume of smoke produced.

In order to assess the requirement for clearance of smoke, it is necessary to recognize the extent of smoke production by a solid fuel fire in a room. The volume of fuel gases present is minimal in comparison to the volume of entrained air, thus it is assumed that the rate of smoke production by a fire is approximately the rate at which air is entrained by the rising column of hot gases and flames (Figure 1 and Reference 10). This rate is dependent on :

a) The perimeter of the fire.
b) The heat output of the fire.
c) The height of the smoke layer above the fire ('Clearance height' y in Figure 1)

Some typical values for the production rate of smoke are tabulated below (Reference 10). The calculation is based on a flame temperature of 800°C in a room with an ambient temperature of 500°C.

Fire Perimeter m	Clear Layer Height m	Volume Rate of Smoke Production. m^3s^{-1}
12	2	13.1
12	3	26.2
20	2	25.0
20	3	50.0

To compare with these figures, the most powerful extractor[1] tested by FEU would remove smoke at $5m^3s^{-1}$, according to the manufacturer's figure. Hence this extractor would certainly not be able to remove smoke as quickly as it was being produced in this situation.

4.2 Quality and density of smoke.

Although the volume of smoke is important it is the quality of the smoke which determines the visibility through it. Smoke varies in quality from light-coloured to black and sooty, containing unburned decomposition and condensation products arising from the destructive combustion of the fuel. The density of smoke, and hence the visibility through it, is dependent not only on the fuel but also on the way that the fuel burns. Typically, flaming combustion of a 220mm square of 3.7mm hardboard will reduce visibility to 4.2m in a $34m^3$ room after 30 minutes. If the hardboard is smouldering the visibility will be reduced to 2.2m under the same conditions. As yet there are no universally accepted tests of smoke quality, so that figures reported will depend on the methods adopted by the particular experimenters.

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1. SRDB Code Number 1, Table 1.

It is useful here to discuss what is meant by 'visibility' and 'optical density' of smoke and how the two quantities relate. 'Visibility' is a subjective measurement since ultimately the quantity relies on observational assessment by the individual of an object in smoke. The optical density of smoke is measured objectively.

The reduction of light as it passes through smoke obeys a logarithmic law. Expressed mathematically it is written (Reference 10).

$$OD_x = \log_{10} I_o / I_x$$

where OD_x = optical density of smoke for path length x.
I_o = original light intensity.
I_x = light intensity after path length x.

Thus an optical density of 1.0 means that 90% of the incident light has been obscured. Although there is no formally agreed standard it is common practice to use a transmission path of 1m in making smoke density measurements.

The most recent and comprehensive study of the relationship between visibility and optical density of smoke has been carried out by Jin (Reference 11). He considered both the smoke quality and the method of object illumination in assessing visibility and found that his results fell into two distinct groups dependent on the object being either forward illuminated or back illuminated. Although Jin is the only person to study the visibility of back illuminated objects several workers have performed experiments on the visibility of forward illuminated objects. The results of Malhotra (Reference 12) and Rasbash (Reference 13) are in reasonable agreement with those of Jin and are shown in Figure 2. As a rough guide visibility and optical density have the following approximate relationships.

a) For forward illumination

visibility (m) = 1.0 / O.D. per metre

b) For back illumination

visibility (m) = 2.5 / O.D. per metre

4.3. Smoke production.

The smoke produced by a fire is hot, and because of this it rises in a plume to the ceiling (Figure 1). As further smoke is produced, it rises also and displaces the smoke which has cooled slightly. In this way the smoke layers down from the ceiling until the whole volume is filled with smoke. This is known as mushrooming. If the fire is extinguished and the smoke allowed to cool it will lose its buoyancy and thus the layers will disperse and the smoke will diffuse into the whole volume. Therefore hot smoke forms layers of different optical densities whereas cold smoke tends to fill a volume uniformly.

4.4 Ventilation requirements.

Since smoke build up in a fire is rapid it is important to consider how, by ventilation, this may be controlled. It is a complex theoretical problem and, within the scope of this report, it is thought necessary merely to outline the principles and conclusions that have been reached. For further study it is suggested that Reference 10 is consulted.

Since, in a fire, smoke rises to the ceiling and fills the room from the top, the majority of studies have been made on the effect of roof vents. To give a guide the amount of venting required to maintain a clear air zone of 2m height over a solid fuel fire is as follows (Reference 10):

Height of ceiling m	Diameter of fire m	Area of roof vents required m^2
3	0.75	2.0
4	0.75	4.0
4	1.50	6.3

The venting requirements of the table are for relatively small fires, but even these are impractical except in very large buildings.

The problem of the vent size required when a room is already smoke logged or where vents are positioned laterally rather than vertically has not, to the author's knowledge, been studied.

4.5 Basic ventilation practice.

To prevent mushrooming of smoke, vertical (i.e. top) ventilation should be carried out where possible. In most domestic properties and in buildings where access to the roof is limited or could prove dangerous, lateral (i.e. cross) ventilation is recommended. To prevent fire spread with this method of ventilation, the direction and strength of the wind is an important factor to take into account when choosing a procedure. If the fire is oxygen starved and smouldering, opening the fire compartment to air can lead to rapid spread. When this condition is suspected discretion is required in making the decision to ventilate.

5. OPERATIONAL USE OF EXTRACTORS.

5.1 The use of extractors in Overseas Brigades.

Although smoke extractors are not in widespread use in the U.K. Fire Brigade their deployment as a 'first line' piece of equipment is common in several countries.

The strategic use of smoke extractors to provide better working conditions for firemen and to enable the seat of the fire to be found quickly whilst reducing smoke damage, is common practice in European and American Fire Brigades. Their use is not well documented because smoke extractor deployment and ventilation is not seen as a novel or new method in firefighting.

By far the most extensive use of extractors is made in the USA, where there is a requirement for every ladder and salvage appliance to carry at least one extractor with a minimum capacity of $142 m^3 min^{-1}$ (Reference 14).

The strategy employed by American Fire Departments is one of intense water attack coupled with ventilation. Ventilation is the secondary responsibility of ladder companies following rescue and, wherever possible, natural ventilation is pursued by opening skylights, vents, windows and doors. Failing this, holes may be cut into roofs, ceilings and walls to produce airflow. When this airflow is inadequate, mechanical ventilators in the form of portable fans are used. The general mode of employment is for the fans to be used to draw smoke out of the fire compartment, i.e. by using them in the suction mode. For this purpose the extractors are placed at the top of an opening such as a window or door since the hot smoke stratifies and rises to the ceiling. In conjunction with this, additional fans may be placed at the bottom of such openings to inject fresh air into the compartment, and thus increase air flow still further. Because of the possibility of the input of fresh air increasing the burning rate, the ventilation is carried out only when charged hose lines are ready. Forced ventilation is, of course, continued after the fire has been extinguished to remove smoke and combustion products from the building.

The French have developed a water driven jet-pump type extractor[1] which has proved successful in removing toxic gases from several basement type situations (Reference 15). This type of extractor has no mechanical moving parts and is particularly useful for removing explosive or flammable gases since it is intrinsically safe.

The German Fire Service favours the use of smoke extractor fans and has developed a series of units in conjunction with a manufacturer[2].

Recent information indicates that the Dutch Fire Brigade does not use extractors but that the Swedish Fire Service make extensive use of them.

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1. Aneti extractor. See Table 1.

2. M & W Ltd. Stuttgart. - Type MWM portable extracting fans.

The ventilation policy of the Fire Service in the USSR is based on the removal of smoke to improve working conditions for the firemen and therefore enable them to find and extinguish the fire rapidly. The use of smoke extractors is widespread especially for basement or other fires where natural ventilation is limited. The recommendation of the Lenningrad Experimental Fire Station (Reference 16) was that three types of smoke extractor should be available to the Fire Service. The three types relate to the airflow capability of the extractors and are designated light, medium and heavy.The recommended tactical use of these fans is that smoke removal should be facilitated as soon as possible and to that end the light type of extractor is deployed on arrival at a fire. The medium or heavy units can then be sent for as required.

FEU is continuing to investigate overseas practice.

5.2 Survey of smoke extraction equipment in U.K. Brigades.

To assess the equipment currently used in U.K. Brigades a questionaire (Appendix C) was circulated to brigades with the assistance of the Chief and Assistant Chief Fire Officers' Association.

Replies were received from 55 brigades, including 31 nil returns. Details are given in Appendix C. Suppliers of smoke extraction equipment are given in Appendix E.

Sixteen of the brigades use only the Angus Turbex high expansion foam generator in the smoke extraction mode for smoke extraction. Three brigades use the Turbex but in addition have electrically driven fans and three brigades have electric fans only.

The survey confirmed that smoke extractors are not in general use in this country.

5.3 Visits to U.K. Brigades and Salvage Corps.

Following the Brigade survey, visits were made to Devon and Merseyside Fire Brigades who had given a positive response to the questionaire (Section 5.2). Both brigades had indicated that they used dedicated smoke extraction equipment, Merseyside having the added back-up of the Liverpool Salvage Corps equipment.

Liverpool and London Salvage Corps were visited as they were known to use extractors regularly.

Further details and photographs of the visits can be found in Appendix D.

5.3.1. Devon Fire Brigade.

From the Brigade Survey, Devon were known to use a number of Supervac P200SE 20 inch fans in addition to Turbex high expansion foam generators. The Supervac fans are carried in pairs on the Emergency Tenders and run from portable generators[1] also carried on these appliances. Generators are not standard equipment on other Devon appliances.

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1. Dale Emergency Products Ltd., Faraday House, Eastfield, Scarborough, Yorks. - Erskine Portable Generators.

The smoke extraction equipment in that brigade has been on the run since 1980 and in that time has been deployed in a number of situations. On most occasions the smoke clearance operation has been successful. It would seem, from the operational experience gained that the method of use of the equipment governs the success of the operation. On the occasions where smoke extraction failed the two extractor fans were used in series, that is, joined together by a length of semi-rigid ducting. Where one extractor was used to inject air, whilst the other exhausted the smoke, the operation was always reasonably successful.

Devon carries semi-rigid ducting for use with the extractors, but no layflat polythene ducting. Since the semi-rigid ducting is bulky, the amount carried is limited. The fans have hooks to enable them to be suspended in doorways from a bar[1] also carried.

5.3.2. Merseyside Fire Brigade.

Merseyside Fire Brigade carry Supervac P124 12 inch fans on first-line appliances. The 110v portable generators carried on these appliances were modified to withstand the starting current surge of the fans (Section 12).

Generally it is the Liverpool Salvage Corps which performs forced ventilation in Merseyside. It usually arrives at an incident in Liverpool at about the same time as the Brigade. The Fire Brigade officer in charge initiates ventilation, usually as soon as possible. All the brigade officers talked to valued the Salvage Corps ventilation equipment and tactics. As a result of this, and with the imminent disbanding of the Corps, the Brigade is considering supplementing the ventilation equipment carried on appliances.

Smoke clearance may be performed during a fire as well as during the later salvage phase. The equipment has also been used successfully to replace stale air during incidents on the underground railway network.

5.3.3. Liverpool Salvage Corps.

The Salvage Corps has considerable expertise in forced ventilation techniques. This is made good use of by Merseyside Fire Brigade. The Corps carries two types of smoke extraction fans: Supervac P200SEZ 20 inch fans and Spitznas axial fans. The latter have a good airflow performance, but are easily affected by tarry deposits on the fan blades from fire debris.

The fans are run from 240v a.c. mains supply.

Smoke extraction equipment is usually deployed immediately the Corps arrives at an incident but the order to switch on is given by the Fire Brigade officer in charge. Extensive use is made of layflat polythene ducting to remove smoke without extending smoke damage. Usually the fans are deployed to extract smoke from the building rather than to inject fresh air.

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1. Dale Electric of Great Britain Ltd. - Doorbar.

5.3.4. London Salvage Corps.

London Salvage Corps uses Woods Aerofoil fans which they have had adapted to their own specification. The adaptation includes an improved handle design which makes carrying the fans much easier. The fans are bought in kit form and made up by the Corps.

Smoke extractors were said to be the most frequently used equipment carried by the Corps. To enable layflat ducting to be used effectively in all conditions the Corps has developed easily fastened straps to hold the ducting onto the fans, and brackets to steady the open end of the ducting around in a wind. These items are detailed in Appendix D.

Again the Salvage Corps expertise in forced ventilation was utilised extensively by London Fire Brigade both in fires and in ventilation operations in the underground railway. It was reported that there had been no flashover accidents caused as a direct result of forced ventilation and that the Salvage Corps did not see this as a problem.

The usual method of operation of the fans was to extract smoke from the building rather than to inject fresh air.

6. COMMERCIALLY AVAILABLE SMOKE EXTRACTORS.

6.1 Types of extractors available.

Trade directories were surveyed for manufacturers and suppliers of smoke extraction equipment. Organisations listed were contacted and a dossier of relevant information was compiled.

The majority of organisations manufactured or supplied fixed installation smoke extraction equipment. Appendix E lists manufacturers and suppliers of portable equipment.

Portable equipment, as required for fire service use, can be classified into two main types:

Type 1 Fans
Type 2 Smoke entrainment devices

Fans are the most common smoke extractors and they can be driven by:

a. Electric motors. Flameproof motors are available.
b. Petrol or diesel engines.
c. Water motors.
d. Compressed air motors.

The majority of the fans are electrically powered. The most common supplies for portable extractors are 240v single phase or 110v single phase. These can be operated from a mains supply, via a transformer if necessary, or from portable or vehicle mounted generators (but see also Section 12).

6.2 Extractors purchased for test.

A list of extractors purchased for test is given in Table 1, which includes an SRDB Code Number alloted to each extractor type.

Five fans were chosen for test, and one smoke entrainment device.
Photographs of the extractors are shown in Figures 3 - 9.

The Angus Turbex was chosen because it is the high-expansion foam generator in most common use in the Fire Service and has a smoke extraction capability. The Symtol Compact Generator was developed under contract to the Home Office for high expansion foam work, and can also be used as a smoke extractor.

From the large variety of electrically driven fans available, the Supervac fans were purchased because they are sold specifically for fire service use, and used extensively in the USA. The Woods fan was chosen because it is used by the London Salvage Corps.

The Aneti extractor is the only known example of a smoke entrainment device which has been used by a fire brigade (Section 5.1).

6.3 Use of ducting with smoke extractors.

Semi-rigid or layflat polythene ducting can be used with extractors. The semi-rigid ducting is used on the inlet side of the extractor and the layflat polythene ducting on the outlet side, where positive pressure exists. Use of ducting allows more versatility in the positioning of the extractors.

6.4 Tests on the extractors purchased.

As indicated in Section 2, the performance of the fans was assessed by three methods.

First, simple measurements of air movement patterns were made by FEU (Section 10.1).

Second, more comprehensive measurements were made by SWIRL[1] using the methods of a British Standard, Reference 2.

Third, fan performance was measured when extracting smoke from a building (Section 10.3).

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1. South Western Industrial Research Ltd. (SWIRL), University of Bath, Claverton Down, Bath BA2 7AY. This report is not yet available (May 1984).

7. CONDUCT OF SMOKE CLEARANCE TESTS IN 'INDUSTRIAL B' BUILDING.

7.1 GENERAL

As indicated in Section 2, tests of various smoke clearance procedures were made in the first floor and basement of 'Industrial B' building at the Fire Service College, using two identical electrically powered fans and both 'hot' and 'cold' smoke.

A second series of tests was made in the basement of 'Industrial B' building using 'cold' smoke only, to compare the range of extraction equipment available.

Smoke was produced for the tests in the manner described in Section 7.2 below. The density of the smoke was monitored throughout by measuring optical density, and a small number of measurements of visibility were also made. Instrumentation for these and other purposes is described in Section 7.2 below.

It will be seen from results of smoke clearance tests reported in Sections 8, 9 and 10.3 that in general the logarithmic plot of optical density fell linearly with time during the clearance process. The gradient of each plot can be taken as a measure of the speed of clearance, and is represented by the 'half clearance time', defined as the time in minutes required to halve the optical density. The quantity is tabulated in the tables of experimental results. Note that, because the optical density is logarithmically related to time, it takes another 'half clearance time' for the optical density to fall from half to one quarter its original level and so on.

The half clearance times were taken from measurements at a height of 2.00m or 1.95m, this being approximately head height (Section 7.3.2). As an indication of the significance of the measurements obtained, optical densities of 2.0 and 0.43 per metre correspond to obscurations of 95% and 50% per metre, and imply visibilities for forward illumination of about 0.5 m and 2.3 m (Section 4.2). The upper density figure approaches the maximum which can be read satisfactorily with the instrumentation used, and the lower figure was judged to represent the point at which the visibility was just acceptable for most operations, and the irritant effects of the smoke were much reduced.

7.2 Smoke production for tests.

7.2.1 Cold Smoke

To achieve reproducible volumes and densities of smoke, artificially generated smoke is most convenient. There are two main types of generator, the theatrical type using heated oil, and pyrotechnic smoke generators.

Initial tests showed that the theatrical smoke generators[1] produced relatively small amounts of smoke which was heavier than air, settled close to the ground, and built up slowly. Even a number of such units would have been slow to produce the required results, with complications of expense, bulk, and electrical and gas supply lines.

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1. Concept Engineering Ltd., 30 White Waltham Airfield Estates, Maidenhead, Berks.. - Mk X 110v 50Hz single phase, remote control smoke machines.

In contrast, a large volume of dense smoke could be produced quickly and simply by using several pyrotechnic generators[1]. The smoke was propelled towards the ceiling. Air temperature rises of 1 to 2 degrees Centigrade were produced in the rooms of 'Industrial B' building, and the smoke behaved somewhat more like 'hot smoke', but soon approaching a uniform density throughout the room. The canisters were convenient to use, and were adopted for the 'cold smoke' tests.

The number of canisters used for each test was chosen to produce an optical density exceeding 3.0 in 5 - 10 minutes throughout the room, 20 being used for each test in 'Industrial B' first floor, 5 in 'Industrial B' basement (Sections 8.1 and 9.1). The canisters stood in a sand tray (Figure 10) and were ignited electrically by an operator outside the test room, using two series-connected 4.5 volt Type H30 batteries and a switching arrangement.

The canisters usually burned for about 7 minutes, but 10 minutes was allowed from ignition before the smoke clearance test commenced.

7.2.2 Hot smoke.

There are difficulties of reproducibility of volume and density of smoke from test fires. The most effective way of producing 'hot smoke' consistently is by igniting a known volume of liquid fuel of defined quality and allowing it to burn out. Hydrocarbons such as diesel oil and kerosene can produce satisfactory smoke for the purposes of the tests, but also produce oily and unpleasant combustion products which deposit on instrumentation and prevent accurate measurements of optical density. Lighter hydrocarbons, such as heptane or petrol, produce smoke in somewhat lesser quantities[2], but the fires necessary would have been large and hot enough to risk damage to the fabric of the fireground building.

A solution was sought by using fires of damp straw, primed by a small amount of diesel oil. About half a bale of the straw was placed loosely in a steel crib about 76 cm x 100 cm x 60 cm deep, making it about one third full (Figures 11 and 12). Generally, the fire was allowed to produce an optical density of at least 3.0 throughout the room despite the layering of the hot smoke before ventilation or extinction.

The fire behaviour was somewhat variable in burning rate, smoke production, and flame height. Variable quantities of steam were also produced by the extinction. Production of the necessary optical density was slow, and the time required varied.

Nevertheless, the fires of damp straw produced adequate conditions for the purposes of the smoke extraction tests, and enabled comparison to be made between the extraction behaviour of 'hot' and 'cold' smoke (Section 8.2.4.(i)).

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1. Standard Fireworks PLC, Half Moon St., Huddersfield, HD1 2JH. - 6 inch white smoke cases, electric ignition.

2. The concentration of fire gases in a room may be detected by monitoring the level of carbon dioxide. This is an alternative to measurements of optical density when smoke density is low. However, optical density measurements were adopted for the present work since they relate directly to the fireman's difficulties in smoke.

7.3 Instrumentation

7.3.1 General

A mobile laboratory was sited adjacent to 'Industrial B' building (Figure 13). Sensing equipment in the room of the building used for the test was cabled to the mobile laboratory, which contained the associated indicating equipment, including video tape recorders and monitors. Communication was maintained between the mobile laboratory and the experimental area in the building by means of battery operated headsets[1]. Conduct of the experiment was controlled in this way. Timing points were maintained in the laboratory, and instructions could be given to all the experimental team simultaneously. When video recorders were in use, all voice communication was recorded on tape.

Access to 'Industrial B' building for the conduct of the tests was limited to periods of two to three days only at one time. The equipment to be used in the building was therefore arranged to allow quick deployment and recovery from the test site.

7.3.2 Smoke density metering equipment

(a) Description

Commercially available smoke density metering equipment[2] was modified by FEU to allow quick deployment at the test site. The sensing equipment of each meter consisted of a light projector and photocell receiver rigidly mounted in a Dexion frame to give a horizontal optical path length of one metre (Figure 14). The associated electronics and indicator calibrated in percentage obscuration were rack mounted in the mobile laboratory and connected to the projector/receiver unit in the test room of the building by two cables. The four smoke density meters were identified as 'red', 'blue', 'white', and 'green'. Electrical signals corresponding to the readings of obscuration were connected to a UV (ultra violet) chart recorder[3] (Figure 15).

(b) Calibration

As a refinement of the maker's calibration, each meter was calibrated by placing neutral density filters[4] between the projector and receiver (Appendix F). In use frequent cleaning of the lenses in the projectors and receivers was necessary to maintain the calibration, particularly in hot smoke tests. The neutral density filters were handled and stored with care to avoid contamination.

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1. General Acoustics Ltd., PO Box 20, Scarborough, N. Yorks. YO11 1DE - GA 11 headset.

2. Babcock - Bristol Ltd., Power & Water Division, 218 Purley Way, Croydon. - Smoke density metering equipment E66-50/5 with Industrial Control Unit.

3. Bryans Southern Instruments Ltd., Willow Lane, Mitcham, Surrey, CR4 4UL. - UV Recorder series 45,000, Galvanometer driver amplifiers model 40501.

4. Kodak Ltd., Box 33, Hemel Hempstead HP2 7EU. - 100mm square gelatine Neutral Density Filters ND 0.1 - 2.0.

(c) Location

The smoke density metering units were positioned at various heights in the test rooms to monitor layering effects. In general, one was as close to the ceiling as possible, and one at head height. The units were generally supported on a scaffolding tower (Figure 16) or on plank trestles (Figure 17).

(d) Observation

The readings of the percentage obscuration indicators were noted by an observer at 30 second intervals throughout the test, and recordings were also made on the UV chart recorder (Section 7.3.2(a)).

7.3.3 Visibility monitoring equipment

As indicated in Section 7.1, measurements of visibility were made. A number of motor vehicle rear (red) fog lamps were mounted at 1 metre intervals on a Dexion frame to serve as back-illuminated objects. A video camera was mounted 1 metre from the nearest lamp (Figure 18). During the smoke tests, video tape recordings were made. These measurements are not reported here.

7.3.4 Temperature measuring equipment

(a) Description

Air temperatures external to the building were recorded by a mercury-in-glass maximum and minimum thermometer. In early tests a similar thermometer was used in the test room, but in later tests K-type thermocouples[1] were used.

(b) Location

The external thermometer was attached to the outside of the building. The internal thermometer was placed next to the topmost smoke density unit. When thermocouples were used, these were arranged at different heights from ceiling to floor in the test room.

(c) Observation.

The thermometers were read at the beginning and at the end of each test. The thermocouples were monitored every 30s by an observer outside the room using digital instrumentation[2].

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1. Electroplan Ltd., PO Box 19, Orchard Road, Royston, Herts - NiCr/NiAl thermocouples.

2. Electroplan Ltd., PO Box 19, Orchard Road, Royston, Herts - Digitron Type 2751-K

7.3.5 Wind speed and direction monitoring

Since ventilation is dependent on the wind speed and direction it was important to record wind conditions throughout the tests.

a) Description

Wind speed was measured with an anemometer and direction with a wind vane, both of which[1] were mounted on a cross arm at the top of a 4m pole (Figure 19). The wind station was connected to a display unit and chart recorder[2] in the mobile laboratory (Figure 20). The signal was also taken to the UV recorder (Section 7.3.2(a)) to ensure that the wind conditions could be correlated with the smoke density readings.

b) Calibration

The wind vane assembly was oriented correctly using a magnetic compass[3].

c) Location

To minimize the effect of buildings on the wind conditions the wind station was erected approximately 100m from 'Industrial B' in an open position.

d) Observation

The chart was marked to denote the beginning and end of each test and the onset of ventilation. In most tests the signal was processed by the display unit to smooth out short-term variations on the chart-recorder trace.

7.3.6 Time

Time was monitored by the experimenters in the mobile laboratory using manually operated split-second-hand stopwatches. The stopwatches were started as the smoke canisters were ignited or as the crib fire was lit.

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1. Vector Instruments, 113 Marsh Road, Rhyl, Clwyd - Wind speed and direction display type D600.

2. Edgecumbe Peebles Ltd., Bothwell, Glasgow - 'Inkwell' Dwarf Recorder.

3. SILVA Sweden AB, Kuskvagen 4, S-191 47 Sollentuna, Sweden - Type 3 compass.

8. TESTS OF SMOKE CLEARANCE PROCEDURES IN 'INDUSTRIAL B' BUILDING FIRST FLOOR.

8.1 Description of test room.

As indicated in Section 2, the first floor room of 'Industrial B' building was chosen as representing a situation where natural lateral (i.e. cross) ventilation is possible and would normally be performed.

Figure 21 is a general view of 'Industrial B' building from the west, and Figure 22 shows the interior of the first floor from the southern corner. Figure 23 is a floor plan. The main part of the first floor room is 17.4m x 9.2m, with no ceiling under a pitched roof. The room has a small extension in the western corner with a conventional ceiling of 3.3m height. The total volume of the room is $880m^3$. An internal door at the south-west end of the room leads onto the staircase. Internal partition walls exist as shown in Figures 22 and 23 to a height of 2.0m.

Doors 2.0m x 1.2m at the east and west corners of the main part of the room give onto the surrounding balcony, and continuous glazing runs along the two long sides. The upper part of this can be opened, providing 22 glazed vents each 60 cm x 26 cm high on each side.

8.2 Method

Figure 23 shows the position of the test equipment. Smoke density meters were secured at heights of 3.90m ('red'), 2.75m ('blue'), 2.00m('white'), and 0.90m ('green') (Figures 16 and 22).

For cold smoke tests, 20 smoke cannisters used for each test were arranged in two groups of 10, one at each end of the room (Figures 10 and 23). A crib fire used for hot smoke tests is shown in Figure 12.

In each cold smoke test, the ventilation procedure was initiated 10 minutes after ignition of the cannisters, this being several minutes after they had ceased to burn (Section 7.2.1). In the single hot smoke test reported, ventilation was initiated 6 minutes after an optical density exceeding 3 had been established throughout the room. The fire was extinguished with water three minutes later. Recorded times were taken as zero at initiation of ventilation.

Tests using natural ventilation involved doors (at the east and west corners) and glazed vents (Section 8.1). At commencement of natural ventilation, the doors and vents were opened speedily commencing at the east corner, and finishing at the north corner. This was considered by the Fire Officer taking part in the project, to conform to normal Fire Service practice.

For forced ventilation tests, electric fans were chosen for convenience. The type used was Supervac P164SEZ, SRDB Code No.4 (Table 1), since this had the highest quoted airflow of those advertised for fire service use. One or two fans were positioned singly in the open doorways at the east and west corners as in Figure 24. In some tests, the fan was fitted to the door opening by a hardboard sheet forming a 'baffle' (Figure 25). The fans were powered from the mains supply to the building through a 110 volt transformer[1].

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1. Tsar Marketing, Transformer Safety and Research Co. Ltd., PO Box 91, Swindon, Wilts SN1 3QF - 3KVA 110v transformer, modified to FEU specification.

8.3 Results

A total of 17 cold smoke tests and one hot smoke test is reported.

Table 2 shows the schedule of tests conducted, with temperatures and recorded wind conditions averaged over the period of ventilation. The wind speed component resolved perpendicular to the upwind (long) side of the building is tabulated, calculated according to Figure 26. Figures 27 and 28 further summarise the ventilation procedures adopted, and the wind conditions recorded for each test.

Smoke density measurements are presented graphically in Appendix G. Calculated half-clearance times (Section 7.1) are given in the final column of Table 2.

Figure 29 A - D are comparison graphs given to illustrate the discussion below. They are derived from the results in Table 2.

8.4 Discussion

8.4.1 Effect of wind speed on natural ventilation.

Tests 5, 8, 9, 11, 18, 19 and 20 used full natural ventilation through doors and windows. The half clearance times (Section 7.1) for these tests are plotted as ordinate in Figure 29 A.

With any ventilation procedure, both wind direction and speed are important. In the series of tests conducted, wind conditions varied in both direction and speed. To simplify analysis, the component of wind speed was calculated perpendicular to the long sides of 'Industrial B' containing the windows and doors which acted as vents. (Section 8.3, Figure 26, and Table 2). The assumption is made that this resolved speed can be regarded to a first approximation as the independent variable controlling the natural ventilation, and it is plotted as abscissa in Figure 29.

Figure 29 A shows a marked effect of wind speed, the recorded half clearance times falling from 1.85 minutes to 0.40 minutes as the resolved wind speed increased from 1.6 to 6.9ms^{-1}. The effect is most marked at speeds below 4 ms^{-1}. An estimate of the reproducibility of the experiments can be made from the closeness of the obscured points to the 'best fit' curve drawn through them,particularly in the case of Tests 8, 9, 19 and 20 which were made at approximately the same resolved wind speed.

Figure 29 A confirms that wind conditions are important in interpreting the results of the tests. The 'best fit' curve provides a reference against which to judge the results of tests conducted with other conditions such as forced ventilation.

8.4.2 Effect of reduced natural ventilation.

Test 21 used natural ventilation through the two doors only. Figure 29 B shows the result plotted against the 'best fit' curve from Figure 29 A. In this test, the wind direction was closely parallel to the long sides of the building, so that the resolved wind speed was zero. Despite this fact, and the reduced area of venting, the half clearance time recorded is shorter than several others obtained, and the experimental point in Figure 29 B relates only roughly to the 'best fit' curve. Evidently, the simple treatment of resolved wind speed as the independent variable is inadequate in this case, and no conclusion can be drawn.

8.4.3 Effect of 'hot smoke'.

Test HS3 is the only test with 'hot smoke' reported in Section 8. Natural ventilation was used.

The plotted point in Figure 29 B is displaced from the natural ventilation curve of Figure 29 A, but the linearity of optical density plotted logarithmically against time is preserved (Appendix G, Figure G18), and the four plots taken at different heights lie close together, as with the cold smoke tests.

Hence it may be concluded that the behaviour in clearance of 'hot smoke' is generally similar to that of 'cold smoke'.

8.4.4 Effect of additional forced ventilation using one or two extractor fans.

In tests 7 and 13 a fan was positioned in the upwind doorway at the west corner to inject air. In tests 10 and 15 a fan was positioned in the downwind doorway at the east corner to extract. In test 16 two fans were used, one at the west to inject, one at the east to extract. This forced ventilation was in addition to full natural ventilation. Figure 29 C shows the clearance times obtained plotted against the natural ventilation curve from Figure 29 A. The effect of the fans is not significant compared with the natural ventilation, but there is some suggestion that the use of a fan to extract may be more effective than using it to inject. This may be due to turbulence produced within the room when injecting air at high velocity. Again, the fan operating to extract in the downwind doorway is partly shielded from the prevailing wind, and so may have more effect than a fan used to inject at the upwind door.

The single test (16) performed with two fans shows no improvement over the use of a single fan to extract.

Visual observations during the tests showed local improvements in visibility were achieved when a fan was used to inject air.

8.4.5 Effect of baffling the fans.

In tests 6, 12, and 14, a single fan was used, fitted to the door opening by a baffle. In test 17 two fans were used in this way to inject and to extract. The results are plotted in Figure 29 D against the natural ventilation curve of Figure 29 A. There is no overall improvement over the use of unbaffled fans, though again there is a suggestion that a fan used to extract is more effective than one used to inject.

Reference 17 recommends the use of baffles to prevent turbulence in the air and smoke, and to prevent smoke re-entering the room after extraction. This recommendation is not borne out in the conditions of the tests, but this negative result can be explained by the domination of the effects of natural ventilation.

8.5 Conclusions.

Under the conditions of the tests:

(i) Natural ventilation depended strongly on wind speed, although only a small improvement occured after the wind speed exceeded 4 ms^{-1}.

(ii) 'Hot smoke' behaved similarly to 'cold smoke'.

(iii) The use of extractor fans to supplement natural ventilation gave no significant general advantage. The effect of natural ventilation dominated.

Test conditions did not permit the relative advantages of using a fan to inject or to extract to be established, nor did they enable the effect of baffles, or of variations in the positioning of fans in doorways, to be established.

9. TESTS OF SMOKE CLEARANCE PROCEDURES IN 'INDUSTRIAL B' BUILDING BASEMENT.

9.1 Description of test room.

As indicated in Section 2, the basement of 'Industrial B' building was used to represent an operational situation where natural ventilation is absent or very limited, so that extraction equipment might be expected to have significant effect.

The basement is a relatively small room 5.8m x 6.3m x 2.6m high under the west corner of 'Industrial B' (Figure 21). Figure 30 shows the floor plan and an elevation.

Along the south west side there are sealed pavement lights, and in the building face above these are three ventilating panels. For the purposes of the tests, two of these were permanently sealed, leaving one effective vent 0.55m x 0.87m close to the west corner of the room (Figure 31). Near the south corner of the room, a doorway 1.2m x 2.6m connects with the stairs leading up to ground level. In the absence of a door, a plywood sheet was fitted to the doorframe for the purposes of the tests. Two circular 'shutters' in this, each0.42m diameter, could be opened to provide natural ventilation (Figure 32). When a fan was used in the doorway, it was placed against the lower shutter, the upper shutter remaining closed.

9.2 Method

Figure 30 shows the position of test equipment. The 'red', 'blue' and 'white' smoke density meters were at heights of 2.50 m, 1.95 m, and 1.20 m respectively, supported on plank trestles (Figures 11 and 17).

For cold smoke tests, a group of 5 smoke canisters was used, located centrally in the room. A crib fire used for the 'hot smoke' tests is shown in Figures 11 and 12.

As described in Section 8.2, in cold smoke tests the ventilation procedure was initiated 10 minutes after ignition of the canisters, this being several minutes after they had ceased to burn (Section 7.2.1). Similarly, in the hot smoke tests, ventilation was again initiated after 6 minutes at an optical density exceeding 3 throughout the room. The 'hot smoke' fires were extinguished with water from a hosereel played through the open vent, the timing being as noted on the graphs of Appendix H. Recorded times were taken as zero at initiation of ventilation.

In tests using natural ventilation, various combinations of the top vent and the plywood 'door' shutters were used (Section 9.1). For the tests of forced ventilation, one or two electric fans, SRDB Code No 4, Supervac P164 SEZ (Table 1) were used, as in Secton 8.2. When a fan was arranged to extract, ducting was generally used. In some tests semi-rigid neoprene ducting was used on the inlet side of the fan, in others layflat polythene ducting was used on the exhaust side to avoid smoke logging the staircase. A 3 m length of semi-rigid ducting was used, and a 15m length of layflat polythene.

9.3 Results

A total of 9 cold smoke and 5 hot smoke tests are reported. Table 3 gives details of the tests with recorded temperatures. The figures given for wind conditions are averages taken over the period of ventilation. The wind speed component resolved perpendicular to the vented (south west) end of the building is calculated according to Figure 26 and tabulated.

Figures 33 and 34 further illustrate the ventilation procedures adopted, and the wind conditions recorded for each test.

The smoke density measurements taken are given in full in Appendix H. The calculated half-clearance times (Section 7.1) are given in the final column of Table 3.

Figure 35 is a comparison graph which reproduces results from Appendix H. For cold smoke tests it compares natural ventilation with the effects of one or two fans.

9.4 Discussion

9.4.1 Natural Ventilation

Tests 23, 27 and HS4 were conducted with natural ventilaton and show very long clearance times, indicative of the very limited effect of the top ventilator.

9.4.2 Effect of wind speed.

The resolved wind speeds varied from positive to negative (Table 3). A positive wind speed indicates a component entering the upper vent, a negative speed means that the building shielded the vent from the direct action of the wind, although smoke, once extracted, would be dispersed by the wind.

Tests 26 and 28 were made with the same fan configuration but with resolved wind speeds of opposite sign. They gave very similar results. Similarly, tests 30 and HS8 each used two fans, but in opposite senses in the two tests. Despite the fact that both tests had negative resolved wind speeds, the results for half-clearance times are similar to each other.

The small effect of the wind speed may be partly explained by the fact that the door communicated via the stairs to the same building face as the upper vent (Section 9.1), so giving a balancing effect.

9.4.3 Forced ventilation

9.4.3 (i) 'Cold smoke' tests

The initial horizontal plateau in the smoke density curves is a consequence of the high initial smoke density obtained, and the poor reading accuracy of the smoke density meters at optical density approaching 3.0 (see Appendix F). Hence the discussion conducted in terms of the constant slope of the main point of the curves, representing the half-clearance time (Section 7.1).

9.4.3 (ii) 'Hot smoke' tests

Some difficulty was experienced in controlling the smoke densities produced by the fires. Extinction of the fires with water produced steam, which in some cases, gave a momentary increase in optical density. Most tests showed a decrease in optical density after commencing clearance, followed by a plateau which is normally terminated when the fire is extinguished. The plateau evidently represents an equilibrium between smoke production and extraction. After the plateau, a clearance curve of constant slope follows, and this is used to calculate the half-clearance times.

With the above proviso, the 'hot smoke' curves preserve the linearity of optical density plotted logarithmically against time, and the plots of optical density at different heights lie close together, as with the 'cold smoke' tests. The behaviour in clearance of 'hot smoke' is generally similar to that of 'cold smoke' in these tests.

The use of a single fan, in whatever configuration, produces a very significant improvement exceeding a factor of 5 in half clearance time over natural ventilation, and the use of two fans produces a further improvement.

Some improvement is produced even while the fire, albeit a small fire, is burning.

9.5 Conclusions.

Under the conditions of the tests, the following results were obtained:

(i) Natural ventilation in the test room gave very slow clearance.

(ii) The wind speed had little effect on conditions in the test room, whether fans were in use or not.

(iii) The clearance behaviour of 'hot smoke' and 'cold smoke' was similar.

(iv) The use of fans gave very significant improvement in clearance over natural ventilation.

(v) Two fans, one to inject, one to extract, gave rather better results than a single fan.

However, it should be noted that the relative merits of various configurations using a single fan for clearance were not established.

10. MEASUREMENT OF FAN PERFORMANCE.

10.1 Measurements of air movement patterns.

Simple preliminary measurements of the performance of each type of fan were made at FEU using a small vane-type anemometer[1] as a probe to explore the pattern of air movement. These measurements have proved difficult to interpret, and are not presented. The tests did, however, provide an initial assessment of the relative effectiveness of the fans.

10.2 Measurement of performance using methods of British Standard.

As indicated in Section 2, more comprehensive measurements of fan performance by a contractor[2] are in hand, using the methods of a British Standard on fan testing (Reference 2).

10.3 Comparative tests of fans in smoke clearance in 'Industrial B' Building Basement.

10.3.1 General.

Sections 8 and 9 describe tests of smoke clearance in 'Industrial B' building designed to examine different procedures, using two identical electrically powered fans, SRDB Code No 4 (Table 1).

The methods described in Section 9 were also used to compare the performance of the various extractors listed in Table 1, SRDB Codes 1 to 6.

10.3.2 Method.

The method followed the description of Sections 9.1 and 9.2, with the following conditions.

The tests used cold smoke provided by a group of four canisters.

Each fan in turn was positioned in the doorway of the basement to extract from the lower shutter in the plywood panel (Section 9.1), the upper shutter being closed. the larger fans required the improvised use of polythene sheeting to connect them to the shutter (Figure 36). The exhaust smoke from the fan was lead up the stairs and out to air through 15m, of 1.8m layflat polythene ducting[3] (Figure 37). The top vent of the basement was open in all tests.

A modified procedure was used for the Aneti Exractor , SRDB Code No. 6 (Table 1), which operates by entrainment of gases in water. The exhaust from the extractor contains the pumped water supply, and so must lead to waste suitably, if water damage is to be avoided. The Extractor was positioned outside the building (Figure 38) the semi-rigid inlet ducting leading through the open top vent. The two shutters in the basement door were open.

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1. Airflow Developments Ltd., Lancaster Rd., High Wycombe, Bucks.

2. South Western Industrial Research Ltd.(SWIRL), University of Bath, Claverton Down, Bath BA2 7AY.

3. Layflat polythene ducting ordering size corresponds to half the circumference of the expanded ducting.

Opportunity was taken during these tests to assess the operational handling of the various extractors. Results are given in Section 11 below.

10.3.3. Results.

The results for the 12 'cold smoke' tests conducted are given in Appendix J. Table 4 summarises the tests, and tabulates the half-clearance times obtained (Section 7).

10.3.4 Discussion.

In Figure 39 the reciprocal of the mean half-clearance time obtained from each fan is plotted against the manufacturers' quoted airflow taken from Table 1. Simple theory suggests that these points should lie on a straight line through the origin. The Woods fan, SRDB Code No. 5, had performance well exceeding this criterion, and the Angus Turbex, SRDB Code No 2, fell short of it. This suggests that practical performance cannot be predicted from the manufacturers' quoted airflow. A possible reason for this may be that test conditions applying to the manufacturers' figures are not standardised. The work being undertaken by SWIRL (Section 2) should supply standardised test results to clarify this point.

The most effective extractor was the Compact Generator, SRDB Code No.1, and the most effective electrically driven fan was the Woods, SRDB Code No.5.

The results obtained apply specifically only to the particular test conditions used, but these are considered to be representative of operational use.

11. HANDLING CHARACTERISTICS OF EXTRACTORS.

11.1 Observations from comparative extraction tests.

During the large-scale comparative tests in 'Industrial B' Basement (Section 10.3) observations of the handling characteristics of the smoke extraction equipment were made in circumstances similar to those encountered in fire brigade operations.

The observations are detailed below:

(i) SRDB Code No 1, COMPACT HIGH EXPANSION FOAM GENERATOR
This was easy to manoeuvre with two persons.
Problems occurred in deployment due to the positions of the water inlet and outlet couplings on the casing. When used with polythene exhaust ducting the outlet hose had to be threaded through the ducting, this was time consuming. The inlet hose had to enter the generator from the smoke filled area. At the end of the test the water from the hoses drained into the basement when they were uncoupled, causing a potential risk of water damage.

(ii) SRDB Code No.2, TURBEX MKII HIGH EXPANSION FOAM GENERATOR
This was difficult to manoeuvre even with two persons due to the weight and size of the Turbex. It was the heaviest of all models tested.
There were problems in deployment due to lack of manoeuvreability and the necessary connection of the inlet and outlet hoses, although this was easier than the Compact Generator above.
Water was sprayed out of the foam-making jets during the course of the test.
Again, on making up, water from the hoses drained out of the couplings causing a potential risk of water damage.

(iii) SRDB Code No.3, SUPERVAC P164 SE
This was easy to manoeuvre by one person and quickly deployed.
There were no problems encountered in use.

(iv) SRDB Code No.4, SUPERVAC P164 SEZ
This was easy to manoeuvre with two persons, and could indeed be manoeuvred single handed.
Vibration in operation caused two screws to fall out from the safety grill on the inlet side of the fan. This caused increased noise and reduced the safety function of the grill.

(v) SRDB Code No.5, WOODS AEROFOIL L TYPE
This was difficult to manoeuvre due to the position and size of the handles. It was second heaviest of all models tested, and required two persons to carry. Nevertheless it was quickly deployed and no problems were encountered in use.

(vi) SRDB Code No.6, ANETI EXTRACTOR
The extractor was easy to manoeuvre single handed and it was quickly deployed. Lack of instructions meant that the optimum operating water pressure was unknown. This was determined by preliminary experiments (7 bar was used).
Water was sprayed about 5m, with the potential of causing serious water damage.

12. ELECTRICAL CHARACTERISTICS.

Tests were carried out on the fans that had been purchased by the FEU to measure the running current and the starting current surge.

12.1 Method.

The fan under test was powered via a 110v transformer from 240v a.c. mains, as described in Section 8. A moving-coil meter[1] with a shunt[2] to enable high currents to be measured was connected in series between the fan and transformer. A second method of current measurement was also adopted using a clamp meter[3] around one current conductor of the fan cable. Suitable safety precautions were taken in performing these electrical tests.

The surge and running currents were measured and an estimate made of the duration of the surge current.

12.2 Results.

The results are given in Table 6.

12.3 Discussion.

The Supervac fans (SRDB Code Nos. 3 and 4) and in particular the high speed[4] P164SEZ had very high surge currents. Even the steady running current for these fans was higher than the starting current for the Woods fan (SRDB Code No 5) which has relatively low starting and running currents.

In arranging to run a fan from a portable generator (or otherwise), it is important to check provision for starting surges as well as running currents. This is confirmed by the experience of Merseyside Fire Brigade (Section 5.3.2) who found such modification necessary when using a Supervac fan.

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1. AVO Ltd., Dover. - AVO Model 8 Multimeter.

2. AVO Ltd., Dover. - AVO current ratio transformer.

3. AVO Ltd., Dover. - AVO clamp meter CA-25.

4. The maker's figure for the P164SEZ is 2860 rpm, and for the P164SE 1725 rpm.

13. DISCUSSION.

Study of the literature has revealed many references to smoke production and movement but little of direct relevance to clearance of smoke in brigade operations. The relevant references are discussed in Sections 3 and 4 of this report. This study together with discussions with FRS, Salvage Corps and representative brigades is considered to have adequately explored existing expertise in the field of smoke extraction for firefighting purposes.

Because no two firefighting situations are the same, a clear definition of the operational requirement is difficult to produce. However, from the present work carried out by the FEU, general guidelines might be formulated which apply to many common situations. These guidelines might then be adapted as required.

Clearance of smoke can be commenced during firefighting operations or at a later stage when the fire has been extinguished, that is during salvage operations. It is difficult to simulate a repeatable a firefighting situation and the tests carried out by the FEU relate more directly to salvage operations than to firefighting operations. In Liverpool and London, when the Salvage Corps were in attendance, it was often practice to commence forced ventilation during firefighting. Early use improves visibility, so facilitating firefighting operations, as well as limiting smoke damage.

This report considers the use of extractors of a physical size which enables them to be carried on firefighting appliances, perhaps first-line appliances. The size of buildings considered and used in the experiments may be described as 'medium-size industrial premises'.

In all but very small fires portable extractors will not remove smoke at the rate at which it is being produced although extraction may produce a local improvement. However, the tests carried out indicate that smoke extractors can make a useful contribution in clearing smoke logging. They are advantageous in all except cross-ventilation situations with high wind conditions, where there may be only marginal benefits. Where natural ventilation is restricted, the use of extractors has a marked effect. Other applications of extraction equipment such as the removal of toxic or flammable atmospheres and the provision of fresh air, were not directly evaluated. However, results obtained in this series of tests are relevant.

As discussed earlier in this report, a major problem with full-scale tests is the variability of wind conditions, which have a significant effect on ventilation. To make further progress without being dependent on the weather, an extensive test facility would be required. A more precise test programme could be designed and carried out. It is doubtful however if the tactical advice that could be given to the fire service after a lengthy test programme would be significantly more than that which can be given at the present time. However, information could usefully be obtained by further work on the performance of indivdual extractors, and factors such as the effect of ducting.

A number of factors govern the choice of the type of extractor. With electrical fans, a generator is required which must be able to withstand the current surge on switching on. The advantages of electrical power lie in the ease of deployment and absence of water damage when compared with water driven fans. Water driven fans require only a pump for power, but the time spent in laying hose must be considered. Water damage which may result as a consequence of their use should be taken into account. Water driven fans may have the advantage of being dual-purpose equipment since they are often designed to function also as high expansion foam generators. This type of equipment can withstand hot gases by using the internal water sprays but with increased risk of water damage. Water-driven equipment is intrinsically safe for use in flammable atmospheres.

Criteria for commencing forced ventilation should follow the instructions given in the Manual of Firemanship (Reference 1) for natural ventilation. The advice is to ventilate as early as is practicable but warning is given that fire spread and flashover can occur as a result.

14. SUGGESTED GUIDELINES ON THE USE OF SMOKE EXTRACTORS

The limited number of discussions with brigade personnel indicated that there was a need for training in the effective use of smoke extractors including the best use of ducting. This section suggests guidelines for training purposes based on experiences gained during this project. However, further work would be required in order to produce more authoritative advice.

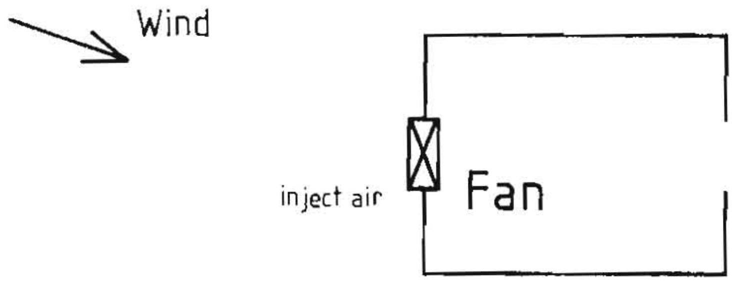
Forced ventilation should only be commenced if it is deemed safe to commence natural ventilation. The criteria for the commencement of natural ventilation are given in the Manual of Firemanship Book 12.

ONE EXTRACTOR

1. Ensure that there is an inlet for fresh air, if possible other than the opening for the fan.

2. Decide whether conditions favour extracting smoke or injecting fresh air with the fan. This will depend on the positions of openings and the wind direction.

3. Position the fan in such a way as to emphasise the wind direction, as below:



4. Where possible, when extracting smoke, position the fan at the top of the opening. Doorbars can be used for suspending fans in doorways. In these instances the fresh air inlet should be low down if possible.

5. If the fan is to be used to inject air, it should be positioned at the bottom of the opening. Outlets for the smoke should be made at a higher level.

6. The use of trunking will be found helpful where external openings are a distance from the fire, or where openings, such as basement vents, are not large enough for the fan. Semi-rigid ducting should be used on the inlet side of the fan whereas layflat polythene ducting may be used on the outlet side.

TWO EXTRACTORS

1. If smoke has to be moved a long way eg through a building , it is best to use a long length of layflat ducting on the outlet of one fan and use the second fan to blow fresh air in. The use of two fans linked in series with ducting is likely to be unsuccessful in a practical situation.

2. Both fans may be used to extract smoke. In this case sufficient inlets for fresh air should be provided. The fans should be positioned at the top of openings.

3. Both fans may be used to inject fresh air. These should be placed at a low level and sufficient high level outlets provided for the smoke.

4. One fan may be used to inject fresh air (at a low level) whilst the second fan extracts smoke from a high level. This is probably the best arrangement where openings are limited.

15. CONCLUSIONS

Smoke extraction equipment of a size practicable for carrying on fire appliances can have a significant effect in clearing smoke logged buildings where natural ventilation is poor for structural reasons, or wind speeds are low. Smoke extractors of practicable size will not keep pace with smoke output of any but the smallest fires, however.

For fire service use, electrically or water-powered fans are appropriate. Electric fans have the advantage of easy deployment. Water powered fans may take the form of dual-purpose equipment, functioning also as high-expansion foam generators and avoid the use of electric power in flammable atmospheres.

ACKNOWLEDGEMENTS

Acknowledgements are made to staff of the Fire Experimental Unit, and to the Commandant of the Fire Service College for permission to make use of fireground facilities.

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TABLE 1 - EXTRACTORS PURCHASED BY FEU FOR TESTS.

SRDB CODE No.	TYPE	MANUFACTURER/SUPPLIER	DIMENSIONS Width x Height x Depth mm	FAN DIAMETER mm	WEIGHT kg	QUOTED POWER REQUIREMENT	QUOTED AIRFLOW m^3min^{-1}	APPROX. COST TO FEU EXC. VAT £
1	'Compact' High-expansion foam generator.	Symtol Engineering Ltd, Unit 9A, Blyth Ind.Est. Blyth, Northumberland.	670 x 600 x 350	555	29	Water power 314 lpm at 7 bar	300 at 7 bar water pressure	995.00
2	Turbex Mark II High-expansion foam generator.	Angus Fire Armour Ltd, Thame Park Rd., Thame.	885 x 910 x 470 Wheels increase width to 1095mm	605	55	Water power 225 lpm at 7 bar	285 at 7 bar water pressure	2182.20
3	Supervac P164SE (16 inch)	Dale Emergency Products Ltd, Faraday House, Eastfield, Scarborough.	482 x 485 x 370	398	24	110v 60Hz a.c. 0.3kW	122	485.00
4	Supervac P164SEZ (16 inch)	Dale Emergency Products Ltd, Faraday House, Eastfield, Scarborough.	477 x 485 x 435	400	33	110v 50Hz a.c. 1.5kW	233	625.00
5	Woods Aerofoil L-type (19 inch)	Woods of Colchester Ltd Tufnell Way, Colchester Essex.	600 x 680 x 535	481	47	110v 50Hz a.c. 0.7kW	125	637.00
6	Aneti Ventilator-ejector	A. Dubois & Co., Rue de la Plaine, 75020, Paris.	317 x 490 x 1630	---	20	Water power 262 lpm at 8 bar	90 at 8 bar water pressure	595.00 (import price)

TABLE 2 - TESTS OF SMOKE CLEARANCE PROCEDURES IN 'INDUSTRIAL B' BUILDING, FIRST FLOOR.

Test No.[1]	Date of test	FAN USED TO INJECT: Without baffle	FAN USED TO INJECT: With baffle	FAN USED TO EXTRACT: Without baffle	FAN USED TO EXTRACT: With baffle	WINDOWS Open	DOORS Open	WIND CONDITIONS: Direction[2] degrees	WIND CONDITIONS: Speed[3] Total ms^{-1}	WIND CONDITIONS: Speed[3] Resolved ms^{-1}	TEMPERATURE: External °C	TEMPERATURE: Peak[4] Internal °C	HALF CLEARANCE TIME[5] minutes
5	16/12/82					X	X	235	5.0	2.1	4.0	9.5	0.793
6	16/12/82		X			X	X	275	3.5	3.2	4.5	9.0	0.986
7	16/12/82	X				X	X	260	6.0	4.6	4.0	9.0	0.736
8	16/12/82					X	X	260	9.0	6.9	5.0	8.0	0.407
9	16/12/82					X	X	255	8.0	5.7	4.5	8.0	0.500
10	16/12/82			X		X	X	260	7.5	5.7	3.0	6.0	0.364
11	17/12/82					X	X	250	2.5	1.6	1.0	8.0	1.850
12	17/12/82		X			X	X	270	5.0	4.3	1.5	4.0	1.275
13	17/12/82	X				X	X	270	4.0	3.5	2.0	5.0	0.886
14	17/12/82				X	X	X	265	5.0	4.1	2.0	7.0	0.700
15	17/12/82			X		X	X	280	5.5	5.2	2.5	7.0	0.700

1. Tests 5 - 21 used 'cold smoke', test HS3 used 'hot smoke'.
2. A wind from the North is represented as 0 degrees, from the East as 90 degrees, from the West as 270 degrees.
3. See Section 8.4.1 and Figure 34.
4. Highest temperature reached at ceiling height.
5. See Section 7.1

TABLE 2 - TESTS OF SMOKE CLEARANCE PROCEDURES IN 'INDUSTRIAL B' BUILDING, FIRST FLOOR.

Test No.[1]	Date of test	FAN USED TO INJECT Without baffle	FAN USED TO INJECT With baffle	FAN USED TO EXTRACT Without baffle	FAN USED TO EXTRACT With baffle	WINDOWS Open	DOORS Open	WIND CONDITIONS Direction[2] degrees	WIND CONDITIONS Speed[3] Total ms^{-1}	WIND CONDITIONS Speed[3] Resolved ms^{-1}	TEMPERATURE External °C	TEMPERATURE Peak[4] Internal °C	HALF CLEARANCE TIME[5] minutes
16	17/12/82	X		X		X	X	255	7.0	4.9	3.5	7.5	0.636
17	17/12/82		X		X	X	X	240	2.0	1.0	3.0	5.0	1.929
18	10/01/83					X	X	235	7.0	3.0	9.0	12.0	0.964
19	10/01/83					X	X	245	10.0	5.7	9.5	10.0	0.486
20	10/01/83					X	X	250	10.0	6.4	9.0	12.5	0.500
21	11/01/83						X	210	7.0	0.0	9.0	12.5	1.429
HS3	10/01/83					X	X	250	8.0	5.1	9.8	52.0	0.850

1. Tests 5 - 21 used 'cold smoke', test HS3 used 'hot smoke'.
2. A wind from the North is represented as 0 degrees, from the East as 90 degrees, from the West as 270 degrees.
3. See Section 8.4.1 and Figure 34.
4. Highest temperature reached at ceiling height.
5. See Section 7.1

TABLE 3 - TESTS OF SMOKE CLEARANCE PROCEDURES IN 'INDUSTRIAL B' BUILDING, BASEMENT.

Test No.[1]	Date of test	TOP VENT			DOOR COVER			WIND CONDITIONS			TEMPERATURE		HALF CLEARANCE TIME[5]
		OPEN	FAN USED TO INJECT	FAN USED TO EXTRACT	OPEN	FAN USED TO INJECT	FAN USED TO EXTRACT	Direction[2] degrees	Speed[3] Total ms^{-1}	Speed[3] Resolved ms^{-1}	External °C	Peak[4] Internal °C	minutes
23	2/02/83	X						240	2.75	2.38			15.00
24	2/02/83			X[6]				240	3.50	3.03			1.43
25	2/02/83			X[6]	X			250	4.50	3.44			1.22
26	2/02/83	X				X		270	7.00	3.50			1.17
27	2/02/83	X						275	7.50	3.17			7.50
28	3/02/83	X				X		5	4.5	-4.10			1.03
29	3/02/83	X					X[7]	5	4.25	-3.80			1.03
30	3/02/83		X				X[7]	10	4.50	-4.20			0.93

1. Tests 23 - 30 used 'cold smoke'.
2. A wind from the North is represented as 0 degrees, from the East as 90 degrees, from the West as 270 degrees.
3. See Section 8.4.1 and Figure 34.
4. Highest temperature reached at ceiling height.
5. See Section 7.1.
6. Tests performed with 3m of semi-rigid ducting on the inlet side of the fan.
7. Layflat polythene ducting on the exhaust side of the fan.

TABLE 3 - TESTS OF SMOKE CLEARANCE PROCEDURES IN 'INDUSTRIAL B' BUILDING, BASEMENT.

Test No.[1]	Date of test	TOP VENT			DOOR COVER			WIND CONDITIONS			TEMPERATURE		HALF CLEARANCE TIME[5]
		OPEN	FAN USED TO INJECT	FAN USED TO EXTRACT	OPEN	FAN USED TO INJECT	FAN USED TO EXTRACT	Direction[2]	Speed[3] Total	Speed[3] Resolved	External	Peak[4] Internal	
								degrees	ms^{-1}	ms^{-1}	°C	°C	minutes
HS4	3/03/83	X			X[7]			205	4.00	3.98		36.2	17.00
HS5	3/03/83			X[6]				205	4.00	3.98		80.0	2.46
HS6	4/03/83			X[6]	X			70	2.00	-1.50			2.37
HS7	4/03/83					X		65	2.00	-2.30			1.60
HS8	4/03/83			X		X		70	1.50	-1.10			1.00

1. Tests HS4 - HS8 used 'hot smoke'.

2. A wind from the North is represented as 0 degrees, from the East as 90 degrees, from the West as 270 degrees.

3. See Section 8.4.1 and Figure 34.

4. Highest temperature reached at ceiling height.

5. See Section 7.1.

6. Tests performed with 3m of semi-rigid ducting on the inlet side of the fan.

7. Opened 15 minutes into the test to try to improve the airflow.

TABLE 4 - COMPARATIVE EXTRACTION TIMES FOR EXTRACTORS PURCHASED BY FEU.

TEST	EXTRACTOR	SRDB CODE No.	HALF CLEARANCE TIME minutes	MEAN HALF CLEARANCE TIME minutes
C8	Compact Generator	1	0.68	0.72
C9	Compact Generator	1	0.75	
C10	Angus Turbex	2	1.57	1.55
C11	Angus Turbex	2	1.53	
C4	Supervac P164 SE	3	1.92	1.90
C5	Supervac P164 SE	3	1.88	
C1	Supervac P164 SEZ	4	1.22	
C2	Supervac P164 SEZ	4	0.99	1.08
C3	Supervac P164 SEZ	4	1.04	
C6	Woods Aerofoil	5	0.90	0.85
C7	Woods Aerofoil	5	0.80	
C12	Aneti	6	3.32	3.32

TABLE 5 - SURGE AND RUNNING CURRENTS FOR FANS PURCHASED BY THE FEU.

SRDB CODE No.	FAN	MEASUREMENT DEVICE	SURGE CURRENT A	RUNNING CURRENT A	DURATION OF SURGE s
3	Supervac P164SE	Moving-coil meter	25	7	1
		Clampmeter	25	7	
4 Specimen 1	Supervac P164SEZ	Moving-coil meter	56	19	10
		Clampmeter	62	20	
4 Specimen 2	Supervac P164SEZ	Moving-coil meter	58	18	10
		Clampmeter	63	20	
5	Woods Aerofoil L-type	Moving-coil meter	19	6	5
		Clampmeter	19	6	

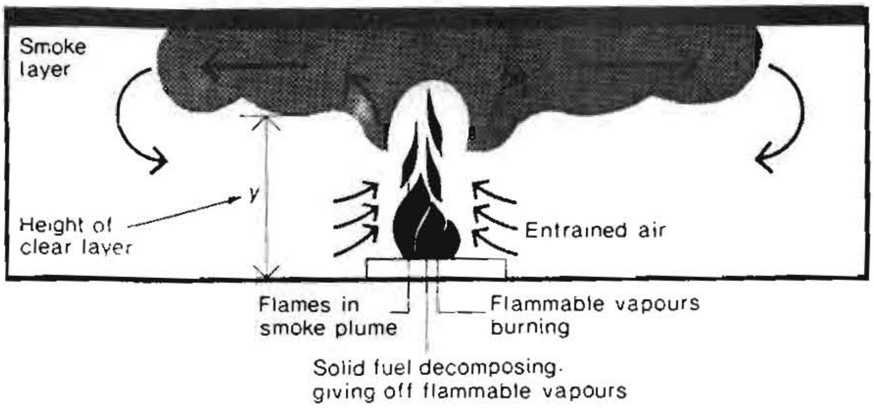


Figure 1

Production of smoke in a fire.
From 'Smoke Control in Fire Safety Design', E.G. Butler and A.C. Parnell. E. & F.N. Spon.

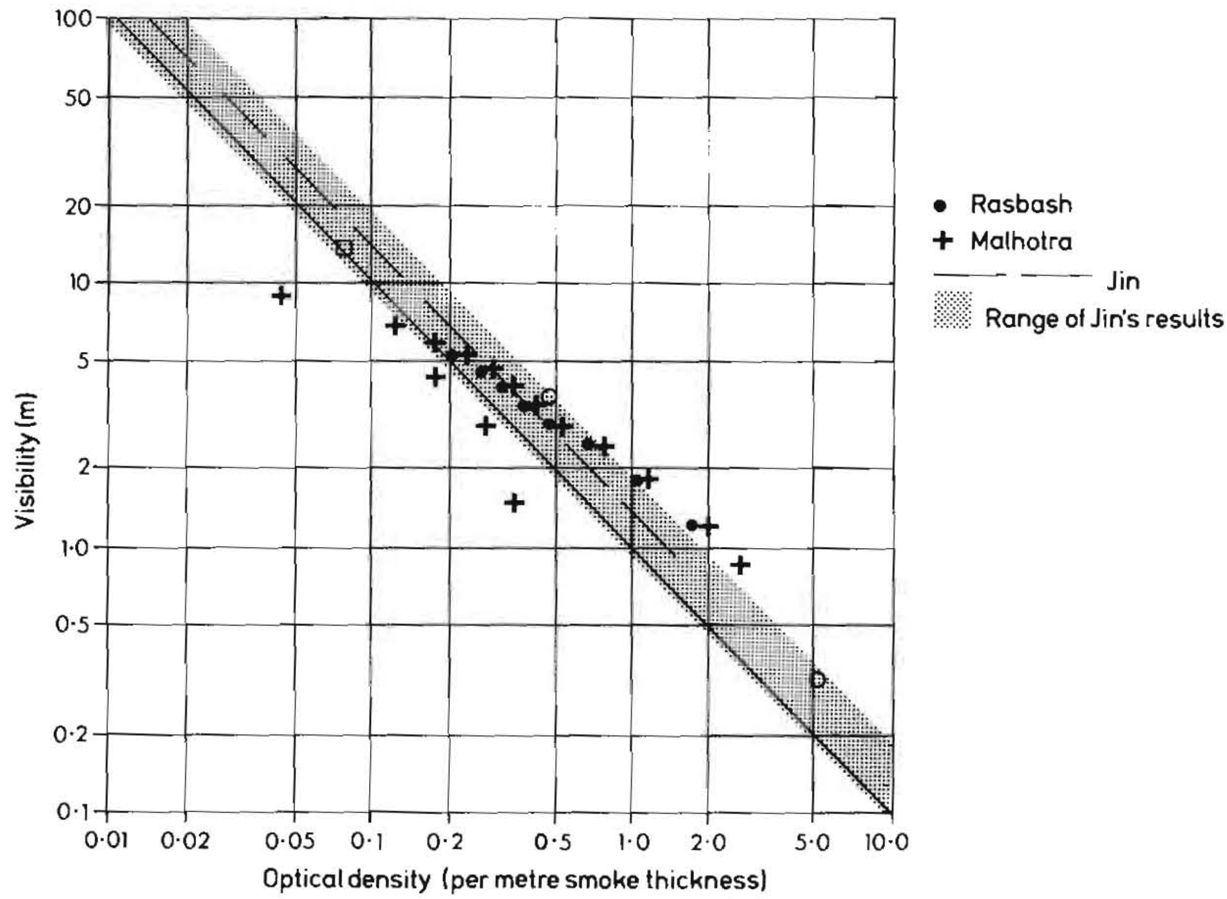


Figure 2

Comparison of published visibility measurements.
From 'Smoke Control in Fire Safety Design', E.G. Butler and A.C. Parnell. E. & F.N. Spon.

Figure 3
COL B3 **Smoke Extractor SRBD Code No.1 : Compact Generator.**

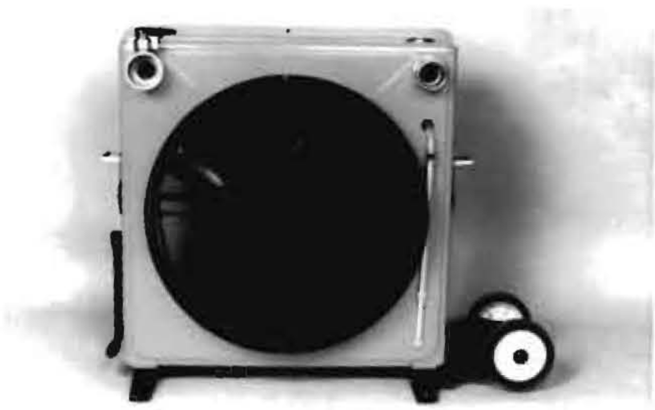


Figure 4
COL B12 **Smoke Extractor SRDB Code No.2 : Angus Turbex.**

Figure 5

Smoke Extractor SRDB Code No.3 : Supervac P164 SE.

Figure 6
COL B8

Smoke Extractor SRDB Code No.4 : Supervac P164 SEZ.

Figure 7
COL B9 Smoke Extractor SRDB Code No.6 : Woods Aerofoil Fan.

Figure 8
COL B6 Smoke Extractor SRDB Code No.7 : Aneti Extractor.

Figure 9
COL A6

Smoke extraction equipment - comparison of sizes.

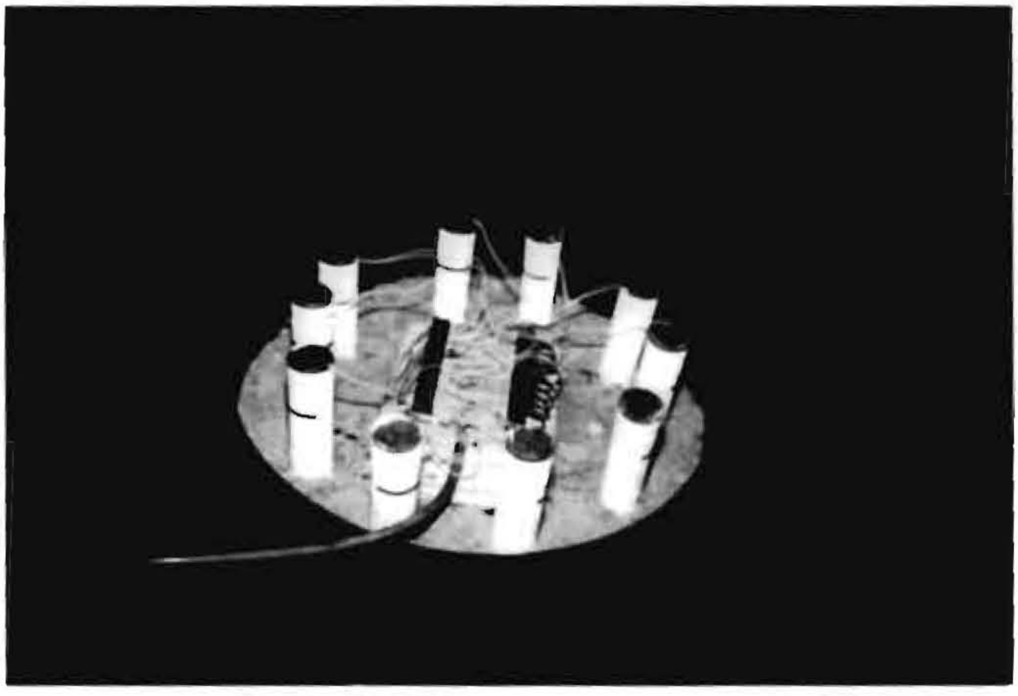


Figure 10
S/58/83

Pyrotechnic smoke canisters in sand tray.

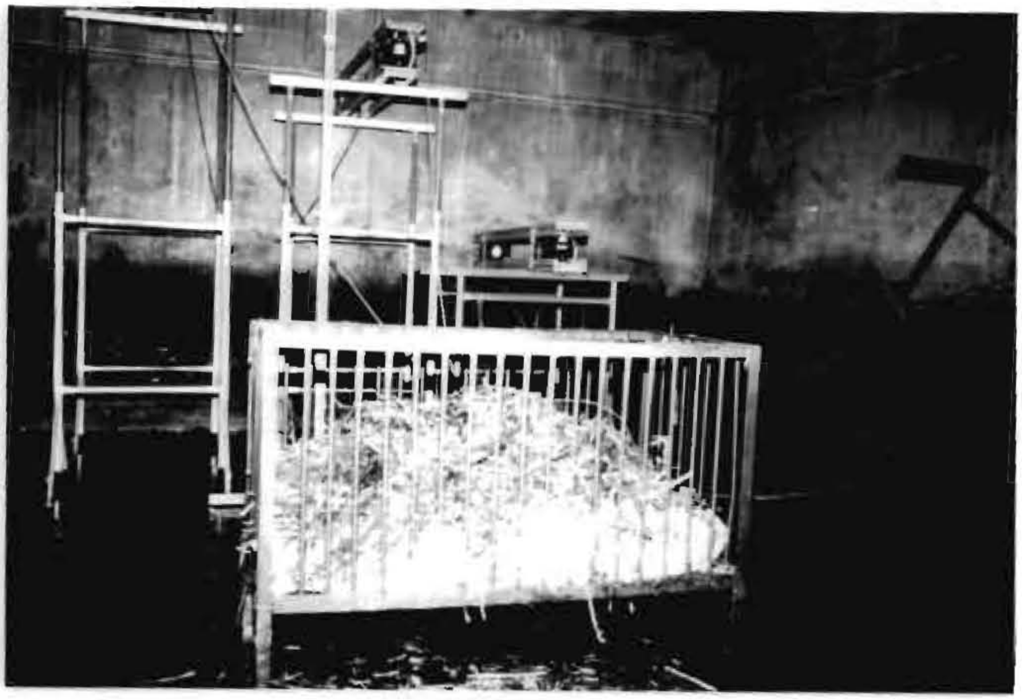


Figure 11
S/226/83 Fireload of crib for hot smoke tests. ('Industrial B' basement)

Figure 12
S/77/83 Crib fire burning. ('Industrial B', first floor)

Figure 13
C/432/82 **Mobile laboratory adjacent to 'Industrial B' Building.**

Figure 14
COL A8 **Smoke density meter - projector / receiver unit.**

Figure 15
S/193/84

Ultra violet chart recorder.

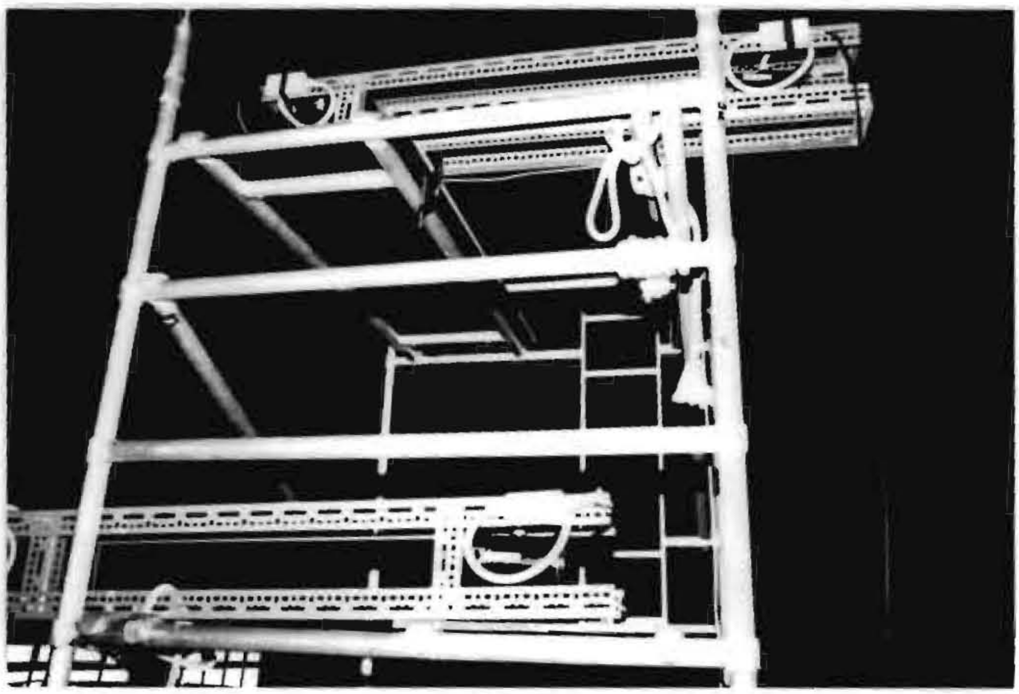


Figure 16
C/27/83

Scaffolding tower with smoke density meters.

Figure 17
S/695/83

Adjustable plank trestles with smoke density meters.

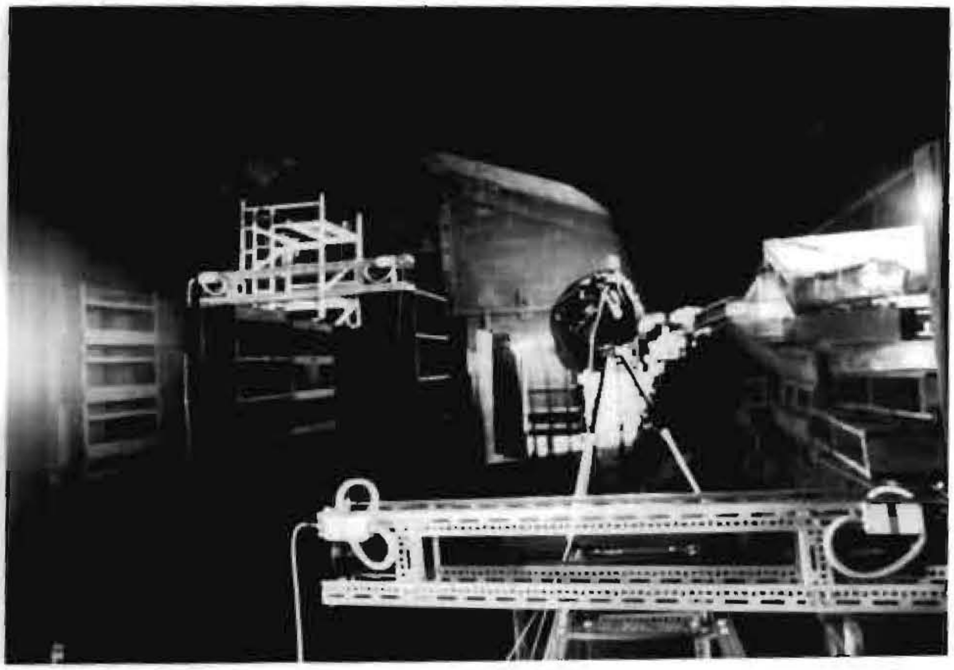


Figure 18
S/99/83

Visbility monitoring rig with video camera.

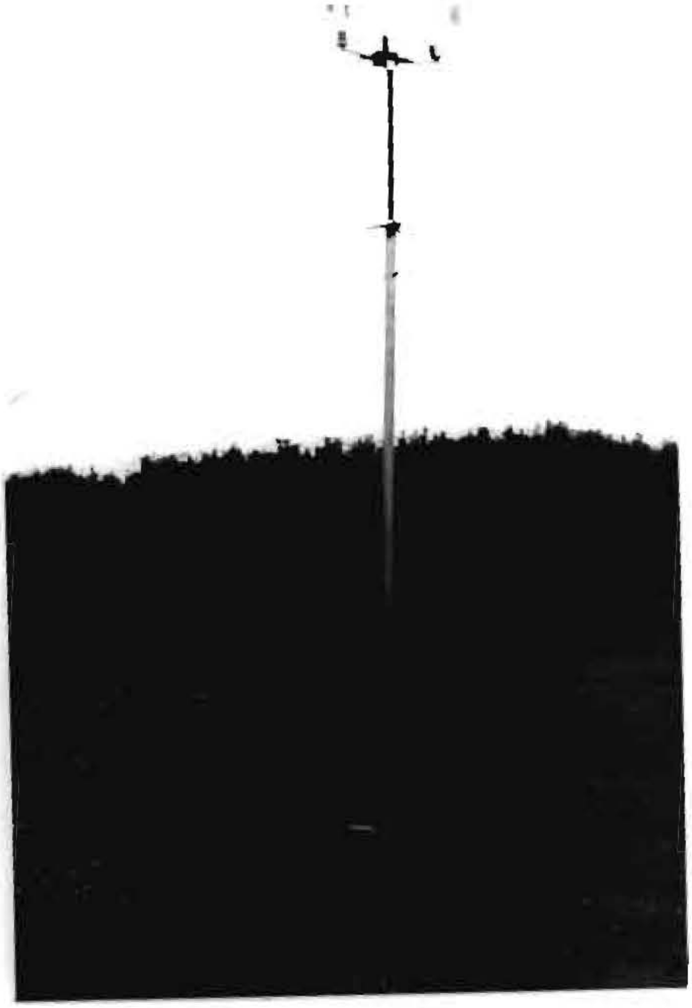


Figure 19
S/681/83 **Wind station.**

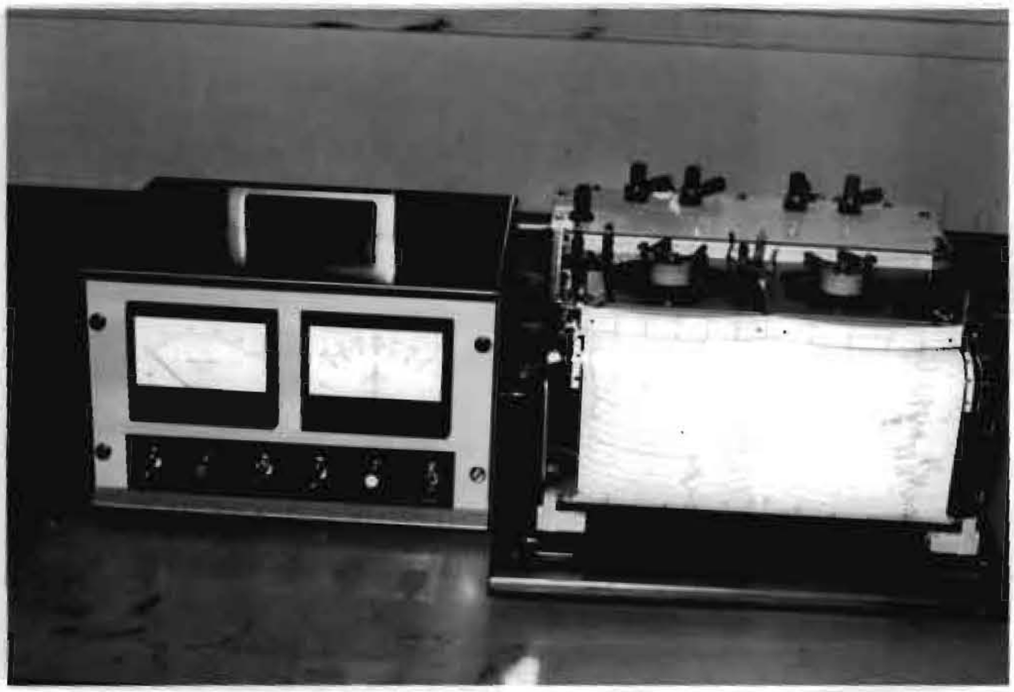


Figure 20
S/191/84 **Wind station display unit and chart recorder.**

Figure 21
C/135/84 **'Industrial B' building from the west.**

Figure 22
S/109/83 **'Industrial B' building, first floor interior.**

Figure 23

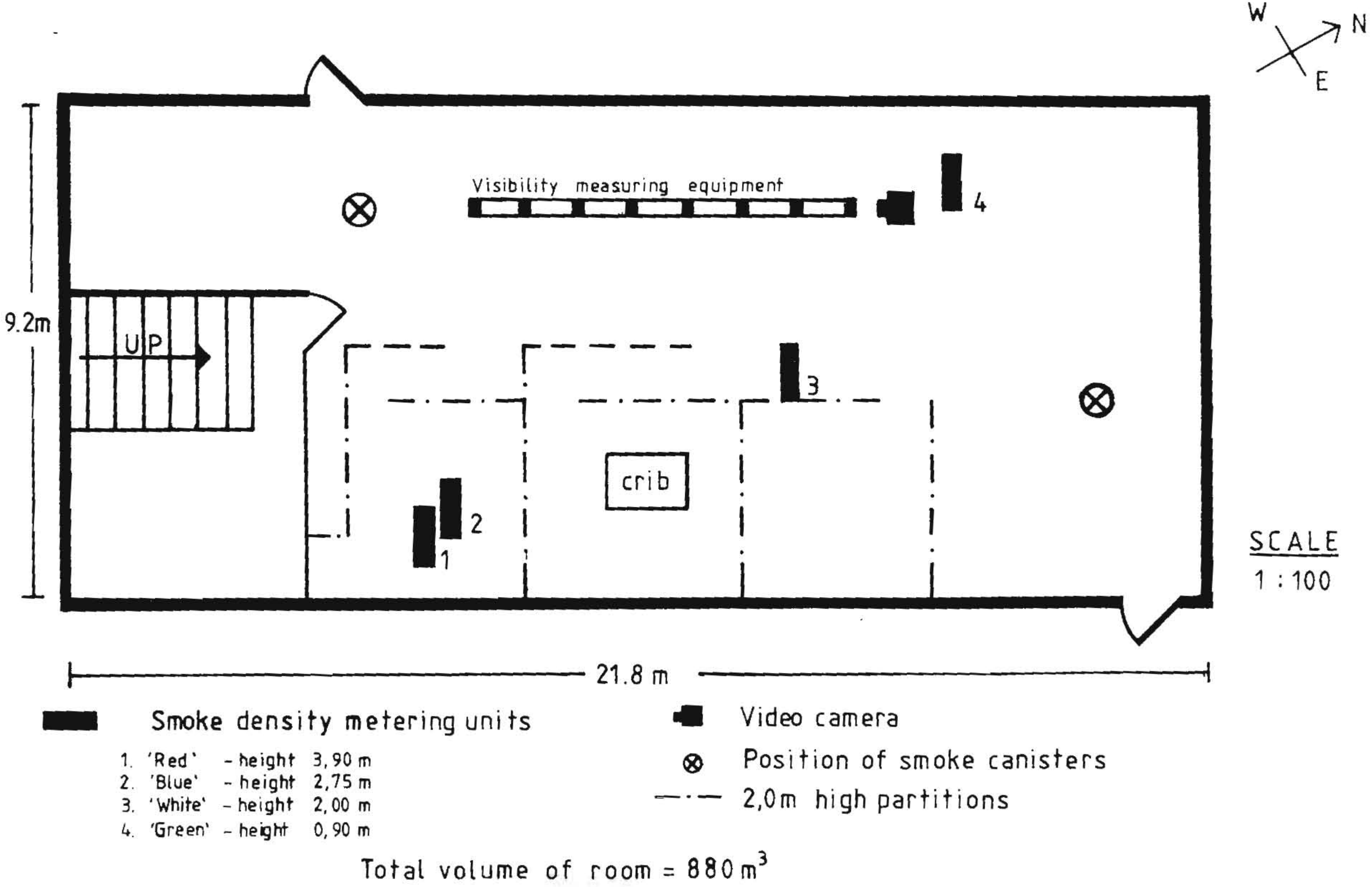


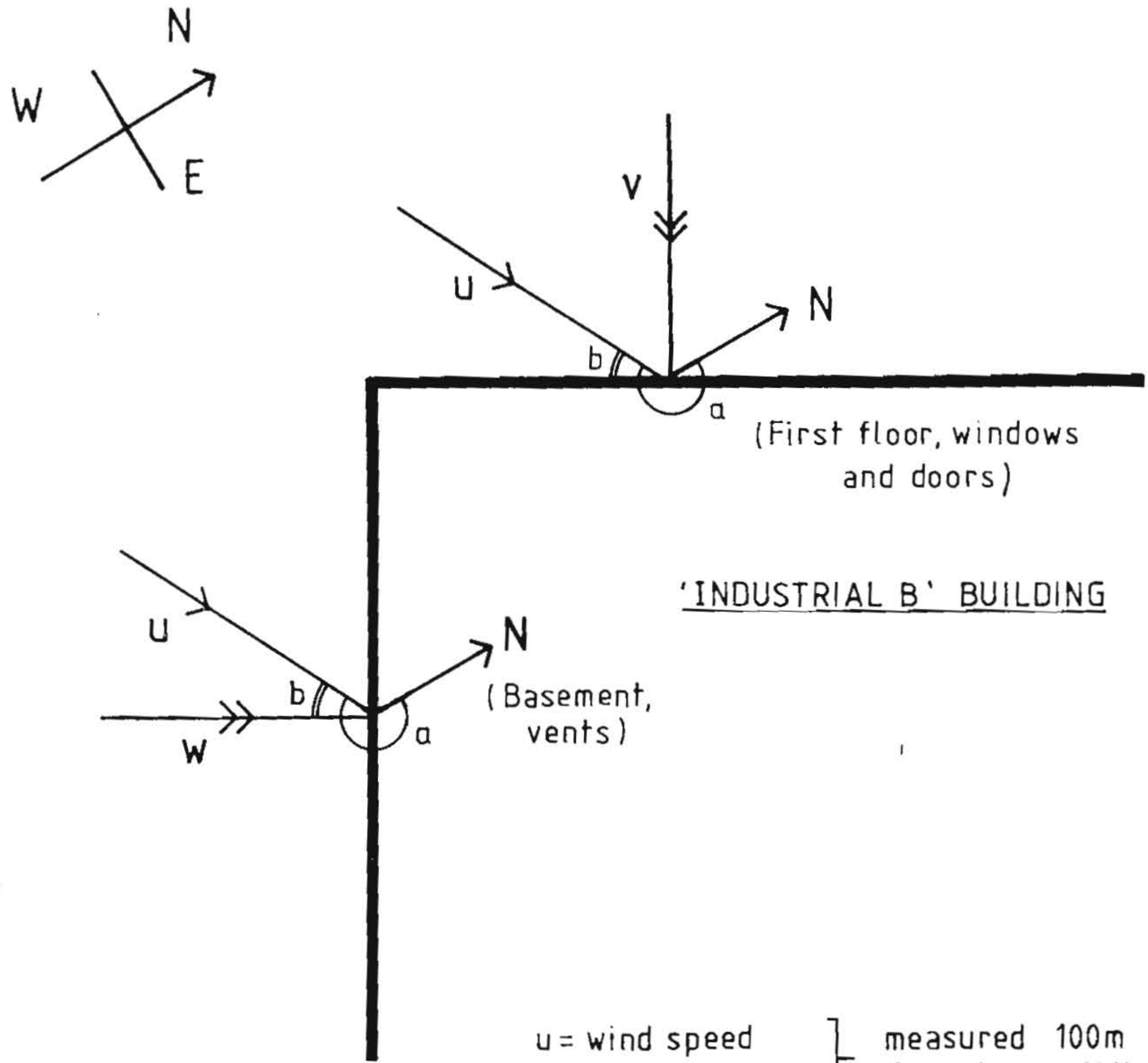
Diagram of 'Industrial B' building, first floor, showing position of test equipment.

Figure 24
C/460/82

Fan positioned in doorway, first floor.

Figure 25
S/15/83

Fan and baffle in doorway, first floor.



u = wind speed } measured 100m
a = wind direction } from the building

v = resolved wind speed perpendicular to first floor windows and doors

w = resolved wind speed perpendicular to basement vents

$b = a - 210°$

$$\underline{v = u \sin b}$$

$$\underline{w = u \cos b}$$

Figure 26

Resolution of wind velocity.

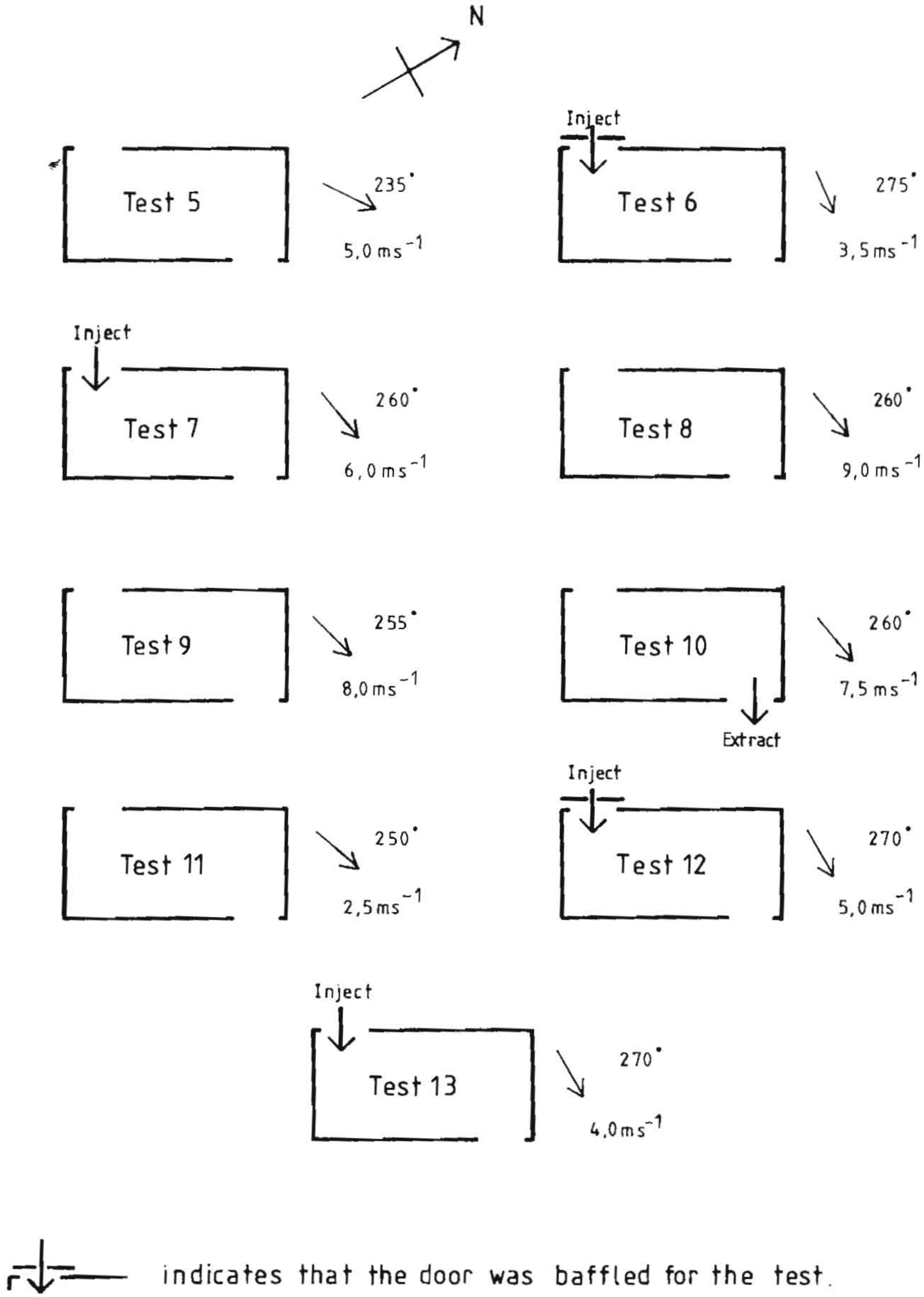
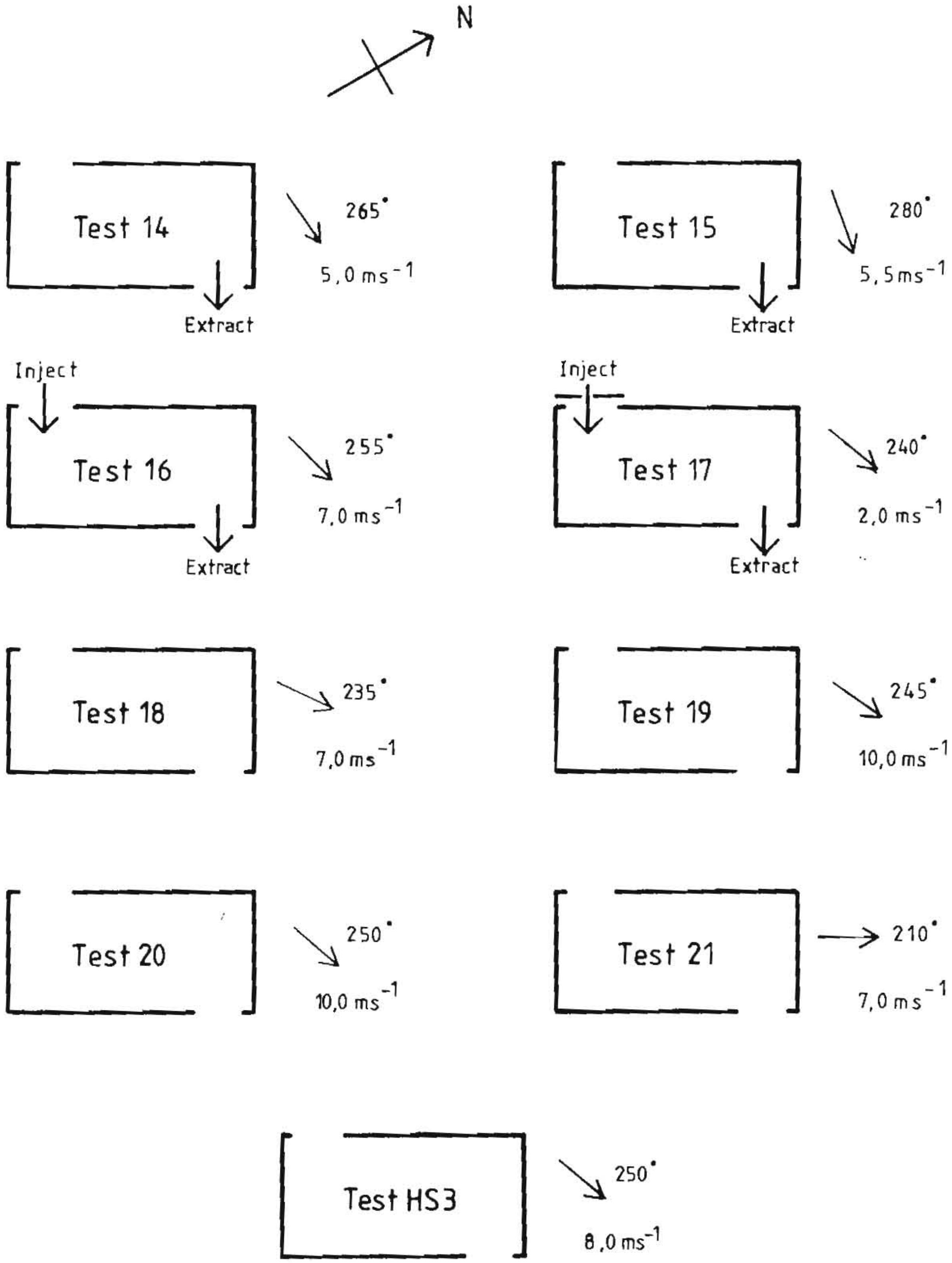


Figure 27

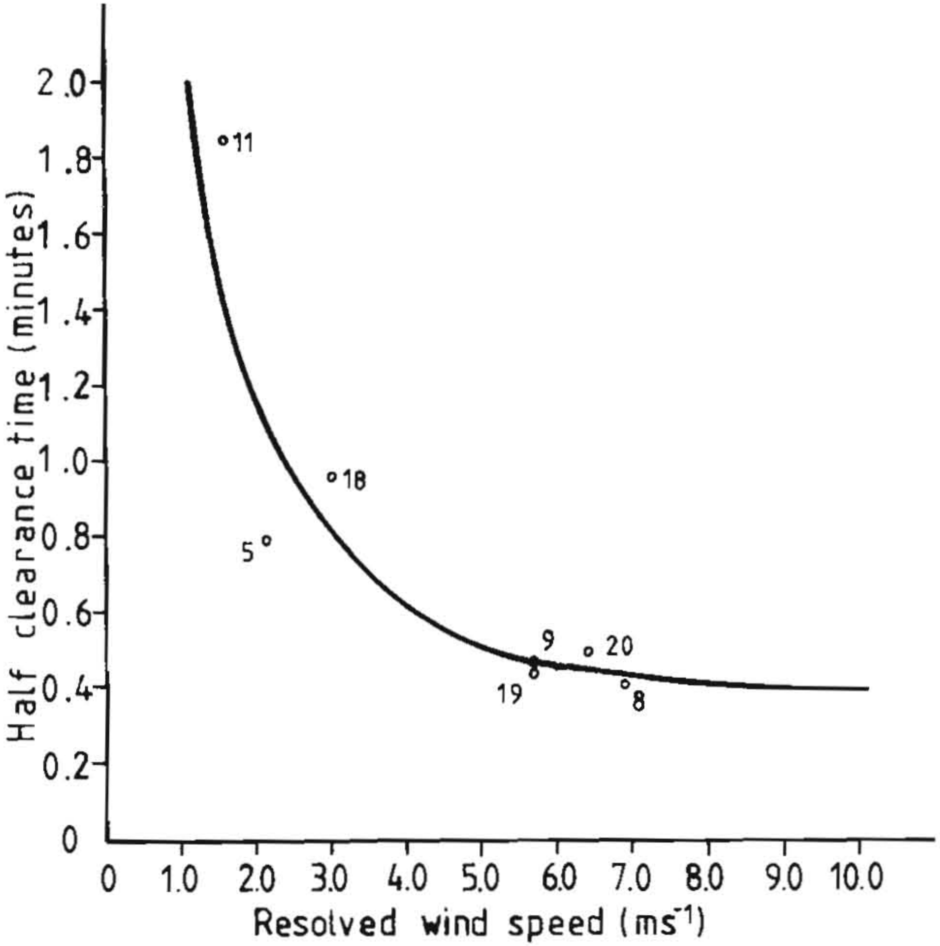
Diagrams of wind direction and speed in ventilation operations - Tests 5 - 13.



 indicates that the door was baffled for the test.

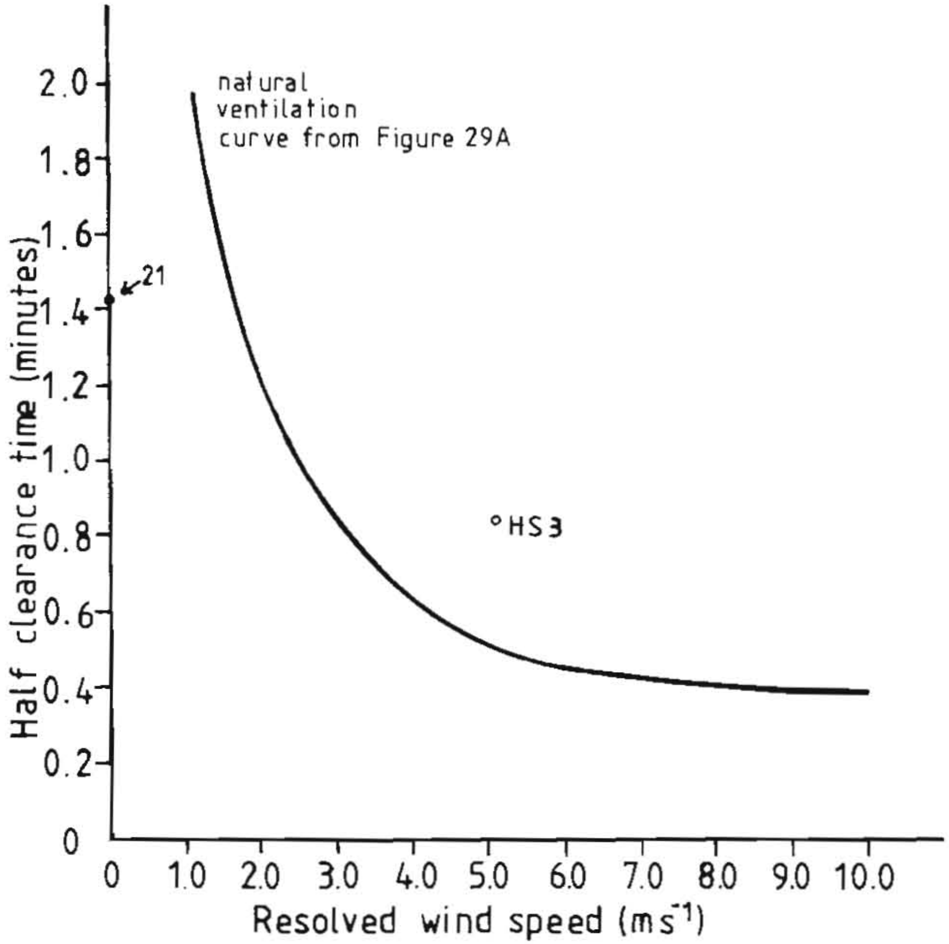
Figure 28

Diagrams of wind direction and speed in ventilation operations - Tests 14 - 21, HS3.



A. Effect of wind speed on natural ventilation.

Test Nos.- 5, 8, 9, 11, 18, 19, 20.

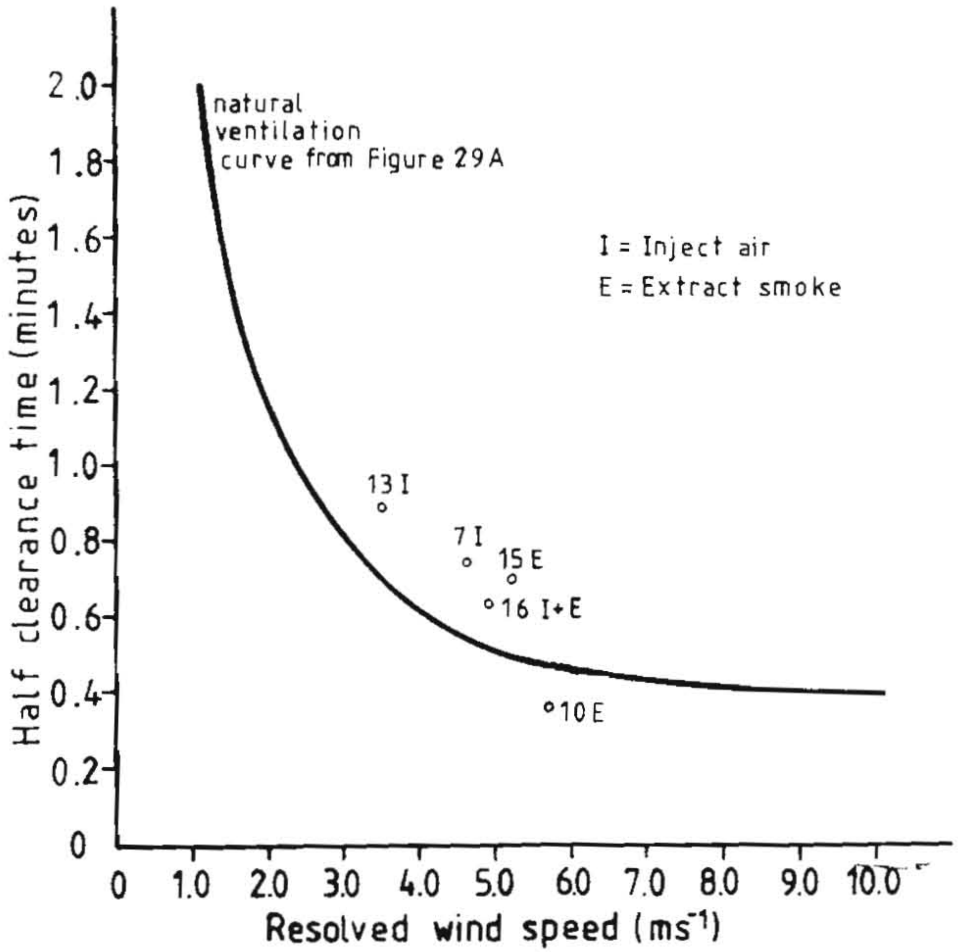


B. Test 21 - Cold smoke, ventilation by doors only.

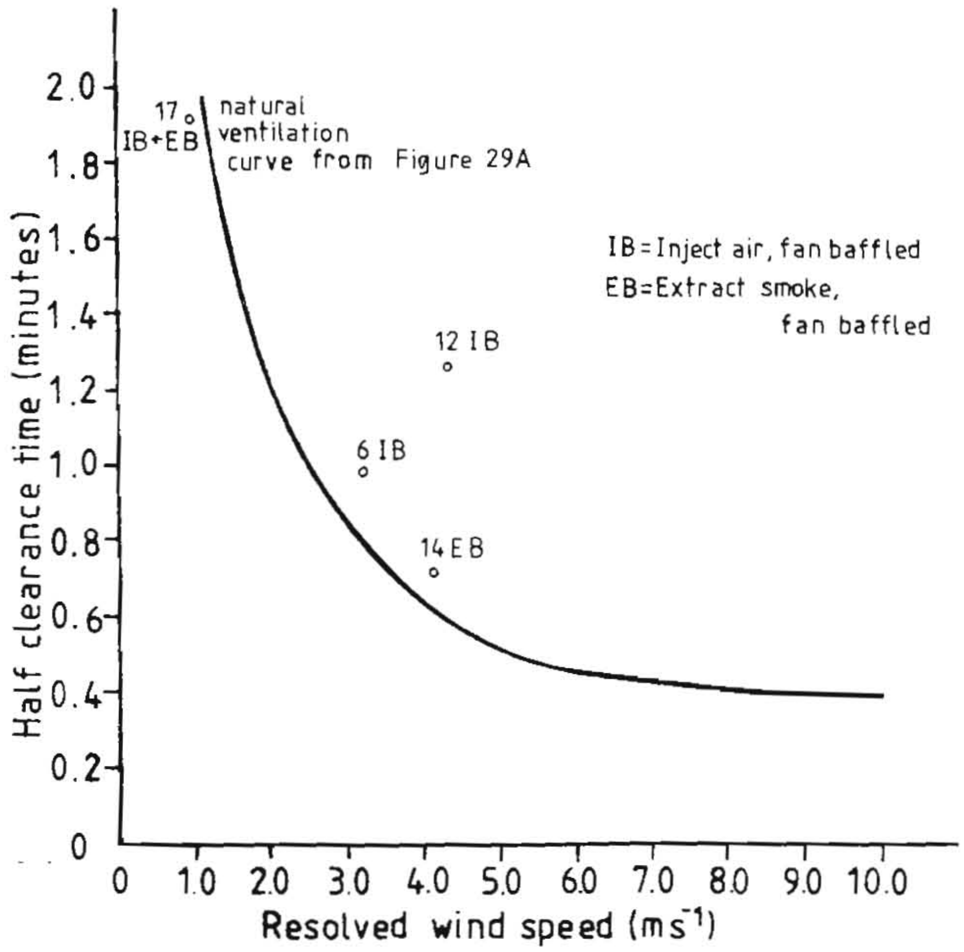
Test HS3 - Hot smoke, full natural ventilation.

Figure 29 (A and B)

Comparison graphs for 'Industrial B' first floor.



C. Effect of adding one or two extractor fans.



D. Effect of baffling the extractor fans.

Figure 29 (C and D)

Comparison graphs for 'Industrial B' first floor.

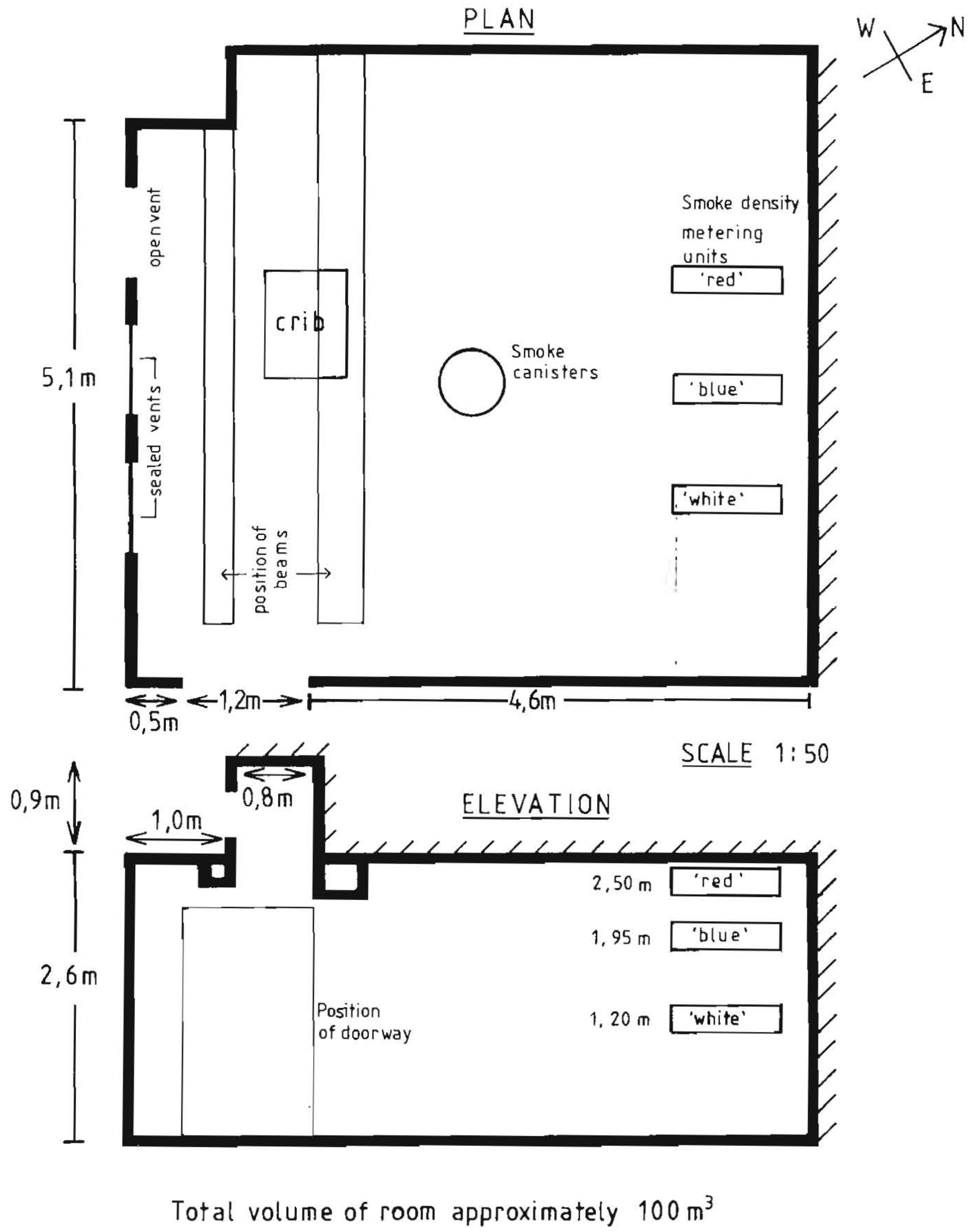


Figure 30
Diagram of 'Industrial B' basement showing the position of test equipment.

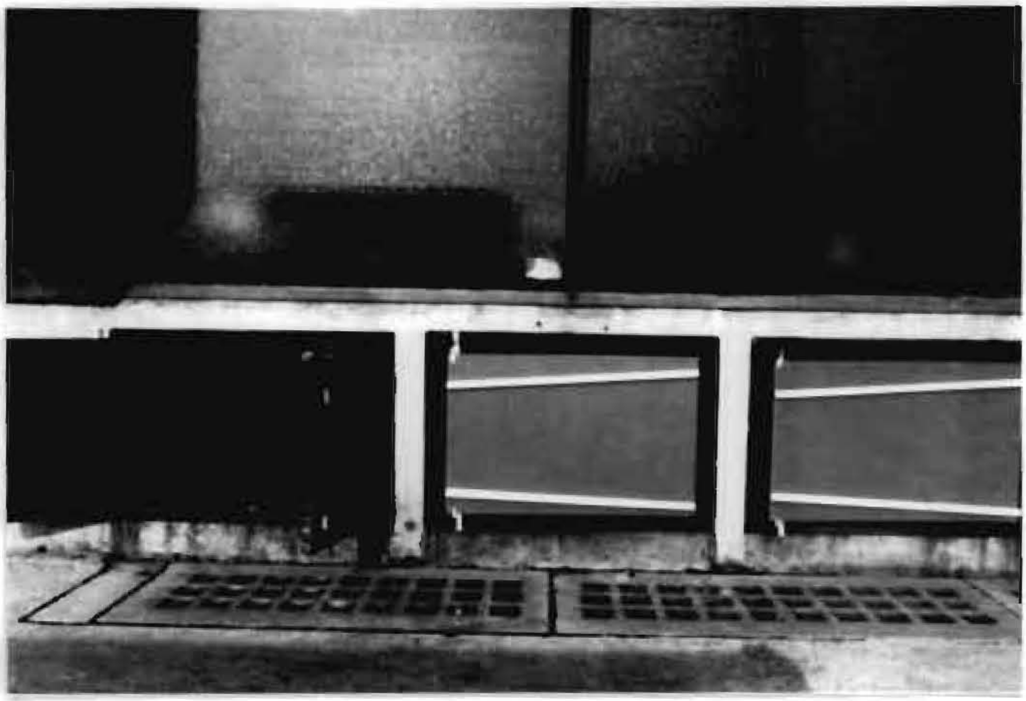


Figure 31
S/228/83 'Industrial B' basement, top vents and covers.

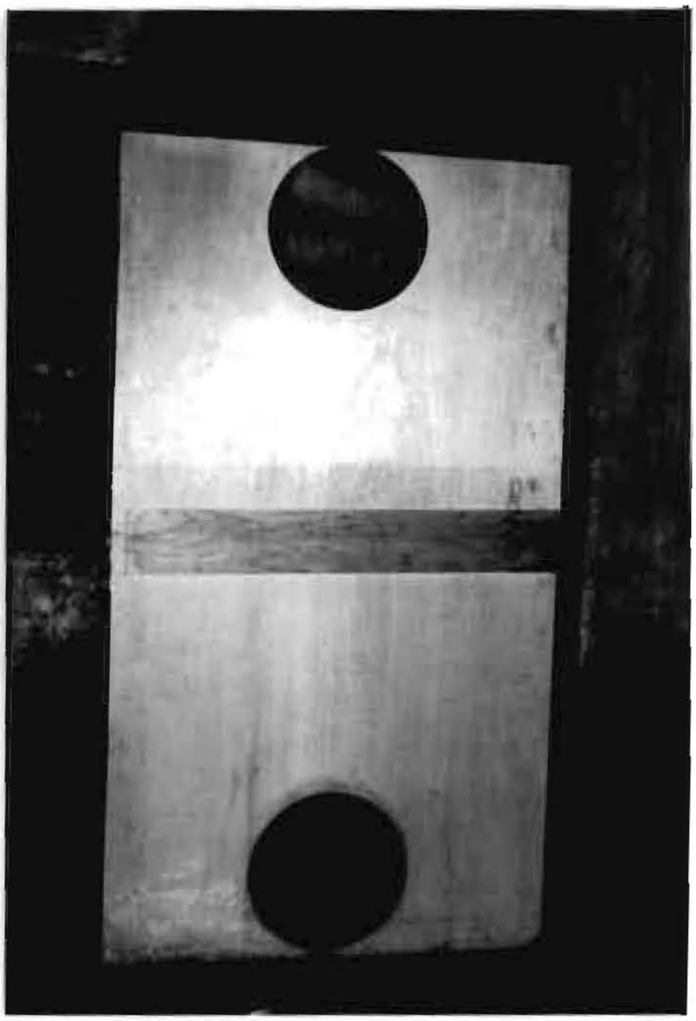


Figure 32
S/701/83 'Industrial B' basement door-way cover showing the shutters open.

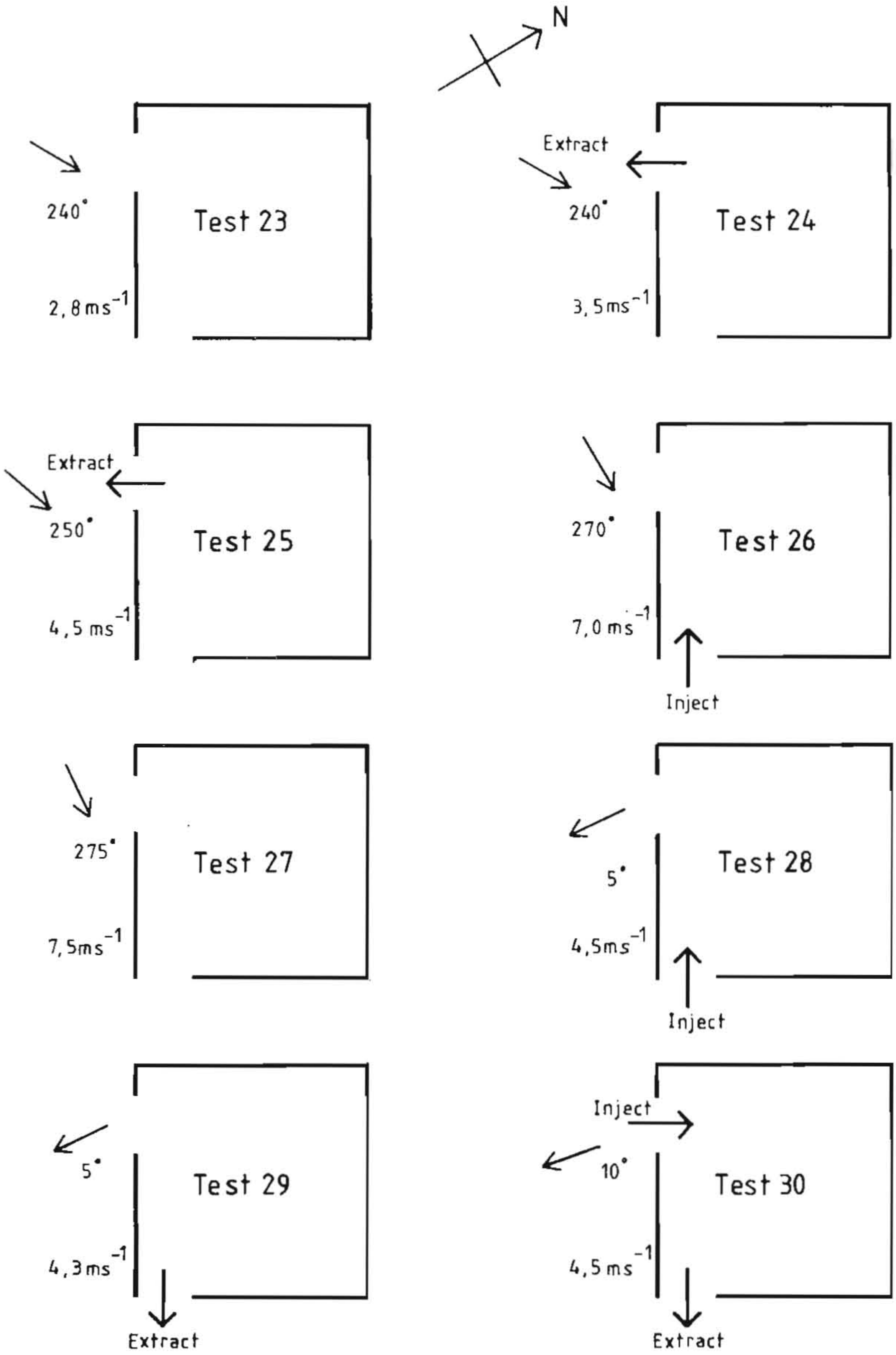


Figure 33

Diagrams of wind direction and speed in ventilation operations - Tests 23 - 30.

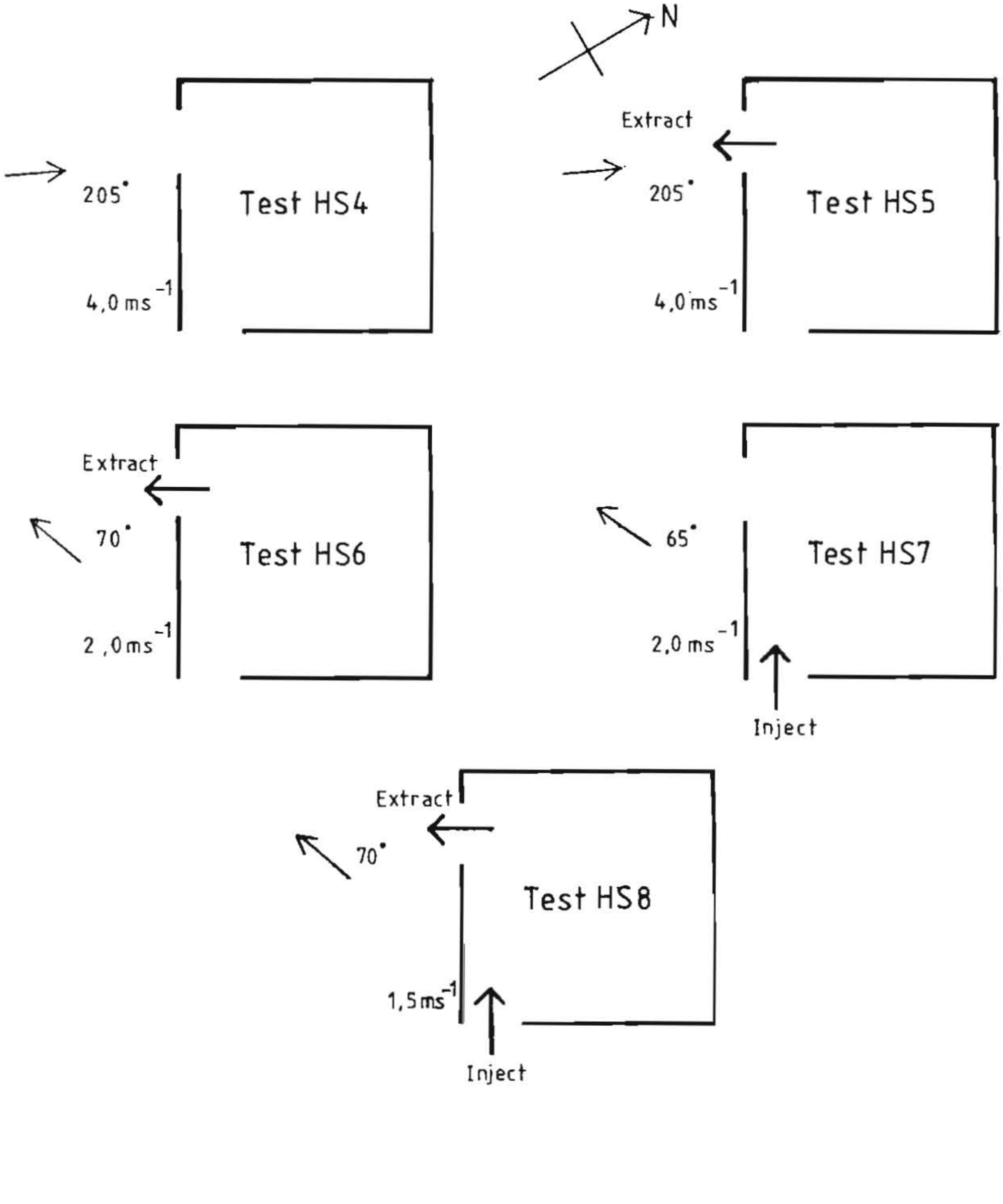


Figure 34

Diagrams of wind direction and speed in ventilation operations - Tests HS4 - 8.

Figure 35

Comparison of ventilation modes in a room where natural ventilation is ineffective

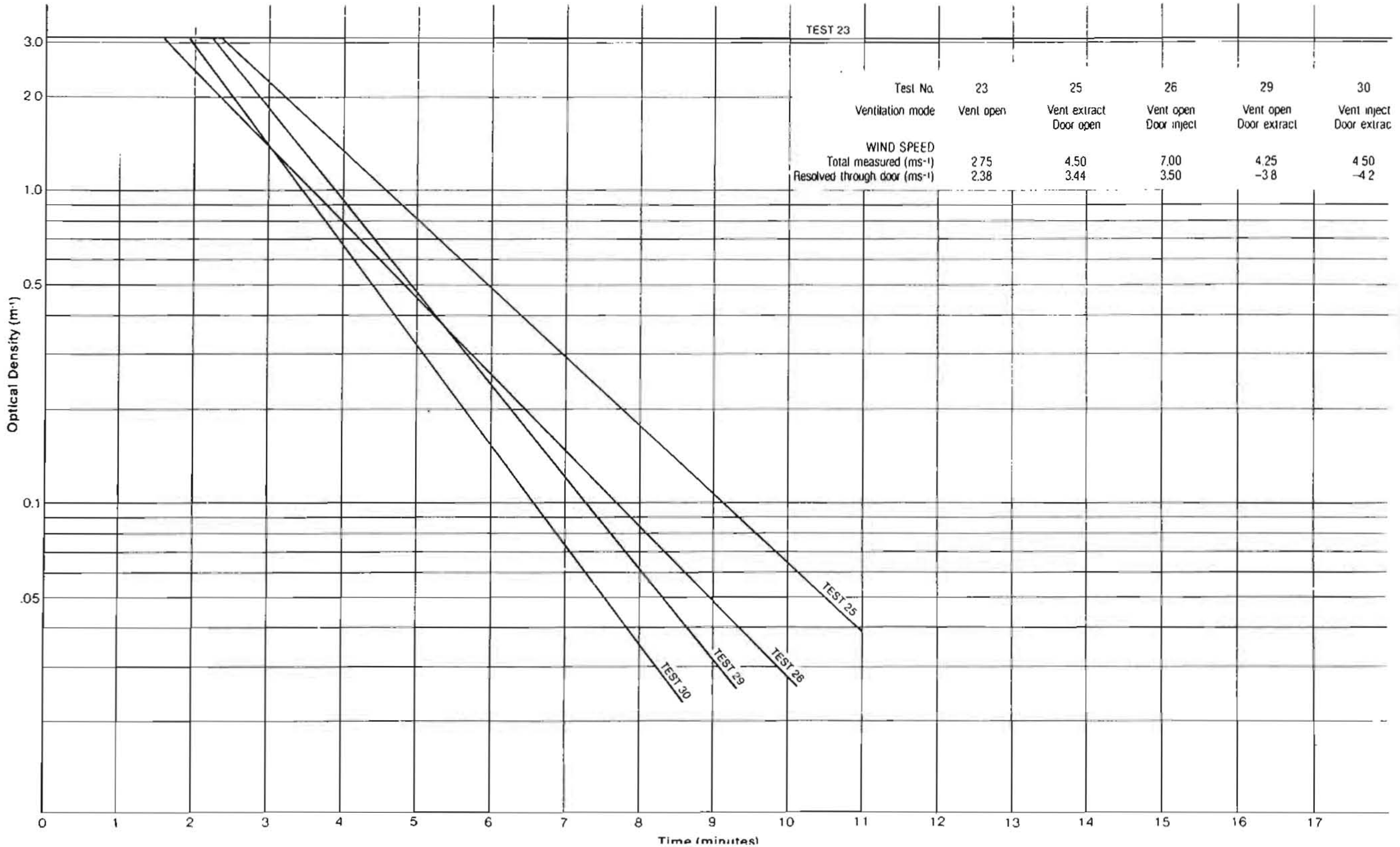


Figure 36
S/673/83 Positioning of the compact generator, SRDB code no. 1, for comparative tests, showing the connection to the doorway.

Figure 37
S/203/83 Smoke exiting 'Industrial B' basement through layflat polythene ducting.

Figure 38
S/687/83

Aneti extractor in use.

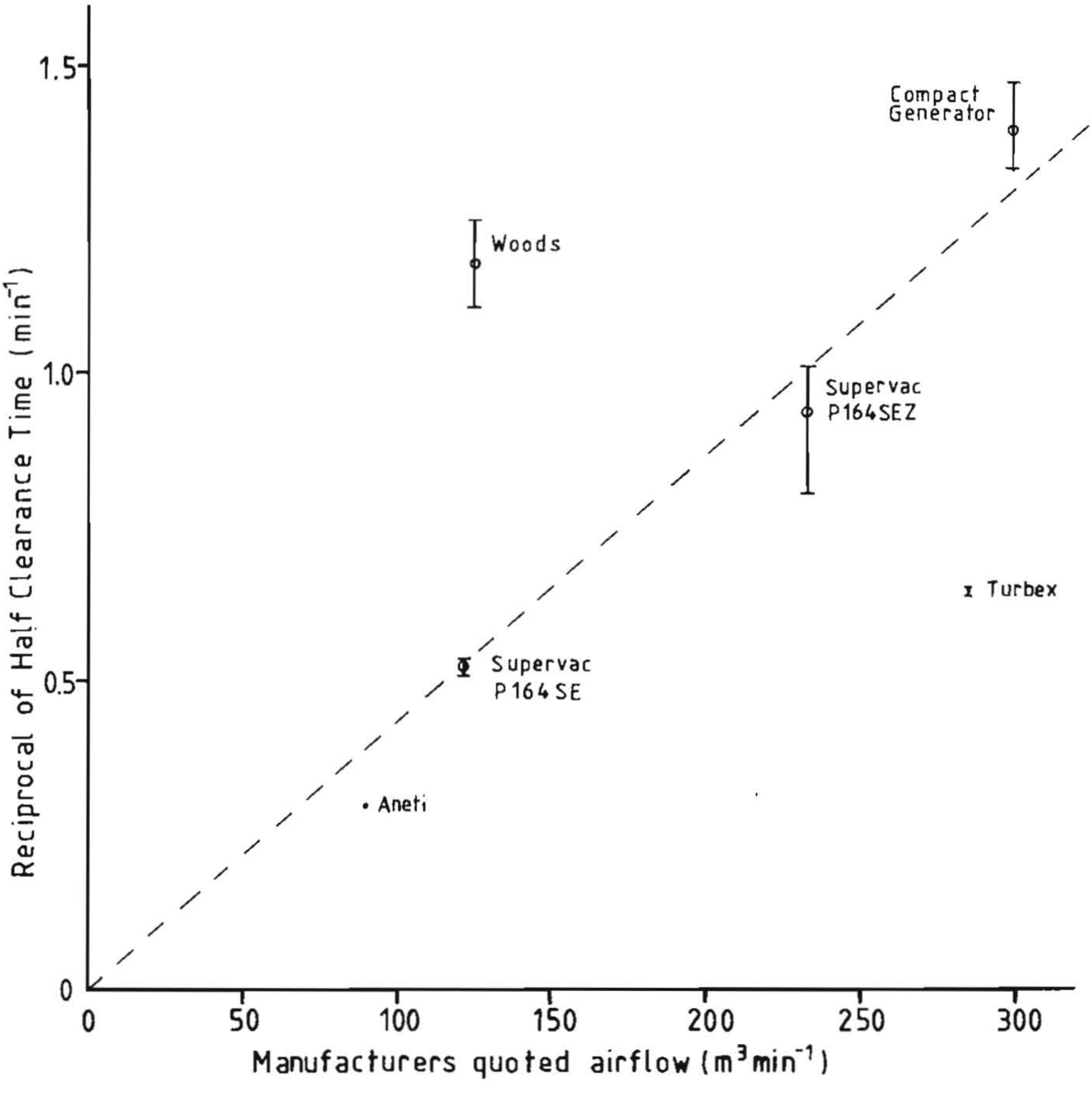


Figure 39

Performance comparison of extractors tested.

APPENDIX A

FIRE DEPARTMENT PROJECT DEFINITION : THE CLEARANCE OF SMOKE IN BRIGADE OPERATIONS

1. BACKGROUND

In fire fighting operations in buildings and confined spaces there is often a need to clear smoke to facilitate entry or rescue work, or to minimise smoke damage. Difficult situations where natural ventilation is limited include basement and ship fires. The smoke problem may be serious with slowly burning smouldering fires, and particular burning materials such as certain plastics will produce dense or toxic smoke. Depending on the circumstances, natural ventilation by convection may be allowed or promoted to achieve smoke clearance. However, special methods and equipment, such as smoke extractors, may be used in addition or as an alternative.

In UK Brigades little use has been made of smoke extractors, although a few appliances carry them, and Salvage Corps are equipped with them. It seems that extractors may be used more commonly in the United States: there is a NFPA recommendation that certain appliances should carry them.

2. OBJECTIVE

The objective is to study the feasibility, costs and benefits of the use of special equipment to clear smoke and, if justified, to formulate recommendations on the use of the equipment in brigade operations and, if necessary, to derive outline specifications for suitable equipment.

3. FURTHER CONSIDERATIONS

The question of clearance of smoke must be considered as part of the larger problem of ventilation in firefighting operations. Injudicious use of extractors may help to spread a fire.

A possible use for extraction equipment lies in producing a reduced pressure in a structure which it is required to fill with high expansion foam. In this way the rate of breakdown of the foam under pressure might be reduced.

In considering specifications for equipment, the question of stowage on an appliance must be considered.

The powered fans known as "extractors" may be positioned to blow fresh air into the structure. Flexible portable ducting may be attached to an extractor or blower. High expansion foam generators may be utilised as air fans. There is also the possibility of using a fog nozzle to promote air movement through an aperture such as a doorway or window.

Some promising results have been obtained in the experimental use of ejector pumps to clear smoke from a ship's hold through 4 inch suction hose. Other experiments with air fans on high expansion foam generators have indicated the possibility of grids, etc in such equipment becoming blocked by combustion products and debris.

11 Feb 1975

APPENDIX B

WORK CARRIED OUT BY THE FIRE RESEARCH STATION OF THE DEPARTMENT OF THE ENVIRONMENT

B.1. Smoke production and movement in tunnels, corridors and shopping malls.

The Fire Research Station (FRS) has studied the rate of production of smoke by a fire, the rate at which it can spread and methods of restricting its spread. Extensive experiments have been carried out both on models and at full scale, including work on a building representing part of a shopping centre (Reference 20), and on the rate of flow of smoke from fires in a railway tunnel in Glasgow (Reference 21). An aim of the FRS work has been to establish the best control method for smoke in a shopping mall. It is difficult to apply results from scale models to situations involving practical forced ventilation, and therefore much of the work has only limited application to the use of portable smoke extractors. A brief outline of the work is given below, however, and further details are available in the references.

FRS assumes that in a shopping mall the fire generally starts in a shop, and if shop fronts are fire resisting, hot smoky gases may be confined to shops of origin. If this is not the case, limitations are placed on the size of the fire and hence the rate of production of hot smoky gases and it is then possible to confine the smoke to a stratified layer beneath the ceiling while the air beneath them is relatively cool and clear. The extent of the layer is limited by dividing the space beneath the ceiling into smoke reservoirs (Reference 22) by screens extending part way towards the floor. Arrangements must then be made to extract smoke from the reservoirs as fast as it flows into them while fresh air must be introduced or allowed to flow into the building to replace the hot gases. Such a system is satisfactory for single storey malls.

The requirements of both natural and power systems for extracting smoke from the smoke reservoirs have been considered (Reference 23). Natural venting systems are liable to be adversely affected by the wind whereas forced extraction systems can overcome wind effects. However, it is difficult to obtain fans which will handle the large volumes of hot gases involved.

The situation in multi-level shopping malls is more complex and requires the modification of the equations for smoke movement. The resultant recommendations for methods of extraction of smoke from multi-level malls are given in a set of papers by Morgan (References 24-26). All the ventilation procedures given in this work apply to fixed ventilation systems installed in the building, although certain principles may be applied to portable systems.

As part of the work on smoke movement, a computer model for analysing the motion of smoke through a multi compartment building was developed. The program was then tested by comparison with results obtained from full scale fires in the Industrial 'A' building at the Fire Service College, Moreton-in-Marsh. The fire tests were monitored for pressure in compartments, flow rates through doors, smoke density, concentration of carbon dioxide[1] and temperature. A 1m^2 tray of kerosene was burned to produce the smoke, and variations in the tests were introduced by opening and closing doors.

---

1. Carbon dioxide concentration in the air is an indication of the travel of fire gases, since the amount produced from burning kerosene can be readily calculated.

These large scale tests showed certain limitations of the computer program, particularly with regard to the temperature and travel of smoke in shafts, and perhaps more significantly, the dilution of smoke by air. Further work in these areas was recommended. The large scale tests on Industrial 'A' formed the basis of another comparative investigation which is discussed further in Section 3.3.

B.2.2. Criteria for ventilation.

Part of the work of FRS has involved investigating the spread of fire in relation to ventilation. This work has been confined to a situation with very poor ventilation (i.e. a room with windows and doors closed) so that the air entered into the fire compartment only through gaps between the windows and doors and their frames. Therefore the application of this work to the current project is limited. It is pointed out in the report that flashover may occur even with minimal ventilation.

B.2.3. Methods of smoke extraction.

The research on ventilation of shopping malls which was discussed in Section B.1 was mainly concerned with fixed ventilation systems. FRS has investigated the use of these systems and has carried out work to improve the heat resistance of honeycomb dampers used in the ducting of such systems (Reference 27).

Morgan and Bullen (References 28-29) have experimented with a ducted water spray to remove smoke by entrainment. From the results obtained with an experimental small size system they predicted the behaviour of a full size system which would be installed in a shopping mall and suggested that it would be a reasonably effective smoke control system.

APPENDIX C

SURVEY OF SMOKE EXTRACTION EQUIPMENT IN U.K. BRIGADES

APPENDIX C

SURVEY OF SMOKE EXTRACTION IN BRIGADES.

Questionnaire sent to brigades

QUESTIONNAIRE

1. Does your brigade use smoke extraction equipment? - YES/NO

If the answer to question 1 is NO, no further questions need be answered, however, please return a NIL reply.

2. What type of equipment is used? Please state - (eg electric fans, high-expansion generator in smoke extraction mode, give make, size etc)

3. How many smoke extractors (including high-expansion generators used as smoke extractors) does your brigade hold?

....

4. Does your brigade produce any technical instructions or operating procedures for using smoke extractors? YES/NO
If YES, a copy of the same would be appreciated.

5. Please give the name of a contact within the brigade for further discussion, if necessary.

Name .... Tel No ....

Rank ....

Appointment ....

Completed questionnaires and nil returns should be sent to:- Divisional Officer A C Wells, Home Officer Fire Research and Development Unit, Fire Service College, Moreton-in-Marsh, Gloucestershire.

Brigade .. .. Date ....

Signed .... Rank ....

FSI/HJP/EGC 16/2/82

APPENDIX C

SURVEY OF SMOKE EXTRACTION IN BRIGADES.

Table C1 - Brigades returning a Nil reply to the questionnaire

Buckinghamshire
Cambridgeshire
Central Region
Cheshire
Cleveland
Derbyshire
Dorset
Durham

Dyfed
Glamorgan (West)
Gloucestershire
Grampian
Gwent
Gwynedd
Humberside

Man, Isle of
Northern Region
Northumberland
Powys
Salop
Somerset
Staffordshire
Suffolk[1]
Surrey
Sussex (East)
Sussex (West)
West Midlands
Wight, Isle of
Wiltshire
Yorkshire (North)
Yorkshire (South)

1 Reply referred to fixed electric fans only.

APPENDIX C

SURVEY OF SMOKE EXTRACTION IN BRIGADES.

Table C2 - Smoke extractors in U.K. brigades

Brigade	Type of Equipment	No. of Units	Technical Instructions or Operating Procedure	Comments
Avon	Angus Turbex	2	Operating Procedure	
Bedfordshire	Angus Turbex	2	Technical Bulletin and Training Note	
Berkshire	Angus Turbex	1	None	
Clwyd	Angus Turbex	2	None	
Cornwall	Angus Turbex	2	None	
Oevon	Angus Turbex Supervac P200SE 20" Fan 115v a.c. 1hp	 6	Operating Instructions	
Dumfries	Supervac P164SE 16" Fan 115v a.c.	2	None (comment made that operation is self-explanatory)	Used with 20'x16" flexible ducting and collapsible polythene tube on delivery side. Operated from 2kW portable generator or 2.5kW Powermite fixed generator on Emergency Tenders.
Essex	Angus Turbex	3	None	No smoke extraction policy but Hi-ex foam units have been used for this purpose.
Glamorgan (Mid)	Angus Turbex Leichstchaum LG100 Hi-ex foam generator, petrol driven. Airscrew Weyrock water turbine fan.	3	None	 Leichstchaum can be adapted to extract smoke.
Glamorgan (South)	Angus Turbex 110v Electric Fans	2 2	References in Training Notes	 15,000 cu ft per min.

SURVEY OF SMOKE EXTRACTION IN BRIGADES.

Table C2 - Smoke extractors in U.K. brigades

Brigade	Type of Equipment	No. of Units	Technical Instructions or Operating Procedure	Comments
Hampshire	Spitznas 300mm diam. Fan. 110v	3	Operational and Training Note.	60 cu m per min.
Hereford & Worcester	Angus Turbex Mk II	1	Note on Operation	
Lancashire	Angus Turbex	1	No detail given	Comments of Station Commander on ventilation given.
Leicestershire	15 inch diam. Fan 100v d.c.	1	None	
London	Angus Turbex Mk II	5	Note on operation	One unit used for training
Lothian & Borders	Angus Turbex	2	None	
Manchester (Greater)	Angus Turbex Mk II	6	Operational Procedure	
Merseyside	Angus Turbex Mk II	4	Turbex information as in Manual of Firemanship	
	Supervac P124S 12" Fan 110v	5	Operational and Training Instruction on Supervac	83 cu m per min.
Norfolk	Angus Turbex	4	Technical and Training Order	
Northamptonshire	Angus Turbex	1	None	
Nottinghamshire	Angus Turbex	2	None	
Oxfordshire	Angus Turbex Mk II	1	None	

APPENDIX C

SURVEY OF SMOKE EXTRACTION IN BRIGADES.

Table C2 - Smoke extractors in U.K. brigades

Brigade	Type of Equipment	No. of Units	Technical Instructions or Operating Procedure	Comments
Warwickshire	Angus Turbex Mk II	3	Operational and Training Instructions	
Yorkshire (West)	K. Blackman 10" Fan Supervac P124S 12" Fan	1 1	Operational Notes on Supervac	

APPENDIX D - INFORMATION OBTAINED FROM VISITS TO UK BRIGADES AND SALVAGE CORPS.

This appendix contains annotated photographs taken on the visits described in Section 5.3.

Figure D1
S/928/83

Devon Fire Brigade - Supervac P200SE fan suspended in a door way from an adjustable door bar.

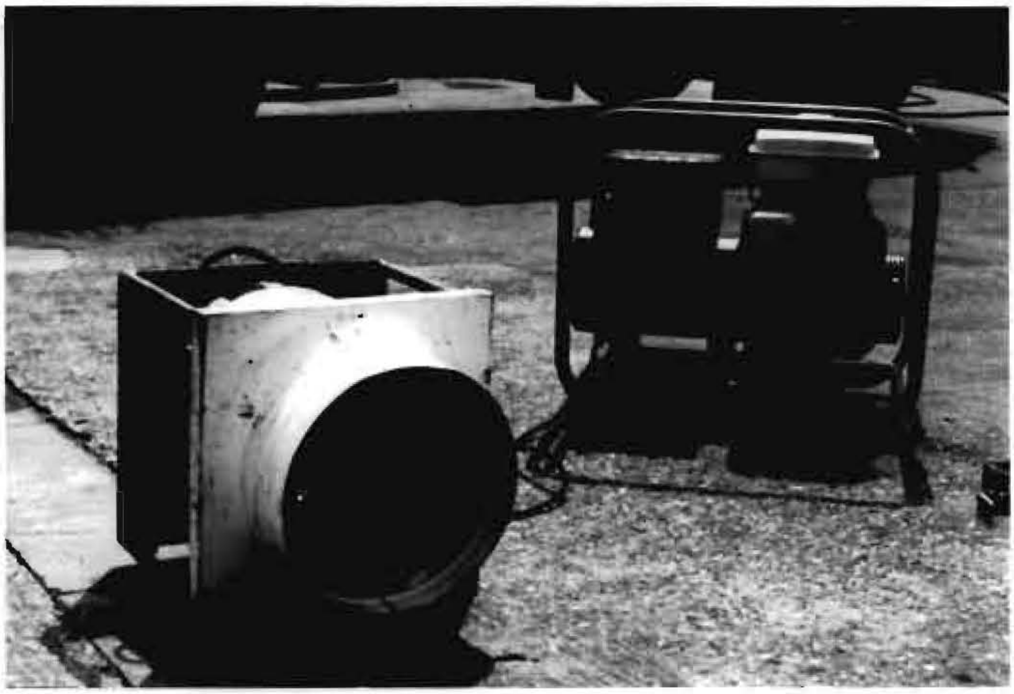


Figure D2
S/564/83

Merseyside Fire Brigade - Supervac P124 fan and 110v portable generator, carried on first-line appliances.

Figure D3
S/570/83

Merseyside Fire Brigade - Stowage of Supervac P124 fan in a first-line appliance locker.

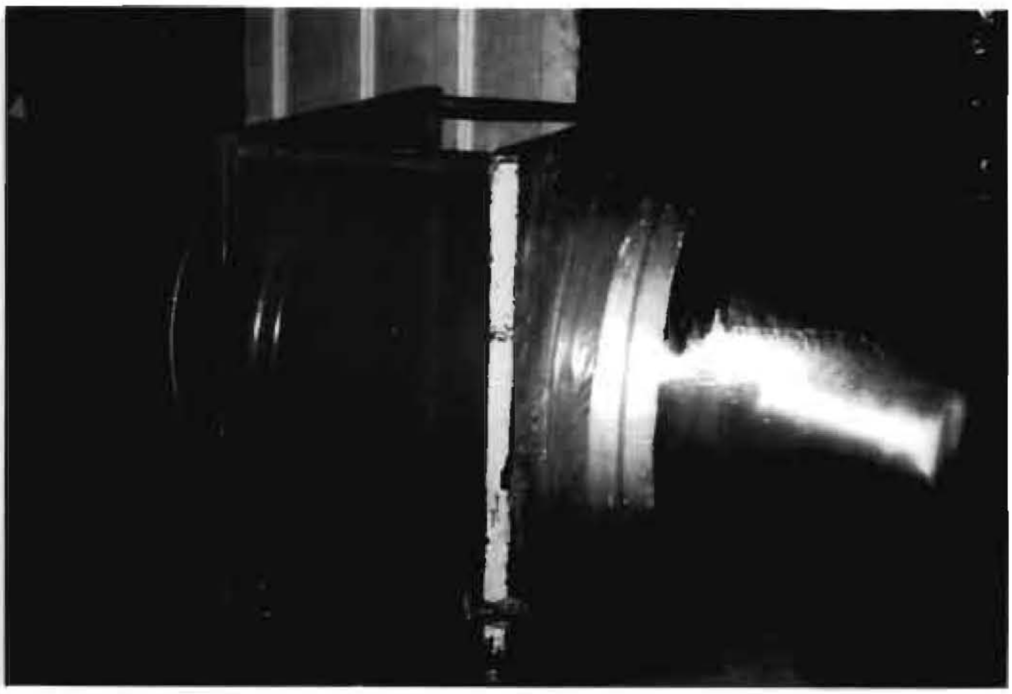


Figure D4
S/571/83

Liverpool Salvage Corps - Supervac P200SE2 fan with semi-rigid ducting attached to the inlet face and layflat polythene ducting on the exhaust face.

Figure D5
S/573/83

Liverpool Salvage Corps - Spitznas Axial fan - easily carried in one hand.

Figure D6
S/627/83

London Salvage Corps - Woods fan showing the modified handles which enable the fan to be carried and stowed more easily.

Figure D7
S/626/83

London Salvage Corps - Bracket designed to keep the free end of layflat polythene ducting from closing or being blown about in adverse weather conditions.

APPENDIX E

SUPPLIERS AND MANUFACTURERS OF PORTABLE SMOKE EXTRACTION EQUIPMENT

TYPE 1 - FANS

a) Electrical motors.

SUPERVAC	Dale Emergency Products Ltd., Faraday House, Eastfield, Scarborough, Yorks. YO11 3UT.
WOODS AEROFOIL	Woods of Colchester Ltd., Tufnell Way, Colchester, Essex.

b) Petrol / Diesel motors.

SUPERVAC	Can be supplied with petrol motors.

c) Water motors.

ELTA	Elta Fans Ltd., Wintersells Rd., Byfleet, Surrey.
TURBEX HI EX FOAM GENERATOR	Angus Fire Armour Ltd., Thame Park Rd., Thame, Oxfordshire.
COMPACT GENERATOR HI EX FOAM	Symtol Engineering Ltd., Unit 9A Cowley Rd., Blyth Ind. Est., Blyth Northumberland, NE24 5TF.

d) Compressed air motors.

COPPUS	George Meller Ltd., Orion Park, Northfield Ave., Ealing, London W13 9SJ.

TYPE 2 - AIR ENTRAINMENT DEVICES

a) Into water.

ANETI	A. Dubois & Co., 29 Rue de la Plaine, 75020, Paris.
NOBLE EJECTOR PUMP	Hughes Engineering Co. Ltd., Briton St., Leicester.

b) Into air.

BRAUER AIRMOVERS	HMC-Brauer Ltd., Dawson Rd., Mount Farm Estate, Bletchley, Milton Keynes, Bucks. MK1 1JP.
COPPUS JECTAIR	George Meller Ltd., Orion Park, Northfield Ave., Ealing, London W13 9SJ.

APPENDIX F

CALIBRATION OF SMOKE DENSITY METERING EQUIPMENT

Section 7.3.2 describes the smoke density metering equipment, its calibration and use during smoke clearance tests.

The maker's calibration in terms of percentage obscuration was refined by an experimental calibration in terms of optical density.

Calibration was carried out after the projector/receiver units had been installed in the test room and connected to the indicators in the mobile laboratory. The calibration was checked before every smoke test.

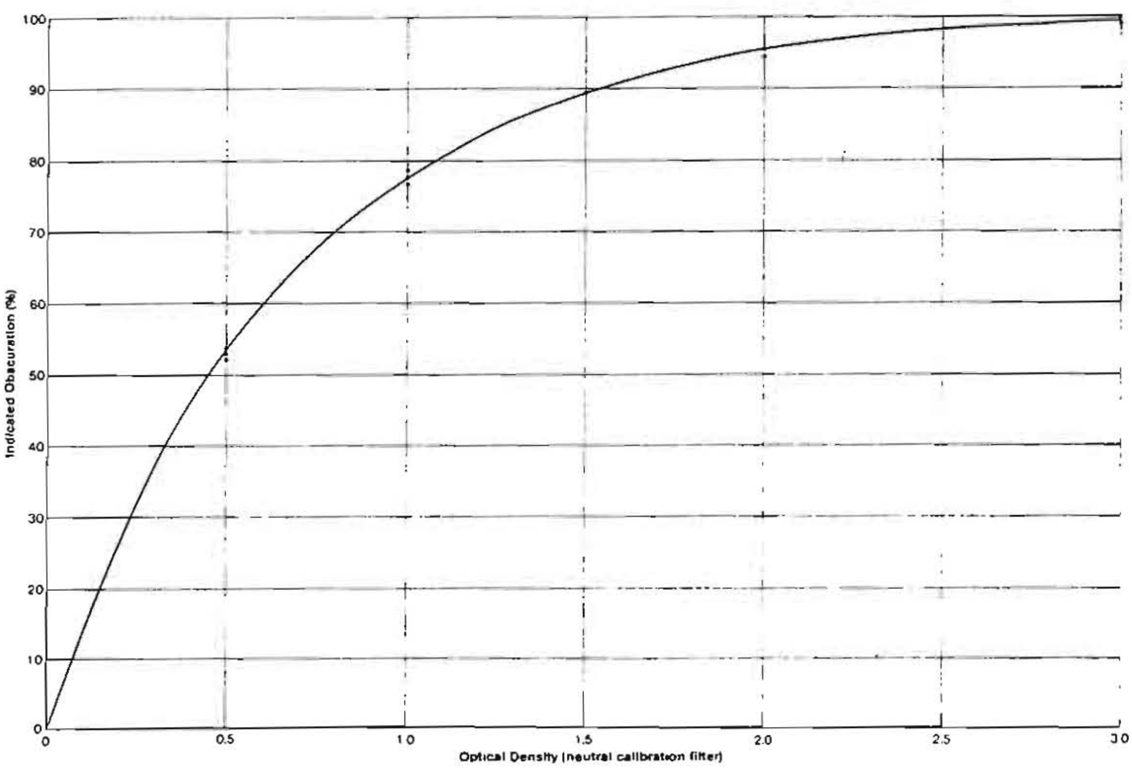
The calibration procedure was for one operator to place a neutral density filter between the projector and receiver, while a second operator read and recorded the reading of percentage obscuration given by the indicator in the mobile laboratory. Communication between the operators was maintained using battery operated headsets.

Each meter was calibrated with six neutral density filters of optical densities 0.5, 1.0, 1.5, 2.0, 2.5 and 3.0. During calibration the UV recorder was run so that calibration lines were produced on the chart record.

From the results calibration graphs (see below) were produced, relating the indicated percentage obscuration to the optical density, and this was used to convert the experimental results of the smoke tests.

The calibration curves illustrate the limitations of the smoke density meters in terms of the reading accuracy of the instruments at the higher optical densities.

Calibration chart for red smoke density meter



APPENDIX G

GRAPHS OF TESTS OF SMOKE CLEARANCE PROCEDURES, 'INDUSTRIAL B' BUILDING, FIRST FLOOR

Figure G1 Test 5

Log-linear graph of Optical Density against Clearance Time for four smoke density meters

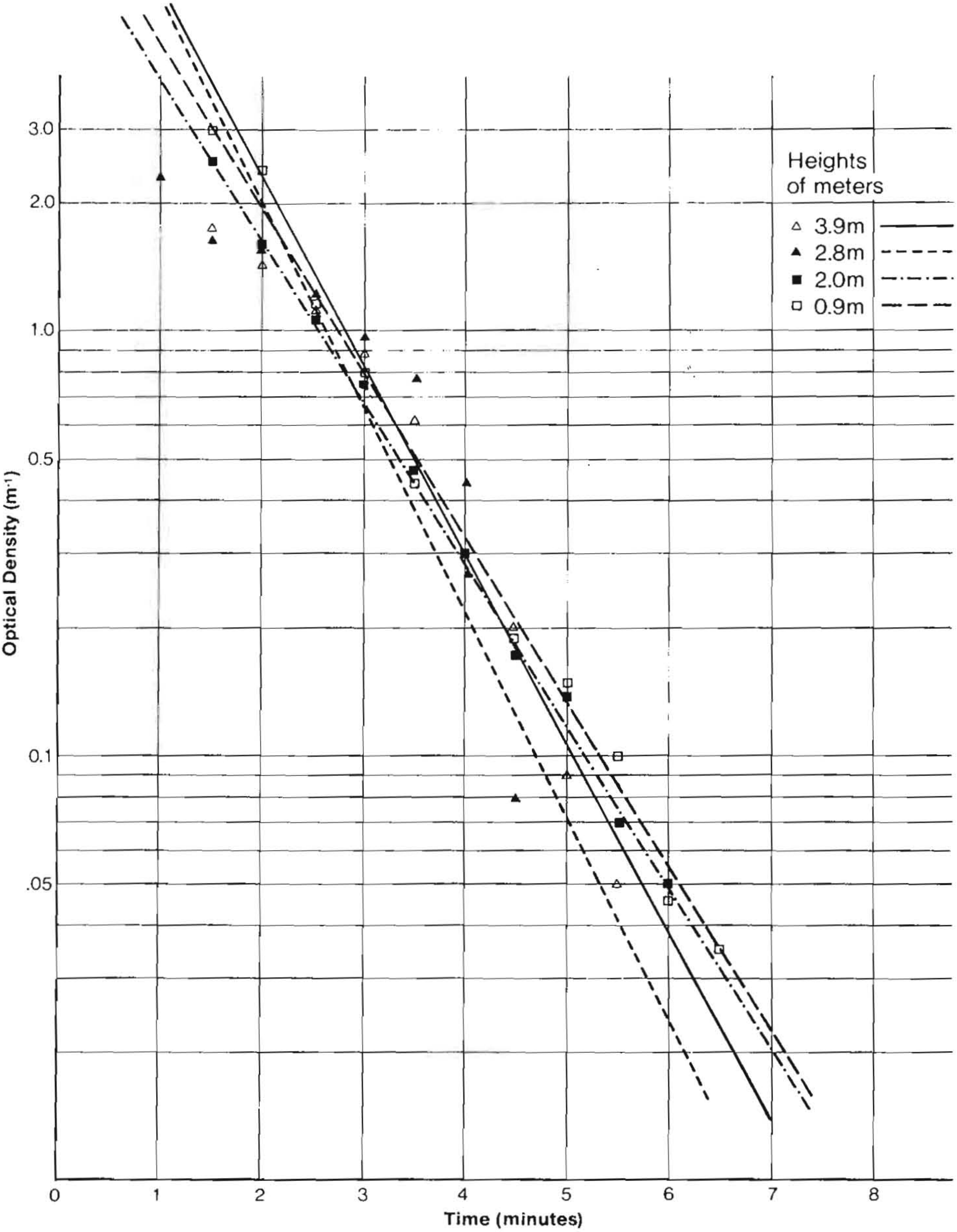


Figure G2 Test 6

Log-linear graph of Optical Density against Clearance Time for four smoke density meters

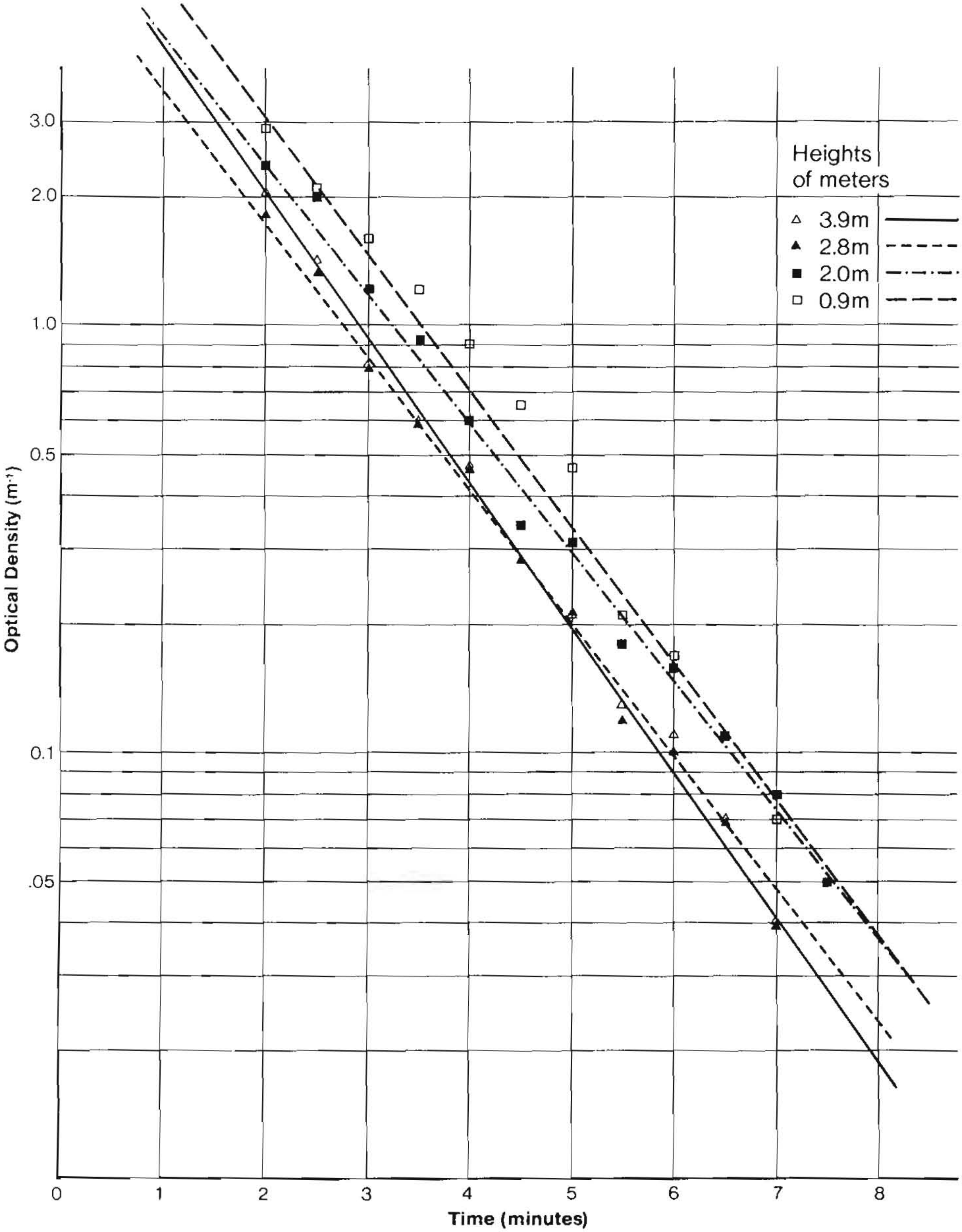


Figure G3 Test 7

Log-linear graph of Optical Density against Clearance Time for four smoke density meters

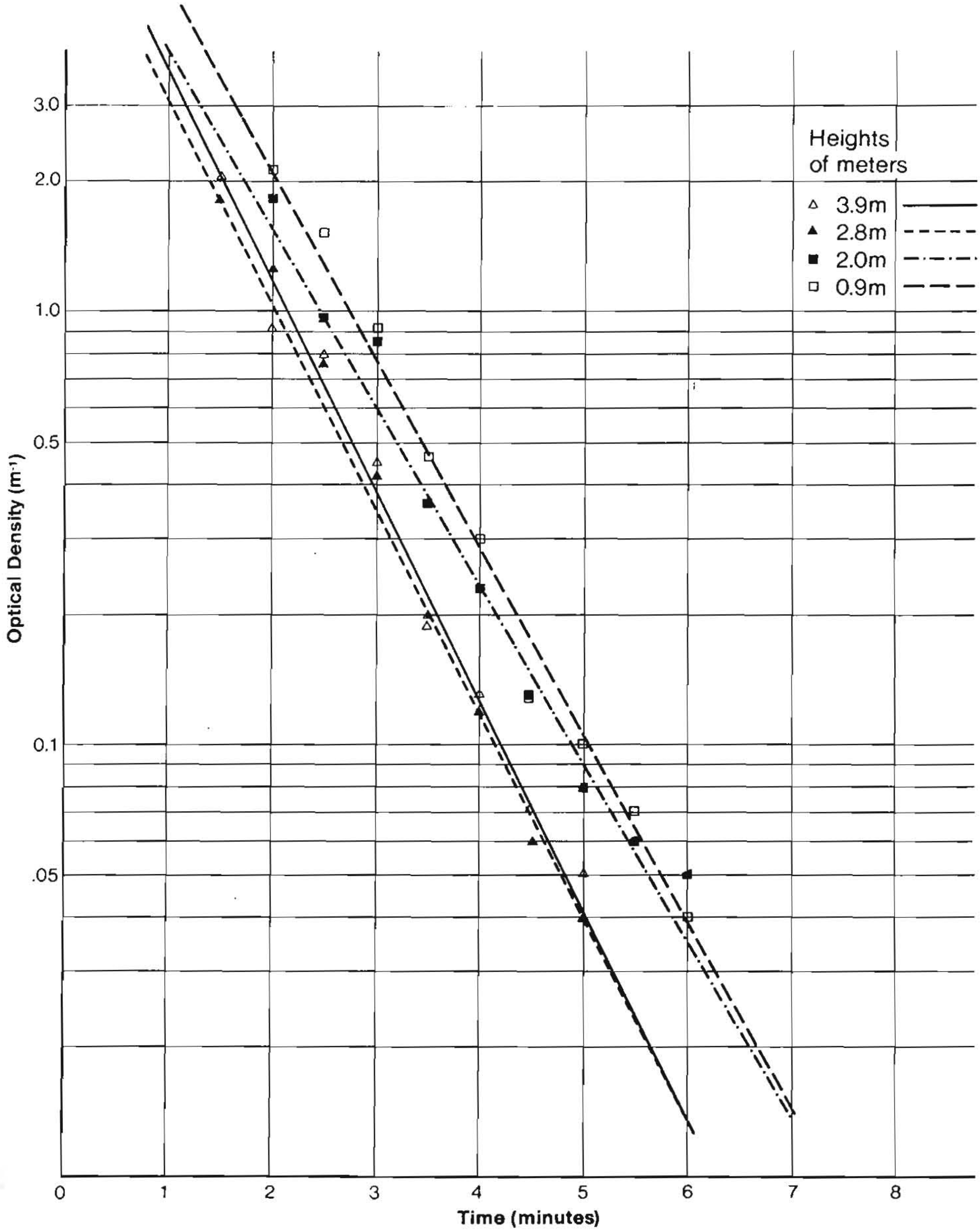


Figure G4 Test 8

Log-linear graph of Optical Density against Clearance Time for four smoke density meters

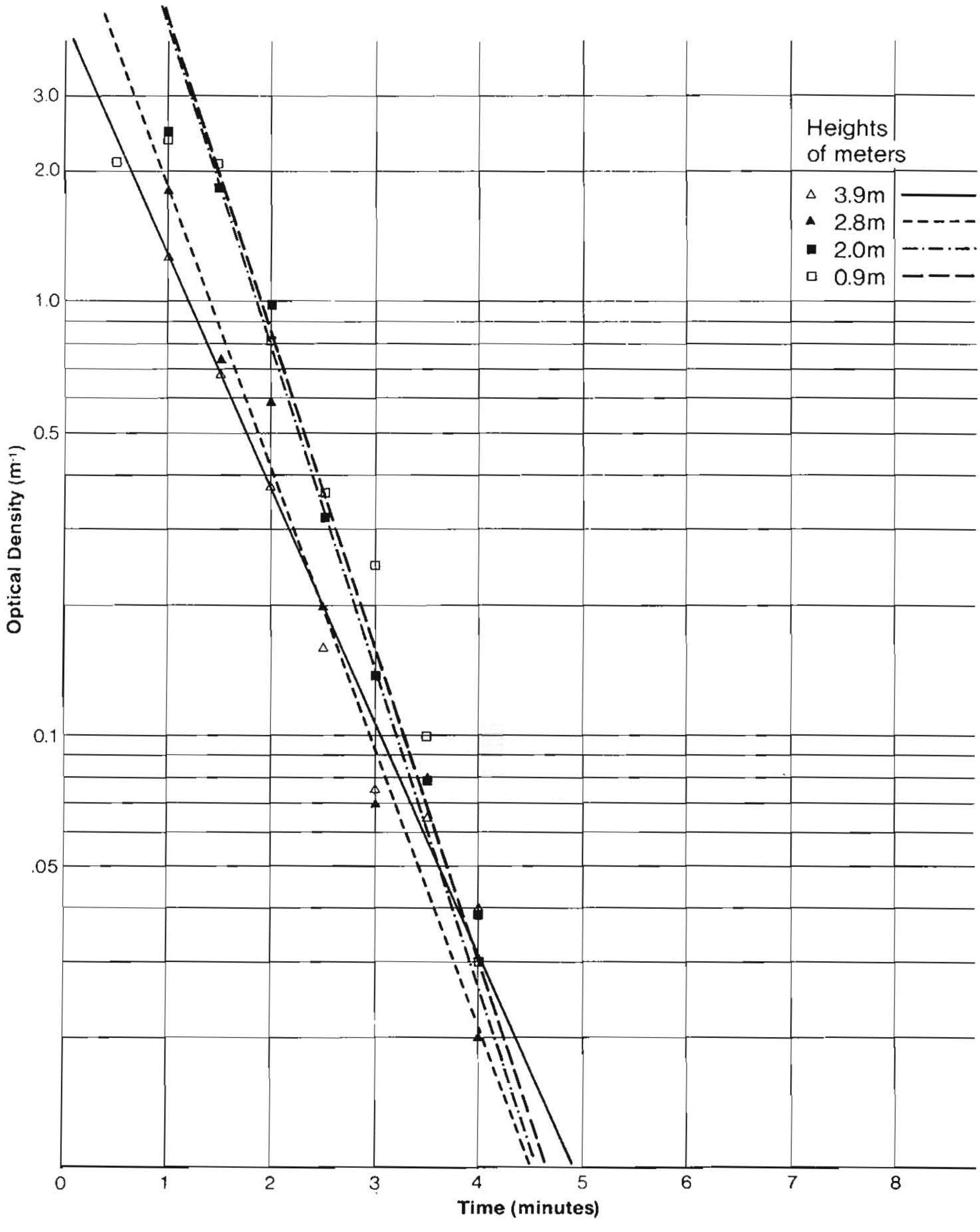


Figure G5 Test 9

Log-linear graph of Optical Density against Clearance Time for four smoke density meters

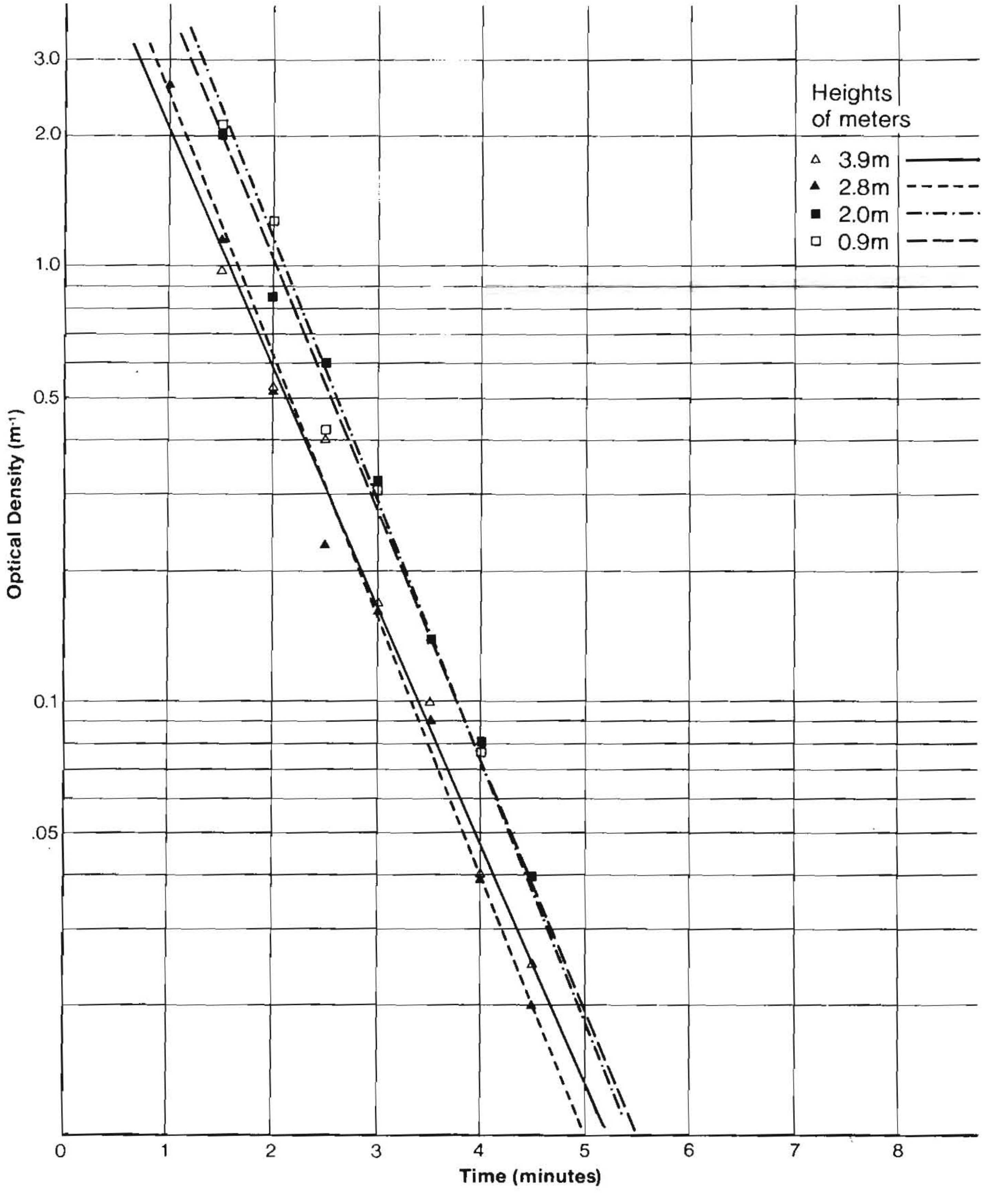


Figure G6 Test 10

Log-linear graph of Optical Density against Clearance Time for four smoke density meters

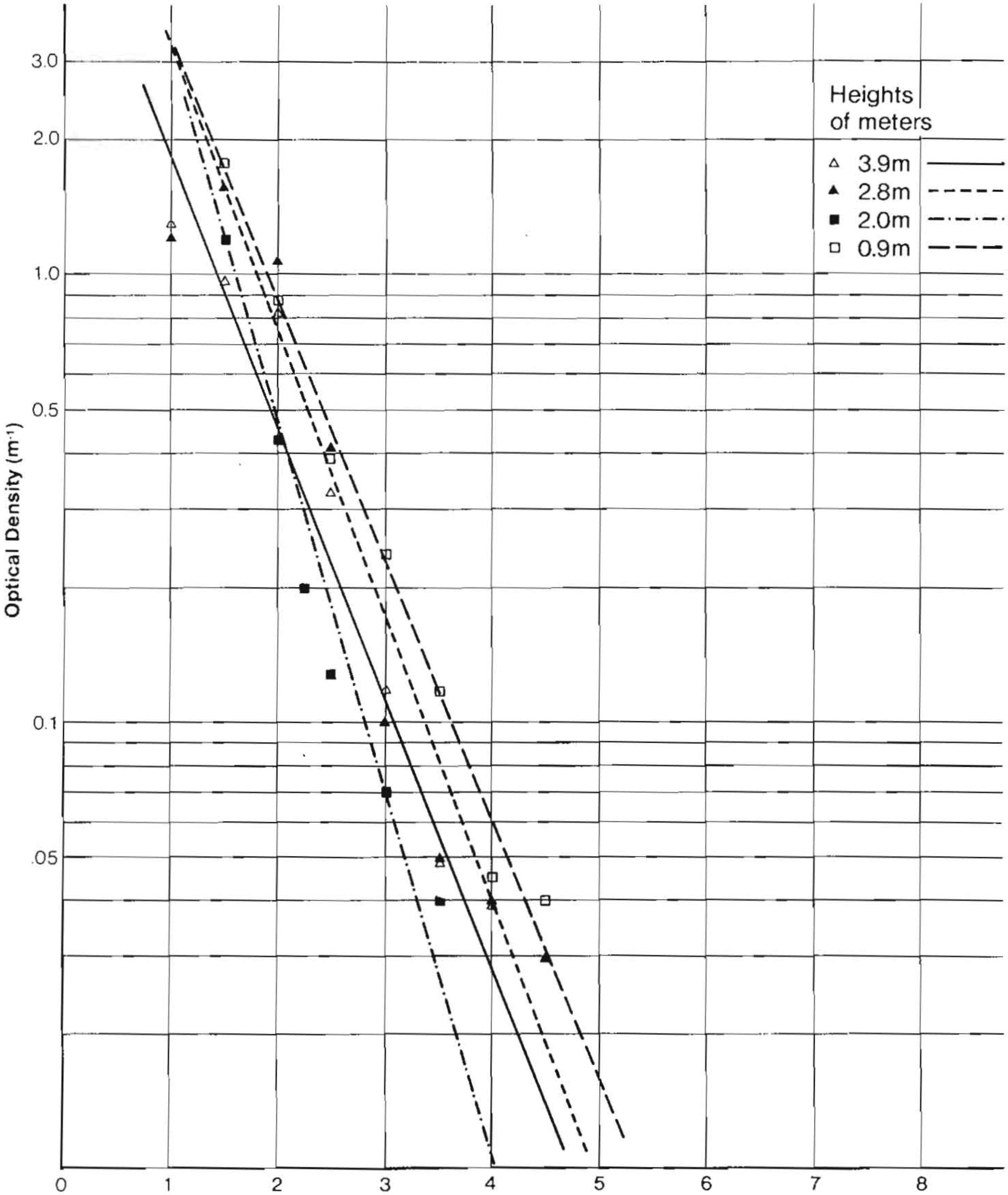


Figure G7 Test 11

Log-linear graph of Optical Density against Clearance Time for four smoke density meters

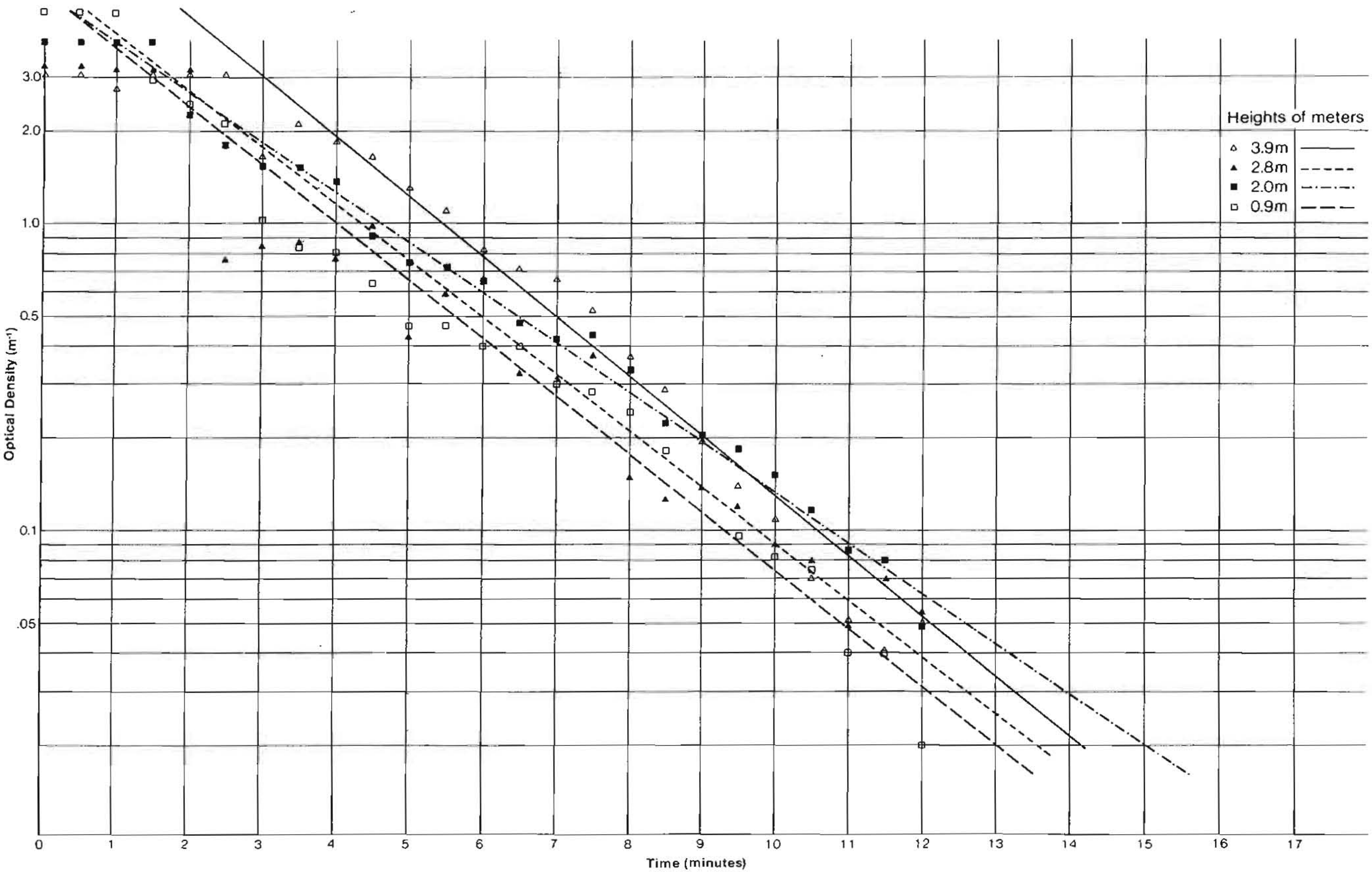


Figure G8 Test 12

Log-linear graph of Optical Density against Clearance Time for four smoke density meters

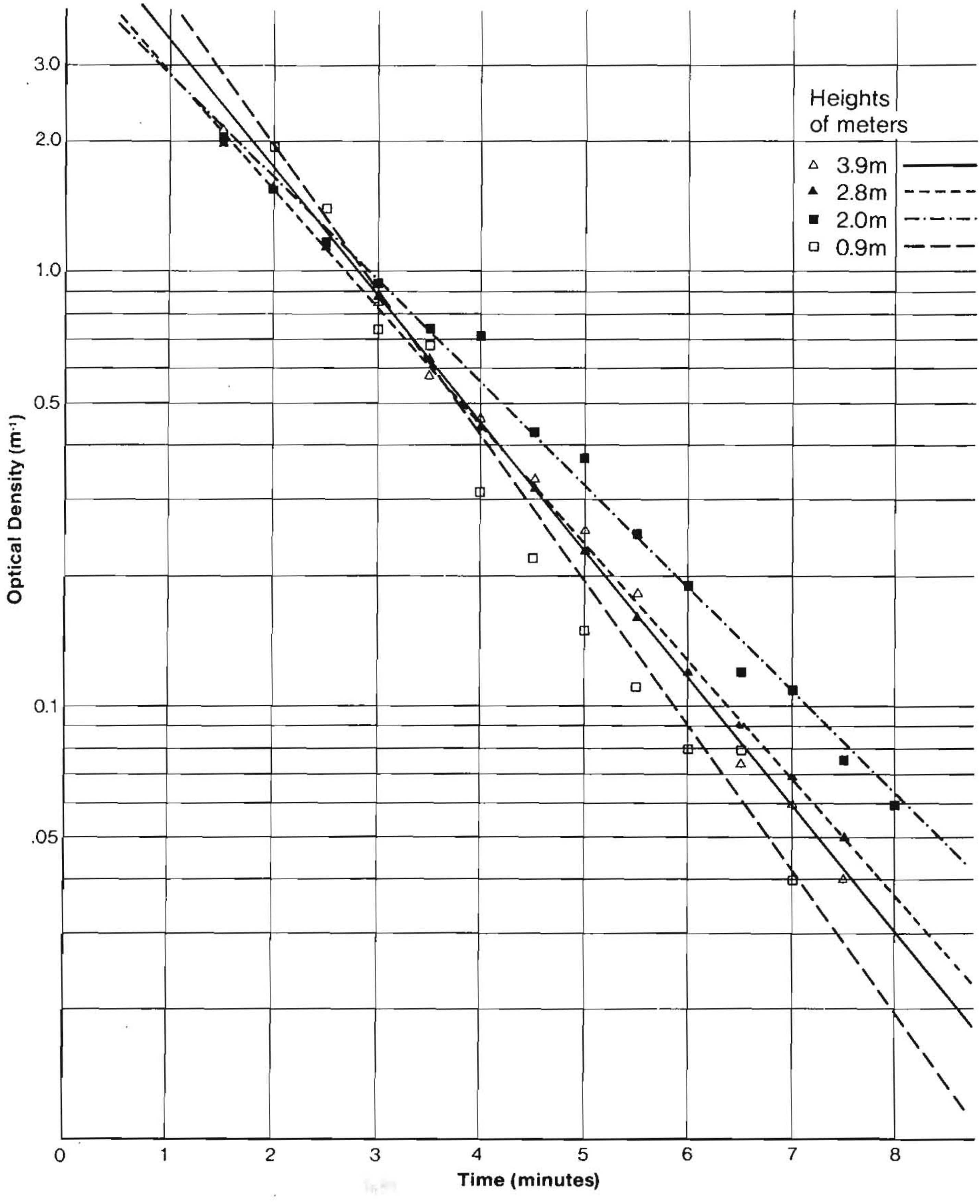


Figure G9 Test 13

Log-linear graph of Optical Density against Clearance Time for four smoke density meters

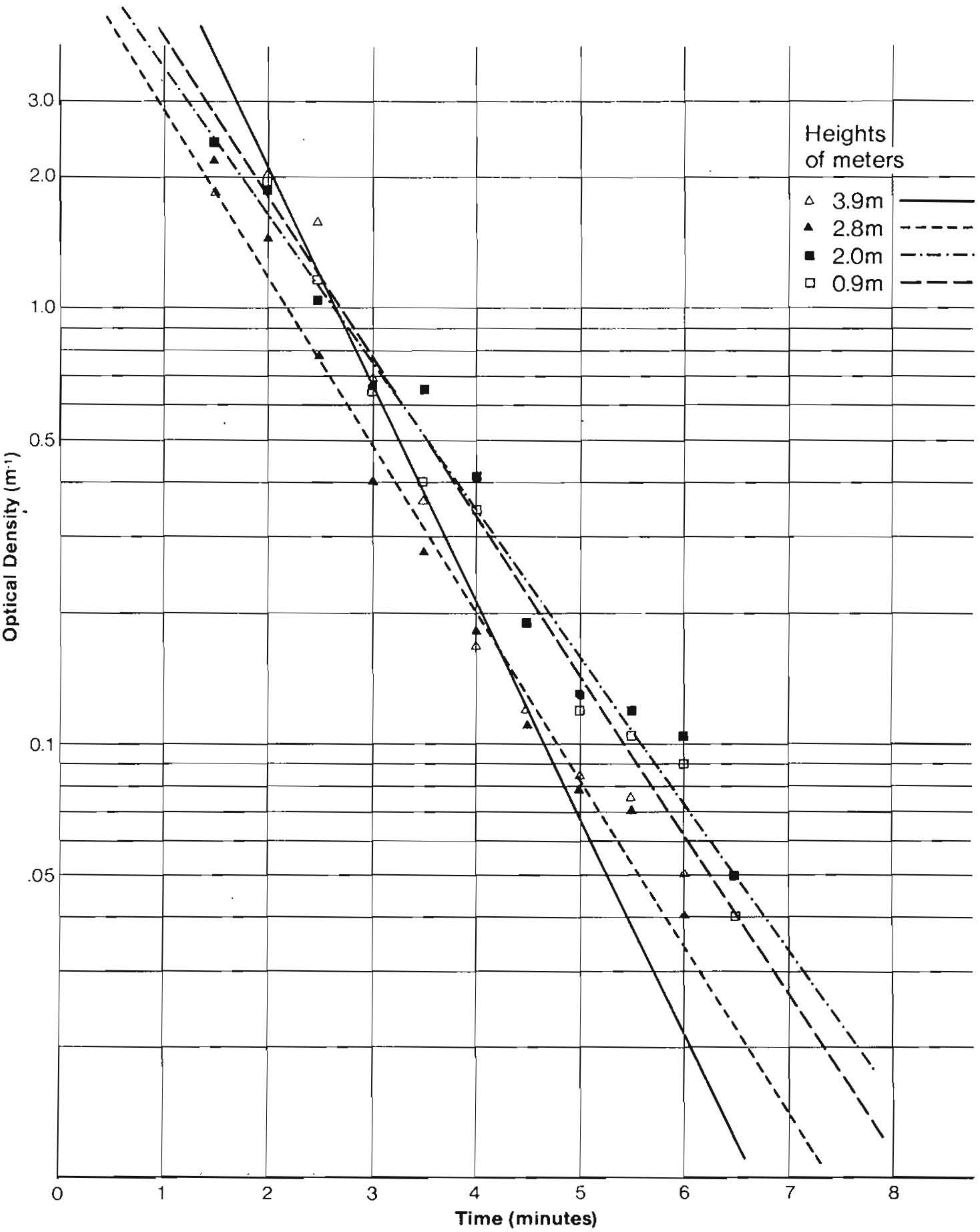


Figure G10 Test 14

Log-linear graph of Optical Density against Clearance Time for four smoke density meters

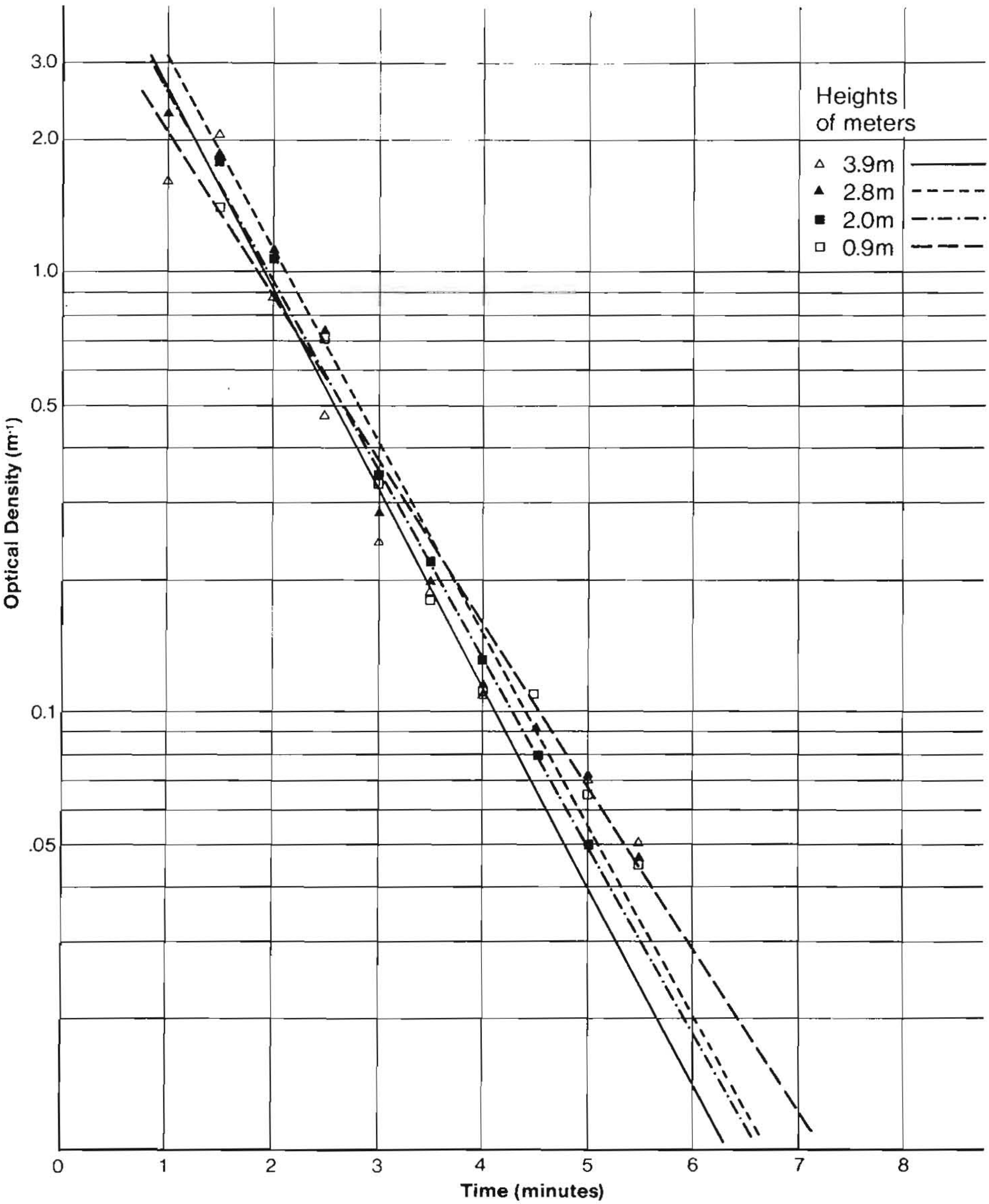


Figure G11 Test 15

Log-linear graph of Optical Density against Clearance Time for four smoke density meters

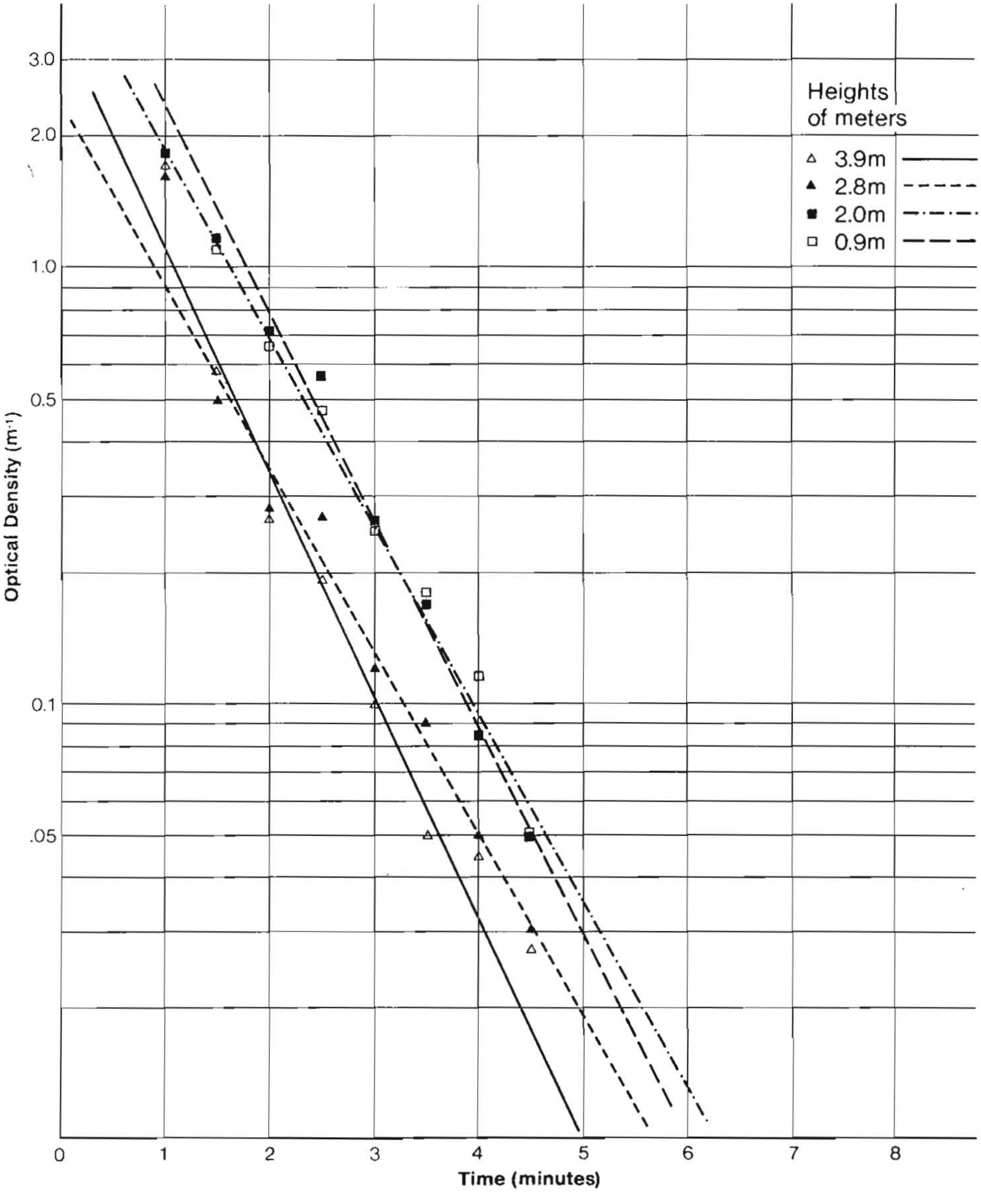


Figure G12 Test 16

Log-linear graph of Optical Density against Clearance Time for four smoke density meters

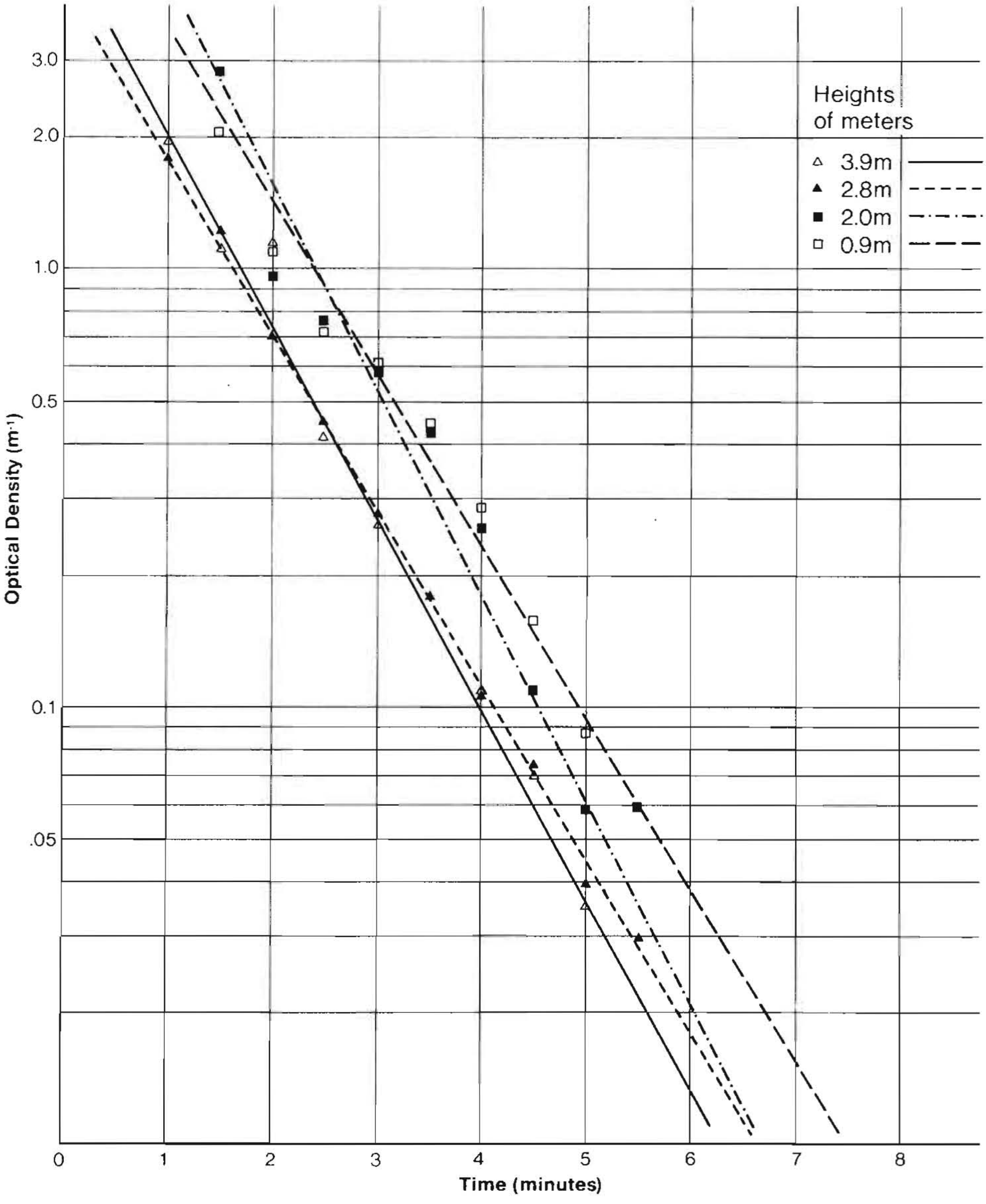


Figure G13 Test 17

Log-linear graph of Optical Density against Clearance Time for four smoke density meters

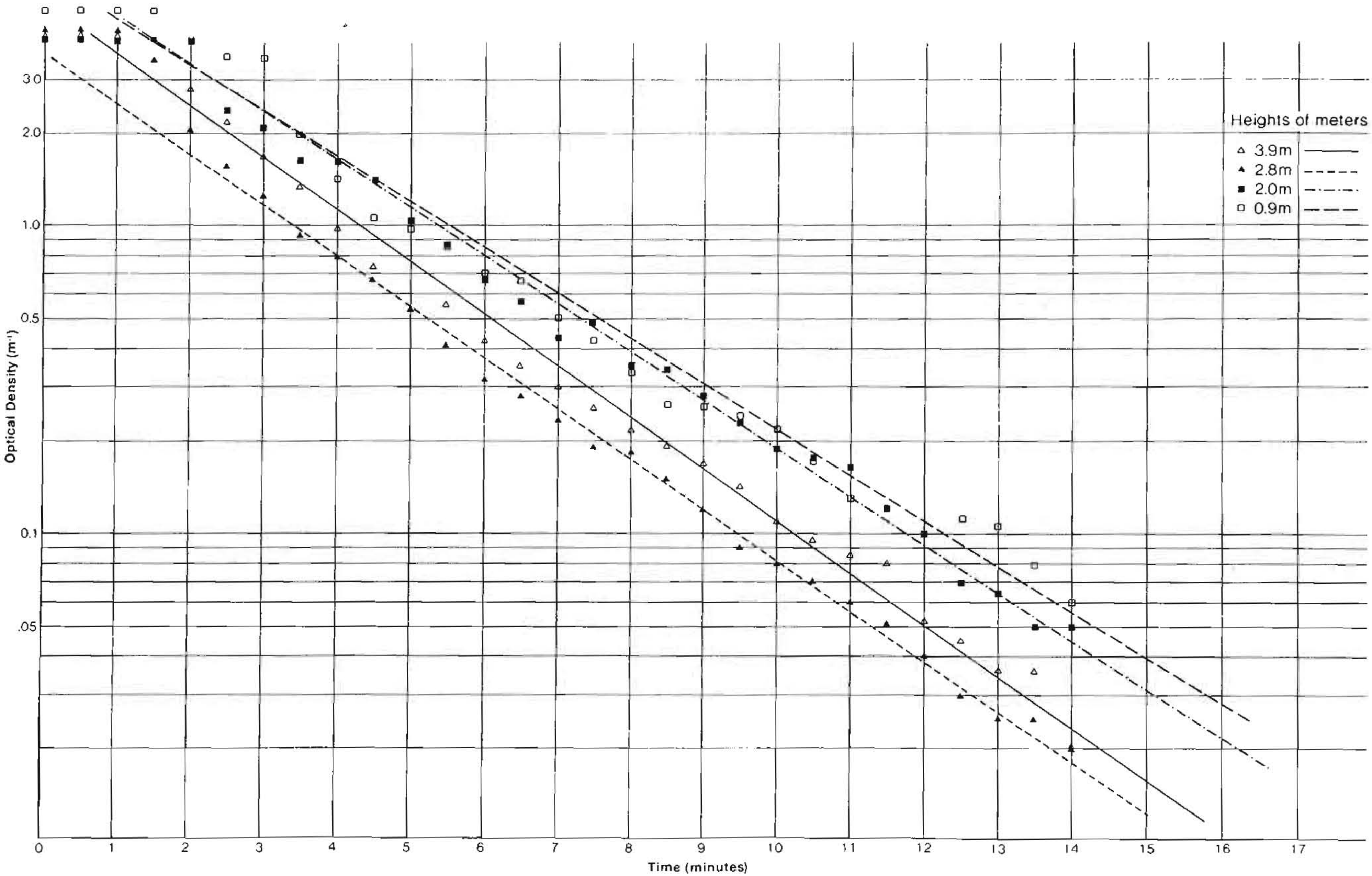


Figure G14 Test 18

Log-linear graph of Optical Density against Clearance Time for four smoke density meters

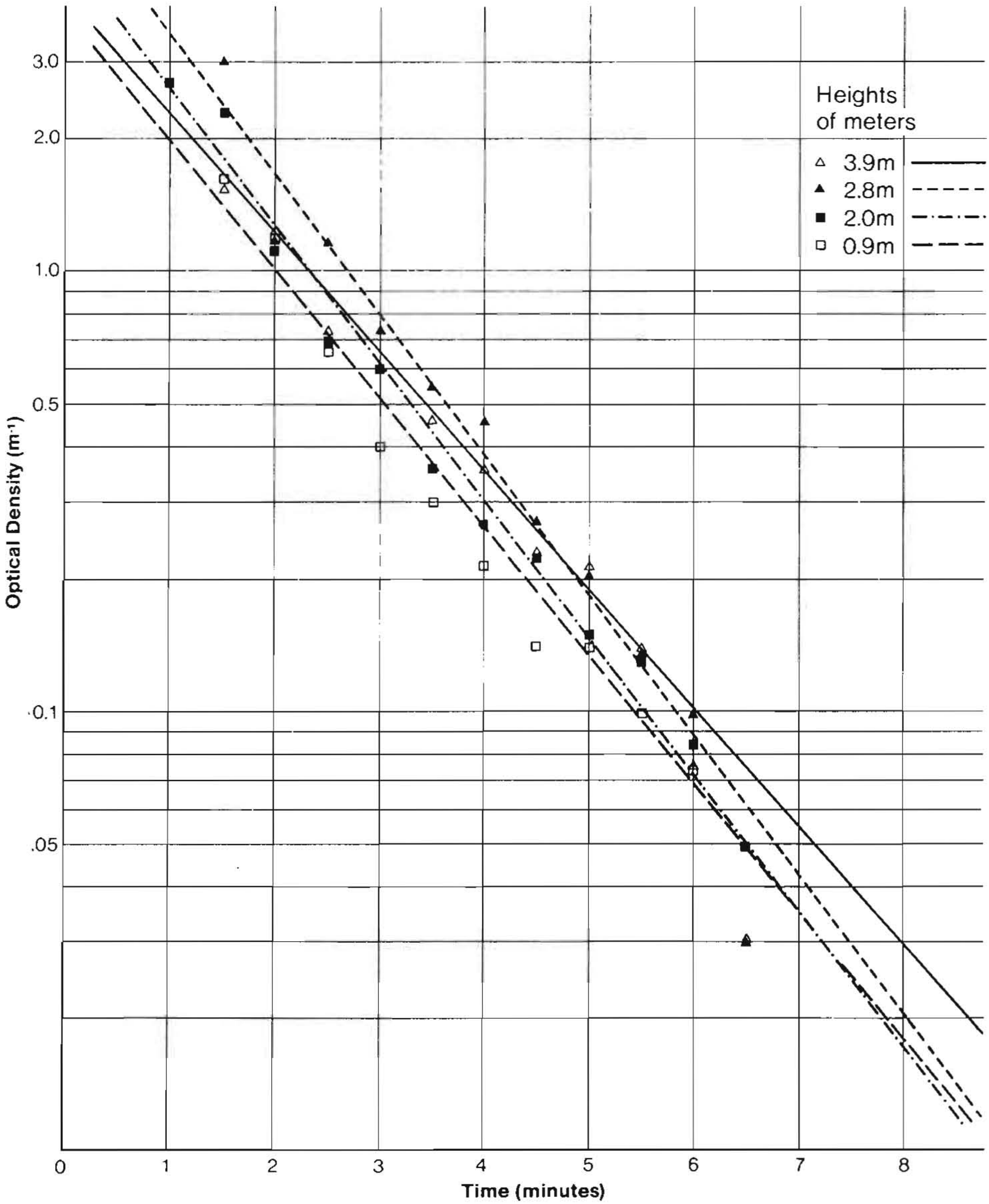


Figure G15 Test 19

Log-linear graph of Optical Density against Clearance Time for four smoke density meters

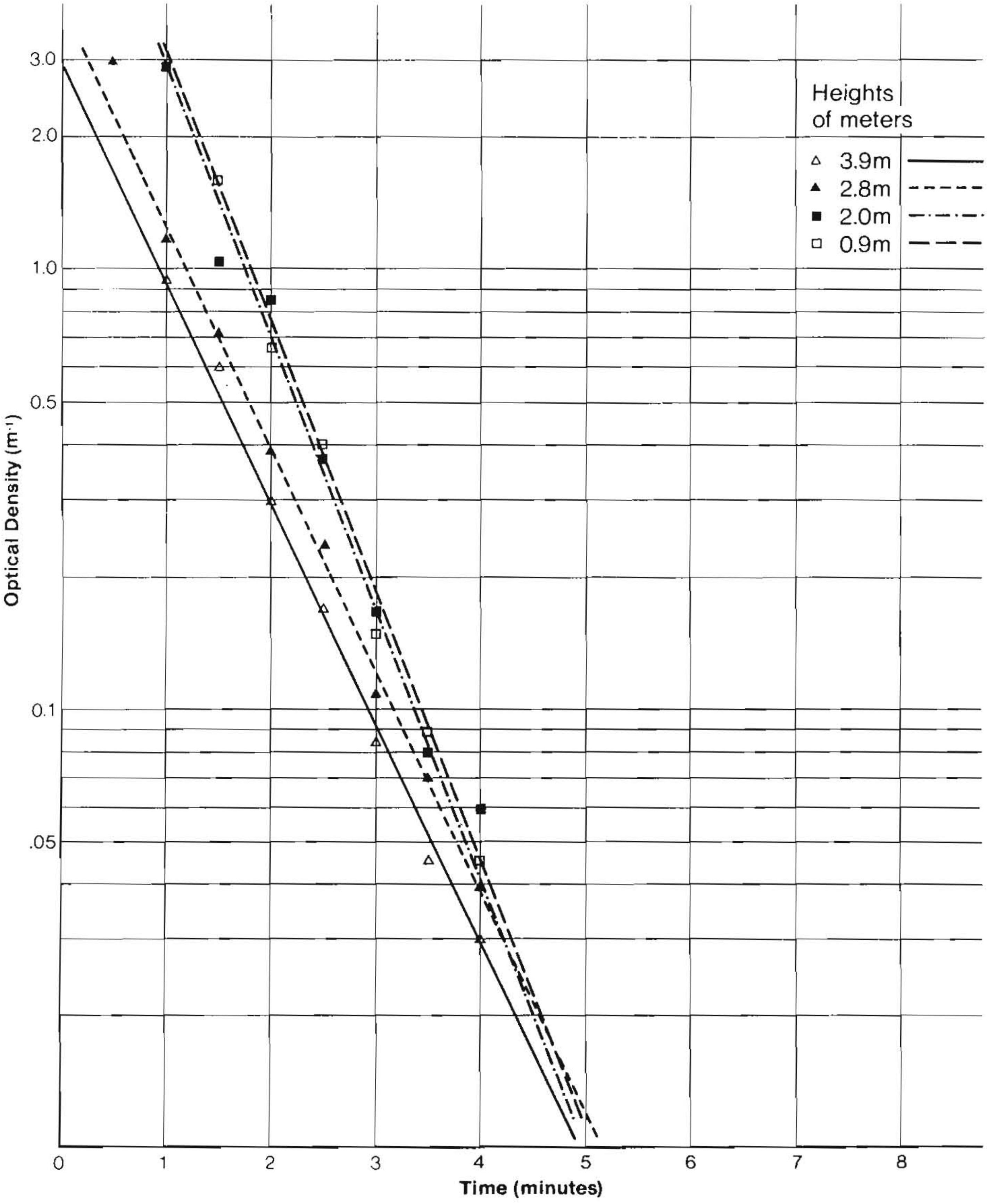


Figure G16 Test 20

Log-linear graph of Optical Density against Clearance Time for four smoke density meters

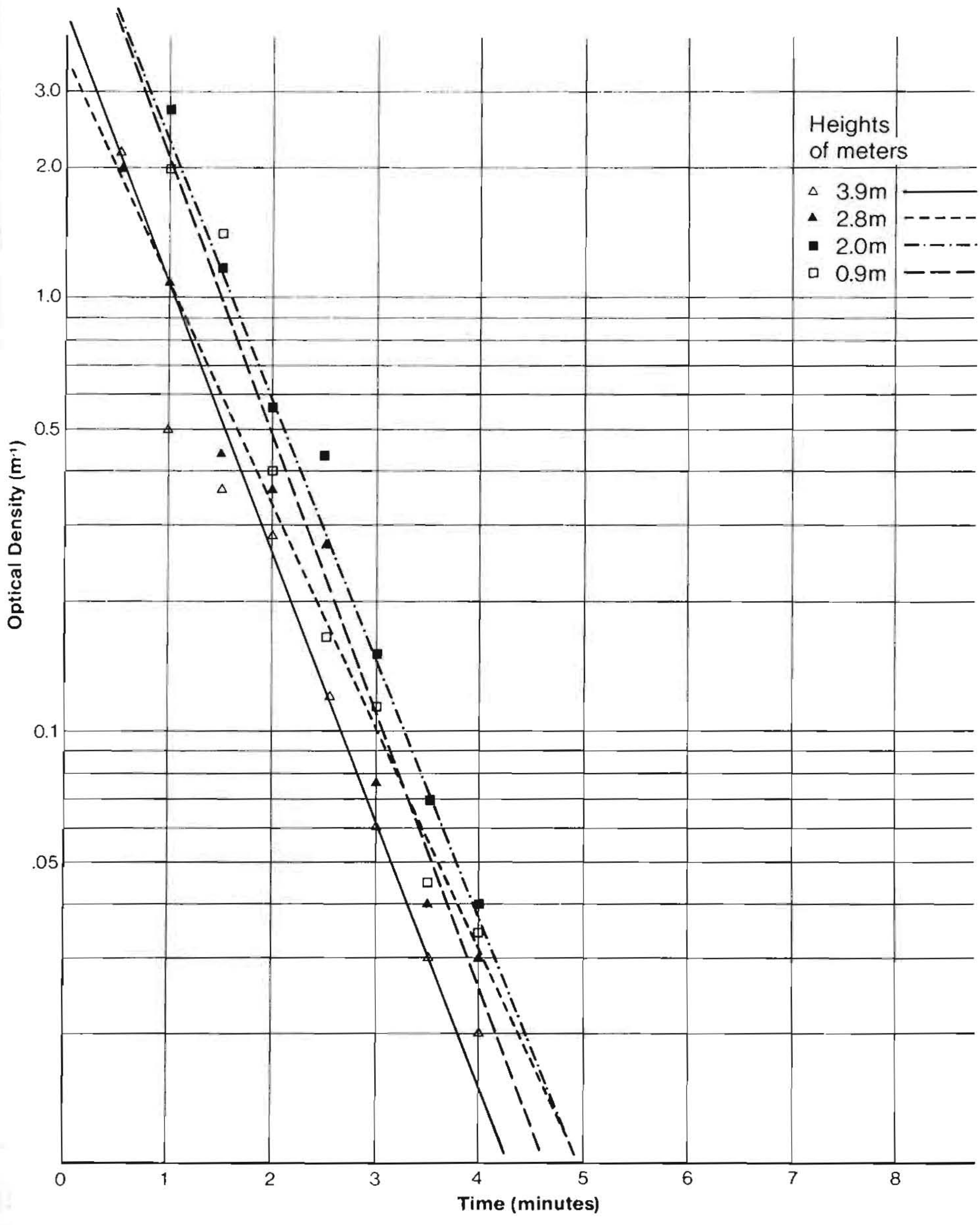


Figure G17 Test 21

Log-linear graph of Optical Density against Clearance Time for four smoke density meters

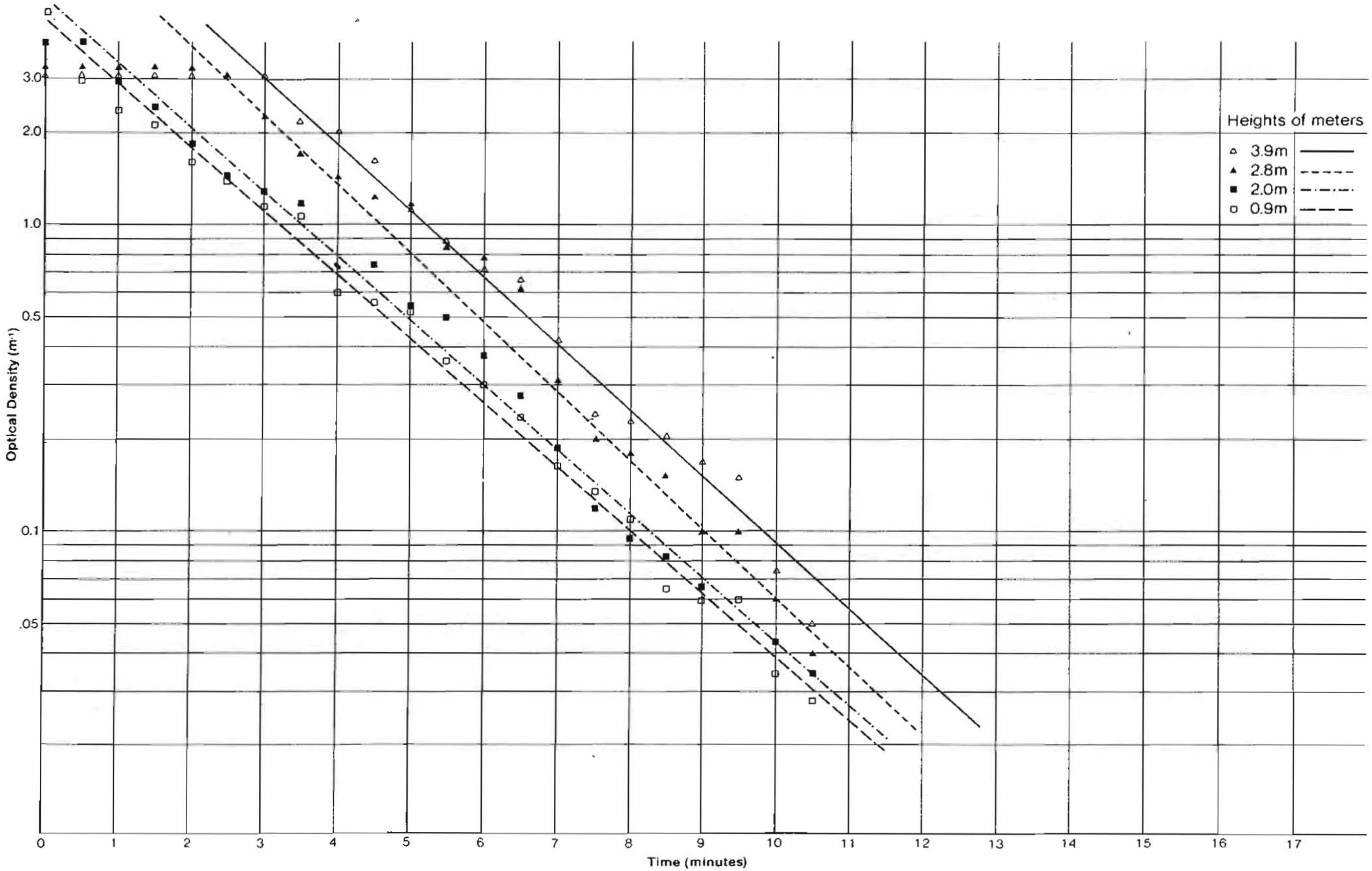
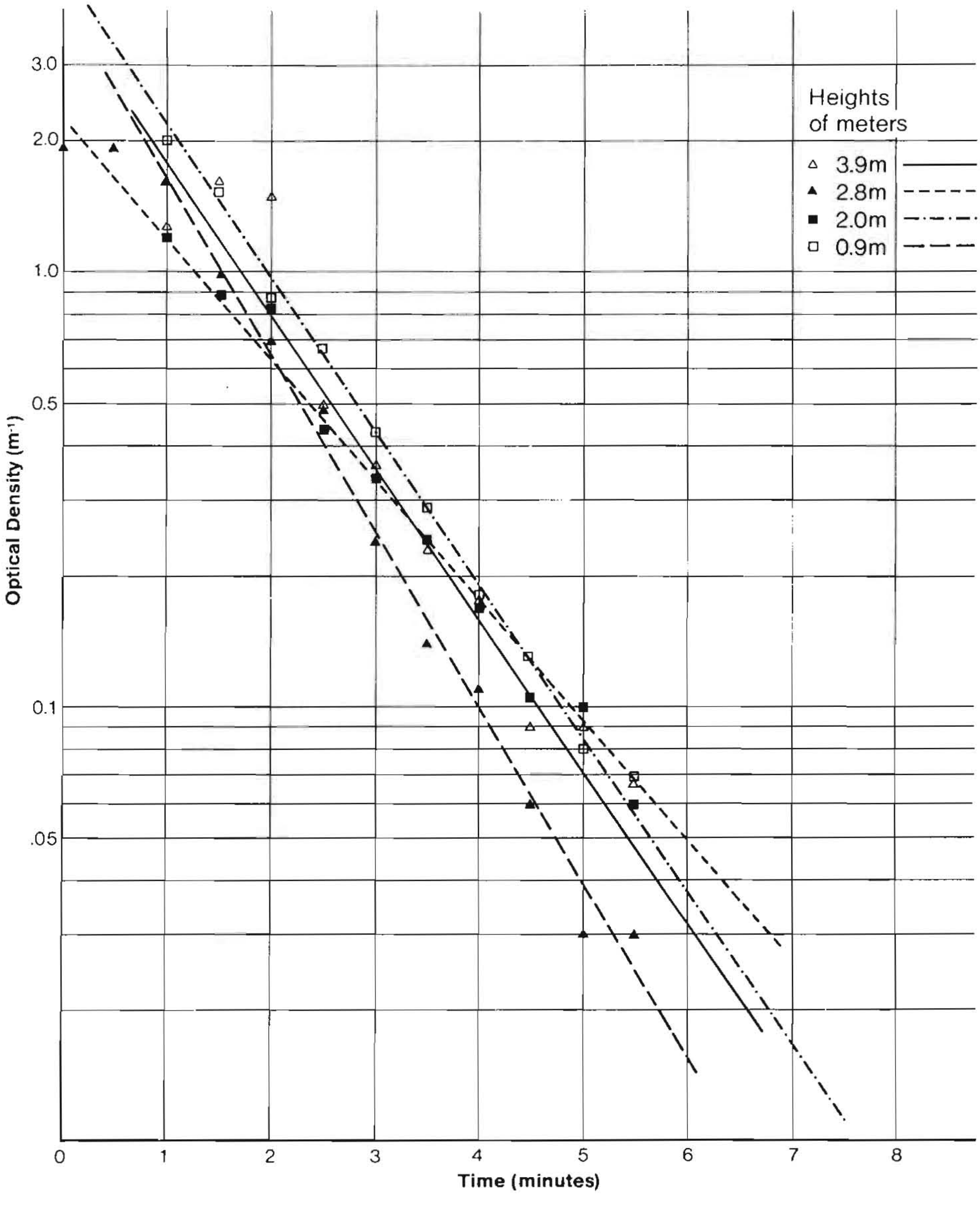


Figure G18 Test 22

Log-linear graph of Optical Density against Clearance Time for four smoke density meters



APPENDIX H

GRAPHS OF TESTS OF SMOKE CLEARANCE PROCEDURES, 'INDUSTRIAL B' BUILDING, BASEMENT

Figure H1   Test 22

Log-linear graph of Optical Density against Clearance Time for three smoke density meters

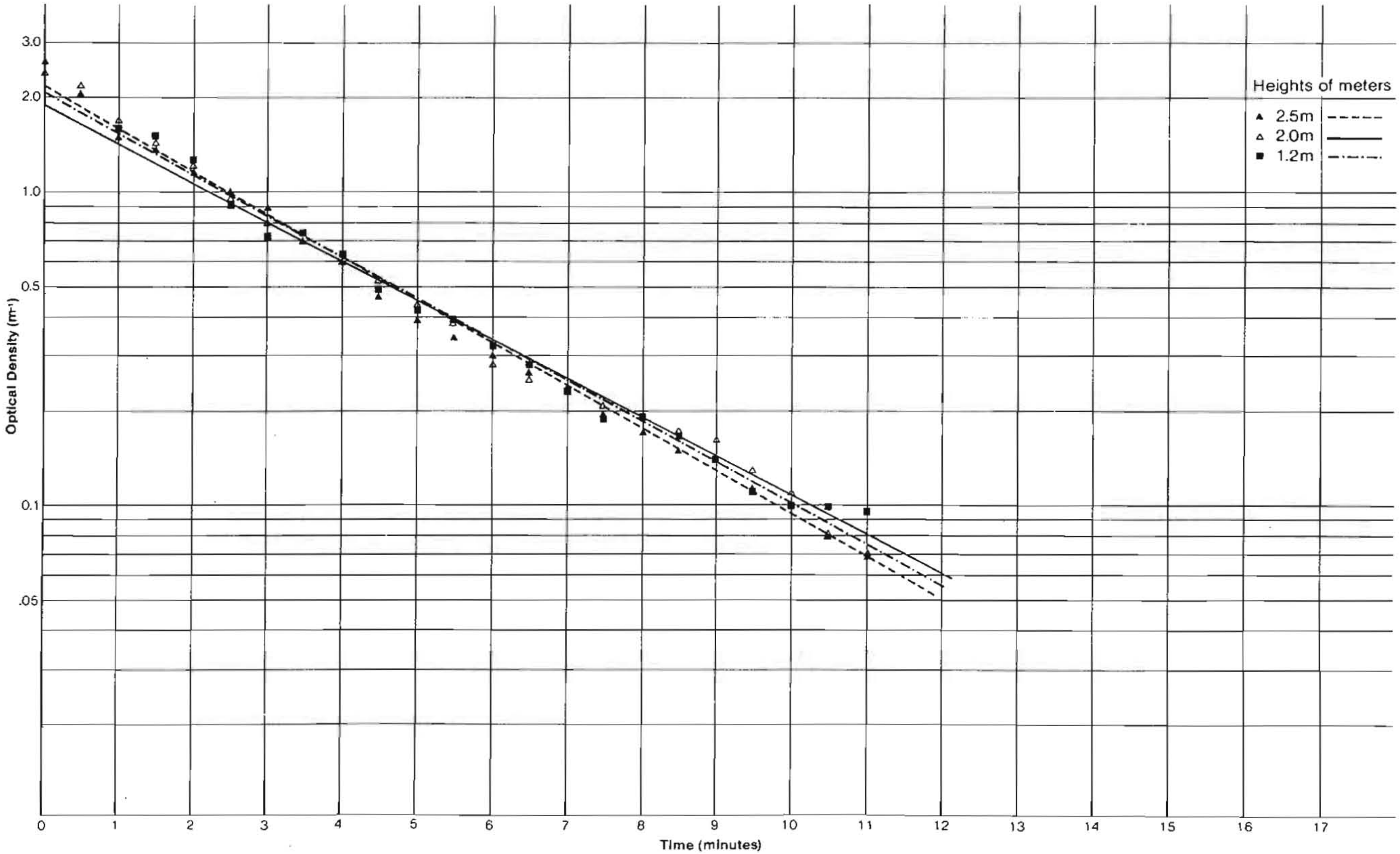


Figure H2 Test 23

Log-linear graph of Optical Density against Clearance Time for three smoke density meters

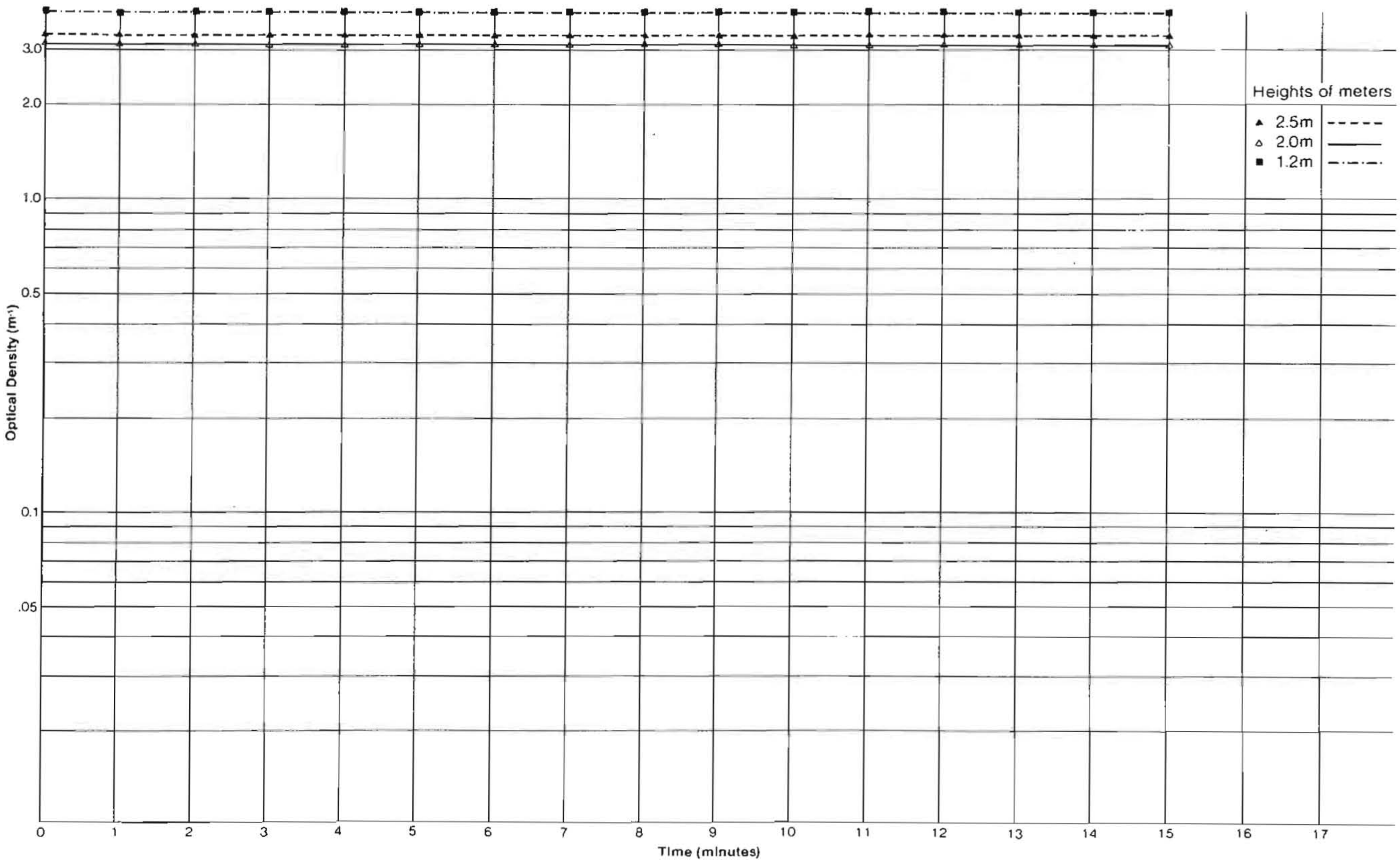


Figure H3 Test 24

Log-linear graph of Optical Density against Clearance Time for three smoke density meters

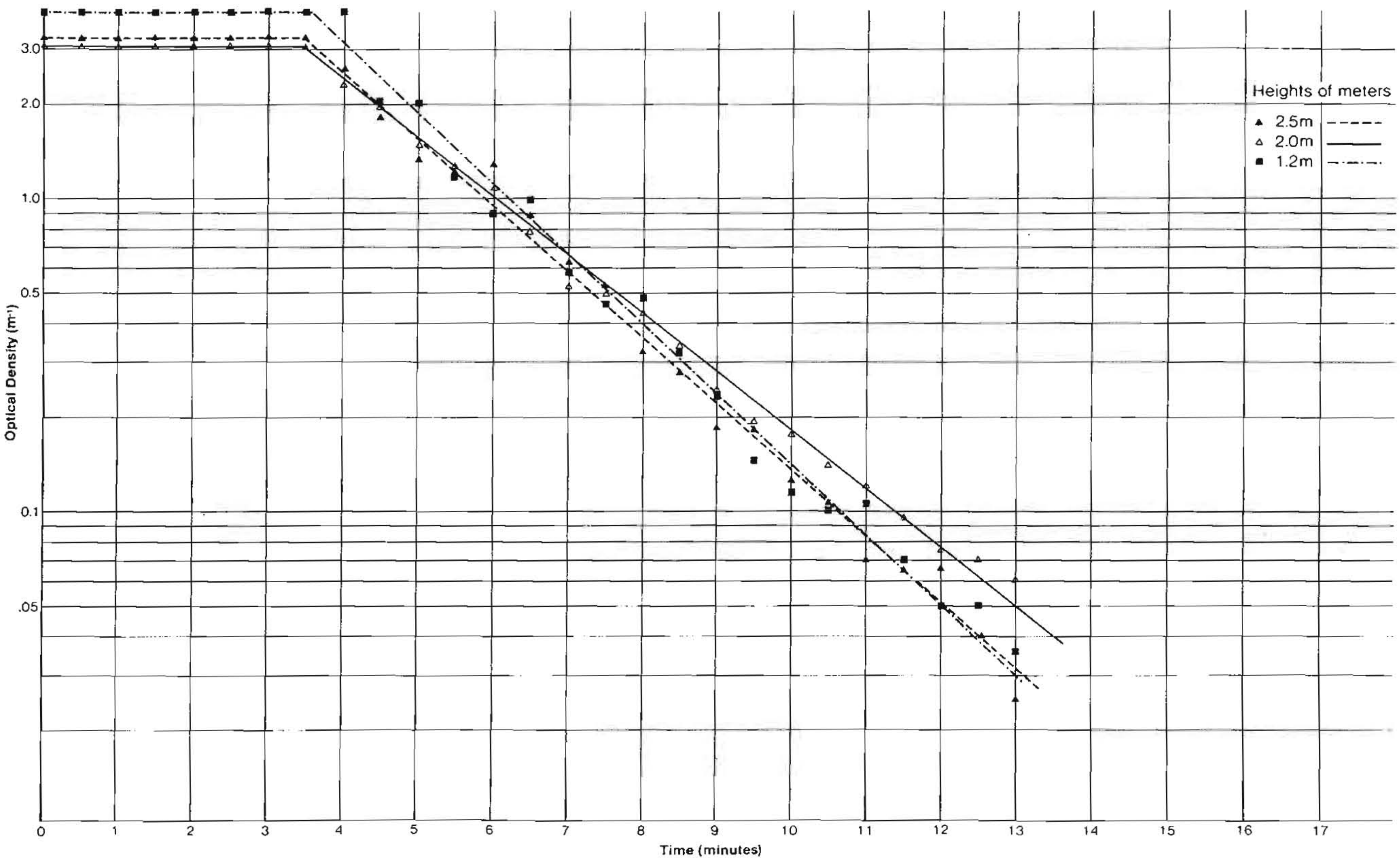


Figure H4 Test 25

Log-linear graph of Optical Density against Clearance Time for three smoke density meters

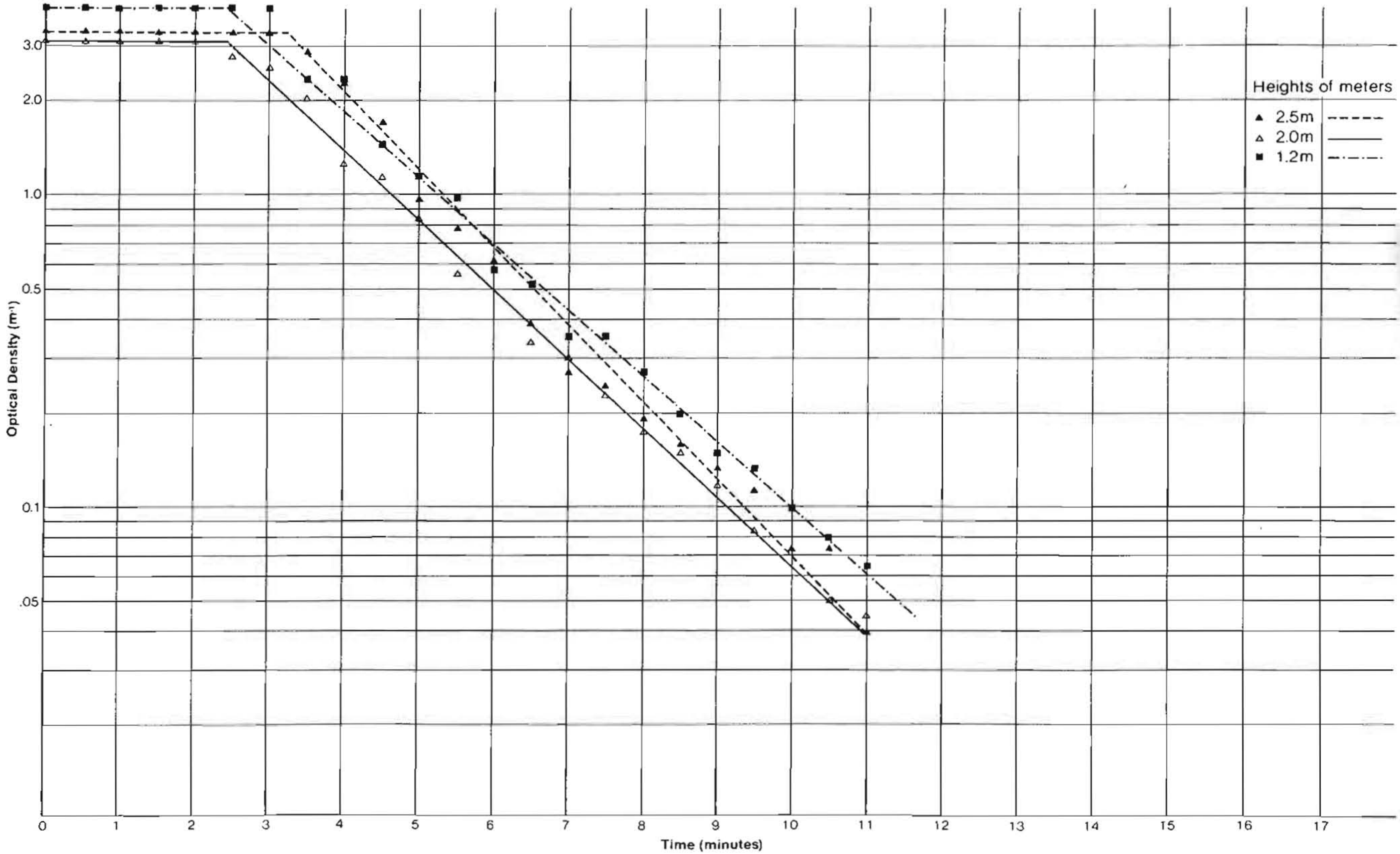


Figure H5 Test 26

Log-linear graph of Optical Density against Clearance Time for three smoke density meters

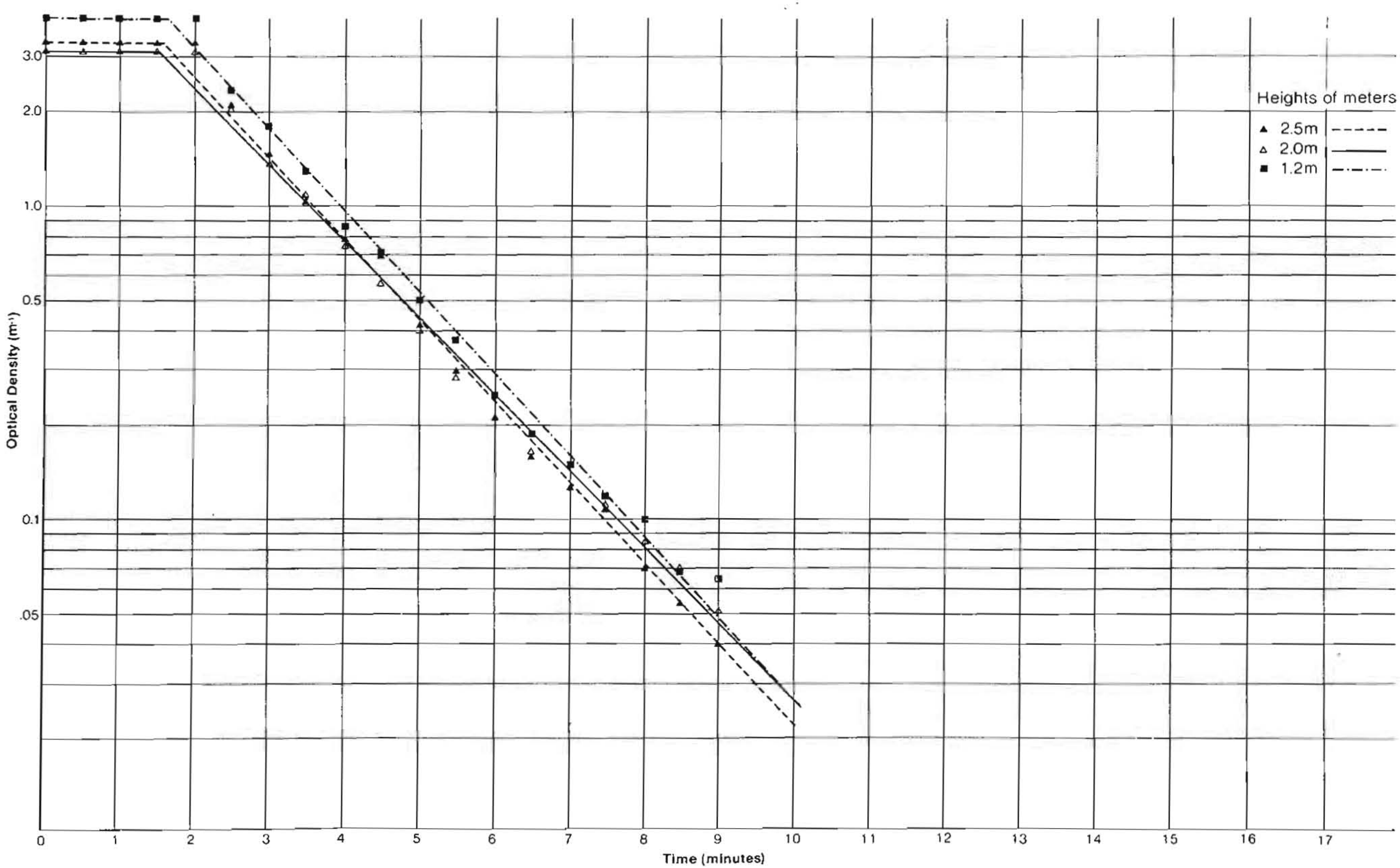


Figure H6 Test 27

Log-linear graph of Optical Density against Clearance Time for three smoke density meters

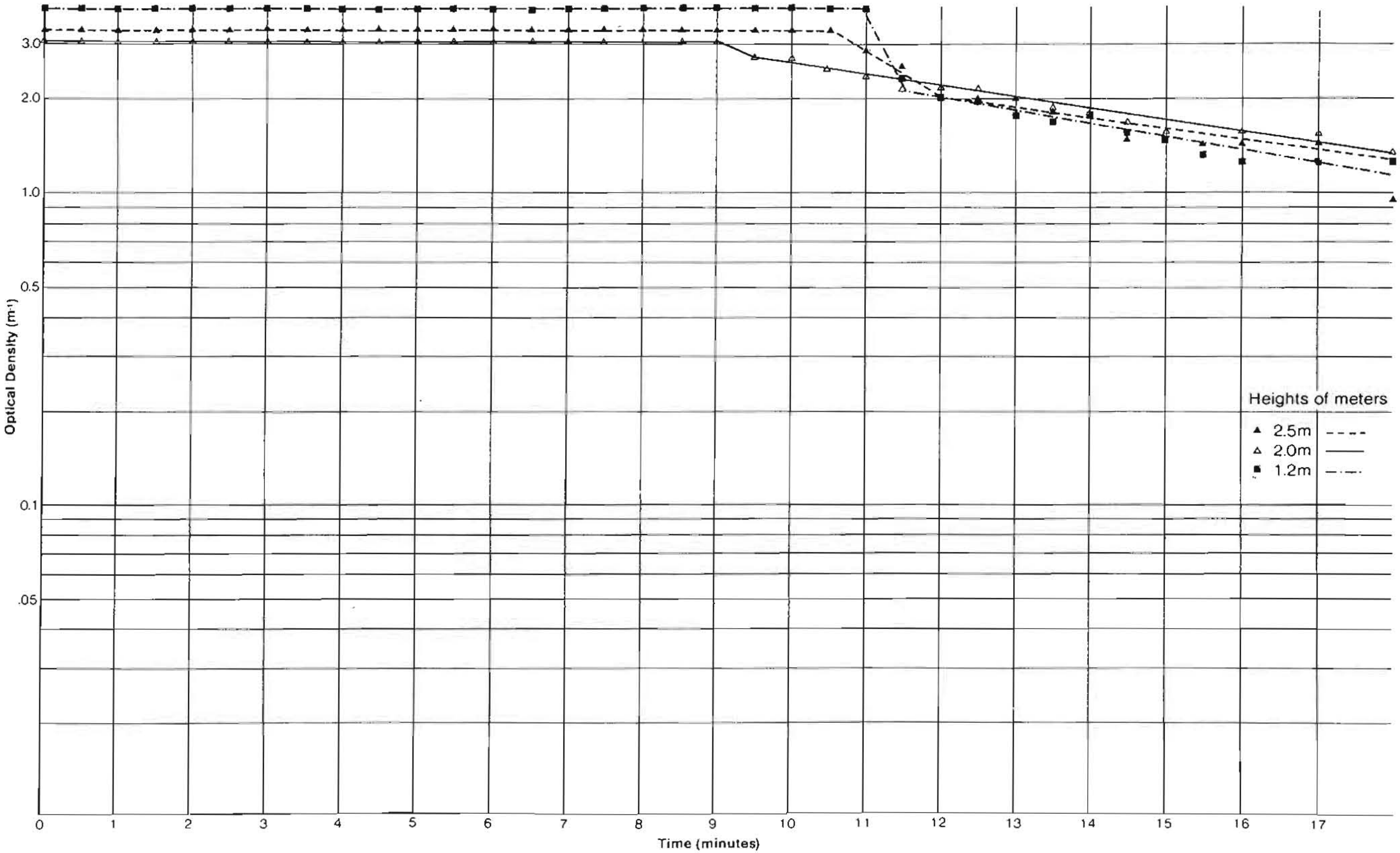


Figure H7 Test 28

Log-linear graph of Optical Density against Clearance Time for three smoke density meters

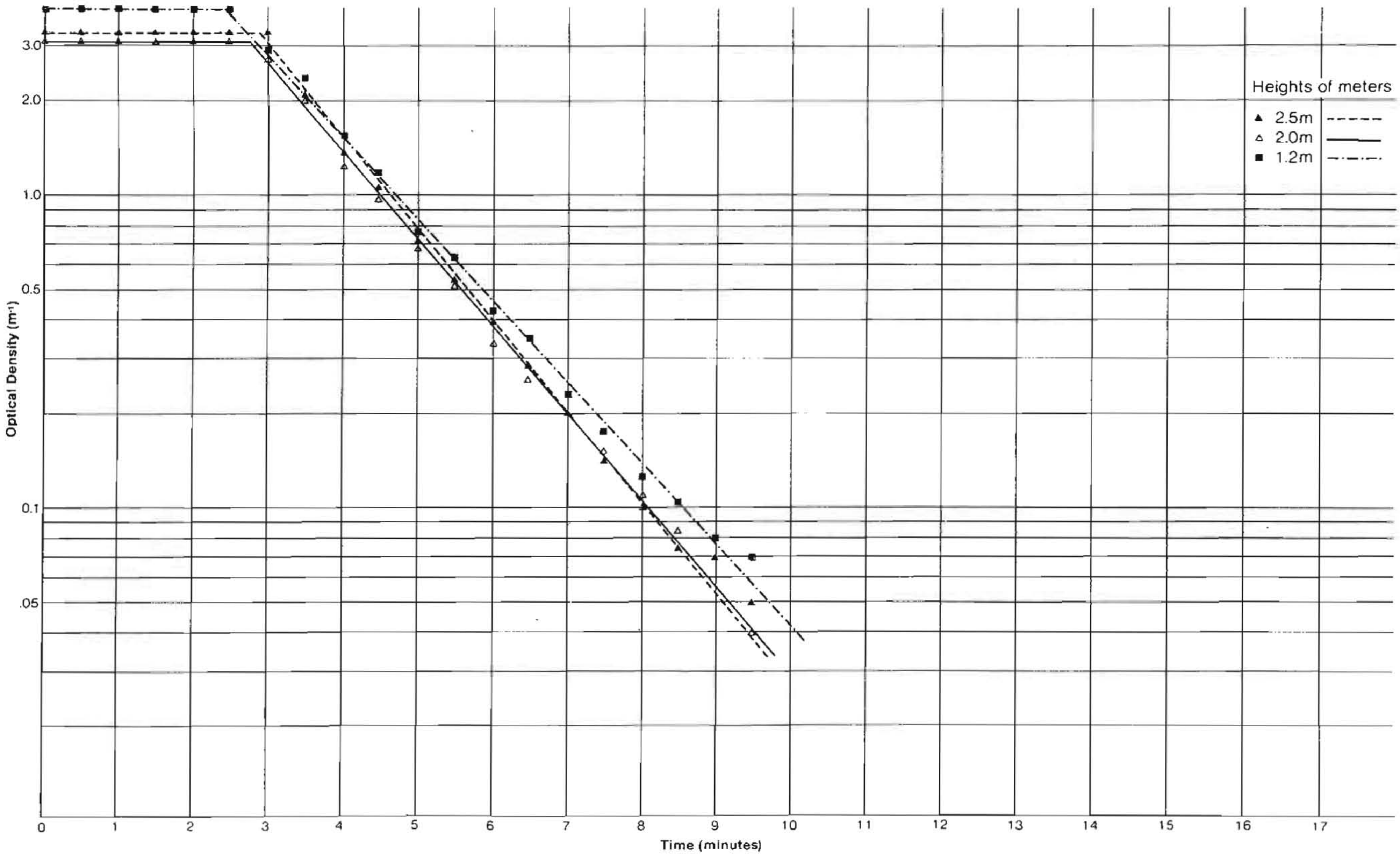


Figure H8 Test 29

Log-linear graph of Optical Density against Clearance Time for three smoke density meters

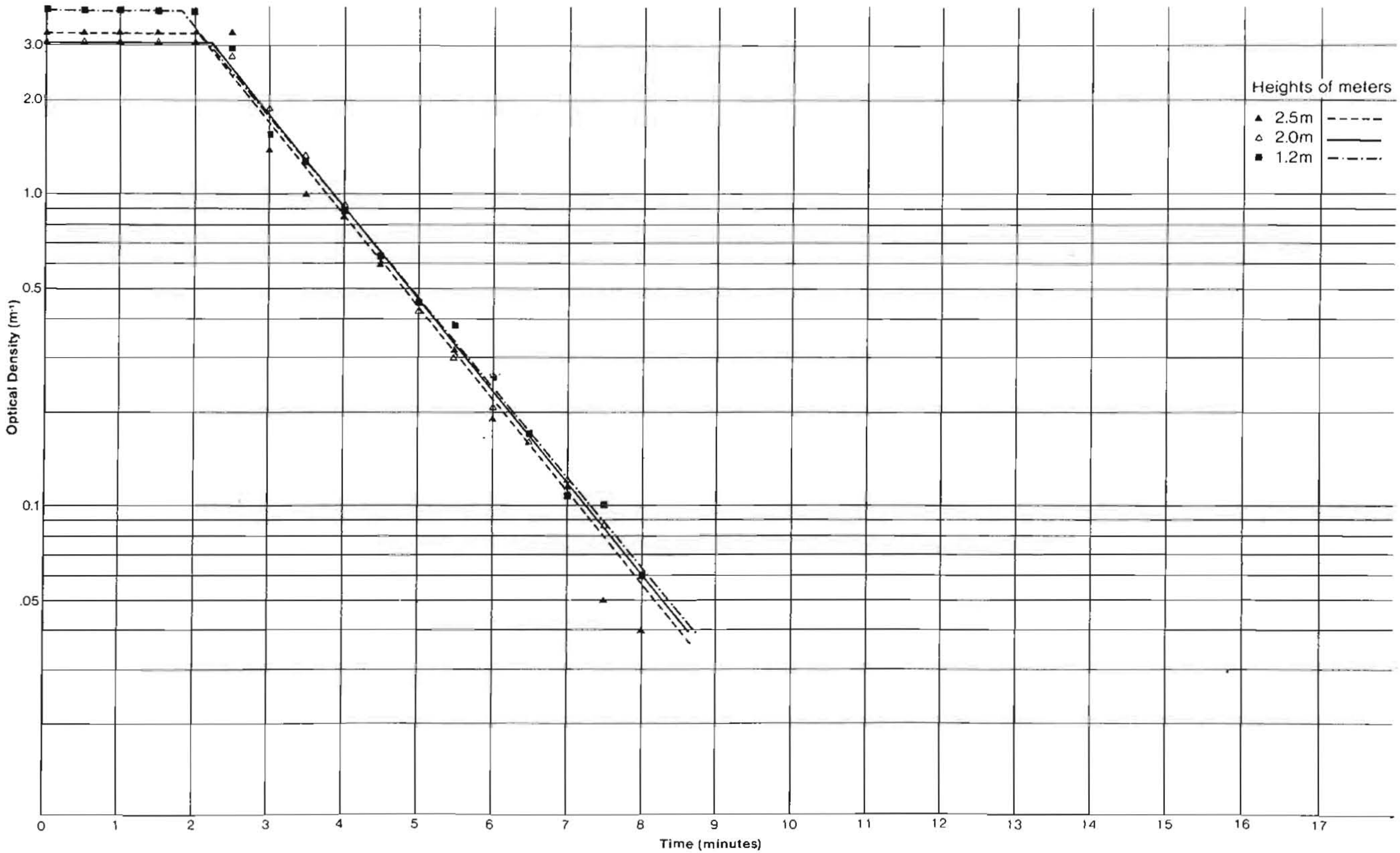


Figure H9 Test 30

Log-linear graph of Optical Density against Clearance Time for three smoke density meters

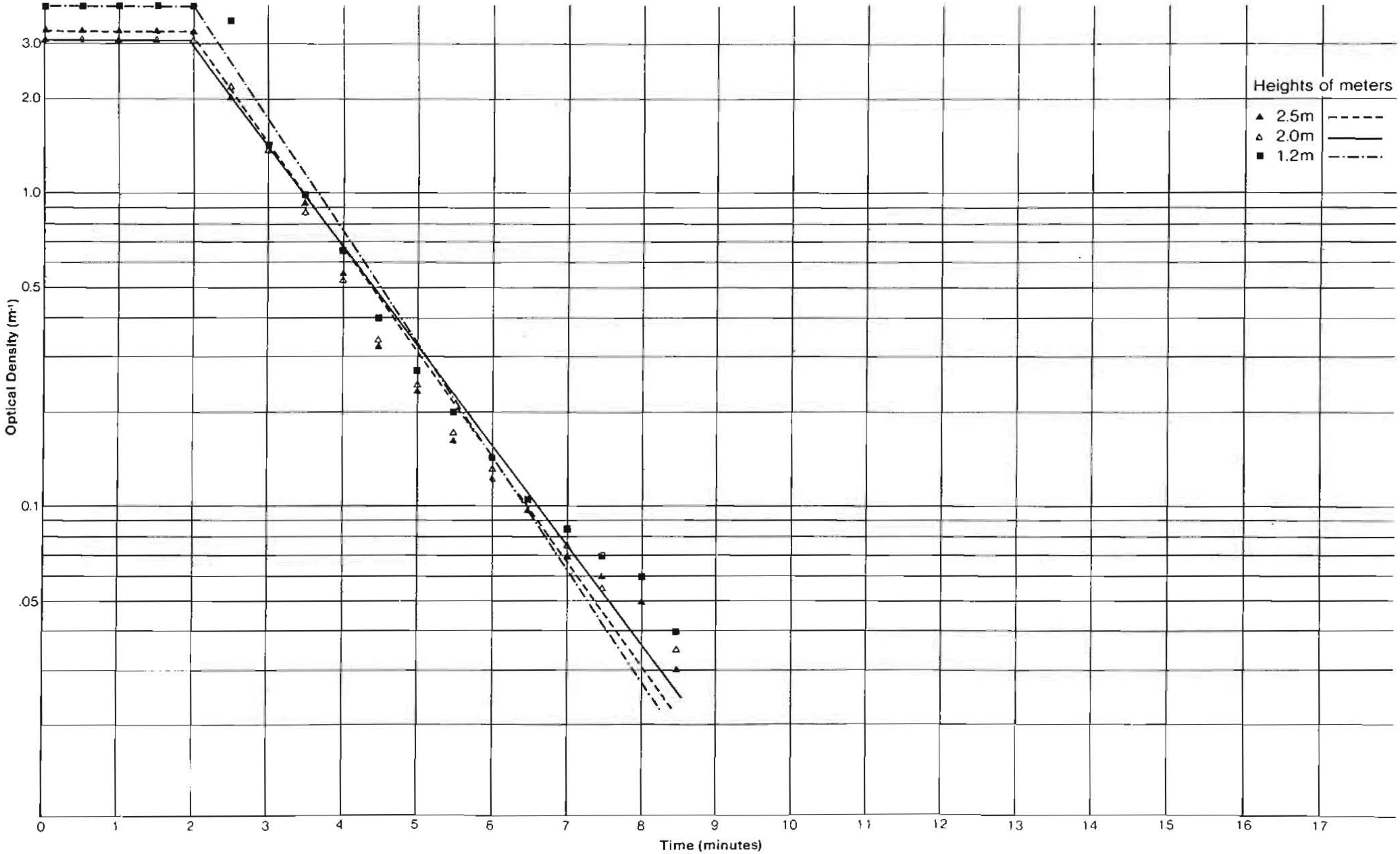


Figure H10 Test HS4

Log-linear graph of Optical Density against Clearance Time for three smoke density meters

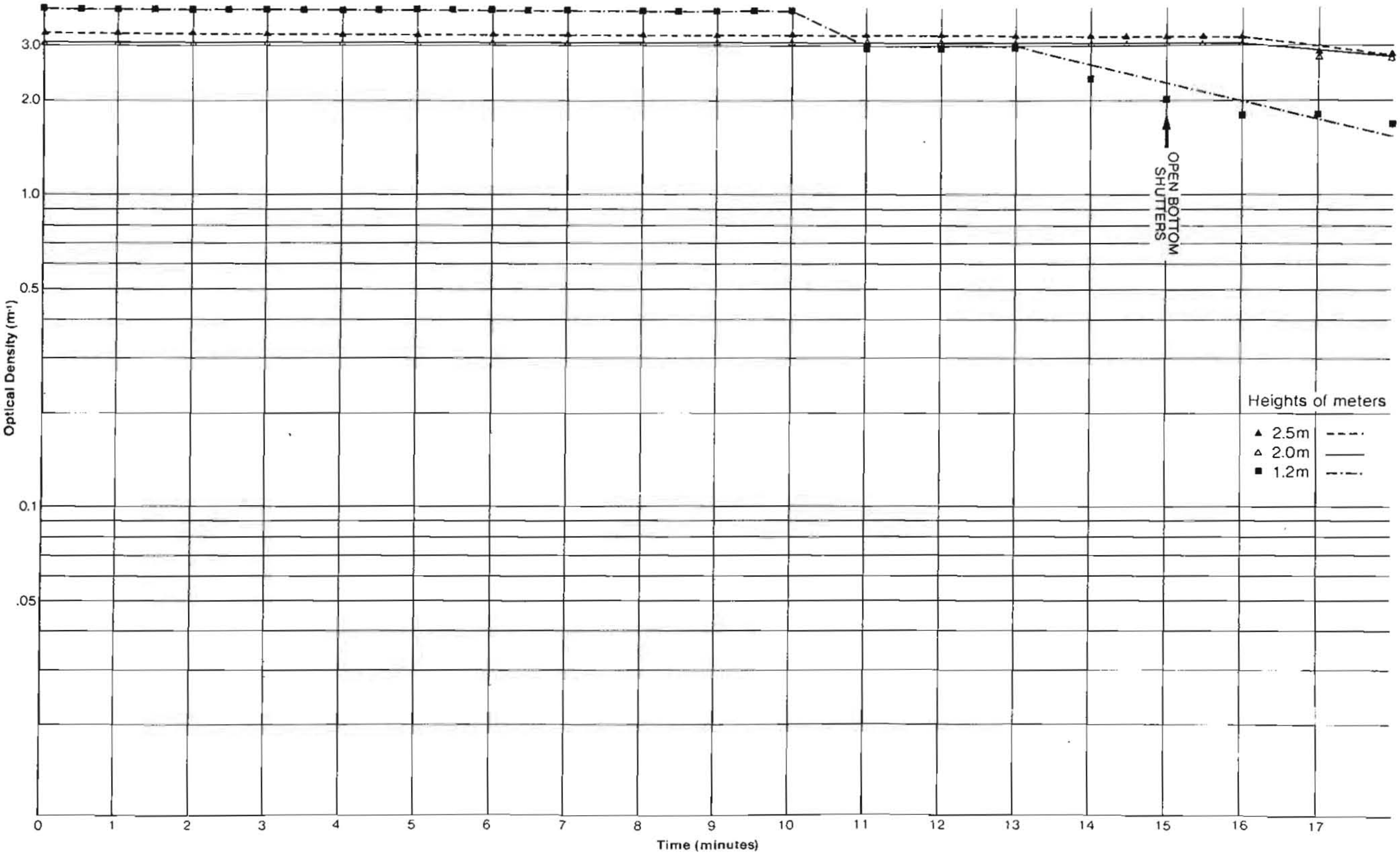


Figure H11 Test HS5

Log-linear graph of Optical Density against Clearance Time for three smoke density meters

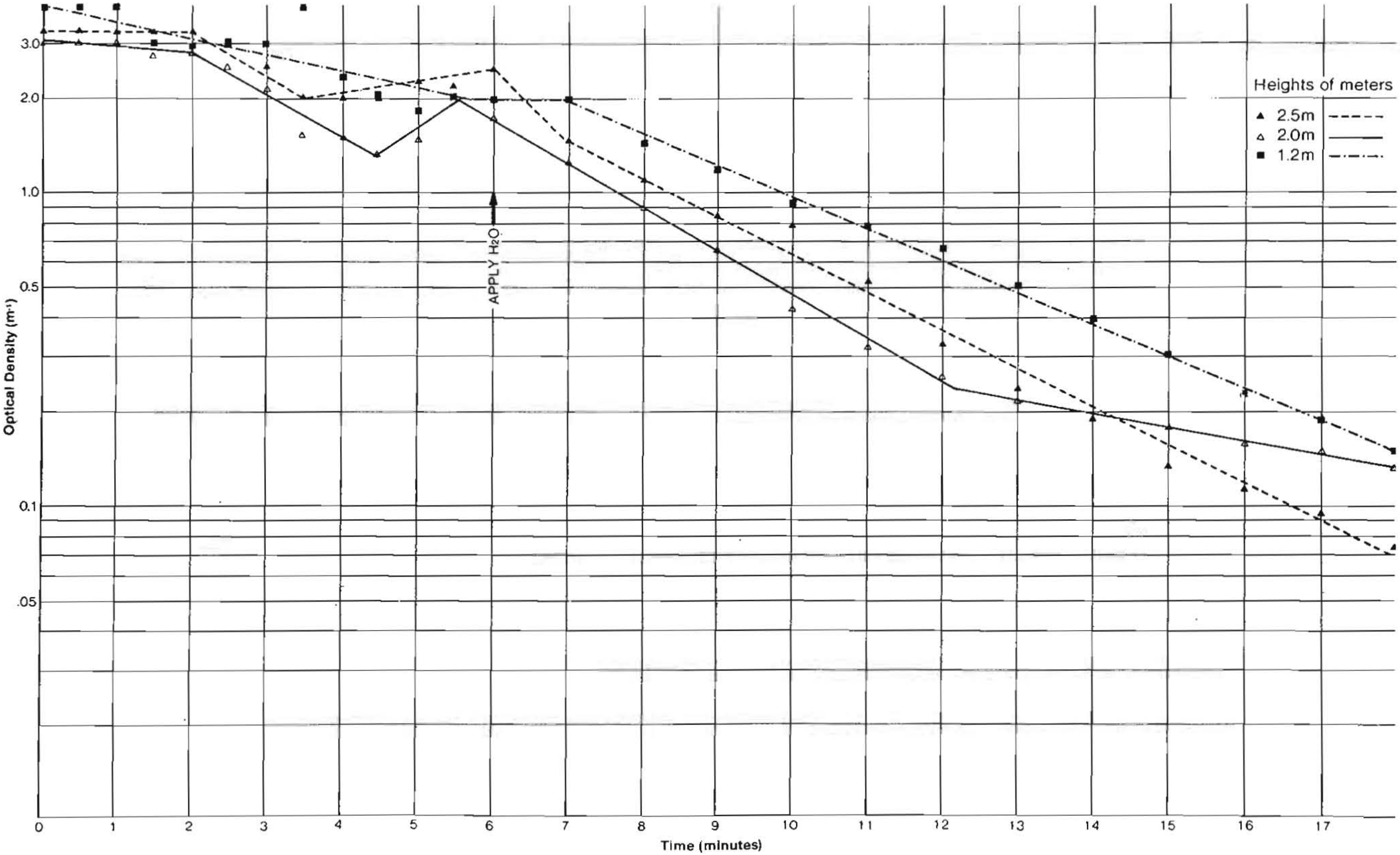


Figure H12 Test HS6

Log-linear graph of Optical Density against Clearance Time for three smoke density meters

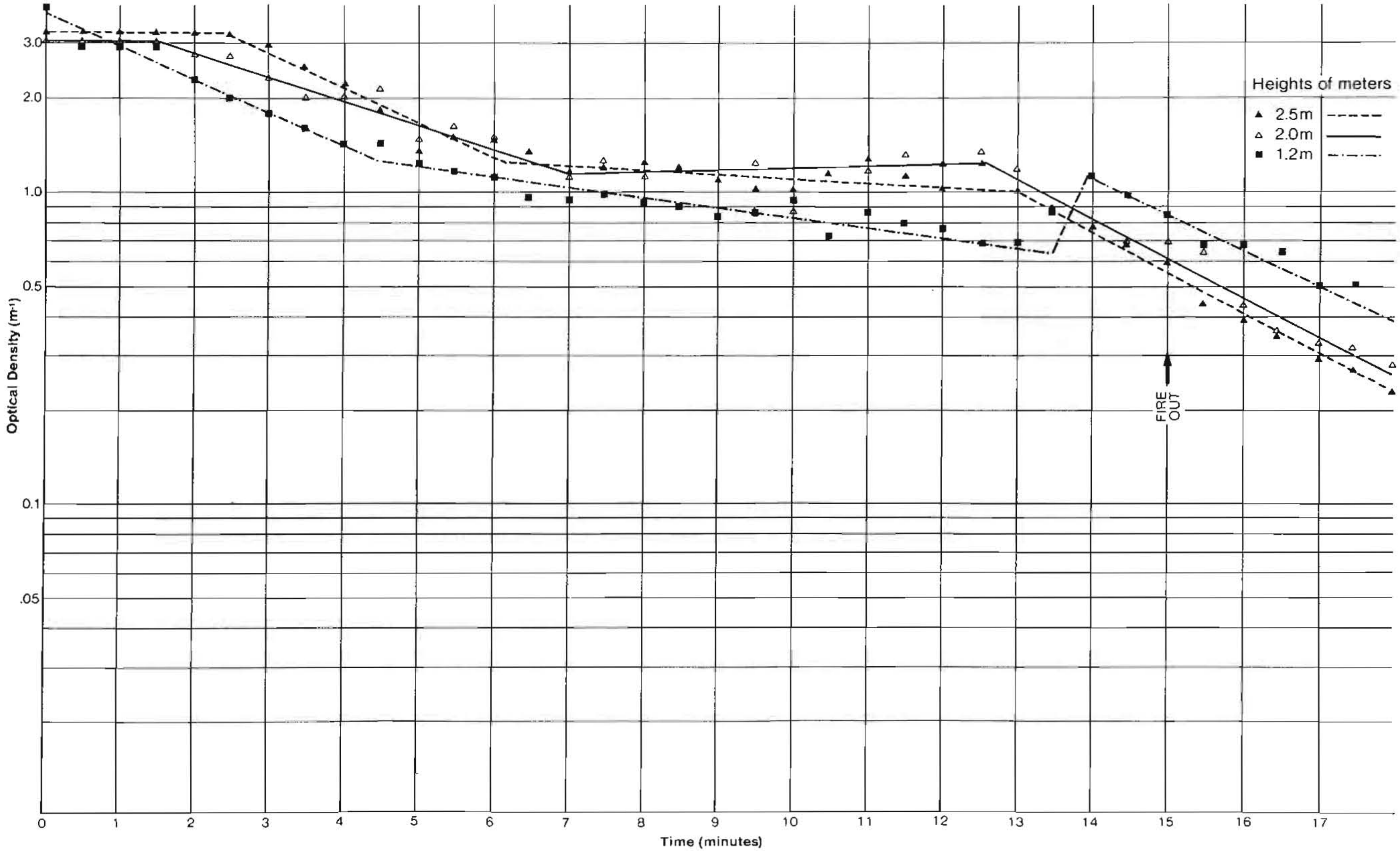


Figure H13 Test HS7

Log-linear graph of Optical Density against Clearance Time for three smoke density meters

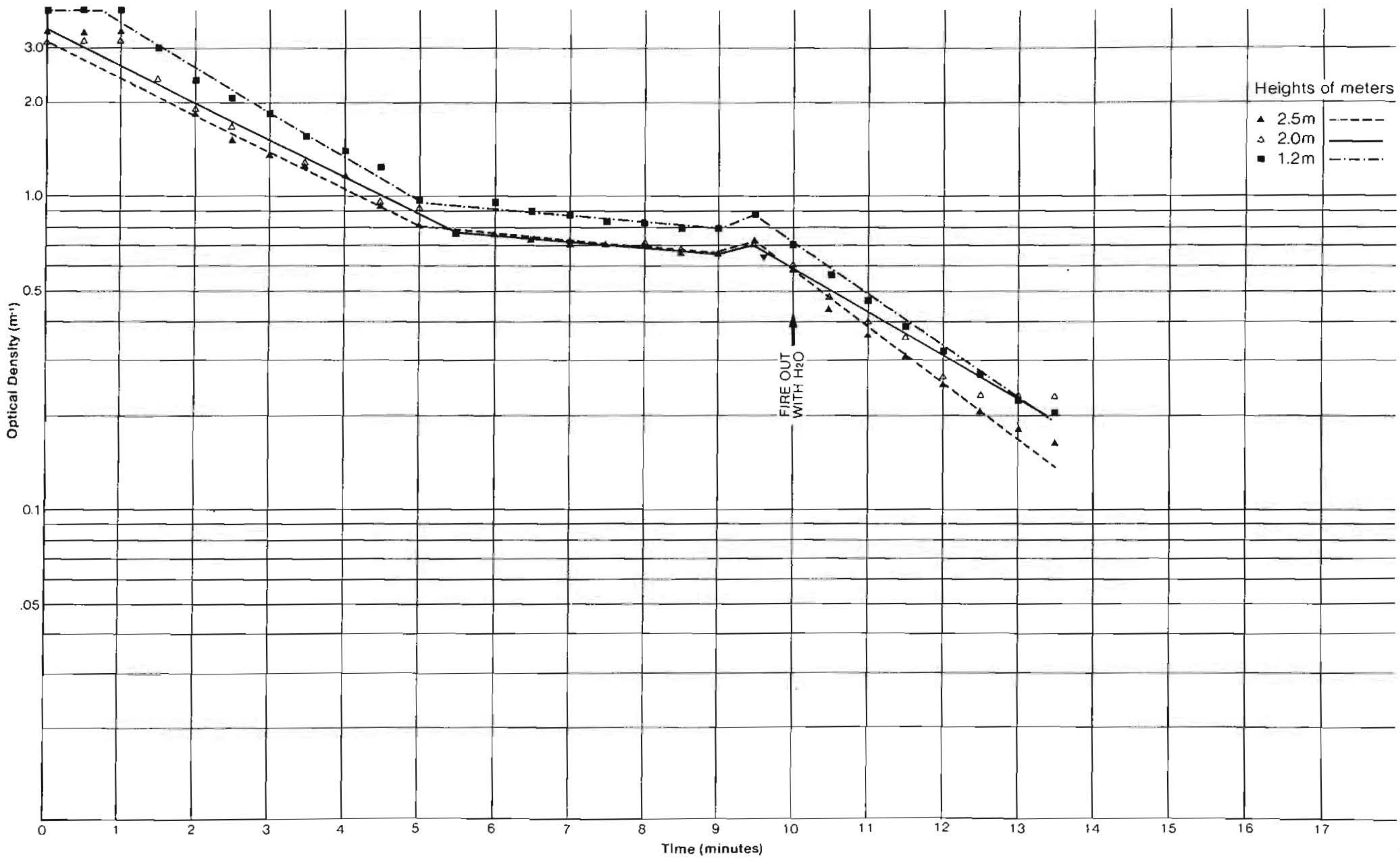
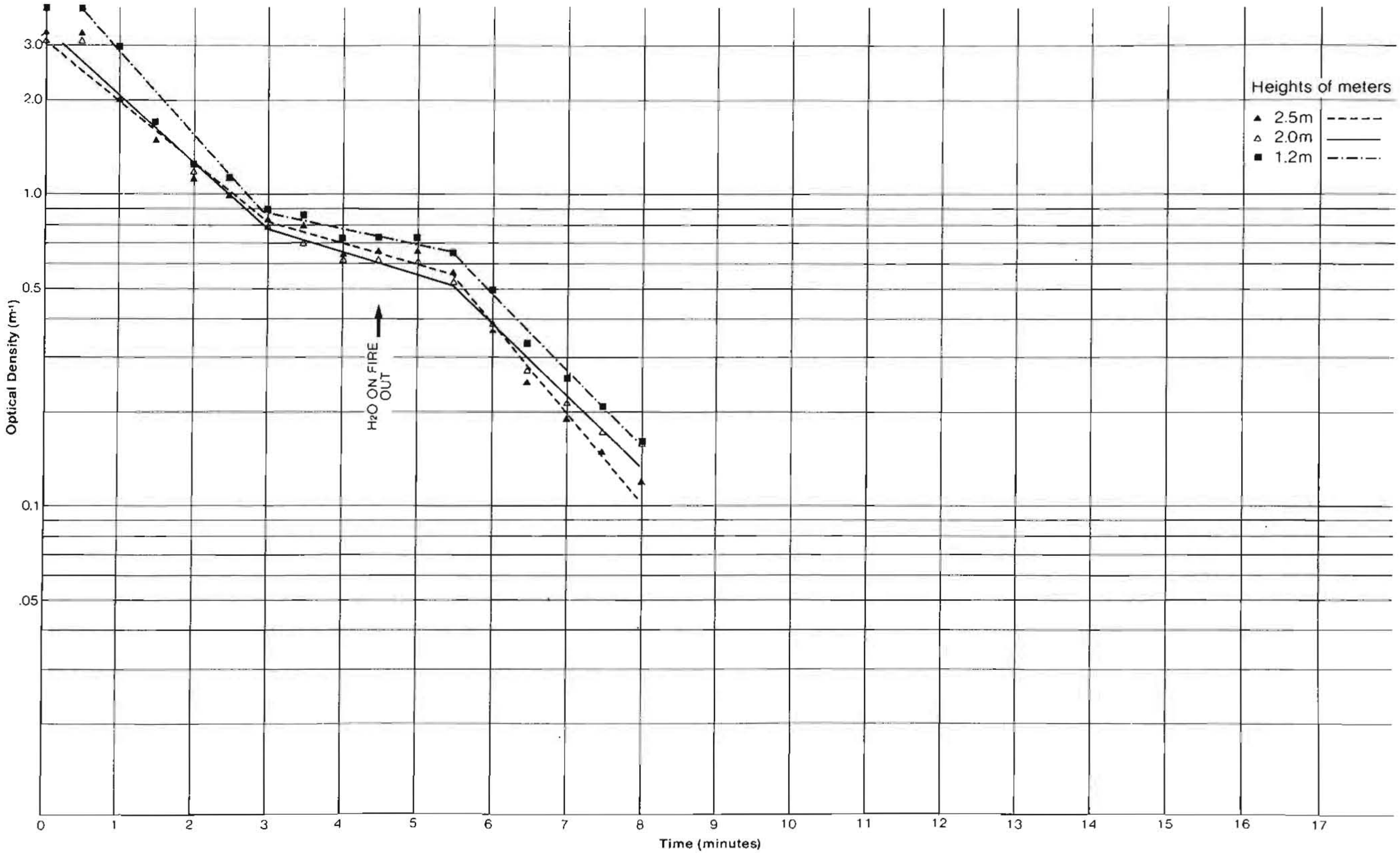


Figure H14 Test HS8

Log-linear graph of Optical Density against Clearance Time for three smoke density meters



APPENDIX J

GRAPHS OF COMPARATIVE TESTS OF EXTRACTORS, 'INDUSTRIAL B' BUILDING, BASEMENT

Figure J1 Test C1 Fan: Supervac P164 SEZ SRDB Code No: 4

Log-linear graph of Optical Density against Clearance Time for three smoke density meters

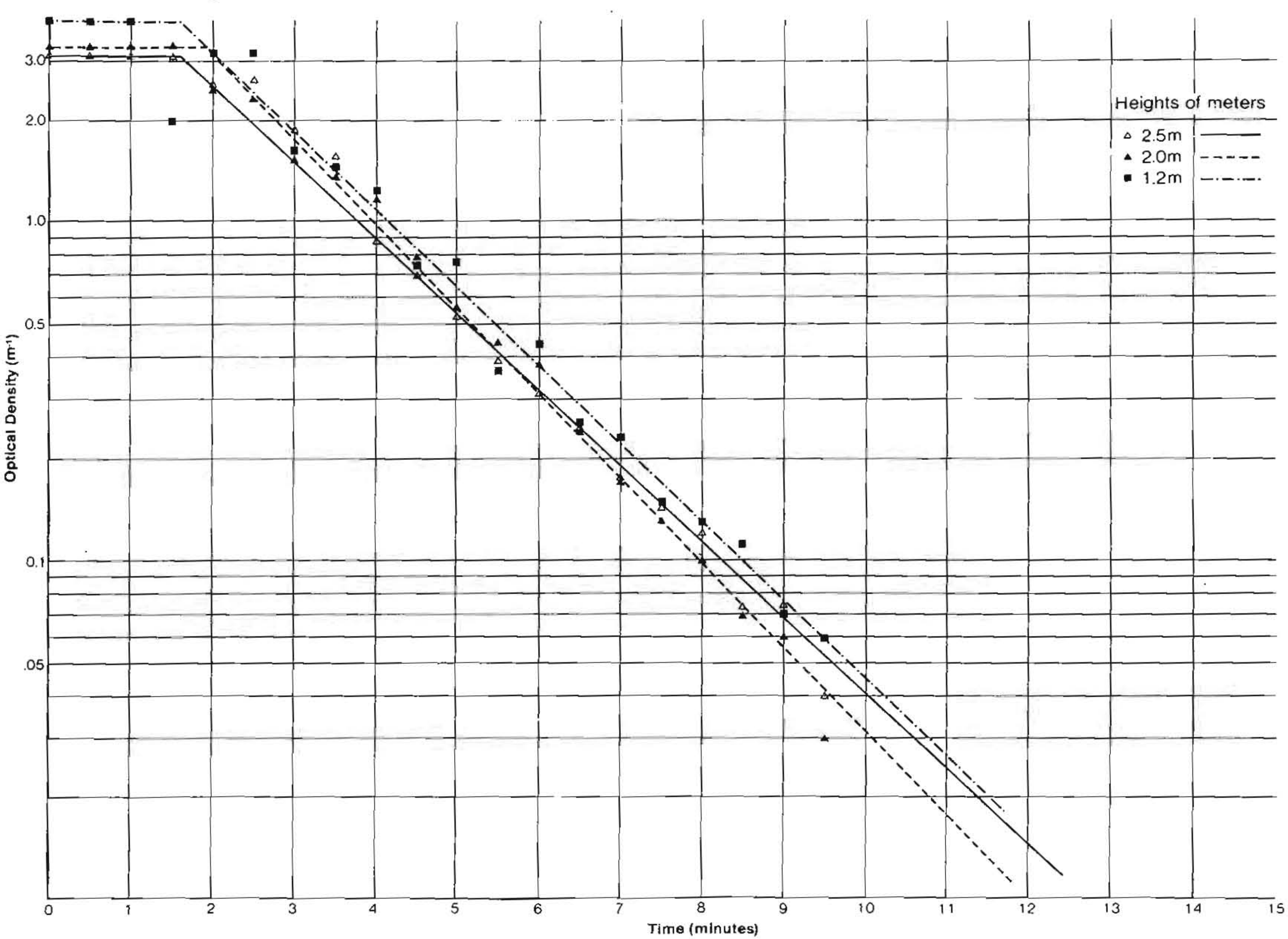


Figure J2 Test C2 Fan: Supervac P164 SEZ SRDB Code No: 4

Log-linear graph of Optical Density against Clearance Time for three smoke density meters

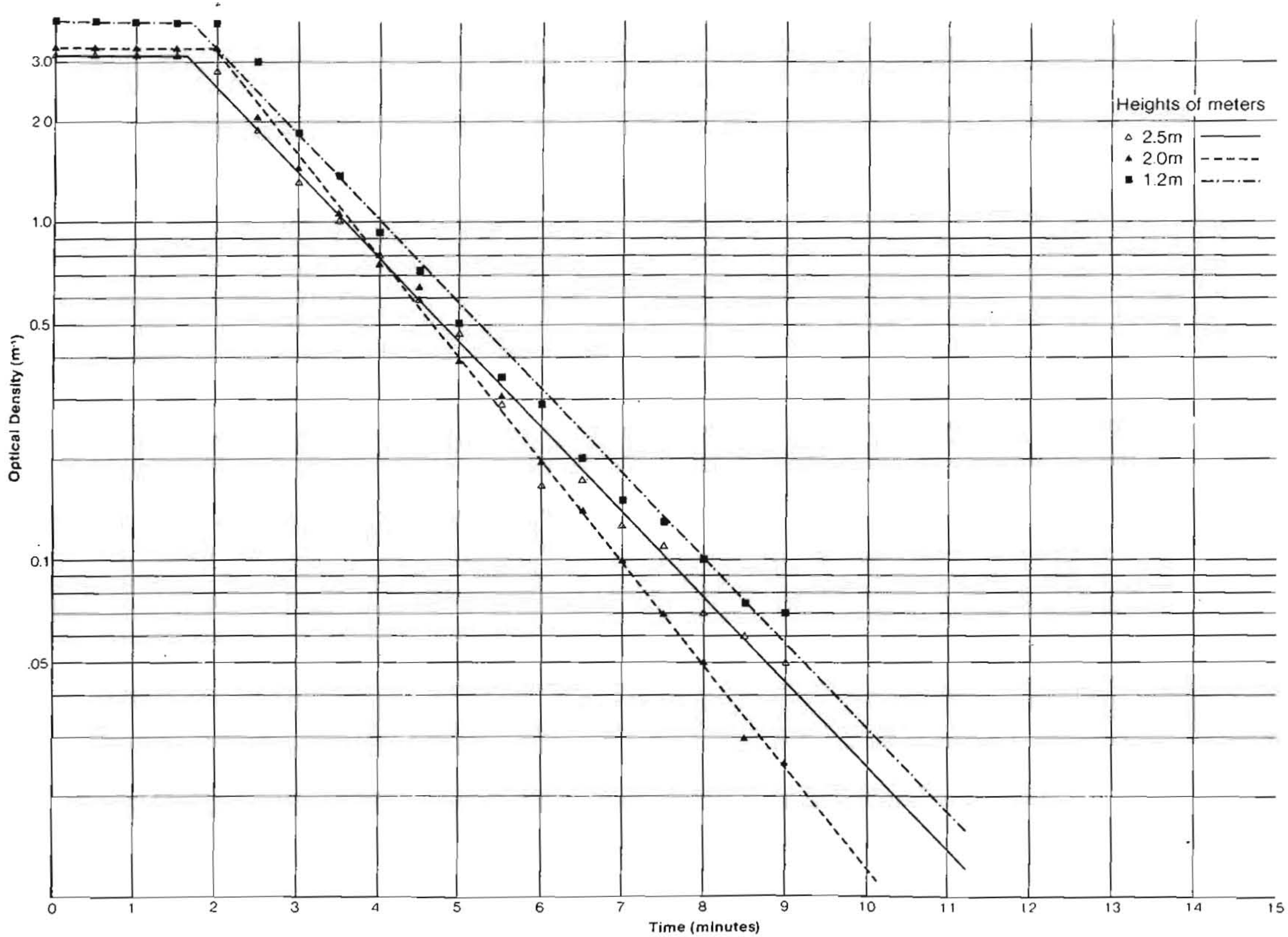


Figure J3 Test C3 Fan: Supervac P164 SEZ SRDB Code No: 4

Log-linear graph of Optical Density against Clearance Time for three smoke density meters

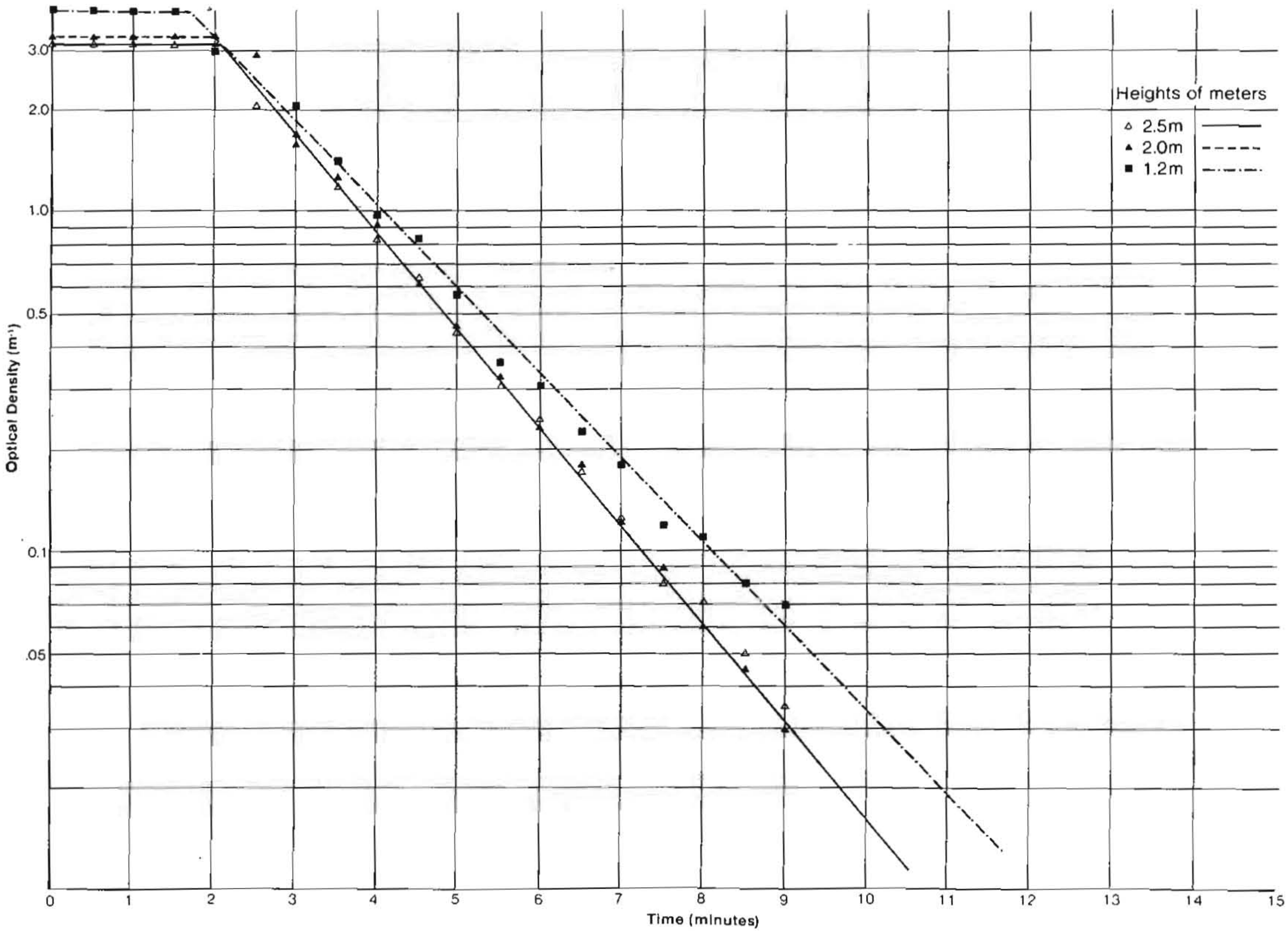


Figure J4 Test C4 Fan: Supervac P164 SE SRDB Code No: 3

Log-linear graph of Optical Density against Clearance Time for three smoke density meters

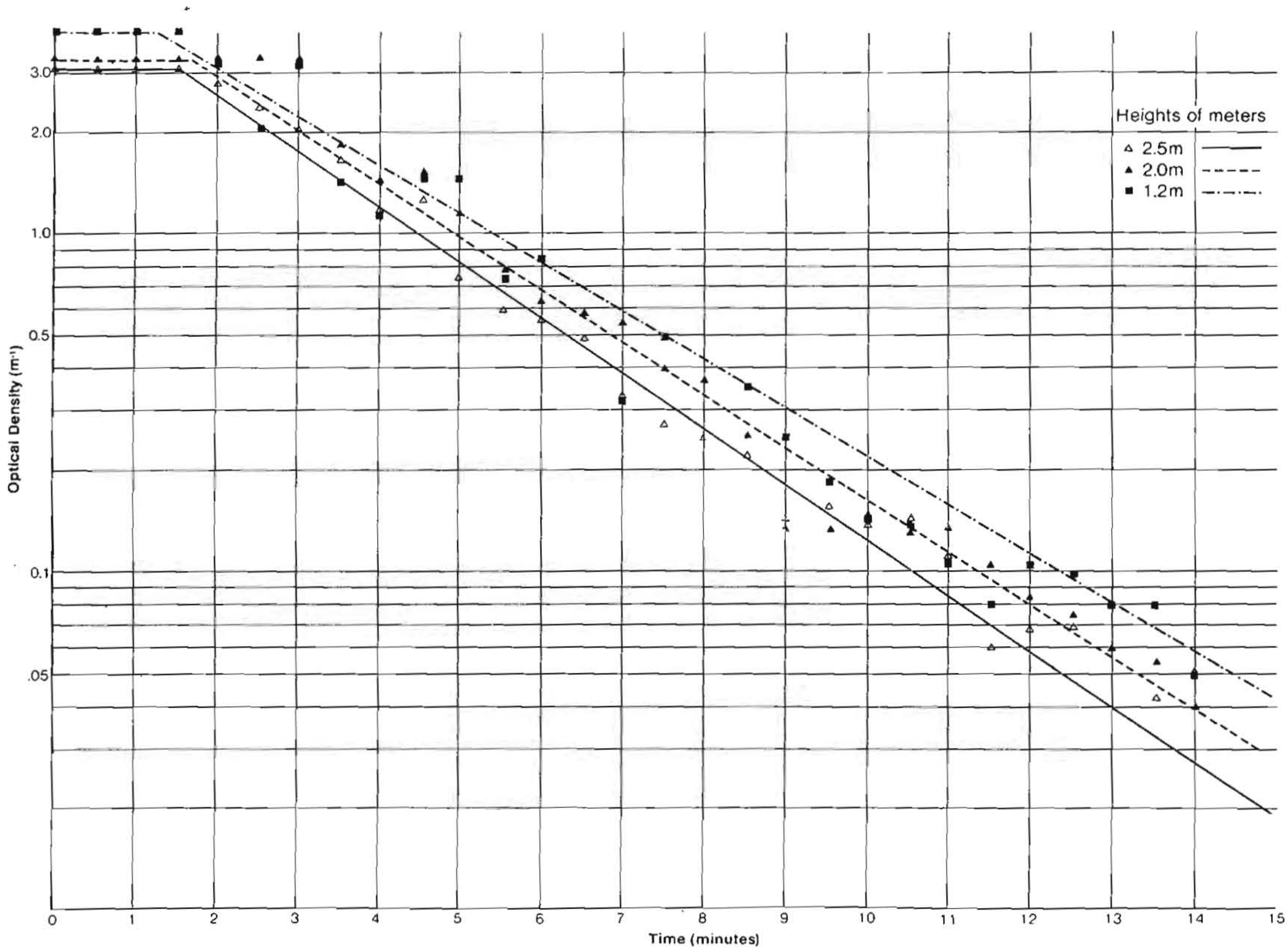


Figure J5 Test C5 Fan: Supervac P164 SE SRDB Code No: 3

Log-linear graph of Optical Density against Clearance Time for three smoke density meters

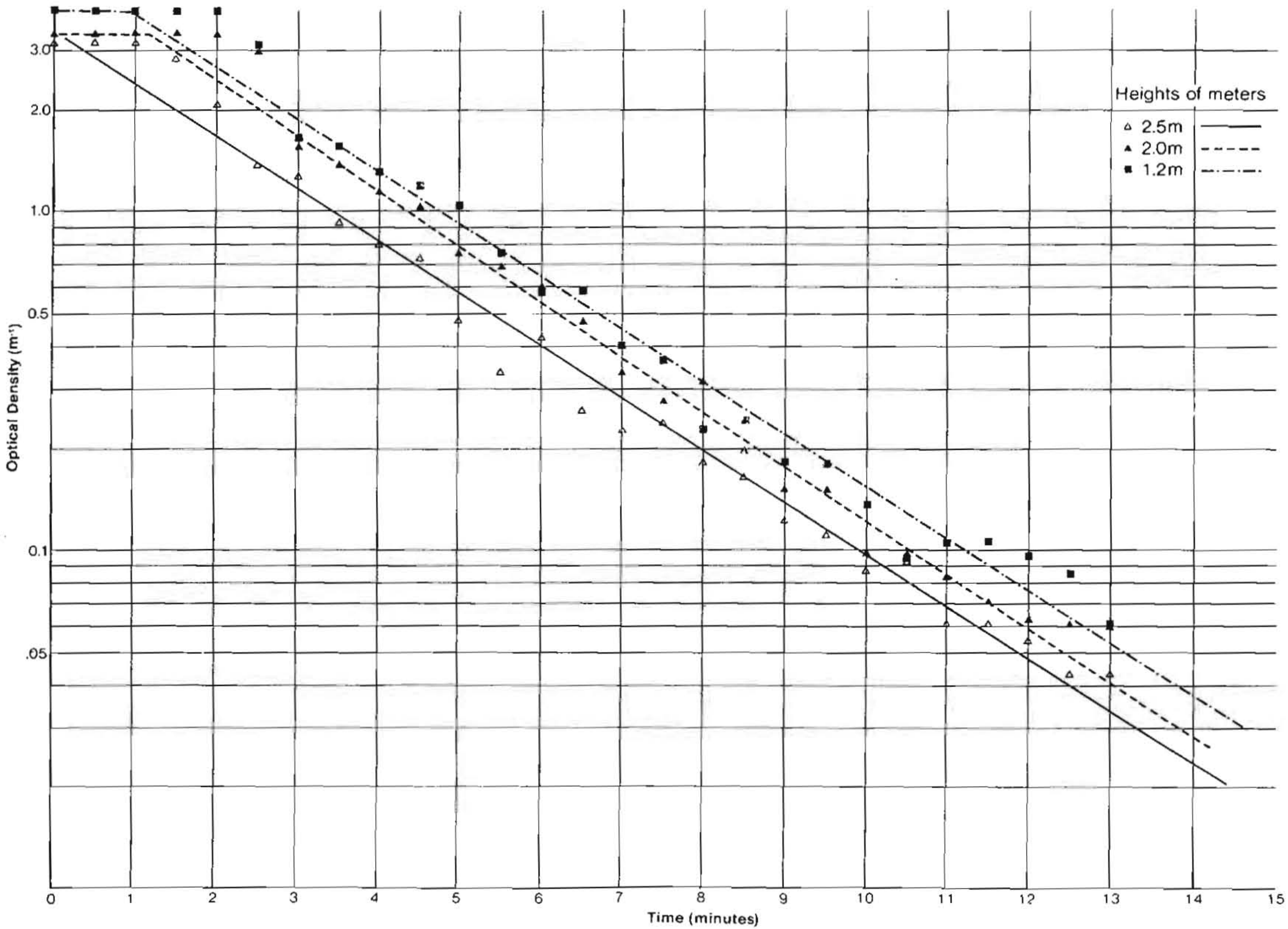


Figure J6 Test C6 Fan: Woods Aerofoil SRDB Code No: 6

Log-linear graph of Optical Density against Clearance Time for three smoke density meters

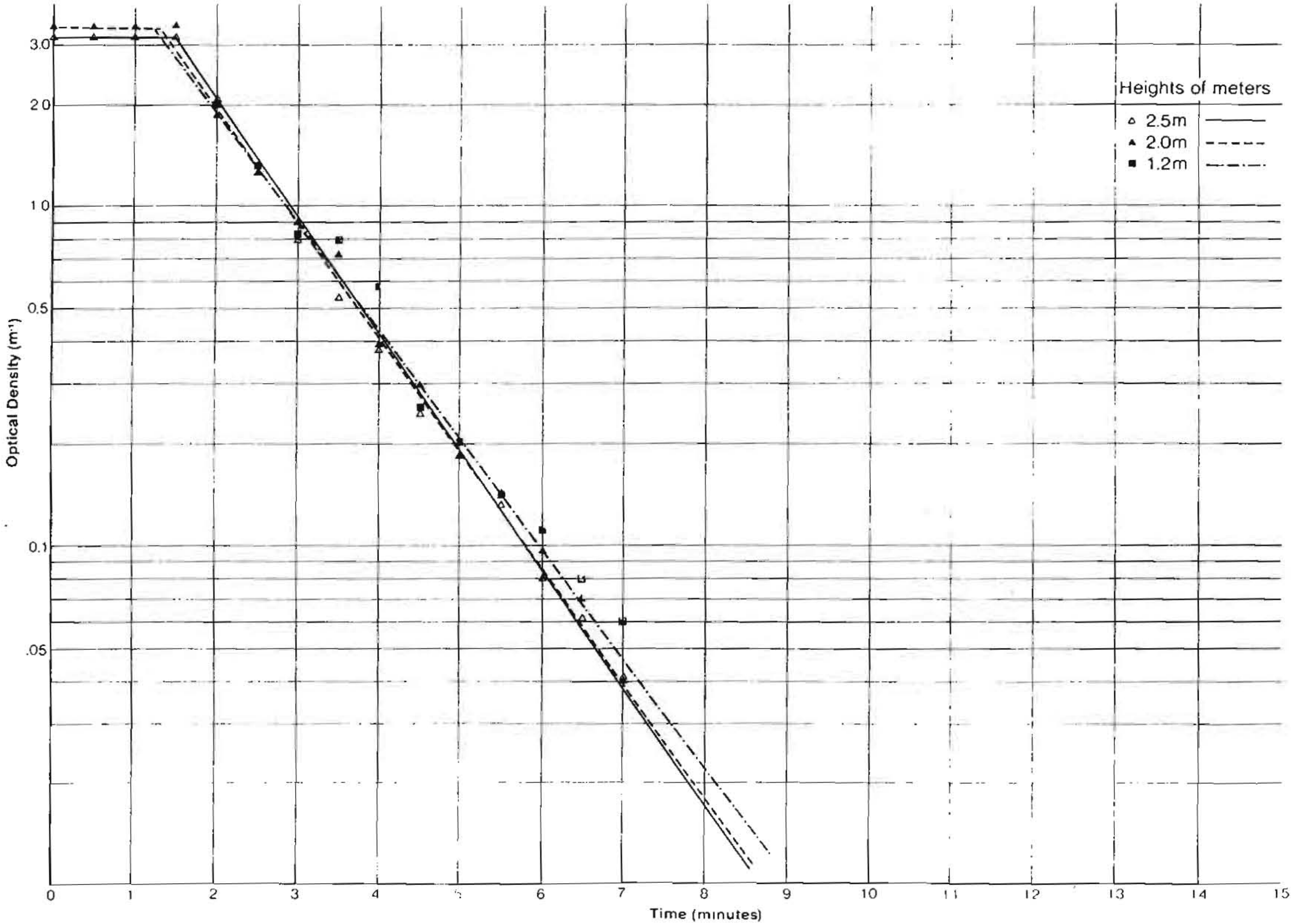


Figure J7 Test C7 Fan: Woods Aerofoil SRDB Code No: 6

Log-linear graph of Optical Density against Clearance Time for three smoke density meters

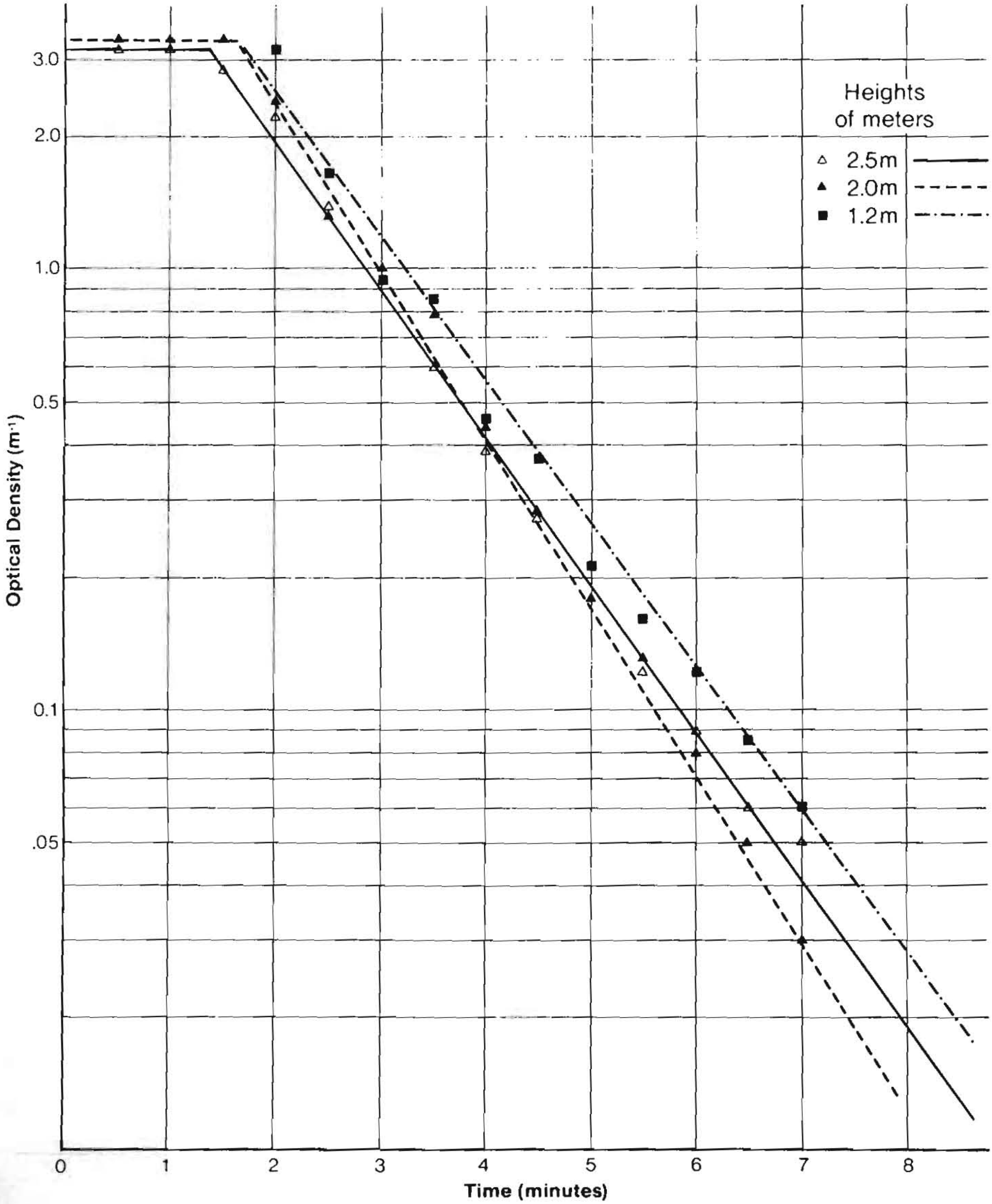


Figure J8 Test C8 Fan: Compact Generator SRDB Code No: 1

Log-linear graph of Optical Density against Clearance Time for three smoke density meters

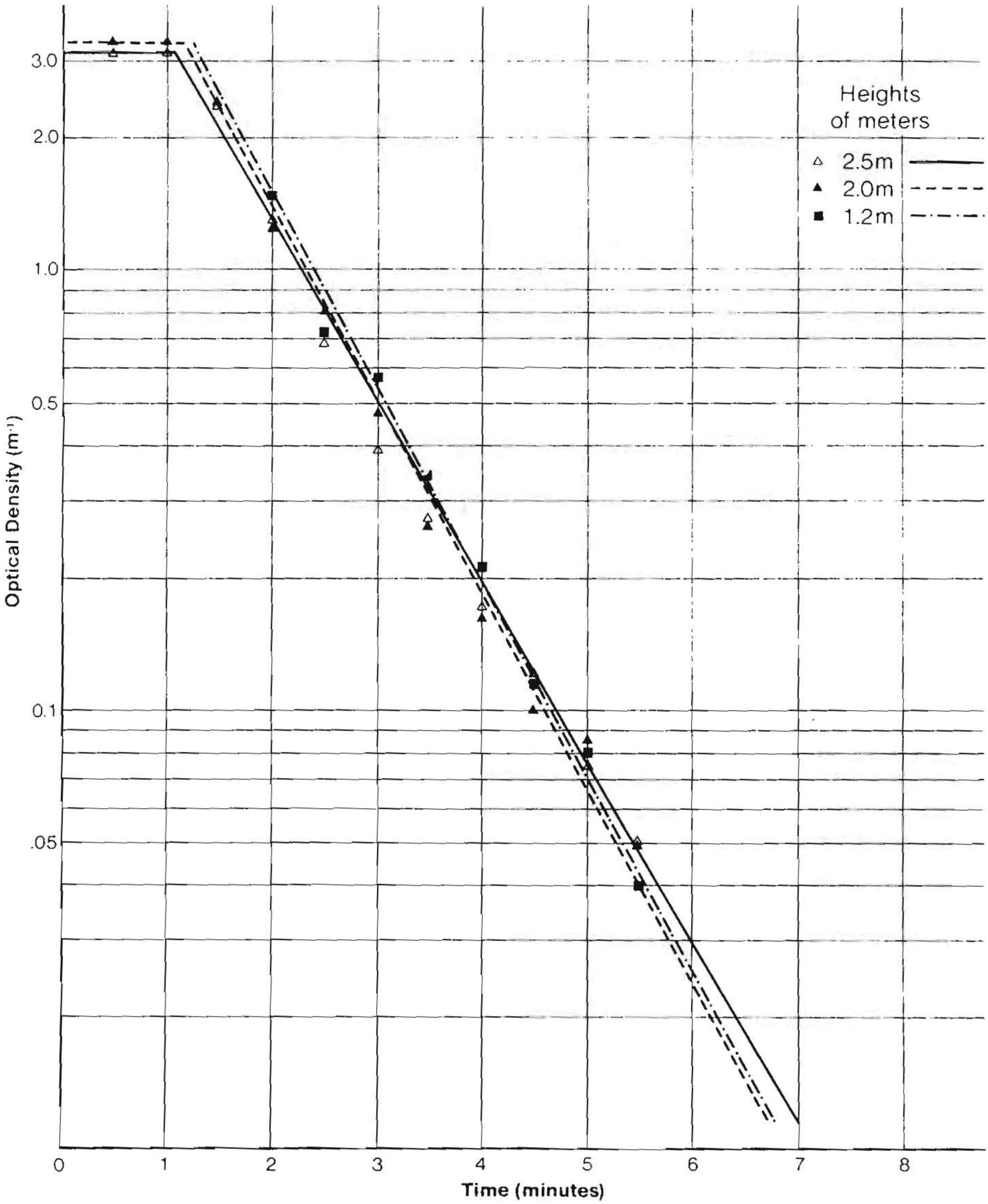


Figure J9 Test C9 Fan: Compact Generator SRDB Code No: 1

Log-linear graph of Optical Density against Clearance Time for three smoke density meters

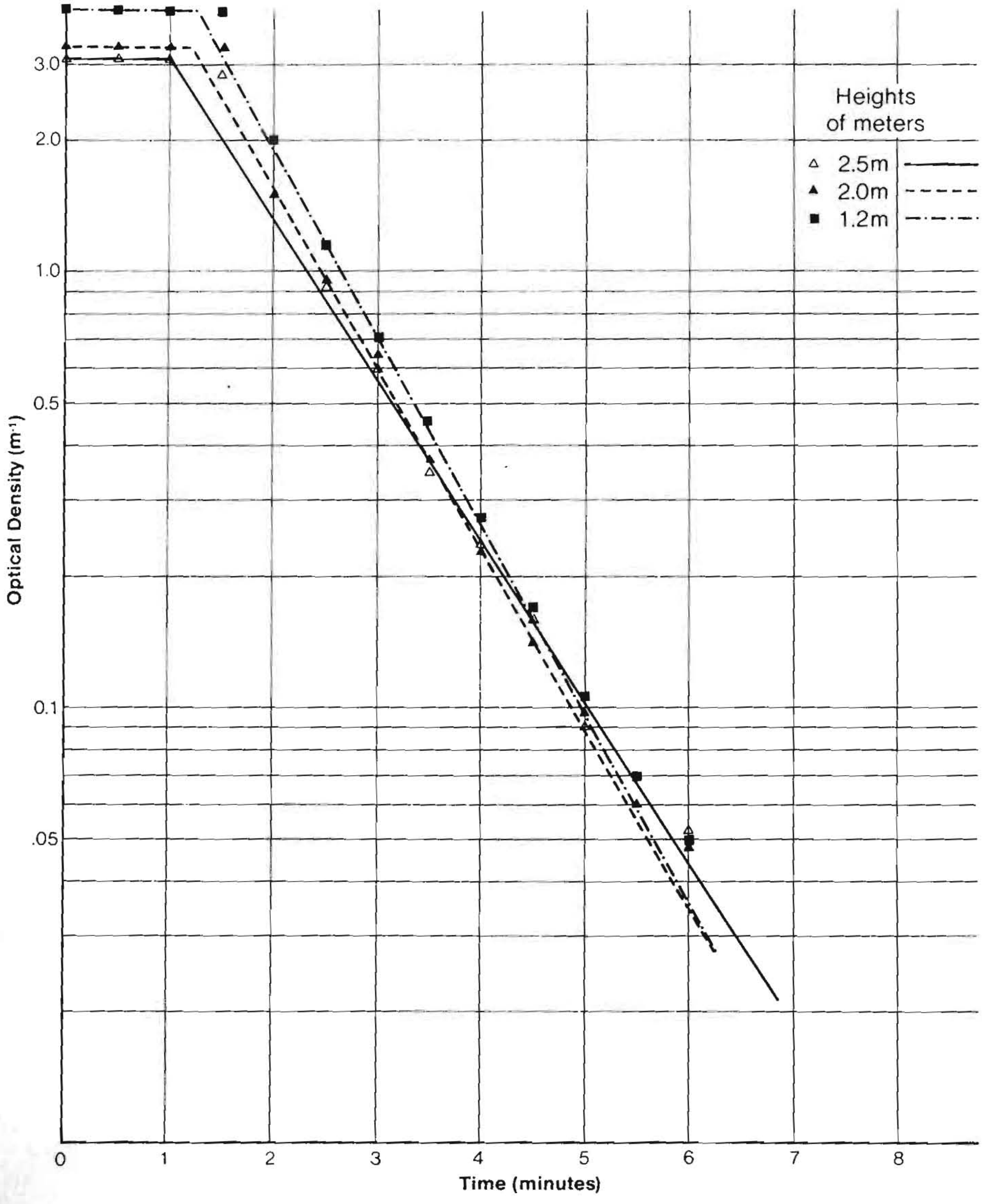


Figure J10 Test C10 Fan: Angus Turbex SRDB Code No: 2

Log-linear graph of Optical Density against Clearance Time for three smoke density meters

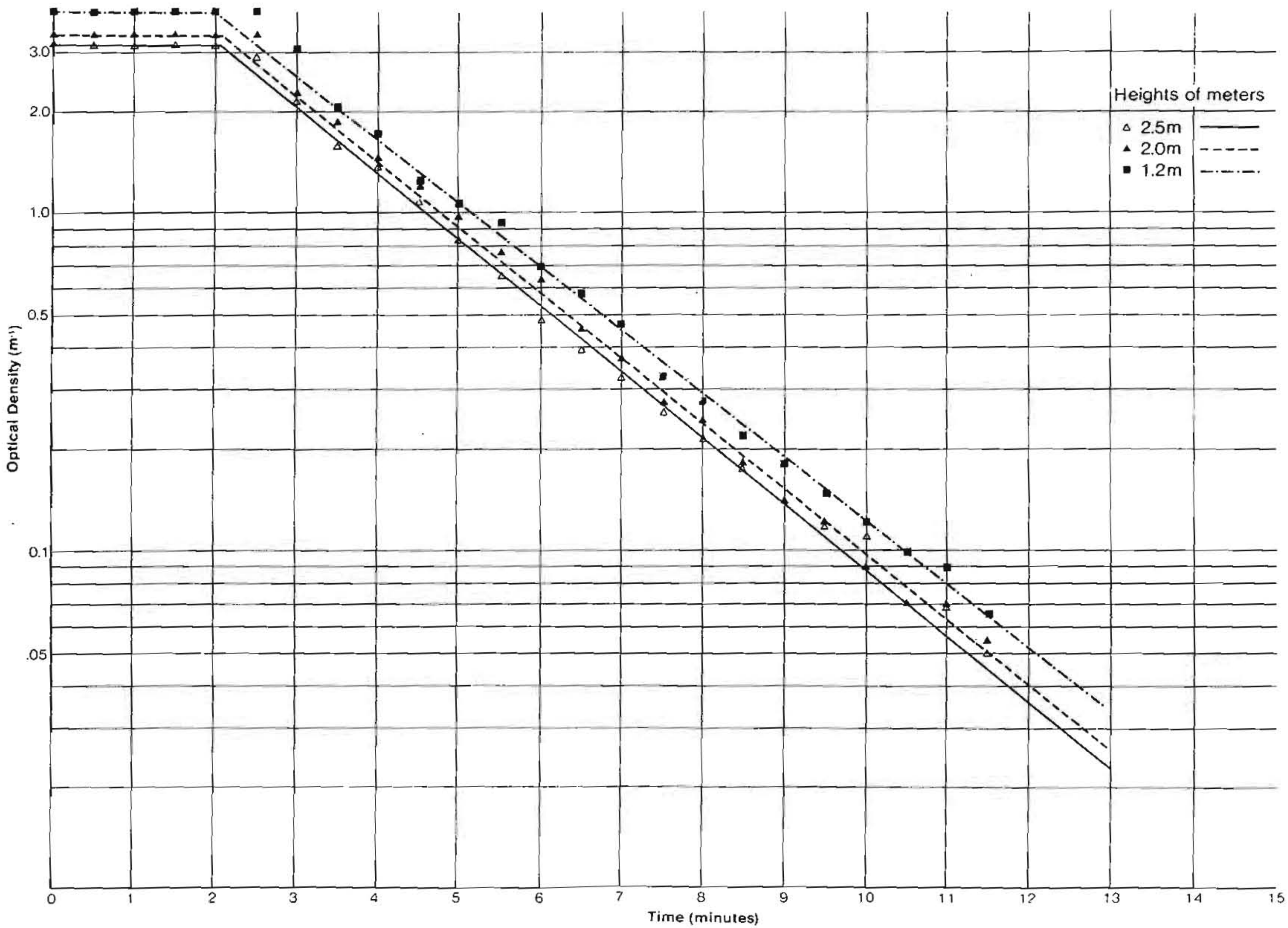


Figure J11 Test C11 Fan: Angus Turbex SRDB Code No: 2

Log-linear graph of Optical Density against Clearance Time for three smoke density meters

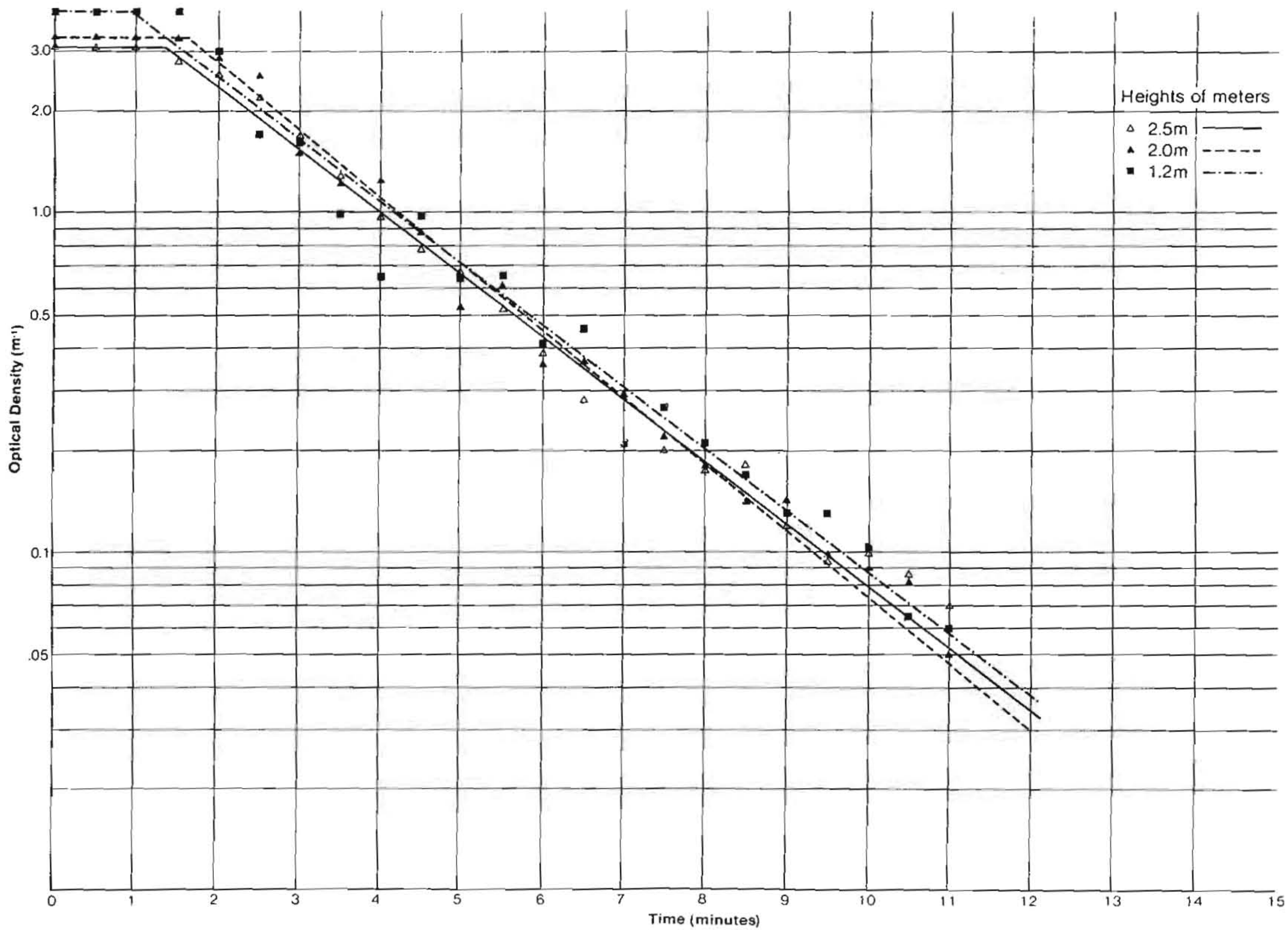


Figure J12 Test C12 Fan: Aneti SRDB Code No: 7

Log-linear graph of Optical Density against Clearance Time for three smoke density meters