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METHODS OF OVERCOMING DANGERS FROM ELECTROSTATIC CHARGES IN FILLING FACTORIES

By A. R. UBBELOHDE, W.D.E. THOMAS

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No. 15·351

METHODS OF OVERCOMING DANGERS FROM ELECTROSTATIC CHARGES IN FILLING FACTORIES

By A. R. UBBELOHDE, W.D.E. THOMAS

Officer Responsible:
Director - General of Ordnance Factories

Printed at I.E.M.E.

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METHODS OF OVERCOMING DANGERS FROM ELECTROSTATIC CHARGES IN HANDLING EXPLOSIVES

(with special reference to Filling Factories)

SUMMARY

Details are given of diverse anti-static precautions proposed in connection with various operations in Ordnance Factories during the period 1940-5. The precautions are classified according to the degree of the risk present.

A. FIRST OR LOWEST DEGREE RISKS

When the threshold ignition energy (see Appendix I) of every constituent (solid, liquid, dust or vapour), which may be encountered in, or brought into a shop exceeds 0.02 joules, the introduction of First or Lowest Degree Anti-static Precautions is generally sufficient in that shop. These include

A.1) the general earthing of all large floating conductors (metal objects),

and

A.2) the minimising of inductive electrical effects resulting from continuous processes of electrification, such as arise with rapidly moving belts or the pneumatic transfer of dust powders;

A.3) other general precautions.

B. SECOND OR HIGHER DEGREE RISKS

When the threshold ignition energy of any material which may be present, or brought into the shop is below 0.02 joules, the more exhaustive Second Degree Anti-Static Precautions are required. These include all precautions listed under I, and, in addition, those listed under B.1 - 6 below.

The detailed implementation of Second Degree anti-static precautions depends on the risks, and is a matter of experience. In general the lower the ignition energy the more rigorously must precautions such as detailed earthing of small conductors be carried out.

B.1, 2, 3, 4 Detailed earthing of operatives and small conductors.

B.5 Humidification of the air without any appreciable lowering of the carbon dioxide content of the air.

B.6 The choice of suitable textiles to minimise electrification and to facilitate the leakaway of static charges.

A list of specifications where these are definitive have been collected together and are given in the Appendix at the end of this monograph.

C. Brief reference is made to the special risks from static which arise owing to the physical and chemical properties of compositions such as aluminised lead styphnate and graphitised lead styphnate.

INTRODUCTION

At the beginning of the period under review, the sensitiveness of explosives to ignition by a static spark was hardly considered on a level with other sensitiveness risks in Ordnance Factories. Comparatively very few anti-static precautions had been introduced in Ordnance Factory operations.

The occurrence of several grave incidents not readily attributable to the more familiar sensitiveness risks, particularly in operations with initiators such as lead styphnate, directed attention to the urgent need for investigation and mitigation of risks arising from the ignition of explosives by static sparks. As this work developed, a scale of the relative sensitiveness of various explosives and combustible mixtures to static sparks was gradually established. Methods of quantitative evaluation of the risks of electrification and ignition have now made it possible to formulate a general scheme for appraising sensitiveness risks from static for the existing explosives, and also for new compositions under development.

An important aspect of this work was the implementation of practical precautions in the factories, when a serious risk of ignition from static had been established. As with other sensitiveness risks, these precautions had to combine the scientifically established requirements for safety with the need for ensuring the fulfilment of safety precautions, even by semi-skilled labour, with the materials available during wartime, and without unduly slowing down production.

Close collaboration between A.R.D. (Swansea) and D.F.F./P facilitated the evolution of practical precautions side by side with the laboratory investigations. Much help was also obtained from general practical information on sensitiveness (Deptl. Safety Officer, A.R.D.) also the early work on spark ignition of initiators, A.R.D. Chorley (1); and from the work of the I.C.I. (2); C.C.R.D. (3); the U.S. Bureau of Mines (4); and the U.S. Bureau of Standards (5).

In its application to factory operations, the work and recommendations on static risks were discussed and reviewed by a committee referred to as The Main Committee on Static Electricity, composed of representatives of D.F.F./P (Mr. Masters, Chairman); A.D.F.F. (Western) (Mr. Edmonds); C.C.R.D. (Dr. Claringbull, Dr. Llewellyn); C.S.A.R. (Dr. Ubbelohde); D.A.S. (Capt. Hoskyns); D.F.F.(E. & S.) (Mr. D.C. Bacon); D.O.F.(X) (Mr. Baggs); H.M. Senior Electrical Inspector, M. of L. and National Service (Mr. H.W. Swann); H.M. Chief Inspector of Explosives Home Office (Major Crawford); H.Q.I.O. (Mr. Hinckley); I.C.I. (Mr. G. Morris).

In the light of experience of accidents, and of a survey of factory risks in Ordnance Factories (6), A.R.D. Laboratory investigations were first directed to the sensitive compositions handled in "Group I", and were extended as required to include compositions handled in other groups, in which static hazards were suspected. The compositions examined during the investigations included the following:

Initiators

Lead azide, service and dextrinated (37)
Lead styphnate of various crystal shapes and sizes (21) (11) (31) (32)
Lead styphnate, graphatised and mixed with lead peroxide (11) (40) (47)
A.S.A. (lead azide, lead styphnate, aluminium) (11) (26) (33) (47)
Lead dinitroresorcinate from both 2.4 and 4.6 D.N.R. (41)

Mercury fulminate and 'A' composition (22)
Barium styphnate (42)
Tin mednate R.D.1306 and compositions based on it (R.D.1614 and R.D.1615) (43)
Tetrazene (44)

Pyrotechnics (33) and (48)

SR.214, SR.223B, SR.227A, SR.227B, SR.232, SR.264A, SR.269M. SR.297B, SR.322, SR.337, SR.346B, SR.361, SR.365, SR.370A, SR.371C, SR.379, SR.399, SR.427, SR.447B, SR.472, SR.562, SR.576A, SR.801B, SR.804, SR.804A, SR.806, SR.907, PN.83M, PN.280, PN.471, PN.472, PN.473 and Ammonium Picrate.

Incendiary Mixes

J bomb (27)
MD.1, RD.2489, HM.1, HM.2 (based on flake aluminium) (29)
Magnesium aluminium alloy (48)

Propellants

NH powders and cordites (9) and (49)

High Explosives

Tetryl) (38)
Tetryl aluminium)
Shellite (10)
Minol and torpex (39) and (45)

The present monograph surveys the measures which were suggested, as well as the modifications actually implemented to eliminate or to minimise the effects of 'static' in the manufacture and filling of explosives and inflammable compositions.

It was early noted that enthusiastic but uninformed attempts to minimise static risks in the factories were likely to enhance risks from other causes, since compositions sensitive to static were frequently also sensitive to impact, friction, etc., or to chemical attack. The relative importance of all these factors had to be assessed comprehensively when the safety recommendations for handling were framed.

A. FIRST DEGREE ANTI-STATIC PRECAUTIONS

First Degree Anti-Static Precautions are recommended for a process, or in a shop, when the threshold ignition energy for every composition or material in the shop exceeds 0.02 joules, i.e., where First or Lowest degree risks are indicated.

The necessary precautions are:

A.1 Earthing of large 'floating' (insulated) conductors

In all cases where direct metallic bond is made, the resistance to earth must conform to the factory electrical inspectorate's requirements. (Appendix ii).

Large 'floating' electrical conductors may present serious static risks by induction of high potentials on them. This can occur by proximity to neighbouring high voltages generated for example by rapidly moving leather belts, electrified dust clouds, etc. If, by chance, the 'repelled' charge on the conductor is removed whilst the 'induced' charge is bound, the subsequent removal of the inducing potential leaves a free charge of electricity distributed on the surface of the conductor. This can then discharge to earth or to another nearby conductor at a different potential. If the energy of such a discharge exceeds the threshold ignition energy of the dust cloud, explosive or inflammable gas present in the air, ignition may result.

Risks on this score are easily overcome by direct bonding of all metal parts of machinery and plant to earth. It is important that all these objects should be well earthed, not merely individually, but bonded together to form one large linked network, in order to eliminate the possibility of stray potentials in the earthing circuit causing appreciable differences of potential between earth leads not connected together. This instruction to use a common network for earthing applies not only to large objects such as metal parts of explosive mixing plants, sieving machines, screens, scales, ovens, detonator drumming plants, etc., but also to certain small metal objects such as door knobs, door handles, etc. (See B.1 (iii) (c)).

The importance of bonding the earth points together to avoid stray earth potentials was illustrated by an incident which occurred at R.O.F. Pembrey, during the emptying of rail waggons containing toluene At the emptying station the solvent waggons were directly earthed by attaching a large crocodile clip (joined to a nearby earthing point) to a paint-free part of the chassis. (The chassis is always in good electrical contact with the waggon wheels and rails system). On one occasion a spark was observed as the 'earthed' crocodile clip was being attached to the 'earthed' chassis, indicating that a potential difference existed between the waggon-rails system and the clip-earth system. No further trouble was experienced after the rails had been bonded together and joined to the same earth point as the lead to the crocodile clip. This ensured the maintenance of a common potential throughout the system.

When there are movable parts in the system (e.g., lead azide or lead styphnate sieving machines), flexible copper braid is preferable to the more usual thick copper strip. Chains are best avoided for grounding because of the poor contact between loose links. If chains must be used they should be as heavy as possible.

It is essential that the grounding system should be regularly inspected and tested for defects or an actual break in the lead. A broken earth lead resulting in a previously well-earthed conductor becoming a 'floating' or insulated conductor may present a very serious risk. Regular and thorough inspection of the whole earthing system is the main precaution to avoid this.

A.2 Static Risks arising from continuous processes

Continuous processes present a difficult problem whenever static risks have to be considered because of the difficulty of preventing a build up of charge and potential on insulated materials which are continually moving. To give one example, the high potentials registered in the vicinity of rapidly moving leather and balata belts have been observed for some time (7). Again records of accidents in 'dusty' processes suggest that the electrification of the dust contributes to the risks, as well as its inflammability (12).

Another main group of continuous processes dealt with includes the 'pneumatic' transfer of dust powders by means of rapidly moving air streams. These have been used as a convenient means of transferring bulk powder from one shop to another, and in 'vacuum cleaning' inflammable and explosive dusts. In either case, rapidly moving dust particles are present, and these tend to acquire very high potentials. Such high potentials present a risk by inducing charges of equal and opposite potential on adjacent conductors, which, on subsequent discharge to earth, or to an operative, may cause ignition of the dust cloud or other ignitable constituent present.

A.2 (i) Electrification of belting

This has been investigated in considerable detail (8). It has been shown that belt electrification can be reduced by using belts made from conducting material, e.g., conducting rubber, if the pulleys are earthed. A specification for the permissible resistance of the conducting belting in terms of dimensions and linear speed of the belting material has been given (see Appendix (viii)). A technique involving a proof plane has also been described for comparing the charges induced by various belting materials, under comparable conditions (8).

A.2 (ii) Pneumatic transfer of powder

(a) Portable 'vacuum cleaner': Cleaners pneumatically operated by compressed air, with suction produced on the Venturi principle, have been used for cleaning up small quantities of (blown) aluminium or waste minol. After being sucked through an aluminium nozzle, clipped to the end of a conducting rubber hose about 30 ft. long, the dust is transferred by the air stream to a receiver where it is wetted with oil. The conducting rubber hose serves as a flexible earth lead, and the other end is joined to the supply of compressed air, which is earthed. Electrical tests on the portable machines in use at R.O.F. Glascoed (24.5.44) showed that the electrical leakaway through the earthed conducting rubber hose was sufficient to prevent a build up of any static charge on the machine, or on the operative holding the metal nozzle.

Quite apart from possible risks from static, some trouble was experienced in selecting an oil sufficiently thick to avoid spitting out oil and waste explosive, but sufficiently fluid to permit the passage of large volumes of air through it. This type of cleaning machine was not developed very far, probably because of inconvenient features (unconnected with electrification risks).

(b) A somewhat larger pattern of pneumatic cleaner was investigated for risks at O.F. Burghfield. This operated on the same principle and was used for removal of waste dust from pyrotechnics. Fairly extensive tests with this machine on the factory burning ground indicated that the fire risks involved were at least no more serious than would be involved in brushing under similar circumstances. It was demonstrated that even if a fire occurred in the hose, it would not propagate to the oil well and ignite the bulk explosive there, so that this method of cleaning up explosive dust is free from risks of large scale damage due to the ignition of accumulated waste.

(c) Pneumatic transfer of NH propellant: This technique was developed in 1943 to mechanise the filling of shell cases with NH propellants. The pieces of propellant were sucked from their transport cases by a nozzle, and transported by the air stream along a metal pipe, to automatic weighing hoppers where aliquot amounts were filled into shell cases travelling on a conveyor belt. One source of trouble in this operation was the formation of an inflammable ether/air atmosphere above the powder in its container (9). Even if sucked away the ether vapour was gradually regenerated from within the pieces of powder. It was essential to replace this inflammable atmosphere by air immediately before the powders were pneumatically transferred. This was done by pushing in an earthed tube with wire gauze end and sucking out the ether. The room where the propellant was transferred from the container to the pneumatic carrier tube was fire insulated from the main shop, as a further precaution. The electrification of the powder in transit was kept low by using an earthed metal tube, and fire curtains were placed at intervals on the conveyor belt to localise any accidents. No accidents were experienced.

(d) Shellite dust clouds: In connection with a 'blue glow' which was reported at R.O.F. Ruddington in the vicinity of the exhaust systems over pots of molten shellite, experiments were carried out at Swansea on the electrification of rapidly moving air streams carrying shellite crystals. These experiments are described in detail in another report (10). They showed that, as in other cases, very considerable charges may be generated by a rapidly moving dust stream. The importance of minimising risks from this cause by the positive earthing of all large floating conductors in the vicinity was clearly brought out by these experiments. A fairly elaborate earthing scheme was recommended. There was no further report of trouble from the factory and in view of the pressure of other work the nature of the blue glow was not further investigated. The blue glow was not itself observed by the scientists concerned with this monograph, but this may have been fortuitous.

A.3 Summary of General Precautions: In dealing with electrification from continuous processes, each case must be assessed on its own merits, but the following general factors apply throughout.

(a) The electrification should be minimised as much as possible, e.g., by using conducting rubber belting running over earthed pulleys, or by using earthed metal chutes for rapidly moving air-dust clouds.

(b) All conductors in the vicinity of the continuous electrification process should be earthed. This will prevent the build up of dangerous charges.

(c) Attention should be paid to the general cleanliness of the shop housing the process under review. It may happen that a comparatively small initial dust explosion can generate an air blast sufficient to disperse much larger amounts of dust from windows, shelves, girders, etc. This can be prevented only by close attention to the regular removal of all waste dust accumulation, and by designing the process so that dust clouds are kept at a minimum.

(d) The finer the dust the greater the risk. 'Fines' separating during operations must be kept under by acceptable methods.

(e) Where the threshold ignition energy lies below 0.02 joules, additional precautions such as humidification, etc., must also be considered. It is particularly important in such cases that each process should be individually examined and approved as being safe on anti-static grounds before full scale operations are begun.

(f) Dust clouds with aluminium: Methods of handling stamped (flake) aluminium for incorporation in 'heater mixes' have been evolved for use at R.O.F. Bishopton (29). Second Degree Risks are involved in the handling of this type of aluminium. (See B.4(ii) below).

(g) Care must be taken when introducing anti-static precautions that the precautions called for by other sensitiveness and compatability risks are not violated.

B. SECOND OR HIGHER DEGREE ANTI-STATIC PRECAUTIONS

'Second' or Higher Degree Risks occur when the threshold ignition energy lies below 0.02 joules, and the smaller the value of this ignition energy the more attention must be given to the detailed precautions outlined below. Before prescribing anti-static precautions for the handling of a composition having a threshold ignition energy below 0.02 joules, information regarding the self-electrification of the powder during the process should be obtained, either by tests on the factory plant, or by a laboratory 'mock-up'. If the self-electrification is appreciable, and is sufficient, for the quantities handled in the operation, to give rise to a spark of sufficient energy to cause ignition, very close attention should be given to the process and the precautions required to prevent ignition. However, even if the self-electrification of the powder is very small, provided the threshold ignition energy is below 0.02 joules, Second Degree anti-static precautions are still required to cover the possibility of a discharge from an operative. The probability of an operative becoming electrically charged is less when the composition handled has a low self-electrification, but operatives can become charged independently of the powder, e.g., by their own body movements (30). In addition to the earthing of all fixed conductors required for First Degree Risks, moveable conductors, including the operatives themselves, must be adequately earthed, and maintained at as near earth potential as possible, since these conductors have appreciable electrical capacity and, if insulated, can accumulate static charges.

B.1 Earthing of Operatives

The continuous earthing of operatives presents a difficult problem since the most positive methods of earthing (a permanent metal tape) is usually impracticable. 'Ad hoc' methods such as the wearing of an earthed metal skull cap or an earthed metal wrist chain have not proved acceptable, both on the score of making the handling of sensitive materials more awkward, and of preventing the operatives moving about.

Methods have therefore been developed whereby the operative is maintained at low potential throughout, without the need for continual vigilance.

B.1 (i) Conducting footwear

The use of conducting footwear combined with the use of earthed conducting floor-covering provides a convenient method of earthing the operative without taking up too much attention. Following the development of conducting rubber (Appendix (iii)) by the incorporation of a suitable form of graphite in the rubber, footwear manufactured from conducting rubber has been fairly generally introduced. It was decided (13) as a first step that operatives in lead azide and lead styphnate drying and sieving shops should wear conducting rubber footwear. This instruction was clarified further (14) when the maximum permissible resistance to earth of an operative wearing approved footwear and standing on an earthed metal plate was fixed at not more than one megohm. Though not stressed at the time, in addition to the maximum of one megohm, a minimum performance resistance of about 1/4 megohm should also be stipulated to avoid fire and electrocution risks. In order to maintain the footwear in acceptable condition, free from insulating dirt, etc., and to eliminate operatives with high skin resistances who would introduce static risks, "personal testers" were installed near the initiator buildings. (Appendix (vii)).

With the loss of the Far East supplies of natural rubber, the supply of conducting rubber was reduced, and the use of conducting footwear was restricted to the azide and styphnate manufacturing and sieving shops in Group I, and in other groups where very high grade static risks existed. Crepe soles, or ordinary rubber footwear, for which the resistance ranges from 1,000 to 10,000,000 megohms, were definitely banned from the initiator group. As a makeshift for conducting rubber, safety shoes in these shops were made from leather soled footwear. This required constant vigilance on the part of factory overseers. Leather soled footwear had a performance resistance varying from 20 to 100 megohms. Attempts were made to render such footwear more conducting by the insertion of cylindrical studs of conducting rubber through the sole and heel, thereby providing a path of lower electrical resistance between the operative's feet and the floor. Plugged footwear proved unacceptable however, due to the plugs falling out and also because of the unequal rates of wear of the leather sole and rubber plug. It was eventually decided (15) to abandon this type of footwear. More recently a modification of the leather shoe has been developed and is being tried out. In this type a sheet of pipped conducting rubber has been stuck on the sole of an ordinary leather shoe, and operatives wearing such shoes give performance resistance of somewhat under 10 megohms. The pipped nature of the rubber confers non-slip properties when the shoes are worn on the cleanways and in the filling shops. Long-term wearing properties of this type of footwear are being kept under further observation.

In operations in which sensitiveness to percussion or friction was thought to be of equal or greater importance than 'static', e.g., the incorporation of flake aluminium into M.D.1 at Waltham Abbey (29), nitroglycerine manufacture at Holton Heath (50), etc., felt-soled footwear was in general use. The performance resistance of operatives wearing such footwear was usually of the order of 1,000 megohms or more. Attempts were therefore made to improve the conductivity of this type of footwear by treating the felt sole with conducting solutions. Solutions tried in these tests were glycerine/water/saponin; borax/boric acid/glycerine/water; glycerine/aquadag/water/saponin; Aquadag mixtures were unacceptable because the graphite blackened the floors. Treatment of the felt with all these solutions resulted in the obtaining of acceptable resistance values whilst the sole was still damp, but as the felt dried, the resistance also increased, and the footwear ceased to possess anti-static properties. Further work to improve the conductivity of felt-soled leather footwear was not pursued, as the production requirements lapsed. With a suitable personnel tester, however, treated felt should not present any grave objection, and a check on its condition would be ensured by the daily resistance tests on the wearers as they entered the area.

In India the problem was simplified by the fact that operatives normally walked barefooted, thereby ensuring a low resistance to earth.

B.1 (ii) Conducting flooring

Metal conducting floors were not permissible on sensitiveness grounds, and one of the earliest attempts to obtain an acceptable earthed conducting flooring was by the use of conducting rubber (Appendix (iii)) which was laid on a smooth floor over earth tapes of thin metal foil bonded to one another and to earth. Scarcity of rubber imposed a restriction on this type of earthed conducting flooring, the use of which was confined to shops where compositions very sensitive to static ignition were being handled.

A type of conducting flooring which has also been developed was based on asphalt, and consisted of bitumen and coke. This type of flooring required careful watching when its use was proposed in shops where sensitiveness to friction and impact were of major importance. Friction sensitiveness tests carried out with small quantities of the asphalt and "filler" admixed with initiators showed that the "filler" used in some cases was harder than rock salt, and therefore should be regarded as unsuitable for use in initiator buildings (18). With another sample of conducting asphalt, sensitiveness tests on the Rotter Impact machine carried out with R.D.X. showed a marked sensitisation when 1% of the powdered flooring was added. The sensitisation was even more marked when 1% of the coke dust "filler" was mixed with R.D.X.

This type of flooring was usually observed to possess electrical resistance properties within the acceptance limits, though tests showed variations in resistance occurred over a period of time (16). The undesirable large negative temperature coefficient of conducting asphalt has also been noted (17). Provided no other sensitiveness risks are introduced by the use of a floor material of this kind, it would seem that conducting asphalt flooring could be quite useful, but with explosives very sensitive to grit (39a) it should be avoided.

A serious objection which applied to all types of asphalt floors was that when they were cleaned with an organic solvent (e.g., acetone) to remove spilt explosive, the acetone seeped into the floor and therein deposited the explosive. A method evolved at R.O.F. Thorp Arch of treating ordinary non-conducting asphalt eliminated the need for the use of acetone. At this factory asphalt floors were treated with an aqueous suspension of graphite, and not only did the floor possess adequate anti-static properties (making good contact with the earth tapes on the side of the room), but cleansing of the spilt explosive (e.g., minol) from the floor was easily possible by means of a scraper. The use of solvents to clean the surface was thus rendered unnecessary. In addition the treated asphalt possessed satisfactory non-slip properties.

A newer development (19) which has far-reaching possibilities, both as a floor and bench top covering in Ordnance factories, hospital operating theatres, etc., is conducting linoleum. (Appendix (iv)). In the manufacture of this linoleum, a suitable form of carbon was incorporated with the oxidised linseed oil during the manufacture, and the finished product was backed with jute in the normal way. Before laying the linoleum on a floor or bench top, the surface was made as plane as possible, and was overlaid with tin strips of metal which were bonded together, and to earth points. The linoleum, cut to approximate size, was then allowed to 'age' for several weeks, and finally cut to the required length. During the actual process of laying, the jute backing was firstly rendered electrically conducting by means of a conducting paint (20), and adhesion of the jute to the floor was then ensured by means of a conducting adhesive (20). The process of development of this conducting linoleum, and its successful trial over a period of 9 months in a filling shop at R.O.F., Bridgend, has been dealt with in another report (19). Further trials in a permanent R.O.F. are to be arranged.

With all types of conducting flooring, the importance of cleanliness cannot be over-stressed. Both anti-static flooring and footwear may be rendered valueless and induce dangerous false confidence through the presence of insulating layers of dust. It is imperative therefore that conditions of scrupulous cleanliness should be maintained, and that a daily personnel test be intorduced at the point where the operatives enter the 'anti-static' area.

B.1 (iii) 'Ad hoc' methods of earthing

'Ad hoc' methods of earthing to supplement the above were introduced as an interim measure principally for operatives who were required to carry out bench operations, during which they remained seated for long periods. It was known that an operative seated on a varnished chair could accumulate considerable charge by normal arm and body movements associated with the carrying out of the operations, unless a leakaway path to earth was provided. To minimise this risk, several 'ad hoc' devices were introduced, with the dual objects of preventing the formaof static charge and to facilitate leakaway of a charge after it has been acquired:-

(a) Elbow rests. These consisted of two pieces of earthed conducting rubber placed as inserts on the wooden bench top in the positions which the operatives would find most convenient and restful to place the elbows. The efficiency of such a method of earthing the operative was greatest when approved cotton (non-woollen) clothing was worn (see B.6 (i)). This use of earthed conducting rubber inserts would be superseded by the introduction of earthed conducting linoleum to rest catch pots, etc., present on the bench. But before this material was available, inserts served to give earthing without the necessity for a complete conducting cover for the bench, a point of practical importance during the rubber scarcity.

(b) Earthed conducting footrests. These footrests of earthed conducting rubber or of metal were placed in a convenient position for the operative to rest his feet in comfort. To derive full advantage from this footrest, conducting footwear was used, but if unavailable, the use of leather shoes was permitted. To ensure that the operative placed his feet on the rest, it was usually found prudent to close the knee-hole with a panel.

(c) Earthed door knobs. As a precaution against the entry of personnel (e.g., powder carriers, or visitors), in a highly electrified condition from the cleanways into the shops, all the shop doors were fitted with bare metal door knobs or handles, and all of these were efficiently earthed by means of a copper tape joined to the common earthing network of the factory (see A.1). Each door was hinged in such a way that it closed itself as soon as it was released after opening, and as each person entering the shop was encouraged to open the door for himself, adequate earthing was provided for everyone entering. The only flaw in this scheme was a tendency for unauthorised propping open of doors on a warm sunny day.

B.2 Handling of initiators during filling and transport

Precautions introduced under this category were designed to mitigate electrification, and also to permit any charge which developed to leak away harmlessly. Modifications to previous practice were as follows:-

B.2 (i) Bulk Initiators. Sieving, weighing, etc.

In designing a preferred container for sensitive compositions, the sensitiveness to ignition by static spark was assessed and compared with the sensitiveness to impact, friction, etc. With compositions based on lead styphnate, all of which are very readily self-electrified, aluminium catch pots have been used, combined with the use of loosely fitting rubber lids to avoid impact risks. In the early days a disc of conducting rubber was stuck on to the base of the catchpot to prevent impact risks during the vibration which occurred in the sieving process. It was, however, observed that, owing to the dusty nature of lead styphnate, a film of styphnate dust formed an insulating layer between the catch pot and metal stand during sieving. This was overcome by the device of using a damp cambric cloth over the earthed tray and under the six catch pots. This cloth was moistened with an aqueous solution containing 20% glycerine, and 0.2% saponin. In this way, the formation of a dust film under the catch pots was prevented (21); the rubber disc stuck on to the base of the catch pot also became unnecessary, since metal to metal contact no longer occurred. Cotton wool swabs wetted with the glycerine/saponin solution were also used to clean up the sieving machine at the end of the sieving process, after all the bulk had been removed. Camel hair brushes, which presented a very serious electrification risk (see B.6 (ii)) could therefore be banned from these shops.

During the subsequent weighing of lead styphnate for incorporation into A.S.A. the metal balance trays were replaced by scoop-shaped conducting rubber pans, which were directly earthed through the metal parts of the balance. (Care was taken with balances having agate knife edges that the pans were earthed in addition to the body of the balance). The operation of pouring initiators was replaced whenever possible and practicable by gentle scooping in which a paper scoop was used under approved conditions of protection for the operative.

With lead azide and mercury fulminate the electrification and general static risks were not considered to be as serious as the sensitiveness risks, and therefore with both of these initiators papier mache pots of superior quality were preferred. As in the case of the styphnate metal catch pots, these catch pots had loosely fitting rubber covers.

An improved design (not, however, implemented during the war) introduced the use of papier mache catch pots in which the papier mache base disc was replaced by a disc of conducting rubber (22). This was originally recommended for use with 'A' composition, but could be used generally with lead azide and mercury fulminate compositions. It was not pressed when originally proposed, because of the backward state of other anti-static precautions such as conducting bench tops, without which this type of catch pot would not lower static risks. With the development of earthed conducting linoleum, this design of catch pot is rendered much more attractive for general use since it ensured anti-static properties without enhancing impact and friction risks.

B.2 (ii) Mixing of initiators

Static risks associated with the mixing and handling of A.S.A. had been largely overcome by the use of (adequately earthed) remotely controlled metal plants for mixing A.S.A. For the mixing of 'A' composition, bakelite jelly moulds and dividing funnels were initially used with papier mache catch pots. With the development of conducting bakelite, jelly moulds and dividing funnels from this composition were made and used (Appendix (xiv)). Conducting bakelite was prepared by incorporating about 20% of graphite of high electrical conductivity and which had a low ash content. (The low ash content was stressed because of the known sensitising action of grit on initiators (18)). With the earlier design of the dividing funnel it was observed that during the pouring operation the powder fell clear of the sides of the funnel, and that therefore the electrification was not appreciably reduced by having a funnel of conducting material. It was recommended, therefore, that the funnel should be redesigned to ensure that the powder should be made to flow over the earthed conducting surface of the funnel during pouring. Though papier mache catch pots were used throughout the period under review for 'A' compositions, p.m. catch pots with conducting rubber bases would be preferred if used in conjunction with earthed conducting table tops.

B.3 Handling of initiators in filled stores

When the filling processes were carried out by the automatic 'Fortress' method, the earthing at all stages was considerably simplified. In the older methods of filling and handling detonators, modifications which had been introduced were all designed to maintain the detonators at low potential throughout the filling process, and also to mitigate electrification. Such changes not mentioned elsewhere in this report are given below.

B.3 (i) Stoving detonators

After varnishing, the detonators were stoved for several hours to remove the solvent. These stoving ovens, made of wood, had sliding trays, on which the detonators were placed in small dishes. The trays, had a wooden framework, with a base formed of a coarse zinc mesh insert about a third up the side to form a perforated bottom to the tray. The small dishes were circular with p.m. sides about 1/2" high, and with a flat base made of coarse copper gauze inserted about 1/4" up the p.m. side. About six or more detonator caps were placed on each dish, the tray was packed with dishes, and then placed in the oven to stove.

Both the zinc based tray and the wire meshed base of the dishes holding the detonators were thus 'floating' conductors, and in view of several grave incidents in connection with stoving, attempts were made to eliminate the risks associated with these conductors. The earthing of the mesh of the tray was arranged by connecting strips of copper from the mesh under the tray, thereby contacting the earthed metal guides on which the tray rested. The effective earthing of the detonators themselves in the p.m. dish proved more difficult, mainly because any metal clip fixed so as to join the metal mesh of the dish with the earthed zinc mesh of the tray soon became insulated by a film of varnish.

An attempt to overcome this was made by the introduction of dishes made from conducting bakelite (see Appendix (xiv)) to hold the detonators. Tests carried out with these dishes showed that they were sufficiently robust, and of sufficiently low electrical resistance to be acceptable, but their conducting properties were easily impaired by the shellac from the detonators. For the varnishing operations these dishes were thus no more foolproof than the original design, since they would need very frequent cleaning (with mild alkali) to maintain their earthing properties. No satisfactory alternative to the p.m. dishes was therefore available. Conducting bakelite dishes, however, were well suited to hold dried detonators on earthed conducting table tops.

On general grounds, as well as on account of static risks, some form of continued stoving of detonators on a conveyor belt would be preferred, in which the collection of large quantities of open detonators in a small space would be avoided.

B.3 (ii) Counting and Inspection of detonators

When detonators in quantity were raked and moved during visual inspection and counting, etc., they were made to slide along soft earthed conducting rubber (with adequate screen protection for the operative (earthed as previously described)).

B.3 (iii) Rumbling of detonators

Evidence that extensive electrification of detonators occurred during rumbling was obtained (25), and several accidents during rumbling are on record. It was important, therefore, that the sawdust used should not have a resistance so high as to prevent leakaway of charges of static to the earthed metal drum case. This aspect of the problem was investigated, and the electrical resistance of a particular sample of sawdust determined at varying moisture contents. (Appendix (xi)). A minimum moisture content to permit leakaway of charge, which also gave adequate cleaning properties, was determined for this sawdust (24). Similar investigations were recommended whenever sawdust from new sources would be used.

B.3 (iv) Packing of detonators

Detonators were packed for 'export' in a papier mache pot containing six layers of 50, each layer separated from the next by thin felt discs. Several blows had been reported, mainly with A.S.A. detonators, when such packs were being closed or opened by an operative. The possibility of a number of detonators in a layer becoming charged by induction from the operative, followed by the separation of the group into two 'islands' of opposite charges, was investigated (26). It was shown that unless adequate earthing facilities existed for the operative, it was possible for charges of opposite sign to be acquired in this way, and having sufficient energy to ignite loose A.S.A. In view of these experiments, it was recommended that all A.S.A. detonators should be individually located in the container. This prevents the formation of 'islands' of detonators in contact with one another.

B.4 Miscellaneous examples of earthing

B.4 (i) J. bomb

Tests were carried out to determine whether static risks were present during the filling of the 22 lb. J bomb. This process involved the pouring of molten naphthalene into the bomb case which contained the heater composition. Spark ignition of naphthalene vapour were found to occur at energies below 0.02 joules, so that Second Degree anti-static precautions were necessary (27). The bomb case was earthed effectively by standing on a metal plate, provided the metal to metal contact was kept free of spilt naphthalene. In practice, during the experimental filling of the J. bomb, thin films of solidified spilt naphthalene invariably formed on the earthing plate, and electrical resistance tests showed that the bomb case had become insulated from the earthing plate. The importance of adequately earthing the bomb case at surfaces which could be kept free from naphthalene, was stressed. The effective earthing of the operatives before they approached the inflammable atmosphere was ensured by fixing a large earthed metal plate on the floor in front of the filling bay. Precautions were taken also to earth all the metal parts of the filling apparatus.

B.4 (ii) Flake Aluminium

In view of the very low threshold ignition energy (0.009 joules), found for flake aluminium (28), stringent anti-static precautions were recommended for its handling (29). In addition, the importance of general cleanliness during operations, and the designing of all processes so as to minimise dust cloud formation, were regarded as factors which were of great value in preventing the spreading of flake aluminium fires. (See also A.2 and A.3 above).

B.5 Humidification of the air without any appreciable lowering of the carbon dioxide content

Static risks are enhanced by a low relative humidity, probably by increasing the surface resistance of insulating bodies (35). In confirmation of this view, it has been reported (36) that explosions, fires, etc., attributed to static have been more prevalent in early Spring when the relative humidity of the atmosphere is generally lowest. Such hazards may be overcome by artificially increasing the relative humidity of the air. However, although the optimum relative humidity on anti-static considerations alone would be as high as possible, other factors necessitate the prescribing of a maximum to the permissible relative humidity. Such factors include the unpleasant and possibly harmful effect on the operatives of spending prolonged periods in a humid atmosphere; the hygroscopic odeliquescent nature of the compositions handled, and the handling difficulties in some processes (e.g., sieving) when the atmosphere is humid. The preferred relative humidity for a given operation must take into account the relative importance of all these factors and any others which apply.

For operations in which anti-static precautions are of primary importance, a relative humidity value of 65-70% has generally been regarded as adequate in this country, and to facilitate inspection, wet and dry bulb thermometer tables have been compiled, showing the maximum permissible difference between the wet and dry bulb temperatures at each room temperature to maintain the relative humidity above 65%. (See Appendix (x)).

Evidence has also been obtained which indicates that the carbon dioxide content of the air is of equal importance with the relative humidity, in the dissipation of static charges (34). Explosions and dangerous accumulations of static had been reported in air at R.H. 65% but in which carbon dioxide content of the treated air had been materially reduced by the wash-humidifying system. It is essential, therefore, that when such systems are used to obtain humidified air, the carbon dioxide content of the air should not be reduced.

<u>Methods of humidification</u>. In view of the importance of humidification as one factor in mitigating static risks, steps were taken in all the shops handling loose compositions based on lead styphnate, to humidify the air. No one method appeared to be in universal usage, but the following methods were introduced in various factories.

<u>B.5 (i)</u>

Injecting a fine spray of moisture into the shop. In one such plant water was arranged to drip over a revolving disc behind which a fan operated to create an air stream. When viewed this plant had not been tried out.

<u>B.5 (ii)</u>

The installation of an elaborate air humidifying system for a part or the whole of a factory. This was not introduced into any factory.

<u>B.5 (iii)</u>

Repeated injections of steam as a fine mist into a corner of the shop, provision being made that the steam could not moisten any surface which should be maintained dry.

<u>B.5 (iv)</u>

In practice, the R.H. was frequently maintained at a safe value by the presence of pails of warm water brought into the shop, and also by pouring warm water on the floor. This procedure was not liked because of the risk of slipping. Another 'ad hoc' device was to paint the heating panels in the wall at frequent intervals with water, using a large paint brush. Immediate evaporation of the water raised the R.H.

In conclusion, it may be stated that whilst the importance of the R.H. was realised, the methods of obtaining permissible R.H. values in shops were almost invariably of an 'ad hoc' nature pending more permanent installations. From this aspect, as well as in order to prevent grit, air conditioning is strongly recommended in shops in Group I.

B.6 (i) Choice of suitable textiles

At the beginning of the period under review, woollen felt and woollen cloths were used to a considerable extent in Group I operations. On general sensitiveness grounds, it had been thought that woollen felt, possessing both softness and resilience, was the most suitable material to line trays and chutes, over which detonators were poured or raked during inspection, etc. Owing to various accidents, suspicion was directed to static risks with felt, and an exhaustive laboratory investigation (30) was undertaken to determine the static risks which were involved in the use of various textiles both in contact with detonators, and as clothing for operatives. Tests employed (Appendix (xii)) included electrical resistance tests at various relative humidities, and also electrification tests, in one of which the detonators (empty) were poured down an earthed metal chute lined on the side with the textile under test. Another electrification test involved insulated operatives carrying out a set of body movements, whilst wearing clothing made from wool or cotton textile. Striking differences were observed in the results with the various textiles, and it was shown that woollen felt and woollen serge gave rise to considerable electrification, far more so than occurred with cotton drill. The tests with woollen and cotton drill overalls indicated that insulated operatives wearing outer clothing of wool serge electrified considerably more than when they wore cotton drill overalls. (Tests with operatives wearing underclothes of various textiles showed no appreciable difference between wool and cotton). Woollen clothing had previously been preferred on all Group I operations because of its greater fire-resistant qualities. In the light of the new findings it was decided that since Group I operations presented a more serious static than fire risk, woollen serge outer clothing and overalls should be banned from Group I and be replaced by fireproofed clothing of cotton drill. As a result of the electrification tests on pouring detonators, referred to above, woollen felt as a lining for chutes, trays and table tops was likewise banned, and replaced by soft earthed conducting rubber.

Difficulty was, however, experienced in obtaining a suitable textile for the packing of detonators. The standard procedure had been to pack the filled detonators for 'export(in a papier mache catch pot, in layers of 25 or 50, separated by pads of woollen felt. After the publication of a report (26) which stressed the importance of individual seating for detonators (especially A.S.A. dets.), the woollen felt pads used were perforated, and so provided a separate and fixed location for each detonator in the container. In view of the undesirable properties of woollen felt, the investigation was further continued to obtain an acceptable replacement for the perforated and unperforated woollen felt pads. The textiles considered included woollen felt rendered conducting by such additions as colloidal graphite and triethanolamine oleate. The latter composition was considered objectionable because of its alkaline character, and the graphite incorporation was not liked both on the score of cleanliness and also because the electrification of detonators poured over the graphitised woollen felt was not appreciably reduced. The low efficiency of the graphite in reducing electrification was attributed to the hairiness of the surface, a factor which also rendered cotton felt unsuitable, when the pressure of the bodies to be earthed was low. Hairiness was also one of the main reasons for rejecting 'fibre-wool' (samples supplied by Courtaulds).

In this connection, the lowest figures for electrification were obtained with a cotton textile (T. Firth A.B.S.) laminated and smooth felted on both sides, and a composite textile consisting of woollen felt faced with smooth cotton drill. The T. Firth material was found to fray badly when cut into discs, and was therefore rejected. The other alternative, in which woollen felt was enclosed in an envelope of cotton drill, was therefore finally adopted. Though a pad of this type did not have such a low electrical resistance as might be desired, the electrification produced by pouring detonators over the surface was so low that the surface was acceptable.

For packing detonators, circular pads of woollen felt sheathed in cotton drill presented little manufacturing difficulties, but similar pads with about 25 perforations, to locate each detonator, proved more difficult. Satisfactory implementation of this idea was finally effected by H.Q.I.O. in collaboration with a trade factory. In these samples the detonator locating holes were neatly sewn around the edges, and the process was capable of mass production. It was proposed to try out these perforated pads on an extended scale to test their durability and performance under factory conditions. In brief, the preferred textile pad for packing detonators, in addition to being soft and resilient, should have a low electrical resistance, a very low tendency to electrify detonators when poured over it (implying a smooth non-hairy surface), and also non-fraying properties when cut or perforated with holes. The most suitable substitute found to date has been the cotton-covered woollen felt.

The use of an outer cotton surface as lining to felt to minimise electrification was also adopted by H.Q.I.O. to speed up the inspection of ZY detonators. Inspection was carried out by means of an 'Inspection book' which consisted of two 6" x 4" cardboard frames each containing a large conducting rubber insert. The frames were hinged together by tape to form a 'book'. The 'book' was lined on the inside with white cotton drill and had a cotton wool cushion between the drill and the conducting rubber to give a degree of resilience. A dish containing 10 detonators to be inspected was placed on one 'cover' of the 'book', which was closed, inverted and opened. After removing the dish the detonators were inspected. The 'book' was again closed, inverted and opened to expose the opposite ends of the detonators. This procedure was rapid and had the advantage of reducing the electrification of the detonators by rubbing on the smooth drill surface.

B.6 (ii) Brushing of loose compositions

Many blows had been reported from time to time during the brushing of sensitive compositions with camel hair brushes. According to time-honoured tradition, this was regarded as the approved method of cleaning catch pots, bench tops, filling machines, etc., contaminated with waste initiator. The electrification associated with the operation of brushing was investigated (31) and (32), and it was experimentally shown that the simple operation of using a camel hair brush to sweep away waste initiators (especially lead styphnate) was an extremely hazardous one - very high charges were acquired by the powder during brushing. Comparative brushing tests were carried out with brushes of standard pattern, but with the camel hair fibres replaced successively by goat's hair, nylon, viscose and graphitised viscose. It appeared, however, that even when earthed fibres of fairly high conductance were used, the operation of brushing produced large electrical charges. The investigation was pursued by testing a 'squeegee' made from T. Firth A.B.S. textile, by the use of which the powder was gathered along rather than brushed. With this type of brush head, the electrification as anticipated, was considerably reduced, but a small scale factory trial showed that the T. Firth material 'held' too much powder and that it soon frayed, and so was not acceptable. No satisfactory replacement for the camel hair brush was found. As a precautionary measure, brushing of sensitive initiators was discouraged whenever possible, and the recommended procedure was to swab waste initiators, preferably with damp cloth or cotton wool, and then to dispose of the contaminated material.

B.6 (iii) Tape for sealing detonator boxes

Attention has been called to the process of tape-stripping from papier mache pots containing detonators, as a source of static electrification. This was based on the visible glow which was observed at the interface when tape is unwound either from a rool or from a paper mache pot.

Special tests showed that an operative stripping white tape either from the roll or from a papier mache pot acquired an appreciable static charge. If the operative was insulated, it was shown that a charge to give a spark of sufficient intensity to ignite A.S.A. detonators could be quite easily acquired in carrying out this operation. Parallel tests with black tape (graphite pigment) showed that the electrification was frequently lowered by a factor of ten or more. No information regarding the difference in chemical composition between the black and white tape was obtained, but the lower electrification and lower electrical resistance of the black tape was believed to be associated with the presence of carbon. Recommendations were made that black tape only should be used in proximity to live detonators, and also that the operatives carrying out the process of tape stripping should be (unconsciously) maintained at earth potential during the operation. This would prevent any risk from induction effects from a charge acquired by the operative.

C. COMPOSITIONS SPECIALLY SENSITIVE TO 'STATIC'

In the main, this monograph is not concerned with the reasons for using specific compositions in service stores. The factories have to adopt methods of handling in accordance with the properties of the materials supplied. However, it is useful to consider any special difficulties in handling, before adopting a new material.

In this connection, brief reference may be made to the exceptional static risks encountered with compositions containing a mixture of insulating crystals, and a conducting material such as powdered aluminium or graphite. In the loose form, the sensitiveness of such compositions to electrostatic sparks is about the same as that of the most sensitive constituent. But when they are pressed, this may lead to the formation of very fine conducting channels throughout the compressed material. Sensitiveness to static is thereby greatly enhanced (11 (40) and (47)) and such compositions should only be recommended if this added risk is worth while for other reasons.

APPENDIX

LIST OF DEFINITIVE SPECIFICATIONS AND METHODS OF MEASUREMENT (WHERE APPLICABLE)

(i) Threshold ignition energy (6a)

In this work the threshold ignition energy is defined as the minimum energy which will give two ignitions per 100 sparks.

The energy E of spark which can be obtained from a charged object depends on its electrical capacity C, and the voltage V to which it is charged, according to the equation $E = \frac{1}{2} C V^2$ (in corresponding units).

The igniting power of a spark depends in a rather complex way on its discharge characteristics, which are controlled by the capacity, voltage, resistance in series with the spark, type of electrode, etc.

To determine the threshold ignition energy, condensers of capacities in the range 20 to 10,000 pF. are variously charged to voltages up to 10,000 volts, and a value is obtained for the minimum energy which can cause ignition in 2 out of 100 trials when the explosive or combustible material under test is placed in the spark gap. This minimum energy is the value obtained with electrode shape, series resistance, etc., most favourable to ignition. Tests have shown that 2% ignitions is the lowest probability which can be conveniently measured by the technique adopted (31).

The choice of 0.02 joule as a critical value, so that threshold ignition energies greater than this are said to require only First Degree Risks, and below this require the more stringent Second Degree Risks, is based on the following considerations:- The largest 'moveable conductor' not earthed under First Degree precautions, in most shops, is the operative himself. Under British conditions of climate an operative is unlikely to become charged to more than 10,000 volts. Since the average capacity of operatives is about 400 pF. it is clear that the maximum energy of a possible spark from any operative is not likely to exceed 0.02 joules. If, therefore, the experimentally determined threshold ignition energy for a composition lies well above 0.02 joules, no risks arising from the electrification of the operative himself or from any moving conductor of smaller capacity need be considered (First Degree Risks). If, however, the threshold ignition energy lies below 0.02 joules, the electrification during every stage in its handling, as well as the electrification of the operative, should be surveyed in detail. (Second Degree Risks). The division at 0.02 joules is convenient and gives a reasonable, practical figure, but it may need modification in other parts of the world with exceptionally dry or exceptionally moist climates.

(ii) Maximum permissible resistance to earth of grounded metal conductors

(Extract from I.E.E. Regulations 1946).

"The electrical resistance of the earth continuity conductor, including metal conduits, the metal sheathing of cables (other than those used in earthed concentric wiring), together with the resistance of the earthing lead, shall, when measured from the connection with the earth electrode to any other position in the completed installation, not exceed ONE OHM."

(iii) Conducting Rubber. Specification for permissible resistance values (Ministry of Supply Specification)

"The whole of the rubber and the solution for fixing is to be a conductor of electricity. A carbon black such as lamp black is to be used - a metallized loading will not be acceptable.

The conductivity is to be measured on a sample 6-in. x 3-in. of the required thicknesses of the sheeting by placing a 3-in. x 1/2-in. wide electrode at one end on the upper surface of the rubber and another at the opposite end but on the under surface.

The weight of the electrodes on the rubber should be 8-oz. at each end of the sample, and it is suggested that 4 brass bars 3-in. x 1-in. x 1/2-in. having an inherent weight of 8-oz. each should be used. Two of these can serve as electrodes, and the other two should be suitably insulated from the rubber.

An identical test is to be made on a similar sample on which conducting solution has been applied to both bottom and top surfaces.

In both tests the resistance between the two electrodes when measured with a 500 volt megger must not exceed 20,000 ohms."

(iv) Conducting linoleum - Provisional acceptance specification (19)

Electrical performance - Laboratory tests

The jute backing to be stripped off a piece one yard square.

(1) Surface resistance

One brass electrode 4" long 1" wide to be pressed down under a 7-lb. load near one side of the square, and a similar electrode to be pressed near the opposite side.

The resistance between these electrodes measured with a 500 volt megger is not to be above 2 megohms or below 1/4 meg.

(2) Transverse resistance

One 4" square electrode to be placed under the linoleum in the middle of the square, and the other electrode on top under a 13-lb. load.

Resistance between these electrodes measured as above not to lie above 2 megohms or below 1/2 meg.

Electrical performance - Factory test

These performance tests cover not only the quality of the linoleum but also the efficiency of laying, including the conducting properties of the conducting paint and conducting adhesive (20) used in the laying.

On floors. A barefooted operative standing at any point on the floor to have a total resistance to earth not exceeding 2 megohms and not less than 1/4 meg.

In place of the operative a single flat brass electrode 4" x 4" total weight not exceeding 13-lb. may be used.

If conducting shoes are worn in the test, the leakaway resistance when standing on an earthed metal plate to be subtracted from the leakaway resistance when standing at any point on the floor, and the difference not to exceed 2 megohms or to be less than 1/4 meg.

On tables. A single flat brass electrode 4" x 4" total weight not exceeding 4-oz. placed anywhere on the earthed conducting linoleum on the table to have a resistance to earth not exceeding 2 meg.

Acceptance for wear. No simple acceptance test can be laid down, but it must be made clear to the manufacturer that the wearing properties should be similar to those of ordinary linoleum.

(v) Anti-static Conducting Varnish and adhesive, for use in the laying of conducting linoleum (20)

The jute backing of the linoleum is painted with the conducting varnish and allowed to become tacky. The floor over which metal earthing tapes (2 thou. thick) have been placed is covered with a thin layer of the conducting adhesive, and the primed linoleum is then pressed down on to the adhesive, to ensure complete contact, and allowed to dry.

Conducting Varnish:	Low oil absorption vegetable black	27	parts	by	wt.
	Pool oxidised Bitumen Grade A	40	"	"	"
	Solvent naphtha	33	"	"	"
Conducting Adhesive:	Low oil absorption vegetable black	28	"	"	"
	Pool Bitumen 60-80 penetration	54	"	"	"
	Solvent naphtha	18	"	"	"

Manufacture. The bitumen is dissolved in the solvent naphtha and the vegetable black incorporated by milling.

(vi) An anti-static oil dressing for use on conducting linoleum (19)

Continued use on conducting linoleum of the usual R.O.F. oil dressing caused a progressive increase in its electrical resistance, and a new oil dressing was evolved, having the following specification:

0.5 cc. of a 5% solution of "perminal W" (a surface active sodium naphthalene sulphonate) in water.

99.5 cc. mineral oil CS.1436A.

Mix thoroughly, and then allow to settle. Decant from bottom layer if slight separation occurs.

(vii) Permissible resistance to earth of operatives wearing approved conducting footwear (14)

The electrical resistance to earth of an operative wearing approved conducting footwear, and standing on an earthed flat metal plate should not exceed 1 megohm. A minimum permissible resistance of about 1/4 megohm would also be desirable to avoid any fire risk through short circuiting to earth of broken electric leads, etc.

The "personnel testers", installed near the initiator buildings, consisted of a small d.c. battery with one terminal joined to a micro-ammeter and the other to a metal platform. The operative stood on the platform, and, by grasping a brass handle, completed the electrical circuit.

The microammeter scale was calibrated to read directly in megohms. Note:- These 'personnel testers' were, however, not introduced as fully as they might have been, mainly due to a lack of attention to the battery, etc., required to operate them. A.C. voltage with a step down transformer and rectifier would have been more suitable than a d.c. battery and should normally be used.

(viii) Specification of the permissible resistance of approved conducting belting (8)

This specification has been calculated on the assumptions

(a) the development of a potential of not more than 250 volts anywhere on the conducting belting, is permissible;

(b) the maximum charge on any surface in air is 2.6×10^{-9} coulombs/sq.cm. (5).

It is usually convenient to measure the resistance R_s over a 2 ft. length or the belt strip; if L is the distance in feet between the contact points made by the belt on the pulleys (approximately the distance between pulley centres), and R is the resistance of the whole belt from one pulley to another.

$$R_s = 2R/L$$

(assuming contacts between pulleys and belt approximate to that between belt and electrodes in the specification resistance test).

The general formula for R_s is

$$R_s \ngtr 3/W \text{ megohm}$$ for flat belts

The general formula for R_s is

$$R_s \ngtr 15/W \text{ megohm}$$ for Vee belts

where W = width in inches of belt touching the pulley surface, i.e.,

for flat belts W = width of belt in inches
for Vee belts W = sum of the lengths in inches of the 2 sides of the belt.

For friction surface type of belting, the material must be homogeneous throughout the thickness, so far as electrical conductivity is concerned, so as to be satisfactory even when the surface layers have worn away. For the envelope type of belting the envelope must be homogeneous throughout the thickness so far as electrical conductivity is concerned and the thickness of this envelope shall at no part be less than 1/32nd of an inch.

Method of measuring R_s

(i) The test belt must not have the ends joined but must be cut so as to form a single strip, 24 inches or more in length.

(ii) The temperature of measurement must be between 15° and 20°C.

(iii) Before testing, the surfaces to be thoroughly rubbed with a clean dry cotton or linen cloth.

(iv) Two electrodes to be used, 24 inches apart.

(a) For flat belts:- Electrode of flat strip brass, 1/2" wide, 1/4" thick, length of strip sufficient to overlap the edges of the belt. Both electrodes to make contact on the same side of the belt, which is that touching the pulleys.

(b) For Vee belts:- Electrodes bent out of brass strip, 1/2" wide, to fit the Vee snugly round the two sides, but of sufficient depth to leave the base of the belt clear.

(v) The weight on each electrode to be 3-lb. dead load for every inch length of the belt strip making actual contact with the brass.

(vi) The D.C. resistance between these electrodes to be measured on a 250 volt or 500 volt 'megger'.

(vii) Keeping the separation of the electrodes constant at 24 inches, the mean resistance for six independent positions of the electrodes on the sample of finished belt should be taken. A toleration of 10% above the calculated value of R_s may be allowed before the belt is rejected.

Note: These values are based on the following considerations:

The area of belt freshly exposed per second (on the side making contact with the pulley) is

$WU \times 12 \times (2.54)^2/60$ sq.cm. where

W = width of the belt in inches

U = linear velocity of belt in ft./min.

Thus the maximum leakaway current is

$$WU \times 12 \times (2.54)^2 \times 2.6 \times 10^{-9}/60 \text{ amps.} = 3.35 \times 10^{-9}\, WU \text{ amps.}$$

If the voltage is not to exceed 250 volts, the resistance R to earth from any point on the belt must not exceed

$$250/3.35 \times 10^{-9}\, WU \text{ ohm}$$

i.e., $R \not> 7.5 \times 10^4/WU$ megohm

Substituting for R as above, the maximum permissible resistance R_s is given by

$$R_s \not> (1.5 \times 10^5)/WUL \text{ megohms}$$

where W = width of belt in inches

U = velocity of belt in ft./min.

L = total length in feet of belt from pulley to pulley.

According to D.F.F. (E. & S.) for flat belts, the UL product can be assumed not to exceed 50,000, i.e., the velocity would be unlikely to exceed 3,000-ft./min. at a pulley separation of 17-ft. This gives the general formula quoted above for flat belts. For Vee belts the UL product will rarely exceed 10,000. This gives the approximate formula as above.

(ix) 'Wetting' solutions for laying dust (21)

The solution which is recommended for wetting cloths for swabbing waste initiators, etc., and for laying under the aluminium catch pots in the sieving of lead styphnate has the following composition:

Glycerine 20%; water 79.8%; saponin 0.2%.

Saponin is included to increase the wetting power, and glycerine prevents chance drying of the cloths in a hot atmosphere.

The use of a damp cloth minimises risks of local initiation of the layer of dust by mechanical or electrical means. This depends on the 'wetting' of the dust by capillary action, which prevents propagation. In support of this, tests show that explosions propagated in dry layers of dust were stopped dead on reaching cloth damped as prescribed, even when this was thickly spread with styphnate dust. (21).

The contaminated cloth with its adherent dust layer should be deposited in a vessel containing 60% nitric acid for 24 hours, to decontaminate from waste explosive. It can then be washed and either used again or destroyed.

(x) Wet and dry bulb thermometers for anti-static use

References: Hygrometer Tables (M.O.265, H.M. Stationery Office, 1943, Price 1/-). Discussion on hygrometry, London, 1921. The Physical Society of London. S.I.D.B. 837/I/1(a).

The relative humidity is defined by the expression:-

R.H. = 100 x/y where x = actual partial pressure (in millibars) of water vapour in the air.

y = saturation partial pressure (in millibars) of water vapour at the air temperature.

(Data obtainable from standard tables).

Anti-static precautions are concerned with relative humidity, because this controls the film of absorbed moisture which hastens the leakaway of static charges.

Plots of leakaway resistance against relative humidity for various insulators show a rapid decrease of resistance, usually at between 60 and 70 per cent. relative humidity. The figure of 65 per cent. is a compromise value, having regard to stability requirements of many explosives, physiological considerations, and experience of what can be maintained by fairly simple means. Exceptional cases may arise where this figure should be adjusted on the basis of resistance measurements and any other considerations.

Wet and dry bulb thermometers are merely an empirical means of estimating the relative humidity. The readings have no value unless they can be reliably correlated with relative humidity. Various experimentalists have shown that the correlation formula

$$x = f - A(t - t') \quad \ldots\ldots \quad \text{I}$$

gives reliable results, provided the factor A is correctly chosen.

f = saturation partial pressure (in millibars) of water vapour at the wet bulb temperature

A = factor for the air speed past the wet bulb

t and t' are the temperatures °F. of the dry and wet bulb thermometers respectively.

(1) Limiting Ventilation

Assmann and others have shown that within the range 0 - 5 m.p.h. the depression of the wet bulb thermometer is sensitive to changes in air speed passing over the bulb, but for speeds between 5 and 90 m.p.h. the depression of the wet bulb is the same as at 5 m.p.h.

Accurate measurements of relative humidity therefore require the maintenance, artificially if necessary, of an air current greater than 5 m.p.h.

Assmann devised an instrument in which air is drawn at a speed greater than 5 m.p.h. over the wet bulb, and drew up tables. Almost identical values are obtained by using a whirling hygrometer (U.S. Weather Bureau Tables).

(2) Less efficient ventilation

When determinations of relative humidity are required in rooms where the air velocity may be less than 5 m.p.h. a more convenient but less accurate method than the use of a whirling hygrometer is to use stationary wet and dry bulbs and to introduce into formula I (above) varying values for the factor A, adapted to different degrees of ventilation. Pertner has revised Jellinek's Tables (the official tables of the Austrian Meteorological Service) and gives 3 values of the factor A, for the following air speeds:

"Calm Air"	0 - 0.5 meter/sec.	A = 0.667	for temper-
"Light Air"	1 - 1.5 meter/sec.	A = 0.444	atures
"Limiting Ventilation"	over 2.5 meter/sec.	A = 0.364	above 32°F.

The effect of using these 3 factors for the same data is illustrated below by an example:

Dry Bulb Temperature 74°F. Wet Bulb Temperature 59°F.

Relative Humidity using	A = 0.667	("calm air") = 25 per cent.
" " "	A = 0.444	("light air") = 36 per cent.
" " "	A = 0.364	("limiting ventilation") = 40 per cent.

For estimating static risks it is safer to use the value of 0.667 for the factor A, ensuring that the calculated value of the R.H. is a lower limit. The actual relative humidity in ordinary rooms (no draughts) probably lies somewhere between the value as calculated for "calm" and "light" air.

Notes on the use of a wet and dry bulb thermometer

(1) The muslin or cambric around the wet bulb should be first washed to remove size and must be kept clean.

(2) The muslin must be kept moist by the addition of distilled water only.

(3) The instrument should be suspended in a central position if possible, and away from all draughts, heating panels, windows, etc., if the formula for "calm" air is to be used.

Use and calibration of hair hygrometers. Zero setting

The hair hygrometer should be suspended in a draughtless room for not less than 60 minutes to reach a state of equilibrium. The R.H. should be determined in this room by means of a whirling hygrometer (using the limiting ventilation tables to compute the value). The zero of the hair hygrometer should then be adjusted so that the instrument reads this value. Zero setting must be done every 2 or 3 months.

Scale reading: The reading of the hygrometer should be determined at one other humidity measured in the same way to check the scale.

SAFETY TABLE FOR ANTI-STATIC PRECAUTIONS

Where other humidity requirements can be regarded as subsidiary to anti-static precautions, the Table A gives the maximum permissible difference between wet and dry bulb thermometers to promote effective leakaway of static.

(xi) Method of determining the moisture content and electrical resistance of sawdust (24)

The following procedure was standardised to measure the electrical resistance and moisture content of any sawdust in an attempt to correlate electrical resistance with moisture content.

Preparation of saw of known moisture content

The sawdust as received for test was first dried to constant weight in an oven at 60°C. To make up a mixture of required moisture content for the resistance tests, about 6 oz. of the dried sawdust was weighed in a small enamelled pan, and the calculated weight of water sprayed from a counterpoised wash bottle. The mixture was then intimately hand mixed in the pan for about 15 minutes, given a final mix in a porcelain ball mill for 3 hours, and allowed to stand overnight to permit any absorption of water to be completed. After removal from the ball mill, its resistance was determined as described below, and a weighed amount (about 2 oz.) freed from moisture by baking at 60°C. to give a check analysis. These analyses agreed to within 0.3% and the mean value calculated from the amounts of water and sawdust initially mixed.

Filling box for measuring resistance with sawdust at required bulk density

A metal (tin plate) disc 14 cm. diameter fitting on the bottom of a circular papier mache container 15 cm. diameter and 2 cm. deep formed the earth electrode (Fig. 2). An 8 B.S.S. mesh copper gauze supported rigidly in a 20 cm. diameter papier mache ring 1 inch deep was laid over the container, and the sawdust was introduced through the mesh until the box was full. The mesh was then removed - this procedure ensured a reproducible filling of the sawdust to the same (low) bulk density of about 0.25 gm./cc.

Measurement of resistance

The insulated electrode, a circular steel disc, 10 cm. diameter, thickness 2 mm. and weighted to 1 lb. was gently placed centrally on the sawdust (Fig. 1). For measuring high resistance (> 100 megohm) with dry sawdust, this electrode was joined to the Lindemann electrometer. With lower resistances, a H.T. battery and microammeter was used.

A plot of the data obtained with a sample of sawdust in use at R.O.F. Bridgend in December 1944 is given in Fig. 3.

The moisture content of sawdust with optimum cleaning properties was discussed in another report (25), and a value of about 16% moisture was suggested. This sawdust would have a resistance of about 10 megohms, in the test described here.

An additional resistance test was carried out with the 16% sawdust. A single detonator sheath was used instead of the upper electrode, and the resistance to earth of this detonator measured. The resistance was found to be 1,000 megohms.

Assuming a capacity of 4 e.s.u. for the detonator (30), any charge on it would be reduced to 1% of its value in about 0.02 seconds with this resistance. This time of leakaway should permit a safe dissipation of static during rumbling.

Specification:-

To test further samples of sawdust of this type, it would be sufficient therefore to determine either (i) the moisture content (preferred value 16%), or (ii) to determine the electrical resistance as described in this test (preferred value about 10 megohms). These values would be acceptable both for adequate cleaning and for dissipation of static charges.

If at any time the nature or origin of the sawdust used was substantially changed, the complete sequence of above tests should be carried out to make sure that the specified moisture of 16% (± 2%) still gave acceptable resistances.

(xii) Methods of determining the electrical resistance and the electrification produced by various textiles (30)

Methods are illustrative and for comparison between different textiles, and alternative procedures are not necessarily excluded.

(a) Resistance measurements

Samples of the textiles to be tested were cut into pieces sufficiently large to cover the surface of an electrode approximately 17 sq. ins. in area. An upper electrode of equal area was pressed down on the cloth, and the resistance between the two electrodes determined firstly under the weight of the upper electrode (4 oz.) and then under an applied load of 13 lb. The measurements were carried out with a Lindemann electrometer and standard capacities for resistances > 100 megohms, and with a H.T. battery and microammeter for lower resistances.

Owing to the pronounced effect of relative humidity on the experimental values of the resistances, all the samples were first exposed for several days in desiccators of controlled humidity at 20°C.

R.H. 1% - conc. H_2SO_4

R.H. 44% - over satd. K_2CO_3 $2H_{20}$

R.H. 70% - 33% H_2SO_4

R.H. 79% - sat. NH_4Cl

Measurements were carried out with the samples as soon as they had been removed from the atmosphere of controlled humidity.

(b) Electrification measurements

(1) Electrification of operative. Measurements were made of the maximum charge developed during various movements by an operative, wearing different types of Ordnance Factory clothing.

The operative wore a suit of the material under test after it had been oven dried at 60° for 3 hours to ensure that the maximum charge was registered. Leakaway of charge was minimised by the operative wearing thick crepe soled shoes. The following is a list of the tests which were carried out, and in which the charge generated on the operative was measured by means of the electrometer and capacities in parallel:

(i) rubbing sleeve on varnished wood (5 rubs up and down)

(ii) rubbing sleeve on smooth line (10 rubs up and down)

(iii) rubbing sleeve on painted metal screen (insulated) (10 rubs up and down)

(iv) stroking sleeve of coat with palm of hand (carried out by 2nd operative)

(v) rubbing sleeve with papier mache box (carried out by 2nd operative)

(vi) rubbing back of coat with palm of hand (carried out by 2nd operative)

(vii) rubbing back of coat with papier mache box (10 rubs).

With the white woollen serge suit, charges of over 1,300 e.s.u. were acquired in some of these tests.

(2) Electrification of detonators in rubbing over textiles. Various operations in R.O.F. procedure involved the sliding or pouring of detonators over cloth. To obtain comparative information on the electrification produced with various textiles the following test was devised: The detonator shells were poured from an earthed metal pot down an earthed metal chute 9" long, inclined at 40° to the horizontal. The various textiles, successively clipped on to this chute so as to cover it, made a V shaped channel for the sliding detonators. The total charge on up to 200 detonators at a time was determined by catching them in an insulated metal catchpot of known capacity after they had slid over the textile. In these, as in all experiments with textiles, it was essential to carry out the experiments after each textile had been humidified to the same extent.

(xiii) Fire-proofing of textiles

One of the objections made to oppose the replacement of woollen clothing in Group I operations by the more acceptable anti-static cotton wear was the greater liability of cotton textiles to burn, thereby increasing the fire risk.

Specification:-

To overcome this, cotton textiles to be fire-proofed after washing, by soaking in a solution containing 1% borax - 1% boric acid, and then dried.

(xiv) Proposed Specification for Conducting Bakelite (51)

(i) The volume resistivity shall not exceed 250 ohms per c.c.

(ii) The surface resistivity shall not exceed 2,000 ohms per centimeter square when determined under the conditions given below:

The test piece shall be a moulded disc not less than 4 inches in diameter and 0.25 ±, 0.010" (6.35 ± 0.25 mm.) thick.

The test piece shall be moulded in either a flash or a positive mould with a moulding pressure of 1-2 tons per sq. in. (158 - 315 Kg. per sq.cm.), the mould temperature being not greater than 330°F. (166°C.).

The test piece shall be moulded for 8 minutes, and shall be tested, after conditioning as specified below.

Conditioning

The test piece shall be conditioned by placing it direct from the mould over calcium chloride in a desiccator where it shall remain for a period of 4 hours. It shall be tested (if possible) in this atmosphere, or in any case, within 3 minutes of removal from it.

Electrical tests

The following tests shall be carried out on each specimen:

(i) Volume resistivity

This test consists in applying a known voltage across the specimen when set up with the electrodes and guard ring as shown in Figs. 4 and 6, measuring the resulting current (I) and calculating the resistance (R) from the expression $R = V/I$.

The volume resistivity is given by Ra/Lo, where Lo is the thickness of the specimen in cms. and a the area under the upper electrode (in sq. cms.) and R is the resistance in ohms. The volume resistivity can be expressed in ohms for a centimeter cube (ohm- cm. cube).

(ii) Surface resistivity

For determining the surface resistivity, the apparatus used is the same as in the test for volume resistivity, but the connections are modified as shown in Fig. 5. The current which passes through the ammeter is that which flows over the surface of the material across the annular gap between the guard ring and the inner electrode (a certain amount of the current so measured will have passed through the body of the material).

The surface resistance (S) of the specimen is found by dividing the voltage by the current as before.

Where r_2 = ext. radius of annular gap, and r_1 = internal radius of annular gap, the following approximate formula suffices for the calculation of the surface resistivity (s) provided that r_1 is much is much greater than $(r_2 - r_1)$,

$$s = \frac{\pi S (r_2 + r_1)}{r_2 - r_1}$$

Since $r_2 - r_1 = 1$ cm. in the case of the electrodes specified above, it follows that for these electrodes

$$s = CS$$

where C = mean circumference of the electrodes.

General Conditions

(1) The source of E.M.F. shall be a 2 volt accumulator.

(2) The difference of potential across the electrodes shall be measured during the period of test by a voltmeter accurate to $\pm$ 0.05 volts and the reading so obtained shall be used as the value of V in the equation $R = V/I$.

(3) The measurement of the current (I) shall be accurate to $\pm$ 10% and shall be the minimum recorded during a testing time of 30 seconds.

Experimental details

For rapidity in handling large numbers of test pieces, the combined circuit given in Fig. 7 may be utilised. For this purpose a 3 pole, 2 way switch is required, the insulation properties of which must be good enough to provide a negligible leakage path for the current during test. The leakage of current through the switch should be less than 1% of the current through the test piece.

The voltmeter should be of the high resistance type, and the 2 volt accumulator should preferably be of at least 40 amp. hour capacity. The ammeter should have a low resistance; its maximum scale reading will depend on the resistivity of the specimen, but normally need not exceed 2 amps. For materials approaching the limiting value a more sensitive meter will be necessary.

Illustration

The currents through the ammeter for the maximum allowable resistivities of the specimen, with the electrode dimensions (see Fig.6) and condition given are obtained as follows:

(a) Volume resistivity

Maximum allowable value of volume resistivity 250 ohms per cm. tube.

Area of specimen under top electrode (for dimensions see Fig. 6) = 19.64 sq.cm.

Thickness of specimen = 0.635 cm.

Maximum resistance as measured = $\frac{250 \times 0.635}{19.64}$ = 8.08 ohms

Assuming E.M.F. of 2 volts, minimum allowable current = 0.25 amps.

(b) Surface Resistivity

Maximum allowable value of surface resistivity 2,000 ohms per cm. square.

Mean circumference of the electrodes = 28.27 cms.

Maximum resistance as measured = 2000/28.27 = 70.7 ohms.

Assuming E.M.F. of 2 volts, the minimum allowable current = 28 milliamps.

Note: The method of testing given follows closely that proposed in B.E.A. I.R.A. Technical Report (reference B/S3) 1935, B.S.S. No.488 - 1933 and B.S.S. No.771 - 1938, which is understood to be in common use for the electrical testing of plastics. Certain modifications are necessitated by the very different electrical properties of conducting plastics as compared with those for which the E.R.A. and B.S.S. tests were designed by the general layout has been found satisfactory for the present purpose.

ACKNOWLEDGEMENTS

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REQ.ⁿ Nº T 342.	CHECKED BY	
DRAWN BY:-	APPROVED BY:- W.O.E. THOMAS	
TRACED BY J.W. Price	PASSED BY:- [illegible]	FOR C.S.A.R.

LOWER LIMIT RELATIVE HUMIDITIES (FOR ANTISTATIC PRECAUTIONS ONLY)

TEMPERATURE DIFFERENCES FOR "WET" & "DRY" BULBS °F..	DRY BULB READINGS °F 80°	75°	70°	65°	60°	55°	50°	45°	40°	35°
1	95·0	95·0	93·8	93·5	92·8	91·4	90·5	88·8	88·4	86·0
2	89·8	89·0	87·9	87·5	85·7	84·0	81·8	79·5	76·9	73·5
3	84·8	84·0	82·0	81·0	78·5	76·3	73·2	70·0	65·4	59·4
4	80·0	79·0	76·1	74·2	71·4	68·0	64·5	59·0	54·2	
5	75·3	73·5	70·7	68·3	64·7	61·0	55·8	50·0	42·4	
6	70·5	68·2	65·4	63·0	57·8	53·0	47·1	40·5	30·9	
7	65·8	63·5	59·9	56·5	51·0	45·5	38·5	30·5	20·6	
8	61·3	58·2	54·4	50·5	44·4	38·2	30·5	21·6		
9	56·9	53·8	49·0	44·5	37·9	31·5	22·0	12·2		
10	52·6	49·0	43·9	39·0	31·8	24·0	14·0			
11	48·2	44·0	38·9	32·8	25·3	16·2				
12	44·0	39·5	33·8	27·1	19·2	ONLY RELATIVE HUMIDITY VALUES				
13	39·8	35·0	28·8	21·5		ABOVE SAFETY LINE ARE CONSIDERED				
14	35·6	30·5	23·8	16·0		ADEQUATE FOR ANTISTATIC				
15	31·7	26·2	19·1	11·0		PRECAUTIONS.				
16	27·8	22·0								

TABLE A.

NOTES FOR USE OF TABLES

1. THERMOMETERS TO BE PLACED IN DRAUGHTLESS CENTRAL SITE. "CALM AIR"
2. MUSLIN AROUND WET BULB TO BE BOILED AND WETTED WITH DISTILLED WATER ONLY
3. FIGURES GIVE A LOWER LIMIT TO PREVAILING HUMIDITIES AND ARE FOR ANTISTATIC USE ONLY
4. FOR DRY BULB TEMPS INTERMEDIATE BETWEEN ANY PAIR OF COLUMNS, THE RELATIVE HUMIDITY SHOULD BE CALCULATED FROM EACH OF THESE TWO COLUMNS, AND THE FINAL RESULT OBTAINED BY INTERPOLATION

ILLUSTRATION

DRY BULB 63°F DIFFERENCE 8°F

RH FOR 65°F & 8°F DIFFERENCE = 50·5%

RH FOR 60°F & 8°F DIFFERENCE = 44·4%

∴ INTERPOLATED VALUE = 48·0%

A.R.D. MONOGRAPH Nº 15351.

METHODS OF OVERCOMING DANGERS FROM ELECTROSTATIC CHARGES IN FILLING FACTORIES.

DRG. Nº A.R.D. 8220

SHEET 3 | 3 SHEETS

15-10-46

FOR C.S.A.R.

VARIATION OF ELECTRICAL RESISTANCE OF SAWDUST WITH MOISTURE CONTENT.

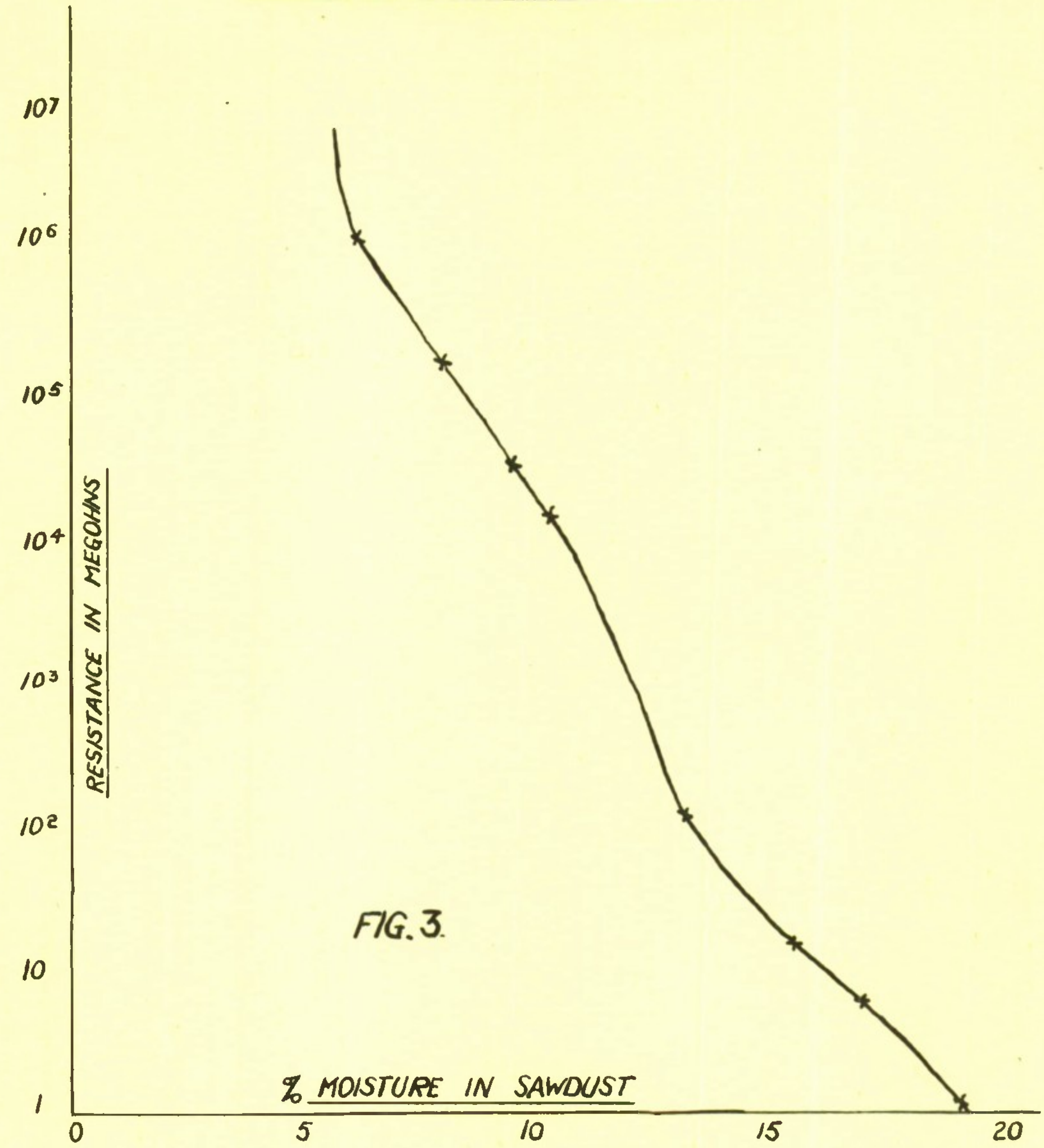

FIG. 3.

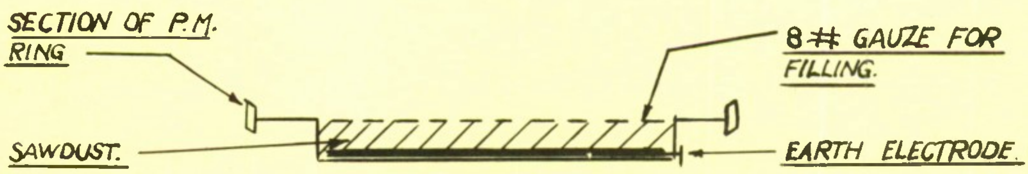

FIG. 2.

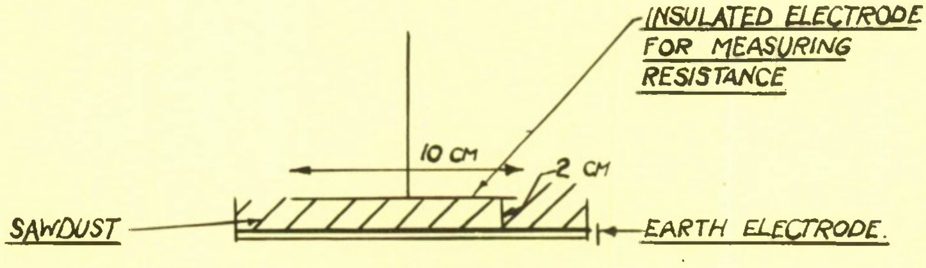

FIG. 1.

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TRACED BY:- | PASSED BY:-

A.R.D. MONOGRAPH No. 15351

METHODS OF OVERCOMING DANGERS FROM ELECTROSTATIC CHARGES IN FILLING FACTORIES.

DRG. No. A.R.D. 8220.

SHEET 1. 3 SHEETS.

15. 10. 46.

FOR C.S.A.R.

APPARATUS FOR PROPOSED SPECIFICATION TESTS WITH CONDUCTING BAKELITE.

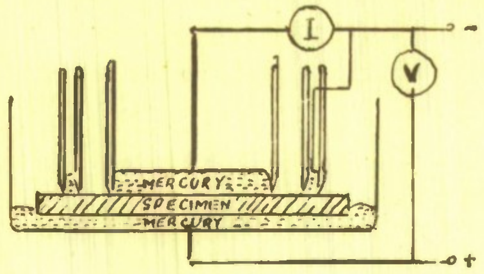

FIG. 4 VOLUME RESISTIVITY TEST

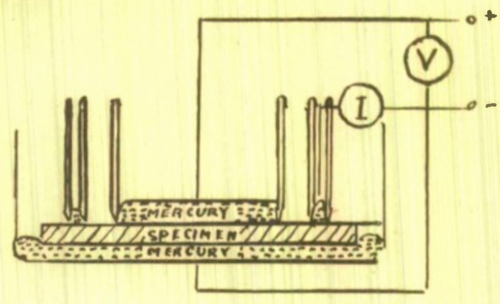

FIG. 5 SURFACE RESISTIVITY TEST

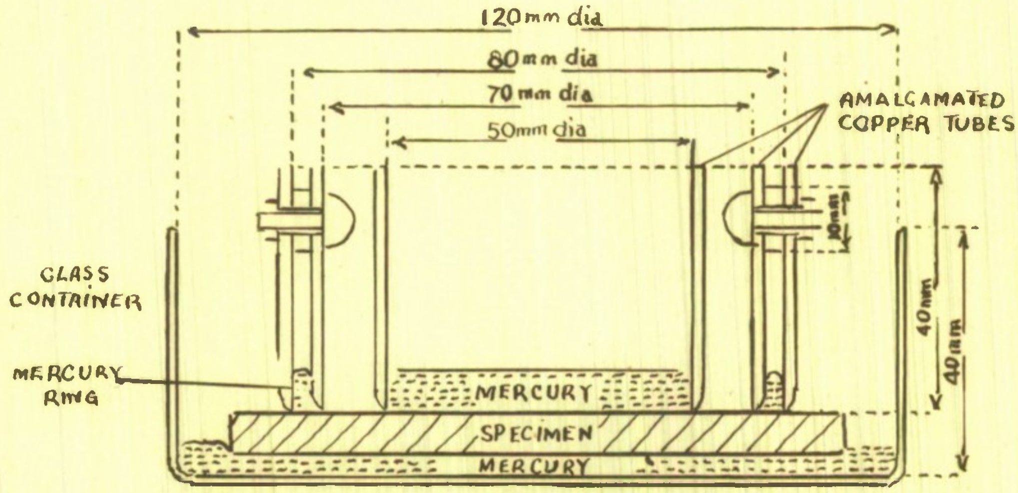

FIG. 6 FORM OF APPARATUS.

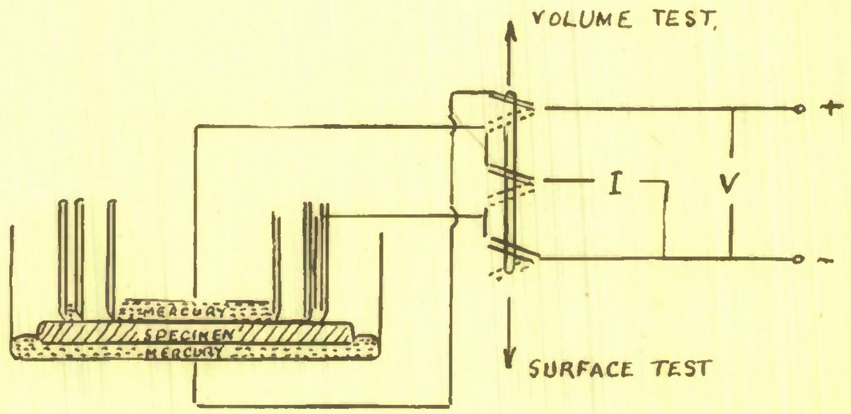

FIG. 7 COMBINED TEST CIRCUIT

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CHECKED BY:-
PASSED BY:-
APPROVED BY:- W.D.E. Thomas

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METHODS OF OVERCOMING DANGERS FROM ELECTROSTATIC CHARGES IN FILLING FACTORIES.

DRG. No A.R.D. 8220.
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15-10-46

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S(G)6	Conducting Bakelite. Progress Report.	A.R. Boyle & G.F. Claringbull
S(G)7	The Electrical Resistivity, static electrification and incendivity to electric sparks of magnesium powder.	A.R. Boyle & G.F. Claringbull
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S(G)22	The electrostatic ignitibility of acaroid resin.	A.R. Boyle & F.J. Llewellyn

S(G)23	The electrostatic ignitibility of calcium silicide.	A.R. Boyle & F.J. Llewellyn
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The Departmental Information Officer,
Armament Research Department,
Fort Halstead,
Nr. Sevenoaks,
Kent.

KEY TO SYMBOLS AND ABBREVIATIONS

Reference letters to Sections

Each major section has been given a principal reference letter, A, B, C, etc. ....

These sections are divided into sub-sections, e.g., A.1, B.3 and so on, and where further sub-division is convenient this is indicated by a further number, e.g., B.3 (ii) and so on.

References to Reports

These are given in the text as numbers in brackets, e.g., (17), which refer to the Bibliography.

Symbols used in the Appendix

E	Energy of a static spark
C	Electrical capacity of a conductor or system of conductors
V	Voltage
pF	Electrical capacity in picofarads (10^{-12} farads)
I	Current flowing
Rs	Electrical resistance, e.g., of a length of belt surface
R	Total electrical resistance of a belt between two pulleys
a	Area under electrode
L	Distance in feet between the contact points made on the belt by the two pulleys
Lo	Thickness of sample
W	Width of (flat) belt in inches <u>or</u> sum of lengths of two sides of Vee belt
U	Velocity of belt in feet/min.
RH	Relative humidity
x	Actual partial pressure (in millibars) of water vapour in the air
y	Saturation partial pressure (in millibars) of water vapour in air at the air temperature
f	Saturation partial pressure (in millibars) of water vapour at the wet bulb temperature
A	Constant
t	Temperature (°F.) of dry bulb thermometer
t^1	Temperature (°F.) of wet bulb thermometer
$r_1 r_2$	Radii of annular gaps
s	Surface resistivity
S	Surface resistance
c	Circumference

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