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**OAK RIDGE
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LABORATORY**

DEVELOPMENT OF THE PROTOTYPE
MUNITIONS CASE MOISTURE METER
MODEL ORNL-1

MARTIN MARIETTA

FINAL REPORT

February 24, 1993

Prepared for the Product Assurance Directorate
U.S. Army Armament Research, Development, and
Engineering Center
Picatinny Arsenal
Dover, New Jersey 07806-5000

By

D. C. Agouridis, T. M. Gayle and W. H. Griest

Oak Ridge National Laboratory
Oak Ridge, Tennessee 37831

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U.S. Department of Energy contract DE-AC05-84OR21400
with Martin Marietta Energy Systems, Inc.

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MASTER

DEVELOPMENT OF THE PROTOTYPE MUNITIONS CASE MOISTURE METER, MODEL ORNL-1

EXECUTIVE SUMMARY

There is a great need for a rapid and simple means of determining the moisture content in combustible cartridge case (ccc) munitions. Previous studies have demonstrated that accumulation of moisture in ccc rounds, such as the M829, leads to softening of the case wall and weakening of the adhesive joint. Moisture in the ccc can lead to incomplete combustion of the case upon firing the round. Currently, there are no facile methods for measuring the moisture content.

A prototype portable meter for non-destructive and rapid estimation of moisture in ccc has been developed. The Munitions Case Moisture Meter Model ORNL-1 demonstrates the feasibility of developing an instrument based on the moisture dependence of dielectric properties, to measure moisture in ccc munitions in storage and in the field. These instruments are simple, inexpensive, lightweight, portable, low-power battery operated, and intrinsically safe. They provide nondestructive, noninvasive, and rapid measurements.

Calibration data for the prototype are not available at this time. Therefore, calibration of the meter and the development of a scale reading directly moisture content in munitions rounds could not be completed. These data will be supplied by the U.S. Army from its tests of the meter with actual munitions. However, experimental results on empty cccs in laboratory conditions demonstrate satisfactory performance of the instrument. Additional work is needed to bring the prototype to its optimum usefulness and accuracy for field measurements. This includes:

- Calibration of the meter scale with full-up munitions.
- Data and evaluation procedures to adjust the performance of the meter for different environmental conditions such as temperature and humidity.
- Studies of the dielectric properties of moist ccc materials, as a function of frequency and temperature, are needed for adjustment of the meter for optimal performance.
- Improvements of the performance of the meter can be made by using measurements of more parameters as inputs in the evaluation process. The technology for such procedures is available in the form of microprocessors, and are currently used in thermometers and other instruments.

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INTRODUCTION

Moisture affects the quality and the performance of many materials and products, because it causes spoilage and failure through the processes of rot, freeze-thaw deterioration, frost heave, and water damage. It also affects combustible cartridge case (ccc) munitions, causing softening of the case wall and weakening of the adhesive joint.¹ Moisture content influences the mechanical, thermal, chemical, and electrical properties of materials. A great deal of effort has been devoted to the understanding, measurement, and control of moisture content in all types of industries. This report describes a meter which detects moisture in ccc munitions materials, via measurement of the electrical impedance of the cases. This prototype development was initiated after a scoping study² suggested the utility of capacitance measurements for determining water in ccc.

The meter is a modified adaptation of a commercial instrument designed to measure moisture in building materials. The modifications consist of changing the geometry of the electrodes and the operating frequency of the meter, and the development of a scale that reads directly the moisture content in munitions cases. The meter provides rapid, nondestructive, and noninvasive measurements; it is portable, battery operated, simple to use, and inexpensive. The meter is intrinsically safe for the environment of the combustible cartridge case ammunition. These merits make this instrument particularly attractive for use in the detection of moisture in munitions cases in the field and in storage. The accuracy of such meters under carefully controlled environments can be of the order of $\pm 0.5\%$. However, because the environment of munitions cases is not controlled, the accuracy of the meter is not expected to be reproducible to this degree, and cannot be determined until enough field data are available.

I. BACKGROUND

Moisture is present in all materials and products. Non-porous materials such as glass, metals, and some plastics absorb films of moisture in their surfaces. Porous materials such as wood, paper, fibers, and textiles, can absorb large amounts of water internally and their moisture content becomes significant. Moisture may be accumulated in the interior of porous materials in capillary spaces due to condensation, and in large voids due to ingress of water. Munitions cases are made of porous materials. The moisture behavior of commercially important porous materials, along with their electrical properties, have been extensively studied and the results are described in the literature.^{3,4} The latter will be helpful in the understanding of the behavior and measurement of moisture in the munitions cases materials.

The moisture content of a porous material depends on the relative humidity (RH) of the environment. The relationships between RH and moisture content are unique for each material and are called **sorption isotherms**; they represent the amount of water taken up by the material at a given RH at a constant temperature. An example of sorption isotherms for paper is given in Fig. 1. Note that the hysteresis in the curves denotes that the moisture content of the material depends upon whether equilibrium has been reached by absorption or desorption of water. Other quantities which are characteristic for each material are: The **equilibrium moisture content**, which specifies the moisture content in ambient environmental conditions; and the **fiber saturation point**, which denotes the point at which the cell walls are completely saturated with water.

The moisture content (mc) of a material, typically expressed in percentage, is defined as

$$mc = \frac{w_w}{w_w + w_d} \times 100 \quad (1)$$

where w_w is the weight of water in the material, and w_d is the weight of the dry material; the weight of the wet material is $w = w_w + w_d$. It is seen that the calculation of mc requires the knowledge of two unknowns w_w and w_d , which must be determined from measurements. The minimum number of measurements needed is two, M_1 and M_2 . Then we have the functional relationships

$$M_1 = F_1(w_w, w_d) \text{ and } M_2 = F_2(w_w, w_d) \quad (2)$$

In turn, by mathematical inversion, we can generally find

$$w_w = G_1(M_1, M_2) \text{ and } w_d = G_2(M_1, M_2) \quad (3)$$

which in turn we can substitute in Eq. (1) to obtain mc.

The above relationships summarize the task required to measure mc. The most difficult part of the task is the determination of the functional relationships F_1 and F_2 , which correlate

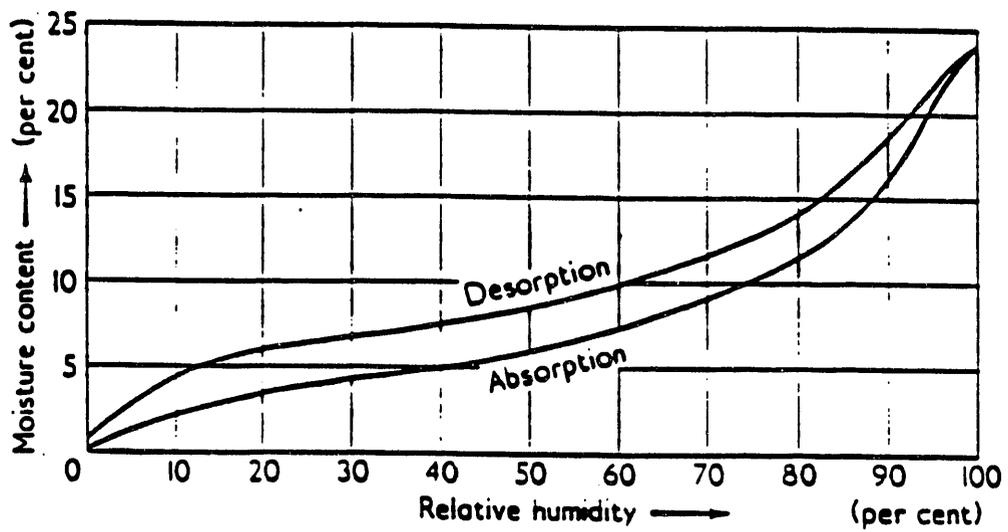


Fig. 1. Sorption isotherms for typical cable paper

measured quantities to the weights of moist materials. For the latter, understanding the physics and chemistry of mixtures containing water, and the physics and chemistry of water binding are essential. Equally important is the understanding of the mechanisms of wetting and drying of materials. Some of the developed theoretical and empirical relationships for F_1 and F_2 are described in Appendix A, in conjunction with the different measurement techniques used to determine moisture content in materials.

II. DEVELOPMENT OF PROTOTYPE METER

The nature of the project requires the cooperation of three parties: The Oak Ridge National Laboratory (ORNL), serving as managing coordinator of the project; the manufacturer TRAMEX Ltd., Chamco House, Shankil, Co. Dublin, Ireland, of the unmodified moisture meter, as provider of engineering documentation, components and parts, and legal permission for modification of the meter; and the user, the U.S. Army, which because of security, is the only source of experimental data on actual munitions rounds.

Communication was established with the manufacturer's officer, Alan Rynhart, with whom we have worked cooperatively and harmoniously during the execution of the project.

The Project Assurance Directorate — Picatinny Arsenal, provides the connection with the U.S. Army which is to use the new meter to collect moisture data on actual munitions rounds and return those data to ORNL for processing.

The details of the execution of the project are described in the following sections.

A. ARRANGEMENT OF PROTOTYPE DESIGN AND PRODUCTION

In a series of letter exchanges with Mr. Rynhart, we outlined the requirements for design and production of the prototype meters:

1. Change the geometry of the instrument's electrodes, from plane to cylindrical, to fit the outer surface of the case wall of the M829 round.
2. Develop a new meter scale to read directly the moisture content of the munitions cases.
3. If necessary, change of the frequency of operation of the instrument to enhance its sensitivity in the new application.
4. Build a small number of prototypes to demonstrate and evaluate the merits of the new design.

The above modifications and the prototype instrument were to be based on the following munitions description data.

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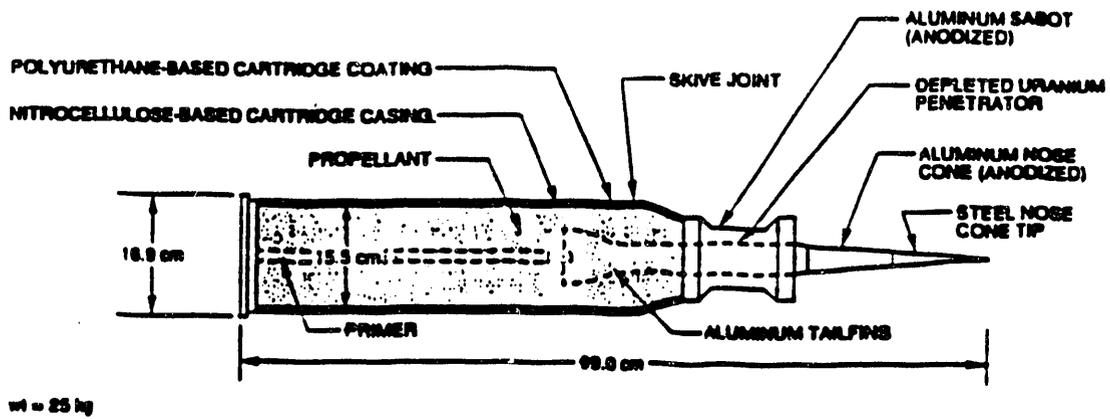


Fig. 2. Diagram of the 120 mm M829 APFSDS Kinetic Energy Round

The M829 round is depicted in Fig. 2. The meter is designed to fit the outer surface of the case sidewall (diameter 154.7 mm). The wall thickness of the case is 3.3 mm. The density of the case is 0.85 g/cc. The composition of the cases consists of the following:

Combustible Cartridge Case Wall:

57.2% Nitrocellulose (13.4% N)
31.0% Kraft Wood Fiber
11.0% Polyurethane Resin
0.8% Acradite II (methyl'diphenyl urea stabilizer)

Adapter Cone:

61.0% Kraft Wood Fiber
27.0% Wood Fiber
12.0% Polyurethane

Adhesive (before curing):

26% solution of nitrocellulose in ethanol, acetone, butyl acetate, and methyl abietate.

The full-up munitions cases (M829 round) contain, within a silk bag inside the case, 17 lbs of JA-2 propellant whose composition is:

59.5 ± 2.0% Nitrocellulose (13.1 ± 0.1% N)
24.8 ± 1.5% Diethyleneglycol dinitrate
14.9 ± 1.0% Nitroglycerin
0.7 ± 0.2% Methyl'diphenyl urea
1.03 - 0.05% Graphite
1.03 - 0.05% Magnesium oxide
≤ 0.25% Graphite glaze

In addition, the following information was available from measurements of moisture content in inert munitions cases using the unmodified moisture meter. The closest accurate scale reading of the instrument was scale #1 (Timber). The most sensitive scale was scale #2 (Felt Roofing).

B. MANUFACTURING AGREEMENT

The above information constitutes the input for the proposed design of the prototype moisture meter. For the execution of the task, we offered the manufacturer the following alternatives:

- (1) The manufacturer provides instrument manuals, circuit diagrams, parts, materials, and legal rights, at a cost to us, so we can make the modifications.
- (2) The manufacturer performs the modifications, under our supervision, for a fixed fee.

The second alternative was negotiated where the manufacturer was to make all the modifications listed in the work statement, except the task of the instrument calibration and scale development. The calibration of the instrument was to be shared with us. Our responsibility was the collection of data from measurement on actual ccc munitions performed by the U.S. Army.

The agreement with TRAMEX Ltd. was to manufacture a prototype instrument titled, **Munitions Case Moisture Meter, Model ORNL-1**, based on the above design data and terms. The prototype was to be a modified version of the company's "TRAMEX Moisture Encounter" instrument, designed to measure moisture in building materials. The total cost of the modifications was specified at \$3160.00. Copies of the prototype were agreed to be manufactured, upon order, for the cost of \$318.00 per unit. Full details of the agreement (proposal) are shown in Appendix B.

C. DESCRIPTION OF THE PROTOTYPE METER AND CALIBRATION PLANS

Full description of the prototype was prepared by the manufacturer and is presented with permission in Appendix C. A total of six (6) instruments were initially ordered for manufacturing. These instruments have been received and are used to collect data for the calibration of the instruments, and the development of an instrument scale suitable for direct reading of the moisture content in ccc munitions rounds. The prototype has three analog scale dials which initially are marked linearly. The plan is to use these dials to record moisture measurement readings in actual munitions rounds, collect data, and return to the manufacturer to print the real scale dials. There is no extra cost for the latter. The data collection plan is as follows:

1. We at ORNL will make moisture measurements in empty combustible cartridge cases to investigate and demonstrate the instrument performance. For this task we purchased three (3) M828 Live Kinetic Energy Round Cases, P/N 12524976, complete with Inert Energy Round Adaptor, P/N 12525643, from Armtec Defense Products Co.
2. The manufacturer, on its own initiative, will acquire the same type of cases from Armtec to make their own calibration measurements.
3. Two (2) instruments (of the purchased six) were shipped to the sponsor with instructions to collect moisture measurement data, on full-up ccc rounds, to be used in the instrument calibration. The data are to be sent to ORNL.
4. ORNL will evaluate the data and forward it to the manufacturer.
5. The manufacturer will print the actual instruments dials. In addition, (if needed) the manufacturer will modify the scale sensitivities to cover (Maximum to Minimum) the anticipated range of measurements.

III. LABORATORY TESTING OF PROTOTYPE METER

An M829 ccc (a "live" case, not an inert case) was dried by placing it in an environment of flowing dry air for several days. The weight of the dried case was $W_0 = 631.3$ g, and measurement by the moisture meter produced moisture readings of zero in all three scales. Then the case was immersed in water for about 110 hours to absorb water. Subsequently the case was removed from the water and was allowed to dry at ambient laboratory conditions. After the outer surface of the case was dried, measurements of the case weight W , and moisture readings S#1, S#2, and S#3 on the three scales of the moisture meter were recorded periodically for several hours, until the case was about dried (1.5% water). A plot of S#1, S#2, and S#3 versus moisture content [$mc = 100(W-W_0)/W$], is shown in Fig. 3. Some noteworthy observations follow.

The maximum water absorbed by the case was only about 10.5%. The first addition of water to the dry case (about 4.5%), causes little change in the moisture meter reading. As discussed in Appendix A, the water that is absorbed first in a porous material is chemically attached to the host material and does not contribute to the change of the dielectric properties of the moist material. The S#1, S#2, and S#3 moisture meter readings are not linear with moisture content. There is a fast transition of the readings between 5% and 9% of moisture content. Similar variations were noticed in experiments with inert cases during the first phase of the project (see Fig. 7 of that report, ref. 2). In the first phase of the project we noticed that the moisture meter was more sensitive to the surface moisture of the case. Accordingly, we could attribute the fast transition of Fig. 3 to surface water. That is, because the case dries from the surface inward, the surface dries fastest and causes the fast drop in the meter reading. However, we notice in Appendix A, Fig. 5, that both the dielectric constant and the loss of porous materials show a fast variation with moisture content. Thus, the fast transition in Fig. 3 could be due to surface water, dielectric constant variation with moisture, or both. To resolve this problem we need to measure the dielectric constant of the combustible cartridge case materials as a function of moisture content. It was observed that the drying process of the case was fast, see Fig. 4. The case dried to the ambient moisture content of about 1.5% in about 8 hours.

As far as the dynamic range of the meter is concerned, we notice that the 10.5% moisture content of the case, covers the upper scale of the meter. Thus, to be able to measure higher moisture contents the upper scale of the meter must be expanded. The low level sensitivity of the meter appears satisfactory.

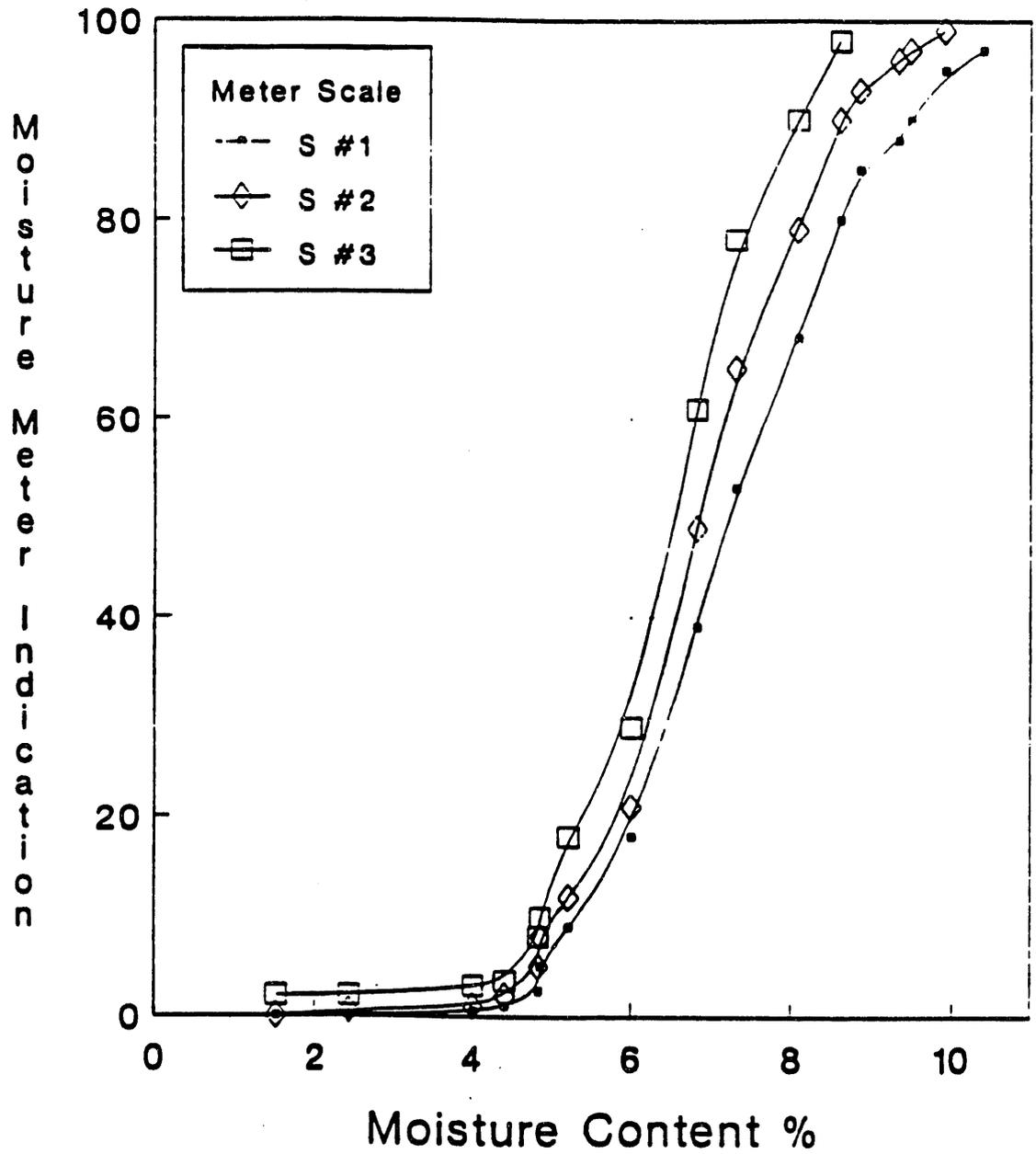


Fig. 3. Moisture meter indications, Scale #1, Scale #2, and Scale #3 versus moisture content in an M829 ccc

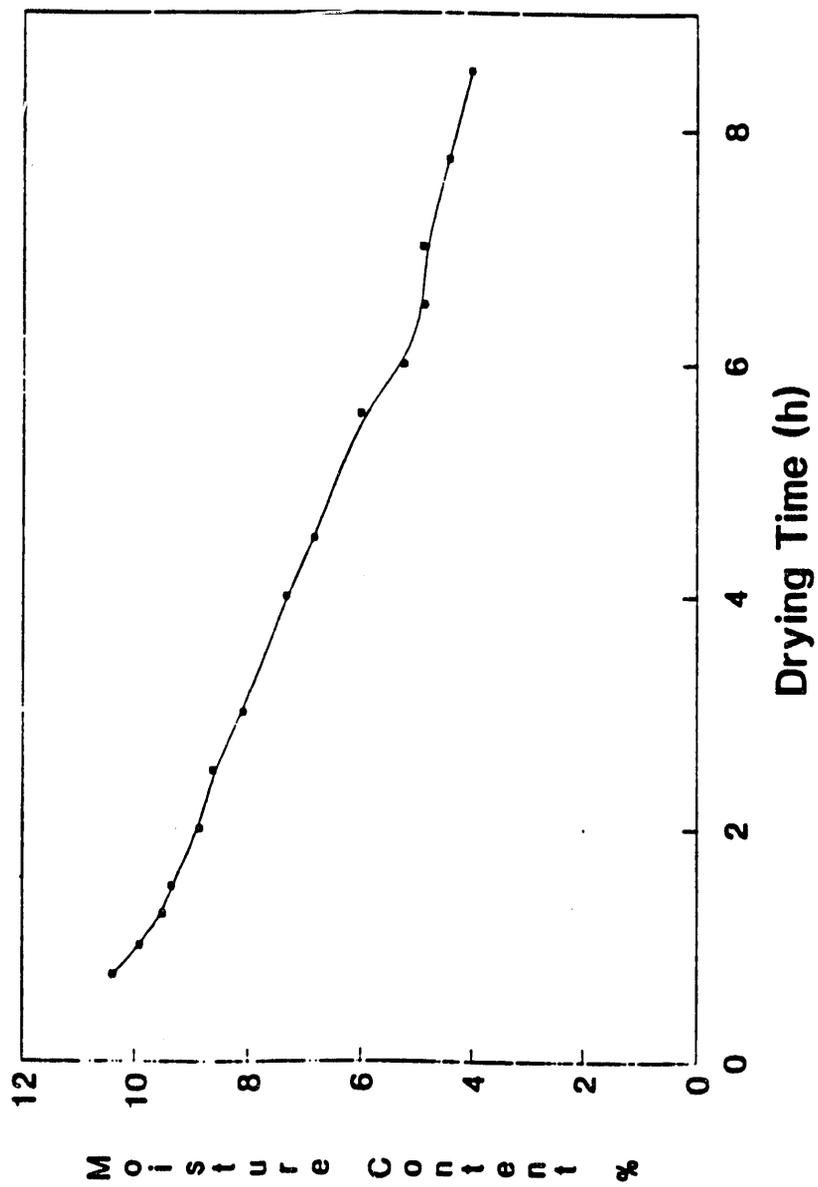


Fig. 4. Moisture Content versus drying time in an M829 ccc

IV. SAFETY EVALUATION OF THE PROTOTYPE METER

Combustible cartridge case ammunition is composed of high explosive materials and their presence constitutes a potentially hazardous environment. A number of techniques and regulations have been developed to allow electrical equipment to be used safely in hazardous areas. A description of the latter can be found in the following:

1. E. C. Magison " Electrical Instruments In Hazardous Locations," Third Edition, Instrument Society of America (ISA), 1972.
2. B. M. Dobratz, LLNL Explosives Handbook, Properties of Chemical Explosives and Explosive Simulants, Chapter 10, Electrical Properties, January 31, 1985.
3. Standards:
FM 3610, based on the US national standard NFPA 493-1978.
UL 913, based on ANSI/UL 913-1988.
4. Code of Practice ANSI/ISA-RP 12.6-1987.

The most practical criterion of safety for many applications is embodied in the **principle of intrinsic safety**. Intrinsic safety requires that the energy produced in the hazardous area, by any sparks caused by an electrical fault, is not sufficient to ignite flammable materials. Thus, equipment used in such areas are designed so that their maximum temperature, even under fault conditions, does not reach the ignition levels of the hazardous materials in the area. Internationally certified laboratories, working to establish standards, are qualified to give a product an intrinsic safety classification and certificate.

The compositions of the components of the M829 round, and other munitions with the same materials and construction, are listed in section (II A). Information about the ignition levels of a material are found in its "Hazardous Component Safety Data Statement (HCSDS)." Table I is a copy of Table 10-1, page 10-1, of reference 2 above. It lists the highest electrostatic-discharge energies tolerated by secondary explosives at 5000 V without ignition. The electrostatic-discharge energy for nitrocellulose (13.4% N) is 0.061 J unconfined (3.1 J confined), for a deflagration type ignition. The HCSDS of the JA-2 propellant is attached to this report (Appendix D); as indicated, the electrostatic-discharge energy of the JA-2 propellant is 3.3 J. The electrostatic-discharge energy of the M829 round ccc is not available to us at this time. Because these cases are composites, consisting mostly of nitrocellulose mixed with other constituents, it is expected that their electrostatic-discharge energy will be larger than 0.061 J. Thus, the safety of the instrument will be conservatively estimated by the comparison of the maximum energy available from the meter, with the material ignition energy of about 0.061 J.

The moisture meter is energized by a 9-V battery. The battery and the entire instrument is enclosed in a plastic case. Contact of the instrument with the munitions case is made via its electrodes, which are made from conducting-rubber and are permanently attached to the instrument. The measurement procedure consists of manually holding the instrument against

the exterior surface of the munitions case, and reading the meter scale. This procedure lasts time t , in the range of about a fraction of a second to perhaps a few seconds. Measurements at the electrodes indicated that the open-circuit voltage output of the instrument is $V_{oc} = 1.3$ V rms, and the short-circuit current is $I_{sc} = 0.2$ mA rms. Thus, the maximum available power from the meter is $P_{max} = V_{oc} I_{sc} / 4 \approx 65 \mu\text{W}$ (microwatts). Thus, the electrical energy ($J = P t$) supplied by the instrument to the munitions case during measurement, is of the order of 0.001 times the ignition energy of the material of the case. We suspect that the electromagnetic (EM) environment of the munitions cases in the field, from radar, communication equipment, and other sources on the tanks, supply much more electrical energy to the munitions cases than the meter. Laboratory measurements have shown no detectable warming of the munitions cases during prolonged contact with the moisture meter. From these we conclude that the operation of the moisture meter is intrinsically safe.

The safety of the meter is also supported by the following laboratory experiments. Munitions combustible cartridge case coupons, about $9.5 \times 2.5 \times 0.4$ cm cut from M829 cases, were sandwiched between copper plates to simulate parallel plate capacitors. These devices were used in the following safety experiments. Sixty (60) V dc (electric field of 15000 V/m) was applied on the devices, with no noticeable warming of the coupon material. Similarly, 5 V peak (1250 V/m electric field), 12.5 KHz signal was applied with no noticeable warming of the coupon material. In a separate experiment, a spark from a Tesla coil was used in an effort to ignite the cartridge case material; it did not ignite.

In conclusion, calculations and experimental results on the munitions case materials, indicate that the munitions case moisture meter is an intrinsically safe instrument. According to safety regulations, the intrinsic safety status of the meter must be certified by licensed authorities. The need for the latter and the anticipated cost will be determined by the user of the instrument.

Table I. Highest electrostatic-discharge energy at 5000 V for zero ignition probability of secondary explosives. (Source reference number 2 in text.)

Explosive	Energy J		Type of Ignition	
	Unconfined	Confined	Unconfined	Confined
Black powder ^a	> 12.5	0.8	None	Deflagration
a	0.025	6.0	Deflagration	Detonation
Lead azine	0.0070	0.0070	Detonation	Detonation
Lead styphnate	0.0009	0.0009	Detonation	Detonation
NC (13.4%N)	0.061	3.1	Deflagration	Deflagration
NG(25°C)	> 12.5	0.90	None	Detonation
PETN ^b	> 11.0	0.21	None	Detonation
a	0.062	0.21	Deflagration	Detonation
Tetryl ^b	> 11.0	4.68	None	Detonation
a	0.007	4.38	Deflagration	Detonation
TNT ^b	> 11.0	4.68	None	Detonation
a	0.062	4.38	Deflagration	Detonation

^aThrough 100 mesh.

^bAs received.

V. CONCLUSIONS AND RECOMMENDATIONS

The results of this project, highlighted by the manufacturing of the prototype instrument Munitions Case Moisture Meter Model ORNL-1, demonstrate the feasibility of the development of instruments, based on the moisture dependence of the dielectric properties of ccc materials, to measure moisture in ccc munitions rounds. These instruments are light weight, portable, low-power battery operated, and inexpensive; provide real time easy, rapid, non-destructive and non-invasive measurements. To the best of our investigation and evaluation, these instruments are intrinsically safe. These attributes make these instruments suitable for use in ccc munitions rounds in storage and in the field.

The execution of the project involved three parties: The Oak Ridge National Laboratory, the manufacturer TRAMEX Ltd., and the user, the US Army. Because of security, calibration data for the prototype, on actual munitions rounds, can come only from the US Army. At the time of this writing these data are not available. Therefore, the calibration of the meter and the development of a scale, reading directly moisture content in munitions rounds, remain to be completed. However, experimental results on empty actual cccs in laboratory conditions, demonstrate satisfactory performance of the instrument.

Besides the collection of actual data needed to complete the calibration of the instrument and to adjust its dynamic range to satisfy its intended application, much more work is needed to bring the prototype to its useful practical status. Appendix A "Survey of Measurement Techniques of Moisture Content," is added to this report to assist in the understanding of the problems involved in the detection and measurement of moisture in materials. Following is a list of recommendations for further work in the development of the munitions case moisture meter. For clarity and identification of the order of importance and immediacy, the needed work is subdivided in three tasks:

Task I.

Because munitions rounds, in storage or in the field, could be found in any location on the globe, the meter must be capable of measuring moisture under all anticipated environmental conditions. Thus, data and evaluation procedures are needed to adjust the performance of the meter under different conditions of temperature and humidity. A feeling of this task can be obtained from results available for moisture meters used in wood products.⁵

Task II.

The objective of Task I can be simplified and completed, when the physics and chemistry of moist ccc materials is understood. For the latter studies are needed of the dielectric properties of moist ccc materials, as a function of frequency and temperature (see analogous results for other porous materials in Appendix A). Such understanding of the dielectric properties will be valuable in the optimal design of the munitions case moisture meter.

Task III.

This prototype meter, like similar low frequency electrical moisture meters available for other applications, utilize the measurement of one parameter (conductance or capacitance) of the moist material under test, to determine moisture content. Because the chosen parameter varies with temperature, frequency and other factors, the range of application and the accuracy of such meters are limited. The latter is depicted in moisture meters used in wood products, in which separate scales are used for different types of wood, with additional adjustments for temperature variations. These problems can be solved by using measurements of more parameters as inputs in the evaluation process. These can be capacitance and conductance measured values in several frequencies. The technology for such procedures is available in the form of microprocessors. Similar procedures are currently used in thermometers and other instruments. Because moisture measurements are very important in many products, advancements in such procedures and technology are anticipated. Task III can be such an effort.

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APPENDIX A

SURVEY OF MEASUREMENT TECHNIQUES OF MOISTURE CONTENT

Methods of measurement of mc can be broadly classified as direct (chemical) methods, and indirect (physical) methods. Direct methods normally require the extraction of the moisture (water) from the material by oven drying, desiccation, distillation, and other chemical techniques. The quantities of Eq. (1), and hence mc, are determined by weighing the extracted water. Direct methods are usually employed in the laboratory and are very accurate. Direct methods are long and costly procedures and constitute the standard methods of determining mc. In indirect methods, the moisture is not extracted from the material; it is determined from measurements of physical parameters of the moist materials whose value depends on the amount of moisture present in the material. These take several forms depending upon the physical property of the water used. The indirect methods offer the feasibility of continuous measurement and control of moisture in industrial processes. Rapid mc measurement techniques have been developed using indirect methods of measurement, testing, and calibration against standard methods. Based on the latter, practical mc instruments have been developed and are in use on-line process instrumentation in the paper, wood, textile, food, and other industries. Commercial mc instruments are developed and calibrated for the particular materials and industries for which they were intended. Therefore, considerable development work is needed to adapt such instruments to different applications. Following is a brief review of some techniques for in-situ, real time moisture measurements in materials, with potential adaptation for measurements in munitions cases; a more extensive survey is given in.³ Note that most instruments and techniques reviewed below are in the development or the prototype stage and are not commercially available at this time. For convenience, the reviewed techniques will be subdivided into two classes: 1) **electrical**, comprising all techniques based on the electrical properties of moist materials, and 2) **nonelectrical**, for all others.

ELECTRICAL TECHNIQUES

Many techniques have been developed to measure mc which are based on the electrical properties of moist materials. These techniques are especially attractive because of the ease of processing electrical signals, and the availability of electronic equipment. We will begin the description of this topic with a brief review of the dielectric properties of materials.^{2,3}

The electromagnetic properties of materials are specified in terms of the quantities: Conductivity σ , dielectric constant ϵ , and magnetic permeability μ . The munitions case materials are nonmagnetic ($\mu = \mu_0 = 4\pi \times 10^{-7}$ H/m). For static (dc) and low frequency cases, $\sigma = \sigma_s$ and $\epsilon = \epsilon_s$ are stated separately. At high frequencies σ and ϵ are expressed by a single parameter, the complex dielectric constant, defined as

$$\epsilon = \epsilon' - j \epsilon'' \equiv \epsilon' - j \sigma / \omega \epsilon_0 \quad (1)$$

where $\omega = 2\pi f$ is the frequency, $\epsilon_0 = 8.854 \times 10^{-12}$ F/m is the permittivity of free space, ϵ' represents the dielectric constant, and ϵ'' represents the losses of the material. The losses of the material are typically expressed in terms of the loss tangent defined as

$$\tan \delta = \epsilon'' / \epsilon' \quad (2)$$

The dielectric constant is often expressed in terms of the molecular polarizability α of the material, via the Clausius-Mosotti equation, given by

$$\frac{N \alpha}{3\epsilon_0} = \frac{\epsilon' - 1}{\epsilon' + 2} \frac{M}{\rho} \quad (3)$$

N is Avogadro's number, M the molecular weight, and ρ the density of the material. There are four physical mechanisms (dielectric polarizations) which can contribute to the polarizability α :

- (1) The electronic polarizability α_e ; caused by the displacement of electrons with respect to the nucleus.
- (2) The atomic (or ionic) polarizability α_a ; caused by the displacement of negative ions with respect to the positive ions.
- (3) The dipole orientation polarizability α_d ; takes place in materials, called polar, that have permanent dipole moments.
- (4) The interfacial (or space-charge) polarizability α_i ; takes place in electrically heterogeneous materials (Maxwell-Wagner effect), and is caused by the charging of the interfaces within the materials.

Each type of dielectric polarization is characterized by a relaxation time τ , which represents the time taken for the polarization to respond to the applied electric field. The contribution to the dielectric constant of each polarization mechanism is a function of frequency $\omega = 2\pi f$ and can be expressed as

$$\epsilon(j\omega) = \epsilon_\infty + \frac{(\epsilon_s - \epsilon_\infty)}{1 + j\omega\tau} \quad (4)$$

ϵ_∞ and ϵ_s are the values of ϵ at the frequencies $f = \infty$, and $f = 0$ Hz, respectively. Substitution in Eq. (1) yields

$$\begin{aligned}
\epsilon' &= \epsilon_{\infty} + \frac{\epsilon_s - \epsilon_{\infty}}{1 + (\omega\tau)^2} \\
\epsilon'' &= \frac{(\epsilon_s - \epsilon_{\infty})\omega\tau}{1 + (\omega\tau)^2} + \frac{\sigma_i}{\omega\epsilon_0} \\
\sigma &= \sigma_i + \frac{(\sigma_{\infty} - \sigma_i)(\omega\tau)^2}{1 + (\omega\tau)^2}
\end{aligned} \tag{5}$$

where

$$\sigma_{\infty} - \sigma_i = \frac{(\epsilon_{\infty} - \epsilon_s)\epsilon_0}{\tau}$$

The quantity σ_i represents the frequency independent ionic conductivity which will be described later.

The total dielectric constant of a material can be expressed as the sum of the four polarization mechanisms as follows

$$\epsilon(j\omega) = \epsilon_{\infty} + \frac{\epsilon_i}{1 + j\omega\tau_i} + \frac{\epsilon_d}{1 + j\omega\tau_d} + \frac{\epsilon_a}{1 + j\omega\tau_a} + \frac{\epsilon_e}{1 + j\omega\tau_e} \tag{6}$$

Each relaxation constant τ_c (or characteristic frequency $\omega_c = 1 / \tau_c$) depends on the material; typical values have the ranges: $\tau_e \approx 10^{-16}$ s., $\tau_a \approx 10^{-12}$ - 10^{-16} s., $\tau_d \approx 10^{-3}$ - 10^{-10} s., and $\tau_i \approx 1$ - 10^3 s. Generally, $\tau_i > \tau_d > \tau_a > \tau_e$, and the contribution of each mechanism decreases with frequency. This is shown diagrammatically in Fig. 1, in which the total molecular polarizability α is plotted as a function of frequency (log f), along with the dielectric loss factor ϵ'' .

The dielectric properties of materials depend on the density and the temperature. There is no analytical expression that describes the temperature dependence. Figure 2 depicts the variations with temperature of the dielectric parameters of dry cellulose at different frequencies.

Electrical Properties of Water.

Water is a polar material which exists as "free" and "bound".⁴ The dielectric properties of water have been studied extensively and the results are described in the literature.⁵ The quantities described in Eq. (2) for the free and bound water are:

$$\begin{aligned} \epsilon_f'(\omega) &= 5 + \frac{75}{1 + (6.3 \times 10^{-11} \omega)^2}, & \epsilon_f''(\omega) &= \frac{4.7 \times 10^{-9}}{1 + (6.3 \times 10^{-11} \omega)^2} \\ \epsilon_b'(\omega) &= 88 + \frac{0.9}{1 + (10^{-8} \omega)^2}, & \epsilon_b''(\omega) &= \frac{9.0 \times 10^{-9} \omega}{1 + (10^{-8} \omega)^2} \end{aligned} \quad (7)$$

The dc conductivity of pure water is $\sigma_i \approx 10^{-9}$ S/m. However, even small amounts of impurities (dissolved ions) can increase this value dramatically. Thus, the ionic conductivity σ_i of the dissolved ions in the water dominates the dc and low frequency conductivity of the water. This conductivity depends on the temperature and is often given as

$$\sigma_i = \sigma_{i0} e^{-a/T} \quad (8)$$

T is the absolute temperature ($^{\circ}$ K) and a is a constant related to the activation energy of the ions. The role of the ionic conductivity on the properties of dielectric materials was incorporated in Eq. (5).

The dielectric properties of water depend on the temperature. Figure 3 depicts the combined temperature and frequency dependence of the loss tangent and the dielectric constant of water. Figure 4 depicts the variation of the dielectric constant of ice with temperature at different frequencies. It is seen that the dielectric constant of ice is very much smaller than that of water. This is explained as follows. In the ice state, the permanent dipoles of the highly polarizable water molecules are "frozen in", and can no longer be aligned by an external field to contribute to the dielectric constant. Besides the ice state, "frozen in" water molecules occur in cases where the water is attached chemically to other molecules (**molecular water binding**). The latter introduces errors in mc measurements of materials, because a portion of the absorbed water can be chemically attached to the host material.

Dielectric Mixtures.

Moist materials are mixtures of water and the host materials. Moisture content measurements rely on the difference between the dielectric properties of the host dry material, and that of the equivalent moist material. The study of the dielectric properties of mixtures has a long history, from Maxwell (1873) to the present. Generally, the contribution of each constituent to the dielectric constant of the mixture, is proportional to the relative volume of the constituent in the mixture. Analytical expressions for the dielectric constant of specific mixtures are available,⁶ but no generalized formula is known at the present. The simplest, but not the most accurate, formula is the linear relationship where ϵ_w , V_w , and ϵ_m , V_m , are the dielectric constants and volume fractions of the water and the host material of the mixture, respectively, where $V_w + V_m = 1$. Note that V_w excludes the dielectrically inactive molecular water which is attached

$$\epsilon = \epsilon_w V_w + \epsilon_m V_m \quad (9)$$

to the host material with "frozen in" permanent dipoles.

Figure 5 depicts experimental results of the variation of the dielectric properties of some protein fibers with moisture content. It is seen that the first addition of water to the dry fibers causes little change in the dielectric properties. It is generally believed, that the water which is absorbed first is attached to the host molecules and, therefore, its molecules are not free to polarize. The latter takes place in all dielectric mixture and can be a source of error in mc measurements.

Frequently, the empirical **logarithmic mixing rule**⁷ is used to determine the dielectric constant ϵ_m , of a mixture from ϵ_1 and ϵ_2 and the volume ratios V_1 and V_2 of the components ($V_1 + V_2 = 1$), as follows

$$\log \epsilon_m = V_1 \log \epsilon_1 + V_2 \log \epsilon_2 \quad (10)$$

This rule is used to determine the dielectric constant of mixtures of high explosive materials.

Dielectric Measurements.

Electromagnetic interactions are described in terms of the electric field **E** and the magnetic field **H**. In a material with conductivity σ , dielectric constant ϵ , and magnetic permeability μ , electromagnetic fields propagate with the speed $v = 1 / \sqrt{\mu\epsilon}$, so that at a distance x from the source the values of the fields are obtained from the relationships $E(x) = E(0) e^{-\gamma x}$, and

$$\begin{aligned} \text{Impedance } \eta &= \frac{E}{H} = \sqrt{\frac{\mu}{\sigma + j\omega\epsilon}} \\ \text{Propagation constant } \gamma &= \sqrt{j\omega\mu(\sigma + j\omega\epsilon)} = \alpha + j\beta \\ \text{attenuation constant } \alpha &\approx \frac{\omega\epsilon''}{2v\epsilon'} \\ \text{phase constant } \beta &\approx \frac{\omega}{v} \left[1 + \frac{1}{8} \left(\frac{\epsilon''}{\epsilon'} \right)^2 \right] \end{aligned} \quad (11)$$

Thus, measurements of the

$$\begin{aligned} \text{attenuation} &= \left| \frac{E(x)}{E(0)} \right| = e^{-\alpha x}, \text{ and} \\ \text{phase angle } \angle \theta &= e^{-j\beta x} \end{aligned} \quad (12)$$

provide the values of α and β , and in turn the values of the dielectric parameters ϵ' and ϵ'' .

At low frequencies, where the physical dimensions of material under test are very much smaller than the wavelength $\lambda = v / f$, the electromagnetic interactions are described in terms of the voltage V , and the current I . The impedance Z is defined as $Z = V / I$, and the admittance $Y = 1 / Z = I / V$. Z and Y are complex quantities and are functions of frequency. Typically, $Z(f) = R(f) + jX(f)$, and $Y(f) = G(f) + jB(f)$, are expressed in terms of the parameters: resistance R , reactance X , conductance G , and susceptance B . The material under test is represented by an equivalent circuit such as: resistor R , capacitor C , inductance L , or connections of R , C , and L . The circuit representation depends on the geometry and the physical dimensions of the material.

For low frequency dielectric measurements, the complex dielectric constant ϵ of a single time constant τ , Eqs. (1) through (4), is represented by the equivalent circuit of Fig. 6. A material with dielectric constant given by Eq. (6), is represented by an equivalent circuit consisting of the parallel connection of four circuits of the type of Fig. 6 corresponding to the four time constants of Eq. (6).

Generally, the equivalent admittance Y of the material under test can be expressed as

$$Y(j\omega) = K \epsilon(j\omega) = G(\omega) + j\omega C(\omega) \quad (13)$$

where K is a geometric constant and ϵ is given by Eq. (6). For example, a rectangularly shaped material of area A and thickness d has $K = A / d$ (parallel plate capacitor representation). Some parameters associated with the representation of Eq. (13) are:

$$\begin{aligned} \text{Dissipation factor } D &= G / (\omega C) \\ \text{Loss angle } \delta, \tan \delta &= D \\ \text{Power factor } \equiv \cos \Theta &= \frac{G}{\sqrt{G^2 + (\omega C)^2}} \end{aligned} \quad (14)$$

where Θ is the phase angle. Figure 7 depicts the equivalent circuit and the phaser diagram of this representation. The equivalent impedance of the material is

$$Z = \frac{G - j\omega C}{\sqrt{G^2 + (\omega C)^2}} \equiv R_s(\omega) + \frac{1}{j\omega C_s(\omega)} \quad (15)$$

Note that all equivalent circuit parameters G , C , R_s , and C_s are functions of frequency. Measurements of these parameters can be made by commercially available impedance analyzer instruments. Some portable capacitance meters use transient time integration to measure capacitance C . These meters are not suitable for measurement of capacitance which varies with frequency.

Generally, the conductance G , the capacitance C , and the electrical losses of porous materials increase with increasing moisture content. These constitute the bases for the mc measurement techniques described below.

Microwave Moisture Measuring Techniques.

The capacity of water to absorb electromagnetic energy in the microwave region, frequencies 0.3 to 300 GHz, is utilized to measure mc in materials. Currently, the microwave techniques are vigorously researched because of the development and availability of inexpensive microwave equipment. These techniques are nondestructive, noninvasive, and noncontacting. The radiation levels are safe because only a few milliwatts of energy is needed. The bulk moisture is measured regardless of the distribution of the moisture within the material. In addition, the effects of the ionic conductivity (caused by electrolytes), and some environmental conditions such as dust and water vapor are reduced in microwave frequencies. A review of this technology can found in the papers of King,⁸ and Kraszewski.⁹

Transmission, reflection, and resonance methods can be used to couple electromagnetic energy to a material. The most popular ones are the **Open-Transmission-Method**, and the **Open-Reflection-Resonator-Method**.

Open-Transmission-Method. This type of moisture detection meter consists of a microwave source, transmitter and receiver antenna horns, and the receiver. The material under test is placed between the two horns. The frequency of operation depends on the material and its thickness, and is typically in the 2-12 GHz range. The instrument measures the attenuation and phase, Eq. (12), of the transmitted signal through the material under test. The moisture detection is based on the differences ΔA and $\Delta \theta$ of the attenuation and phase of the moist and dry material, respectively. The translation of the ΔA and the $\Delta \theta$ indications into mc measurements require elaborate algorithms. The thickness of the material under test, typically a few centimeters, is an essential parameter of the algorithm.

Open-Reflection-Resonator-Method. Such equipment consist of an open microwave resonator, whose open face is placed against the material under test. Thus, the material under test becomes a part of the closed resonator and as such affects its resonance frequency f_r , and its loss (Q-factor). Measurements of the changes in Δf_r and ΔQ , resulted from the moisture in the material, are used to determine the mc of the material. This method measures moisture from

one side only, and as such the depth of penetration of the electromagnetic energy (skin effect) is an important factor. The latter, typically less than a few centimeters, is determined by the frequency of operation and hence by the size of the resonator.

In spite of the large research and development effort, the microwave moisture measuring instruments are still in the prototype stage. Instruments for specific applications, such as agricultural products,¹⁰ building materials,¹¹ mining,¹² and munitions materials,¹³ have been developed. The translation of the measured quantities to mc readings require elaborate algorithms. The noncontacting property of these techniques make them attractive for mc measurements in dynamic processes such as conveyors, shakers, or hoppers in which microwave transparent windows are installed. These techniques are not suitable in munitions cases applications, except as a means of calibration and in conveyor loading docks for munitions cases.

Low-Frequency Moisture Measuring Techniques.

These techniques are based on the concept of representation of the material under test (specimen) by its equivalent electrical impedance or admittance, Eqs. (13), (14), and (15). Such instruments have been under development since the late 1920's. The nomenclature of this technology is very confusing. Electric moisture meters such as resistance-type (conductance-type), power-loss-type and capacitance-type (classed as dielectric-type) are commercially available. Most of these meters have been developed for mc measurements in wood products. The USDA Forest Service, Forest Products Laboratory, Madison, WI, provides, to the interested reader, the instructive document "General Technical Report, FPL-6, 1975",¹⁴ along with a literature search report, and a list of the manufacturers of electric moisture meters. The technical description of the operation of these meters is obscure because of proprietary interests.

To make electrical measurements, the specimen must be converted into a two-terminal electric circuit, by the addition of two suitable electrical contacts. Two types of electrodes are typically used: surface-contact electrodes, and pin-type electrodes. Surface-contact electrodes do not penetrate the specimen; they can have several forms,¹⁴ and can be made from metal, wood, conducting rubber, or other suitable materials. Pin-type electrodes are made to penetrate the specimen; the simplest electrodes have metal poles consisting of nail-like pins that are driven into the specimen.

The key parameter in the description and understanding of the operation of these moisture meters is the equivalent admittance of specimen, Eq. (13). In effect, the meters measure the variation of the admittance with moisture present in the specimen. In the following description we will use the nomenclature of.¹⁴

Conductance (Resistance)-Type Moisture Meters. Basically, these meters are portable battery-operated wide-range ohmmeters. They detect moisture via measurement of the conductance G , Eq. (13), of the specimen. As discussed above, G increases with moisture and depends on the frequency of operation. Because G is dominated by the ionic conductivity (dissolved electrolytes) it depends strongly on temperature, Eq. (8). There exist commercially available meters¹⁴ for wood products and other materials. Conductance-type meters use pin-type

electrodes. Because of the latter these instruments are not suitable for moisture measurements in munitions cases.

Dielectric-Type Moisture Meters. This classification includes **Capacitance**, **Power-loss**, and **Capacitance Admittance** types of moisture meters. These terms refer to the parameters of the equivalent electrical admittance, Eq. (13), of the specimen. The function of these meters, can be best explained in terms of the following electrical circuit concepts.

Resonant Circuit Method. This technique is equivalent to the open-reflection-resonator-method, used in microwave frequencies, which was described above. Connection of the specimen [admittance of Eq. (13)] across a parallel R_0LC_0 circuit, results in a parallel R_pLC_p resonant circuit with $1 / R_p = 1 / R_0 + G$, and $C_p = C_0 + C$. The response voltage V of this circuit, to the current source I , is

$$V(j\omega) = \frac{I R_p}{1 + j Q [\omega/\omega_r - \omega_r/\omega]} \quad (16)$$

where

$$\begin{aligned} \text{Resonance Frequency } \omega_r &= 1 / \sqrt{LC_p}, \text{ and} \\ \text{Quality Factor } Q &= \omega_r C_p R_p \end{aligned}$$

Trade Nomenclature: Capacitance-Type Meters use a frequency discriminator to provide a reading proportional to the change in the resonant frequency f_r of the circuit. In the **Power-loss-Type Meters**, the RLC circuit is part of a low-power oscillator. The meter reading is proportional to the reduction of the amplitude of oscillations, resulting from the power losses in the moist material.

Capacitance Admittance Type Meter. This meter is effectively a resistance-capacitance bridge circuit. Connection of the specimen to the meter unbalances the bridge. The meter dial reads this bridge imbalance, which is related to the moisture content of the specimen.

The moisture reading of all these meters depends on temperature and the frequency of operation. The temperature variations are difficult to predict theoretically, they are typically determined experimentally. The ionic conductivity is the most troublesome parameter in these meters because of its strong temperature dependence. The ionic conductivity effects reduce as the frequency of operation is increased. The latter is a factor in the recent popularity of the microwave techniques in moisture measurements.

The electrodes of the commercially available dielectric-type moisture meters are of the surface-contact nonpenetrating type. They are designed according to particular applications, and are not typically interchangeable. That is, the electrodes of the dielectric-type moisture meters are integral parts of the instruments. Because of the nonpenetrating type of the electrodes, these meters provide nondestructive and noninvasive moisture measurements. The latter make these meters attractive for measurements of moisture in munitions cases.

Overview.

The useful range of electrical type moisture meters is from about 5 to about 30 percent moisture content. The accuracy of measurements depends on the control of the environment; 0.5-1% of moisture accuracies have been reported. Microwave type moisture meters are complex instruments which detect moisture via measurement of several parameters; such as amplitude and phase of propagated electromagnetic energy in the specimen, and the density of the dry specimen. In contrast, low frequency type electrical moisture meters are simple inexpensive instruments. Typically, they detect moisture via measure of one parameter only, such as conductance or capacitance. Because of the limited information used to detect moisture, the low frequency meters are limited to specific applications (effectively, a separate meter for every application). The versatility of low frequency moisture meters can be expanded by the inclusion in the detection process, the measurement of more than one parameter. Detection of moisture in agricultural products have been reported¹⁵ using RF impedance measurements at two frequencies.

Nonuniform distribution of moisture (gradients) in the specimen lead to erroneous results. Because the electrical current follows the least resistance path, the instruments tends to measure the mc of the wettest path between the two electrodes. Thus, moisture gradients result in errors in the estimation of the average mc. Electrode surface contacts may be sources of errors, especially films of water in the surface, dirt, and corrosive products. Thus, it is pertinent to wipe the surface of the specimen clean and dry before the meter electrodes are attached to it.

NONELECTRICAL TECHNIQUES

Following is a brief description of some important mc measuring techniques, which are based on nonelectrical properties of moist materials. These techniques are not suitable for mc measurements in munitions cases sought in this project, but they may be used for calibration purposes.

Nuclear Magnetic Resonance (NMR).

NMR is a physical phenomenon that is widely used as a research and diagnostic tool in science, medicine, and industry. A variety of applications of NMR have been developed in measurements of mc in many industrial products [1, refs.# 56-58], including munitions materials.¹⁶ The theory and instrumentation of NMR in mc measurements are described in the literature [17, Ch. VII].

The NMR method is perhaps the most direct of all methods available for measuring cm, because is not affected by interferences such as temperature, presence of impurities, and moisture gradients. While the NMR measurement in itself is instantaneous, data reduction is needed to obtain the mc reading.

Infra-Red (IR) Techniques.

Water molecules absorb energy from the electromagnetic spectrum in a variety of rotational and vibrational modes. The near-infra-red (NIR) region (wavelengths $\lambda = 0.7$ to $2 \mu\text{m}$), with water absorption bands located at about 0.76, 0.97, 1.18, and $1.93 \mu\text{m}$ have been used to measure mc in materials. The absorption band at about $1.93 \mu\text{m}$ is the most common.¹⁷ The IR system (spectrophotometer) consists of a IR source (LED, laser-diode, or a tungsten halogen lamp with interference filter and chopper), the subject under test, and a photocell. For measurement of mc, the subject is illuminated in sequence by radiation of two wavelengths: The water absorption radiation λ_a , and a nonabsorption or reference radiation λ_r . Examples of wavelength pairs (λ_a, λ_r) used are: (1.93, 1.7), (0.97, 0.90) and (1.94, 2.08) μm . The photocell intensity outputs P_a , and P_r can be calibrated to measure mc; typically as a function of $(P_r - P_a)$, or $(P_r - P_a) / (P_r + P_a)$. The IR method is highly accurate, with errors in the order of $\pm 0.1\%$.

While the accuracy is commendable, the IR method has its drawbacks. IR radiation interacts with organic compounds containing hydroxyl, ester, and amide groups and water in bound state. These are sources of error. The most important disadvantage of the IR technique is the depth of penetration. IR radiation penetrates less than 1 mm into most solid materials, therefore, IR provides strictly a surface measurement. IR techniques are used in commercial processes involving relatively thin layers of materials [1, refs.# 59-62], such as paper, iron ore, and grain and seeds.

Nuclear Techniques, Neutron Thermalization.

Moisture content in materials can be measured by detection of hydrogen atoms given off by thermalization of neutrons. Such instruments are used in soil engineering [1, refs.# 46-53], and are typically designed to operate over large effective volumes.

Thermal Conductivity Techniques.

This technique relies on the increase of the thermal conductivity of porous materials with increasing moisture content. Basically, it is a transient heat-flow technique, where the temperature rise of the material is measured at a distance from an applied heat source. Some applications of this technique are described in the literature [1, refs.#70-75].

Ultrasonic Techniques.

Mechanical (or elastic) waves are means of transferring energy through elastic (materials possessing elasticity) media. The absorption and velocity of mechanical waves depend on the medium through which they propagate. When these waves encounter substances of different physical properties (elastic impedances), they undergo reflections and refractions. These principles have been used as diagnostic tools in science, medicine and industry in a wide range of techniques, known as nondestructive testing (NDT). Sonic, ultrasonic, and surface acoustical waves (SAW) are classes of such mechanical waves. Ultrasonic waves are especially attractive in NDTs, because the energy can be generated in the form of thin almost non-divergent beams that can be directed to specific locations of specimens under test. A vast amount of literature

is available in ultrasonic applications.

The velocity of ultrasonic waves in a solid material decreases as its moisture content increases. This principle has been used in the development of instrumentation to measure moisture content in materials such as soil,¹⁷ wood,¹⁸ food products,¹⁹ and epoxy.²⁰ Ultrasonic techniques are suitable for measurement of high percentage levels of moisture content. Ultrasonic measurements require some form of mechanical coupling to transfer energy from the source to the specimen; water immersion is a common couplant. The accuracy of the measurement depends on the homogeneity of the material. Inhomogeneities and discontinuities such as joints and cracks are sources of error. Moisture content accuracies of $\pm 1\%$ have been reported. Sonic (sound waves) techniques have been used to measure moisture content since the 1930's. Surface acoustics waves (SAW) technology is also exploited in the measurement of moisture content.²¹

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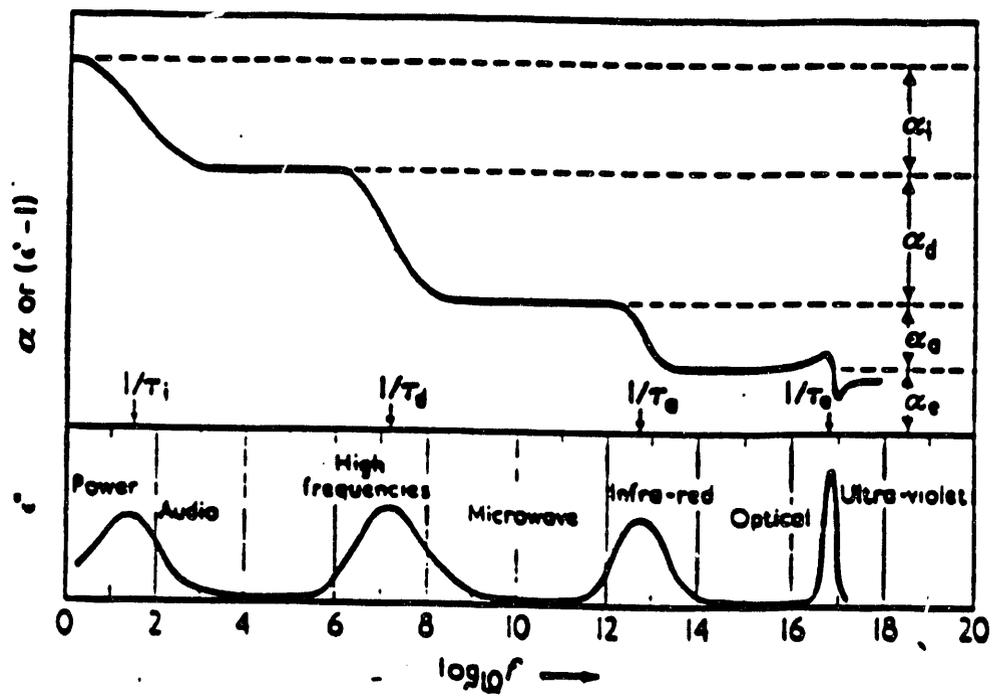


Figure 1. Dielectric constant and absorption: (a) molecular polarizability α against $\log f$; (b) dielectric loss factor ϵ'' against $\log f$

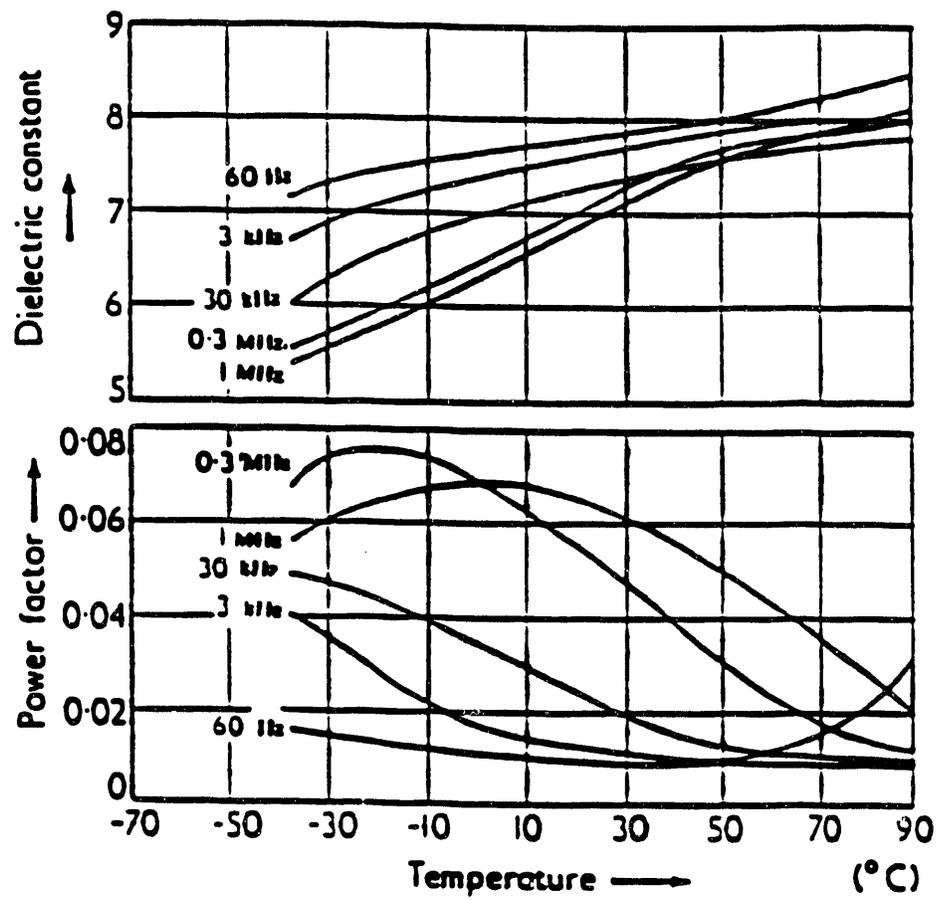
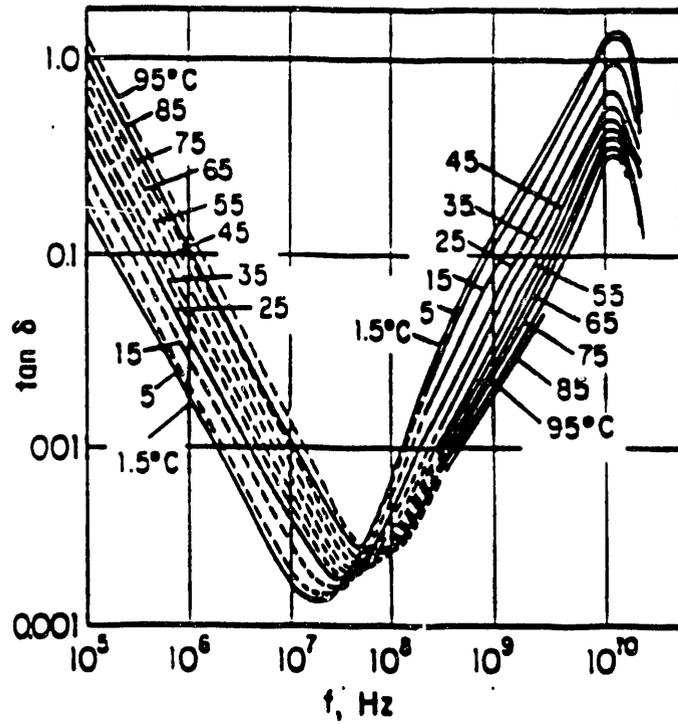
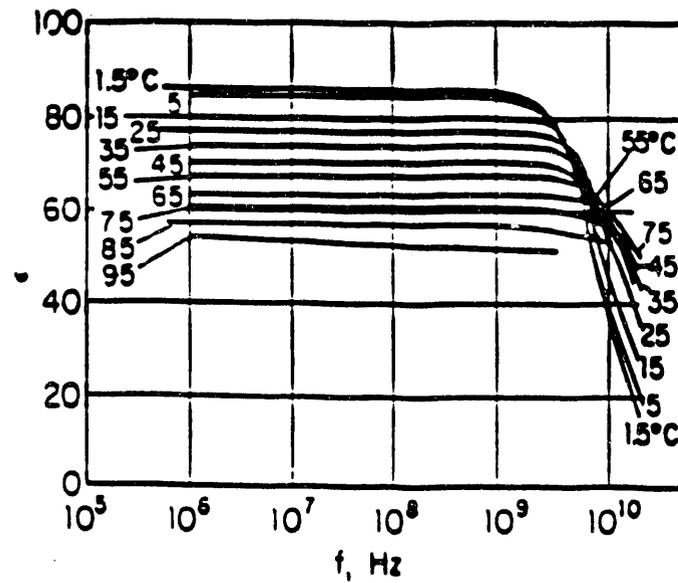


Figure 2. Variation of dielectric constant and power factor of dry cellulose with temperature at various frequencies



(a)



(b)

Figure 3. Loss tangent (a), and dielectric constant (b) of water as a function of frequency and temperature

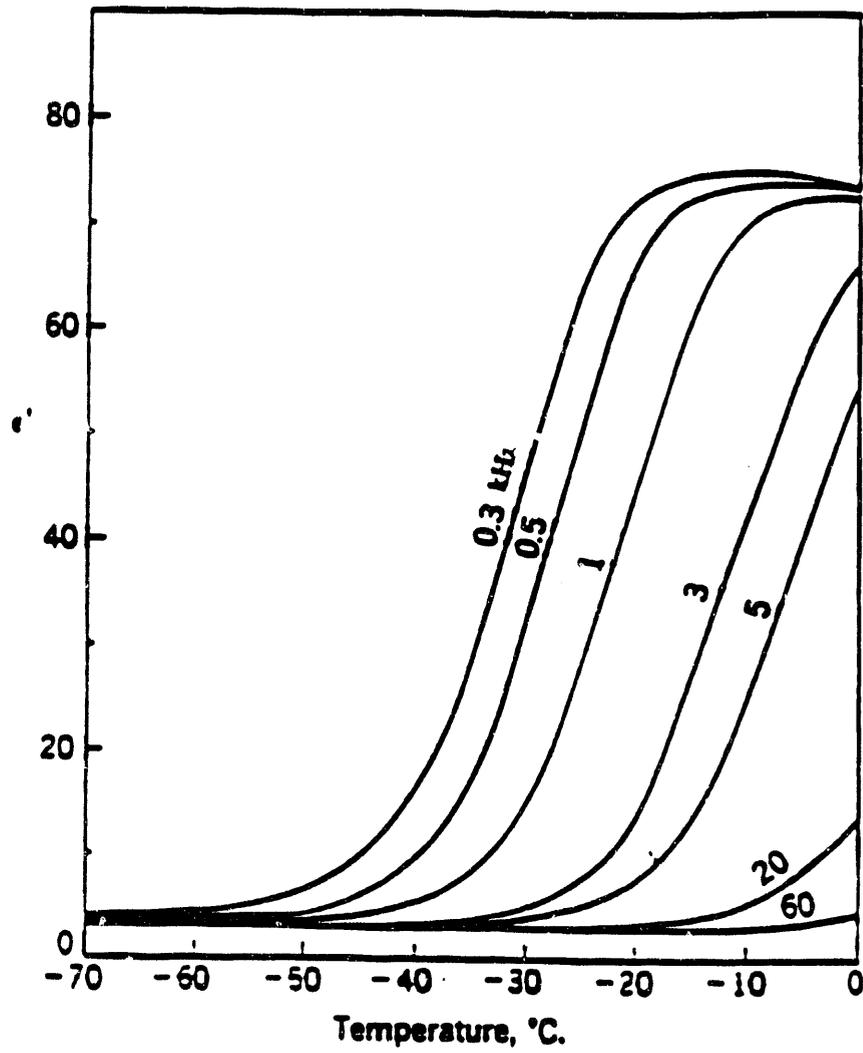


Figure 4. Variation of the dielectric constant of ice with temperature at different frequencies (kHz)

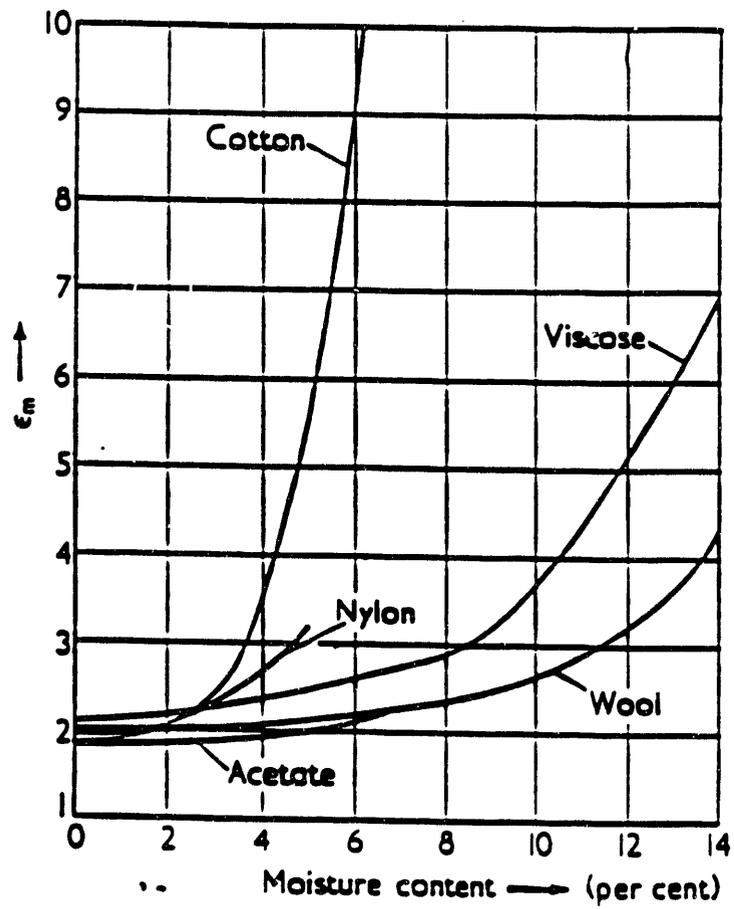


Figure 5a. Variation of effective dielectric constant ϵ_m of yarns with moisture content at a kHz

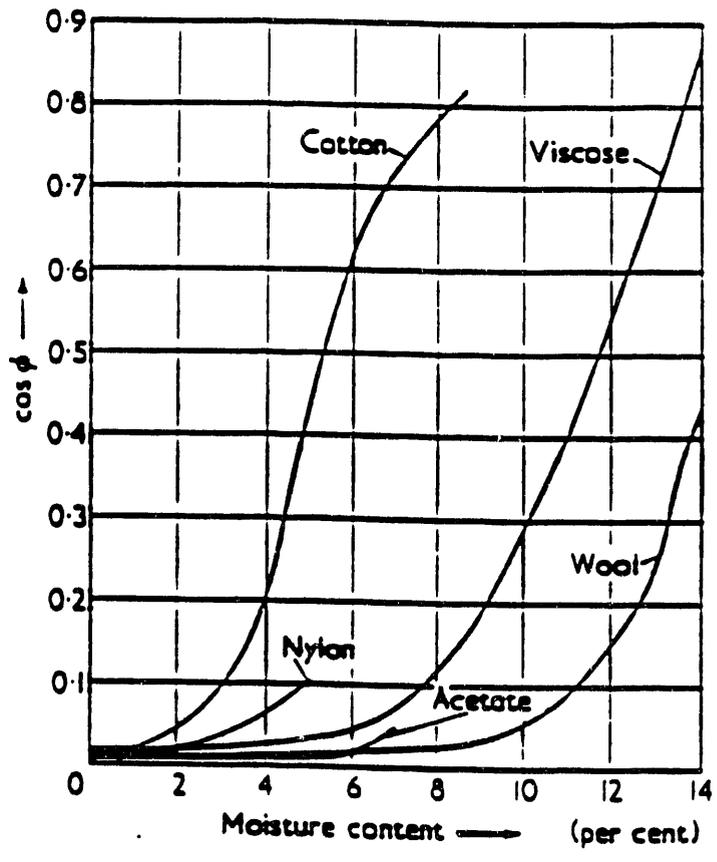


Figure 5b. Variation of power factor $\cos \phi$ of yarns with moisture content at 1 kHz

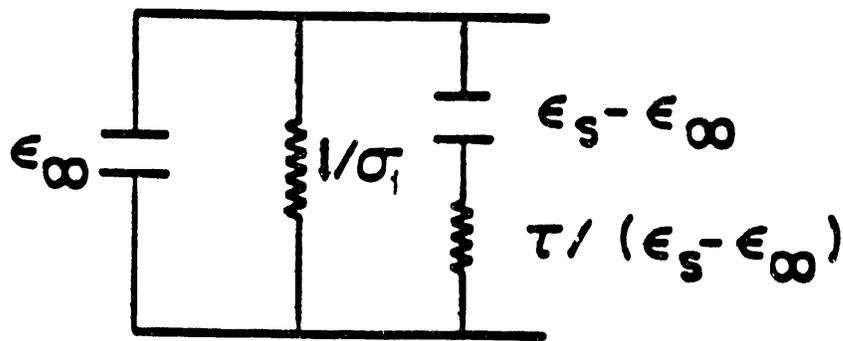


Figure 6. An equivalent circuit that models a single time-constant relaxation of a dielectric

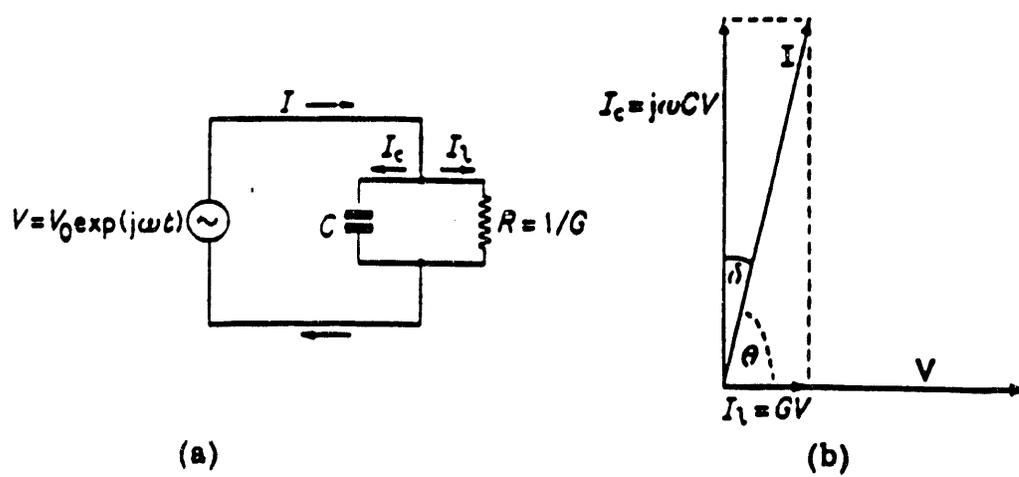


Figure 7. Lossy dielectric (a) equivalent circuit and (b) phasor diagram

APPENDIX B
MANUFACTURING AGREEMENT

PROPOSAL

Tramex Limited, Chamco House, Shankill, Co. Dublin, Ireland.
 From : Alan Rynhart

Re : Proposed new moisture meter for munitions cases for Advanced Measurements Group, Oak Ridge Laboratory

PARTICULARS :

Item One :

To modify the geometry of the electrodes from plane to cylindrical to fit external dia. 154.7mm of munitions case parallel to the length of the instrument.

- 1.1 CAD Development, to release stage, of electrode shape to fit 154.7mm dia. Drawings will be provided showing details of shape and construction. Appropriate footprint size to be decided.
 Development work 10 hours @ \$80.00/hour = \$ 800.00
- 1.2 Producing Master Plot of CAD drawings = \$ 120.00
- 1.3 Production of new display for analogue dial with appropriate range and numeric information. This price includes allowance for marking calibration on scale following your initial testing procedure. Having determined the acceptable ranges a production version will be produced with easy colour referencing
 Development work 6 hours @ \$80.00/hour = \$ 480.00
- 1.4 Production of electrodes cast in moulded rubber with conductive rubber vulcanised to concave surface. These will be trialed in various degrees of Shore Hardness to determine the most suitable electrode seat design. The selected Shore Hardness will be used on your prototype models.
 Development work 12 hours @ \$80.00/hour = \$ 960.00

Item Two :

To modify the electronic circuit and develop a scale to read the moisture content of the munitions cases directly. As it has been found that the most meaningful readings are given on Scale 1 (timber), we would propose changing the control resistance on the three ranges of sensitivity to give the following :

- Scale 1. Similar to current Scale 1 (390k resistance)
 - Scale 2. Less sensitive (470k resistance)
 - Scale 3. More sensitive (270k resistance)
- (Note. All three scales are interactive)

2.1 Development work 10 hours @ \$80.00/hour =	\$ 800.00
TOTAL	\$3160.00

Contd.....

Page 2.....

Item Three :

- 3.1 To supplying one prototype instrument incorporating
the above modifications
As above \$3160.00 plus one unit @ \$318.00 = \$3468.00
- 3.2 Further copies of same @ \$318.00 each

Delivery Schedule :

- | | |
|------------------|--|
| Items 1.1 to 1.3 | 1 week from date of acceptance of proposal |
| Item 1.4 | Production of rubber electrode. 10 days from date of
acceptance of new design |
| Items 2.1 to 3.1 | Production of modified instruments. 15 days from date of
acceptance of new design |

Note : All prices quoted include delivery costs by Federal Express but do not
include duty, customs clearance or any other local charges

To accept this proposal, please sign and return with the relevant purchase order
no. to Trame Limited, Chamco House, Shankill, Co. Dublin, Ireland.

Accepted for and on behalf of
Oak Ridge National Laboratory

APPENDIX C

PRINCIPLES OF OPERATION OF THE MUNITIONS CASE MOISTURE METER

February 11th. 1993.

PRINCIPLES OF OPERATION OF THE ORNL-1 MUNITIONS CASE
MOISTURE METER

Designed for Measurement of Moisture in Combustible
Cartridge Cases.

Instrument Description.

The ORNL-1 is a hand held, battery powered, portable instrument 6" x 3.2" x 1.6" (150 x 80 x 40mm) designed for the non-destructive measurement of moisture in combustible cartridge cases. (See Fig 1).

This instrument is a modification to a range of commercially available non-destructive meters manufactured by TrameX Ltd. which are used for the moisture determination of a large range of materials in the marine, construction and lumber industries.

Modified co-planer electrodes specifically designed to fit the geometry of the external surface of a cylindrical cartridge case 154.7 mm dia. are fitted to the base of the ORNL-1. (See Fig.2).

To ensure optimum contact these electrodes are manufactured from moulded rubber with shore hardness of 20 and surfaced with conductive rubber of 8 ohms-cm resistivity manufactured to BS 3187 and BS 2050.

During operation the instrument is held in contact with the case and a low-frequency signal (12.5Khz) is transmitted from electrode A) and received by electrode B) (See fig. 3).

These signals respond to the conductivity of moisture in the material being tested (in this instance non-woven fibre matrix containing Kraft paper, nitrocellulose fibres and binding resins) and are expressed as a percentage moisture content on an analog dial.

Method of Operation.

The ORNL-1 is best described as an Optimised Impedance Meter which has been developed to take advantage of the benefits of both the resistance (pin type) and capacitance techniques, as already described in the main body of this report, while at the same time overcoming many of their separate limitations.

February 11th. 1993.

Page 2 of 2.

Specifically:

(a). Like resistance meters, the ORNL-1 responds to conductivity in the material being tested and this feature provides a good range of sensitivity to moisture content. (For example fig.4 shows a 7-fold change in relative permittivity but a 1000- fold change in conductivity over the same moisture range.)

(b). As with capacitance meters, it is fitted with plate electrodes rather than probe needles in order to provide non-destructive testing.

(c). Capacitance type meters measure the fringe field which is proportional to the square of the depth.(See fig.5). In contrast the sensitivity of the ORNL-1 is inversely proportional to the depth. Because the ORNL-1 measures resistance as well as capacitance an improved and more sensitive degree of measurement is provided.(See Fig 6).

Note. It is significant that the gap length between the electrodes is greater than that used in fringe field type meters. this feature is important as it reduces the fringe field capacitance to a relatively small value.(See Fig.7).

Ranges of Sensitivity.

The instrument is fitted with three ranges, the sensitivities of which are controlled by resistors R7R, R8P and R9T as shown on attached circuit diagram. (See fig.8) In order to optimise results of previous tests carried out by the Instrument and Controls Division at Oak Ridge, the circuit has been modified by changing these resistors to the following values.

Range 1. 220K.
Range 2. 270K.
Range 3. 330K.

It is anticipated that final calibration tests to be carried out will confirm that these ranges of sensitivity will cover the full range of moisture levels from dry to wet expressed as a percentage of dry weight.

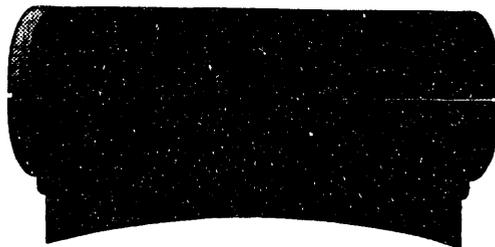
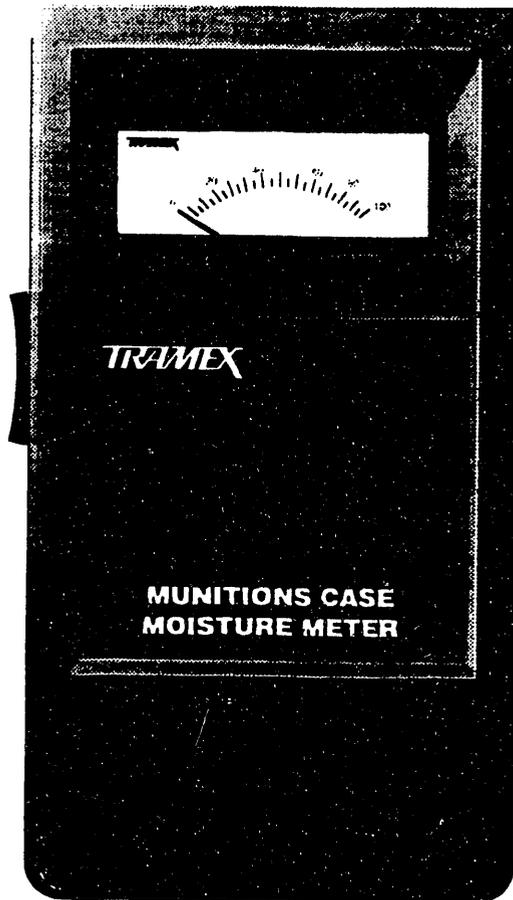
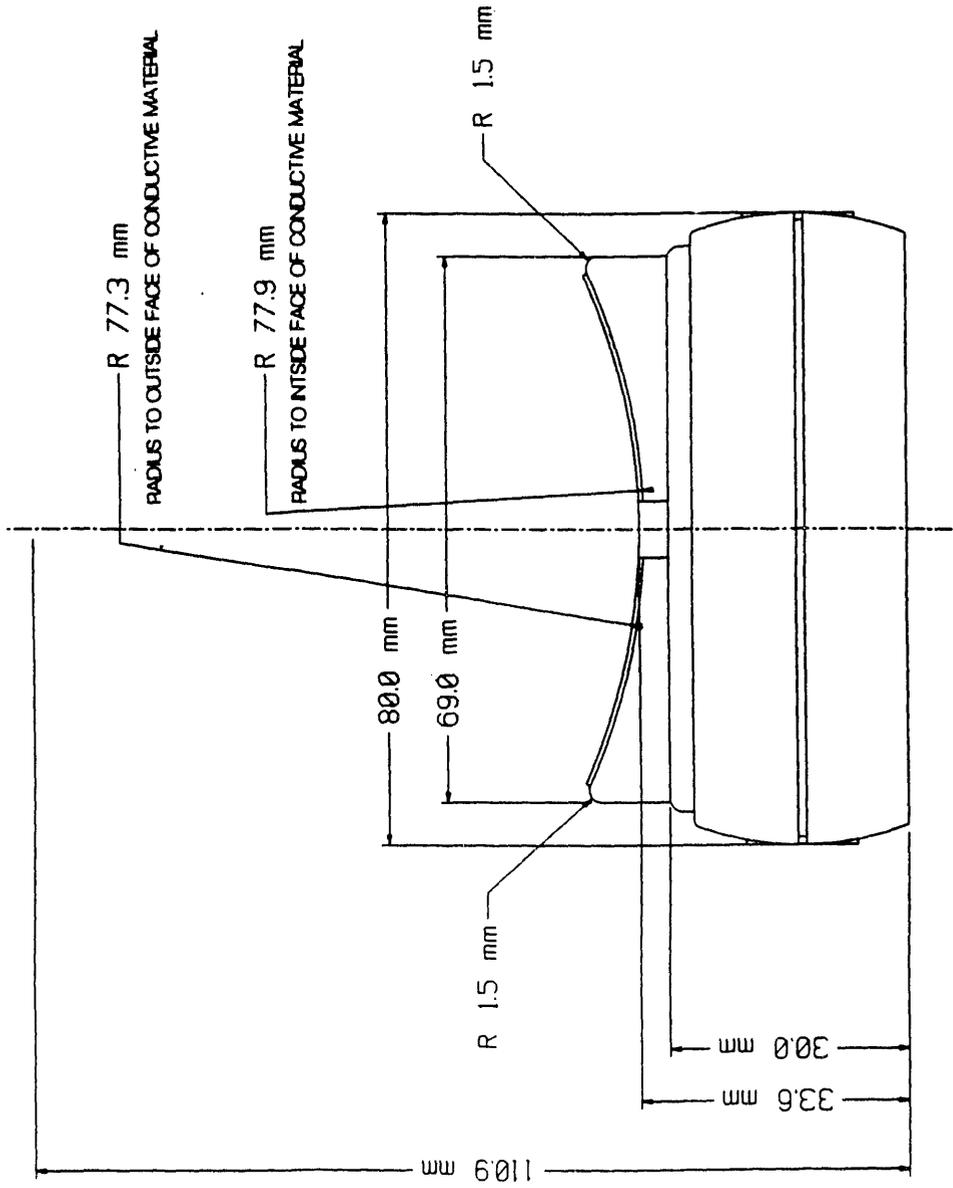


Figure 1.

**MUNITIONS CASE MOISTURE METER
PRODUCT SPECIFICATION**

TRAMEX



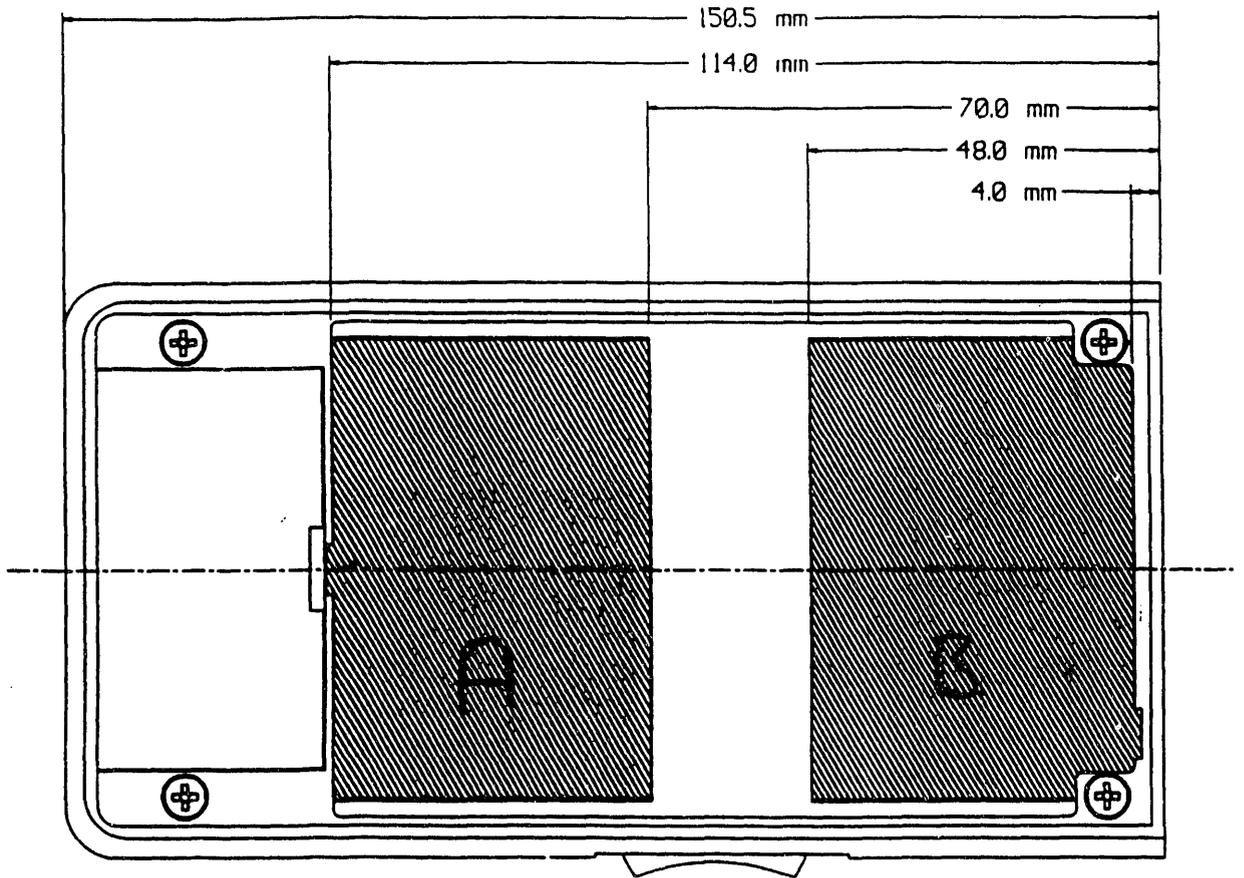


Figure 3.

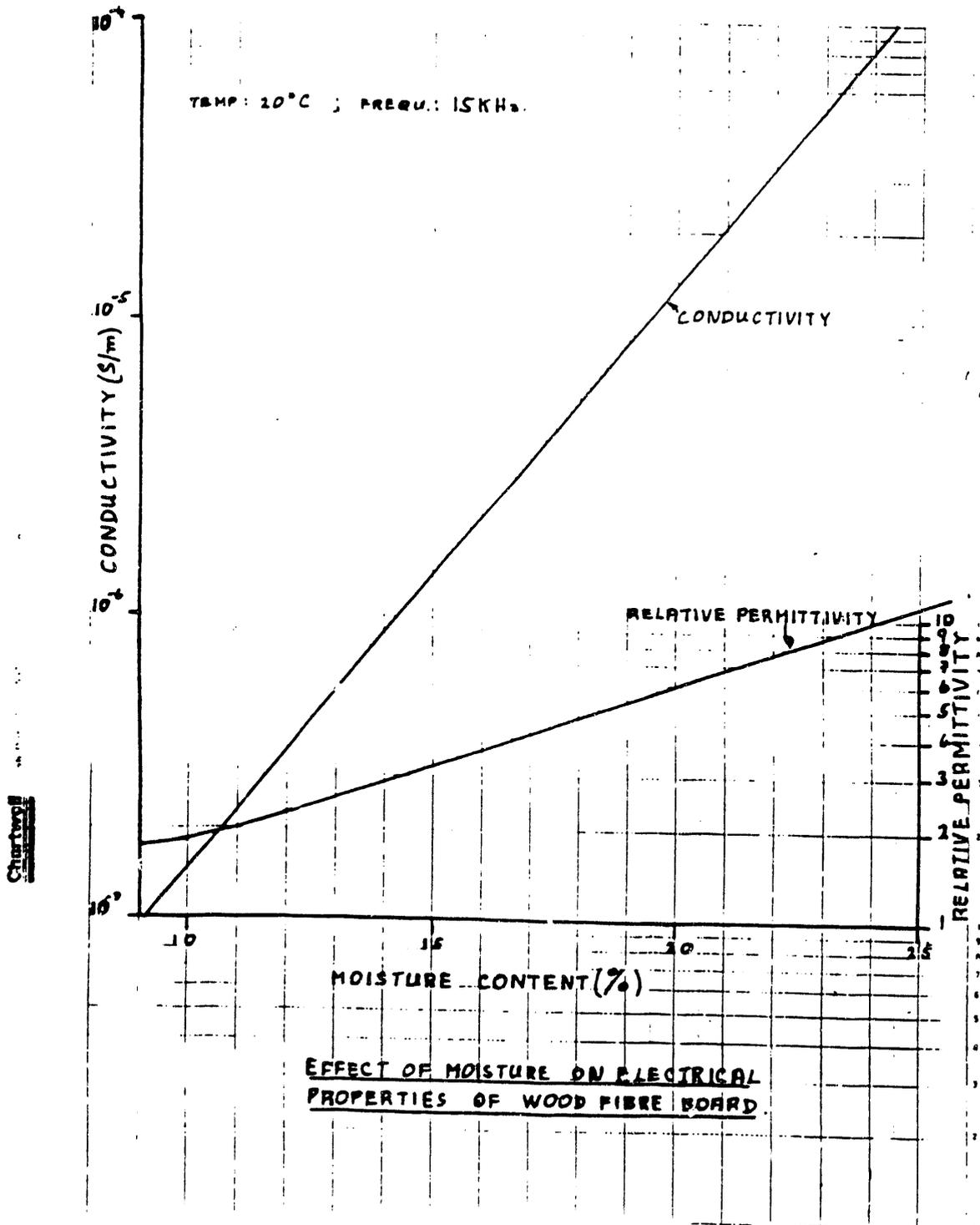
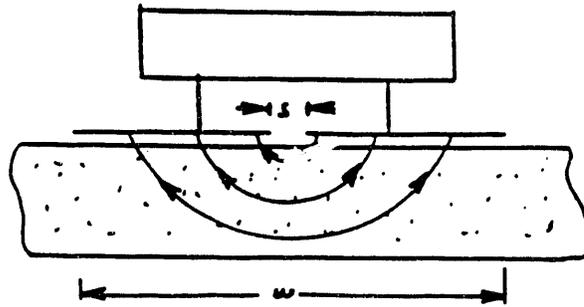
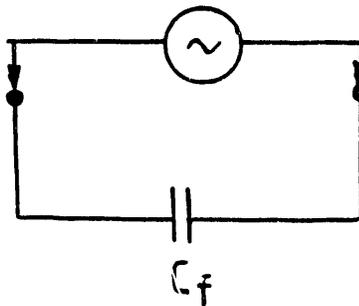


Figure 4.



FRINGE FIELD CAPACITANCE METER



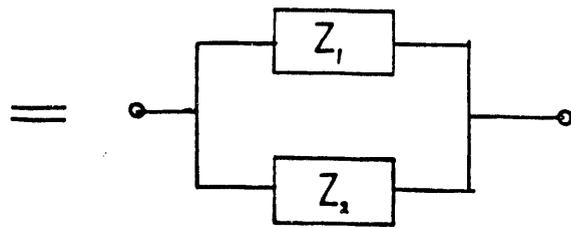
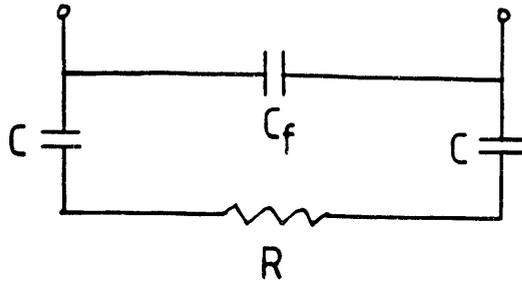
FOR ELONGATE ELECTRODES: $C_f \approx \frac{\epsilon_r}{4\pi\epsilon_0} \times \frac{K'(m)}{K(m)}$

($K'(m)$ and $K(m)$ are the complete elliptical integrals whose modulus, m , is given by $m = w/s$)

EQUIVALENT CIRCUIT.

FRINGE FIELD CAPACITANCE METER

Figure 5.



$$Z_1 = -\frac{j}{2\pi f C_f}$$

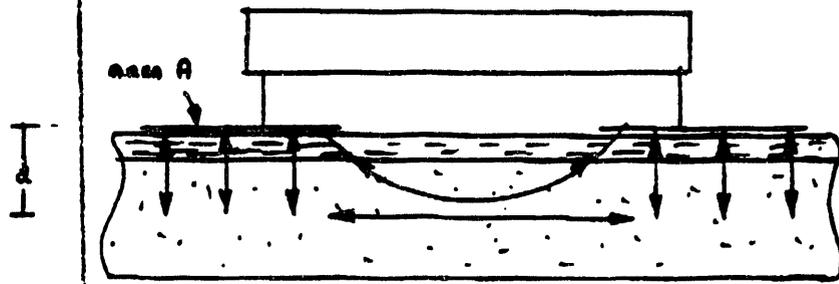
$$Z_2 = R - \frac{j}{2\pi f C}$$



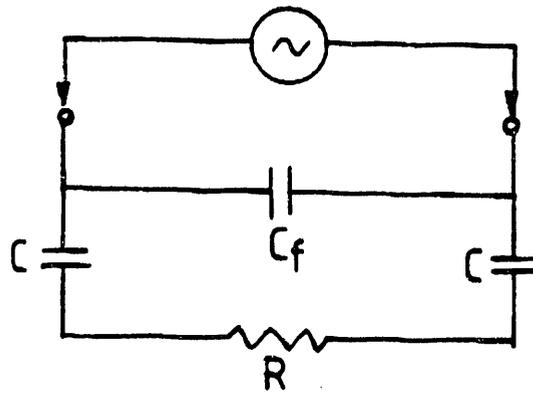
$$Z = \frac{Z_1 Z_2}{Z_1 + Z_2}$$

IMPROVED IMPEDANCE METER: ANALYSIS OF COMPLEX IMPEDANCE.

Figure 6



IMPROVED IMPEDANCE METER



EQUIVALENT CIRCUIT

$$C = \frac{\epsilon_r A}{4\pi\epsilon_0 d}$$

IMPROVED IMPEDANCE METER.

Figure 7.

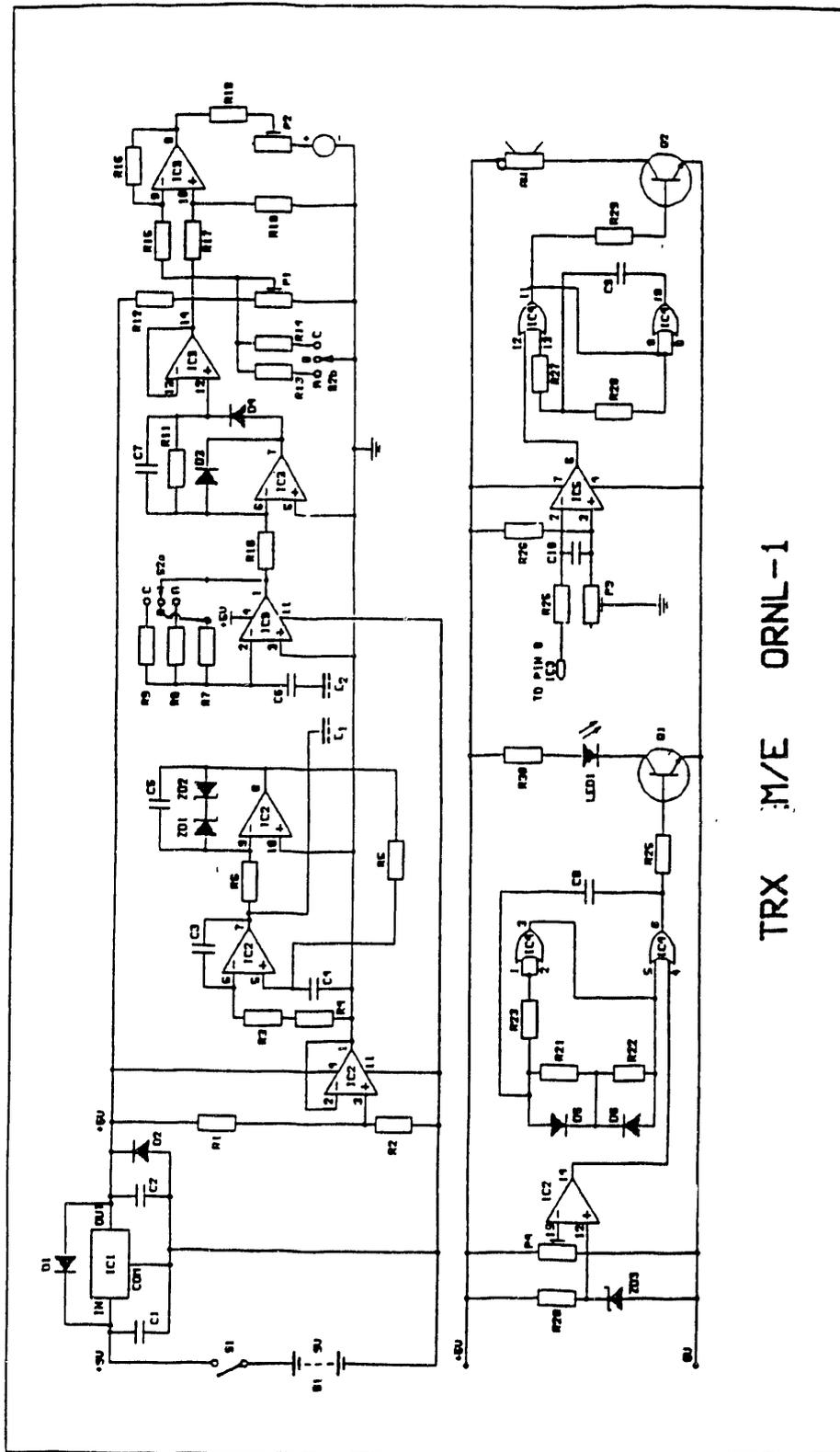
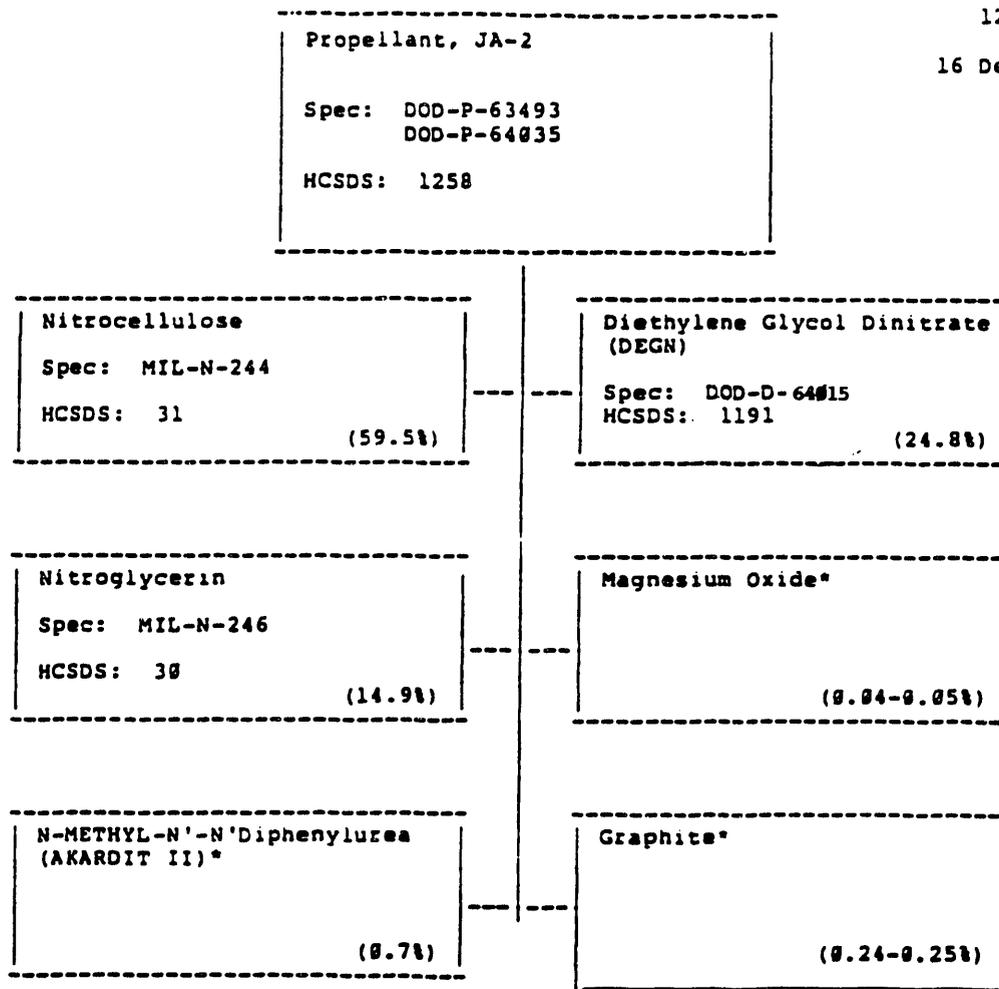


Figure 8.

APPENDIX D
HAZARDOUS COMPONENT SAFETY DATA STATEMENTS (HCSDS)

HAZARDOUS COMPONENT SAFETY DATA STATEMENT (HCSDS)			1 DATE PREPARED (YYMMDD) 87 Dec 16	REPORT CONTROL SYMBOL MRL (AR) 1687
2 MATERIAL/COMPONENT/ASSEMBLY Propellant, JA-2		3 NUMBER 1258	4 REVISION E	
5 APPLICABLE FEDERAL ACQUISITION REGULATION (FAR) SAFETY CLASS 28.7182				
PART I - SENSITIVITY (Apparatus and Comparison Values)				
6 FRICTION TEST **	7 IMPACT TEST **	8 ELECTROSTATIC DISCHARGE TEST Bureau of Mines 3.1 Joules		
PART II - HAZARDS				
9 FIRE High	10 AUTO IGNITION TEMP 163°F (329°F)	11 FLASH POINT NA	12 DECOMPOSITION PRODUCTS Toxic, Avoid Inhalation and Ingestion	
13 FLAMMABLE AND/OR EXPLOSIVE LIMITS		14 EXPLOSION Moderate	15 EXPLOSIVE TEMP (5 Sec) ****	16 DUSTS Unknown
a LOWER PERCENT NA	b UPPER PERCENT NA			
17 HEALTH HAZARD INFORMATION (Toxicity) Moderate by inhalation or ingestion. Contains NG and DEGN			18 UNPACKED (in-process) HAZARD CLASS (Specify Quantities Involved) Class 1.3	
19 SPECIAL REQUIREMENTS (If additional space is needed, use plain bond paper): Ref-Spec: DOD-P-63493, DOD-P-64835 There are no approved packaging drawings (See Attached Sheet) **See Attached Sheet ****Explosive Temperature: 218°C (424°F) NSN: 1376-01-177-9229 Ref-DOD-P-63493 1376-01-177-9238 Ref-DOD-P-64835 Classifications* Tri-Service Coordinated *** Propellant Explosives (Solid), Class B*****				
PART III - SHIPPING/STORAGE CLASSIFICATION OF ITEM WHEN PACKED IN ACCORDANCE WITH APPROVED PACKING DRAWINGS				
20 DOD HAZARD CLASSIFICATION 1.3	21 DOD STORAGE COMPATIBILITY GROUP C	22 DOD HAZARD CLASSIFICATION Class B Explosive*****	23 DOT CONTAINER MARKING CR***	
24 PREPARED BY (INITIALS)				
a TYPED OR PRINTED NAME R. W. BATSON	b SIGNATURE <i>R. W. Batson</i>	c ORGANIZATION Safety Office, ARDEC		
25 CONCURRED IN BY				
a TYPED OR PRINTED NAME R. W. SHOOK	b SIGNATURE <i>R. W. Shook</i>	c ORGANIZATION Safety Office, ARDEC		
26 SAFETY CHIEF OR AUTHORIZED REPRESENTATIVE				
a TYPED OR PRINTED NAME C. PETERS	b SIGNATURE <i>C. Peters</i>	c ORGANIZATION Safety Office, ARDEC		
The information relating to safety (herein referred to as "safety data") contained in this document is limited to those instances when the document is provided as a part of a procurement/production package which involves the development, testing, storage, manufacture, modification, renovation, demilitarization, packaging, transportation, handling, disposal, inspection, repair or any other use of the item, (material/component/assembly) which is specified in the contract. The safety data contained herein are examples which shall be used by the contractor to alert contractor personnel as well as other personnel of hazards associated with the procurement/production		of the item. No representation is made that compliance with the information provided will prevent any accident to persons or property or that additional warnings may not be appropriate. Neither the foregoing nor any act or failure to act by the Government in regard to alerting personnel to the hazards of the item shall affect or relieve the contractor of responsibility for the safety of contractor personnel or property and for the safety of the general public in connection with the performance of the contract, or impose or add to any liability of the Government for such safety.		

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*Information on hazards associated with commercial chemicals can be obtained from the supplier. Such information may already be available in the DOD Hazardous Material Information System (HMIS) DOD 6050.5.L, which is available from the US Government Printing Office, Superintendent of Documents, Washington, DC.

Sheet 2 of 6

Special Requirements: (Con't)

1. The JA-2 propellant is a 7-hole Diglycol powder with nitroglycerin; no solvent. It is sensitive to friction, impact, electrostatic discharge and heat or flame. Precautions should be taken to prevent accidental exposure to these stimuli.

2. CAUTION: Explosives must be tested for compatibility with any material not specified in the production/procurement package with which they may come in contact. Materials include other explosives, solvents, adhesives, metals, plastics, paints, cleaning compounds, floor and table coverings, packing materials and other similar materials, situations and equipment. Explosives include propellants and pyrotechnics.

3. There are no approved packaging drawings. Packaging is covered in specification. Classifications* are for shipment and storage when item is packaged in accordance with specification or sections of 49 CFR as follows:

Definition: Section 173.88(f)
Packaging: Section 173.93
Marking: Section 172 Subpart D and Section 173.93(f) & (g) (1)
Labeling: Section 172 Subpart E (172.411) Explosive B Label

UN Ident: 0161
**DOT Authorization - Ref; EX-8303084 for DOD-P-63493
- Ref; EX-8411161 for DOD-P-64035
Classifications* Tri-Service Coordinated.

4. Hazard Classification Test (TB 700-2) Department of Defense Explosives Hazard Classification Procedures - Sep 82.

- a. Detonation Test - No explosions in five (5) trials.
- b. Ignition and Unconfined Burning Test - No explosions, samples burned.
- c. Thermal Stability Test - No explosion, ignition or change in configuration.
- d. Card Gap Test - 50% Point 45 Cards
- e. Impact Sensitivity Test-

<u>Height, In</u>	<u>Explosion Flame or Noise</u>	<u>No of Trials Exhibiting</u>	
		<u>Decomposition, Smoke, No Noise</u>	<u>No Reaction, Smoke or Noise</u>
10	0	0	10

5. Sensitivity (Comparison Values):

Electrostatic Discharge, Bureau of Mines Apparatus:

<u>Explosive</u>	<u>Joules</u>
Lead Azide	0.007
PETN	Confined 0.21/Unconfined 0.06
TNT	Confined 4.4/ Unconfined 0.06
RDX	>11.03
Black Powder	Confined 0.8/ Unconfined >12.5
M1 Propellant	11.03
M9 Propellant	5.2
M30 Propellant	>12.5

6. TNT Equivalency (%) at Scaled Distance:

<u>Distance</u>	<u>Ft/Lb/1/3</u>	<u>m/Kg 1/3</u>	16.33 Kg (1)		33.11 Kg (1)		32.66 Kg (2)	
			(36 lb)	(4)	(73 lb)	(110 lb)	(110 lb)	(110 lb)
			<u>P%</u>	<u>I%</u>	<u>P%</u>	<u>I%</u>	<u>P%</u>	<u>I%</u>
3.0		1.19	235	281	269	217	361	286
5.4		2.14	191	187	220	198	219	147
9.0		3.57	126	213	152	214	136	180
18.0		7.14	279	266	266	211	265	179
40		15.9	155	104	160	117	135	77

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Distance		24.95 Kg (3) (55 lb)		49.9 Kg (3) (110 lb)		32.66 Kg (3) (72 lb)	
<u>Ft/Lb/1/3</u>	<u>m/Kg 1/3</u>	<u>P%</u>	<u>I%</u>	<u>P%</u>	<u>I%</u>	<u>P%</u>	<u>I%</u>
3.0	1.19	81	34	323	179	191	245
5.4	2.14	67	68	177	107	141	88
9.0	3.57	74	94	88	120	93	133
18.0	7.14	98	79	177	192	206	132
40	15.9	103	74	186	72	175	110

NOTES:

- (1) Simulated Shipping Container
- (2) Full Scale Shipping Container
- (3) Simulated Dryer Bed
- (4) Pressure
- (5) Impulse

7. Radford Test Values

- a. Impact: Material exposed to impact energy of a falling weight.
Results measured and expressed as joules per square meter of contact.
(Ref- Radford Rpt 100.10, dated Sep 76)

Threshold Initiation Level (TIL)

<u>Material</u>	<u>Condition</u>	<u>Energy, N/m²</u>
JA-2 Propellant	Stick	8.4x10 ⁴
Lead Azide	Dry, Solid	2.2x10 ⁴
TNT	Dry, Solid	6.7x10 ⁴
RDX	Dry, Solid	2.7x10 ⁴
Black Powder	Granules	5.4x10 ⁴
M1 Propellant	Flake	1.4x10 ⁴
M9 Propellant	Flake	1.7x10 ⁴
M30 Propellant	Fines	2.2x10 ⁴

Sheet 5 of 6

- b. Friction: Material exposed to friction generated between stationary wheel and sliding surface (anvil). Results are expressed as newtons per square meter of contact surface at anvil speed used for test (Ref- Radford Rpt 100.10, dated Sep 76)

Theshold Initiation Level (TIL)

<u>Material</u>	<u>Condition</u>	<u>Nm² @ m/sec</u>
JA-2 Propellant	Stick	5.00x10 ⁸ /2.4
Lead Azide	Dry, Solid	3.05x10 ⁸ /2.4
TNT	Dry, Solid	4.87x10 ⁸ /2.4
RDX	Dry, Solid	3.59x10 ⁸ /2.4
Black Powder	Granules	>12.2x10 ⁸ /2.4
M1 Propellant	Flake	4.15x10 ⁸ /2.4
M9 Propellant	Flake	2.34x10 ⁸ /2.4
M30 Propellant	Fines	5.71x10 ⁸ /2.4

- c. Electrostatic: Material exposed to energy stored in a charged capacitor. Results are expressed in joules as the minimum initiation level (Ref- Radford Rpt 100.10, dated sep 76)

<u>Material</u>	<u>Condition</u>	<u>Energy, Joules</u>
JA-2 Propellant	Stick	3.3
Lead Azide	Dry, Solid	0.0028
TNT	Dry, Solid	0.5
RDX	Dry, Solid	0.5
Black Powder	Granules	0.53
M1 Propellant	Flake	1.26
M9 Propellant	Flake	>5.0
M30 Propellant	Fines	0.26

STATEMENT (HCSDS)		(FORM 100)	CONTROL SYMBOL
2 MATERIAL / COMPONENT / ASSEMBLY COMPONENTS, COMBUSTIBLE		92 Oct 21	MIL (ARI) 1687
3 NUMBER CABLE FEDERAL ACQUISITION REGULATION (FAR) SAFETY CLAUSE 28.7100		860	4 REVISION L
PART I - SENSITIVITY (Accelerations and Comparison Values)			
5 FRICTION TEST NA	7 IMPACT TEST NA	8 ELECTROSTATIC DISCHARGE TEST NA	
PART II - HAZARDS			
9 FIRE Low	10 AUTO IGNITION TEMP NA	11. FLASH POINT NA	12. DECOMPOSITION PRODUCTS Toxic, Avoid Inhalation and Ingestion
13 FLAMMABLE AND/OR EXPLOSIVE LIMITS		14 EXPLOSION Low	15 EXPLOSIVE TEMP (5 Sec.) NA
a LOWER PERCENT NA	b UPPER PERCENT NA		
16 DUSTS NA		17 HEALTH HAZARD INFORMATION (Toxicity) Not Toxic	
18 UNPACKED (in-Process) HAZARD CLASS (Specify Quantities Involved) Not Listed		19 SPECIAL REQUIREMENTS (If additional space is needed, use plain bond paper)	
<p>Ref-Dwg: See Attached Sheet Spec: See Attached Sheet</p> <p>* See Attached Sheet for DOD/DOT/UN Marking</p>			
PART III - SHIPPING / STORAGE CLASSIFICATION OF ITEM WHEN PACKED IN ACCORDANCE WITH APPROVED PACKING DRAWINGS			
20 DOD HAZARD CLASS/DIV 4.1	21 DOD STORAGE COMPATIBILITY GROUP C	22 DOT HAZARD CLASSIFICATION 4.1	23 DOT CONTAINER MARKING *
24 PREPARED BY (Initiator)			
a TYPED OR PRINTED NAME R. W. PATSON		b SIGNATURE <i>R.W. Patson</i>	c ORGANIZATION SAFETY OFFICE ARDEC
25 CONCURRED II. BY			
a TYPED OR PRINTED NAME R. W. SNOOK		b SIGNATURE <i>R.W. Snook</i>	c ORGANIZATION SAFETY OFFICE ARDEC
26 SAFETY CHIEF OR AUTHORIZED REPRESENTATIVE			
a TYPED OR PRINTED NAME C. R. PETERS, D. F.		b SIGNATURE <i>C.R. Peters</i>	c ORGANIZATION SAFETY OFFICE ARDEC
<p>The information relating to safety (herein referred to as "safety data") contained in this document is limited to those instances when the document is provided as a part of a procurement/production package which involves the development, testing, storage, manufacture, modification, renovation, demilitarization, packaging, transportation, handling, disposal, inspection, repair or any other of the item, (material/component/assembly) which is specified in the contract. The safety data contained herein are examples which shall be used by the contractor to alert contractor personnel as well as other personnel of hazards associated with the procurement/production</p>		<p>of the item. No representation is made that compliance with the information provided will prevent any accident to persons or property or that additional warnings may not be appropriate. Neither the foregoing nor any act or failure to act by the Government in regard to alerting personnel to the hazards of the item shall affect or relieve the contractor of responsibility for the safety of contractor personnel or property and for the safety of the general public in connection with the performance of the contract, or impose or add to any liability of the Government for such safety</p>	

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1. In accordance with applicable parts of 49CFR for proper description, packaging, marking and classification, the following Hazard Classification is assigned to the subject item:

DOD Hazard Class/Div/SCG: 4.1C
DOT Hazard Class: 4.1
(Section 173, Subpart C, Section 173.52)
DOT Label: Flammable Solid, n.o.s.
(Section 172, Subpart E (172.420 (c) & (d))
DOT Proper Shipping Name (PSN): Flammable Solid, n.o.s.)
(Section 172, Subpart B and Section 172.101)
UN Serial Number: 1325
DOT Container Marking: Flammable Solid, n.o.s.
UN: 1325
NSN: (As applicable)
Part Number: (As applicable)
(Section 172, Subpart D, Section 172.301(a) and
172.320(a))
Packaging Method: Group II or III (as applicable)

2. Combustible cases, containers or tubes are pyroxylin plastic type combustible forms containing a high percentage (58 to 78) of nitrocellulose of 12.6 or as high as 13.6 percent nitrogen content. The HCSDS covers several pyroxylin plastic type compositions (HCSDS-1098) processed into cases, containers or tubes.

a. Case, f/Charge, Propelling 155mm, M203A1

Assy	9345091	NSN: 1320-01-219-7856
Wrapped Body	9345094	Material - 9345109
Body Molded	9345098	Material - 9345109
Rear Cap	9345095	Material - 9357034
Igniter	9345097	Material - 9357034

Spec: MIL-C-70461
Weight - 2.25 lbs (1.02 kgs)
Approved Packaging Drawings - 9390469, 9390470, 9390476
Packing Group - III

Alternate Case, f/Charge, Propelling, 155mm, M203A1

Body Molded Wrapped	12598552	Material - 9345109
Rear Cap	9345095	Material - 9345109
Igniter	9345097	Material - 9345109

Spec: MIL-C-70461

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Weight - 2.25 lbs (1.02 kgs)
Approved Packaging Drawings - 9390469, 0390470, 9390476
Packing Group - III

b. Container, f/Charge, Propelling, 155mm, M215 (Mod Charge)

Body	9381688	Material - 9395767
End Cap	9395755	Material - 9395767
Base	9395754	Material - 9395767

Spec: None
Weight - 0.5 lbs (0.23 kgs)
Approved Packaging Drawings - None
Packing Group - III

c. Container, f/Charge, Propelling, 155mm, M216 (Mod Charge)

Body, Incr A	9344132	Material - 9395767
Body, Incr B	9381687	Material - 9395767
End Cap	9357961	Material - 9395767
Base	9344130	Material - 9395767

Spec: None
Weight - 0.6 lbs (0.27 kgs)
Approved Packaging Drawings - None
Packing Group - III

d. Container, f/Charge, Propelling, 155mm, XM230 (Unicharge)

Body	12630741	Material - 12630742
Cap	12630737	Material - 12630742
Tube, Center Core	12630734	Material - 12630742
Adapter	12630735	Material - 12630742

Spec: None
Weight - 0.5 lbs (0.23 kgs)
Approved Packaging Drawings - None
Packing Group - III

e. Container, f/Charge, Propelling, 50mm, M204

Assembly	9312697	NSN: 1310-01-064-2839
Top	9312699	Material - 9381562
Bottom	9312700	Material - 9381562
Closure	9312786	Material - 9277371
Adhesive	9255426	Material - HCSDS - 757

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Spec: MIL-C-48868
Weight - 0.006 lbs (0.003 kgs)
Approved Packaging Drawings - 9313703, 9313727
Packing Group - III

f. Container, f/Charge, Propelling, 81mm, M205

Assembly	9278773	NSN: 1315-01-105-4073
Top	9278774	Material - 9381562
Bottom	9288775	Material - 9381562
Closure	9312786	Material - 9277371
Adhesive	9255426	Material - HCSDS - 757

Spec: MIL-C-70501
Weight - 0.006 lbs (0.003 kgs)
Approved Packaging Drawings - 9313703, 9313727, 9298796
Packing Group - III

g. Case, f/Cartridge, TP-T, 120mm, M831

Case Assy	12526679	NSN: 1315-01-177-9227
Case	12526655	Material - DOD-C-63486
Cap	12526656	Material - DOD-C-63486
Disc	12526285	Material - DOD-C-63486

Spec: DOD-C-63486
Weight -
Approved Packaging Drawings - None
Packing Group - II

h. Case, f/Cartridge, HEAT-T, 120mm, M830

Case Assy	12526253	
Case	12526655	Material - DOD-C-63486
Cap	12526656	Material - DOD-C-63486
Disc	12526282	Material - DOD-C-63486

Spec: DOD-C-63486
Weight -
Approved Packaging Drawings - None
Packing Group - II

i. Case, f/Cartridge, TPDS-T, 120mm, M865/M827

		NSN: 1315-01-178-7626
		NSN: 1315-01-179-5969
Case	12524976	Material - DOD-C-63487
Ring	12524926	Material - DOD-C-63487

Spec: DOD-C-63487

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Weight -
Approved Packaging Drawings -
Packing Group - II

j. Case, f/Cartridge, APFSDS-T, 120mm, M829

Casing 12524976 Material - 12524936
Spec: DOD-C-63487
Weight -
Approved Packaging Drawings -
Packing Group - II

k. Case, Cartridge, 152mm, M205

Body 9252186 Material - 9247366
Base 9252187 Material - 9247366
Spec: MIL-C-50534
Weight - 0.8 lbs (0.36 kgs)
Approved Packaging Drawings - None
Packing Group - III

l. Container, f/Charge, Propelling, 120mm, XM230

Container Assy 12577568
Top 12577526 Material - 12577622
Bottom 12577523 Material - 12577622
Closure 12577525 Material - 9277371
Spec: MIL-C-71034
Weight - 0.03 lbs (0.015 kgs)
Approved Packaging Drawings - None
Packing Group - III

Igniter Tubes

<u>P/N</u>	<u>Weight, lbs</u>	<u>Material</u>	<u>Spec</u>	<u>Pack</u>
9285248	0.3241	9247366	MIL-I-48252	X
9285215	0.3087	9247366	MIL-I-48252	X
9281772	-	9247366	MIL-I-48252	X
9325882	0.2844	9247366	MIL-I-48252	X
9279018	-	9247366	-	-
9285271	-	9247366	MIL-I-48252	X
9285241	-	9247366	MIL-I-48252	X
11829101	-	9247366/ 9331378	MIL-I-48252	X

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9331404	-	9331378	MIL-I-48252	X
9289172	0.3000	9247366	MIL-I-48252	X

X Approved Packaging Drawing - 9282963

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