AD-786 425

CAUSES AND CONTROL OF CONDENSATION IN SHRINK FILM UNIT LOADS UNDER OUTDOOR STORAGE CONDITIONS

Anderson Miller

Army Natick Laboratories
Natick, Massachusetts

September 1974

DISTRIBUTED BY:

NTIS
National Technical Information Service
U. S. DEPARTMENT OF COMMERCE
5285 Port Royal Road, Springfield Va. 22151

Approved for public release.
Distribution is unlimited.

AD___________________

TECHNICAL REPORT

75-6-FEL

CAUSES AND CONTROL OF CONDENSATION IN SHRINK FILM UNIT LOADS UNDER OUTDOOR STORAGE CONDITIONS

by
Anderson Miller

Project Reference:
Production Engineering

Series: FEL-3

Food Engineering Laboratory
U. S. ARMY NATICK LABORATORIES
Natick, Massachusetts 01760

ib

CONTENTS

AD 786 495

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER 75-6-FEL	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) "Causes and control of condensation in shrink film unit loads under outdoor storage conditions"		5. TYPE OF REPORT & PERIOD COVERED
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Anderson Miller		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS US Army Natick Laboratories Natick, MA 01760 FEL		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS		12. REPORT DATE September 1974
		13. NUMBER OF PAGES 52
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

CAUSES	METALS	COVERINGS	MILITARY REQUIREMENTS
CONTROL	FOOD	VENTILATION	STUDIES
CONDENSATION	CANS	LOAD CONFIGURATION	PREVENTION
STORAGE	EXPOSURE	POLYMERIC FILMS	DAMAGE
CORROSION	SHEATHING	SHROUDS (POLYETHYLENE)	

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The can corrosion problem which has been associated with Type 1, Class E unit loads in outdoor storage can also be expected to be encountered with shrink film unit loads which are exposed to outdoor storage. In FY 72 a study was initiated to determine the major causes of condensation within these loads and develop methods which might reduce the damage caused by condensation after prolonged outdoor storage.

52

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

20. This study consisted of experimental tests, laboratory tests, outdoor tests instrumented to record temperature build-up within the loads, and a final field test under actual storage conditions at Sharpe Army Depot, Lathrop, California. The NLABS recorder was also used in some of the loads tested in outdoor tests to measure temperature and humidity changes within the loads during day and night exposure. The laboratory tests consisted of exposu . tests under controlled conditions and the use of infrared heat lamps to simulat. infrared rays of the sun in outdoor exposure.

TECHNICAL REPORT

FOREWORD

This study was conducted under Production Engineering Project 7, Task 10, Control of Condensation in Shrink Film Unit Loads.

The study consisted of Laboratory tests and outdoor exposure tests of shrink film unit loads of bright metal canned subsistence and other items under various weather conditions. Various types of shrink film material such as clear film, green film, black film and different variables were studied and tested to first determine the cause of condensation.

The results of the tests showed where the source of the moisture which causes condensation was and methods which may be used in reducing condensation by controlling the moisutre content of the material which is shrink wrapped.

ABSTRACT

The can corrosion problem which has been associated with Type 1 Class E unit loads in outdoor storage can also be expected to be encountered with shrink film unit loads which are exposed to outdoor storage. In FY72 a study was initiated to determine the major causes of condensation within these loads and develop methods which might reduce the damage caused by condensation after prolonged outdoor storage.

This study consisted of experimental tests, laboratory tests, outdoor tests instrumented to record temperature build-up within the loads, and a final field test under actual storage conditions at Sharpe Army Depot, Lathrop, California. The NLABS recorder was also used in some of the loads tested in outdoor tests to measure temperature and humidity changes within the loads during day and night exposure. The laboratory tests consisted of exposure tests under controlled conditions and the use of infrared heat lamps to simulate infrared rays of the sun in outdoor exposure.

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION

The problem of condensation within unit loads has been occurring since the palletization or unit load method of consolidation of shipping packages first began. It became more apparent when polyethylene shrouds were added for protection against rainfall during shipment to and storage of supplies in Southeast Asia in the mid-sixties. During that time several attempts were made to determine the cause of the problems, and efforts were made to prevent or reduce the amount of condensation occurring in unit loads. Success in these studies was hampered by the many uncontrolled and unpredictable variables which existed in outdoor storage conditions and by the lack of laboratory techniques to simulate the conditions or elements which cause condensation.

With the introduction of polymeric shrink film as a shroud for unit load protection, it was expected that the condensation problems would be similar, if not worse, than it was in the unit loads with polyethylene shroud and V2s fiberboard sheathing. In the shrink film loads the film would be the only barrier; whereas, the standard unit load contains a fiberboard sheath over the film.

The reason for considering shrink film for unit load protection is that such a method would be more economical because of ease of application, lighter weight, less packaging material required, and the ability of the film to shrink and form a tight load. In commercial shipment, shrink film packaging is being used to contain a wide variety of items in over-the-road shipments. However, along the commercial routes the loads are always kept under covered storage or warehouse conditions; and, condensation has not been a problem. Therefore, no studies have been conducted by industry on the causes or prevention of condensation. For military use this type of environment would not always be practical; therefore, the extreme environmental conditions must be considered and steps taken to provide adequate protection against the elements. It is for this reason that this study was conducted and expanded to develop a test method which could be used for testing various films in the future.

To initiate the study, a literature search was conducted to determine the materials which are readily available and more economical to use for shrouding unit loads. A survey was also conducted to determine the variables to be tested using full size unit loads, and eventually using reduced size loads so that more sample loads could be tested. Data on surface heating effects of radiant solar energy were reviewed, along with other radiant energy sources such as infrared, ultraviolet, and incandescent filament lamp systems available.

Previous tests have been conducted on the can corrosion problems which sometimes occurred in the regular unit loads when they were exposed to outdoor storage for extended periods of time. During these tests, condensation which occurred in outdoor storage could not be duplicated using standard test procedures and environmental chambers alone in the laboratory, primarily because solar heating was neglected. Since it was necessary to simulate outdoor conditions in the laboratory and to maintain control over some of the variables which existed, the tests were established to use new procedures and apparatus to produce condensation in the loads.

MATERIAL AND EQUIPMENT

Films

The shrink-film polyethylene shrouds used for the full-size and the reduced-size unit loads were 4 mil and 5 mil furnished by FMC Corporation; and 6 mil, 7 mil, and 8 mil furnished by Weldotron Corp. The films used for the tray packs were

5 mil polyethylene (FMC), 4 mil nylon reinforced polyethylene (Griffolyn Corp.), and 3 mil polyvinylchloride (Reynolds Aluminum).

Containers

The fiberboard containers used for making up the loads were V2s Solid, V3c Corrugated - 1.4MN/m^2 (200 lb.) Test Domestic Corrugated - and 1.9MN/m^2 (275 lb.) Test Wax-Impregnated Containers. The wood containers used were Style 2 nailed wood boxes fabricated in-house to fit the 1016 mm X 1219 mm (40" X 48") pallet in a 2 X 2 pattern.

Other Materials

Nominal 25.4 mm X 101.6 mm (1" X 4") boards were used to construct the slatted frame for the "ventilated load" tested. For the "insulated top" load, a 6.35 mm (1/4") particle board sheet 1219.2 mm X 1016.0 mm (48" X 40") was placed on top of the load under the film prior to shrinking the film. The inner loads of canned items were made up of number ten cans of canned beets purchased from DPSC. Other loads were made up of items other than cans, such as clothing, paper, dry cereals and metal retrograde items.

Shrink Wrap Equipment

The shrink film of the full size shrink film unit loads tested in the initial outdoor tests was applied at the Naval Supply Center at Newport, R.I., with an infrared heat ring designed for shrink wrapping unit loads. The loads prepared in-house were heat shrunk with a portable propane heat cannon furnished by Weldotron Corp. Figure 1.

Heat Source

The heat source used to simulate the elements of the sunlight which causes the condensation was designed and fabricated in-house.

The apparatus used as the heat source provided simulated sunlight reflection which first consisted of 150W and 200W incandescent light bulbs mounted under a plywood frame which was fixed over the unit load. The board was covered with aluminum foil to act as a reflector. It was constructed so that the bulbs or lamps could be adjusted at various heights above the load. The number of bulbs or lamps used could be increased or decreased over the test period along with adjustments in the height of the bulbs above the load to increase or decrease the temperature within the load. Figure 2.

If the incandescent bulbs did not produce the desired results, infrared heat lamps could be substituted in the heat source by merely changing the bulbs.

Environmental Conditions

The environmental chambers in the laboratory were used to condition the loads for tests. These conditions were 22.8°C. (73°F.) - 50% R.H., 37.8°C. (100°F.) - 90% R.H., and 60°C. (140°F.) - 10% R.H. The cycling chamber 0.6°C. to 71.1°C. (33°F. to 160°F. and 20% - 90% R.H.) was used to simulate the outdoor day and night air temperature.

Recorders

The change in temperature within the loads and the air temperature around the loads were taken with thermocouples connected to a Honeywell recorder. Figure 3.

This unit was used in both the outside tests and the tests in the laboratory. In addition to this unit, the NLABS recorder developed by the Engineering Science Division, GEPL, was used to record the temperature and humidity of some of the loads tested in the final phase of the study. Figure 4.

PROCEDURE

Load Variables and Tests

The load variables tested were selected as representatives of the most practical and economical method which might be employed in making up unit loads. A series of five tests in sequence were carried out with each succeeding test designed to use the results of the preceding series.

These tests were:

1. Preliminary Tests.
2. Outdoor I Tests.
3. Laboratory/Indoor Tests.
4. Outdoor II Tests.
5. Final Field Tests.

Preliminary Tests

Three unit loads were made up in accordance with Military Specification MIL-L-35078, except that in one load shrink-film was substituted for the fiberboard sheathing and polyethylene shroud. In the remaining loads shrink-film tray-packs were used as the inner load, Figure 5. One of the tray-pack loads was sheathed with V2s sheathing and cap, and the final tray-pack load had only a cap. Each of the loads was placed in outdoor storage test for sixty days, and the changes in temperature within the shrouded loads were taken using thermocouples attached to a recorder which recorded the temperature at 15 minute intervals. The thermocouples were placed at the top, middle, and bottom of the loads. The tray-pack load, which was covered with a cap only, was not instrumented with thermocouples since it was not an inclosed load. All of the loads were visually examined periodically for increase in condensation and corrosion of the surfaces of the cans. The data obtained from these tests were used to determine the method to be used for the final phases of the study.

Outdoor I Tests

The results of the preliminary tests showed that the greatest temperature changes occurred at the top of the load; therefore, all of the variables tested outdoors were instrumented with a thermocouple only at the top of the load. The load variables tested in this phase of the study were as follows:

1. Control (a) regular unit load made up in accordance with MIL-L-35078.

2. Control (b) regular unit load shrouded with polyethylene shrink film tightly shrunk with a heat source. These loads did not have a cover sheet on the pallet base.

3. Inclosed Control (c) regular load shrouded with shrink film, with a sheet of polyethylene which covered the pallet deck and extended up the sides. When shrunk with the heat source, the two films bonded together to form a fully inclosed load. See Figure 6.

4. Black Polyethylene Top - regular load made up similar to load number 3 except a sheet of black polyethylene used to cover top of load under the shrink film.

5. Insulated - Regular unit load made up similar to load number 3 except a 6.35 mm (1/4") thick particle board was placed over the top to provide insulation against the sunlight. (one load tested)

6. Ventilated load - Regular unit load made up similar to load number 3 except the top of the load was provided with a slatted frame under the film for ventilation of the top. (one load tested)

7. Green Film load - Regular unit loads made up similar to load number 3 except that green inhibitor-treated polyethylene shrink film was used.

8. Aluminum Foil top - Regular unit load made up similar to load number 3 except that the top was covered with aluminum foil under the shrink film to reflect the heat.

9. Treated Container load - Regular unit loads made up similar to load number 3 except that all of the inner containers were made up of wax-resin impregnated fiberboard containers.

10. Wood Box load - This load was made up of twelve Style 2 nailed wood boxes (610 mm x 508 mm x 305 mm (24" x 20" x 12") shrink wrapped with 8 mil clear polyethylene film. The load was totally inclosed as in the regular loads above. Figure 7.

11. Retrograde - The retrograde load was made up of a 1016 mm x 1219 mm (40" x 48") pallet load of surplus electric motors and compressors from the storage area. Before shrink wrapping, all sharp edges of the items were covered with polyethylene and taped. An 8 mil heat-shrinkable polyethylene bag was placed over the load and shrunk tightly. Before loading, a polyethylene sheet was placed on top of the pallet which bonded to the shrink film bag and formed an inclosed load. Figure 8.

12. Reduced-Size loads - The reduced-size unit loads were made up similar to the inclosed loads, except that they were approximately 1/4 the size of the full-size unit load. Figure 9.

NOTE: The above loads will be referred to by number and/or title only for the remainder of this report.

A minimum of 2 loads each of the variables - No. 2 Control (b), No. 3 Inclosed, No. 4 Black polyethylene top, No. 7 Green film, No. 8 Aluminum foil top, were tested in outdoor storage for up to sixty days. One load each of variables No. 1, Control (a) load, No. 5 Insulated load, and No. 6 Ventilated load were tested. The test on these variables were discontinued because Number 1 was only intended to be used for one exposure test and Numbers 5 and 6 did not prevent corrosion and are impractical for large scale use. In addition to recording the temperature, the loads were examined throughout the test for condensation and evidence of corrosion of the cans. After completion of each exposure period, a sample of the fiberboard was taken from the top of the containers in the top layer of the loads and the moisture content of the board was determined by the oven-dry method.

One of the inclosed loads was instrumented with an NLABS temperature-humidity recorder in addition to the thermocouple recorder to measure the changes in the humidity within the loads during the day-night change in temperature. The effect of temperature changes on the change in the humidity was also determined from the recordings.

Two additional loads of the tray packs were tested in this phase of the study also. One load consisted of tray packs made up of 3 mil polyvinylchloride shrink film, and one load of 5 mil polyethylene, each made up on a pallet base with a V2s fiberboard cap only, and strapped 2 lengthwise and 2 girthwise with plastic straps. Since each load was not inclosed, no instrumentation was used to measure temperature changes.

These loads were examined periodically for condensation and corrosion within the packs over a period of 55 days in outdoor storage.

Laboratory/Indoor Tests

The recorder charts from the outdoor tests were examined for temperature extremes to establish a basis for the indoor tests. The laboratory tests were then designed to test one or more full-size loads of each type tested outdoors except load numbers 5, 6, 10 and 11. Loads 5 and 6 were considered impractical from an economical standpoint. Loads 10 and 11 were not considered for inclusion in the laboratory tests since the reaction of the wood load would be similar to fiberboard, and the reaction of the retrograde load would be similar to that of the tray pack included in the preliminary tests.

The first test consisted of conditioning a load at ambient room temperature and subjecting it to the light source using 120 and 200 watt incandescent bulbs. The number of bulbs used and the height of the bulbs above the load were adjusted to attempt to simulate the temperature build-up as experienced in the outdoor tests which reached a high of 63.3°C. (146°F.). After a series of tests which did not produce a temperature build-up as rapidly as the outdoor direct sunlight conditions, the incandescent bulbs were replaced with 375 watt infrared bulbs. The 375 watt infrared bulbs showed that a rapid temperature build-up could be accomplished but the areas of the film immediately under the bulbs began to melt after a short period of time. This was an indication that the heat was too intense and that lower watt bulbs would probably eliminate this problem.

Based on these observations, the 375 watt bulbs were replaced with 250 watt infrared heat lamps. After several adjustments in the height of the bulbs above the load, the temperature build-up approximated that which had been recorded under direct sunlight in the outdoor tests. The heat source containing 250 watt infrared heat lamps was then used throughout the remainder of this phase of the study to test all of the selected variables. The full-size and reduced-size loads were tested after conditioning under the following conditions:

1. Ambient room temperature and relative humidity (indoors).
2. High-temperature, high-humidity - 37.8°C. - 90% R.H. (100°F. - 90% R.H.) for 4 hours to 24 hours.
3. Hot-dry conditions - 60°C. - 10% R.H. (140°F. - 10% R.H.) for 24 hours.

The reason for using both high humidity and dry conditions was to vary the amount of moisture picked up by the materials within the loads. The moisture content of the materials within the loads was measured using the oven-dried method on samples taken from the loads. Tests were conducted both on loads which were conditioned after shrink wrapping and on loads which were conditioned prior to shrink wrapping. The variables tested, using reduced-size loads, were subjected to the heat source for a minimum of seven days under cycling conditions as shown in Table I.

TABLE I

Temperature build-up of loads subjected to the heat source.

No. 2 Control (b)	3	10 days ea	15.6°C. - 60°C. (60°F. - 140°F.)	15.6°C. - 26.7°C. (60°F. - 80°F.)
No. 3 Inclosed Load	3	12 days ea	17.8°C. - 60°C. (64°F. - 140°F.) & 17.8°C. - 54.4°C. (64°F. - 130°F.)	17.8°C. - 23.9°C. (64°F. - 75°F.) & 21.1°C. - 22.2°C. (70°F. - 72°F.)
No. 4 Black polyethylene top	1	5 days	17.8°C. - 54.4°C. (64°F. - 130°F.)	17.8°C. - 23.9°C. (64°F. - 75°F.)
No. 7 Green Film Load	1	5 days min	17.8°C. - 54.4°C. (64°F. - 130°F.)	17.8°C. - 23.9°C. (64°F. - 75°F.)
No. 8 Aluminum Foil top	1	5 days min		17.8°C. - 23.9°C. (64°F. - 75°F.)
No. 9 Treated Container	3	14 days	17.8°C. - 54.4°C. (64°F. - 130°F.)	17.8°C. - 23.9°C. (64°F. - 75°F.)

Polyvinylchloride Film

An additional load similar to No. 2 control (b) was made up using 3 mil polyvinylchloride shrink film and tested at a temperature build-up of 54.4°C. (130°F.) to determine if a different material would reach the same temperature as polyethylene film.

Loads with Different Thermal Capacity

In order to determine if the thermal capacity or the specific heat of the contents of the loads would have any effect on the amount of condensation produced, reduced-size unit loads similar to the control (b) made up of various items other than can subsistence, were tested. The items used in these tests were clothing, dehydrated cabbage, paper and dry cereals.

Moisture Source Tests

After all load variables were tested under the conditions which caused condensation, studies were initiated to determine the source or sources of the moisture which causes condensation. The first step was to conduct tests on No. 3 inclosed loads under various humidity conditions, ambient room temperature, 37.8°C. (100°F.) - 90% R.H., and 60°C. (140°F.) - 10% R.H. For these tests the load was made up and shrink wrapped prior to conditioning. The shrink wrapped loads were then subjected to the selected conditions to determine if the outside environment would have a greater effect on the amount of moisture generated within the load.

Moisture Content of Fiberboard

The moisture content of the fiberboard was taken on loads tested under hot-dry conditions - 60°C. (140°F.) - 10% R.H., and ambient room temperature conditions. Two full-size loads, each made up similar to Load No. 3 inclosed load, were tested under each of these conditions.

Further tests were conducted on two reduced-size fully inclosed loads containing V2s packs and on two full-size fully inclosed loads containing wax-impregnated containers after conditioning under the above conditions. The packs for all of the above loads were conditioned for at least 48 hours prior to shrink wrapping. The moisture content of the V2s packs in these loads were taken by cutting a sample of the board from the top of the containers in the top layer of the loads. The amount of moisture difference in the wax-impregnated loads were measured by placing a preweighed sample of solid fiberboard in the load and reweighing the sample to determine amount of moisture gained, if any. The moisture contents of the packs were determined under the above conditions using the oven-dry method as specified in ASTM Standard D-644.

Moisture Content of Loads under Standard Conditions

Upon completion of these tests, four reduced-size loads were made up of V2s and corrugated packs and tested after conditioning at 73°F. - 50% R.H. for four days and shrink wrapped. Each of the loads was subjected to the heat source and a temperature build-up of 130°F. was obtained. The loads were then examined for condensation on the film and the cans. The moisture content of the packs were taken on samples of boards cut from each pack immediately after test.

Measurement of Change in Moisture Content of Load

The purpose of this series of tests was to determine the effect of the various temperature-moisture conditions and moisture contents of the material within the load on the amount of condensation produced. The tests were conducted on three reduced-size loads after conditioning one load at 60°C. (140°F.) and 10% R.H. for 48 hours and after conditioning two loads at 37.8°C. (100°F.) and 90% R.H. for 16 hours. All three loads were conditioned before shrink wrapping. The moisture content of the packs at the top of these loads were determined before test, immediately after test, and a final measurement after oven-dry, as follows:

> A sample of board similar to that of the containers was weighed after conditioning with the packs. A second weighing was made after completion of the test and a final weighing made after the samples had been oven dried. The purpose of taking three measurements of the moisture contents of the material at the top of the load was to determine the amount of moisture build-up in the material in that area as a result of moisture being drawn up from other areas of the load as the temperature changes.

After completion of all the indoor tests, the results were tabulated and a comparison made of the results which had been obtained in earlier outdoor tests, where applicable.

Outdoor II Tests

After completion of the laboratory tests, the methods which showed promise in reducing or eliminating condensation in the laboratory tests were scheduled for retest in outdoor conditions in both the full size and reduced-size unit loads. For the first group of loads tested, three reduced-size loads were made up of No. 10 size V3c corrugated containers of canned subsistence and conditioned at 60°C. (140°F.) - 10% R.H. for one week. They were then shrink wrapped and placed in outdoor storage along with a fully inclosed control load which had been conditioned at 22.8°C. (73°F.) - 50% R.H. for one week. The loads were allowed to remain outside from 23 May to 1 June 1972, to be exposed to direct sunlight on all sides and the tops. During the test, the loads were observed for evidence of condensation and after tests the moisture content of the board in the top containers was taken.

The second group of loads tested consisted of one wax-impregnated container load conditioned at ambient room temperature, one load conditioned at 37.8°C. (100°F.) - 90% R.H. for 48 hours, and one V2s container load at 60°C. (140°F.) - 10% R.H. for 48 hours instrumented with the NLABS temperature humidity recorders and exposed to outdoor tests during the months of June, July and August 1972. The purpose of these tests, in addition to comparative evaluation, was to record the actual fluctuation in the temperature and humidity simultaneously with changes in outdoor conditions.

In addition to conducting tests on the above loads, tests were conducted on additional loads of treated containers (wax-impregnated), shrink-film loads of retrograde items and loads made up of nailed wood boxes. Bright metal tin plate samples were placed throughout the load of retrograde items to act as corrosion indicators.

Final Field Tests - Sharpe Army Depot - Lathrop, Calif.

After completion of all laboratory tests and outdoor tests at NLABS, a final field evaluation study was planned for tests under actual storage conditions at Sharpe Army Depot, Lathrop, California. The final field tests conducted were on loads representative of the variables which show through laboratory tests the causes of condensation and methods which prevented condensation. These loads consisted of the following variables:

Loads

1-3f Control: Three pallet loads of items packed in corrugated containers.

4-6f Two pallet loads of retrograde items fastened to heavy wood skids and placed directly on pallets. One load of small parts in nailed wood boxes and fiberboard cases.

7-9f Three pallet loads of retrograde with minimum amount of wood skidding placed on pallets covered with V3c corrugated fiberboard.

10-12f Three pallet loads of retrograde items with no wood crating, skids or fiberboard material placed on pallets covered with polyethylene which extended approximately 18" up the side of the loads.

Since most of the items contained corrosion at the beginning of the tests, indicator tin plate and SAE 1010 steel plates were fastened to the items at the top of the loads prior to shrink wrapping. Each of the loads was then shrink wrapped with 6 mil polyethylene bags and placed in outdoor storage in an area exposed to open sunlight. The loads were allowed to remain in open storage from 13 December 1972 to 9 February 1973. They were then examined for corrosion of the plates which were placed at the top of the load in each load variable.

RESULTS

Preliminary Tests

1. The results of the preliminary tests show that the problem of condensation in shrink film unit loads was similar to that which had been experienced in regular unit loads made up in accordance with Military Specification MIL-L-35078, and that occurred in our test locale.

2. The tray pack containers in unit loads in sheathing and cap, and in cap only; i.e., without polymer shroud, did not show any evidence of condensation. The cans did not sustain any corrosion after approximately 2 months in outdoor storage.

3. The temperature recordings taken inside the loads in the preliminary tests indicated that the greatest change in temperature occurs in the top of the unit load. There was no significant change in the temperature from the bottom of the top layer of containers to those at the pallet base during the change in temperature from day to night-time conditions.

4. Since it was determined that the greatest or most significant changes in temperature within the load occurred at the top of the load, the laboratory tests and further outdoor tests were conducted with the loads instrumented for temperature and humidity recordings in this area.

Outdoor I Tests

1. During the outdoor tests, the greatest amount of condensation occurred on the days when the loads were exposed to the greatest amount of sunlight. This indicated that sunlight has a more direct effect on the build-up of condensation than any other element in outdoor exposure.

2. Condensation occurred in all of the variables tested on unit loads with shrink film shrouds as the outer protection. The load with an aluminum foil cover on top of the load under the film had less condensation than the remaining loads; however, it was still considered not satisfactory for preventing can corrosion. None of the remaining load variables exhibited satisfactory performance in reducing condensation in the loads.

3. The temperature build-up within the loads as measured by the thermocouples on the first series of tests on the different variables are shown in Table II.

TABLE II

Temperature build-up within loads subjected to Outdoor Storage Conditions

			High	Low
a.	No. 2	Control (b)	56.7°C. (134°F.)	14.4°C. (58°F.)
b.	No. 3	Inclosed	56.7°C. (134°F.)	15.6°C. (60°F.)
c.	No. 4	Black Polyethylene Top	57.8°C. (136°F.	14.4°C. (58°F.)
d.	No. 5	Insulated Top	43.3°C. (110°F.)	13.3°C. (56°F.)
e.	No. 6	Ventilated Top	43.3°C. (110°F.	14.4°C. (58°F.)
f.	No. 7	Green Film	54.4°C. (130°F.)	14.4°C. (58°F.)
g.	No. 8	Aluminum Foil Top	44.4°C. (112°F.)	14.4°C. (58°F.)

The outside temperature measurements, during the time period in which the temperature build-up in the loads was recorded, showed a high of 30°C. (86°F.) and a low of 13.3°C. (56°F.).

4. The results by observation show that the amount of condensation is more directly related to the rate of temperature build-up than to the maximum high which is reached within the load. The chart on the temperature recorder indicates that on bright sunny days the rate of build-up of temperature is rapid. (This is indicated by the slope of the recorder curve. A rapid rate of temperature build-up is shown as a steep curve; whereas, when the temperature build-up is gradual, the curve is more of a flat pattern.) To substantiate these recordings, it was noted that during the outdoor tests, more condensation was observed within the loads on bright sunny days than on days which had less sunlight.

5. The moisture content of the samples of board taken from the top of containers in the top layer of each load are shown in Table III.

TABLE III

Moisture Contents of Fiberboard Taken from Top Layer of Containers of Shrink-Film Loads Exposed to Outdoor Storage

	% Moisture
a. No. 2 Control (b)	5.85
b. No. 3 Inclosed	9.46
c. No. 4 Black Polyethylene Top	6.76
d. No. 5 Insulated Top	6.98
e. No. 6 Ventilated Top	7.72
f. No. 7 Green Polyethylene	6.72
g. No. 8 Aluminum Foil Top	7.60

6. Repetition of these exposure tests on additional loads similar to loads Number 3, 4, 7, and 8 produced the same results throughout the exposure period. Loads Number 5 and 6 were considered impractical for use in large procurements.

7. The results of the load instrumented with the NLABS recorder are shown in Figures 10 - 13. As noted on the curves, the 8th, 9th, 11th and 12th, which were sunny days, indicated that the humidity inside the load reached 95%, while on three rainy and humid days (6th, 7th and 10th), the indicated humidity inside the load never exceeded 75%. This was further indication that the amount of available sunlight has a more pronounced effect on the humidity level inside the shrink film unit load than the amount of available moisture in the air around the load.

8. There was no evidence of corrosion or condensation in the tray pack loads made up of polyvinylchloride film and polyethylene film (with V2s cap only), and subjected to 55 days in outdoor storage beginning the 1st of Sep 1971.

9. The information gathered in these outdoor tests established a basis for conducting laboratory tests which could closely simulate the outdoor conditions which cause condensation in shrink film loads.

Laboratory/Indoor Test

1. Examination of the loads during exposure test showed that condensation occurred when the temperature within the load was rapidly increased to 43.3°C. (110°F.), or above. The use of the incandescent bulbs produced the desired temperature of over 43.3°C. (110°F.), but it appeared that the build-up was not rapid enough; therefore, very little or no condensation was produced on loads conditioned at ambient room temperature.

2. After reconditioning the load and subjecting it to the heat source equipped with 250 watt infrared heat lamps, the temperature build-up, up to 54.4°C. (130°F.), was accomplished almost immediately. In a period of approximately one-half hour, heavy condensation collected on the inner surface of the film at the top of the load. Visual inspection of the loads indicated that the amount of condensation which collected became gradually less as the load was cycled between simulated day and night conditions. The decrease in the condensation was probably caused by the water droplets evaporating each day and recondensing on the colder can surfaces causing increased corrosion of the cans.

3. All of the load variables tested under ambient conditions showed similar results with heavy condensation after the first heat exposure test and the amount of condensation becoming gradually less under continued cycling. Similar results were shown in the loads made up of items with different thermal capacity.

4. The results of the tests of the loads which were first shrink wrapped and then conditioned at high-temperature high-humidity conditions showed that there was no significant change in the amount of condensation generated over that which resulted at ambient conditions. Similar results were obtained on shrink-wrapped loads tested after conditioning at 22.8°C. (73°F.) and 50% R.H. This would indicate that the outside conditions had little or no effect on the amount of moisture build-up in the load after shrink wrapping.

5. The moisture content of fiberboard samples taken from shrink-wrapped loads after the containers had been conditioned at various temperature and humidity conditions prior to shrink wrapping and tests are shown in Table IV.

TABLE IV

Moisture Content of Containers Conditioned at Various Conditions

Sample No.	Pre-Conditioning	Percent Moisture
1	22.8°C. (73°F.) - 50% R.H.	5.2%
2	22.8°C. (73°F.) - 50% R.H.	4.9%
3	37.8°C. (100°F.) - 90% R.H.	9.9%
4	37.8°C. (100°F.) - 90% R.H.	10.5%
5	60°C. (140°F.) - 10% R.H.	3.49%
6	60°C. (140°F.) - 10% R.H.	3.52%
7	60°C. (140°F.) - 10% R.H.	3.20%

6. Condensation in loads which sample Numbers 3 and 4 were taken from was more severe than in all other loads. The conditions were such that water droplets formed on the inner surface of the film and wetted the containers and cans in the top layer of the load. The loads from which samples 1 and 2 were taken showed condensation on the inner surface of the film and on the surface of the cans which was considered severe enough to cause corrosion over an extended period of time. The loads which had contained samples 5, 6, and 7 did not show any evidence of condensation in any area of the load over the entire test period of these loads.

7. Repetition of these tests on additional loads showed similar results in the condensation pattern. (For additional loads, three of the above loads were broken down, dried out and one each conditioned at each of the above conditions and shrouded with new shrink film bags.)

8. The change in the moisture content of the containers in the top layer of fully inclosed loads subjected to the light source are presented in Table V.

TABLE V

Change in Moisture Content of Containers Tested After Conditioning at Various Conditions

Pre-Conditioning	Orig. Wt. GMS.	Wght. (2) * GMS.	Dry Wt. GMS.	% Loss	Final Moist. Cont. PERCENT
1. 37.8°C (100°F) - 90% R.H. 16 hrs.	48.65	46.35	45.95	1.90	5.87
2. 22.8°C (73°F) - 50% R.H. 48 hrs.	23.90	23.48	22.35	1.79	4.60
3. 60°C (140°F) - 10% R.H. 43 hrs.	39.46	-----	38.10	----	3.57

* See Page 12

Loads 1 and 2 of Table V showed a loss of 1.96% and 1.79% of the moisture in the top of the containers of the top layer after a four hour test on the load using the light source. The moisture content of the samples after oven drying were 5.87% and 4.60%. There was no evidence of condensation in load No. 3 which had a moisture content of 3.57%; whereas, loads 1 and 2 sustained light condensation on the cans and on the inner surface of the film on top of the load.

9. All of the results of the laboratory tests indicate that the condensation which occurs in the loads is directly related to the amount of moisture in the material which is shrink-wrapped. Condensation did not occur in fiberboard container loads where the moisture content of the board in the top layer containers did not exceed 3.5 - 4%. Loads which contained little fiberboard (tray packs) had no condensation as a result of exposure to the light source. The loads with treated fiberboard (wax-impregnated) containers sustained less damage than regular fiberboard loads due to corrosion caused by condensation.

<u>Outdoor II Tests</u>

1. The three reduced-size loads which were tested after conditioning at 60°C. (140°F.) - 10% R.H. for one week prior to shrink wrapping did not show any sign of condensation; whereas, condensation had collected on the inner surface of the film of the load conditioned at 22.8°C. (73°F.) and 50% R.H. for one week before shrink wrapping. The moisture content of the containers in the top of the reduced-size loads are shown in Table VI.

TABLE VI

Moisture Content of Containers in Top Layer of Reduced-Size Loads

Load	Conditioning	% Moisture Content
1	60°C. (140°F.) - 10% R.H.	3.4%
2	" " "	3.9%
3	" " "	3.6%
4	22.8°C. (73°F.) - 50% R.H.	5.5%

2. The full-size wax-impregnated container loads conditioned at ambient room temperature prior to shrink wrapping had very little condensation and the loads conditioned at 37.8°C. (100°F.) - 90% R.H. for 48 hours before shrink wrapping had heavy condensation on the inner surface of the film at the top of the load. The V2s loads conditioned at 60°C. (140°F.) - 10% R.H. before shrink wrapping had no condensation on the film.

3. The load containing the retrograde items did not show any evidence of condensation over the entire outdoor test period, which was extended indefinitely - July, August, September 1972 - May 1973 - to present. The load which was made up of nailed wood boxes with material taken from stock and without conditioning had heavy condensation on the film at the top and top edges of the load. The moisture content of a sample of one of the top boxes was 12.15% after test. These boxes were made up and tested without preconditioning.

4. The results of the NLABS recorder charts taken within the load are shown in Figure 10, 11, 12 and 13.

Field Test - Sharpe Army Depot - Lathrop, Calif.

The metal plates which were placed inside the loads subjected to 60 days outdoor exposure had sustained corrosion in loads numbers 1f, 2f, 3f, 5, 6f, 7f, and 9f. Examination of these loads showed by observation that the amounts of corrosion on the plates were proportional to the amount of moisture in the source; i.e., wood and/or fiberboard, within the load. The control loads - 1f, 2f, and 3f had sustained major damage due to corrosion and loads 5f, 7f, and 9f had sustained light-to-moderate damage due to corrosion. The plate in Load No. 6f, which was made up of wood boxes and fiberboard, had become completely covered with pitted rust as a result of an extremely heavy amount of condensation. The fully inclosed loads - 10f, 11f, and 12f - which did not contain a source for moisture did not show any evidence of corrosion.

The results of these tests substantiated the results obtained in the laboratory, which show that if the moisture content of fiberboard is above 4%, condensation would occur. The moisture content in all loads containing fiberboard was above 4%. The board in the control loads had an average moisture content in the top of the containers at the top of the load of 8.6% at the beginning of the test and 12.1% at the end of the test. The board covering the open top of the nailed wood boxes had a moisture content of 9% at the beginning of the test and 12.9% at the end of the test. The gain in moisture content of the board in the top area of the loads was probably used by moisture being driven from the board in lower areas of the load and absorbed by the top layer of the top containers when condensation occurred.

The photographs showing the corrosion of the plates placed in the loads are shown in Figures 13 - 16.

DISCUSSION

The results of the tests conducted in this study clearly indicate that the major cause of the condensation problem is the amount of available moisture within the load after shrink wrapping. The moisture in the materials is driven off when the sunlight heats up the inside of the load in a "greenhouse" effect causing it to rise to the top of the load. Since the temperature within the load can rise to as high as 71.1°C. (160°F.), the hot moist air contacts the cooler film and metal cans in that area and condensation forms. When this condensation on the film evaporates back into moist air, the moisture does not escape but goes back into the material nearest the top of the load to be released again the next day, when exposed to sunlight. As this cycle continues, corrosion begins to build up on the cans or metal items within the loads causing damage.

The results also showed that using simplified changes in the type of film or makeup of the load such as different colored film, ventilation, or insulation of the tops do not prevent condensation from occurring. The aluminum foil technique tended to retard theproblem for a short period but eventually the damage of can corrosion occurred as in the other variables tested in the first phase of the study.

The reason all previous tests in the laboratory had not produced condensation was because simulation of intense solar heating, primarily in the infrared region, which caused a rapid heat build-up, was not used along with the other conditions. When the heat source used in this study was equipped with incandescent bulbs, the heat build-up was not rapid enough to cause condensation within the loads because much of the radiation from the bulbs was probably absorbed by the film. The temperature build-up was accomplished more rapidly with the infrared heat lamps because the film may be more transmissible by infrared radiation than by radiation from regular light of incandescent bulbs. This is probably the reason that infrared radiation penetrated the film and caused the materials and air within the load to be heated quickly and drive off the moisture of the fiberboard to cause condensation.

It appears that moisture in excess of 3-4% is more readily driven from the fiberboard when the temperature approaches approximately 54.4°C. (130°F.). The 3-4% moisture which remains in the board probably requires a higher temperature for removal. Therefore, the moisture level below 3-4% apparently is not readily available for causing condensation under normal outdoor exposure conditions of unit loads. The results of the tests using wax-impregnated boxes show that the amount of condensation can be reduced by a treatment of the board which will lower the moisture content. Wax-impregnated fiberboard is not moisture proof, but it does have a greater resistance to moisture than regular untreated board. Therefore, if a better method of lowering the moisture content of regular fiberboard is developed, the problem could possibly be completely eliminated in fiberboard loads. There was no problem with the fully inclosed retrograde load, and loads made up of plastic materials as the inner packs, as were shown with the tray pack loads. The tray packs and retrograde items did not contain any material which provided a source of moisture. The load made up of wood boxes showed more condensation than all loads tested because the moisture content of wood is normally higher than domestic or weather-resistant fiberboard.

The temperature recordings, temperature-humidity recordings and the results of the moisture content determinations under various conditions show that the major factors which contribute to the condensation problem are: (a) direct sunlight, (b) the material which makes up the load, (c) the amount of available moisture in the material, and (d) length of time of exposure.

CONCLUSIONS

It is concluded that:

1. The major cause of the condensation problem in shrink-film units is the available moisture within the materials in the load being driven off by the rapid temperature build-up caused by direct exposure to sunlight.

2. The outside humidity conditions have little or no effect on the amount of condensation which occurred on the inside of a fully inclosed shrink film load.

3. Regular untreated fiberboard or wood containers cannot be expected to be shrink wrapped and placed in outdoor exposure for prolonged periods of time without experiencing condensation on the inside of the load.

4. A process which will lower the moisture content of the containers to be shrink wrapped will aid in reducing the amount of condensation caused by moisture being driven out of the containers by temperature build-up in the load.

5. Items which do not act as a source for moisture should not present any condensation problems when shrink wrapped in a fully inclosed shroud.

6. The infrared heat lamps can be used to test the properties of new or different films used for shrink wrapping unit loads in the future, for condensation resistance.

7. The use of wax-impregnated containers for canned subsistence shows promise as being one method by which condensation in shrink wrapped loads can be reduced.

8. The use of shrink-wrapped tray-packs appears to be the most effective method of preventing condensation to date in canned items.

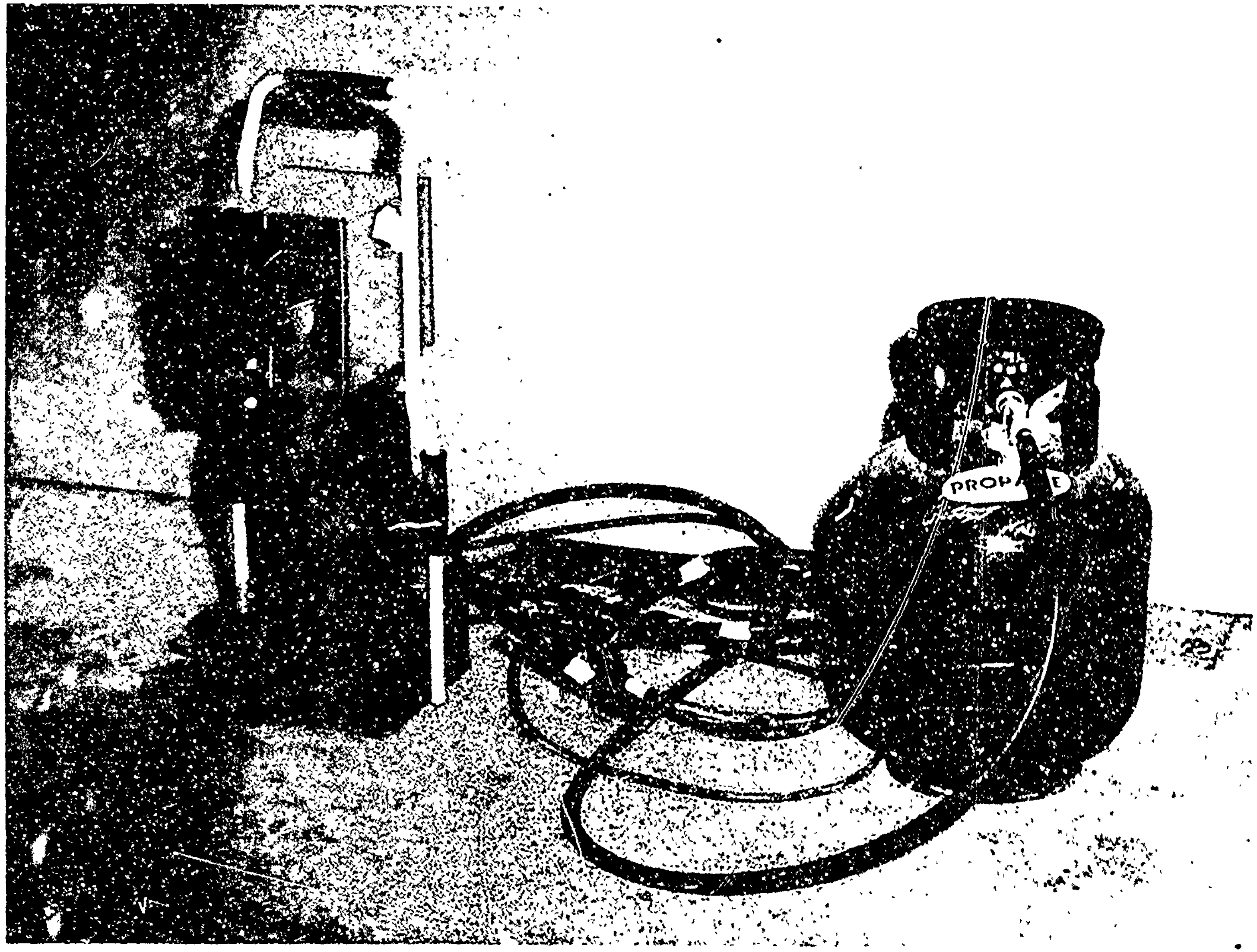


FIGURE 1

The portable propane heat cannon used to shrink wrap loads for test.

FIGURE 2

The heat source fabricated in-house which was used to simulate sunlight through the use of infrared heat lamps. The aluminum foil shown was used as a reflector.

FIGURE 3

The Honeywell recorder used to record the temperature changes throughout the test.

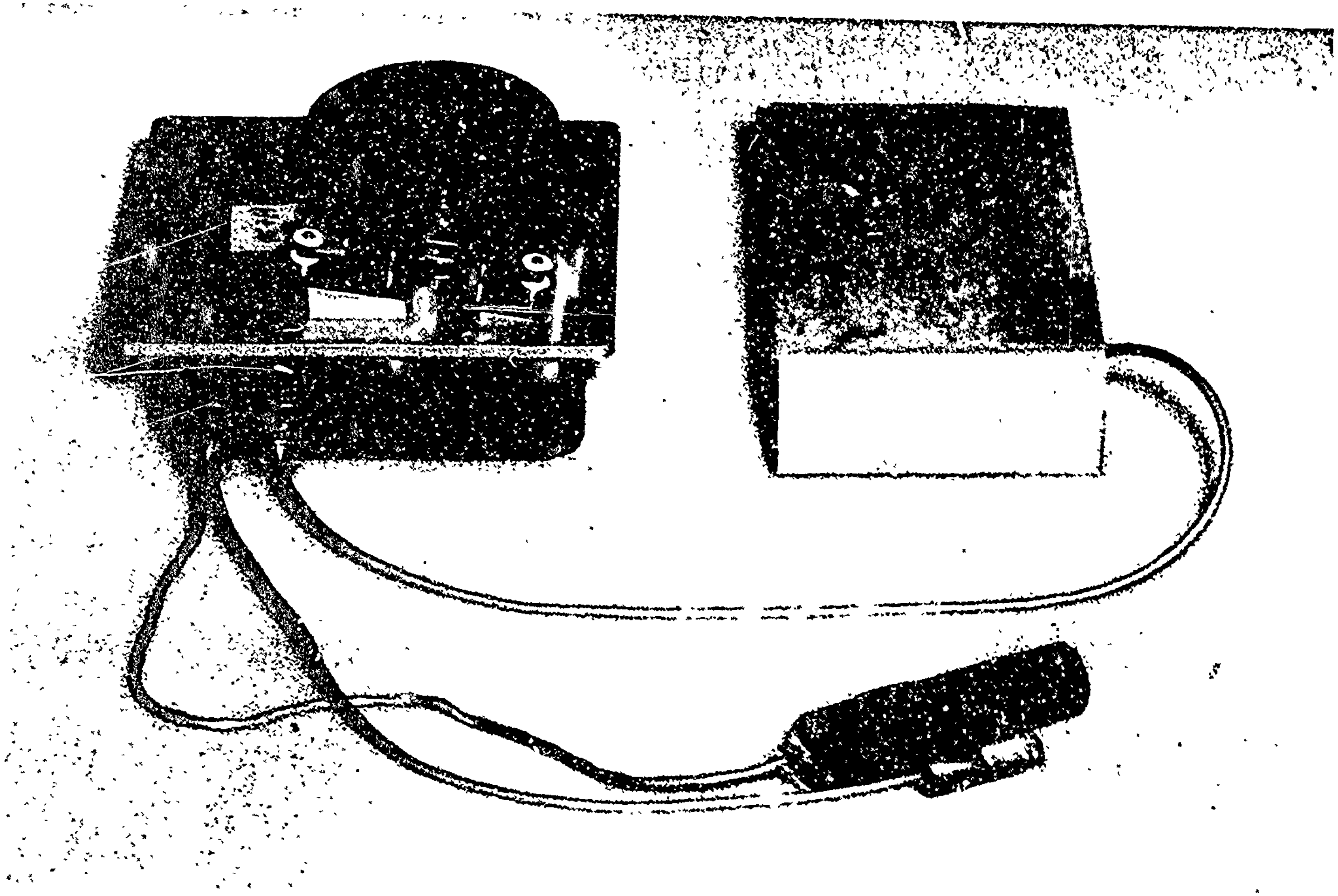


FIGURE 4

The Natick Laboratories' recorder used to measure temperature and humidity changes in the outdoor tests.

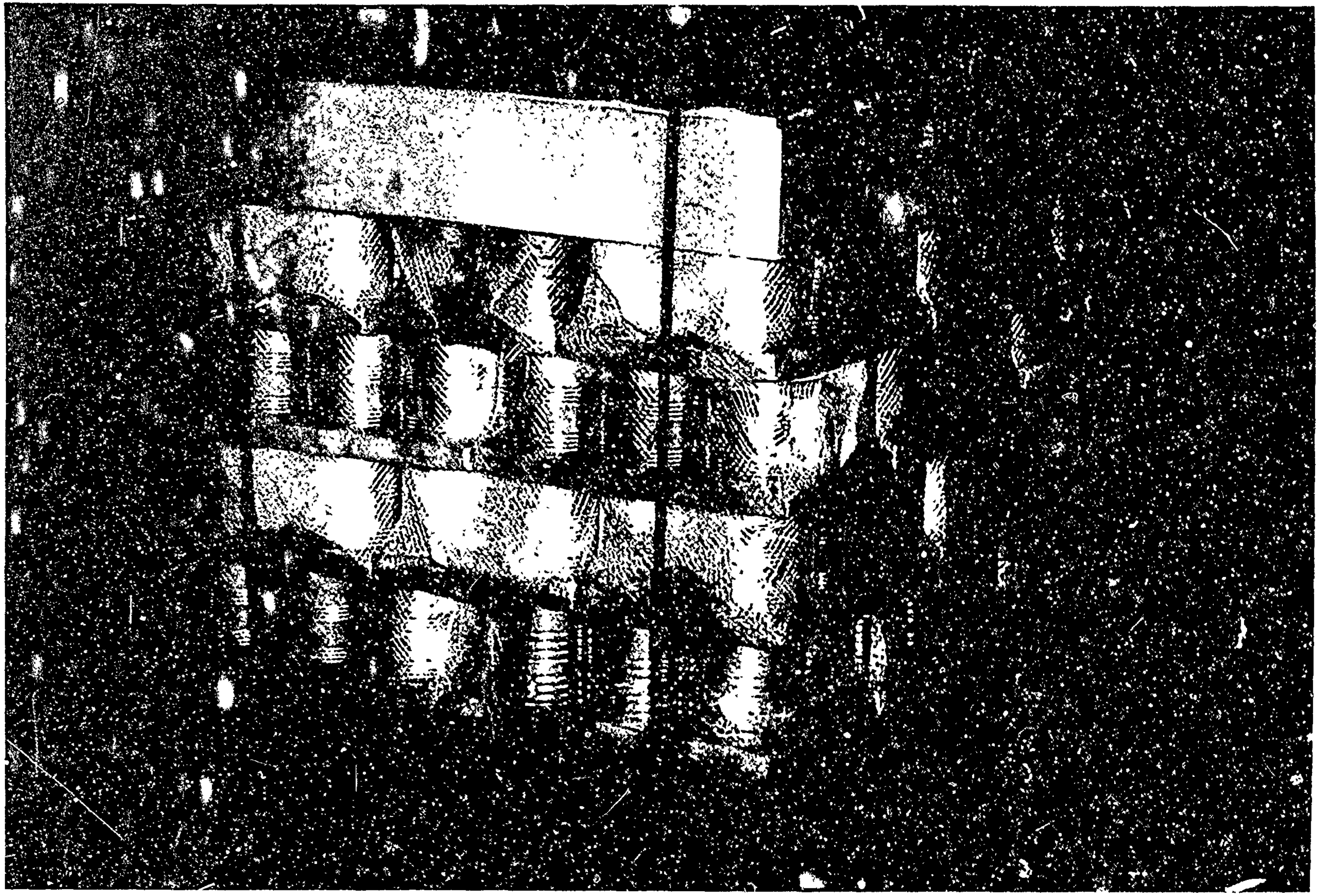


FIGURE 5

Example of a pallet load of shrink-wrapped tray-packs strapped two lengthwise and two girthwise with plastic straps. Only a cap is used as protection.

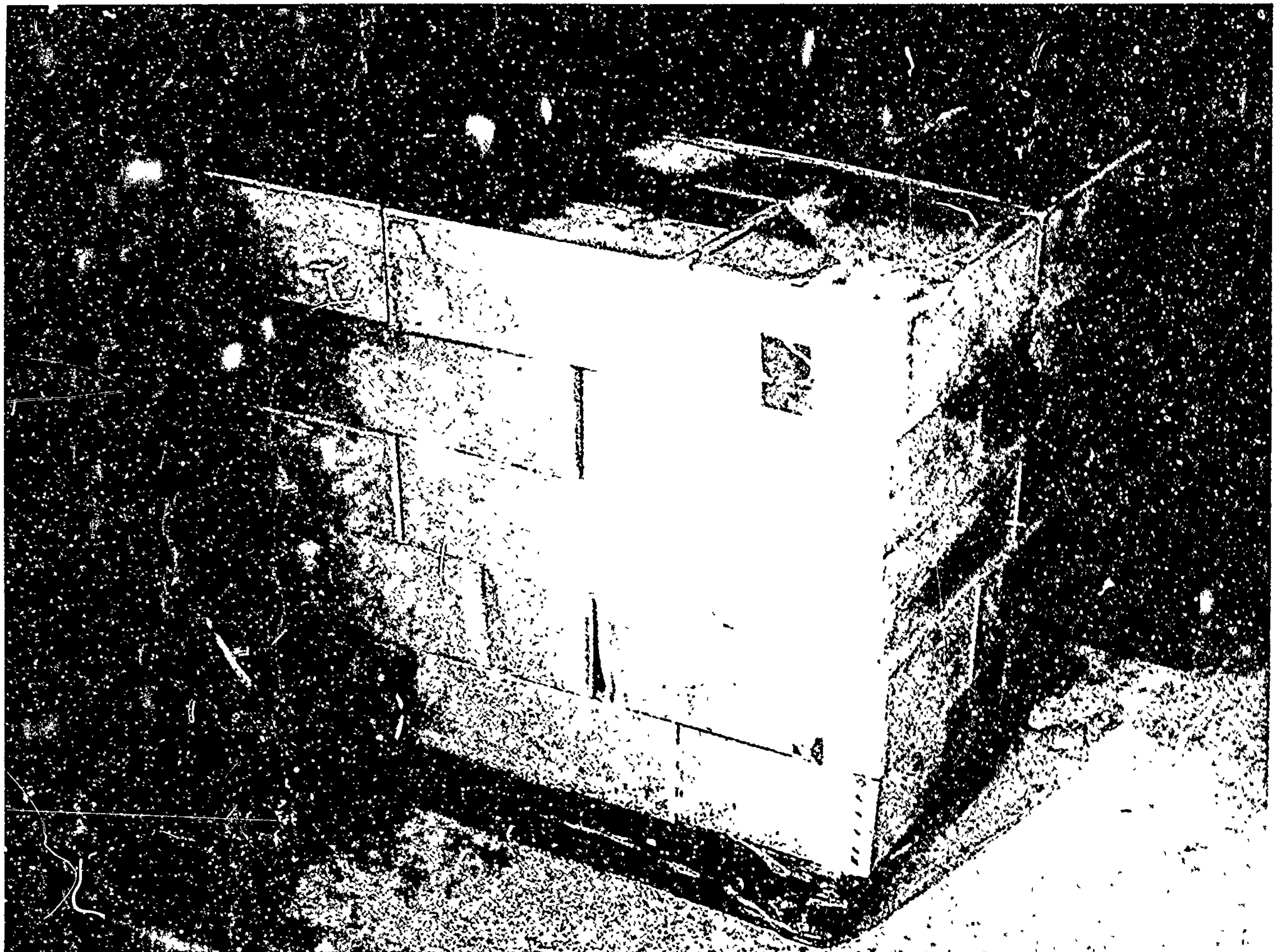


FIGURE 6

Example of fully inclosed shrink-film unit load of fiberboard packs of canned subsistence items.

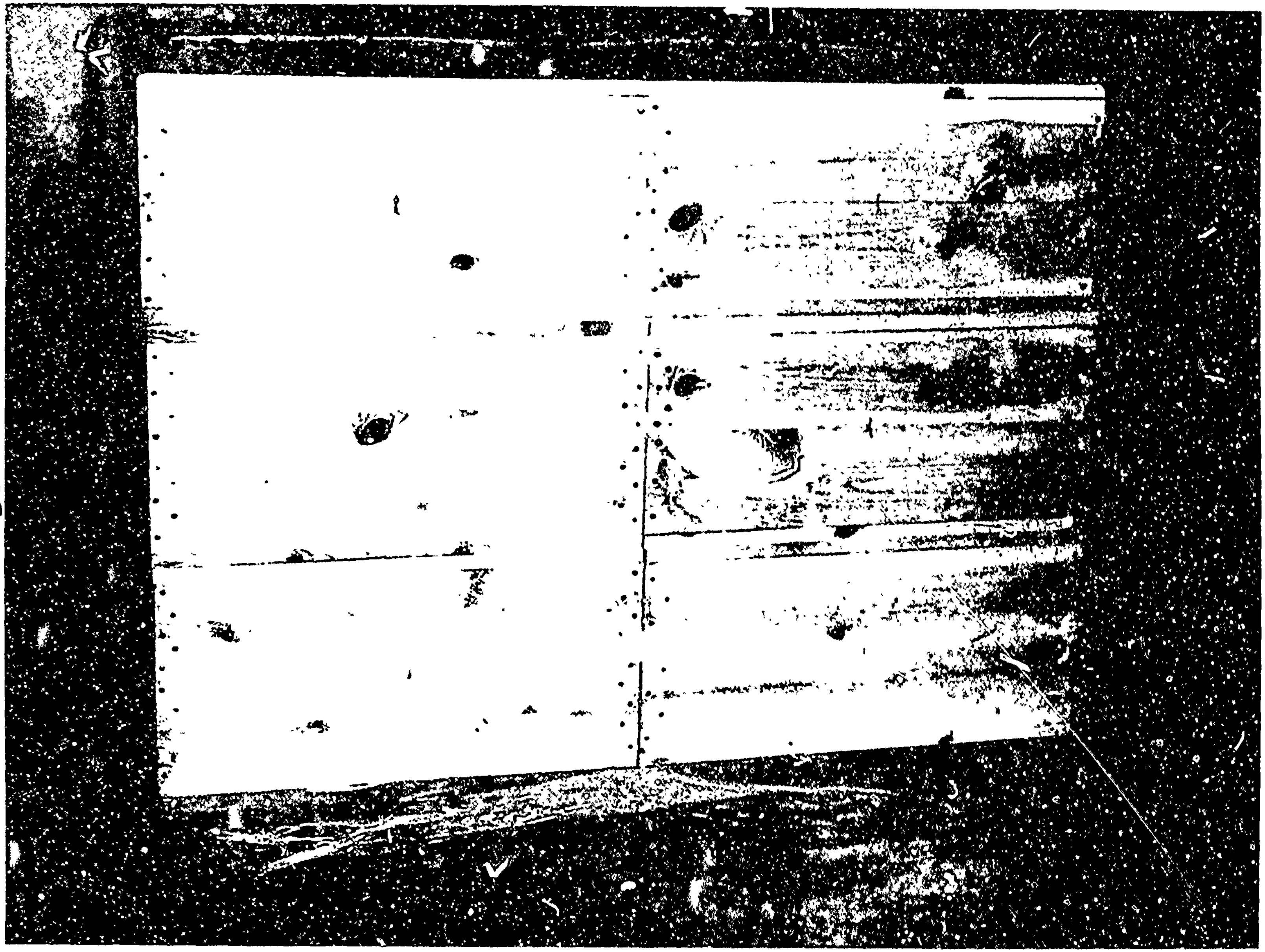


FIGURE 7

Example of shrink-film unit load of nailed wood boxes.

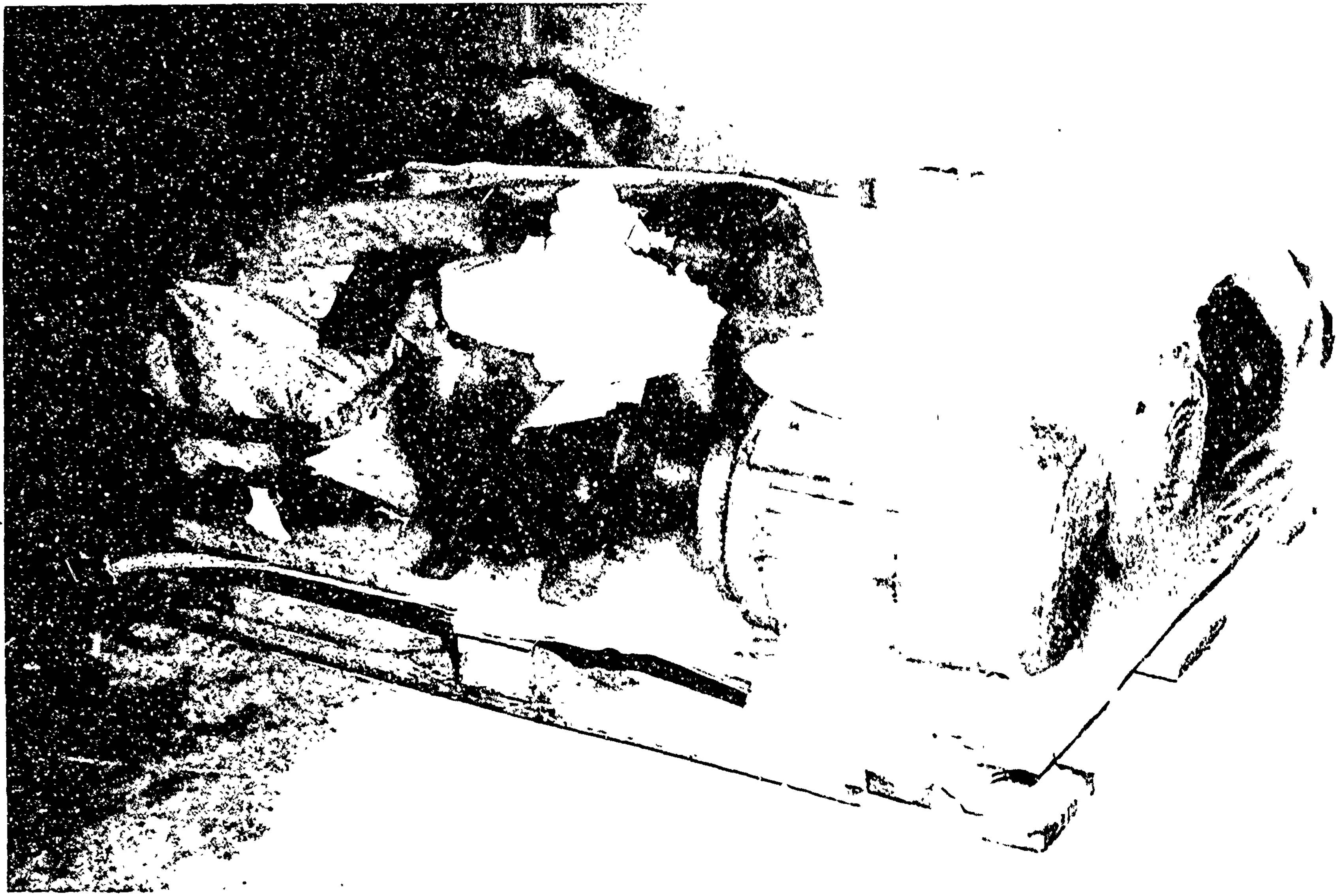


FIGURE 8

Example of pallet load of mixed retrograde items fully inclosed in polyethylene shrink film.

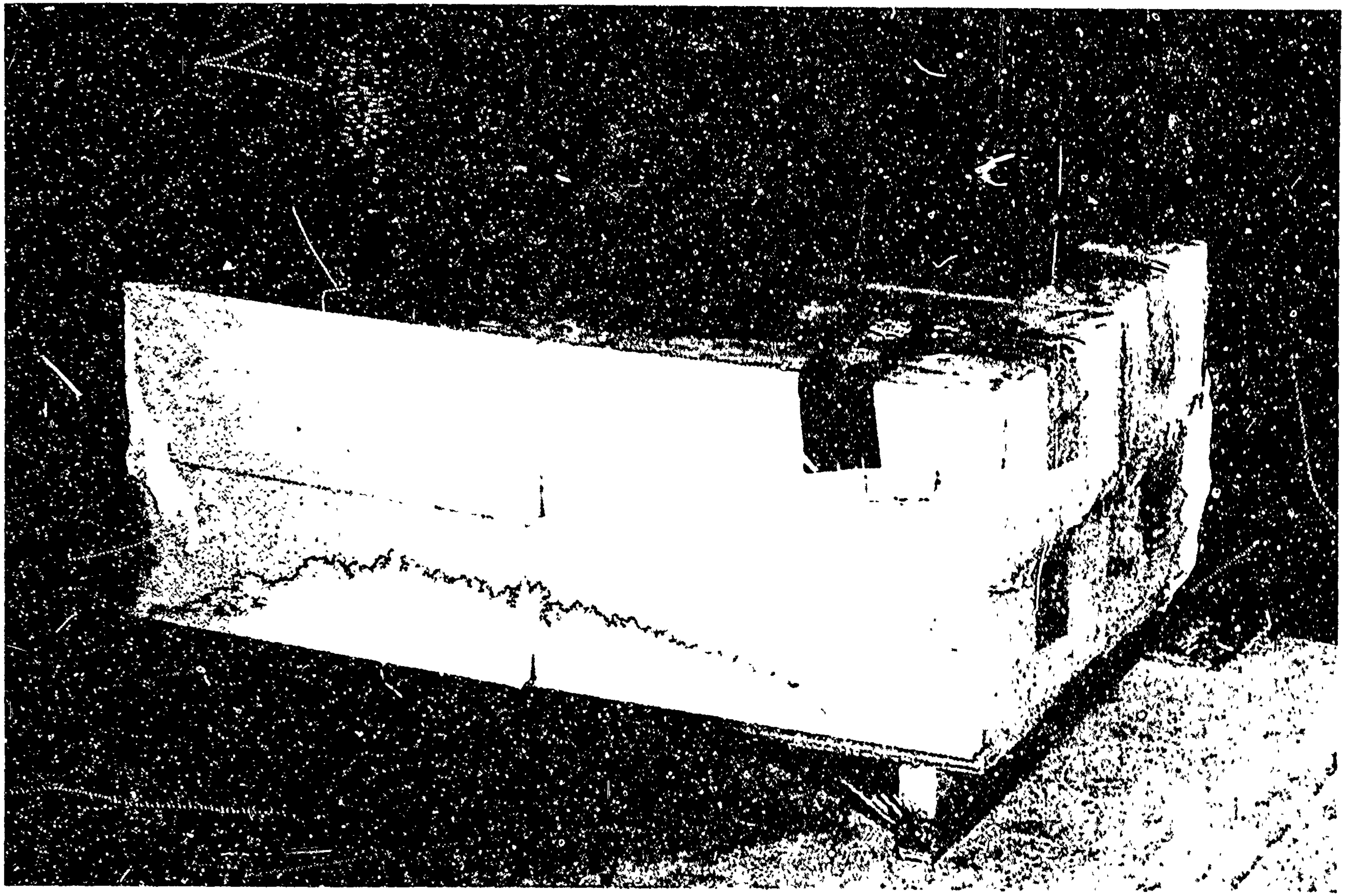


FIGURE 9

Example of a reduced size unit load used for tests. The load is approximately one-fourth the size of a regular unit load.

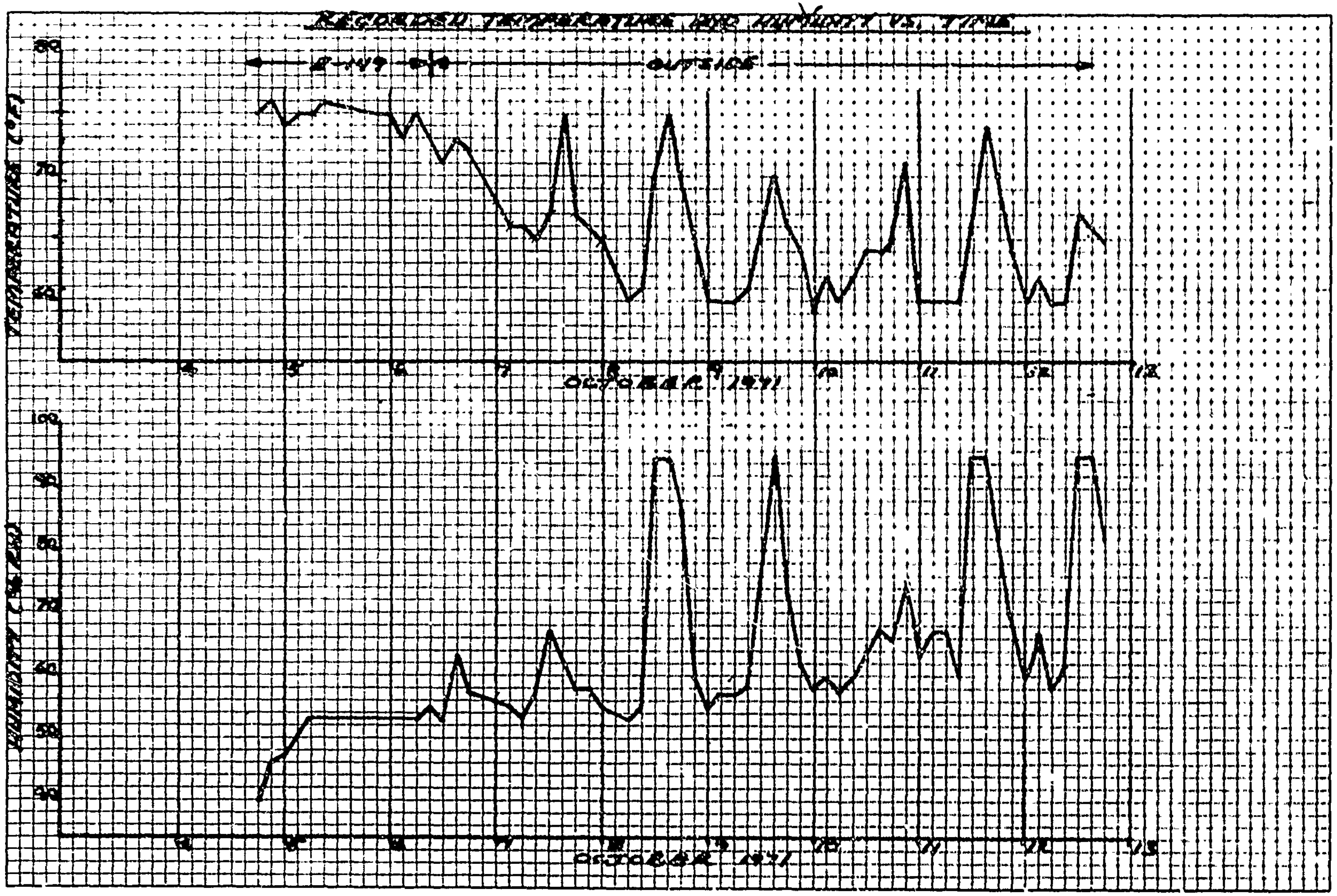
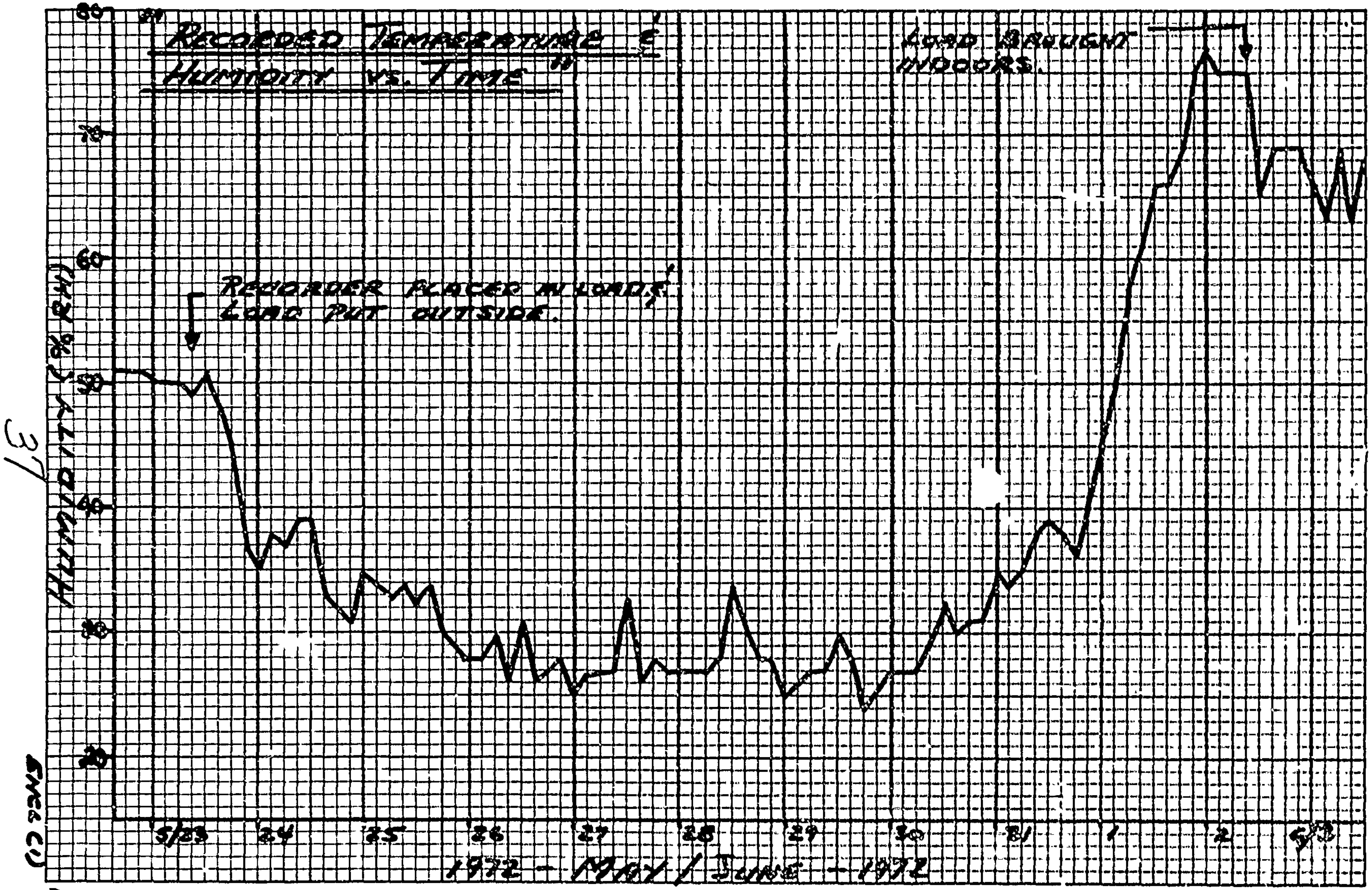


FIGURE 10

Results of the temperature-humidity recordings taken with the NLABS Recorder. On the 8, 9, 11 and 12th, which were dry sunny days, the humidity reached 95%; whereas, on the 6, 7 and 10th, the days were rainy and humid and the humidity inside the load was much lower.

Encl. (2)



37

FIGURE 11

Humidity recordings of the inside of a shrink wrapped load which has been conditioned at 140°F and 10% R.H. prior to shrink wrapping. No temperature recording was made due to a malfunction in the recorder.

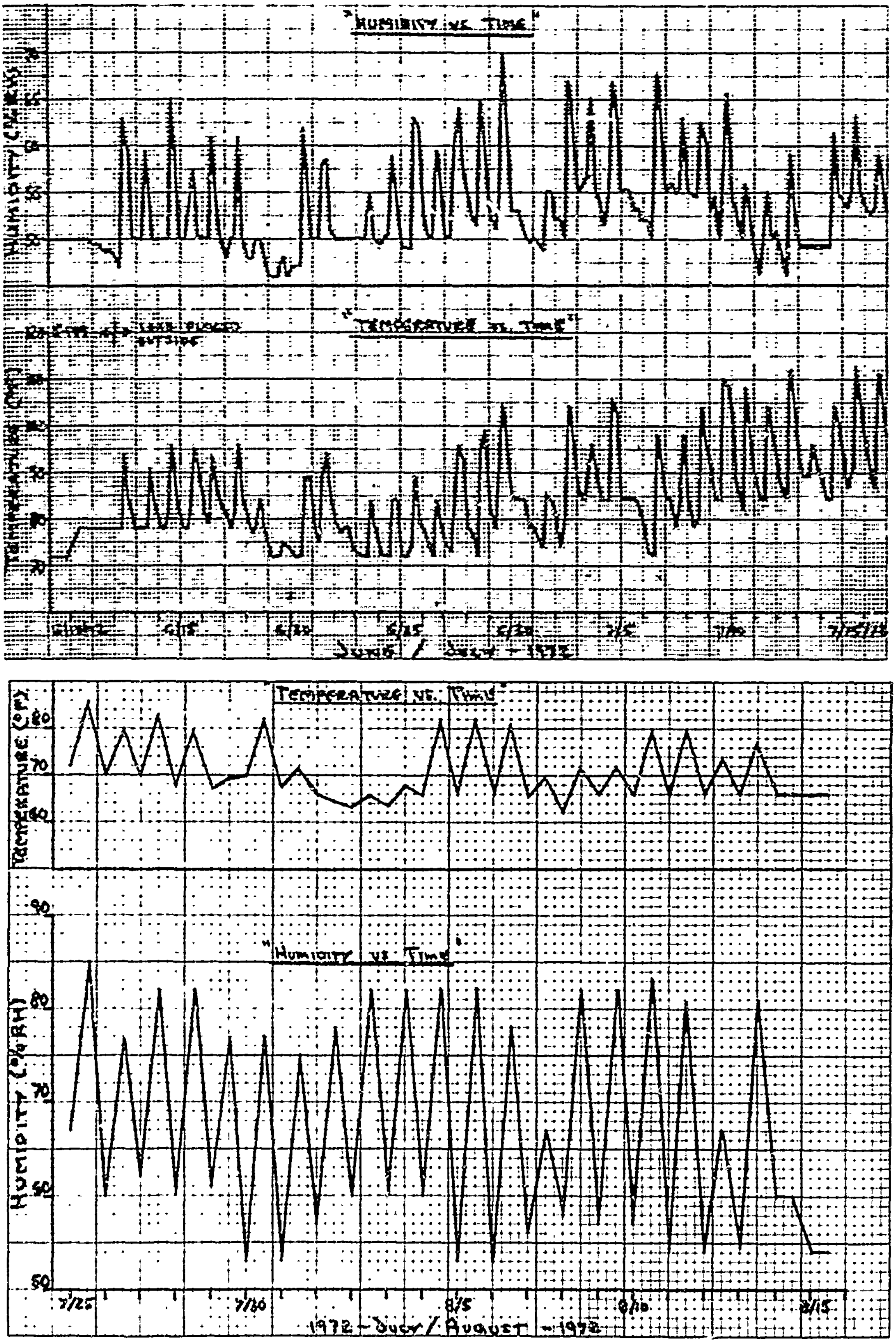


FIGURE 12

Temperature and humidity recordings taken inside a load which had been conditioned at ambient room temperature prior to shrink wrapping.

Outdoor Field Tests

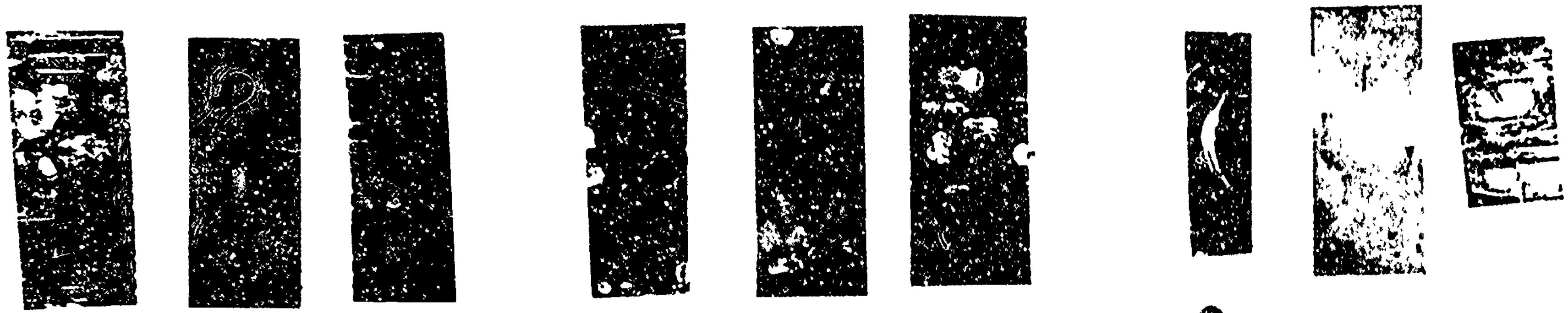
Twelve Loads Tested In Outdoor Storage At Sharpe Army Depot From December 15, 1972 Through February 9, 1973.

39

FIGURE 13

Temperature and humidity recordings taken inside a load which had been conditioned at 100°F, 90% R.H., for 16 hours prior to shrink wrapping.

FIGURE 14



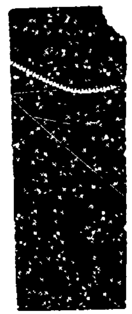
CONTROL 1 CONTROL 2 CONTROL 3

FIBERBOARD PACKS PLACED ON PALLET BASE TO FORM UNIT LOADS OF APPROXIMATELY 800-1200 LBS. ALL LOADS THEN SHRINK WRAPPED WITH 6 MIL POLYETHYLENE FILM.

MOISTURE CONTENT –	BEGINNING OF TEST	END OF TEST
1	9.1 %	12.8
2	6.9 %	10.7
3	9.9 %	12.7

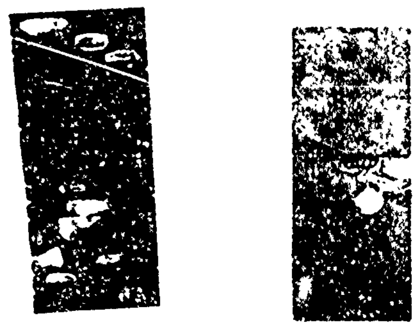
SAMPLES TAKEN AT TOP OF LOADS

FIGURE 15



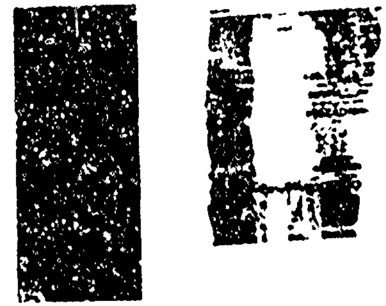
LOAD 4

LARGE ENGINE WITH LITTLE BLOCKING AND BRACING PLACED ON A PALLET BASE AND SHRINK WRAPPED.



LOAD 5

SMALLER ENGINE IN HEAVY WOOD CRATING PLACED ON PALLET BASE AND SHRINK WRAPPED.



LOAD 6

SMALL PARTS IN OPEN NAILED WOOD BOXES. BOXES COVERED WITH FIBERBOARD AND SHRINK WRAPPED.

MOISTURE CONTENT OF FIBERBOARD

BEGINNING OF TEST	END OF TES
11.9%	13.2%

FIGURE 16

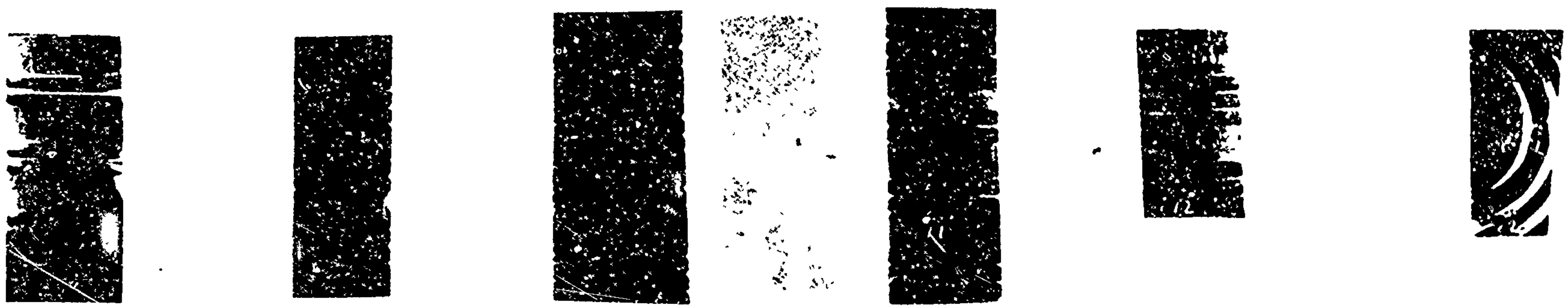
LOAD 7

LOAD 8

LOAD 9

LARGE MOTORS WITH MINIMUM AMOUNT OF WOOD BLOCKING AND BRACING PLACED ON PALLETS COVERED WITH ONE SHEET OF FIBERBOARD AND SHRINK WRAPPED.

FIGURE 17



LOAD 10 LOAD 11 LOAD 12

LARGE BOILER UNITS IN 10 AND 11 AND LARGE MOTORS IN LOAD 12 PLACED ON PALLET WITH POLYETHENE SHRINK BAGS ON BOTTOM AND TOP TO FORM FULLY ENCLOSED LOADS. NO WOOD OR FIBERBOARD INSIDE LOADS.