EXPLORATORY STUDY OF TEMPERATURES PRODUCED BY SELF-HEATING OF ELECTRICAL CONDUCTORS SURROUNDED BY POLYURETHANE INSULATION

Steve Reesor

ABSTRACT

The objective of this research project presented in this paper was to investigate under laboratory conditions the temperatures that could develop on residential electrical wiring encapsulated in sprayed-in-place polyurethane insulation.

This project included a review of existing studies that have been done on conductor self-heating when surrounded by thermal insulations. The studies reviewed indicate that maximum service temperatures of residential branch circuit wiring is routinely exceeded depending upon the location of the wiring in the structure and the levels of insulation installed around the wiring.

The results of the laboratory study show that temperatures on conductors surrounded by polyurethane insulation can slightly exceed the maximum service temperature for the wire insulation, under maximum rated ampacities for the two most prevalent residential wire types: 14AWG and 12AWG, both rated at 90° C.

This study and the literature suggests that either intermittent temperatures over the rated maximum of the wiring is acceptable to both the wiring manufacturers and the various electrical codes or that the electrical code should change to reflect reality.

Contents

1. INTRODUCTION

In the spring of 1998, the ULC S705.1 committee for "Standard for Thermal Insulation - Spray Applied Rigid Polyurethane Foam, Medium Density, Material Specification" and the Canadian Urethane Foam Contractors Association decided to re-visit the issue of electrical branch circuit wiring encapsulated in polyurethane foam insulation.

The conduction of current in electrical wiring generates heat which is usually dissipated by conduction and convection when the wiring is exposed.
When the wiring is covered by thermal insulation the temperatures of the electrical insulation and wiring will significantly increase. With the widespread use of sprayed-in-place polyurethane foam insulation, the groups decided to examine the entire issue of residential wiring and insulation use with respect to the Canadian Electrical Code.

The research project undertaken by these groups showed that studies conducted by the National Bureau of Standards (NBS) almost 30 years ago have shown that temperatures as high as 150°C can occur on electrical conductors surrounded by thermal insulation. In fact, under many circumstances the maximum service temperature for currently used residential wire NMD90 was exceeded. These elevated temperatures and the issue of long term reliability of the electrical wiring enveloped in thermal insulations is re-visited in this report.

2. OBJECTIVES

The objective of this study was to assess in a laboratory test the self-heating of electrical conductors buried in polyurethane foam in a typical residential stud wall. The two most prevalent wire types used in residential branch circuit wiring were investigated at the two most common installation depths in a wood frame wall subjected to their maximum rated ampacities according to the Canadian Electrical Code.

The study was divided into two parts: part one reviews past studies of residential branch circuit wiring enveloped in thermal insulations; part two deals with the laboratory investigation of the self-heating of electrical conductors in sprayed-in-place polyurethane foam insulation in a mock-up stud wall.

3. PART ONE: REVIEW OF PAST STUDIES

Three past studies are reviewed here and each provides interesting results on the issue(s) of conductor self-heating with respect to thermal insulations. The earliest work was done by the National Bureau of Standards in the United States in 1978 as a result of insulation retrofits due to the fuel shortages in the 1970's.

3.1. BEAUSOLIEL et al 1978

The first study was performed by Beausoliel, Meese, and Galowin[1] in 1978 at the Center for Building Technology, National Engineering Laboratory at the National Bureau of Standards in Washington D.C.

The study was commissioned by the Department of Commerce and the Department of Energy resulting from concern that increasing insulation levels in existing residential construction may result in combustion and smoldering of building materials due to overheating of electrical wiring or devices. At the time of this study it was also noted that no data were available on actual documented fires in thermal insulation or electrical conductor overheating at the time of this study.

The test procedure used involved a low voltage supply system for simplification and safety concerns. The argument being that the heat generated in the conductors would be the same as if it had been done on a 120 volt supply. They further stated that study was concerned primarily with temperatures on wiring and not with the possibility of conductor insulation failure which might be accentuated by the use of the 120 volt supply.

Generally their test procedure was as follows:

1.) Temperatures were measured at 5 minute intervals at current of 10A, 15A, 20A and at slightly higher currents. The conductors were installed in simulated attic and empty wall stud spaces as might exist prior to any installation of insulation for energy conservation purposes. The simulated attic consisted of ceiling joists 40cm (16") on centre with a gypsum board bottom representing a ceiling. No isolation of space was maintained above or below the mock-ups, i.e. ambient above and below the mock-ups. The wall sections consisted of 50mmx102mm (2"x4") frame walls covered with 13mm (½") exterior grade plywood and 13mm (½") gypsum board. However the wall sections were primarily used to evaluate the potential for retrofitted insulation to penetrate outlet boxes and temperatures reached on wire

binding screws within outlet boxes.
Some temperature measurements were made on the conductors and are presented here. The results for cellulose insulated mock-ups are resented as the study indicated the Urea Formaldehyde insulated walls were not cured properly prior to test. Levels of insulation in the cellulose wall would be R6.6 on either side of the cables.

2.) These mock-ups were then insulated with typical levels of insulation, and with insulation types prevalent at the time, and the temperature measurements repeated.

This study focused on 12AWG and 14AWG copper wire at the time rated for 60° C service temperatures typically used in residential branch circuits.
The majority of measurements were performed on the #12 wire due to its greater resistance heating at rated current than #14.

Overcurrent measurements were established based upon the criteria that circuit breakers and fuses do not quickly open circuits which are slightly over-rated. The Underwriters Laboratories Standard 489 (still applicable) for Molded-Case Circuit Breakers requires circuit breakers to open within one hour at 135% of their rated current. Overloads of 135% of rated current or less can therefore result in relatively long overload periods before the circuit breaker will open the circuit.

The study looked at a number of combinations of single and multiple conductors resting on a single layer of R11 fiberglass batt insulation and enveloped by single and multiple layers of batt insulation.

3.1.1. DISCUSSION OF TESTS IN SIMULATED ATTIC

Figure 1 from the study shows a comparison of measured temperatures on 12AWG cables carrying rated and 135% of rated current surrounded by thermal insulation. The following observations were made:

1.) Paralleled cables at 20A surrounded by on layer of R11 insulation reached 115°C (239° F) in 150 minutes. With one side of the assembly exposed to 22°C (72°) ambient air temperatures the cables reached 39.4°C (103°F) in 40 minutes.

2.) A single cable carrying 20A surrounded by insulation (one layer) reached 66.7°C (152°F) in 95 minutes.

3.) Paralleled cables carrying 135% of rated current surrounded by one layer of insulation reached 147.8°C (298°F) in 60 minutes.

4.) A single cable carrying 135% of rated current surrounded by one layer of thermal insulation reached 97.8°C (208°F) in 60 minutes.

5.) Maximum temperatures recorded on a single cable in a simulated attic space at rated currents with the cable covered with R66 over the cable and R11 under the cable was 71.1°C (160°F) which is only 6.1°C higher than the temperature, 65°C, measured on the cable covered by R11.

3.1.2. DISCUSSION OF RESULTS IN SIMULATED WALL

The maximum temperature reached at rated current capacity for 12AWG (20A) wire in empty stud wall cavity was 43.9°C (111.1°F) and for the same stud wall insulated with cellulose was 63°C (145.5°F). The results of filling(injecting) insulation into stud walls indicated that there was a significant chance that insulation could penetrate junction boxes.

3.1.3. STUDY RECOMMENDATIONS

Amongst other things, but most pertinent here, the study indicated the need for a comprehensive study of temperatures that may develop on residential electrical wiring covered by thermal insulation. It went on to suggest that temperature measurements on wiring in buildings be carried out with various amounts of thermal insulation, using a range of electrical currents and ambient temperature conditions.

It also suggested that long-term tests of cables including cycling at slightly higher than rated currents while surrounded by thermal insulations of various types are needed to determine if electrical insulation will fail.

The work conducted by NBS has been of sufficient concern for the US Department of Energy to include the following statement in their Installation Practices for Thermal Insulation:

> "Insulation should be placed in a ceiling to a uniform depth up to the UNDERSIDE of electrical wiring, provided that a reasonable unobstructed open air space is permanently retained above such wires"

3.2. ODA 1981

The second study was performed by S.J.Oda, Engineer, Thermal Insulation Organic Section of the Chemical Research Department of Ontario Hydro.
The study was titled "The Effects of Thermal Insulation on the Reliability and Safety of Residential Electrical Wiring". The study was divided into three parts covering temperature measurements (which we will focus on primarily), accelerated aging, and corrosion testing.

The study was commissioned as a result of provincial chief electrical inspectors and the Canadian Standards Association expressing concern over increasing insulation levels covering electrical wiring in existing residences. The problem was described as: the conduction of current in electrical wiring generates heat which is normally dissipated by conduction and convection when the wiring is reasonably exposed.

The objectives of the study unfortunately focused on identifying suspect retrofit insulation types for further rigorous testing. The only foamed-in-place insulation was urea-formaldehyde. A variety of wiring types, predominantly 60°C insulation rating were evaluated stressing the importance of using older wiring types as a "worst" case in conducting laboratory experiments with electrical wiring. Slightly over current situations were also measured depending upon the normal operating characteristics of the wiring.

The primary test of relevance was the heat dissipation test, which determines the temperature rise of a single non-metallic sheathed cable as a function of insulation thickness and electrical current for attic temperatures of 23°C and 50°C. The test involved the construction of a simulated ceiling joist space 1.55m long by 0.61m wide with 2X12 wood joists to contain cellulose fibre insulation. An electrical conductor (14AWG copper) was installed lengthwise in the joist space so that the cable ran parallel to the ceiling at a distance of approximately 3.8cm.

3.2.1. HEAT DISSIPATION TEST RESULTS

Test results shown in Figures 2 and 3 illustrate that conductor temperatures on a single cable carrying rated currents (15A for 14AWG cable) were 75°C at an ambient air temperature of 23°C, and 86°C at an air temperature of 50°C (simulating summer attic temperatures) respectively. These temperatures exceed the recommended maximums for older 60°C rated conductors with insulation levels as low as R10 enveloping the cables.

Further these temperatures rose when this configuration (RSI 2.27 [R13] below conductor, and RSI 4.72 [R27] above) was subjected to 20A; measuring 116°C at an ambient of 23°C, and 130°C for an attic ambient of 50°C. Oda summarized saying that ALL insulation types evaluated have the potential to create heat dissipation problems if installed over 60°C rated cables, while none of the ten insulations appeared to affect the electrical properties in accelerated aging tests.

He also went on to state that with the exception of superficial effects, accelerated aging tests with energized wiring surrounded by wet insulation did not adversely affect the mechanical and electrical properties of either insulated cables or bared electrical conductors.

3.2.2. STUDY RECOMMENDATIONS

The recommendations of this study included an examination of alternate solutions (ie different overcurrent protection, fire-resistive conduits) be examined to minimize potential overheating problems.

It also suggested that laboratory studies determine the effects of conductor temperatures greater than 60°C caused by high levels of thermal insulation on the long term integrity of the electrical insulations.

3.3. SOCIETY OF THE PLASTICS INDUSTRY, 1995.

In April 1995 the Society of the Plastics Industry (SPI) had standard wood stud walls wired with standard 12 and 14AWG conductors, insulated with sprayed-in-place polyurethane foam, and subjected them to 13A and 18A current loads for the purpose of measuring temperature rise of the conductors.

3.3.1. TEST CONSTRUCTION

An 455mm (18") wide by 1220mm (48") wood frame cavity was constructed using 90mm (2x4) wood studs placed 405mm (16") on-centre with 12.7mm (½") gypsum board attached to one side and standard 12 and 14 gauge no-metallic sheathed copper wire 90°C rated wire was routed through the studs at heights of 405mm

(16") (12AWG) and 810mm (32") (14AWG). Current flowed from a wall receptacle, through the 12 gauge wire, then the 14 gauge wire, and through a resistance load. Burial depth within the polyurethane foam insulation was not specified in the sample preparation notes. Calls to the laboratory that performed the testing and to the SPI representative who commissioned the study could not verify burial depth.

Two thermocouples were placed on each wire 1/3 and 2/3 the distance between the studs. The cavities were insulated with polyurethane foam reported to be 29 kg/m^3 - 32 kg/m^3 (1.8-2.0 lbs/ft^3) density. Again, the in-place density was not tested.

3.3.2. TEST RESULTS

Test results shown in Figures 4 and 5 indicate that for 13A loading the 12AWG conductor reached an average surface temperature of 39°C after the 12 hour test period. The 14AWG conductor reached a maximum of 51.1°C.

For the 18A loading the 12AWG conductor reached 48.9°C, and the 14AWG conductor reached 72.3°C.

4. PART TWO: LABORATORY EVALUATION OF RESIDENTIAL STUD WALL

The review of pertinent literature indicates that maximum temperature ratings of conductors, especially older wiring types rated for 60°C are routinely exceeded. Further, that conductor temperatures for 90°C rated cables within attic spaces subjected to typical loadings of 15 and 20 amps (rated ampacity for 14AWG and 12AWG conductors at ambient temperatures, 23°C) are also routinely exceeded.

It is also noted that there is not a wealth of data on temperature measurements of conductors within insulated stud walls.

4.1. TEST OBJECTIVES

The objectives of this study as defined by the Canadian Polyurethane Foam Contractors Association was to construct a mock-up wooden stud wall wired with typical residential electrical wiring (14AWG and 12AWG conductors) at two burial depths within the stud cavity from the interior finish. These mock-ups were then tested at the rated ampacities for these conductors at Underwriters Laboratories of Canada in Scarborough, Ontario.

Currents of 15 and 20 amps were selected based on the fact that they are the rated maximums that these conductors should be subjected to as per the Canadian Electrical Code.

4.2. SAMPLE PREPARATION AND TEST METHOD

Two samples were prepared, each a 1220mm (48") square wood stud wall. The walls were constructed of 90mm (3 5/8") wood studs spaced 405mm (16") O/C. The outside of each stud wall was 11mm (7/16") oriented strand board.

A continuous length of electrical wire (CSA labelled, NMD90) was run through the stud wall using holes drilled firstly at the stud centre line at 45mm (1 13/16") depth, then back in the opposite direction at 25mm (1") depth, spaced 405mm (16") apart.

Sample A was wired with 12AWG (20A current rating) and Sample B with 14AWG (15A current rating).Thermocouples were located on each wire at the midpoint of the stud wall, and on each wire 25mm (1") from the stud at the edge of the stud wall. The cavities of both samples were filled with sprayed-in-place polyurethane insulation (typical CCMC evaluated formulation meeting ULCS705.1 material standard) with a density of 28kg/m^3.(1.75 lb/ft^3). The front face of the panels were covered with 12.7mm (½") gypsum board to complete the mock-ups.

A low voltage set-up was employed similar to that used by Beausoliel et al in their study. The samples were supported horizontally on concrete blocks. The cables were connected to a 20 V AC power supply and at the other end a variable resistor was installed and adjusted to produce steady-state currents of 20A in Sample A and 15A in Sample B. Ambient temperature in both cases was the laboratory temperature at approximately 23°C.

4.3. TEST RESULTS

Test results shown in Figures 6 and 7 indicate that temperatures rose swiftly for approximately 4 hours and then stabilized, fluctuating slightly reflecting changes in the ambient temperature. In both test samples the central burial depth of 45mm reached the highest temperature (over 90°C). The tests were run for 24 hours, the current disconnected and samples allowed to cool before cutting apart for conductor inspection.

The insulation was cut away to expose the wire at the two central locations which experienced the highest temperatures. No degradation of the conductor insulation or the polyurethane insulation was visible.

Maximum temperatures reached were 93°C for 12AWG at 20A at 45mm burial depth, and 95°C for 14AWG at 15A at 45mm burial depth. In both cases temperatures for the shallower burial depth of 25mm resulted in conductor temperatures of approximately 90°C and slightly lower. Exit temperatures from the insulated stud walls indicate rapid cooling to 60°C under load. Upon cessation of the test, both conductors returned to ambient temperature within one hour.

5. SUMMARY

1.) The review of pertinent literature indicates that maximum temperature ratings of conductors typically used in residential branch circuits, especially older wiring types rated for 60°C, are routinely exceeded.

2.) Conductor temperatures for 90°C rated cables within attic spaces subjected to typical loadings of 15 and 20 amps (rated ampacity for 14AWG and 12AWG conductors at ambient temperatures, 23°C) are also routinely exceeded.

3.) There is a lack of information on temperature measurements of conductors within insulated stud walls. Of the available information all results are for 90mm stud walls while most new homes are still being constructed with 140mm stud walls with insulated sheathings.

Though polyurethane is also installed in 90mm frame construction it is not typically installed full depth. It is usually installed to 50mm depth to the backside of the sheathing and the remainder of the void is filled with fiberglass insulation. There is a suggestion in the results of past work that fiberglass insulation dissipates heat much quicker than the air-tight polyurethane foam insulation. In such an assembly, it may be expected that conductor temperatures may stay below the 90° C maximum temperature rating as the wiring would be within the fiberglass insulation.

With changes to some of the provincial building codes, allowing reduced overall R-values of wall assemblies, 90mm stud construction may come back into favour. As such conductor temperatures embedded in polyurethane foam within these wall types will be relevant.

6. RECOMMENDATIONS

1.) The reality of elevated insulation levels and current construction practices are such that either installation practices of all insulations should be reviewed with respect to heat dissipation of electrical conductors, or the Canadian Electrical Code should be changed to reflect wiring more suitable for the environments for which they are intended.

7. REFERENCES

APPENDIX "A" ULC Report "Self Heating of Electrical Conductors in Polyurethane Foam Insulation"

INCORPORATED 1920

UNDERWRITERS' LABORATORIES OF CANADA

When Replying
Please Refer to

G36.1
27940

April 20, 1998

Mr. Steve Reesor, P.Eng.
Great Northern Insulation
935 Keyes Drive
Woodstock, ON
N4V 1C3

Subject: Self-Heating of Electrical Conductors in Polyurethane Foam Insulation

Dear Mr. Reesor:

This letter report describes testing carried out on March 31 and April 1, 1998 to measure the temperatures achieved adjacent to wires carrying their rated current and surrounded by foamed-in-place polyurethane insulation.

SAMPLE PREPARATION

Two sample panels were prepared, each representing a 1220 mm (48 in.) square section of wood stud wall. Stud width was 90 mm (3-5/8 in.) and spacing was 405 mm (16 in.) O/C. The back of e ch panel was covered with 11 mm (7/16 in.) oriented-strand board.

A continuous length of electrical wire (CSA labelled, rated NMD90) was run through drilled holes first at the stud centre line at 45mm (1-13/16 in.) depth, then back in the opposite direction at 25mm (1 in.) depth, spaced 405 mm (16 in.) apart.

General Offices and Testing Station 7 CROUSE ROAD, SCARBOROUGH, ONTARIO, CANADA M1R 3A9 Telephone (416) 757-3611
Fax: Accoutning (416) 757-8915 Engineering (416) 757-1781 Follow-Up Services (416) 757-3788 Standards: (416) 757-9540
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Sample A was wired with 12 AWG, 2 conductor cable with a current rating of 20A, and Sample B with 14 AWG, 2 conductor cable rated at 15A.

Four thermocouples were installed in each panel: one on each wire at the midpoint, and one on each wire 25 mm (1 in.) from the stud at the edge.

Figures 1 and 2 show the two panels before insulation was installed.

The cavities of both sample panels were filled with foamed-in-place polyurethane insulation of density 28 kg/m3 (1.75 lb/ft3), cut back flush with the studs. Figures 3 and 4 show the panels after insulating.

The front faces of the panels were covered with 12.7 mm (1/2 in.) thick gypsum wallboard.

METHOD

The sample panels were supported horizontally on concrete blocks. Each cable was connected at one end to a transformer with a rated output of 20 Vac, and at the other end to a set of 2 variable resistors in parallel. The resistors were adjusted to produce a steady-state current of 20 A in Sample A and 15A in Sample B. Figures 5 and 6 show the test apparatus.

The data recording equipment to which the thermocouples were connected was started at 8:55 am, March 31, 1998. It was noted that the starting ambient temperature was 23°C, and that sample temperatures had risen to the range of 35 oc during the few minutes requtred for resistor adjustment.

RESULTS

Sample temperatures rose rapidly for approximately 4 hours, then seemed to stabilize. Figures 7 and 8 show the ambient temperatures and 4 sample temperatures for each of the two panels. In both panels, it was noted that the central location reached the highest temperature (over 90 °C). After 24 h, the current was disconnected and the samples allowed to cool.

POST-TEST OBSERVATIONS

After the test, the insulation was cut away to reveal the wire at the two central locations in each panel. No degradation of the insulation was visible. Figures 9 and 10 show the panels with wallboard removed and the insulation cut back, while Figure 11 shows cross-sections cut from the two panels in the area where the highest temperatures were reached.

We trust that this information is sufficient for your purposes; should anything further be required, please do not hesitate to contact us.

Yours very truly,

Howard J. Spice, P.Eng.
Project Engineer
Construction Materials

FIGURE INDEX

File G36 .1
Application No. 27940
April 20, 1998

REPORT
on

SELF-HEATING OF ELECTRICAL CONDUCTORS IN POLYURETHANE FOAM INSULATION

Great Northern Insulation
Woodstock, ON

UNDERWRITERS' LABORATORIES OF CANADA

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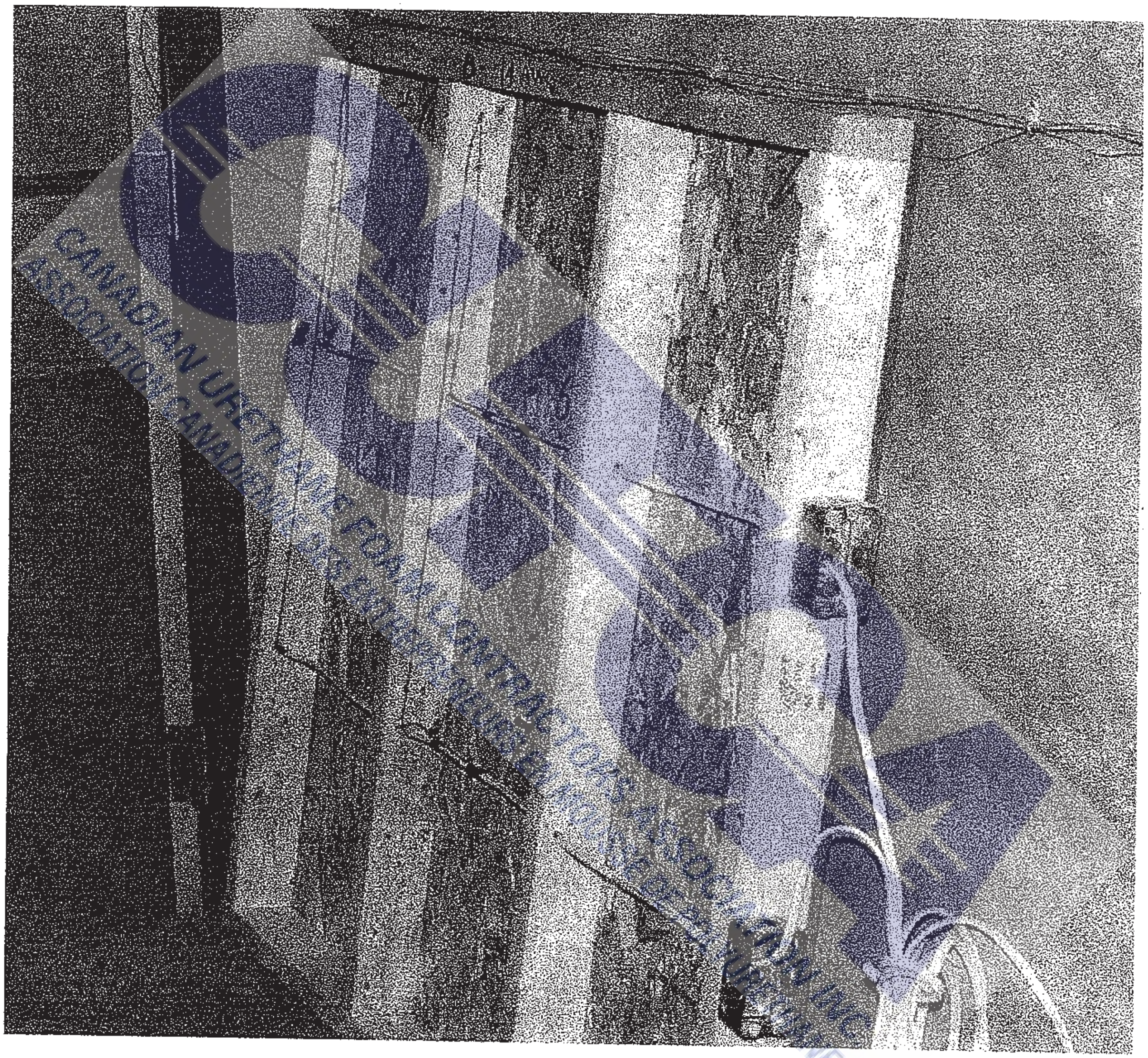
PANEL A, SHOWING THERMOCOUPLE LOCATIONS 1 TO 4 BEFORE INSULATING

FIGURE 1



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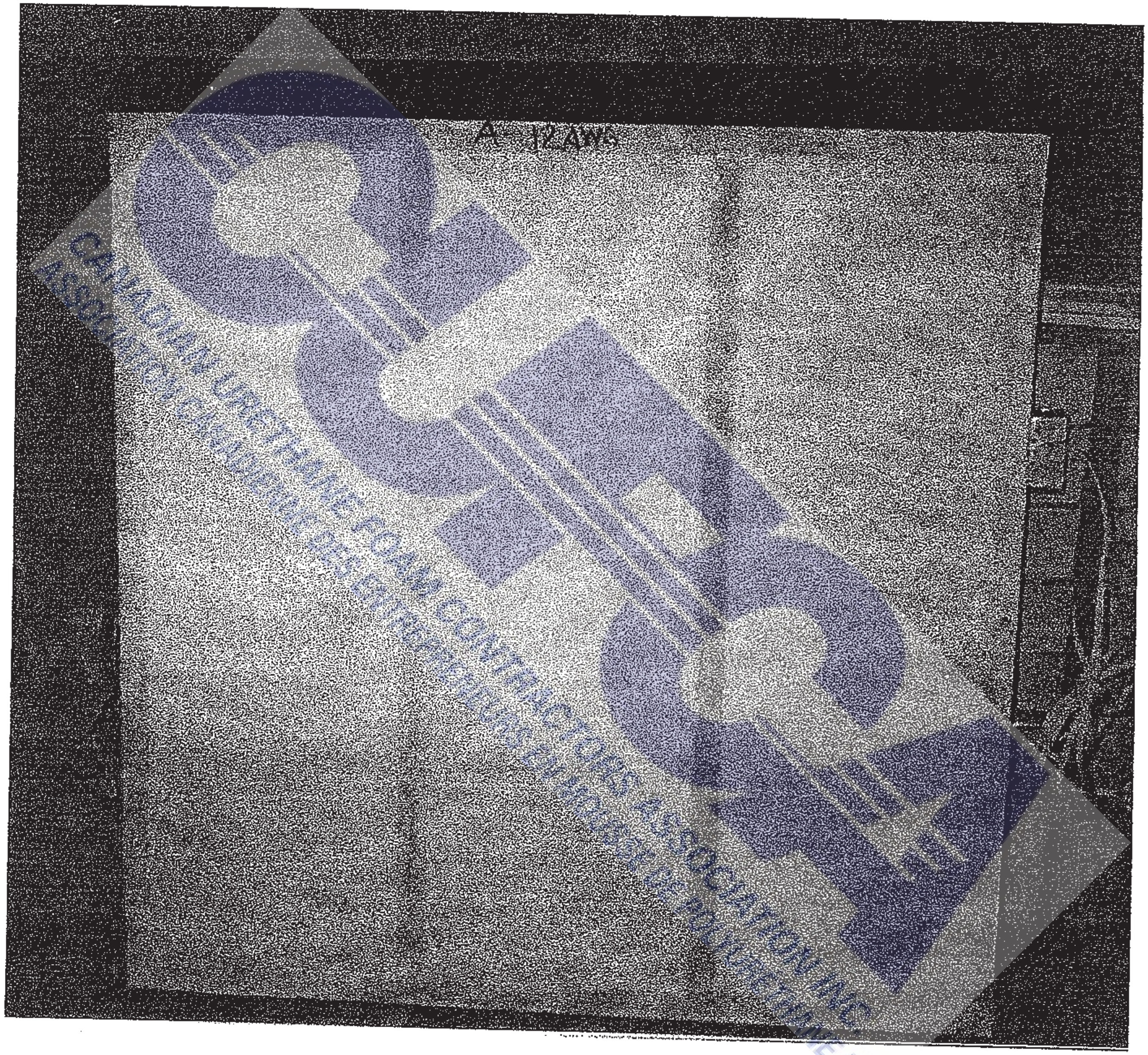
PANEL B, SHOWING THERMOCOUPLE
LOCATIONS 5 TO 8 BEFORE INSULATING

FIGURE 2



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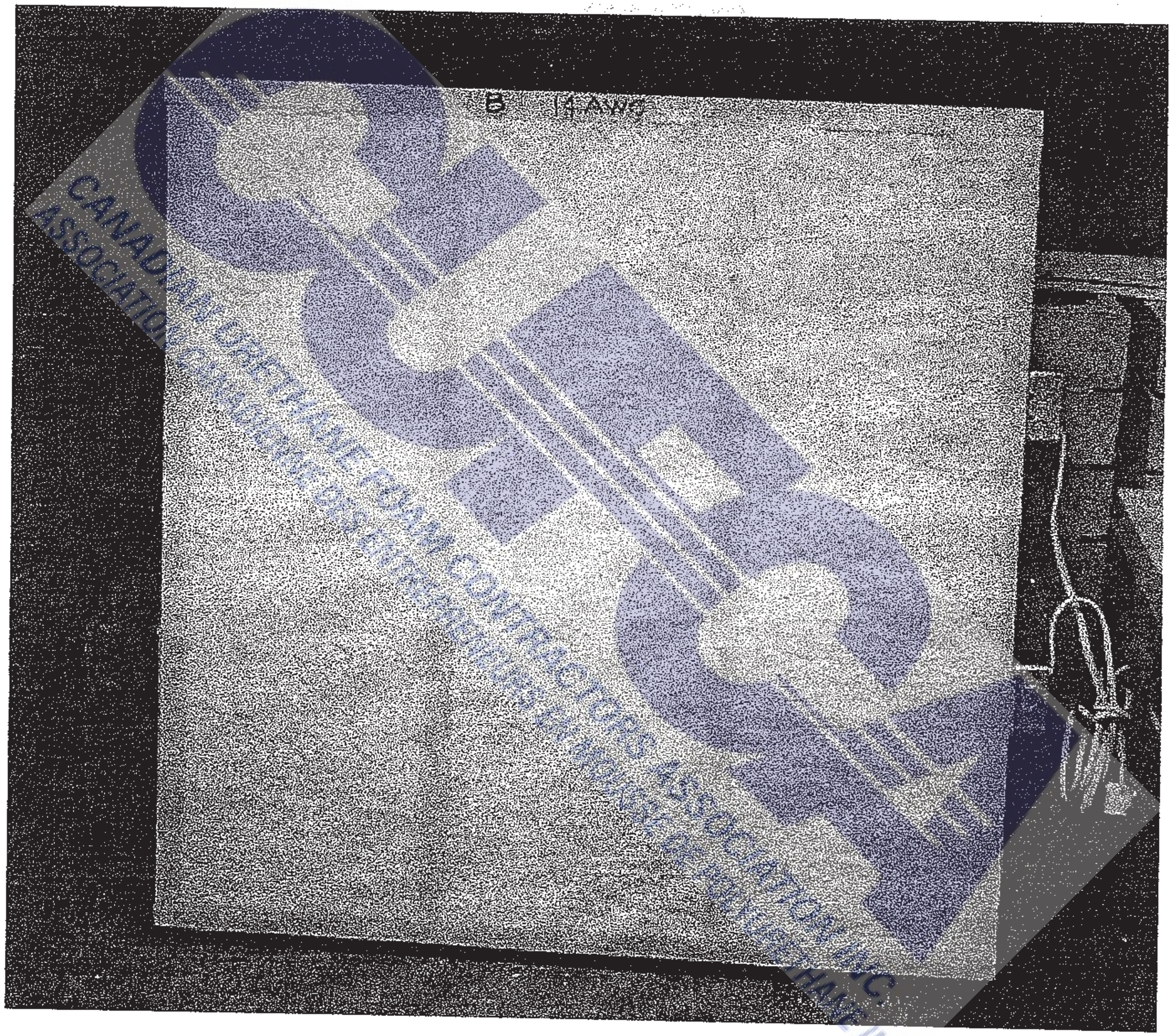
PANEL A AFTER INSULATION INSTALLED

FIGURE 3



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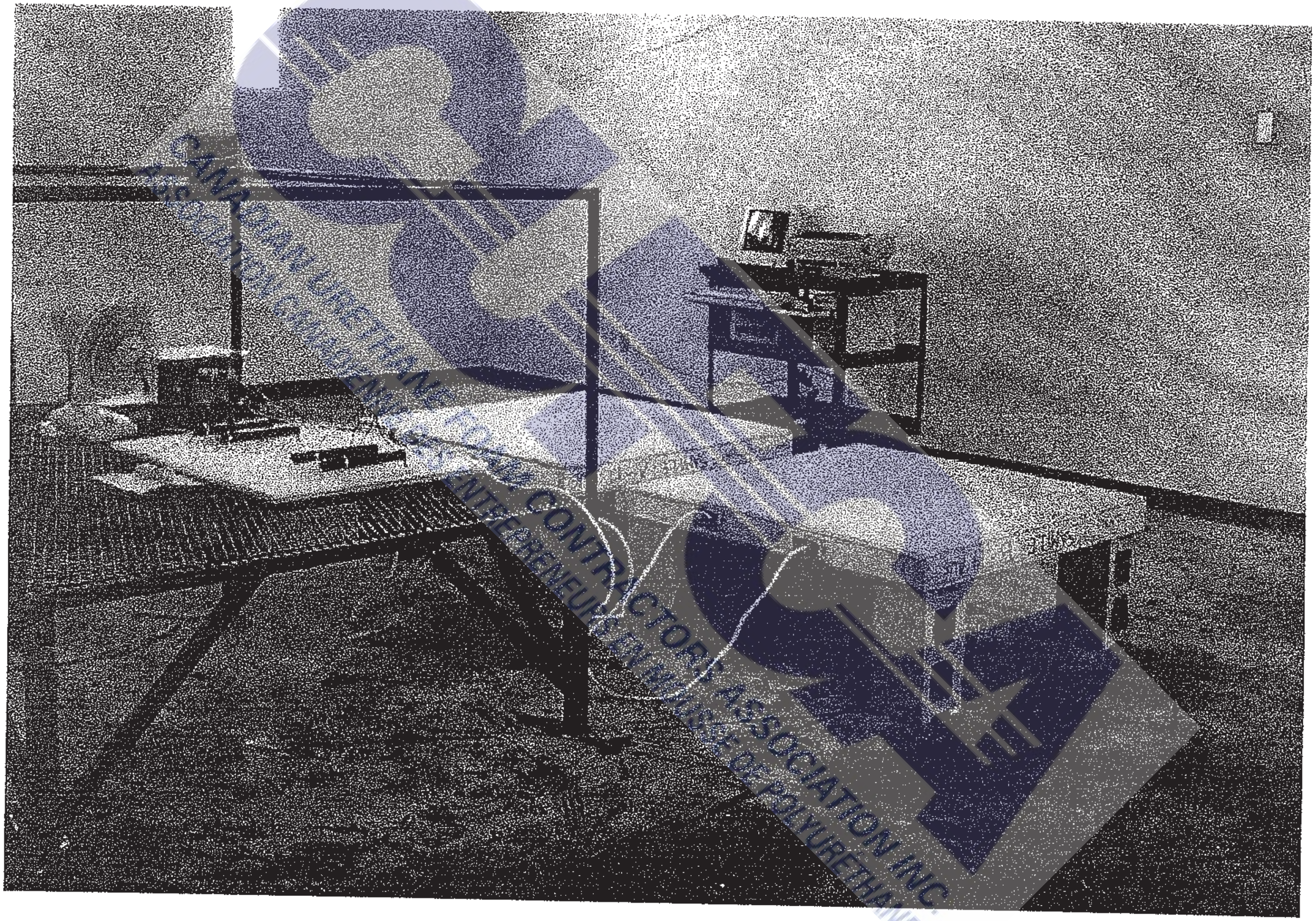
PANEL B AFTER INSULATION INSTALLED

FIGURE 4



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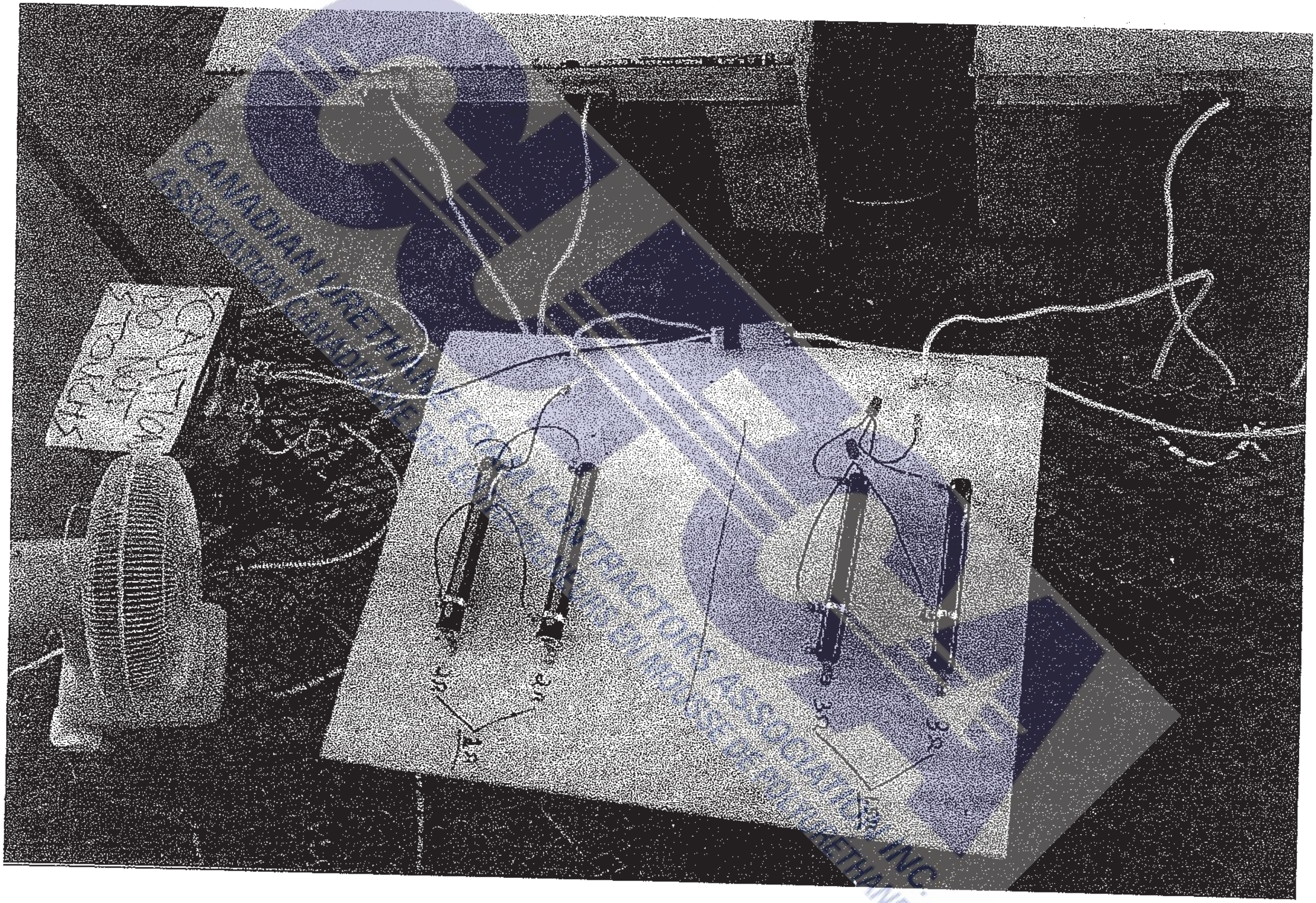
GENERAL ARRANGEMENT OF
TEST APPARATUS

FIGURE 5



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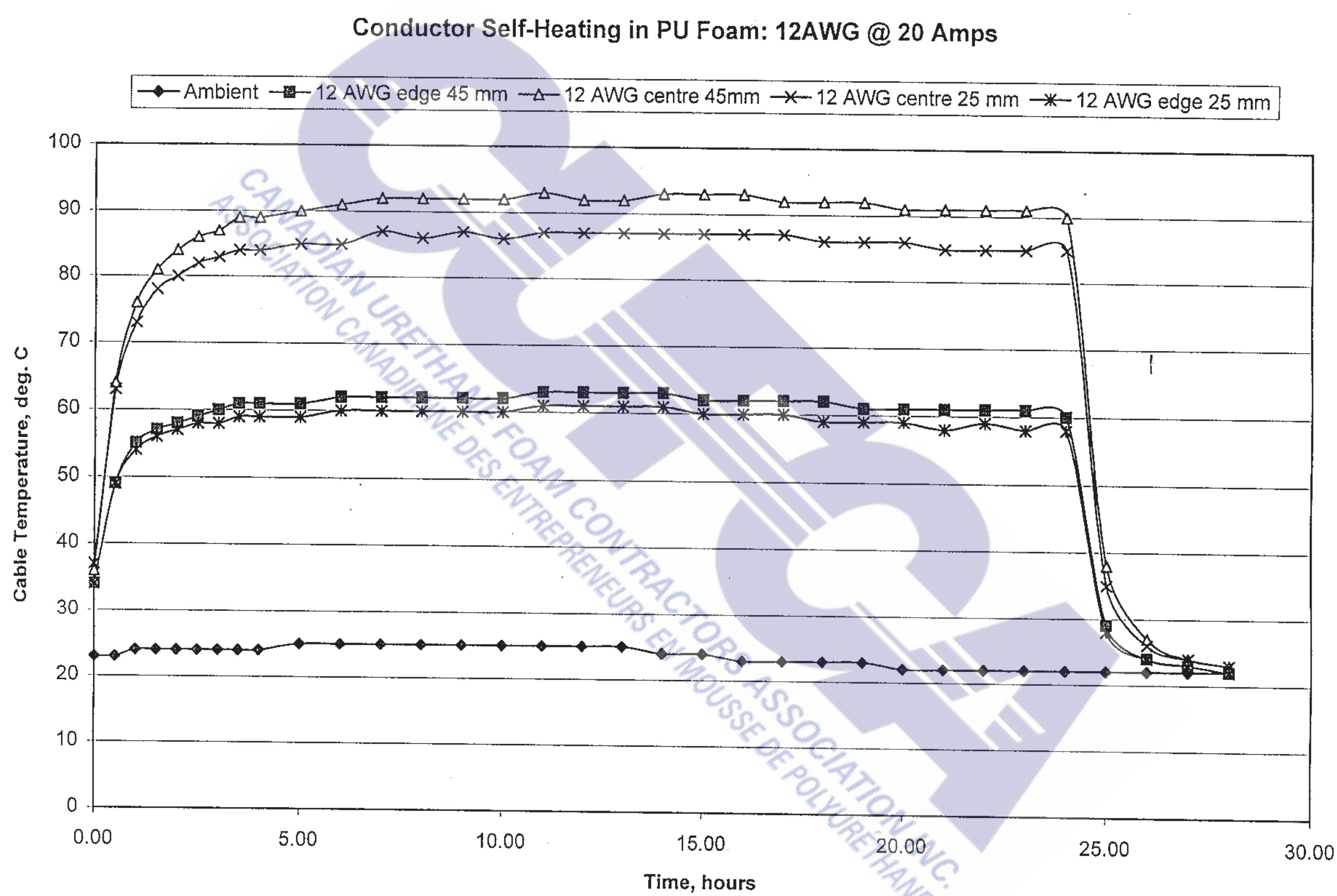
ELECTRICAL COMPONENTS

FIGURE 6



Conductor Self-Heating in PU Foam: 12AWG @ 20 Amps
Ambient
12 AWG edge 45 mm
12 AWG centre 45mm
12 AWG centre 25 mm
12 AWG edge 25 mm
Cable Temperature, deg. C
Time, hours
0
10
20
30
40
50
60
70
80
90
100
0.00
5.00
10.00
15.00
20.00
25.00
30.00

Figure 7

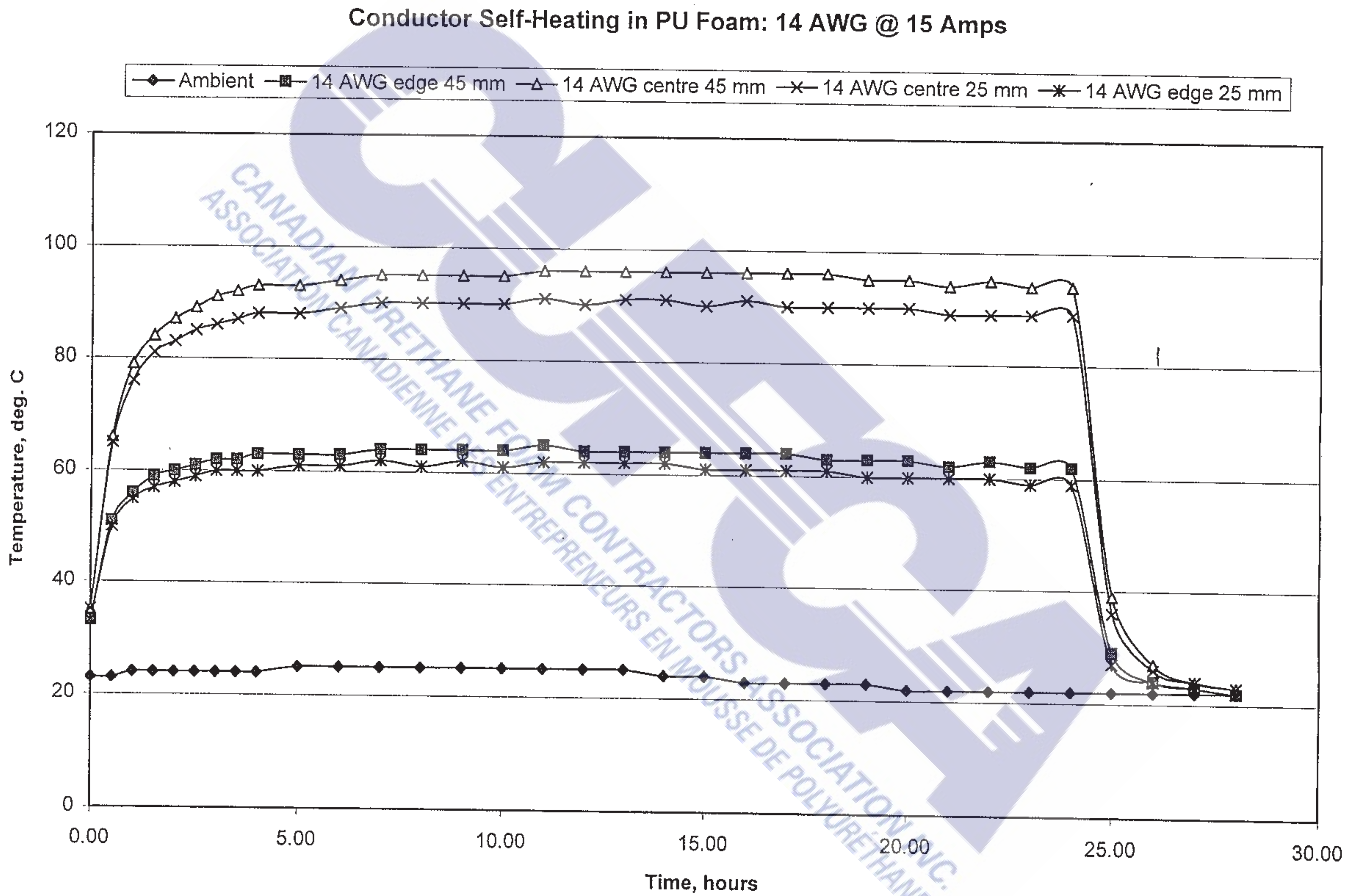

Conductor Self-Heating in PU Foam: 14 AWG @ 15 Amps
Ambient
14 AWG edge 45 mm
14 AWG centre 45 mm
14 AWG centre 25 mm
14 AWG edge 25 mm
120
100
80
60
40
20
0
Temperature, deg. C
0.00
5.00
10.00
15.00
20.00
25.00
30.00
Time, hours
CANADIAN URETHANE FOAM CONTRACTORS ASSOCIATION INC.
ASSOCIATION CANADIENNE DES ENTREPRENEURS EN MOUSSE DE POLYURÉTHANE INC.

Figure 8

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POST-TEST APPEARANCE, SAMPLE A

FIGURE 9

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POST-TEST APPEARANCE, SAMPLE B

FIGURE 10

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CROSS-SECTIONS FROM CENTRAL AREA OF PANELS

FIGURE 11