Deterioration of Radio Equipment in Damp Tropical Climates and Some Measures of Prevention*

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ABSTRACT. The effects of damp tropical conditions on the materials and components used in radio apparatus are described. Difficulties encountered with radio signals equipment under the severe field service conditions of the Pacific War are outlined. Deterioration due to moisture and organic growths and means for avoiding such deterioration are dealt with, as well as laboratory methods for testing the suitability of materials for damp tropical use.

1—Introduction

The conditions of climate, transport, and storage, to which large quantities of radio-communication equipment have been subjected during the past three years, are without precedent in the history of radio communication. Storage of this equipment for relatively long periods with an average relative humidity of 90 to 100 per cent and temperatures ranging between 75° and 100°F. was a condition not previously envisaged in ordinary peace-time manufacture. Other conditions, such as long-distance marine and air transport, temporary subjection to salt spray, rain, water immersion, and tropic sun, have not only brought about direct failure of equipment, but have greatly accelerated the deterioration normally caused by the atmosphere of damp tropical regions.

In the year 1942, many of the problems arising out of these conditions were new to the manufacturer of radio-communication equipment throughout the world ; his tropical problems of the past were not parallel. In consequence, radio equipment designed and produced to standards of performance and endurance which had proved satisfactory in both temperate and dry tropical climates found its way into damp tropical areas. As a result of this complaints were received, late in 1942, of deterioration of equipment in the damp tropics. In common fairness to the radio-communication industry, it should be pointed out that such complaints were in no way confined to radio apparatus but to many materials and other complex equipment. Nor were they confined to manufactures from any particular country.

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It is interesting to reflect that when the tomb of King Tutankhamen, in the Valley of the Tombs of the Kings at Thebes, was opened in 1922, the first time after 4,000 years, linen shawls cast over the gold and silver treasures were still recognisable, loaves of bread on palm fibres and bouquets of flowers, were sufficiently preserved to be identified, while it took just 30 days in a damp tropical atmosphere to produce the evidence of decay, shown in figure 1. This shows a startling contrast between the effects of dry and humid atmospheres.

Under damp tropical conditions, most organic materials must be regarded as perishable. Materials that are relatively stable in temperate climates may decay like food stuffs in the damp tropics, though rarely as rapidly. Food stuffs are normally regarded as perishable materials in any climate and measures for their protection, such as hermetic sealing and refrigeration, are common. Under those measures the normal growth of moulds and bacteria which promote decay are discouraged and the chemical actions which promote decay are retarded.

Hermetic sealing is a proven means of protection and obviously should be applied as widely as practicable to components and complete equipments for damp tropical use. At the same time, any small leakage in an otherwise sealed container can set up conditions within the container more detrimental for the enclosed materials than an open ventilated construction. Consequently, components in equipment which is originally fitted in a hermetically sealed container should be, themselves, suitable for tropic exposure as a second line of defence.

This paper is a summary of observations most of which result from research carried out in the laboratories of Amalgamated Wireless (Australasia) Ltd. The work was done as part of a joint effort in co-operation with other laboratories, particularly National Standards Laboratory, Sydney, during the war, when the need was urgent. Field reports and examinations of items of equipment returned from service from time to time, and field liaison supplied by Australian and U.S. Forces, have helped to direct the research. The methods of protection suggested in this paper are not put forward as the best or the only means of protection, but as those developed to suit manufacturing and supply conditions at the time, when the supply position was particularly bad and when the need was urgent.

The aims of the research were :—

1. The development of testing technique for damp tropical conditions,
2. Finding what materials were unsuitable for damp tropical use. with a view to their elimination.
3. Finding what materials were immune to damp tropical influences, with a view to their use.

4. Finding suitable treatments for certain materials otherwise unsuitable, to render them immune from tropical decay.
5. Finding practicable means of protecting vulnerable radio components and equipment against damp tropical influences.

The scope of this paper covers the behaviour and treatment of materials and components actually exposed to tropical atmospheres, rather than the behaviour of the internal parts of small components, already hermetically sealed.

2—General Observations of Mould Growth

Nature of Mould—Moulds and mildews are minute fungi which are made up of large numbers of closely interlaced thread-like filaments called the hyphae. At intervals, the vegetative hyphae branch off into sporangia bearing branches, each sporangium giving rise to hundreds of microscopic spores. These spores are blown about by the wind or may be carried by insects and, when they lodge on a suitable medium and have sufficient moisture and the optimum temperature, they germinate in a similar fashion to the seeds of higher forms of plant life. If conditions are unfavourable, spores may remain dormant for long periods and may be included in materials during processing, awaiting only suitable conditions for germination.

During growth, moulds give off secretions containing enzymes or organic catalysts which bring about chemical decomposition of the medium. Thus, moulds derive nutriment from the organic material on which they grow. Mould can grow on debris consisting of organic dust, and consequently can appear to grow profusely on materials which, without the debris, would not support growth. One case of interest was observed recently where a painted iron tray, having mounted on it an oil-filled transformer, was well covered with mould. The tray had been stored for some time and, due to a leakage of the oil, the painted iron chassis had become covered by an oil-held film of organic dust. Mould grew on the dust, but when the tray was cleaned down it was in excellent condition. At first sight it appeared as though the mould were growing on the paint. With certain paints this is possible. Mould has not been found to grow on metal, although patches of it sometimes appear on metal surfaces due, without doubt, to organic dust held on the surface of the metal. A minute quantity of dust is sometimes sufficient. A growth of crystals due to corrosion of metal is sometimes mistaken for mould.

The mycelium of moulds may penetrate the surface layers of material or may grow only on the surface. Sometimes, although appearing to grow outwards from the surface, considerable penetration of the material may take place. In some cases the mould, once established, may injure the adjacent material through the action of by-products of its growth. For example, optical glass to which mould is attached may be etched so badly as to become unserviceable.

Susceptible Materials—Some materials on which mould is known to grow are :—

Timber and plywood, casein and gelatine glues, cotton, canvas, linen ;

Paper and cardboard (see figure 10), cellulose acetate tape and sleeving, other cellulose materials ;

Leather (see figure 1), cork gaskets, gum on envelopes, Empire-cloth tape and sleeving ;

Emery cloth, hessian, felt, adhesive tapes ;

Blankets, rope and string, some waxes, some phenolic laminates, some phenolic mouldings.

Some of these materials disintegrate in time, as a result of mould growth.

Growth on Debris—Metal (iron) surfaces have been seen with quite healthy mould growth on them, but it is not likely that the iron could provide the necessary nutrient. Organic dust collected on the surface is undoubtedly the source of nutrient.

It is unfortunate that, whatever it is that supplies nutrient, surfaces to which the mould adheres, such as optical glass or metal, may be etched and damaged by the products of its growth. Growth on debris has been confirmed in the laboratory, but the etching effect which is reported, and has been suspected, has not been confirmed in the laboratory. Photographs of ruined optical glass have been examined, and considerable wastage through this effect has been reported.

Examination of growth on organic dust shows that small quantities of dust can support growth of mould. Most of this debris growth appears to take place during storage, and presents quite a problem as equipment must be stored in closed packages, and the consequent darkness and absence of draught constitute two factors which encourage mould growth. Storage for a few weeks only is sufficient to cause damage in some cases.

Some Effects of Mould—It is known that moulds may be responsible for the decay of most organic materials in nature and certain moulds will bring about the breakdown of specific organic materials. In this way mould may grow on some materials without causing mechanical weakening of the base material. For instance, the nutrient for the mould may be derived from organic matter which does not contribute to the strength of the material.

On the other hand, mould may grow on cotton fabrics, paper, wood, hemp, and similar materials in which the actual cellulose is the nutrient.

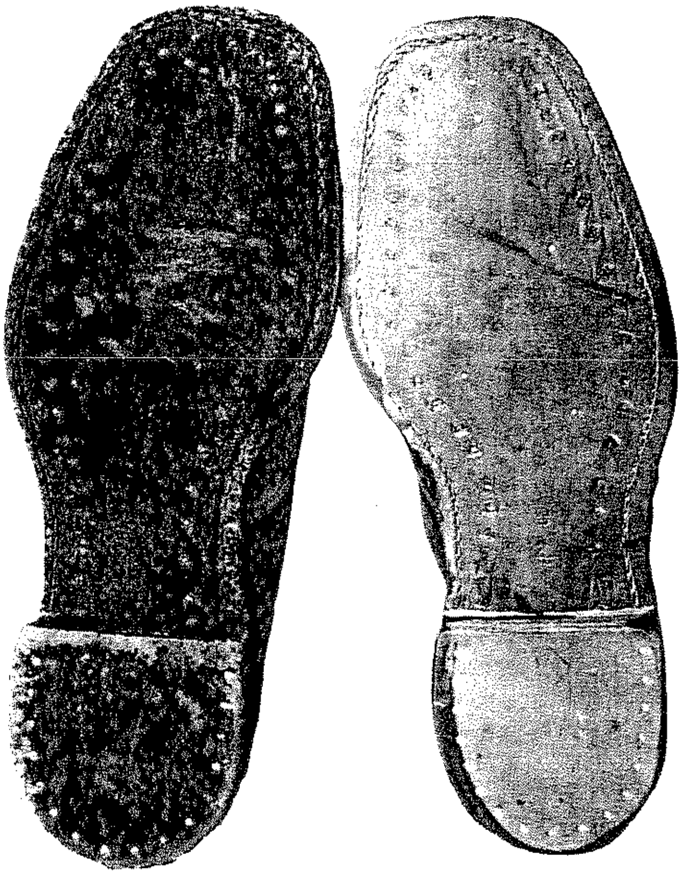

FIGURE 1—Showing mould on Army boots.

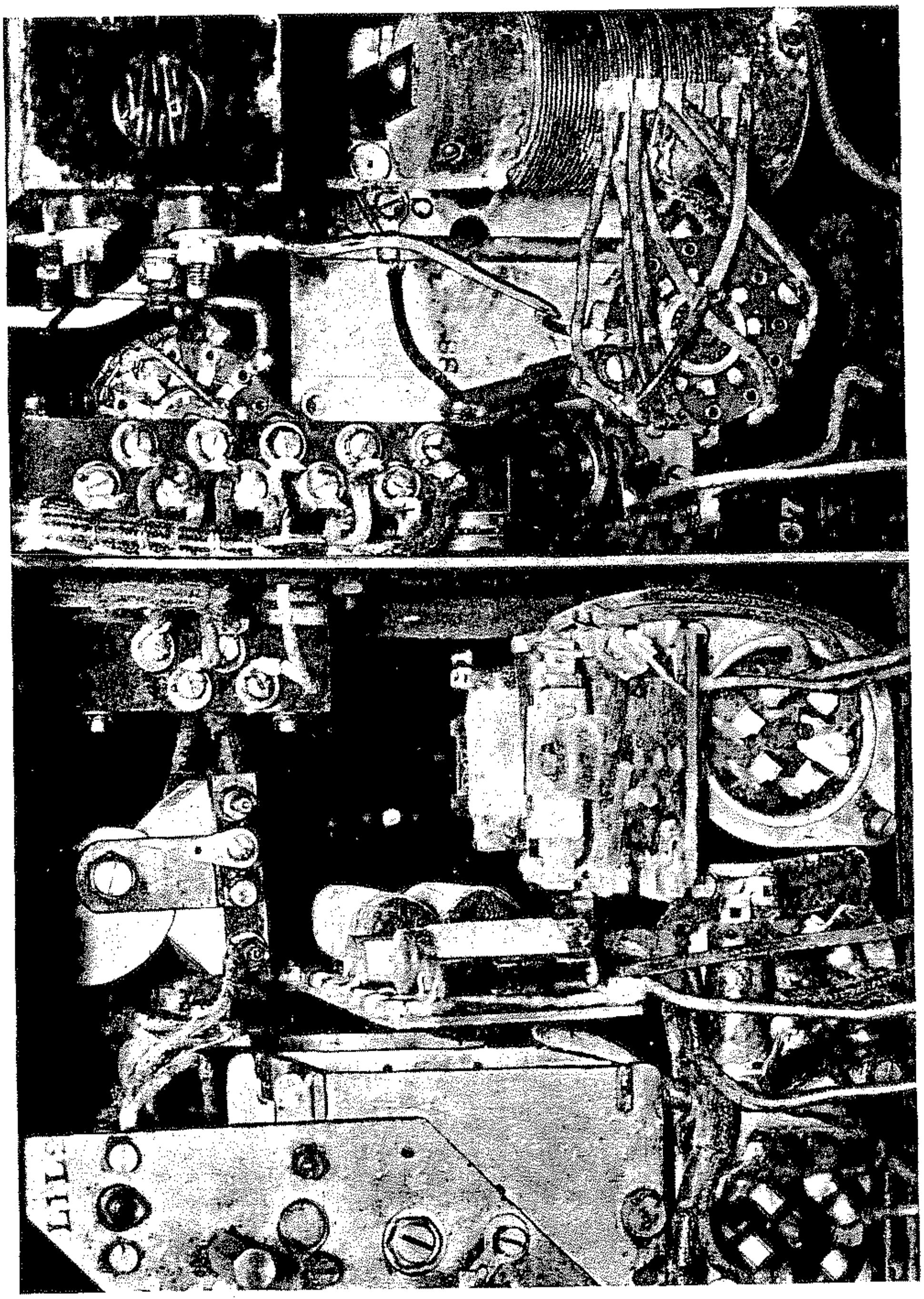

FIGURE 2—Part of field radio equipment, showing mould growth.

The cellulose is thus broken down and the material is rotted to disintegration. For example, *Stachybotrys* and others are said to have this effect on the canvas of tents, and *Aspergillus glaucus* appears to rot leather rapidly.

Apart from mechanical weakness, moulds can seriously affect electrical insulation in the following ways :—

(1) Mould holds water and can cause surface leakage ;

(2) Mould rots the surface of some materials, thus changing the material from its original form ;

(3) The mycelia of moulds are conducting.

3—Damp Tropical Conditions and Testing.

During the year 1942, complaints were received from tropical war fronts to the effect that mildew was appearing in radio equipment and that the effect of the mildew, together with the effect of damp atmosphere, was rendering radio equipment inoperative. Complaints concerning mould growth increased and, in January 1943, researches on the subject of mould growth in radio equipment were initiated. During 1943 many reports were made by experts and others visiting damp tropical areas, and these reports were studied. Helpful co-operation was obtained from officers of the armed forces, which resulted in mould-infected radio components being returned from damp tropical areas for investigation.

Prior to this, we had associated mould with food and clothing under bad storage conditions, and if we had seen any radio equipment with mould in it, we would immediately have blamed unsuitable storage conditions and let it go at that. It became quite obvious, however, that the storage and usage conditions from which these complaints arose during 1943 could not be improved, and radio equipment was required which would stand up to these conditions. Figure 2 shows a non-tropical field radio badly affected by mould growth.

The first and most urgent job was to reproduce the worst damp tropical conditions, so that materials, components and equipment could be tested in the laboratory, without the delay involved in sending them to damp tropical areas. The specification in common use at that time, for tests involving humidity, was British Specification K110, or its equivalent derived therefrom, which involved a dry-heat test to 70°C., followed by two temperature and humidity cycles to 61°C. and 95 per cent relative humidity.

Two types of humidity chamber for carrying out the above tests were used. In one there was no forced circulation of air, but in the type shown in figure 3 provision was made for this.

It became obvious that this test did not involve normal damp tropical conditions—for one reason moulds would not grow on organic materials during this test. While this test was used for all items, a laboratory set-up for the study of tropical mould and mildew was planned.

A study of meteorological records showed that in tropical regions of the South-West Pacific, of which New Guinea is typical, rainfall varies between 40 and 250 inches per year, depending upon the particular area. Milne Bay was described by observers as typical of New Guinea in that it is a wet locality, but at the same time records show only 60 to 100 inches of rain per year in that area. The northern coastline is recorded at 100-150 inches per year, with areas up to 200 inches per year.

Minimum normal shade temperature for the island is about 70°F. and maximum normal shade temperature about 85°F., although occasionally higher shade temperatures have been recorded—as high as 97.5°F. at Port Moresby in January, 1930. At the northern and north-western parts of New Guinea, it is possible that higher temperatures may be encountered. It should be remembered that the north-western tip of New Guinea is within about 30 miles of the Equator.

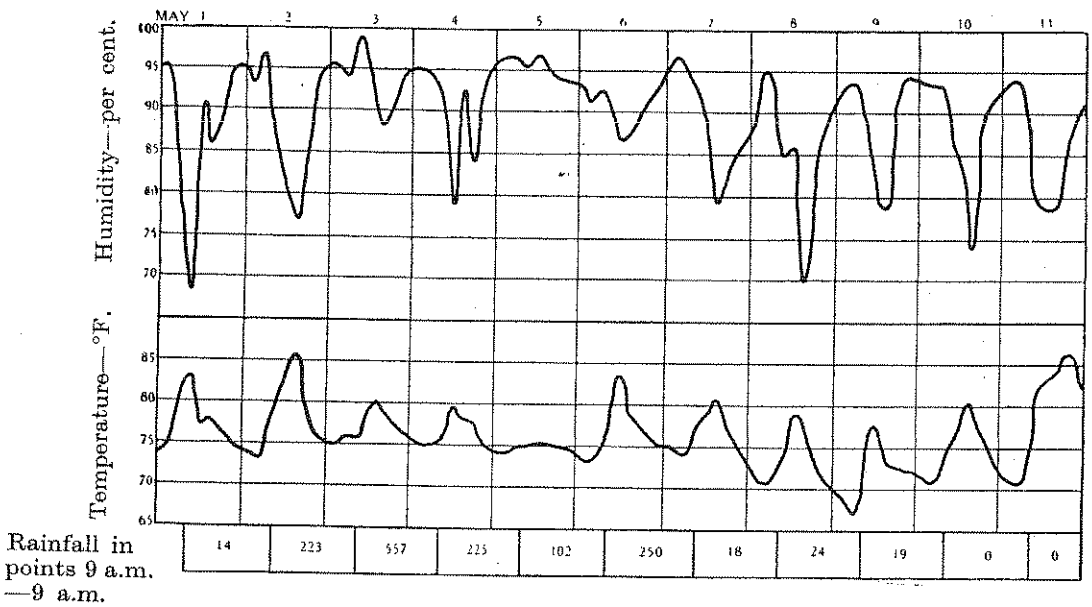

FIGURE 4—Relative humidity, temperature and rainfall during May at Milne Bay.

Records show the annual rainfall for New Britain as 150-250 inches per year, Gasmata having over 250 inches per year. The temperature in these areas falls only about 5°F. at night. In some areas the ground and the vegetation are always wet; the ground is a sea of mud. This applies particularly to the rubber-growing areas. Under these conditions corrosion of metals and mould growth can take place over night.

Figure 4 shows the temperature and humidity, over a period, at Milne Bay. A study of these records showed that the most severe tropical con-

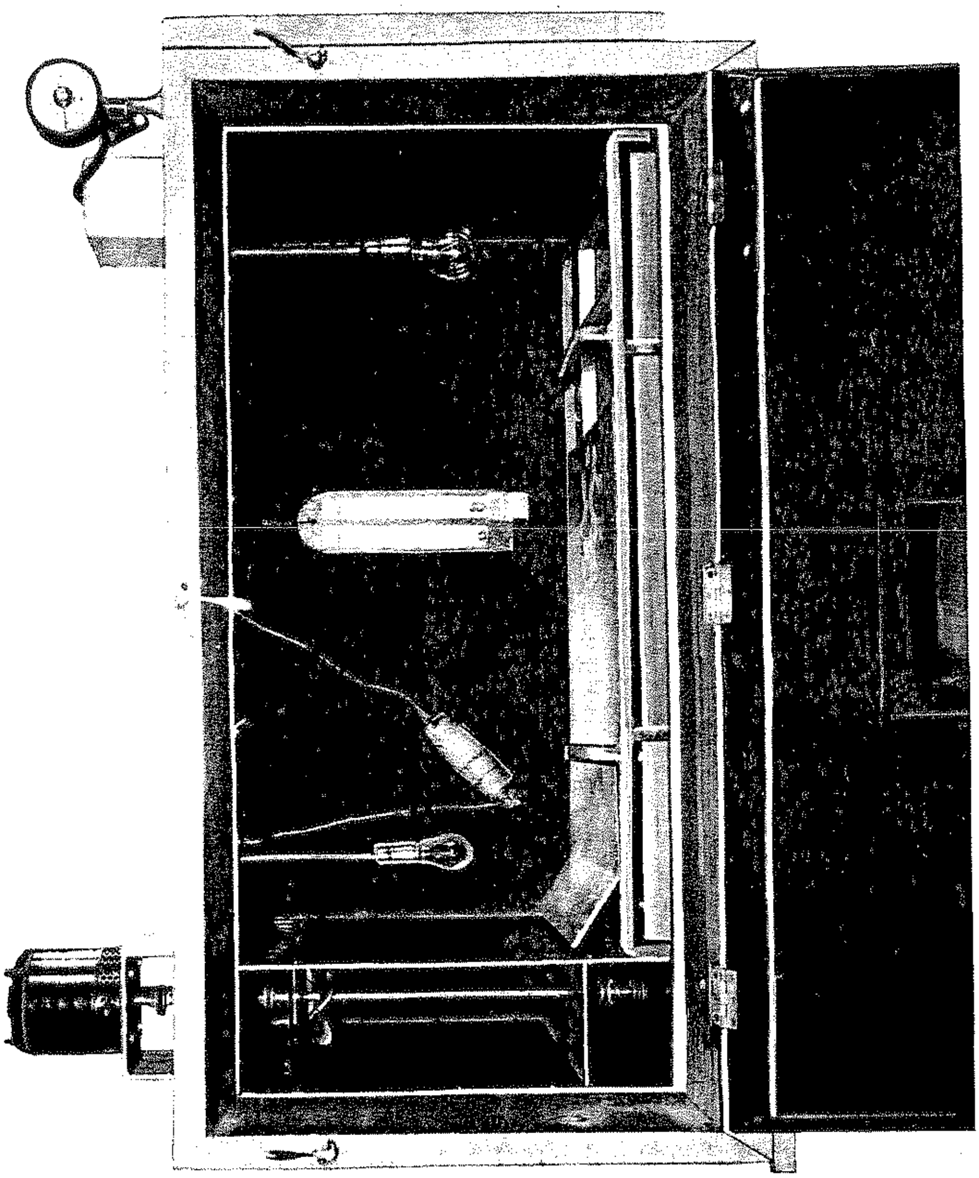

FIGURE 3—Humidity chamber with circulating fan.

FIGURE 5—Spraying mould test chamber with mixed spores.

dition likely to be encountered in damp tropical storage was that of having a saturated atmosphere with condensation and a mean temperature of 86°F., so it was decided to set up a chamber maintaining this condition and to find out whether moulds would grow readily in it. The chamber shown in figure 5 was built, having electric heaters under the floor of the chamber which was covered with trays containing water, so that the air in the chamber would be warmed by heat passing through the water. This proved successful in producing a saturated, or very nearly saturated, atmosphere with continuous condensation on the metal walls of the chamber which were not lagged.

Various organic materials, such as wood, leather, cotton duck, etc., were inserted into the chamber and, placed in contact with these, were other materials returned from the tropics on which mould had grown. The result was a copious growth of mould, and it was then known that a reasonably useful method of testing materials for their susceptibility to mould growth, had been evolved.

4—Laboratory Test Technique

Early in 1943 there was little information available here on mould testing of materials although standard methods of preparing cultures were available, consequently a practical technique had to be developed in a very short time.

Source of Mould Cultures—To test materials for their resistance to mould growth in damp tropical climates it was considered most satisfactory to carry out the tests with the types of moulds actually encountered in these areas. Samples of many types of materials on which mould growth had been observed were forwarded to the laboratory from the South Pacific Islands, the majority of specimens coming from New Guinea. Some of the types of material received were leather; canvas untreated, and also treated with some fungicides; paper in the form of labels and insulation generally treated with some kind of wax, varnish or lacquer, or untreated; painted metals; cellulose acetate, laminated phenolic bonded sheets with paper or canvas laminations; and complete field radio sets.

As many samples as possible were collected, and the cultures of moulds used for the tests were actually taken from these samples in case they possessed some particular affinity for the material or were more than usually resistant to any fungicide that may have been present. As far as could be detected, most of the types of moulds collected appeared to be types prevalent in these areas and in Australia.

Mould grows readily in Northern Australia and somewhat less readily in Sydney under the normal conditions encountered, although if conditions are suitable, for instance, in damp weather storage, the locality appears unimportant.

Preparation of Cultures—Potato-dextrose-agar is used for cultures and is prepared in the following way :—

200 grammes of potato is cut into small pieces and boiled vigorously for several hours, then allowed to settle and cool and the liquid decanted. To this liquid is added 20 g. of ground agar-agar powder and the volume made up to 1,000 c.c. This is then boiled and sterilised. The usual method of sterilisation being in an autoclave, though the solution may be sterilised by boiling gently for 6 to 8 hours under a reflux condenser.

Sterilisation is essential to kill all mould spores and bacteria present in the jelly, as subsequent germination of these would interfere with the growth of the required mould type.

Test tubes plugged with cotton wool, or petri dishes, sterilised in an autoclave or by baking in a hot air oven at a temperature of 110°C. for 6 to 8 hours, are used for the cultures. After sterilisation of the test tubes and petri dishes, the sterile boiling agar solution is poured, about ½ in. in the bottom of the tubes, which are then replugged and allowed to cool and set in a position inclined about 20° to the horizontal ; about ¼ in. is poured into the petri dishes and allowed to cool and set with the lid on.

Another method is by the inoculation of nutrient broth. The broth used is Richards Solution which contains, besides organic matter in the form of sucrose, the minerals potassium nitrate, potassium phosphate, magnesium sulphate, and ferric chloride. The minerals are present in only minute quantities. The broth is transferred to flasks in 50 c.c. lots and is sterilised. Inoculation is carried out in the same way as for tube cultures. It is important, however, to inoculate the broth in such a way that the spores are kept on the surface of the liquid, otherwise germination will not take place.

Inoculation of Cultures—The sterile jelly is inoculated with spores of the required mould by drawing a loop of sterile wire first across the surface of the sample of mould to be cultivated and then across the surface of the agar jelly. During this operation care should be taken that the jelly is exposed to the atmosphere as little as possible and the wire used for inoculation is sterilised in a naked flame each time it is used.

The test tubes are then plugged with the sterile cotton wool and the petri dishes covered with their lids. These are then kept in a dark box and examined from day to day. Mould growth continues until, within a few days, healthy mould colonies grow and form large quantities of spores for further use. These are usually kept for one month before use.

These cultures need not be kept at any particular temperature as they grow very well on the potato agar jelly at ordinary atmospheric temperatures in Sydney, but in cold climates during the early growing period they should be kept warmer than about 20°C. Incubation at 30°C. is satisfactory. A collection of mould cultures in an incubator is shown in figure 6.

Testing of Materials—Tests on materials are carried out under conditions as closely as possible representative of those found in the Pacific areas where mould growth has been observed. The materials are exposed to as many different types of spores as possible.

The materials to be tested for their resistance to mould growth are suspended in the chamber and sprayed with a mixture of mould spores. They are then left undisturbed for a period of 4 weeks or longer, depending on the results obtained. Observations are usually made after the first 48 hours, and then at 24 or 48-hourly intervals, again depending on the rate of growth.

It was decided to adopt a standard method of inoculation of samples by spraying with a standard mixture of mould spores.

To obtain a spore mixture for inoculation of test chambers, cultures of different types of mould listed below are taken and approximately 5 ml. of sterilised distilled water are added to each culture. The tubes are shaken until a spore suspension is obtained. The various spore suspensions are sprayed by means of an atomiser in the test chamber about once every two or three weeks.

Another method of obtaining a spore mixture or spore suspension is by using a bran mixture, which is obtained by mixing bran and water until a thick paste is formed. This is placed in a jar and sterilised. It is inoculated and left for a few weeks, after which the infected bran is dried and bottled. It is highly important that the bran be completely dried, otherwise contamination will occur. In order to use this mixture, it is mixed with water, shaken, and the bran filtered off. This method is not entirely satisfactory. Because of the difficulty of filtering the bran efficiently, the spray gun becomes clogged with small fragments of bran, and at the same time the bran which is sufficiently small will be sprayed on to samples under test and mould may grow on the bran, giving the impression of growth on the samples.

Because of these disadvantages, it is considered that the first-mentioned method is the more satisfactory.

Standard Moulds :—

(1) *Aspergillus niger*,
(2) *Memnoniella echinata*,
(3) *Penicillium luteum*,
(4) *Penicillium* No. 40,
(5) *Rhizopus nigricans*,
(6) *Aspergillus glaucus*,

Common Tropic Moulds which have been added :—

(1) *Aspergillus ochraceous*,
(2) *Aspergillus flavus*,
(3) *Aspergillus tamarii*.

Test Chamber—A steel cabinet with a lid (figure 5) is used as a test cabinet. This consists of a base compartment containing electric heaters thermostatically controlled. The main compartment directly above consists of uninsulated sheet steel sides and base, with an insulated roof. A covering of water is kept over the floor of the main chamber, the heaters below causing the water vapour to rise and saturate the atmosphere in the chamber. Condensation continually takes place on the walls of the cabinet but the insulation on the roof prevents condensation there, so that droplets do not fall on the articles being tested and so waterlog them. The temperature of the chamber is maintained at between 80° and 86°F.

Other Test Methods—The humidity-mould chamber described above (figure 5) is a simple device for reproducing the worst damp tropical conditions, that is, saturated atmosphere with condensation at a 'Milne Bay' temperature, and the use of mixed mould spores to simulate the natural conditions. It has, however, some weaknesses, as results of electrical measurements so obtained are not consistently reproduceable.

At times in summer in Sydney, air temperature exceeds 86°F., at which temperature the mould chamber should be maintained. On these occasions there is no condensation on the walls of the chamber and results differ from those obtained in cooler weather. Consequently the chamber should be kept in a room whose temperature does not exceed 86°F.

Also, for mould tests it is sometimes desirable to keep the specimens away from sources of unwanted contamination. Consequently, the following technique has been adopted, in addition to that already described :—

(1) *Petri Dish Tests of Material*—This procedure is similar to that now contained in U.S. Army-Navy Electronics Standards Agency Proposed Specification Project 90-2, 1944, for "Moisture and Fungus Resistant Material and Treatment of Communications Electronic and Associated Electrical Equipment."

A petri dish with potato-dextrose-agar is prepared, as previously described for test tube cultures, and is inoculated with the mould required for test. The material is placed in the centre of the agar jelly and is wetted with spore-suspension in sterile distilled water. The petri dish is then placed in an incubator at 30°C. ± 1°C. See Figs. 7 and 8.

For the testing of waxes and compounds two procedures are used, the one is described in the abovementioned U.S. Proposed Specification, in which a square of filter paper is impregnated with the wax to be tested as shown in Figure 7*a*, and the other in which a solid piece of the wax is used, as shown in Figure 8.

It should be remembered when interpreting the results, that one test indicates the ability of the combination of wax and paper to support mould growth, and the other is a test of the wax alone.

For testing varnishes and lacquers a similar procedure is used, but also varnish films without paper are tested. Varnish films on glass plates have been tested, as it has often been wrongly reported that certain varnishes support mould growth, when it should have been stated that they do not protect certain materials against mould growth.

Any solid materials may be tested by the above methods.

(2) *Individual Jar Tests*—In these tests which have the advantage of isolating the specimens, glass jars with phenolic screw tops having breather holes plugged with sterile cotton wool, are used, and each jar has 1-2 in. of sterile distilled water covering the bottom. The specimen is inoculated and suspended above the water in the jar by a wire from the inside of the lid. The jars are kept in an incubator at from 25° to 30° C.

Interpretation of Results—Observations as to the presence of mould growth may usually be made with the naked eye or hand lens. However,

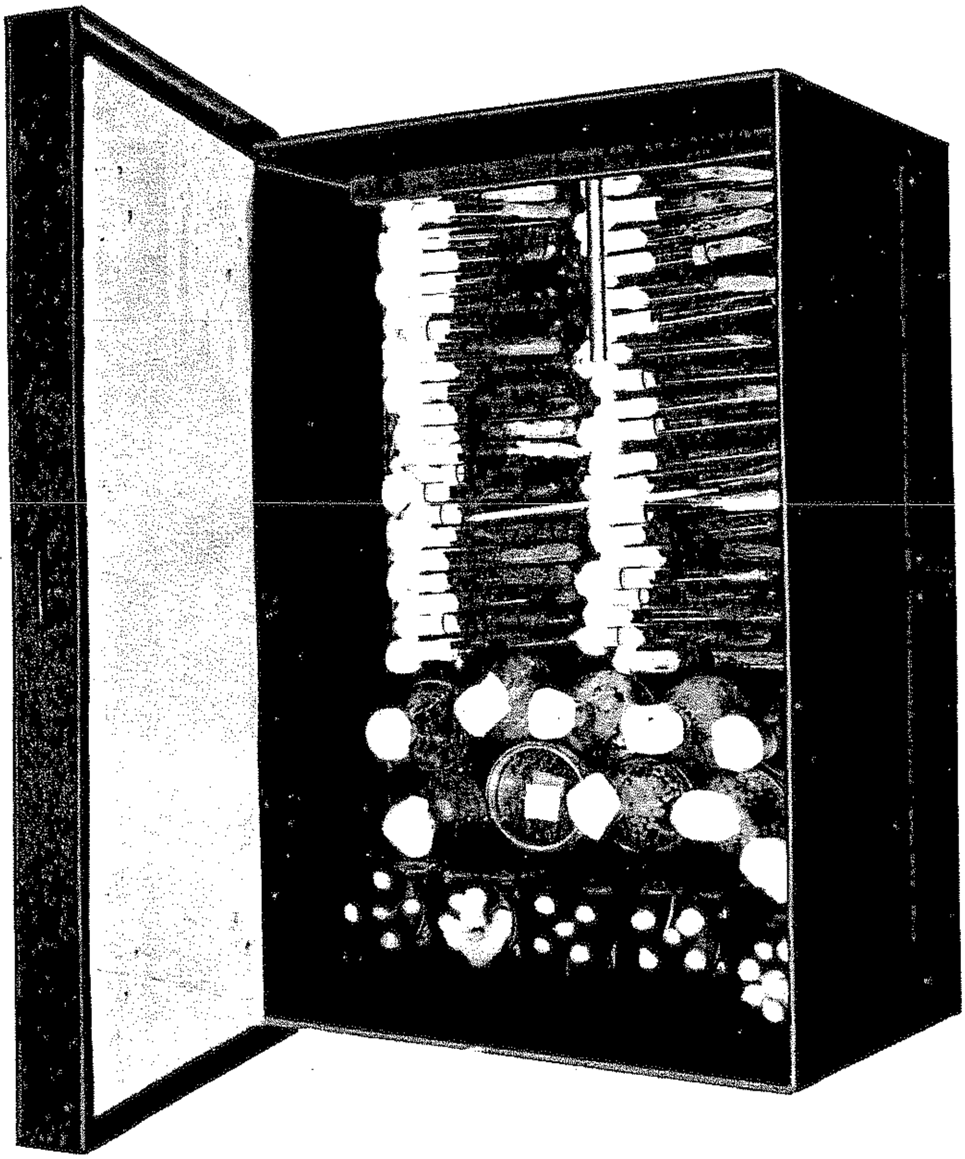

Figure 6—Tropical mould cultures in incubator.

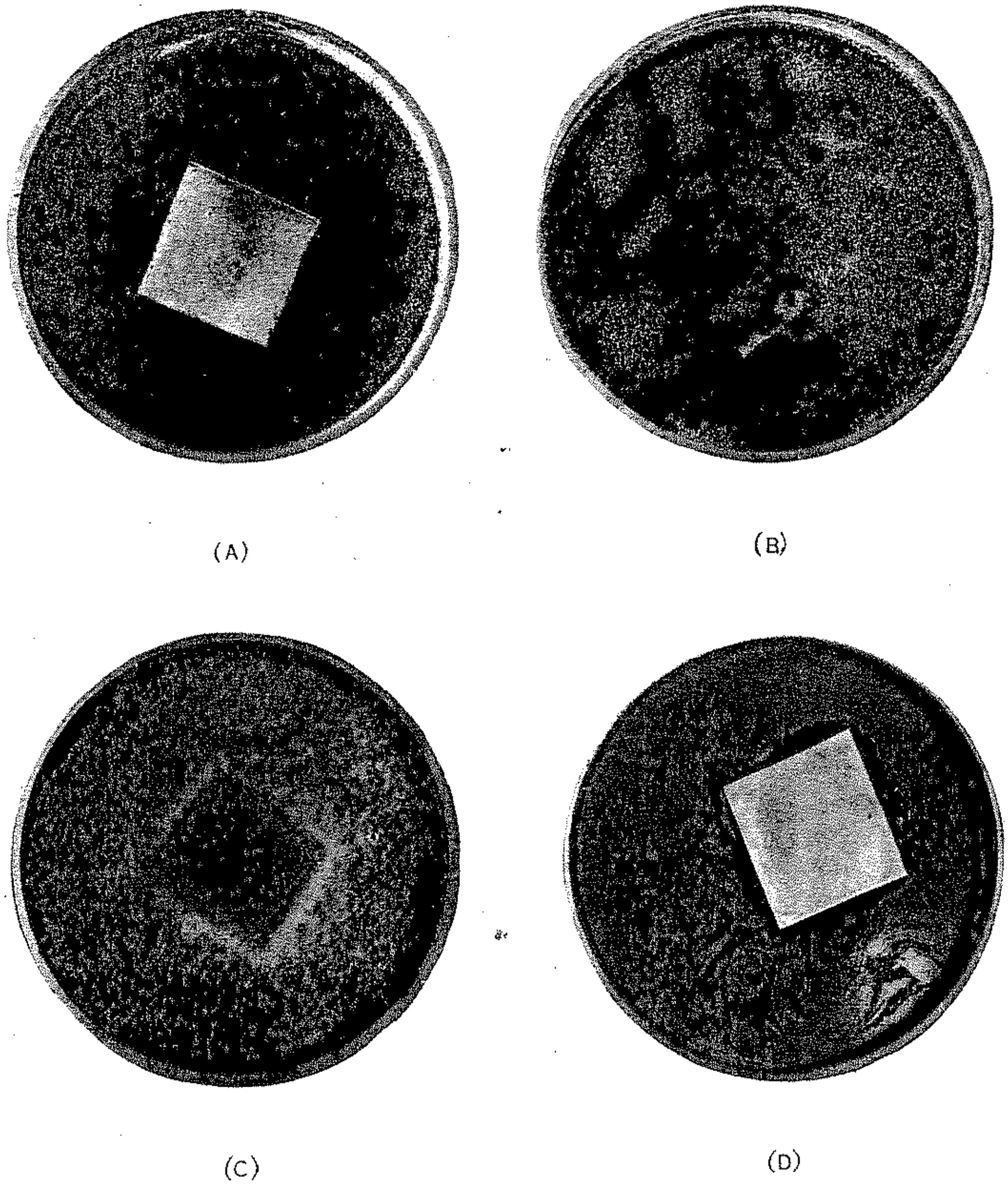

FIGURE 7—Mould tests of ceresine-estergum applied to paper.

(a) 1% trichlorphenol in the wax.
(b) Paper untreated.
(c) Wax containing T.M.T.
(d) 10% trichlorphenol in the wax.

with materials that do not support a vigorous growth of mould, or on which the mould does not form fruiting bodies, microscopic examination may be necessary.

The effect of mould on the material under test must be considered in relation to the use of that particular material. A microscopic growth on an optical instrument might be far more serious to the operation of the instrument than a vigorous growth in a less critical position, such as may be found on the cotton or leather casing.

Tensile strength tests on leather or cotton duck will indicate the degree of deterioration in these materials but will not measure the waterproofness of a tent. In the same way, microscopic growth on the surface of an insulating material may not decrease its strength mechanically, but may considerably impair its electrical properties while it is present.

All mould growths are extremely sensitive to external conditions, and any slight variations of these must also be considered when the results of tests are recorded.

Other factors that may cause irrelevancies in results are parasites on the mould growths. These may be plant parasites or mites which breed readily when conditions are suitable for mould growth, and in some cases may devour all the growth.

Fungicides—When the use of materials known to support mould growth cannot be avoided, it is essential to treat such materials with poisons known as antiseptics, or fungicides, to prevent mould growth.

Unfortunately, mercuric fungicides were not available at the time, but many others were tried out. Water-soluble fungicides were soon eliminated on account of their tendency to leach out in humid conditions. Some tests were carried out to determine any undesirable corrosive effects.

Results indicate that it is not likely that any one fungicide can be selected as standard and used indiscriminately for all types of material to achieve satisfactory results, but rather that each problem of fungiciding must be treated individually, and the most satisfactory treatment found in laboratory tests be selected.

The treatment selected for rubberised canvas used for equipment case covers, is an instance. Copper naphthenate, which is a very effective fungicide when applied to canvas or duck and similar materials, was not considered safe where rubber was present. The author has not very definite evidence of the destructive effect of copper naphthenate on rubber, but has been warned by rubber chemists of the danger, and consequently has not recommended its application in close proximity to rubber.

The material concerned consists of a laminated structure, having two sheets of canvas bonded by a thin sheet of rubber. Salicylanilide which would probably have been recommended, was not available in sufficient quantity. A new fungicide, which has been under examination, was applied to this material with good results ; this is known as T.M.T. Its full name is Tetramethylthiurambisulphide, and it is used in the rubber industry. It was found to be soluble in methylated spirit, or solvent naphtha to the extent required, that is 0.16 gramme per 100 c.c. of solvent. This solution was sprayed on to the fabric, and tests showed it to be effective. This proportion, 0.16 g. per 100 c.c., is the maximum solution which can be obtained at atmospheric temperature, consequently the solution used is saturated. Benzol has since been found to be a suitable solvent.

Fungicides in Paints and Varnishes—It has been observed that vigorous mould growth occurred on some organic materials protected by a coating of paint, varnish or lacquer, the growth taking place either on the varnish or the material underneath. Tests on varnishes, lacquers, and paints, did not indicate that they at any time supported a vigorous mould growth by themselves, and microscopic examination of the films showed that the growth seemed to occur where there was a tiny break in the coating or where organic debris had lodged on the surface.

It was thought that possibly the incorporation of a fungicide in the protective coating would overcome this difficulty, but up to the time of writing, results by this method have not generally been satisfactory. The addition of Shirlan (salicylanilide) to a cellulose lacquer on paper seemed to give a fair but temporary protection to the paper, but the inclusion of this fungicide as well as others seemed to result in blushing and lack of transparency of the lacquer. Inclusion of chlorinated phenolic compounds was found to be unreliable owing to their volatility and, if any heat is used in the drying or polymerisation of the varnish, all the phenolic compound may be evaporated. In paints, copper naphthenate has given some protection and phenol compounds some temporary protection, but none of these methods is really reliable when applied to material that is very susceptible to mould attack.

Better results than adding the fungicide to the protective coating have been obtained by the treatment of the material first with a suitable fungicide and then applying a high quality varnish, lacquer or paint, as the position required. In this way, the susceptible material is protected, as the fungicide is free to act in it as a poison, and any defects in the film are not troublesome. This does not take care of any debris, but a general method of overcoming this trouble has not yet been evolved.

Fungicides in Waxes—In order to find whether fungicides retained their fungicidal properties after they had been incorporated in waxes, tests were carried out on a mixture of ceresine estergum treated with copper naphthenate, trichlorphenol and T.M.T. Tests were also carried out to determine the amount of fungicide mecessary for effective prevention of mould growth.

The procedure adopted was to inoculate the medium in a sterilised

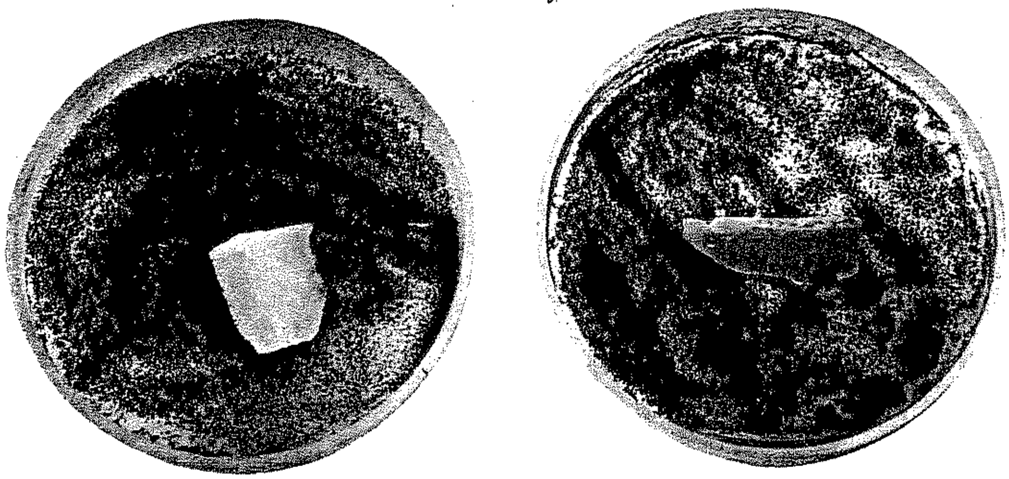

FIGURE 8—Mould test—solid wax—aspergillus niger.

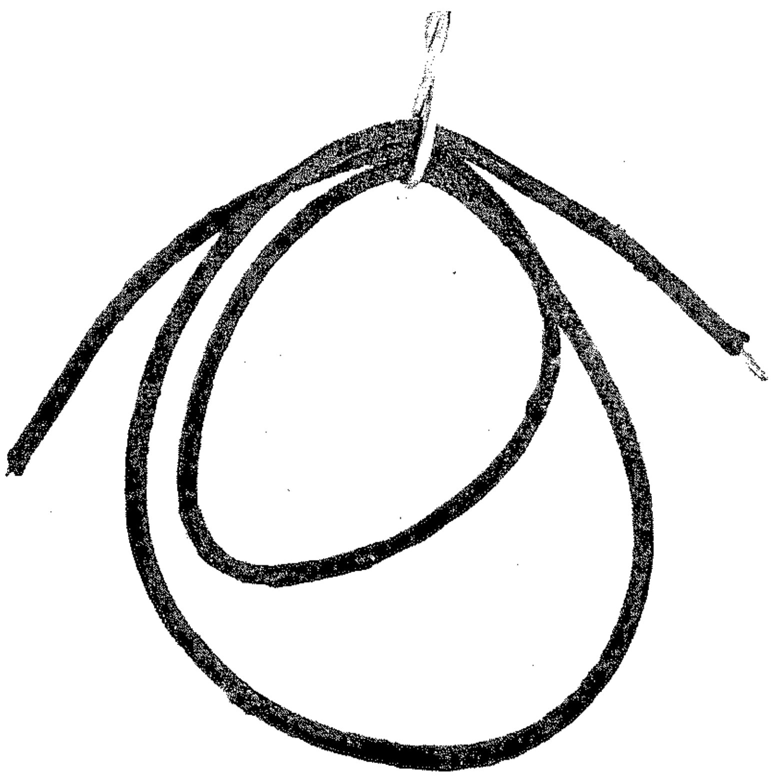

FIGURE 9—Mould on lacquered cotton-covered hook-up wire.

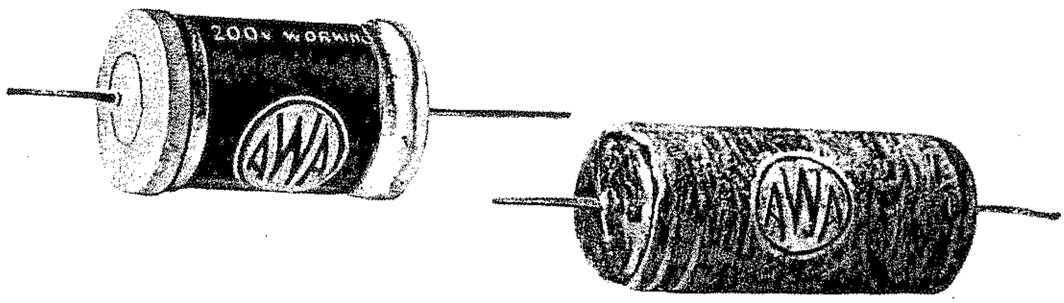

FIGURE 10—Moulded and glass solder-sealed capacitors.

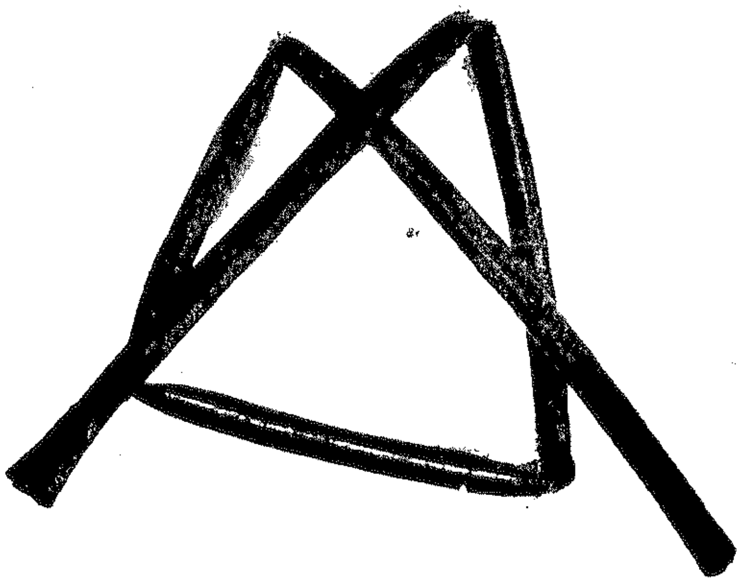

FIGURE 11—Mould on varnished cambric sleeving.

petri dish, and then add a specimen of filter paper impregnated with the wax to be tested. The dish was then placed in an incubator at 30°C. for 28 days. Several specimens were treated in each case. Observations were made after 5, 10, and 28 days; results were as follows :—

Filter Paper Untreated.—In all cases mould grew over the filter paper. (See figure 7*b*.)

Ceresine-estergum Untreated.—In all cases, the mould growth extended to some degree over the surface. This was limited to about ⅛ in., with the exception of *Rhizopus nigricans* which grew vigorously all over the surface. This would indicate that the wax did not protect filter paper against mould growth, or rather that the mould could grow on the wax-paper combination. Tests made on the wax by itself indicated that it did not support mould growth (figure 8).

Ceresine-estergum Treated with Copper Naphthenate.—In no case did the mould grow on the specimen, although the growth was quite vigorous around the edges. In the specimen inoculated with *Memnoniella echinata*, an area of inhibition up to ¼ in. wide occurred where the specimen was in direct contact with the medium. The incorporation of the fungicide seems to have prevented growth to a certain extent.

Ceresine-estergum Treated with T.M.T.—There was very little difference between these samples and those which were untreated. A vigorous growth extended all over the surface in some cases, and up to ⅛ in. in others. No prevention was evident, and it seemed that, due to decomposition during its incorporation into the wax, the T.M.T. had lost all its fungicidal properties. This decomposition was indicated by an overpowering sulphurous odour given off when the wax was treated with T.M.T. A test specimen treated with T.M.T. is shown in figure 7*c*.

Ceresine-estergum Treated with Trichlorphenol.—In all cases except that inoculated with *Rhizopus nigricans*, the mould growth was stunted and undeveloped all over the Petri dish, even after 10 days. In some cases, the growth was only mycelial, there being no sign of sporulation. In the sample inoculated with *Pencillium* No. 40, an inhibited area ½ in. wide was evident (see figure 7*d*). In this area, there was little or no growth at all. This fungicide seems to be the most effective of those tested in the wax, since it not only prevents growth on the specimen but also inhibits it all over the testing dish.

The amount of fungicide necessary for effective prevention of mould growth seems to be quite large. Tests carried out using Trichlorphenol as the fungicide, showed that, while a wax treated with 10 per cent by weight of the fungicide was quite effective in preventing growth, the same wax treated with about 2 per cent was not so effective and in some moulds did not even prevent growth on the sample. For copper naphthenate, 10 per cent by weight was effective to a certain extent, but for complete prevention, greater percentages would be necessary.

At the same time the mineral waxes commonly used were found not to support mould growth when tested by themselves, as shown in figure 8.

5—Mould in Radio Equipment and Its Prevention

Observations of Equipment—Mould has been found growing in certain parts of radio equipment under the following conditions :—

(1) After storage indoors in Sydney when no particular attention has been paid to storage conditions.

(2) In apparatus and components returned from New Guinea and Pacific Islands.

(3) After a test period in an artificial tropical atmosphere in the laboratory.

Figure 2 shows mould growing in a field radio. The parts showing most mould growth are :—

Cotton-braided cables and wire (Belden 'Ravine'—see figure 9);
Paper labels on components (see figure. 10);
Latex solution cement;
Varnished cotton covered wire coils;

Varnished cambric sleeving (see figure 11);
Edges of phenolic laminated paper and canvas sheet;
Cellulose acetate sleeving and tape;
Leather handles and cases (see figure 1);
Canvas covers and cases (see figure 12);
Cords for tying cables and components;
Woodwork;
Aerial guy ropes;
Cardboard dry batteries.

Connecting Wire—The growth on cotton-braided rubber-covered wire, having a thin coat of lacquer, such as Belden 'Ravine' which has been very widely used here, is very prolific and it is noticeable in every case that the black-coloured wire appears to be the most affected. Cases encountered have not been sufficiently long under the damp conditions to cause obvious disintegration of the cotton, but as the mould holds water in a saturated atmosphere the surface insulation becomes just a few ohms per yard. Samples of this wire, each treated by immersion in one of the following fungicides (antiseptics) and tested for a period of several months, against an untreated control sample, in the laboratory mould incubator showed immunity from mould :—

Copper naphthenate	1% in kerosene.
Trichlorphenol	1% in kerosene.
Salicylanilide	1% in methylated spirits.

For use in damp tropical areas it would be necessary to water-proof the cotton braid after application of a fungicide, to prevent surface leakage when damp. As the rubber cannot be baked at temperatures much in excess of 80°C. without injury, many types of air-drying lacquer were tried and dried at 70°C. with the aid of lamps. Very few were found that did not soften and whiten after some hours in a saturated atmosphere. Of those which withstood this test, none retained sufficient flexibility.

Treating the cotton fabric with a lacquer in which the fungicide (any of the above) was incorporated, without first treating the cotton with fungicide, was found not to prevent mould growth. Mould grew on the cotton through minute cracks in the lacquer and it was apparent that the fungicide was not active for protection of the cotton. As a result of this investigation it was decided to discontinue the use of cotton-covered wire for all exposed wiring in all equipment.

Tests of plasticised polyvinyl chloride covered wire, carried out over a period of three years, have shown that this material is not susceptible to mould growth. It appears not to be affected by humidity or exposure to weather and sunlight. It displayed a tendency to flow under pressure, to become brittle at low temperatures, and to soften at elevated temperatures, but as these factors were allowed for in its application, it gave satisfactory results after extensive tropical exposure. Consequently, P.V.C.-covered wire and P.V.C. sleeving (spaghetti) are being widely used in wiring which is not subjected to mechanical pressure, or temperature in excess of 80°C.

Reports from the field, laboratory tests, and observation of returned equipment, have shown that plain vulcanised rubber-covered wire, not exposed to direct sunlight, is quite satisfactory for chassis and rack wiring. This type of wire is used in all cases where temporary short circuits may occur in circuits of low resistance such as filament circuits where overheating may immediately ruin P.V.C. covering.

Vulcanised rubber does not normally grow mould. One isolated case has been observed in the laboratory where a roll of vulcanised rubber has grown mould quite strongly, but there appears to be something peculiar about that particular sample, as growth on vulcanised rubber has not been observed after a considerable time in the tropics.

A large quantity of Belden heat-resisting rubber-covered wire has been used with satisfactory service, as has also a large quantity of locally produced vulcanised rubber-covered wire. An exposed outer rubber covering for wires and cables is not regarded as satisfactory for long cables external to equipment where exposed to direct sunlight, weather, and soil ; for this purpose some external protecting cover for the rubber is indicated. In some cases P.V.C. tubing is being used for this outer covering. It is considered that fibreglass braiding may be ideal, but this is not available in Australia.

Fungiciding of cotton braid with either salicylanilide, trichlorphenol, or copper naphthenate, will prevent mould growth, but there is said to be some danger with the effect of free naphthenic acid on the cotton and the effect of copper on the rubber if copper naphthenate is used. In laboratory work these effects have not been noticed, and the copper naphthenate tried here may be free from this trouble, but until life tests have been carried out this fungicide (which is now being used for the treatment of aerial ropes) will not be used near rubber.

Varnished Spaghetti Sleeving—Varnished cambric (Empire Cloth) of the usual yellow or black variety, which consists of cotton or artificial silk tube treated with a varnish, is quite unsatisfactory in the damp tropics. The varnish used for this purpose (no details are available of its make-up as this refers to imported material) softens and falls off, leaving the cotton bare to grow mould. Wherever possible P.V.C. sleeving is used and is very satisfactory, as it does not support mould growth.

In some places in aircraft transmitters, particularly at radio frequencies where rigidity is essential, ebonite (hard rubber) tubing is used.

Paper Labels—(See figure 10). Paper labels were used very widely on components to carry type numbers, ratings, etc. These proved a very prolific field for mould growth, which under suitable conditions rendered the printing illegible.

In some cases a solution of latex in ammonium hydroxide is used as an adhesive, particularly for affixing labels on the smooth surfaces such as phenolic mouldings. Mould grew wherever this latex spread. This is now poisoned with salicylanilide ('Shirlan Powder'), using 20 grammes of the salicylanilide powder per 1 gallon of latex solution in which it is soluble. This has proved effective as far as the latex is concerned.

Paper labels are sometimes covered with a good thick film of cellulose nitrate lacquer which has been said to be effective in prevention of mould in this case. Laboratory tests contradict this. Paper labels should be avoided, as, apart from obliteration of the printing, the paper is rotted to disintegration by mould.

Phenolic Laminated Sheet—Mould has been seen growing on the edge of high-grade paper-base phenolic laminated sheet, such as XXXP-SR Synthane and XPLW/30 Dilecto, but in these cases the growth has been small and it is believed that debris collected in the rough surfaces of the sheared edges provided the nutrient. Some vigorous growths have taken place on poorer grades of this material, such as XP. It has been said that phenol resin is a fungicide, but in spite of this, vigorous growths have occurred on valve sockets and other parts. Varnish impregnation by dipping in a particularly good alkyd resin varnish, which is then baked at 130-140°C. to give a thoroughly cured film, has proved helpful in prevention of mould growth. The application of good water-resisting varnish seems in other cases also to inhibit growth, provided the base material is solid and has a smooth surface of simple contour, and provided also that it is not one of the very good sources of nutrient.

Canvas or linen-base phenolic laminated sheet of various sizes has grown mould to such an extent as to be damaged thereby. Where conditions necessitate use of this material it is varnish treated as above, and tests definitely indicate that this affords a temporary protection only. It is suggested that the fabric should be treated with some fungicide before impregnation with the resin in manufacture. The use of fabric base sheet, as distinct from the paper-base material, for electrical insulation is discouraged, as the water absorption of the fabric, which varnish treatment definitely does not prevent, is very high, and electrical properties are quickly ruined by high humidity. Cases have been seen in which swelling of the canvas fibres is so great as to cause bursting of the material. It has been necessary to use paper-base phenolic material in places where other materials, such as high-grade ceramics, would be superior for tropical use, on account of the supply position in Australia.

Varnished Cotton Covered Wire Coils—Large r-f coils wound on phenolic laminated paper formers, 8 in. diameter and larger, using artificial silk or cotton covered wire, are normally bank wound for low-frequency work. These coils are varnish impregnated during winding and are given several varnish dips and baking treatments after winding. Mould has grown very readily on them and the Q has been reduced thereby from a value greater

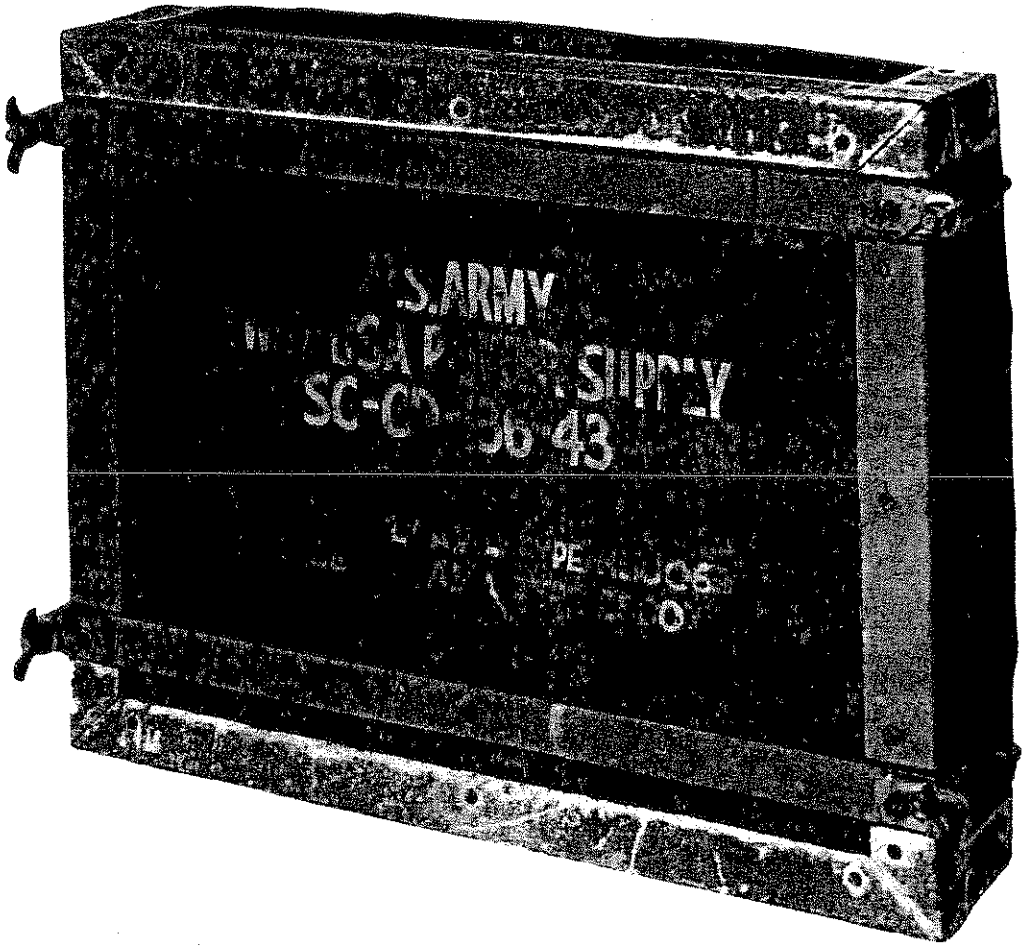

FIGURE 12—Old type canvas-covered plywood case after exposure to tropical conditions.

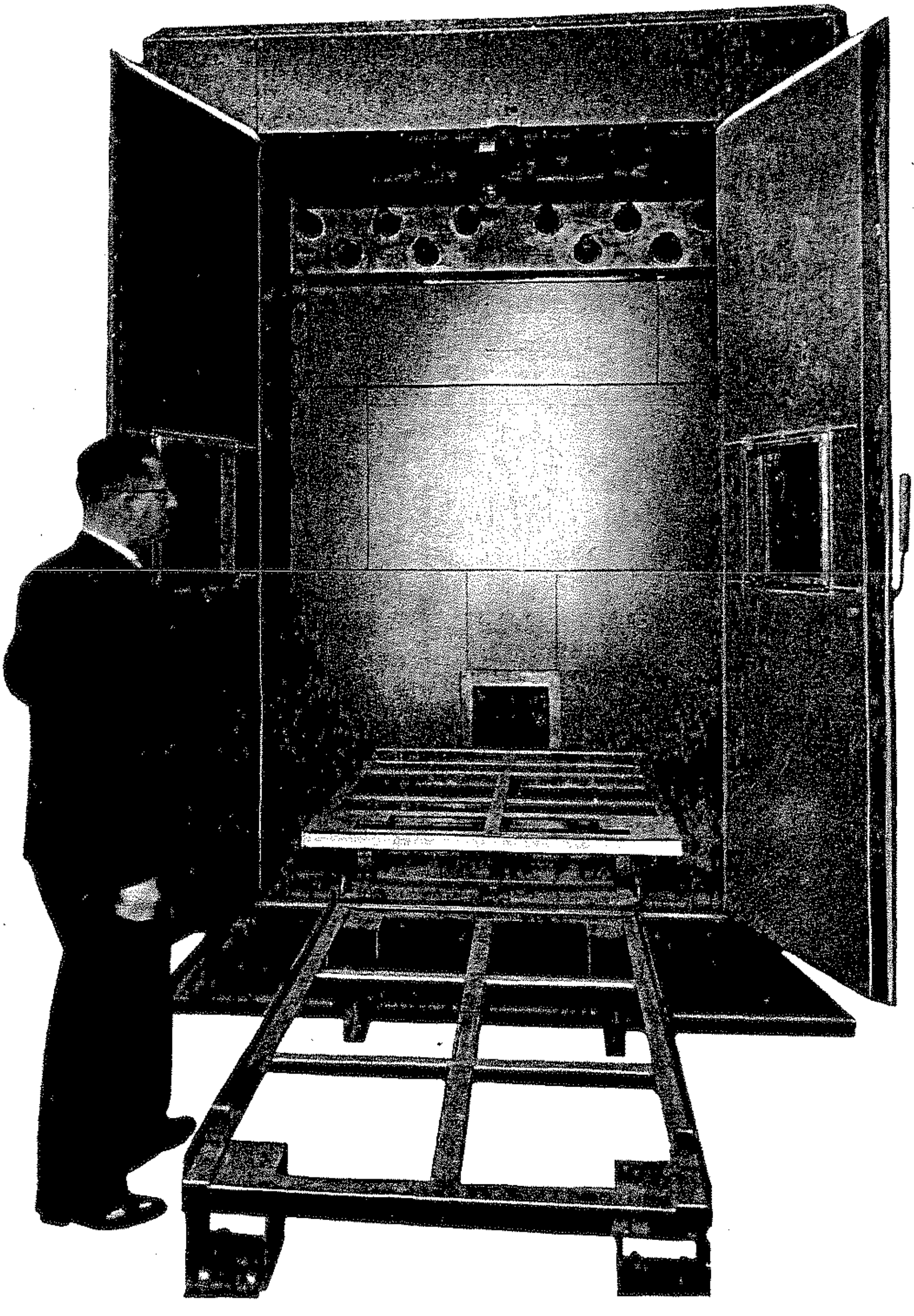

Figure 13—Cyclic humidity test room.

than 300 down to 97. Baking for considerable periods failed to restore or improve the Q of 97. This is one very definite instance of permanent insulation damage by mould, and an example of the lack of protection afforded even by a high grade of varnish.

The use of a varnish incorporating a fungicide is not a satisfactory preventive. Impregnation of the cotton or artificial silk with a fungicide, followed by a varnish treatment, is considered to be the most effective prevention, but these measures have not yet been put into production. Laboratory work to determine the effect of fungicides on the copper and on the electrical characteristics of the coil, is not complete.

Cellulose Acetate Sleeving and Tape—Cellulose acetate sleeving used originally was highly plasticised and perished rapidly, apparently through some physical or chemical action with the plasticising agent.

Cellulose-acetate sleeving used subsequently was much more rigid and did not perish under ordinary local conditions. In New Guinea and also in the laboratory mould incubator, mould grew rapidly on the sleeving, and its use was discontinued. Polyvinyl chloride was substituted.

Adhesive cellulose acetate tape, used for colour-marking and strapping cables together, also grew mould and its use was discontinued. Cord treated with trichlorphenol or 1 mm. P.V.C. tubing was substituted.

Leather Handles and Cases—Leather is one of the materials most quickly attacked by mould. (See figure 1.) In the mould incubator in the laboratory, leather will become covered with mould in a few days. Reports from New Guinea state that leather in any form grows mould and disintegrates very rapidly. As there does not appear to be any known method of prevention applicable to leather, its use should be avoided as far as possible and webbing or some other fabric which can be treated, should be used in its place. This practice has been put into operation generally. Leather can be protected from mould during storage by spraying with a fungicide such as trichlorphenol. This should be applied as a 0.2 per cent. solution, but it will not penetrate the leather ; consequently, if the leather is disturbed and the coating of trichlorphenol moved, the leather will be exposed to mould growth. Leather disintegrates also through the effect of high humidity alone, the effect being apparently through dissolving some constituent from the leather which then hardens and cracks. Many experiments have been conducted here with the use of such substances as Neatsfoot Oil and other things on military boots, and in all cases mould has grown freely on the leather during the tests. Most of the tests on leather have been done at the request of officials of the Allied Services in Australia.

Canvas Covers and Cases—(See figure 12). Tests on many varieties of canvas or duck from various sources have been carried out mainly at the request of the above authorities, and with the exception of Birkmyre (British) canvas which is treated in some way by the manufacturer, they have all grown mould freely. We have found that canvas treated by soaking in 1 per cent solution* of copper naphthenate, or 1 per cent solution of salicylanilide in methylated spirits, or trichlorphenol, was resistant to mould growth. It has been said that copper naphthenate is likely to weaken the canvas through the action of naphthenic acid. The author has not encountered this effect.

Cords for Tying Cables and Components—Cords used for tying bunched cables and for tying components together, grow mould rapidly, this mould spreads to the cables and is likely to cause trouble. Impregnation of cord with any of the three fungicides mentioned is quite effective.

Aerial Guy Ropes—In this case, copper-naphthenate impregnation is recommended. Here there is no danger from corrosion which might possibly exist where copper naphthenate is used inside apparatus on fine wires and near switch contacts.

Woodwork—Most types of woodwork show mould growth and are also attacked by termites. Soaking in copper naphthenate solution is particularly effective with woodwork, both in prevention of mould growth and prevention of termite attack. Creosote is also very satisfactory, but operatives do not like using it, and it was also in short supply in this country.

Dry Batteries—Quantities of dry batteries made with the customary untreated-cardboard containers have been sent to tropical areas with bad consequences. Treatment of the cardboard with paraffin has been tested in the laboratory and has been found unsatisfactory, as mould grows rapidly on the waxed cardboard. Moisture is absorbed, the adhesive dissolves, and the case becomes very wet and disintegrates. The zinc cells corrode. It is recommended that dry batteries for tropical areas be sealed in metal cases filled with a plastic bitumen, having a 'ball-and-ring' test of about 85°C. For terminal insulation, ceramic or mica-filled phenolics are recommended, but the highest grade of laminated phenolic paper-base sheet treated with the best available insulating varnish and baked, may prove satisfactory, provided adequate terminal spacing is allowed.

Plywoods—Ordinary plywood made with casein or gelatine glues is useless in the tropics. These glues are water soluble and the plywood rapidly comes apart. Mould grows almost as readily on these glues as on the agar jelly especially selected for cultures. Urea formaldehyde or phenol resin glues are satisfactory. The wood should be treated with copper naphthenate to protect against moulds and termites.

Packing of Equipment—It has been stated that the greater number of casualties to electrical and other equipment has taken place during storage

*The 1 per cent refers to 1 per cent copper deposited in the treated material as a fungicide. This usually means 10 per cent of the liquid copper naphthenate to 90 per cent mineral turpentine or kerosene.

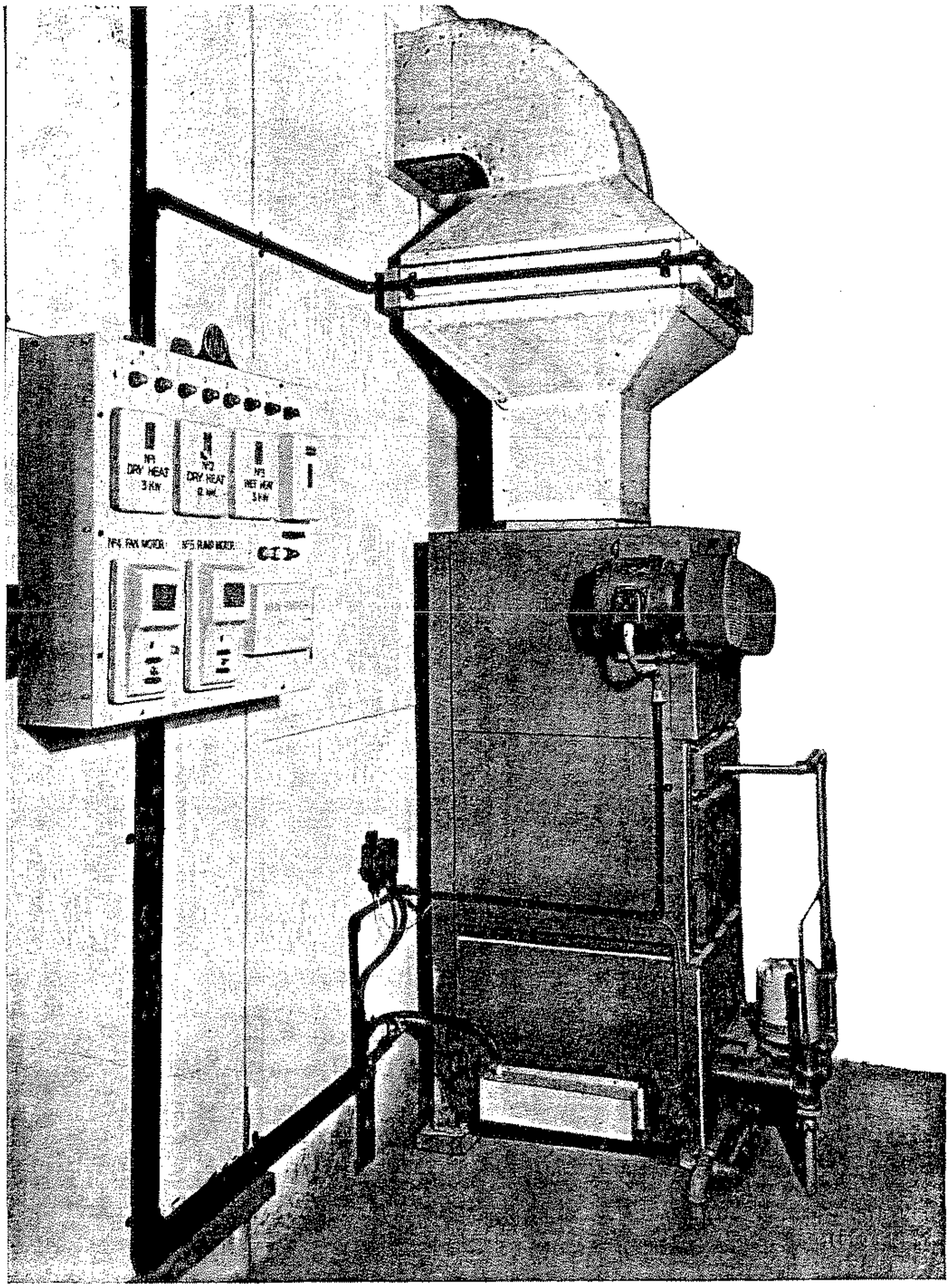

Figure 14—Air-conditioning plant for humidity test room.

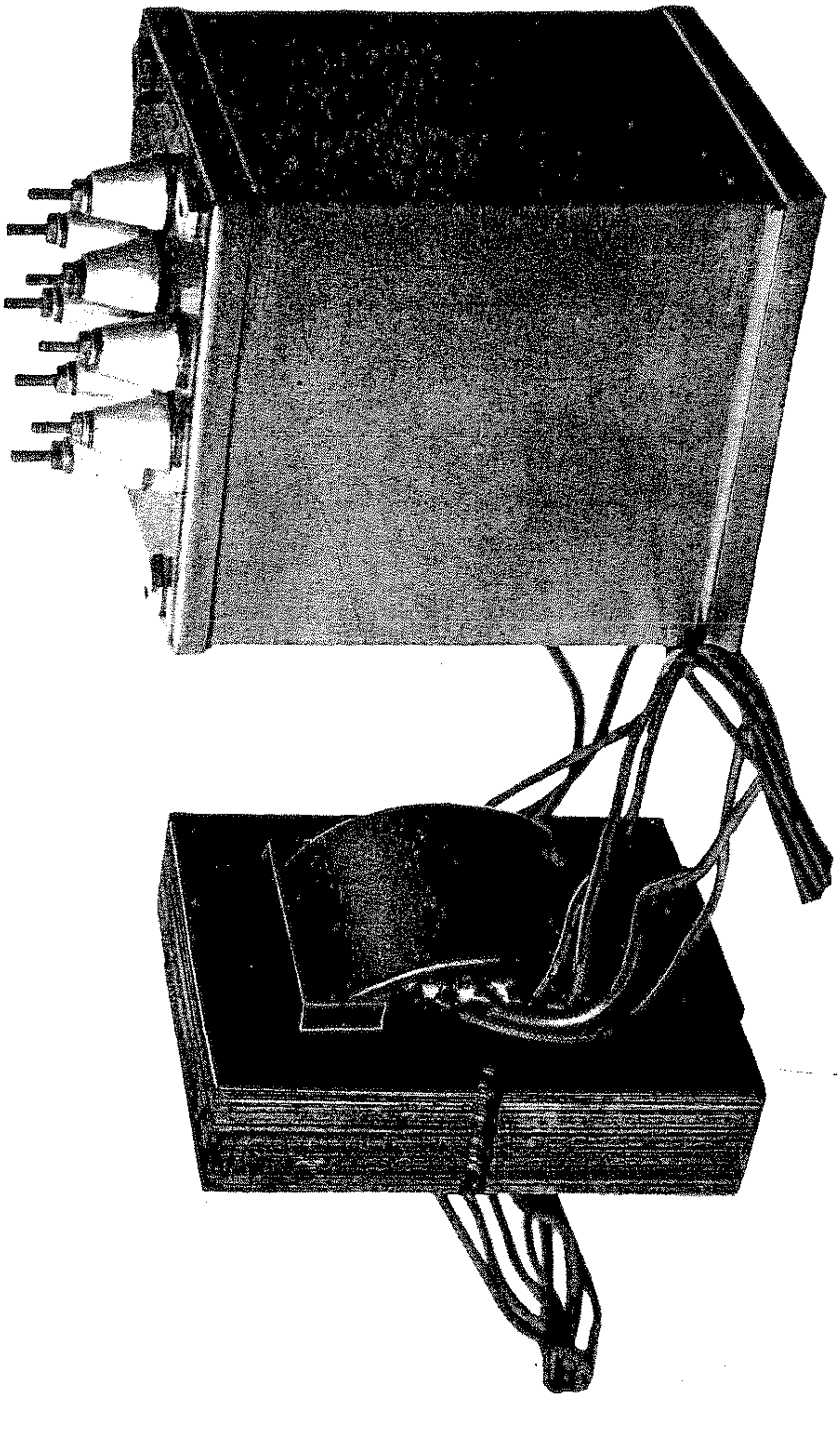

Figure 15—Open and sealed transformers.

and transport. This means that packing is of great importance. It is apparent that packing in air-tight waterproof containers, which are dry internally, will render it impossible for mould growth or corrosion to take place in the packed equipment, but this is difficult to achieve. Containers must be such that they are not damaged by :—

(1) Surface condensation ;
(2) Moulds ;
(3) Termites ;
(4) Spray.

As many packages are transported as deck cargo and are also sometimes wetted by rain and salt-water immersion, it is essential that they be reasonably immune to salt water, and it is essential also to provide some extra protection so that some inevitable damage in transit does not weaken the package in such a way as to render it susceptible to damage by factors (1), (2), (3) or (4) in subsequent storage. Where outer wooden crates are used, the timber should be treated by immersing in copper naphthenate solution to prevent mould and termite attack, as it has been reported that wooden crates, which have been stored in tropic areas, have fallen to pieces rapidly.

6—Humidity Test Methods

Static Humidity Test—This test involves the immersion of samples in a saturated atmosphere at 86°F. for 28 days, as described under section 4 (Test Chamber).

In some cases, closed glass jars, containing water and enclosed in ovens at controlled temperature, are used.

In some instances, measurements were made while the sample was in the chamber, but generally after removal from the chamber. In most cases, a ½-hour recovery period at room temperature was allowed before measurements, to allow surface water to evaporate. Unless otherwise specified, figures shown were obtained by the latter method.

Conditions for the 'static humidity test' were selected to simulate bad damp storage conditions which have been encountered and which have caused considerable damage. It is reasonable to assume that radio equipment would, after removal from such storage, be given an opportunity to dry out before being put into use. Consequently, measurements are made at ½-hour, 1 hour, and several hours after removal, in order to distinguish between temporary and permanent deterioration.

Humidity and Temperature Cycles—A test with high humidity and cyclic variation of temperature, similar to that described in British W.T.B. Spec. K110 and embodied in Australian Allied Services Specification, CL1001B, was used.

This test comprises one dry-heat run of 6 hours at 70°C., followed by a number of cycles as follows :—

1. Sample at room temperature placed in chamber at 15° to 30°C.
2. Raise temperature to 60°C. and relative humidity to not less than 95 per cent at this temperature, with forced air circulation and maintain for 6 hours.
3. Turn off source of heat and humidity, and allow chamber to cool for about 16 hours.
4. Repeat cycles 1, 2, 3, as many times as specified.

For experimental purposes 10 cycles has been selected as a useful indication, and if the relative humidity is above 95 per cent deterioration is generally greater than for an equal time in the 'static humidity test.'

Most of the cyclic tests were carried out in chambers of the type shown in figure 3, but a larger humidity test chamber measuring 8 ft x 8 ft x 12 ft inside, as shown in figure 13, was built to handle complete transmitting equipment. The inside of the chamber was built entirely of copper and was supplied with circulating air of the required moisture content by the air-conditioning plant shown in figure 14. With the assistance of National Standards Laboratory, Sydney, a special electric recording psychrometer was made to measure relative humidity in the chamber.

7—Effects of Humidity on Components, and Prevention thereof

Power Transformers—Open-coil types of power transformers are unsatisfactory for use in tropical conditions ; water is absorbed through voids in the varnish impregnation, lowering the insulation resistance, and condensation takes place on the unit, forming water paths around barriers on the open ends. Even though the wire itself may be protected by a layer of insulating varnish, there remains only a small separation between high-voltage windings which will break down easily when moist, forming a carbon track and permanently damaging the units.

It is quite common for the insulation resistance between windings of this type of transformer to be reduced from thousands of megohms to a few thousand ohms after a week's exposure. In some cases in the past, complete breakdown of the units has been reported after the set has been left exposed to a tropical thunderstorm.

To withstand tropical service, power transformers are now being impregnated by a vacuum process using petroleum asphalt. Material with a 'ball-and-ring' test (A.S.T.M.) of 85°C. is used. Each is then tanked in a welded sheet-iron can filled with a reasonably plastic high-melting-point petroleum asphalt, leaving an air space for expansion at the top. Bitumen with a 'ball-and-ring' test of 120°C. is used. The can is sealed by soldering the flanged lid in place. Terminals of porcelain are fitted in the base extending into the filling compound to reduce surface leakage. The porcelain terminals are compound filled (see figure 15) ; most of the transformers for ordinary service equipment are made that way.

The advantages of this method are obvious, as the transformer can be operated quite safely after complete immersion in water, and as the sealing compound completely fills the space around the transformer, condensation in tropical climates cannot have any effect on the transformer's internal insulation. The danger of undried varnish in the transformer with its effect on insulation, is eliminated.

It has recently been found practicable to vacuum impregnate coils for open transformers with petroleum asphalt instead of the usual varnish, without any danger of much running of the impregnating material even up to 100°C. A measure of protection better than that afforded by available insulating varnish is provided. A series of tests with a wide variety of insulating varnishes showed that the ordinary paper-interleaved coil cannot be waterproofed with varnish. Oil immersion is perhaps the ideal method and transformers for high voltage and special applications are oil filled as shown in figure 16.

Audio Transformers—The same remarks apply to these transformers, as to power transformers, although the main trouble encountered is due to electrolytic action on the fine copper wire, causing open circuits, rather than insulation breakdown as in power transformers. The ordinary type of audio transformer is relatively small, and until recently common practice has been impregnation with either petroleum asphalt or ceresine estergum, followed by insertion in a drawn can, usually having an open end, which is then filled with a plasticised gilsonite mixture through which the leads are brought out. This mixture will not flow for long periods at 70°C.

Cotton-braided wire, such as Belden 'Ravine,' should not be used for these leads as moisture or water can gain access to the coil along the 'wick' formed by the cotton braid. If V.I.R.-covered wire is used, moisture may gain access between the rubber and the wire. This may be prevented by fitting a metal ferrule on the coil end of the lead, and this ferrule compresses the rubber on to the wire. Bare tinned copper wire, or wire surrounded by a perforated plastic sleeving (polyvinyl chloride) which allows penetration of the filling compound to the actual bare wire, may be effective for leads.

In many cases small audio coils, after vacuum impregnation with petroleum asphalt are inserted in small pressed metal cans, each of which has a flat metal base with rubber-covered leads through it, the base being then soldered on to the can. The rubber-covered leads are brought through small holes in an internal rubber sheet, thus providing a moisture-proof seal. Each can is then pressure filled with petroleum asphalt through a small hole which is subsequently solder sealed.

Large audio transformers or modulation chokes are treated in the same way as power transformers.

Foil Paper Capacitors—The ordinary paper-wrapped, wax-coated, tubular paper capacitor is unsatisfactory for tropical conditions, as moisture rapidly lowers the insulation resistance. Insulation resistances of the order of 100,000 ohms/microfarad are very common after a few weeks in service. Severe trouble has also been encountered with various metal cased types and with phenolic moulded capacitors.

Many capacitors contained in metal tubes have poor end seals which do not stand up to tropical conditions. Rubber end seals perish in some cases, and moisture seeps in. Phenolic moulded types have generally been unsatisfactory, as the seal between metal leads and the phenolic moulding is not perfect. With these capacitors, soaking in wax is recommended as a protective measure.

Tubular paper capacitors encased by an injection moulding process in a gilsonite-base compound, have been made for many years and have given good service. Figure 10 shows this capacitor alongside a solder-sealed glass-cased capacitor. In this illustration, mould is shown growing on the paper label, which has since been eliminated. Owing to the difficulty in getting moulding compounds to adhere to the tinned copper-wire lead, treatment of the lead with a rubber compound prior to moulding was adopted. This measure prevented leakage of moisture along the lead and rendered the capacitor entirely suitable for damp tropical conditions.

As the paper capacitor is such a critical component in radio equipment, thorough investigations were made to produce a hermetically sealed unit before the lead sealing of the moulded capacitor was completed. This investigation led to the development of the metal to glass sealed capacitor, shown in figures 10 and 16.

Punching Phenolic Sheet—Punching phenolic sheet is widely used in radio equipment for such things as valve sockets, coil bases, intermediate-frequency transformer bases, and component assembly panels. Figure 17 shows such a panel with components mounted on it, together with test specimens for resistance tests to the British Standard Specifications No. 1137 and No. 547.

There are very many grades of phenolic sheet. Canvas and linen-based sheet have no value as electrical insulators when exposed to damp conditions, on account of water absorption by the canvas or linen.

It is difficult, if at all possible, to make large quantities of radio equipment in this country without the use of phenolic sheet, because sufficient quantities of other suitable materials are not available. Only the highest

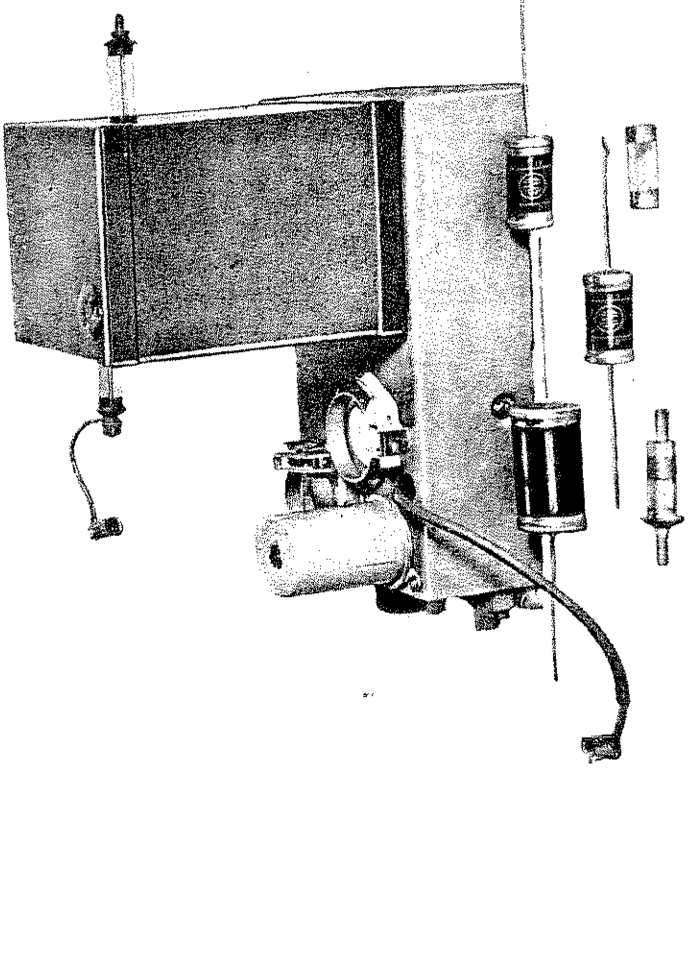

FIGURE 16—Metal-to-glass seals for capacitors and transformers.

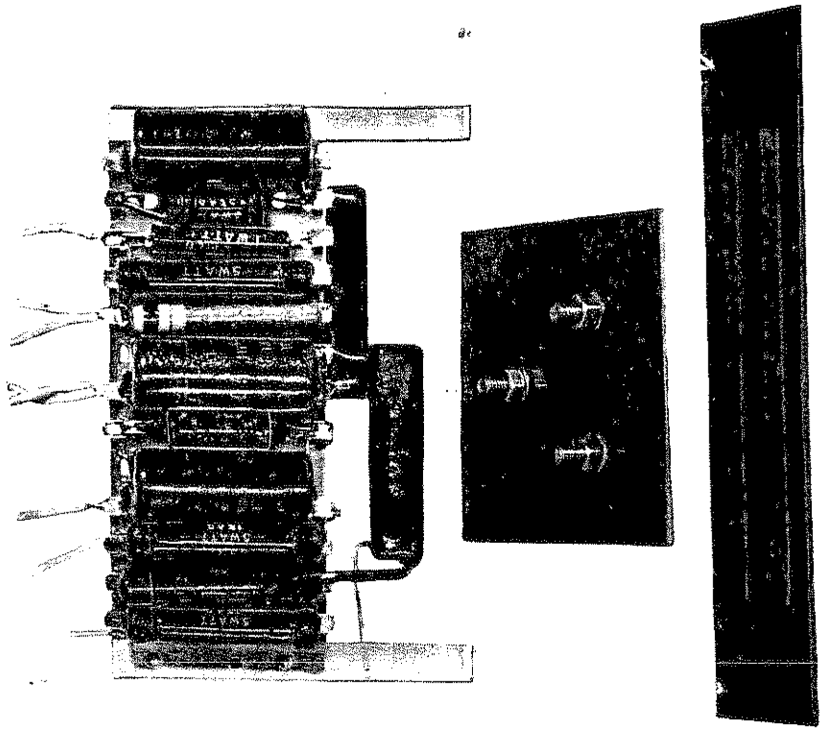

FIGURE 17—Tropic-proofed assembly and phenolic test pieces.

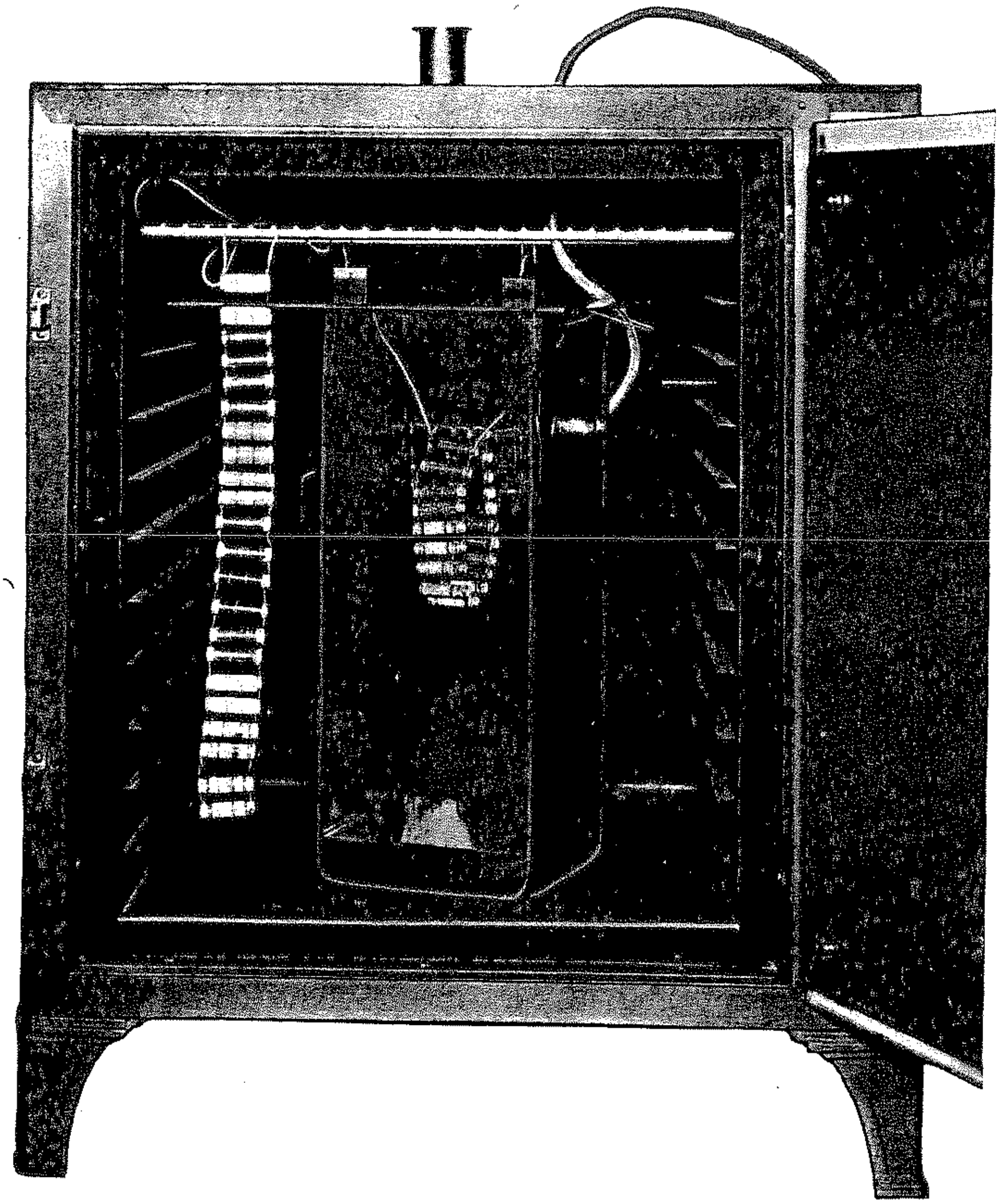

Figure 19—Corrosion test for insulating material.

grades of paper-laminated phenolic sheet should be used and, as an added protection after all punching operations, the panels should be treated with the highest grade water-resistant baking varnish. On the highest grades of material, severe humidity test for a prolonged period does not show any prolonged protection offered by the varnish treatment, but slightly less severe conditions do show improvements due to the application of varnish. Furthermore, in this application a good varnish has not been known to have detrimental effects.

B.S.S. 1137 contains a clause specifying a certain insulation resistance after 24-hours water immersion, and high-grade materials usually pass this test without difficulty.

Figure 18 shows how the equivalent r-f resistance of three typical grades of paper-based phenolic sheet decreases with time of exposure to a saturated atmosphere at 40°C. Unfortunately, long exposure to saturated atmosphere causes some damage to some of these materials, as the fall in resistance is more rapid with each successive exposure. This laminated material is a better insulator for humid conditions than wood-filled phenolic mouldings, but is inferior, both in power factor and resistivity, to good ceramic materials.

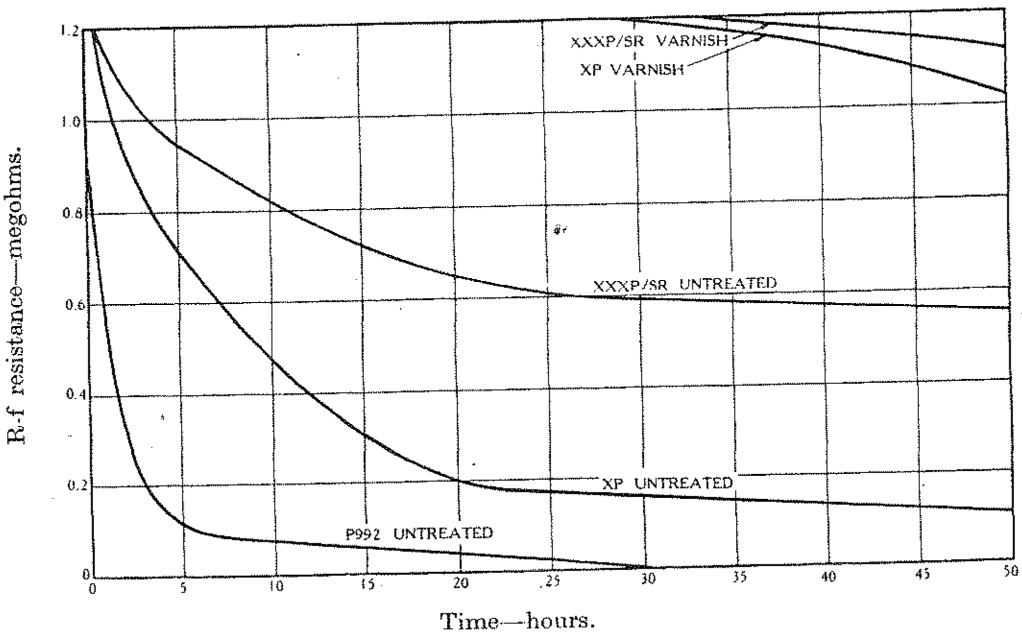

FIGURE 18—Equivalent parallel resistance of S.R.B.P. sheet at 455 kc between terminals $\frac{3}{16}$ in. apart in saturated atmosphere at 40°C.

Ceramics—Ceramics give trouble through both water absorption and surface wetting. With high grades of ceramic materials, water absorption is not serious, but surface wetting can cause low resistance along the surface.

This is not always very serious, but in some cases where sufficient power is not available to dry it out, as with tuning-capacitor insulators, a serious loss in Q may result. In some cases the surface characteristic has been improved by treatment with a thick coat of polystyrene solution. This polystyrene coating does not prevent water absorption by the ceramic in the case of poor ceramics, but forms only a non-wetting surface. Varying reports concerning the advantages of 'Drifilm' have been received from overseas, but the material has not been available for test.

Phenolic Mouldings—Table 1 shows some comparative results obtained between wood-filled and mica-filled phenolic mouldings. Wood-filled phenolics are badly affected by saturated atmosphere or water immersion, the wood flour particles absorbing moisture and swelling, causing a roughening of the surface and consequent poor electrical properties. High-grade mica-filled phenolic mouldings are very much better.

Tests to B.S.771.	Mica-filled.	Wood-filled.
Surface resistivity (Megohms)	> 900,000	320
Dielectric strength	7.5 kV for 1 min.	Breakdown at 3 kV
Water absorption (7 days)	12 mg.	166 mg.

TABLE 1. Results of tests on moulded phenolic specimens.

Mica Capacitors—Table 2 shows comparative results of humidity tests on mica capacitors moulded from wood, mica-filled phenolics, and wax-treated mica-filled phenolics. Wood-filled phenolics are not suitable for tropical sealing, and mica-filled phenolics are very much better. At the same time, adhesion of the phenolic materials to wire leads cannot be ensured, and dipping in wax effects a definite improvement.

Corrosive Influence of Materials—Figure 19 shows a set-up for testing materials for their corrosive influence under humid conditions with polarising voltage. The materials, such as waxes, papers, varnishes, etc., are coated on the outside of glass tubes, and a few turns of copper wire are wound on the tubes near the ends, with a one-inch space between. A potential is applied between these windings, and the tubes are suspended in a closed glass jar above a free water surface. The jar is maintained in an oven at the required test temperature for some weeks. This test is particularly

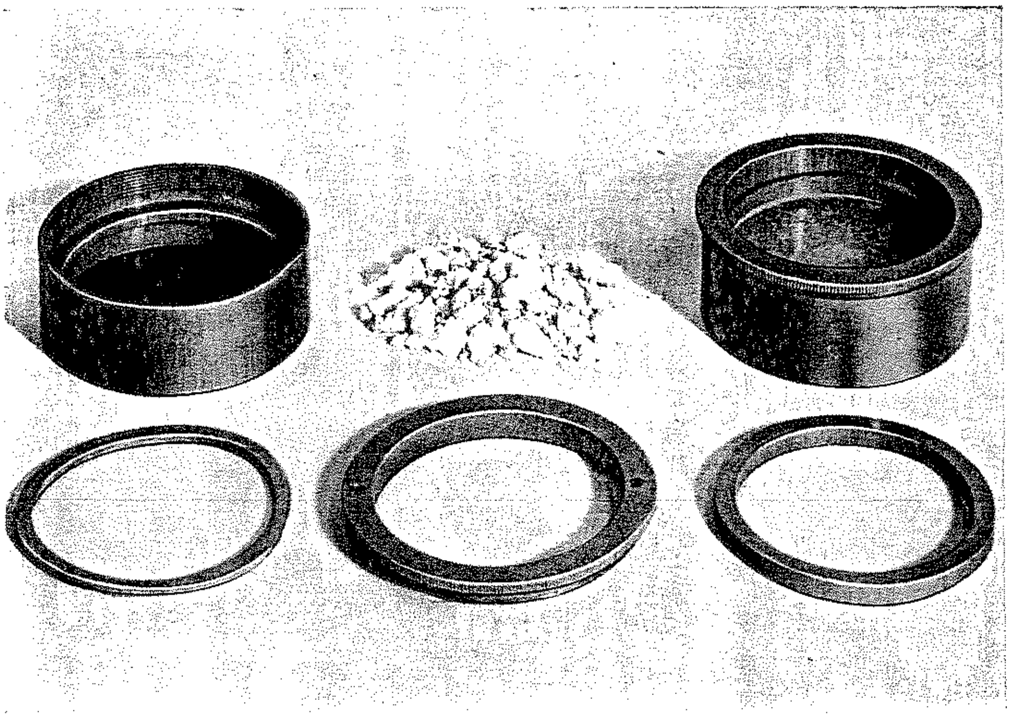

FIGURE 20—Moisture vapour permeability test cup.

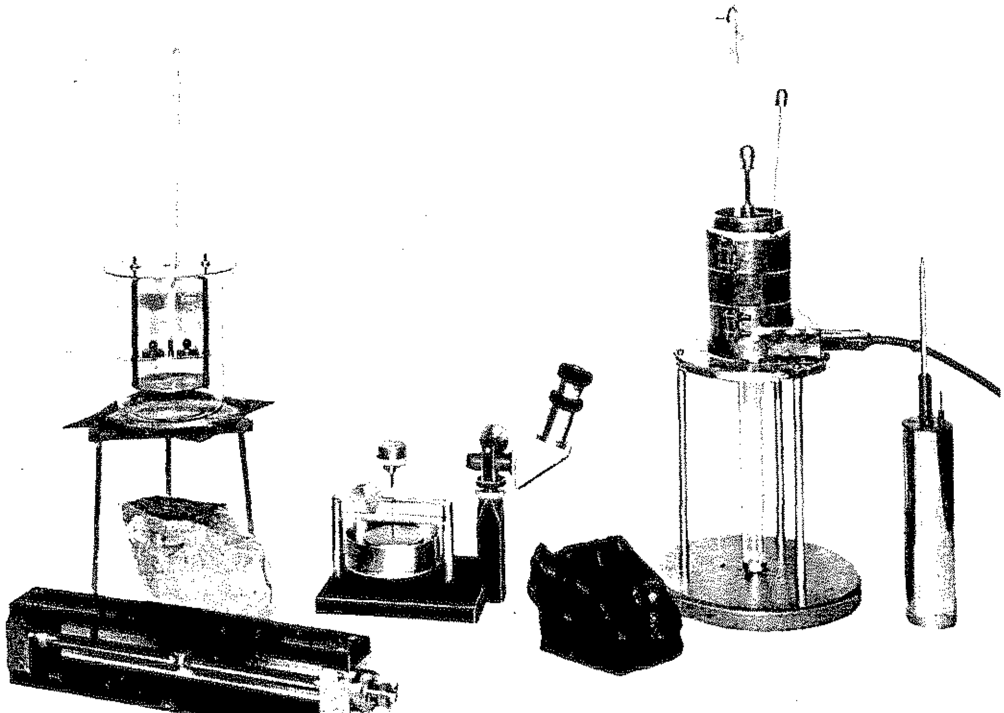

FIGURE 22—Laboratory apparatus used for bitumen testing.

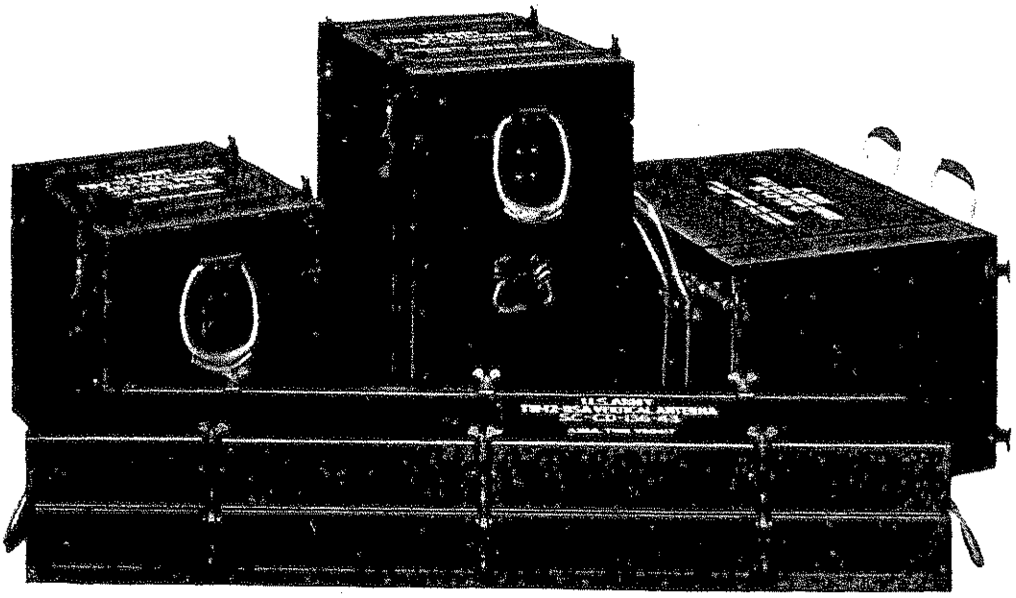

Figure 23—Radio equipment in tropic-proofed transit cases.

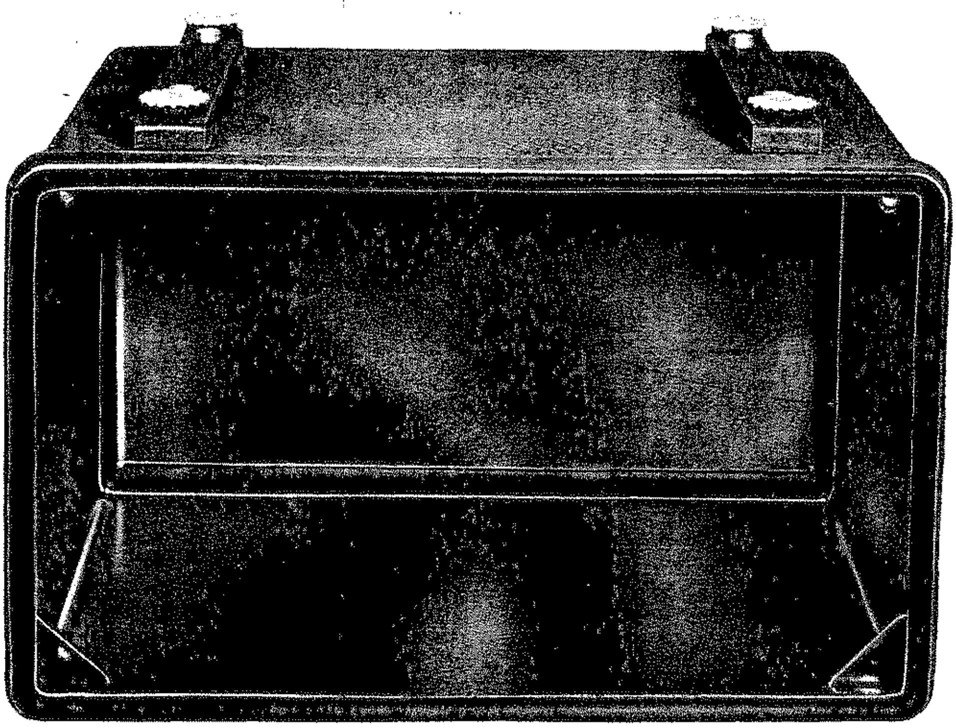

Figure 24—Moisture-proof case for radio receiver, showing rubber seal.

Measurements made initially, and after 20 humidity cycles.				
Type of moulding.	Resistance—Megohms		Q	
	Initial.	Final.	Initial.	Final.
Wood flour filled	> 50,000	30	> 2,000	330
Mineral filled	> 50,000	4,000	> 2,000	2,000
Mineral filled and wax treated	> 50,000	50,000	> 2,000	2,400

TABLE 2. Results of tests on moulded mica capacitors.

important for materials used in tropical equipment, as the presence of moisture accelerates any electrolytic action.

Many insulating materials have been subjected to this test and some correlation between the pH value of the aqueous extract of the material and its actual corrosive influence has been found. Certain materials, including a particular glassine paper which has shown an acid pH test, have caused corrosion on copper wire in the above test within a few days.

Varnish Testing—Table 3 shows the results of tests on a high grade water-resistant insulating varnish. The type of specimen used for surface resistivity measurement, made by coating 2 mil. Kraft paper, had an electrode arrangement similar to that required for testing phenolic sheet in B.S.S. 547. For tropical sealing applications the most important property of the varnish is its resistance to the diffusion of moisture through it. This is measured by coating 2 mil. Kraft paper with varnish, so as to form a total thickness of 0.005 in. with two dips, and using this as a diaphragm in the diffusion test cup, shown in figure 20. Calcium chloride is used as the desiccant. Figure 21 shows rates of diffusion for different varnishes. The diffusion test is carried out in a saturated atmosphere.

Specific gravity at 60°F.	0.920
Percentage of solid	51.1
Surface resistivity in megohms	880,000
Dielectric strength (a) conditioned	1,700
in volts per mil. (b) 24 hrs. in water	1,100
Moisture diffusion constant, g./hr./cm/mm Hg.	2.5×10^{-8}

TABLE 3. Results of tests on sealing varnish test specimens.

Many tests are required when an accurate comparison between the merits of insulating varnishes is to be made. These tests should be selected from a consideration of the application of the varnish. Moisture permeability, while of primary importance with a sealing varnish, may not be as important with a coil-impregnating varnish as dielectric strength, drying properties and solvent effects on enamel wire.

Tests have been developed to compare all of these different properties. Only a very small proportion of the varnishes tested were satisfactory for general use. Surface resistance properties under moist conditions are sometimes important and one Australian manufacturer produced a 'No Wet' varnish in which these properties were improved to a remarkable degree. Tests performed on rotary machines and many other components treated with varnishes selected on results of laboratory tests, have established the value of such tests.

Sealing and Filling Compounds—Many radio components are sealed or impregnated with bituminous or wax compounds. Transformer coils are vacuum impregnated with bitumen or petroleum asphalt, while some coils are sealed by dipping in suitable compounds (commonly called waxes). Capacitors are wax impregnated and moulded in other compounds. Other meltable materials again are used for filling metal-cased components. As each of these materials must have properties to suit each particular application, a considerable amount of laboratory work has been involved in their

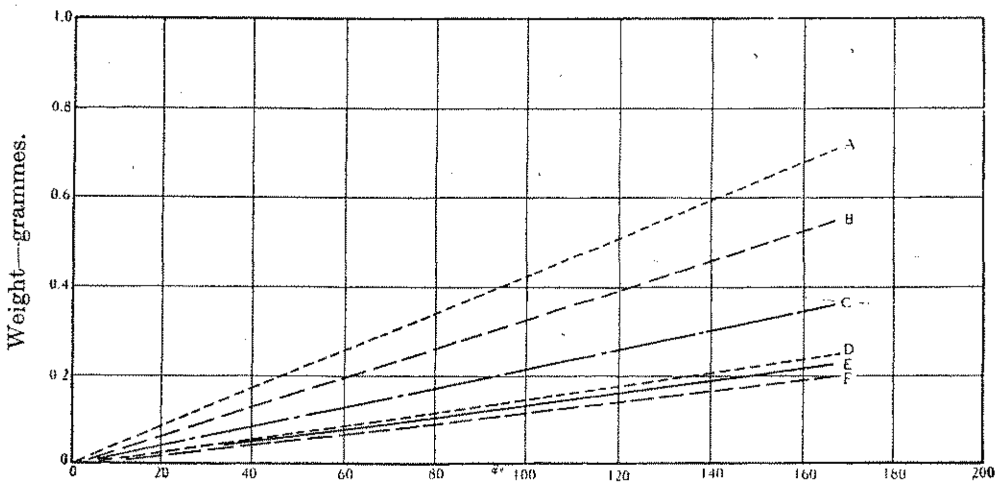

FIGURE 21—Moisture vapour permeability tests on varnish films.
A. American varnish compounded from cachew nut shell liquid.
B. Plasticised P.V.C. solution.
C. American varnish.
D. Oleo-resin phenolic varnish.
E. Oleo-resin varnish.
F. Alkyd resin solution.

development and application. Similar work has to be carried on continuously to control these properties in manufacture.

Tests for some of the properties of these materials are set out in British and American Standard Specifications, the more important being ball-and-ring softening temperature, dielectric strength, power factor, dielectric constant, rate of flow, penetration and adhesion. Water absorption is usually negligible. Apparatus required for these tests is shown in figure 22.

Tropic-Proof Equipment Cases—An effective method of protecting equipment until it is opened up for actual operation, is to enclose the equipment in water-proof equipment-carrying cases, as shown in figure 23. These cases are constructed from water-proof plywood covered with canvas, and each lid is sealed by means of a synthetic rubber gasket. All of the materials used have been treated to render them moisture, mould, and termite-proof.

Another effective means of protection is to seal the equipment in a metal water-proof case by means of a rubber gasket (figure 24), which the front panel of the equipment compresses, giving a water-proof seal. A quantity of silica gel is sealed inside the metal case with the equipment, to dry the air initially enclosed. This desiccant is capable of adsorbing up to 40 per cent of its own weight of water provided it is thoroughly dried before use, but it should be renewed if the moisture-proof seal is broken at any time.

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