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PREVENTION OF DETERIORATION OF ELECTRONIC
EQUIPMENT STORED IN TROPICAL AREAS

The attached Report was prepared for USOM/Saigon Public Safety Division by the Radio Industries Company of Kansas City, Kansas. The report was prepared in order that the Public Safety Division would have this information available for translating into the Vietnamese language for the Government of Vietnam Department of Interior combined Telecommunication Service.

The information included in this report concerns the deterioration of electronic equipment stored in tropical areas.

PREVENTION OF DETERIORATION OF ELECTRONIC EQUIPMENT STORED IN TROPICAL AREAS

I. INTRODUCTION

This report concerns the problem of deterioration and corrosion of electronic equipment and components stored in tropical areas, and was prepared on the basis of a survey of the literature available in books, periodicals, and unclassified government reports. The problem of deterioration of electronic equipment while in use in tropical areas is covered in a subsequent report.

Temperature such as encountered in tropical areas is not in itself a cause of deterioration. The presence of large amounts of moisture in the air at these temperatures does however, cause severe deterioration of electronic equipment. Some of the effects of moisture are reversible in that the component returns to a satisfactory operating condition after being dried out prior to use. Other effects such as corrosion, growth of fungus, and deformation of insulating materials are irreversible and require maintenance or repair before the equipment is in satisfactory operating condition. Electronic equipment for use in tropical should be designed to minimize the effects of moisture. Spare parts should be packaged in moisture proof containers. Dehumidified

storage is probably the best means of preserving equipment without recourse to special packaging. A totally enclosed building such as a quonset hut without ventilation, or dehumidification, is probably the worst condition for storage of equipment, electronic or otherwise.

The report is divided into five parts: one, effects of moisture on electronic components; two, effect of temperature and humidity on deterioration; three, dehuminified storage; four, prevention of deterioration; five, recommendations.

II. EFFECTS OF MOISTURE

1. General Effects on Electrical Materials:

The presence of moisture on the surface of insulating materials reduces the surface l eakage resistance, but unless the equipment is operated while damps, such that electrical discharge occurs across the surface of a material which will carbonize, no effects of surface moisture remain after the equipment is dried out. The absorption of moisture by organic insulating materials may create permanent mechanical deformation of the material, and perhaps even disintegration. (Ref. 3, p 16)

2. Resistors:

The absorption of moisture into the material from which resistors are made will create changes in electrical resistance. These effects are essentially reversible except that

a 10% change is allowed for composition resistors exposed to 104° F at a relative humidity of 90 to 95% for a period of 250 hours (Ref. 3, p 35). For film type resistors a change of 5% may occur over long periods of time when exposed to high humidity (Ref. 3, p 41.) The moisture absorbed by a precision wire wound resistor may not be driven off under normal conditions of operation since such resistors normally have little self-generated heat, and are usually located deliberately in the cooler parts of the equipment. The absorbed moisture would thus in practice have an irreversible effect on the value of resistance when stored under humid conditions. The effect of humidity on composition potentiometers is the same as for composition resistors (Ref. 3, p 65.). Wire wound potentiometers present some problems in addition to those mentioned for wire wound resistors. The phenolic card or form upon which the resistance wire is normally wound will absorb moisture. This moisture can lead to a mechanical breakage of the wire and/or a destruction of the wire by electrolysis when the equipment is later operated (Ref. 3, p. 68.).

3. Capacitors:

The moisture absorbed by the dielectric material of a capacitor will decrease the dielectric strength, the insulation resistance, and the life of the capacitor. The losses in the capacitor, both dielectric and resistive, will increase

with a corresponding reduction in the Quality Factor, (Q), of the circuit. Moisture on pressure contacts which are not gas tight may cause an increase in contact resistance, or in some cases an open circuit (Ref. 4, p. 88). Under conditions of high humidity, the insulating material of ceramic capacitors may absorb sufficient moisture to cause silver ion migration when the capacitor is used with a high dc potential across it. The migration of silver ions may cause a short circuit in a relatively short period of time (Ref. 4, p. 109). Since electrolytic capacitors must contain moisture in order to function, the problem is to keep them from drying out during storage and operation (Ref. 4, p. 119). The storage of electrolytic capacitors may also allow the oxide film to deteriorate such that it must be reformed before the capacitor can be used. The film can be reformed by applying a reduced dc potential to a series combination of a resistor and the capacitor. The dc potential is increased as a reduction of the leakage current indicates that the film is reforming (Ref. 4, p. 119). The above statement applies to electrolytic capacitors in equipment which is being stored, or is otherwise inactive, as well as to spare parts not installed in equipment. Moisture is extremely detrimental to the life of paper capacitors. Very small amounts of moisture absorbed by the dielectric material will increase the rate of chemical reaction

within the capacitor, and severely shorten the life of the capacitor.

4. Transformers and Chokes:

Power transformers, interstage transformers, and filter chokes used in military electronic equipment are hermetically sealed. The only effects of moisture are therefore external surface leakage when damp and possible corrosion of the case, terminals and connections. The life of unsealed power transformers and chokes will be severely shortened by the absorption of moisture. Radio frequency and intermediate frequency transformers, and radio frequency chokes are subject to deterioration if not hermetically sealed. The absorption of moisture by the insulating material around and between the windings reduces insulation resistance, changes the distributed capacitance, and therefore, the Quality Factor, (Q) of the coil. Since such radio frequency components have little self-generated heat under normal operating conditions, the absorbed moisture will be driven off slowly, it at all, under conditions of operation. Inductors and transformers such as those used in the radio frequency sections of radio transmitters are not much affected by moisture unless it is absorbed by the insulating material which supports the coil, or coils. In this case the shunt resistance across the coil will be decreased, the Quality Factor, (Q) reduced,

and the circuit may be detuned. It is probable that sufficient heat would be generated by adjacent vacuum tubes to drive off the absorbed moisture under conditions of operation.

5. Vacuum Tubes and Semiconductors:

Since vacuum tubes and semiconductor devices are hermetically sealed, moisture can not react upon the interior of the device. Moisture on the surface, if not removed by the heat generated by normal operation of the circuit, would cause reduced insulation resistance and possible malfunction of the circuit. Dry disc rectifiers are not usually hermetically sealed and hence may be damaged by absorption of moisture.

6. Switches and Relays:

Moisture absorbed by the insulating material of a switch or relay will lower the insulation resistance. For low voltage applications, the leakage resistance may be low enough to cause a malfunction of the circuit. For higher voltage applications arcing may occur which will further damage or even destroy the component. Corrosion of the metal parts of the switch may lead to mechanical failure (Ref. 3, p. 186). Switches have not self-generated heat, and relays only that heat produced by the coil when energized. These components may, or may not dry out satisfactorily under normal operation.

7. Fungus:

Tropical conditions of temperature and humidity are very favorable to the growth of fungus. Although under most circumstances the presence of the moisture, without which the fungus could not grow, is more damaging than the actual fungus growth, the presence of the fungus may also have added to the deterioration. Unbraided plastic insulated hookup wire has been found to maintain good insulating properties in the presence of 100% relative humidity without fungus, whereas in the presence of fungus, the insulation resistance dropped from one million megohms to five megohms (Ref. 5, p. 6-24).

8. Corrosion:

Electronic equipment is generally constructed from materials which either inherently resist corrosion rather well, such as aluminum, copper, and brass, or which have been plated with corrosion resistant materials. Galvanic action may occur when two dissimilar metals are placed in contact with each other in the presence of moisture. For example, brass and aluminum should never touch directly. Procurement specifications for military electronic equipment are designed to eliminate this kind of problem by requiring suitable plating or other surface treatment to passivate the more active material. Any iron or steel used in the construction of military electronic equipment is

required to have suitable corrosion resistant plating or other surface treatment after completion of manufacturing and before assembly to prevent damage by humidity.

III. EFFECT OF TEMPERATURE AND HUMIDITY ON DETERIORATION

1. Moisture:

The amount of moisture which penetrates into a given substance is a direct function of the partial pressure of the water vapor in the air when equilibrium has been established. The partial pressure of the water vapor is a function of the absolute humidity, that is the weight of moisture present per unit volume. A localized increase in the temperature over a sizeable area including the air surrounding sources of moisture (lakes, rivers, vegetation) will permit an increase in the absolute humidity; however, the relative humidity may increase, decrease, or remain unchanged. Relative humidity is the ratio of the absolute humidity to the maximum possible absolute humidity at the temperature given. Thus as the general level of temperature rises, more moisture may be available to penetrate stored materials. The graph of Figure I shows the absolute humidity, grains per cubic foot, as a function of temperature and relative humidity. For example, it can be seen from this curve that the amount of moisture penetration under conditions of 85° F

and 95% relative humidity would be approximately the same as for a temperature of 95° F and 70% relative humidity. Thus the amount of moisture absorbed by a given material or component would be approximately the same at 85° F, 95% relative humidity as at 95° F and 70% relative humidity.

As the temperature falls during the afternoon and evening, the amount of water vapor per unit volume is substantially constant, and therefore the relative humidity increases. When the temperature lowers sufficiently to cause 100% relative humidity, dew forms. The condensation of moisture on metal surfaces promotes corrosion not only of the ordinary sort, but also galvanic action between disimilar metals. If the equipment contains regions which are not well ventilated and drained, moisture may accumulate on the inside. If a space is partially sealed, moisture will accumulate on the inside by a process known as "breathing". As the temperature falls, moist air is drawn into the space and upon further reduction in temperature condensation will take place. When the temperature rises air will be driven out by expansion, but some of the water will remain. As the process is repeated, moisture will accumulate. Thus, a poor seal is worse than no seal at all under conditions of high humidity and cycling temperature (Ref. 5, p. 6-23).

2. Temperature:

The rate at which chemical reactions proceed increases with temperature by a factor of two to three times for an 18° F (10° C) increase in temperature (Ref. 8, p. 236). Thus, corrosion and other chemical deterioration would be expected to take place at a rate of one-third to one-half as fast at a temperature of 80° F as at a temperature of 98° F, if other conditions such as absolute humidity were the same. In general, an increase in temperature without a significant decrease in absolute humidity, would be expected to increase the rate of corrosion and other chemical reactions of deterioration. The exact balance between increase in temperature and decrease in absolute humidity to give the same rate of deterioration, would depend upon the particular chemical reaction involved in the deterioration.

IV. DEHUMIDIFIED STORAGE (DHS)

1. Background:

The United States Navy began in the early 1940's an investigation of the advantages of dehumidified storage for the materials usually found on inactive naval vessels. Material was stored for a period of four years in constant humidity chambers and inspected periodically for deterioration. Four different

levels of relative humidity were maintained in the four test chambers. The temperature was not regulated and fluctuated as the outside temperature changed. These tests demonstrated that most material deteriorated very little, if any, when stored under conditions of 30 to 35% relative humidity (Ref. 11, p. 23). The exception to this generalization which is of interest in this report are dry cells. The dry cells stored under conditions of high humidity were found to have a longer shelf life than those stored under drier conditions. This result is not unexpected since dry cells are not really dry and must have some moisture present in order for the chemical reaction to take place. It is possible that dry cells made today are better sealed and would not dry out under a condition of 30 to 35% relative humidity. Although not reported in this test, unsealed electrolytic capacitors would be subject to deterioration if the electrolyte drys out, and hence may be subject to more deterioration when stored under low relative humidity, than when stored under higher relative humidity.

On the basis of the success with the controlled humidity storage tests, the United States Navy began in 1949 a program of construction of warehouses for dehumidified storage. The floors, walls, and ceilings were sealed with a moisture proof barrier and all doors and windows sealed with weather stripping. Desicant

type dehumidifying machines were used for reducing the level of relative humidity. These machines have two beds of desicant. The air to be dehumidified is circulated over one bed, while outside air is circulated over the other bed and discharged outside again. The bed which is being dried out is also heated by electric heaters to promote the drying process. The role of the two desicant beds is then reversed and the process continues. The construction and operation of the U.S. Navy dehumidified warehouses are covered in Reference 7.

2. Recent Developments:

The usual dehumidified warehouse requires special sealing of all surfaces to reduce the penetration of moisture through the walls, floor and ceiling. It may be quite difficult to seal some existing structures adequately for use as dehumidified storage, (DHS). A new method which can be adapted either to the construction of new DHS warehouses, or to the adaptation of existing storage to DHS, makes use of burlap material with an extruded polythene film on each side. This provides a very adequate moisture barrier for side walls and ceilings. Enough light will be transmitted to eliminate the need for windows. This material has been used for DHS by the U. S. Army. (Ref. 10, p. 285).

The use of DHS by the military is expanding as reported by Lt. Col. Oliver Dinsmore in the January, 1962 issue of Materials Protection (Ref. 1, p. 66).

Extensive use of DHS has been made by the U.S. Navy in preserving both naval vessels and the equipment found on board those units of the fleet placed on inactive status. All port holes and hatches were sealed and dehumidification machinery installed. Those units of the fleet which have been returned to service were found to be in good condition.

V. PREVENTION OF DETERIORATION

1. Good Design:

The prevention of deterioration begins with securing equipment which has been properly designed to resist deterioration. Some of the more important considerations are:

a. High quality, hermetically sealed components should be used wherever possible. Examples of components which should be hermetically sealed are transformers, chokes, relays, meters, capacitors, precision resistors.

Much progress has been recently made in sealing out moisture by the use of plastic coatings. The component to be protected is dipped in a suitable material (the material used by Westinghouse is called Fosterite) and

allowed to dry. Components may be encapsulated by placing them in a suitable mold and filling with an expoxy compound (Ref. 5, p. 6-12). These processes have the advantage of eliminating the necessity of a sealed metal case, and hence may be more economical than the components hermetically sealed in a metal case.

b. Hermetically sealed or encapsulated sub-assemblies such as filters, transistorized power supplies and multivibrator circuits should be used where possible.

c. Corrosion and fungus resistant materials should be used in the construction of such things as switches, jacks, plugs, terminal boards, sockets, and wire insulation.

d. Although MFP treatment, (coating with special moisture proofing and fungicidal materials) has been extensively used, it appears to be of debatable value. A test was conducted by the U.S. Navy on eighteen Navy communications receivers exposed in a quonset hut on the edge of the jungle. Some of the receivers had been given the MFP treatment and the others had not. The MFP treatment did not appear to contribute either to the operability or to the service life of the receivers. There was no doubt that corrosion and the growth of fungus was retarded by the MFP treatment, but the amount did not seem to have a significant effect on the

operability or service life of the receivers tested (Ref. 5, p. 681). A MFP coating is no substitute for the hermetic sealing or encapsulation suggested above, or for the use of materials which inherently resist moisture and fungus.

e. Electric heaters should be incorporated into the equipment to provide a convenient means of keeping the temperature of the equipment above the dew point when the equipment is not operating.

f. The mechanical design should provide adequate ventilation and avoid moisture traps.

2. Recommendations for Storage:

Since it may not always be possible to provide the best storage conditions, several alternatives are presented along with a list of things to be avoided:

a. Dehumidified storage (DHS) is the best means of preserving not only electronic equipment, but also most other material stored under conditions of 30 to 35% relative humidity deteriorated very little, if any. These tests included all types of material likely to be found on board an inactive naval vessel. (Ref. 11, p. 23). Two exceptions to the generalization are dry cells and electrolytic capacitors.

b. Moisture proof packaging is the best alternative to dehumidified storage as described above. Procedures for moisture

proof, packaging of equipment are given in "Preservation, Packaging and Packing of Military Supplies and Equipment", (Ref. 12). It is probably desirable that all spare parts be so packaged even if DHS is available in order to provide protection up to the time of use including any transportation that may be involved.

c. If neither dehumidified storage nor moisture proof packaging is possible, the equipment should be stored in a well ventilated area, elevated above the ground, and protected from rain. If means are available, such as built-in electric heaters, the temperature of the equipment should be kept above the dew point. Under extreme conditions a dew point of 88° F has been observed, (Ref. 9, 24). As long as the temperature of the equipment is maintained above the dew point, additional increases in the temperature of the equipment and surrounding air does not seem to be helpful unless there is a reduction in the absolute humidity.

d. Storage at elevated temperatures may be thought to give some protection to equipment, but proper conditions may be difficult to attain. As noted earlier in this report an increase of temperature gives a reduction in relative humidity, but not in absolute humidity. It is the absolute humidity which determines the amount of moisture

which will be absorbed by a particular material. If the temperature of both the material and the surrounding air is increased with no reduction in absolute humidity, the amount of moisture absorbed will remain substantially unchanged. Any chemical process of deterioration would take place at an increased rate as noted earlier. If the temperature of the material is increased, but not that of the surrounding air, then the amount of moisture absorbed by the material will be reduced because at higher temperature the vapor pressure of the moisture in the material will be greater than that of the moisture in the surrounding air at a lower temperature. The moisture in the material will be reduced until the vapor pressure of the remaining moisture in the material is equal to the vapor pressure of the moisture in the surrounding air. Thus it can be seen that if the temperature of the equipment is maintained at a higher temperature than the surrounding air, and if the surrounding air is replaced by fresh air, the moisture level in the equipment will be reduced over that which it would be if at the same temperature as the surrounding air. On the other hand, if the surrounding air is heated and circulated around the equipment, the amount of moisture in the equipment will not be reduced, and chemical deterioration will take place at a faster rate. The only satisfactory

way to maintain the equipment at a temperature above that of the surrounding air is to supply heat to the equipment by a means such as electric heaters installed in the equipment.

It is probable that the cost (amount of energy) required to maintain the equipment at a temperature sufficiently elevated to reduce the absolute humidity inside of components satisfactorily, would be at least equal to the cost of operating a dehumidified storage facility.

e. Air conditioning, considered as both a reduction of absolute humidity and temperature, would not be particularly advantageous for the storage of electronic equipment as compared to a reduction of only the absolute humidity. The initial cost of a refrigerated storage facility, as well as the operating cost would exceed the cost of providing only reduced absolute humidity. With the reduced temperature storage, there would be a significant amount of energy required to remove the heat which was transmitted through the surface of the storage facility.

f. Under no circumstances should equipment be stored in unventilated buildings such as quonset huts. Totally enclosed buildings will tend to breathe as noted earlier for components and equipment, and the humidity inside such a building will be higher on the average than the surrounding outside air (Ref. 6, p. 57).

VI. RECOMMENDATIONS

1. Electronic equipment for use in tropical areas should be constructed of high quality, moisture and fungus resistant material. It should be well ventilated and drained to prevent the accumulation of moisture by "breathing".

2. Electronic equipment should be stored in as dry an environment as possible. Dehumidified storage, DHS, should be used if possible. Moisture proof packaging should be used if DHS is not available.

3. Storage at elevated air temperatures such as 125° F is not helpful in preventing deterioration, and may actually promote deterioration caused by chemical reactions. If the equipment temperature can be elevated above that of the surrounding air, by means of internally mounted electric heaters, and if the equipment is well ventilated, the moisture absorbed by the equipment can be reduced. This latter condition if attainable in storage, might be superior to no special protection, but is inferior to DHS.

4. Refrigeration, a reduction of both temperature and absolute humidity, is not superior to storage at low values of absolute humidity as well as a reduction in temperature would certainly cost substantially more than the reduced humidity alone.

5. Electrolytic capacitors should be checked for excess leakage after storage, and reformed, if necessary, before use.

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ABSOLUTE HUMIDITY
(grains of water/cu. ft.)
as a function of
TEMPERATURE AND % RELATIVE HUMIDITY

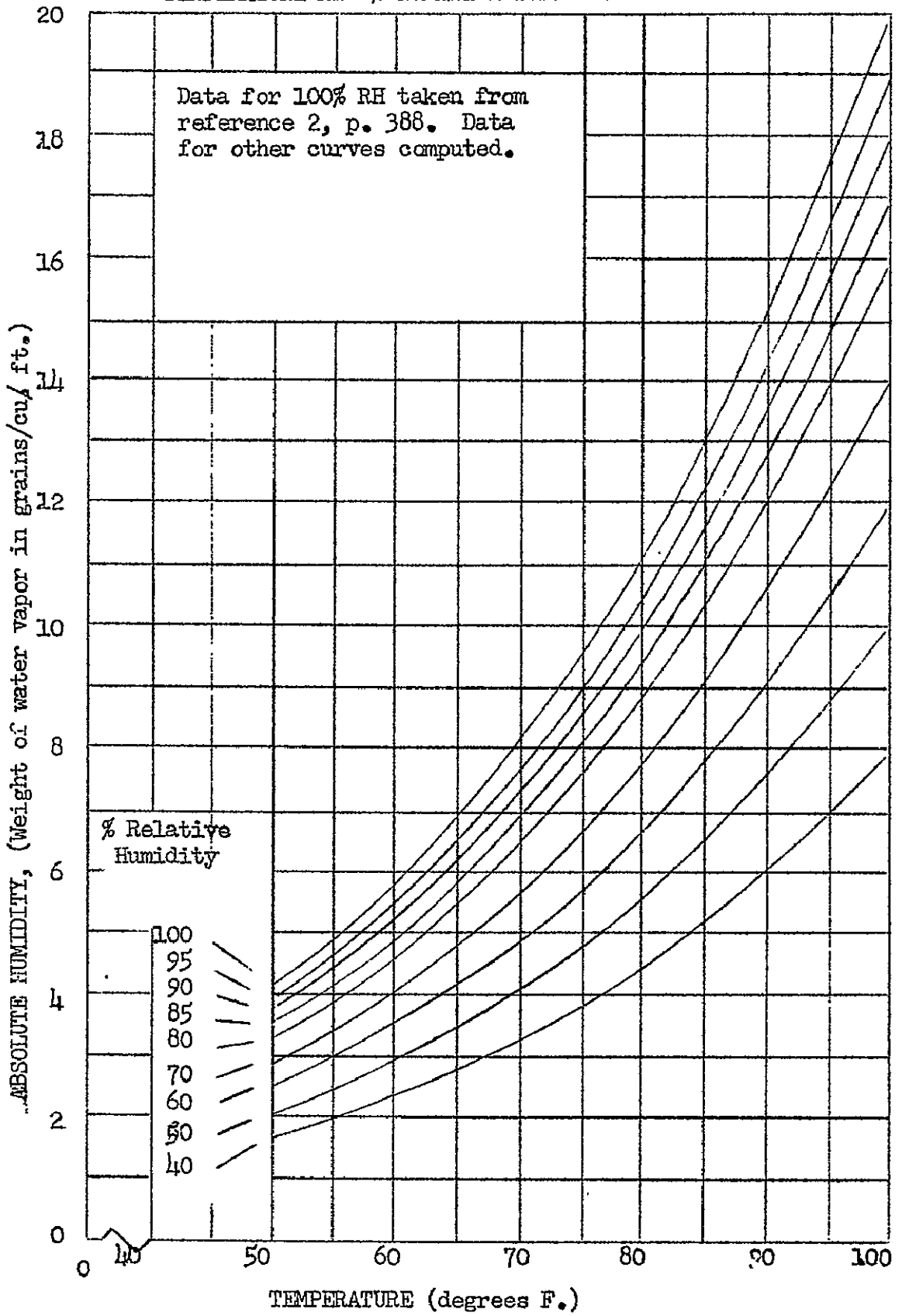

Figure I.