TRANSCO PRODUCTS INC.

# CLINTON NUCLEAR STATION

# VENTILATING DUCT

# FLAME GUARD

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FINAL REPORT

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## INTRODUCTION

The Clinton Nuclear Station has supply air and return air ducts that provide ventilation for Safety Class I electrical equipment in the control building. The ducts pass through a switchgear room near column row 122V at the 781'-0" elevation in the auxiliary building. The ventilation air provides for cooling the equipment essential for safe shutdown.

A second ventilation duct system provides cooling air for the switchgear room. Therefore, in the event of a fire in the switchgear room, both systems could be disabled by this single fire. To eliminate this possibility, Transco undertook a program to develop an insulation system for the supply and return air ducts passing through the switchgear room. This system was to have the capability of experiencing a 3-hour fire (as defined by ASTM-E119) without allowing the air to undergo more than a 12 deg. F rise (from 73 deg. F entering to 85 deg. F exiting) as it passed through the ductwork in the switchgear room.

The system developed, termed "FLAME GUARD" by Transco, combines high-temperature insulation capable of withstanding operating temperatures to 2300 deg. F (Cer-Wool, by CE Refractories) with high-thermal-performance insulation (Microtherm, by Micropore International) in a sandwich construction which also contains protective stainless steel facings and stainless steel vapor barriers. Proceeding from the fire-side of the FLAME GUARD system, the construction is as follows (see Figure 1): outer lagging of 24 ga. stainless steel; (1) layer of 2-inch thick 8 lb/cu.ft. Cer-Wool; (7) layers of 1/2-inch thick Microtherm; 0.002-inch thick stainless steel foil vapor barrier; (1) layer of 1/2-inch thick Microtherm.

Although the FLAME GUARD system can be applied to other fire protection situations, the particular configuration described here is unique to the Clinton project outlined above. For example, the ducts to be treated are approximately 38 feet in length; because a 12 deg. F air temperature rise applies, longer ducts would require more insulation while shorter would require less thickness.

Another aspect of the problem addressed was the extent of insulation required on the steel support structures for the ductwork. Both calculations and testing indicate 4'-6" of the support steel (from the ductwork) must receive FLAME GUARD.

This report describes the developmental analyses and testing performed by Transco to determine the proper configuration for FLAME GUARD and provides support for its capability to meet the design requirements outlined above.

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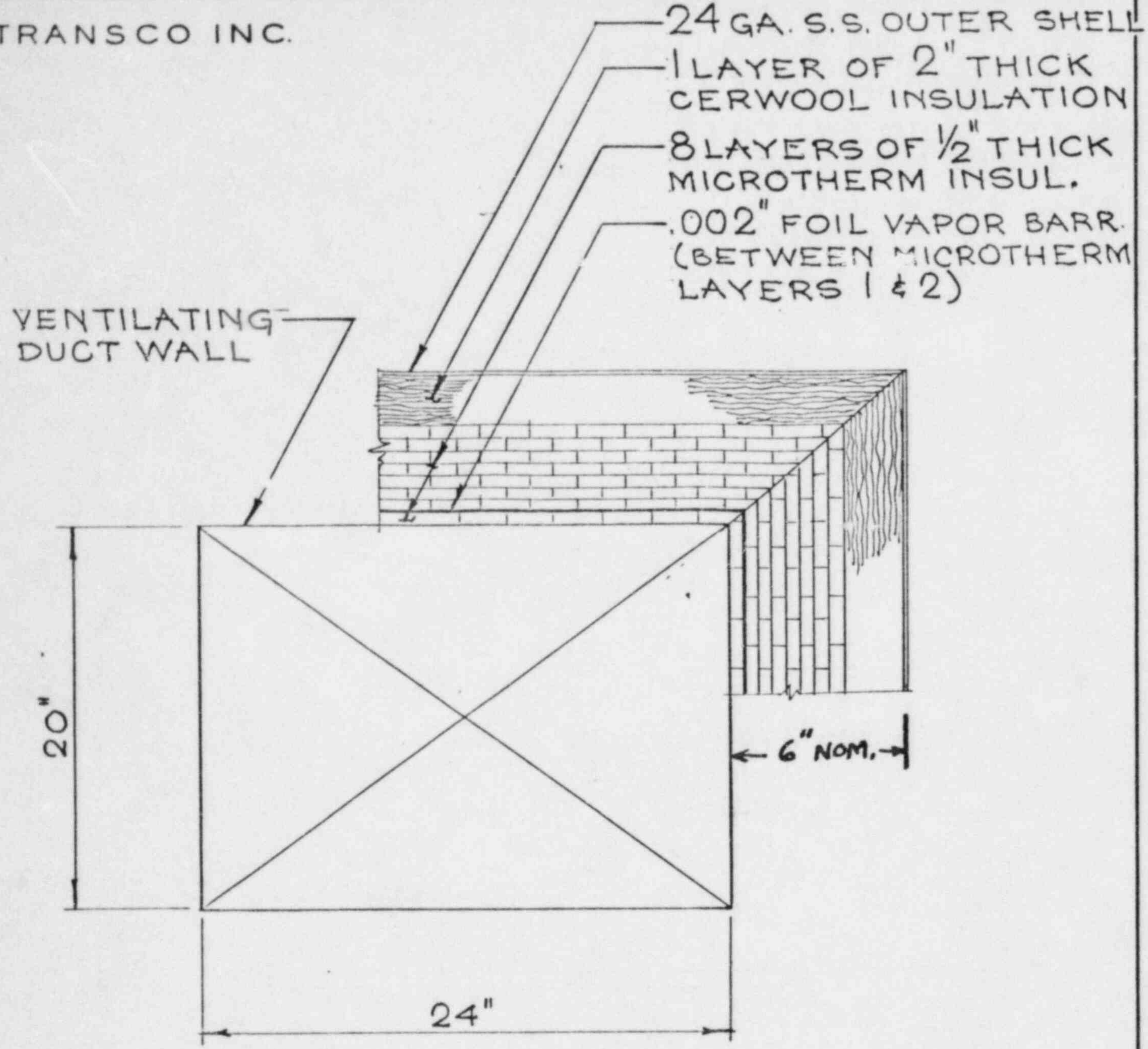



# TRANSCO "FLAME GUARD"

(TYPICAL)

CLINTON POWER STATION

FIGURE 1

## PRELIMINARY MATERIAL SELECTION

Transco contacted several companies which either manufacture insulation products or are familiar with such products and solicited their recommendations for materials which (a) proven fire-environment capabilities and (b) which was both thin and light in weight. These companies included:

Owens-Corning
Johns-Manville
Carborundum
Babcock & Wilcox
Fiberfrax
Combustion Engineering
W. R. Grace Co.
Micropore International
TSI, Incorporated
Portland Cement Association, Construction Technologies Lab.

These companies' unanimous recommendation was that either alumina silica blanket or subliming materials be investigated by Transco.

Subliming materials are frequently applied in such areas as beam and cable tray coatings. When these materials are exposed to flame or high temperatures, they sublime (pass directly from the solid to vapor state). One product, Thermalog by TSI, Inc., sublimes near 600 deg. F.

However, Transco found that subliming materials generally had relatively high thermal conductivities, high density, and may also suffer from product inconsistency due to the mixing process required. This line of products was therefore discarded as a possible material for FLAME GUARD.

Further study of alumina silicate blanket materials showed them to be non-combustible, capable of withstanding temperatures of 2300 deg. F, light (3-8 lb/cu.ft.), and to have relatively low thermal conductivities and neglible water absorption and shrinkage characteristics. This material was therefore selected as one primary component of the FLAME GUARD system. Specifically, 8 lb/cu.ft. density Cer-Wool by CE Refractories was selected.

In the interest of minimizing interference problems with installation of the insulation system, Transco looked for a material with a very low thermal conductivity vis-a-vis Cer-Wool. The objective was to minimize the total insulation thickness by using the Cer-Wool to reduce the temperatures to such levels that better insulating materials could be used behind the Cer-Wool; in particular, Microtherm by Micropore International.

As long as Cer-Wool of sufficient thickness is used on the fire-side of the combination to reduce the Microtherm temperature to 1700 deg. F or less, Microtherm properties are well suited for the present application. (The physical properties of Microtherm are illustrated on the following 4 pages.) Also, the potential advantage to be gained by using a Cer-Wool/Microtherm combination in lieu of all Cer-Wool, in terms of reduced total thickness, can be seen from Figure 2 showing a comparison of thermal conductivities.

In summary, Transco's studies of suitable materials to be used in the FLAME GUARD system resulted in the selection of a combination of Cer-Wool ("hot" side) and Microtherm ("cold" side). Analyses and testing was then required to determine the appropriate thicknesses to ensure no more than a 12 deg. F air temperature rise in the (approx.) 38-feet long supply and return ducts when exposed to the ASTM-E119 3-hour fire test.

Although mineral wool thermal conductivities are considerably greater than Microtherm's, some published literature reviewed by Transco indicated that its "thermal diffusivity" was quite low. (The importance of this will be seen in the discussions presented below.) Because of mineral wool's low cost, Transco therefore included testing of mineral wool to determine if it could be used in combination with Cer-Wool.

## ANALYSES AND TESTING -- PROCEDURES AND RESULTS

### A. Steady-State

The problem of determining appropriate insulation thicknesses for the FLAME GUARD system was first approached from a steady-state viewpoint. Consider Figure 3 illustrating a section of the ductwork and an incremental volume of air:

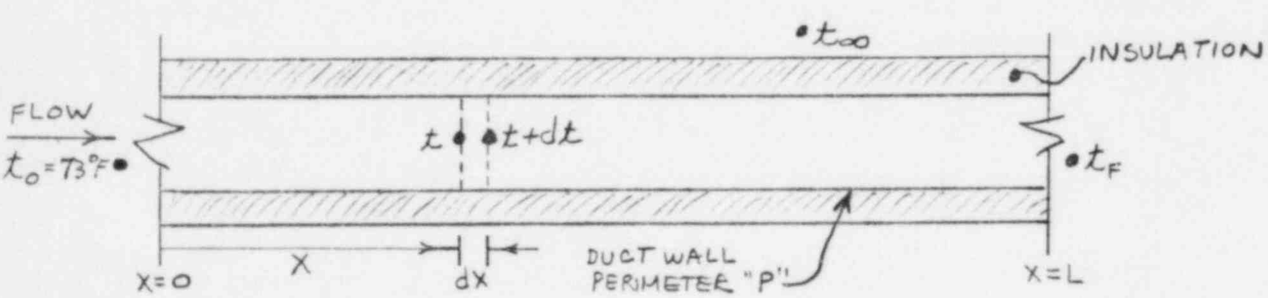



FIG. 3-Energy balance on incremental volume of air in ductwork

# PHYSICAL, CHEMICAL AND GENERAL PROPERTIES OF MICROTHERM

## INTRODUCTION

MICROTHERM is a very high efficiency thermal insulation material with a thermal conductivity only one third that of most high temperature insulation materials in the temperature range 400 - 1000°C.

MICROTHERM has a microporous structure which is also opacified to prevent infra red radiation passing through. It is even better as a thermal insulation than "still air". When it is used in air or other gases it gives a better insulation performance than any other known insulation.

The only way to produce a lower thermal conductivity is to use an evacuated system which, in general industrial applications, is not feasible, and in more sophisticated systems is usually very expensive and requires pumping down facilities.

The low thermal conductivity of MICROTHERM makes it possible to perform any insulation task with a much thinner layer of insulation than would normally be needed, with a consequent saving in the overall size of the insulated equipment and often a reduction in weight of the insulation and its containing structure.

MICROTHERM is used on all types of equipment to give low surface temperatures and to reduce heat losses.

MICROTHERM is totally incombustible, is resistant to damage by vibration and mechanical shock and has a high resistance to compression. It is generally easy and pleasant to handle.

## CONSTRUCTION

The principle constituents of MICROTHERM are microporous silicas, ceramic fibres and opacifiers which are intimately mixed and bonded to form a panel, block or moulded shape. The block may be contained in an envelope of glass cloth to provide for robust handling and flexibility.

The range of products produced by different applications of the glass cloth are more fully discussed in section 3 to 7 of this brochure.

All MICROTHERM products have the general properties described in this section of the brochure.

## MOISTURE AND HUMIDITY

MICROTHERM normally has a moisture content of 1 - 3% by weight. This can increase if it is stored in damp conditions. Dry storage is important.

The thermal and mechanical performances of MICROTHERM are not affected by severe changes in humidity or temperature.

Liquid water, however, does have an adverse effect on normal MICROTHERM and contact with water must be avoided. If MICROTHERM has become thoroughly wet its structure is irreversibly damaged by substantial shrinkage.

Where contact with water is unavoidable then the water resistant grade – Hydrophobic MICROTHERM – should be specified.

## HYDROPHOBIC MICROTHERM

Normal MICROTHERM is made up from extremely fine structured particles of amorphous silica which are linked together to form a cellular structure. When the cells are perfused with water the structure is damaged by capillary forces.

To avoid this damage a water resistant MICROTHERM has been developed in which the silica particles are coated with a hydrophobic chemical to inhibit water entering the structure. This water resistant MICROTHERM can be totally submerged in water without suffering damage within the following limits:

(1) Maximum time of submersion at room temperature is 72 hours. After this length of time the MICROTHERM must be dried.

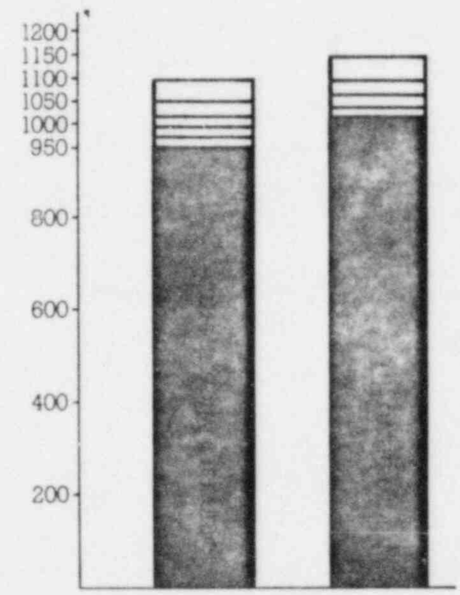
(2) The water must not contain surface tension reducing agents such as detergents.

(3) The temperature must not exceed 350°C. Above this temperature the hydrophobic MICROTHERM reverts to the properties of normal MICROTHERM and is no longer water resistant.

Water resistant MICROTHERM is ideal for situations where refractory cements are cast against it as in some furnace constructions.

## OPERATING TEMPERATURE

MAXIMUM OPERATING TEMPERATURE MICROTHERM




MICROTHERM is available as a standard formulation or as a high temperature formulation (MICROTHERM HT).

Standard MICROTHERM withstands prolonged exposure to 950°C and MICROTHERM HT has a similar life to 1025°C.

Both can be used for short periods at higher temperatures which depend on the exact nature of the application.

The glass cloth in which MICROTHERM may be encased as panel or slatted blanket retains its integrity up to 650° – 700°C. Above this temperature it devitrifies slowly. This has no effect on the thermal performance of the MICROTHERM but mechanically MICROTHERM panels may be difficult to handle when the glass cloth skin has been damaged.

MICROTHERM panel is usually contained between other materials and continues to perform its insulation function without the glass cloth envelope.

On the rare occasions when it is essential that the skin remains intact at very high temperatures then the glass cloth may be supplemented or replaced by other high temperature fabrics or fibres.

# CHEMICAL ATTACK

MICROTHERM is resistant to most chemicals including the vapours of hydrochloric acid and sulphuric acid but contact with most liquids must be avoided.

However, MICROTHERM can withstand direct contact with liquid sodium at temperatures below about 450°C. At higher temperatures the presence of the alkali earth metals accelerates the high temperature shrinkage of MICROTHERM.

Generally the chemical properties of MICROTHERM are those of its principle individual constituents – silica and titania.

# HEALTH

MICROTHERM is safe to handle. There are no known health hazards associated with its use. No health hazards are known to be associated with any of the individual constituents of MICROTHERM. If the MICROTHERM is machined in a way such that large quantities of dust are generated then normal precautions associated with the handling of nuisance dusts are necessary.

MICROTHERM contains no asbestos.

# CHEMICAL ANALYSIS

**CHEMICAL ANALYSIS OF STANDARD MICROTHERM BY WEIGHT.**

| | | | |
|---|---|---|---|
| $SiO_2$ | 64.68% | MgO | Trace |
| $TiO_2$ | 31.90% | MnO | Trace |
| $ZrO_2$ | 0.23% | $Na_2O$ | 0.06% |
| $Al_2O_3$ | 2.37% | $Nb_2O_5$ | Trace |
| $Fe_2O_3$ | 0.33% | $V_2O_5$ | 0.15% |
| $Cr_2O_3$ | 0.07% | S | 0.02% |
| $P_2O_5$ | 0.02% | Cl | 0.01% |
| $B_2O_3$ | Trace | $H_2O$ + | 0.03% |
| CaO | 0.04% | $H_2O$ – | 0.03% |

In addition MICROTHERM may be contained in glass fabric treated with organic starch and sewn with glass thread coated with P.T.F.E.

**CHEMICAL ANALYSIS OF GLASS CLOTH BY WEIGHT.**

| | | | |
|---|---|---|---|
| $SiO_2$ | 54.2% | MgO | 4.7% |
| $Al_2O_3$ | 15.2% | $Na_2O$ | 0.6% |
| CaO | 17.3% | $B_2O_3$ | 8.0% |

# LEACHABLE CHLORIDE

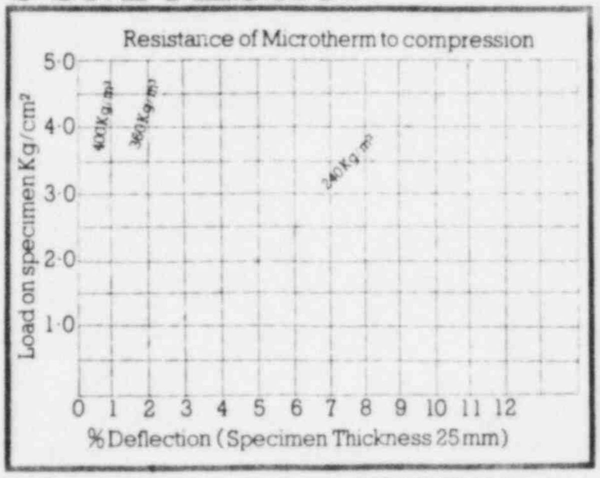
Independent tests give the following figures which indicate that all types of MICROTHERM may be used satisfactorily in contact with stainless steel. (It is widely used on the stainless steel pipework of the cooling circuits of nuclear reactors). However, the whole question of stainless steel attack is the subject of debate and continuing investigation, so testing in each situation is advised.

Summary of results from tests in accordance with the American Specification RDT M12 – 1T MIL–1–24244A (SHIPS) are:

Leachable (Cl + F) content 100ppm

Leachable (Na + $SiO_3$) content 4000ppm.

# RESISTANCE TO COMPRESSION

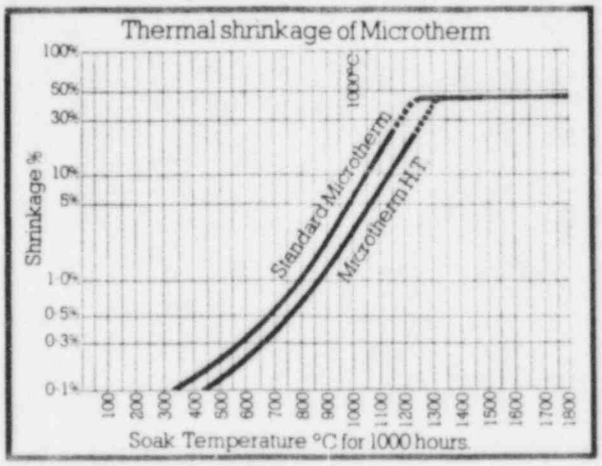



The criteria for the selection of MICROTHERM density are cost and handleability. High densities are available where high resistance to compression is important but the higher the density the greater the cost.

# THERMAL SHRINKAGE AND EXPANSION

At high temperatures the thermal expansion of MICROTHERM is small and can be ignored in practice. It has a resilient structure and no great stresses are created.

After prolonged periods at high temperatures a small amount of shrinkage can be measured (on the cooled block).




# VIBRATION

Acoustic

Tests in acoustic chambers carried out in connection with aircraft applications show that MICROTHERM is unaffected by high noise levels of varying frequency.

Mechanical

MICROTHERM by itself is not very strong but only continuous flexing causes the structure to break up. Where mechanical vibration is encountered MICROTHERM must be well contained so that it can move with the vibrating structure. Properly applied it gives indefinite life on diesel exhaust pipes and pipework of ships and aeroplanes.

MICROTHERM does not shake down nor do its individual constituents separate out.

# COMBUSTIBILITY

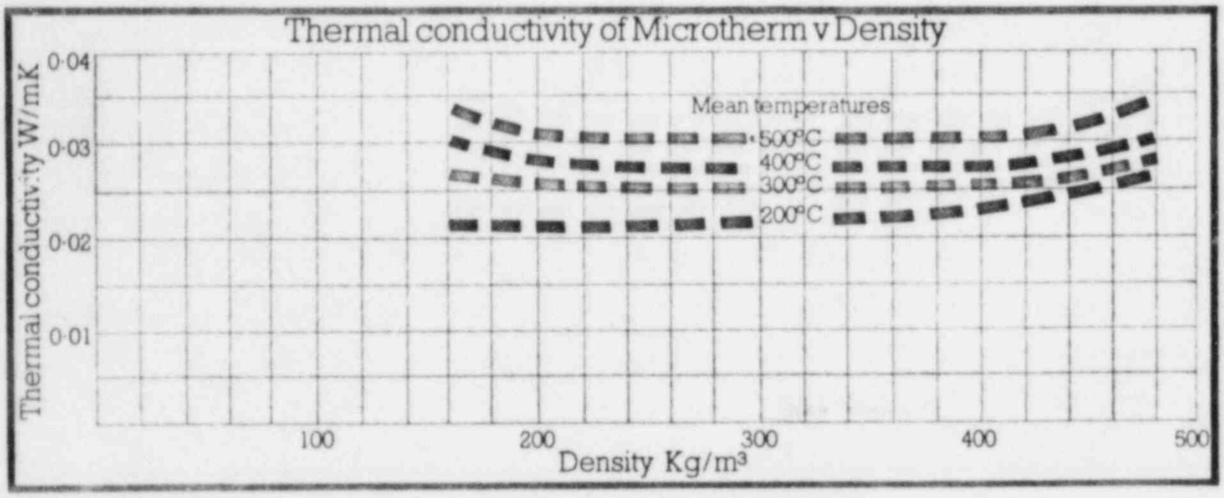
Because MICROTHERM is a vitreous ceramic material contained in glass cloth it is entirely incombustible. Organic materials present are those used for the finishing treatment of the glass cloth and glass thread. Quantities are too small to ignite but when heat is applied they produce a brown colour before being completely removed by oxidation.

Organics are also present in Hydrophobic MICROTHERM but again in quantities too small to ignite.

MICROTHERM has been tested to the American Standard A.S.T.M.E.-84 and shownto be incombustible and to have zero flame spread.

MICROTHERM has also been classified "incombustible" in tests to ISOR1182 by the University of Ghent.

# EFFECT OF DENSITY CHANGE ON THERMAL CONDUCTIVITY

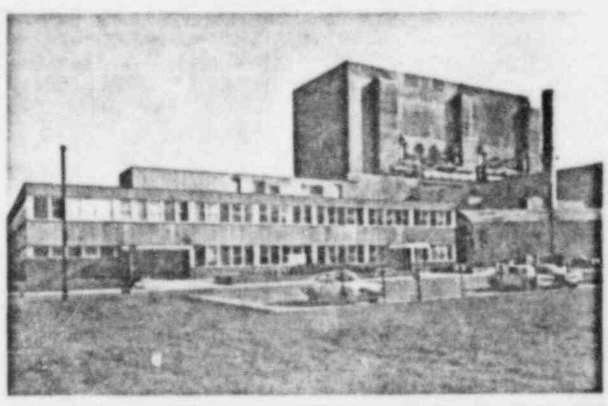


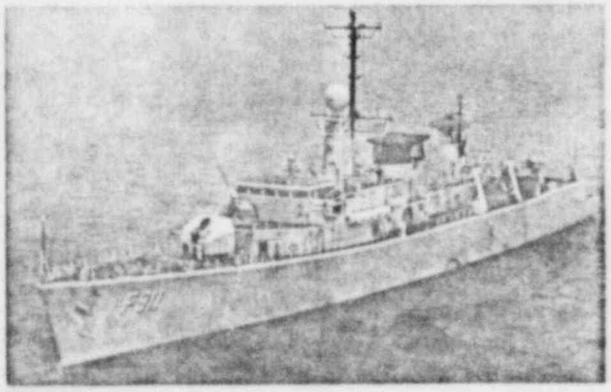

Within the density range 190 – 320 kg/m³ there is a little change in thermal conductivity.

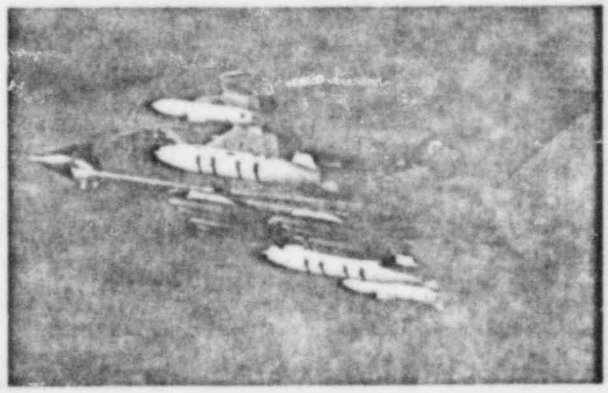
# APPROVALS

MICROTHERM is approved for use on Civil and Military aircraft, on Naval Vessels and Military vehicles. It is also widely used on nuclear generating plant around the world.

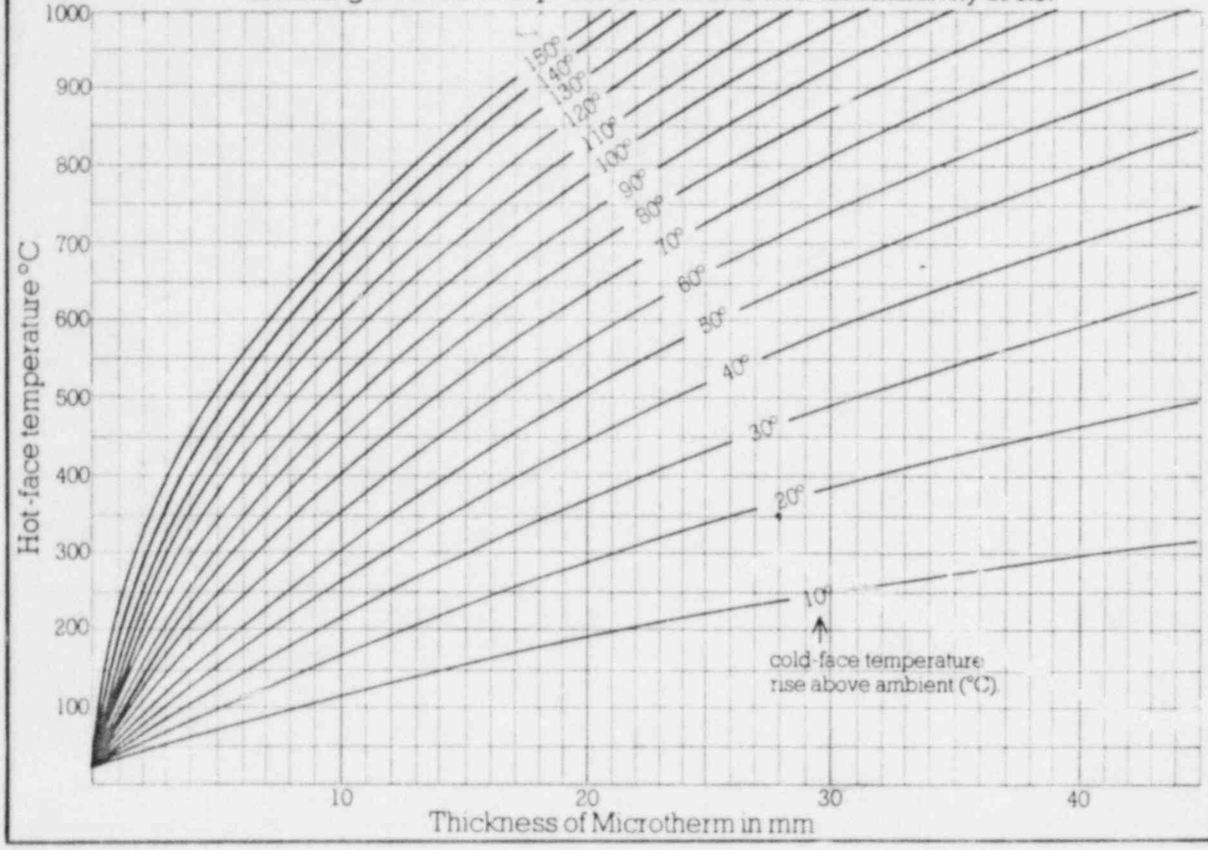
1. The C.E.G.B's Hartlepool nucle[illegible] power station equipped with two Advanced [illegible]s Cooled reactors, designed and built by the Nuclear Power Company Limited.
2. Belgian Naval Vessel built by Cockerill Yards with exhaust system insulated with Microtherm.
3. Tornado Aircraft with Microtherm heat shield and Microtherm Pipe Insulation – Courtesy B.A.C.



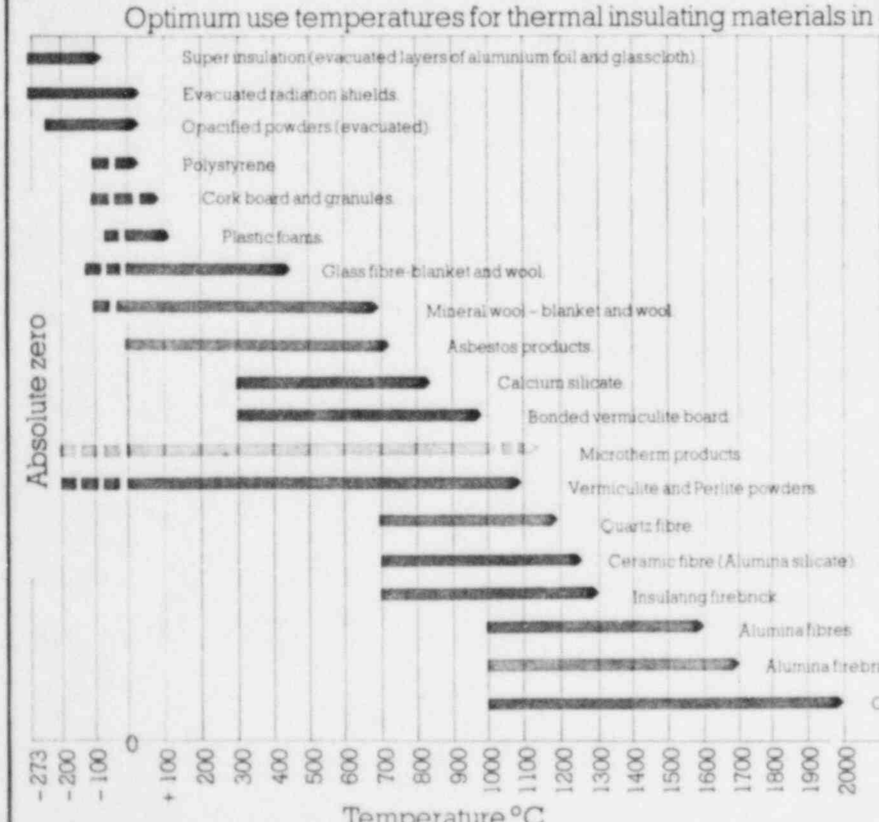




Typical Surface temperatures which can be expected when using MICROTHERM assuming the surface is plane and vertical with an emissivity of 0.9.



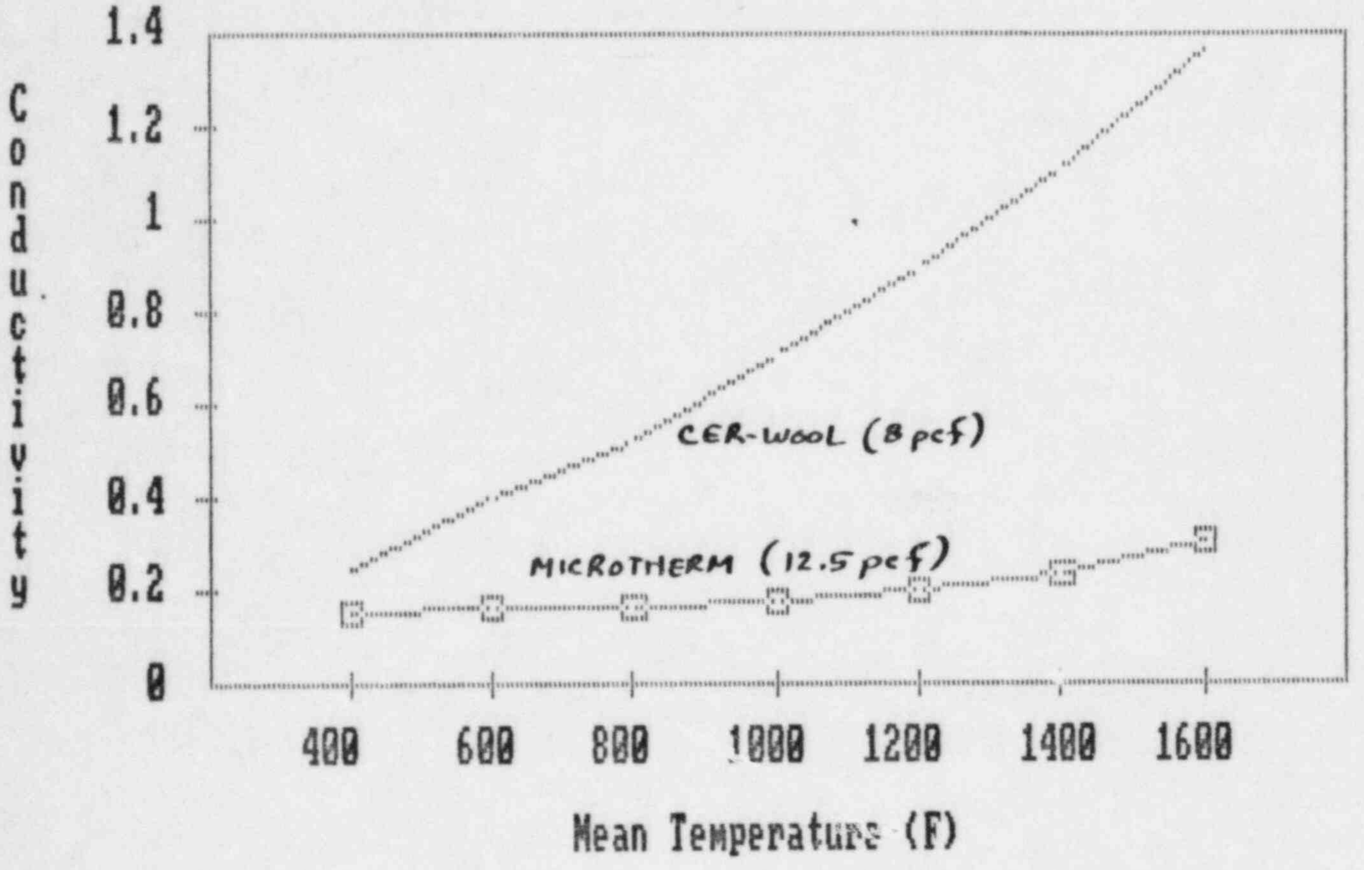

Optimum use temperatures for thermal insulating materials in common useage.




NOTE: Dashed lines indicate that insulations used in this range require special conditions (hermetic sealing, limited period of exposure etc.)

Many factors affect the choice of insulation to be used i.e. space available, chemical resistance, weight, performance, handleability, formability, malleability, compressability, porosity, availability, compatability, and so on. This table shows the temperature range for which insulations are commonly used, but there may be exceptional cases.

Figure 2 - Thermal Conductivity (Btu-in/hr-sq.ft.-F)



An energy balance on the incremental air volume is:

$$\dot{m}Cpt+UPdx[t_{\infty}-1/2\{t+(t+dt)\}] = \dot{m}Cp(t+dt) \qquad \text{....Eq. (1)}$$

where U = overall heat transfer coefficient
t = temperature
dt = differential temperature
Cp = specific heat of air
$\dot{m}$ = air mass flow rate
x = distance along duct
dx = differential distance
P = duct perimeter

If second-order terms in the differentals are neglected, Eq. (1) can be written:

$$dx/(\dot{m}Cp) = - dt/[UP(t-t_{\infty})] \qquad \text{....Eq. (2)}$$

Equation (2) has the solution

$$t(x) =[1-\exp\{(-UP/\dot{m}Cp)x\}]t_{\infty} + \exp\{(-UP/\dot{m}Cp)x\}t_o \qquad \text{....Eq. (3)}$$

which also may be written as

$$U = -(\dot{m}Cp/Px)\ln[(t_{\infty}-t)/(t_{\infty}-t_o)] \qquad \text{....Eq. (4)}$$

This latter form is of interest since it expresses the steady-state overall heat transfer coefficient U in terms of the air temperature at a distance x from the duct entrance (x=0). U is related directly to the thickness of the insulation and its "effective" thermal conductivity $k_{eff}$. In particular, setting x = 38 feet at which point the temperature of the air is set at 85 deg. F, and using the value of 0.24 Btu/lb-F for Cp, 7.33 feet for the duct perimeter P, and 19,235 lb/hr for the air mass flow rate $\dot{m}$ (corresponding to 4360 cfm of 13.6 cu.ft./lb air), Eq. (4) becomes

$$U = 0.108 \text{ Btu/hr-sq.ft.-F} \qquad \text{....Eq. (5)}$$

Assuming the fire-side of the insulation remains at the ASTM-E119 temperatures at all points in time, U is related to the conductive resistance $l/k_{eff}$ of the insulation and the convective resistance h of the air film at the interior duct surface according to

$$U = 1/[l/k_{eff} + 1/h] \quad \text{....Eq. (6)}$$

where the total insulation thickness is represented by l, in inches. From Eq. (6), the relationship between the effective thermal conductivity and the total thickness of the insulation is

$$k_{eff} = 1/[1/U - 1/h]\ l \quad \text{....Eq. (7)}$$

The value of the internal convective film coefficient is estimated from the ASHRAE Handbook of Fundamentals (1972, p. 42):

$$h \cong 0.00365\ (G^{0.8}/d^{0.2}) \quad \text{....Eq. (8)}$$

where G = mass velocity of the air (lb/hr-sq.ft.)
= 5771 lb/hr-sq.ft.
d = 4 x (duct cross sectional area/total perimeter)
= 1.82 feet.

Therefore, h = 3.3 Btu/hr-sq.ft.-F, and Eq. (8) becomes

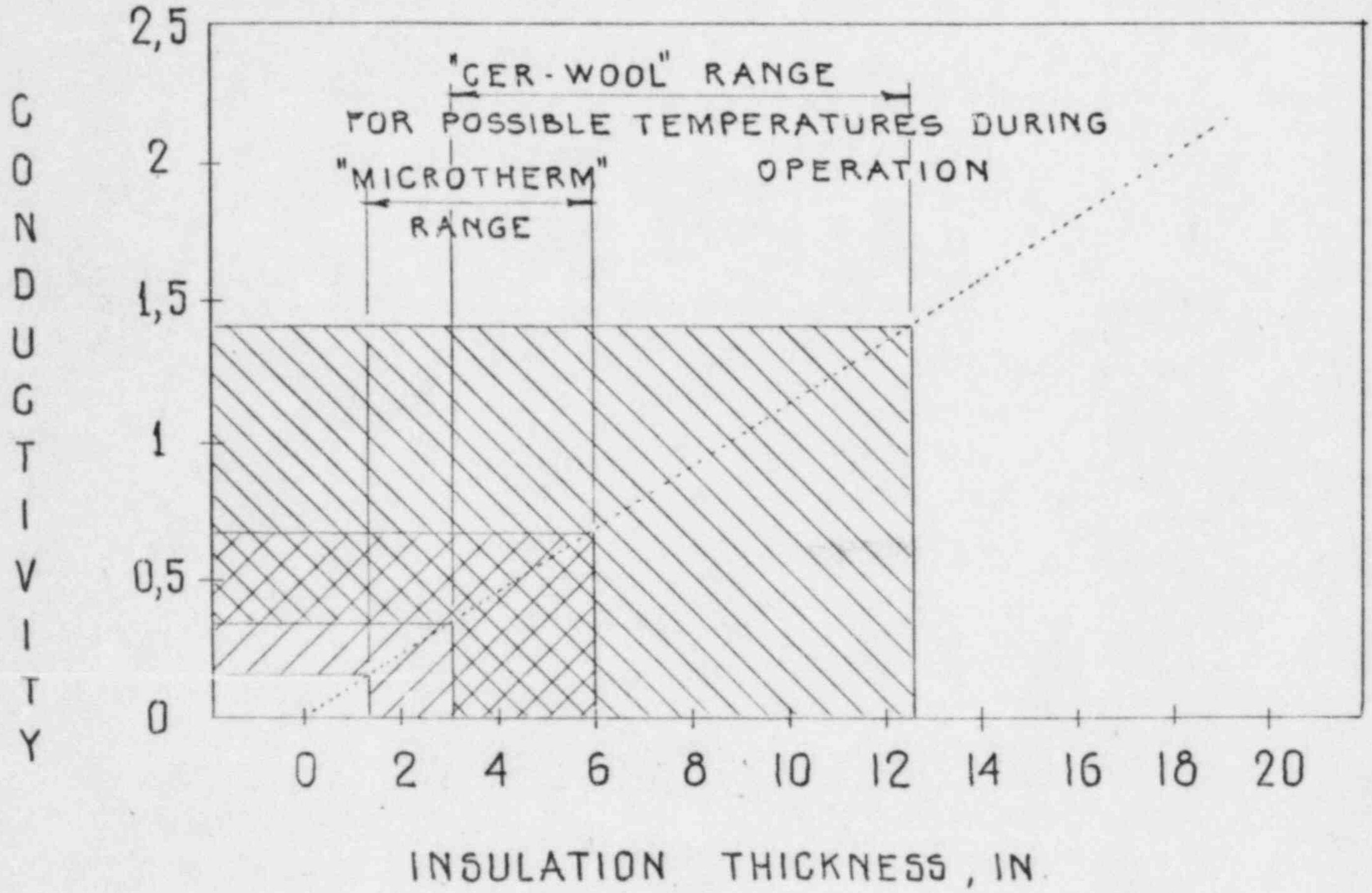
$$k_{eff} = 0.112\ l \quad \text{....Eq. (9)}$$

Equation 9 is plotted in Figure 4, illustrating the required relationship between the effective thermal conductivity and the overall thickness of the insulation to ensure the air temperature exiting the 38 feet of duct in the switchgear room does not exceed 85 deg. F when the entering air is 73 deg. F.

Remembering the fact that the thermal conductivity of a porous material varies with temperature (see Figure 2), the possible range of thicknesses for either all Cer-Wool or all Microtherm applied to the duct is shown in Figure 4 for the temperatures encountered from 73 deg. F up to the 1925 deg. F maximum of the ASTM-E119 procedure.

Although this steady-state analysis provides some insight into the potential minimum and maximum insulation thicknesses, it is not adequate to establish the minimum acceptable thickness to limit

FIG.4 - $K_{EFF}$ VS THICKNESS (SEE EQ. 9)



interferences in the actual installation. Its primary limitations are (a) the assumption of no variation in thermal conductivity with temperature and (b) the assumption of no thermal capacitance (heat storage capability) of the insulation. Therefore, Transco had to undertake a more realistic transient analysis procedure in which these limiting assumptions could be relaxed. In the hope of minimizing analysis time, these assumptions were addressed individually to see if a successful analytical model would result.

## B. Transient Analysis -- Thermal Capacitance Effects of Insulation

Cer-Wool properties (8 lb/cu.ft.) were selected to determine the adequacy of a transient analytical model including the effects of the insulation's thermal capacitance. Actual lab testing on a nominal thickness of 14-inches of Cer-Wool was conducted to (a) provide information on a suitable "time/temperature averaged" thermal conductivity to use in the analytical model and (b) establish a baseline for comparison form analytical results.

Test TTR-30N (note: all TTR tests referred to in this report are included at the end of the report) discusses in detail the analytical procedure used to evaluate transient temperatures inside the insulation. A standard "Schmidt" approach was used, as referenced in many heat transfer texts.

Referring to Figure XII in TTR-30N, it is seen that, except for the end points (faces of the insulation), the transient analysis which does not account for variations in thermal conductivity with temperature does not adequately represent the actual situation. For example, at location #6 (about 5.4 inches from the hot face) the measured temperature exceeds the calculated temperature by nearly 700 deg. F.

## C. Transient Analysis -- Thermal Capacitance of Insulation and Thermal Conductivity Variations.

The analytical model derived to include the effects of both the thermal capacitance and variations in thermal conductivity of the insulation considers the elemental configuration in Figure 5 below.

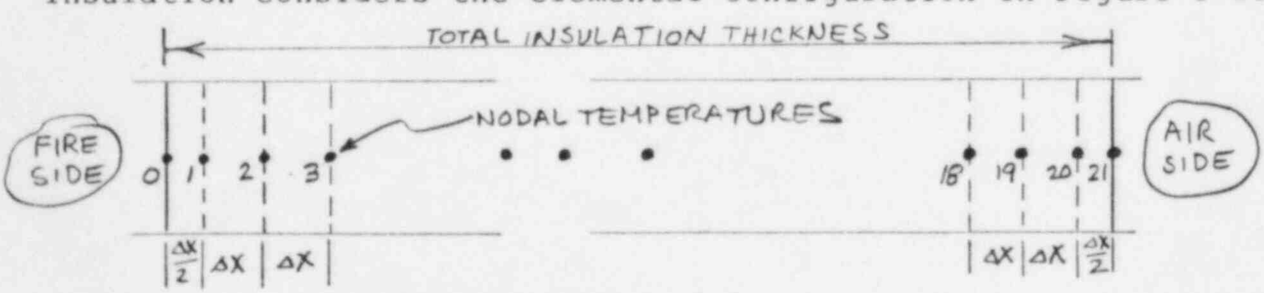



FIG. 5-Elemental Representation of Insulation for Transient Analysis

Twenty-one elemental (nodal) temperatures were selected to characterize the insulation thickness depicted in Fig. 5. The model is built around 12-inches of Microtherm.

Equating the difference in heat flow into and out of each element for a short duration of time to the increase in the elements internal energy, the expressions governing the transient heat transfer process are:

Nodal Point "0"

```
t(0,0) = 73 F                                        ....Eq. (10a)

t(0,n*dt) = f(ASTM Profile)                          ....Eq. (10b)
```

Nodal Point "1"

```
t(1,0) = 73 F                                        ....Eq. (11a)

t(1,n*dt) = t(1,{n-1}*dt)+(B/dx)*[t(0,{n-1}*dt)-
               1.5*t(1,{n-1}*dt)+.5*t(2,{n-1}*dt]
                                                     ....Eq. (11b)
```

Nodal Point "m"; m=2,3,...,19

```
t(m,0) = 73 F                                        ....Eq (12a)

t(m,n*dt) = t(m,{n-1}*dt+(B/dx)*[t({m-1},{n-1}*dt)-
               t(m,{n-1}*dt+.5*t({m+1},{n-1}*dt)]
                                                     ....Eq. (12b)
```

Nodal Point "20"

```
t(20,0) = 73 F                                       ....Eq. (13a)

t(20,n*dt) = t(20,{n-1}*dt+(B/dx)*[.5*t(19,{n-1}*dt)-
               1.5*t(20,{n-1}*dt)+t(21,{n-1}*dt)]
                                                     ....Eq. (13b)
```

Nodal Point "21" (Adjacent to duct wall)

```
t(21,0) = 73 F                                       ....Eq. (14a)

t(21,n*dt) = [h*t(air)+(2*k/dx)*t(20,n*dt)]/[h+(2*k/dx)]
                                                     ....Eq. (14b)
```

In the above equations, the following boundary conditions were assumed to prevail:

1. t(Ø,n*dt) = temperature of "Ø" nodal point after a time increment of (n*dt) = ASTM-E119 profile

2. t(21,n*dt) = temperature of the (last) "21" nodal point after a "n" time increments each of duration "dt" adjusts instantaneously such that the the conductive heat transfer rate due to the temperature gradient between the "2Ø" and the "21" nodal points always equals the convective heat transfer from the "21" node to the air in the duct. A convection coefficient of h=5 Btu/hr-sq.ft.-F and constant air temperature of t(air)=73 F was assumed for the calculations.

3. The thermal conductivity "k" varies with temperature in accordance with the manufacture`s data.

4. Parameter values and definitions:

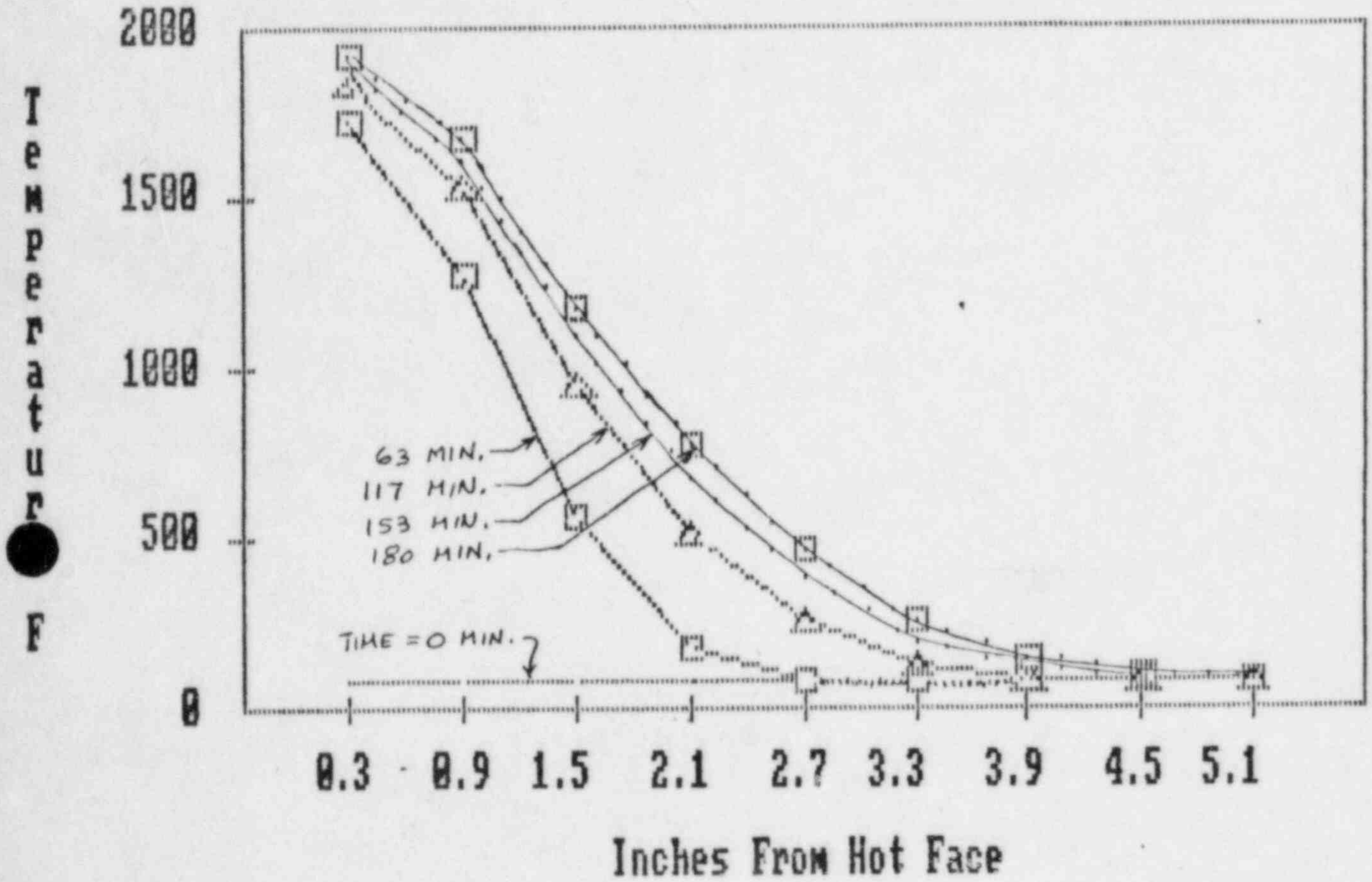
   k=thermal conductivity as a function of insulation temperature
   dt=time increment=Ø.15 hours=9 minutes
   dx=element width=.6 inches=.Ø5 feet
   rho=density of Microtherm insulation=12.5 lb/cu.ft.
   cp=specific heat of Microtherm insulation=.24 Btu/lb-F
   B=(2*k*dt)/(dx*rho*cp)
   t(air)=air temperature in duct=constant=73 F
   t(m,n*dt)=temperature of "m"-th nodal point after "n" time increments each of "dt" duration.
   n=number of time increments; n=1,2,...,2Ø.

Figure 6 shows the results of the above transient (numerical) model for 12-inches of Microtherm in terms of the predicted temperature profile inside the insulation at various times during the 3-hour ASTM-E119 fire test. Note that distances only up to about 5-inches from the hot face of the insulation are shown since beyond this point no temperature increase is predicted even at the end of 3 hours.

## D. Selection of Insulation Thicknesses

Figure 6 illustrates the results of the most comprehensive model developed by Transco in the analytical area. These results were used to select tentative final insulation thicknesses to be confirmed as adequate by actual test results.

Fig. 6 — Time/Temp Profiles in 12" MicroTherm



A conservative criterion of allowing no temperature increase of the duct wall (adjacent to the air flow) was used to select the insulation thickness. Based on this, and referring to Figure 6, it is seen that about 5-inches of Microtherm is sufficient. Remembering, however, that (standard) Microtherm cannot be subjected to more than 1700 deg. F, the problem of applying an appropriate thickness of Cer-Wool on the fire-side (hot face) was still unsolved.

In order to determine how much the Microtherm thickness could be reduced and, simultaneously, how much Cer-Wool must replace this amount of Microtherm, the following criterion was applied: for the transient numerical model to remain valid, it is necessary that the following relationship be satisfied:

$$[k_m/(rho_m cp_m (dx_m^2))]\text{Micro.} = [k_c/(rho_c cp_c (dx_c^2))]\text{Cer-Wool} \quad \text{....Eq. (15)}$$

From Eq. (15), the relationship between the thickness of Microtherm $dx_m$ to be replaced by an equivalent thickness of Cer-Wool $dx_c$, can be expressed as:

$$dx_c = [(k_c/k_m)(rho_m cp_m/rho_c cp_c)]^{1/2} dx_m \quad \text{....Eq. (16)}$$

Using the appropriate values for the physical parameters, the relationship between equivalent thicknesses of Microtherm and Cer-Wool is:

$$dx_c \cong 2.65(dx_m) \quad \text{....Eq. (17)}$$

Referring to Figure 6, it is seen that if approximately 1-inch of Microtherm is replaced on the hot side, the maximum temperature at the Cer-Wool/Microtherm interface will be about 1700 deg. F. According to Eq. (17), this requires about 2.65-inches of Cer-Wool to replace the 1-inch of Microtherm. Transco chose, for practical reasons, to use 2-inches of Cer-Wool for testing. Therefore, the final FLAME GUARD configuration (regarding insulation types and thicknesses) became 2-inches Cer-Wool/4-inches Microtherm, as illustrated in Figure 1, contingent upon tests showing its adequacy.

## E. Testing and Model Validation

Test TTR-34N presents the measured results for the final FLAME GUARD configuration. (Note that the test included the exterior stainless steel lagging and vapor barrier which is part of the actual FLAME GUARD system--however, these components are not expected to have significant impact on the comparison of measurements with model results.)

Figure IV of TTR-34N shows the relevant data for evaluating Transco's final proposed configuration for the Clinton ventilating ducts as well as for evaluating the adequacy of the model used in its preliminary selection. The test data shows that, at the end of the 3-hour fire test period, (a) the interface temperature between the Cer-Wool and Microtherm is about 1700 F and (b) neglible temperature rise is experienced at the cold side of the Microtherm (i.e., adjacent to the duct wall); these are precisely as predicted by the analytical model which includes both thermal capacitance and variable thermal conductivity of the insulation.

Figure 7 shows a final comparison of predicted and measured results. It compares the 3-hour temperature profile curve of Fig. 6 with the TTR-34N results, shifted in accordance with the "thickness equivalency" relationship discussed above. The model results and measurements compare quite favorably.

F. Problem of Steel Duct Support Structures

Test TTR-31N addresses both the analytical and testing aspects of the necessary extent of application of FLAME GUARD to the duct support steel. In summary, the results show about 4'-6" of steel (measured from the duct) must be treated to avoid heat transfer to the duct and air.

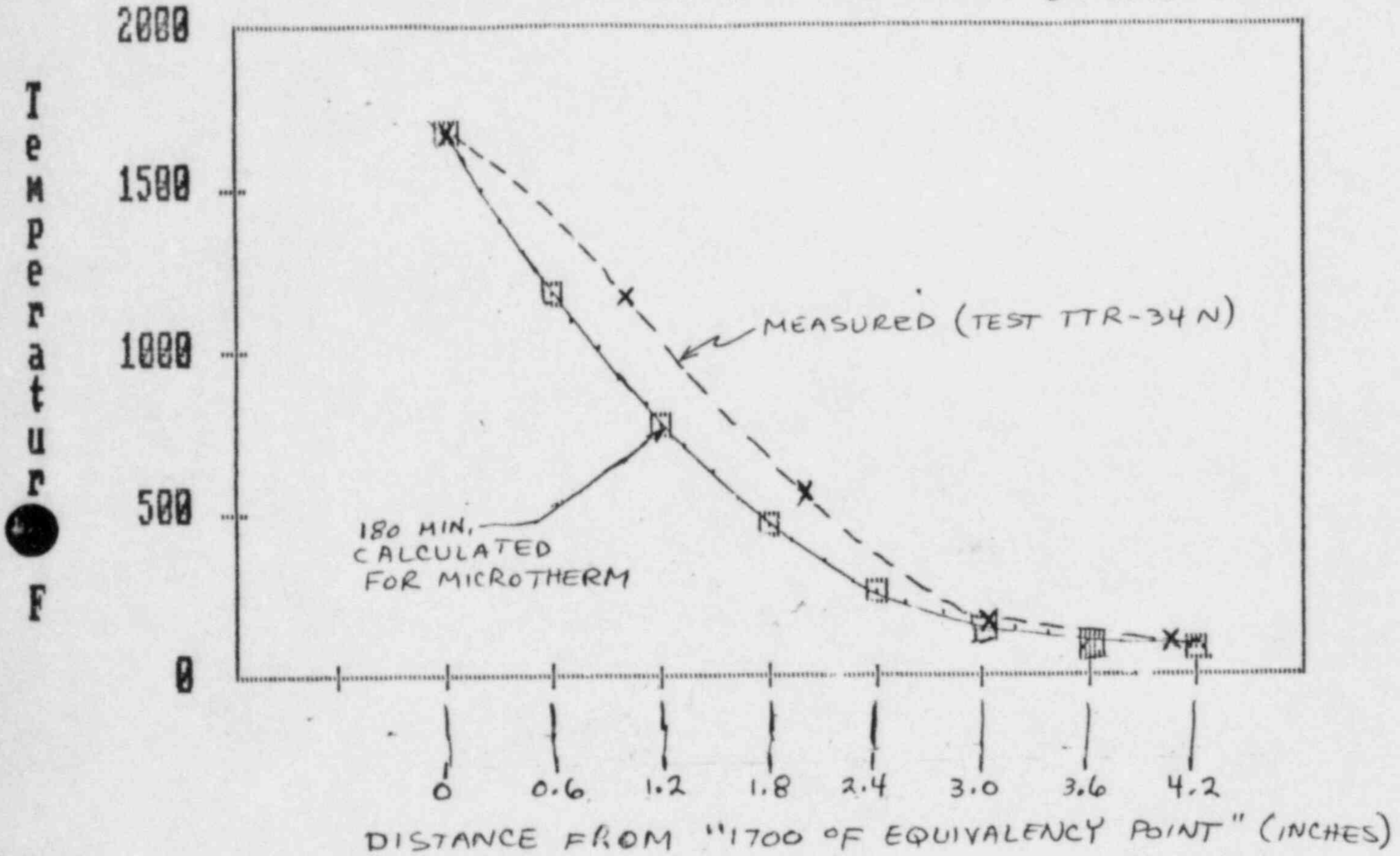
G. Alternative System Evaluation -- Mineral Wool/Foils

During its developmental program, Transco encountered two potentially cost- and/or space-saving aspects of insulation systems that seemed worth investigating. The first was the published fact that mineral wool had a very low thermal diffusivity, which in the final analytical model was the governing factor for insulation thickness. The second was that foils used between layers of insulation might provide better insulation characteristics than the same total insulation thickness without the foils.

No analytical approach was used to investigate these possibilities, however testing was conducted to determine their effects. Regarding the use of mineral wool, testing showed (TTR-32N) that it was not suitable due to the great thickness required. The foil concept did, however, indicate the possibility of reducing the total thickness.

TTR-33N therefore addressed the foil concept with the Cer-Wool product. However, unlike the case for mineral wool, the foil did not seem to have such a space-saving potential.

FIG. 7 - COMPARISON BETWEEN NUMERICAL MODEL AND MEASURED RESULTS -- PROFILES AT END OF ASTM 3-HOUR TEST



Based on the results of the testing, Transco excluded the use of mineral wool and foil in the final FLAME GUARD system.

## CONCLUSION

This program of analysis and testing was undertaken by Transco to develop a practical fire-protection insulation system for the ventilating ducts at the Clinton station which would limit the temperature rise in the air to 12 deg. F when exposed to a 3-hour ASTM-E119 fire test. The resulting system was termed FLAME GUARD by Transco.

Both analytical results and actual tests show FLAME GUARD to meet the design requirements at Clinton.

The FLAME GUARD insulation must be applied both to the ductwork and about 4'-6" of all steel duct supports. Typical installation details and scope are illustrated on Transco Dwg. Nos. DB-3822-SK1, -SK2 and -SK7, attached.

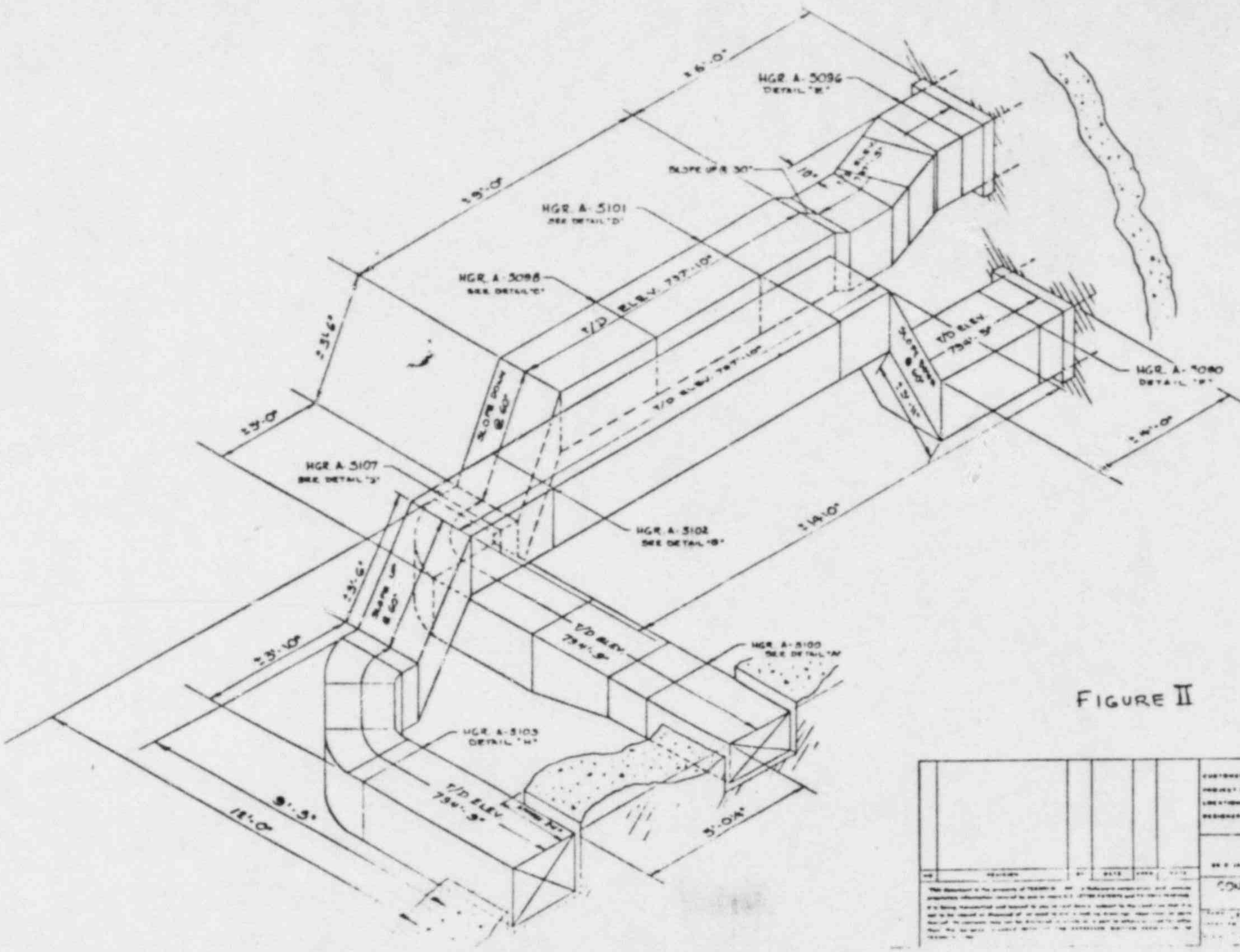



FIGURE II

ILLINOIS POWER
VENTILATING DUCTS
CLINTON N.P.S.

TRANSCO INC.

CONTROL ROOM VENTILATING DUCTS
CLINTON N.P.S.

SK-3822-SK1

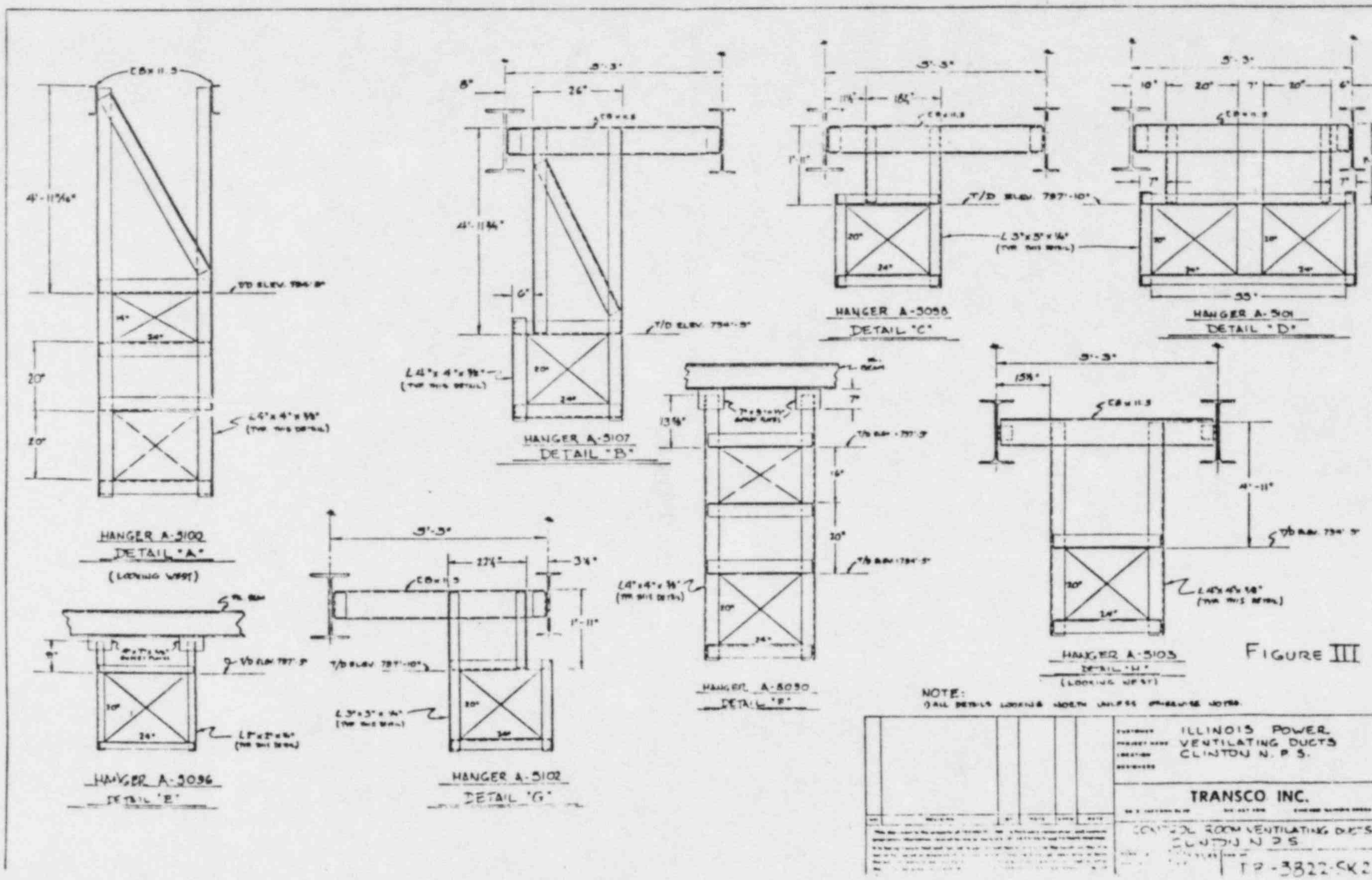
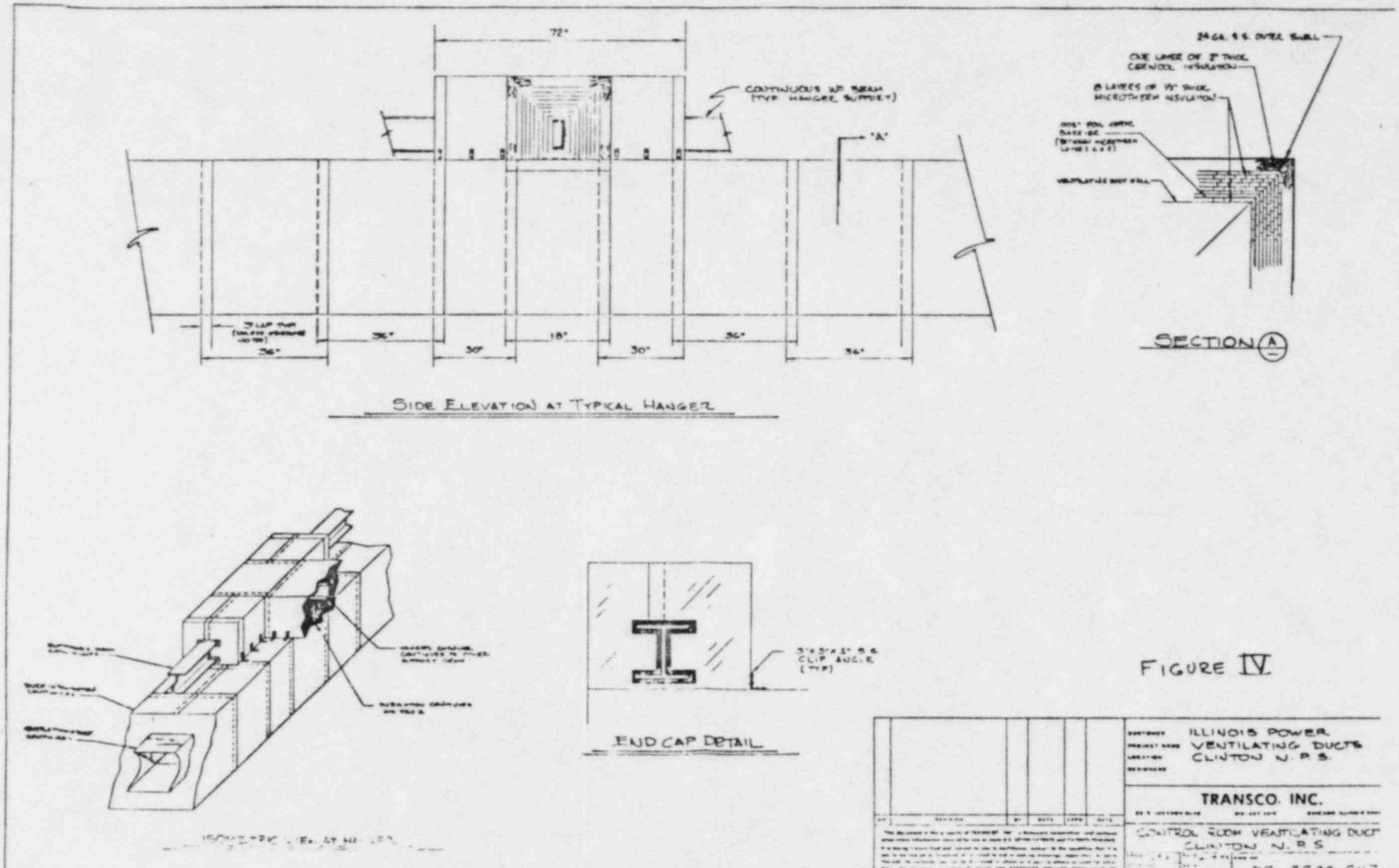

HANGER A-5100
DETAIL "A"
(LOOKING WEST)
C8x11.5
4'-11 5/16"
20"
20"
L4"x4"x3/8" (TYP. THIS DETAIL)
HANGER A-5107
DETAIL "B"
5'-3"
8"
26"
4'-11 3/4"
6"
T/D ELEV. 794'-5"
L4"x4"x3/8" (TYP. THIS DETAIL)
HANGER A-5098
DETAIL "C"
5'-3"
18 1/2"
T/D ELEV. 797'-10"
L3"x3"x1/4" (TYP. THIS DETAIL)
HANGER A-5101
DETAIL "D"
5'-3"
10"
20"
7"
20"
6"
7"
7"
33"
HANGER A-3096
DETAIL "E"
HANGER A-5102
DETAIL "G"
5'-3"
C8x11.5
27 1/4"
3 1/4"
1'-11"
T/D ELEV. 797'-10"
L3"x3"x1/4" (TYP. THIS DETAIL)
HANGER A-8030
DETAIL "F"
13 3/4"
7"
16"
20"
L4"x4"x3/8" (TYP. THIS DETAIL)
HANGER A-5103
DETAIL "H"
(LOOKING WEST)
5'-3"
15 3/4"
C8x11.5
4'-11"
T/D ELEV. 794'-5"
NOTE:
1) ALL DETAILS LOOKING NORTH UNLESS OTHERWISE NOTED.
ILLINOIS POWER
VENTILATING DUCTS
CLINTON N. P. S.
TRANSCO INC.
TP-3822-SK2

FIGURE III


72"
CONTINUOUS WF BEAM (TYP. HANGER SUPPORT)
"A"
36"
30"
18"
30"
36"
36"
SIDE ELEVATION AT TYPICAL HANGER
24 GA. S.S. OUTER SHELL
ONE LAYER OF 2" THICK CERWOOL INSULATION
8 LAYERS OF 1½" THICK MICROTHERM INSULATION
SECTION A
3"x3"x1" S.S. CLIP ANGLE (TYP)
END CAP DETAIL
FIGURE IV
ILLINOIS POWER
VENTILATING DUCTS
CLINTON N.P.S.
TRANSCO. INC.
CONTROL ROOM VENTILATING DUCT
CLINTON N.P.S.

TRANSCO INC.
TEST REPORT No.: TTR-30N

TEST REPORT
TEMPERATURE RESPONSE OF
8LB/$Ft^3$ CER-WOOL TO A THREE HOUR
ASTM E-119 FIRE TEST
PERFORMED AT SKOKIE, ILLINOIS, APRIL 14, 1983

Test Performed by: Construction Technology Laboratories,
Fire Research Department Personnel

Reported by: W. D. Brown
W. D. Brown, P.E.
Mgr. Product Development
Insulation Products Division

## 1. INTRODUCTION

The Schmidt calculational technique has been used to predict the temperature response of a wall of eight (8) pound per cubic foot density Cer-wool to a three (3) hour fire. The temperature of the fire being defined by ASTM E119.

The Schmidt method is ideal for one dimensional unsteady state problems with varying boundary conditions.

The Schmidt method can be either a graphical or computer technique. The wall section of interest is divided into equal width segments. Temperature plots are then made on the assumption that the temperature at a point one inch in from the front face (or one division) must equal the average of the front face temperature, and the temperature two inches in from the front face: The temperature three inches in from the front face must equal the average of the temperature two inches in and four inches in from the front face: etc. This is a simplified explanation. For a complete explanation, a heat transfer text may be consulted. After a temperature versus thickness plot is made, the total wall thickness is obtained by solving the following equation:

$$t_o - t_f = c_p L^2 p / 2k$$

Where:

$t_o - t_f$ = The time increments between temperature averages, In this case, ten minutes, or 10/60 hours.
$c_p$ = The specific heat of the material, in BTU/Lb-°F.
$k$ = Thermal Conductivity in BTU/Hr-Ft-°F.
$L$ = Distance between planes, in feet.
$p$ = Density in Lbs/Ft$^3$.
$n$ = Number of wall increments (discussed in the following paragraphs).

A table was made to predict the thickness of Cer-wool required to totally isolate a steel surface from the affects of a three (3) hour fire. The table is in Appendix I.

Each horizontal row of the table is the predicted temperature profile in that ten minute time increment. Each column represents a plane L feet thick spaced nL feet from the front face. The actual dimension L being determined by the above equation.

To weight the thermal conductivity and specific heat by the time averaged temperature, all temperatures were added in each column, and the total number of time increments in each column were noted.

The total temperature, in all the columns divided by the total number of time increments-yield a time weighted temperature in this case of 550.4°F. This temperature was then used to determine thermal conductivity, and specific heat values. Substituting the values of specific heat and thermal conductivity in the Schmidt equation (above) yielded a distance between planes of 0.9214 inches.

The Schmidt calculation in Appendix I indicated that 12.9 (14 x 0.9214) inches of Cer-wool will thermally isolate a body from the affects of a three hour fire. The cold face should see a two degree temperature rise at the end of the three hours.

The purpose of this test is to validate the calculational technique.

## 2. TEST APPARATUS

The test assembly was mounted on the Construction Technologies Laboratories gas fired pilot furnace. The test assembly consisted of a horizontal 24 gage stainless plate laid over the furnace opening. The plate was reinforced by 3 x 3 x 1/4" angles spanning the furnace opening. The furnace opening is about 30 inches square (See figure I).

On top of the plate, seven (7) layers of two (2) inch thick Cer-wool were stacked. The actual thickness varied between 1-3/4 and 2 inches. The layers were 36 inches square. Beginning at the steel plate, each interface had three (3) thermocouples mounted in it; one at the center, and two on quarter points (See Figures IV and V).

The test assembly was completed with three two-inch thick peripheral wraps of Cer-wool and a 24 gage stainless steel plate mounted on top of the assembly.

Figures II and III show the nearly completed test assembly, less top thermocouples. Thermocouples were later placed on the top of the cover plate. No thermocouples were placed between the bottom of the steel plate, and the top of the first layer of Cer-wool. The furnace is instrumented normally for 24 thermocouples. To record the temperature on the bottom surface of the steel plate would have required an additional three thermocouples over the furnace's standard 24.

Bricks were placed on the periphery of the top cover to minimize air spaces between the plate and the insulation. Figures IV and V show the completed assembly. Note the steel weights placed on the thermocouples to assure metal-to-metal contact between the thermocouples and the plate.

The furnace is a gas fired, negative draft furnace capable of producing a temperature/time curve in accordance with ASTM E-119. Flue gas is inducted from the bottom of the furnace to the building chimney by an induced draft fan, located below the floor. The furnace had four (4) burners, one on each wall. The burner plane is located approximately 30 inches below the test assembly bottom plate.

The thermocouples are connected to a computer in the control room.

## 3. TEST RESULTS

The test results are shown in Figures X, XI, and XII. Figures X, XI, and XII are the measured and calculated temperature profile in a 14 increment (14 x 0.9214 - 12.9 inches) thick wall of Cer-wool, at one hour, two hours, and three hours into the fire.

In reviewing the three curves the following three points are obvious:

1. The slopes of the curves, dT/dL for the measured and the calculated are approximately equal on each graph.

2. The asymptotic approach to room temperature of the measured and calculated are approximately identical in regard to slope. The calculated temperature curve lags the measured by approximately 1"-1½" of material thickness, in the intermediate temperatures.

3. The temperature profile in the intermediate temperatures (at the midpoint of the wall) are on the order of 400, 600, and 700°F difference between the measured and the calculated temperatures.

The calculation was to determine the thickness required to assure the three-hour fire did not reach the cold face. The calculation is based on the hot face and cold face temperatures being known; and the thermal coefficients being determined by time and temperature weighting of the thermal properties over the entire three-hour fire. The hot face temperature is 1925°F, and the desired cold face temperature is 75°F.

Due to the weighting, the predicted value by the Schmidt calculational technique should be most accurate at the three (3) hour point; and at the indicated cold face temperature. Comparing the two asymptotes of the calculated and the measured, on the three-hour graph, Figure XII, at the cold face, the method seems accurate.

Specifically, the calculational technique predicted at 12.9 inches from the hot face, the temperature would rise approximately 2°F, assuming negligible resistance beyond the 12.9 inches (14 spaces times 0.9214 inches/space). Due to manufacturing tolerances, the Cer-wool piles of seven layers had a actual dimension of between 12.5 and 13 inches thick. The back face rose 2°F at the end of the three hour test. This is exactly the temperature the Schmidt technique predicted. When it is considered that there is a front face temperature of 1925°F, the Schmidt calculational technique seems remarkably accurate.

At intermediate temperatures, however, the accuracy falls off significantly.

THICKNESS ERROR IN PREDICTING THE 100°F THICKNESS, AND 1000°F THICKNESS

To quantify the accuracy of the calculational technique, a defined temperature may be chosen to compare the thickness predicted by the calculation, and the thickness actually measured. The thickness required to provide a 75°F temperature cannot be read from the graphs with any degree of accuracy, because the temperature line is nearly horizontal at this point.

Choose the 100°F as the temperature point to compare the thickness predicted with the thickness of material measured. By the calculated curve of Figure XII, at the end of three hours at (10.5 spaces x 0.9214 inches/space=) 9.67 inches into the pile, the temperature should be 100°F. At 12.1 inches times 12.75/14, or 11 inches into the pile, a 100°F temperature was measured.

The 0.9214 multiplier on the calculated thickness is the actual L in the Schmidt calculation. Fortunately, the 12.75/14 inches multiplier for the actual pile height is 0.910. Hence both thickness multipliers are almost the same.

Using an error equation for equal temperature thickness of:

100 (calculated thickness-measured thickness)/Measured thickness = percent of thickness error.

The error in the Schmidt calculational technique when used to predict the thickness at the intermediate temperature of 100°F three hours into the fire is:

$100(9.67-11)/11 = -13\%$

Using the same equation at the 100°F point for the two and one hour temperature profiles, the error is -14 percent, and -17 percent respectively.

However, at the 1000°F point for the three hour curve, the error is on the order of 55 percent.

The raw data recorded by Construction Technologies Laboratory, Fire Research Department is Appendix II, available upon request from Transco Inc.

## 4. CONCLUSIONS

The Schmidt calculational technique is accurate for Cer-wool when used to predict the thickness and temperature of a cold face for a one dimensional body experiencing a well defined temperature transient. However, the thermal coefficients must be weighted by time and temperature.

The Schmidt calculational technique has reduced accuracy at temperatures and thicknesses between the hot face and the cold face.

Approximately 13 inches of $8 lb/Ft^3$ Cer-wool will isolate a steel member from the effects of a three (3) hour ASTM fire.

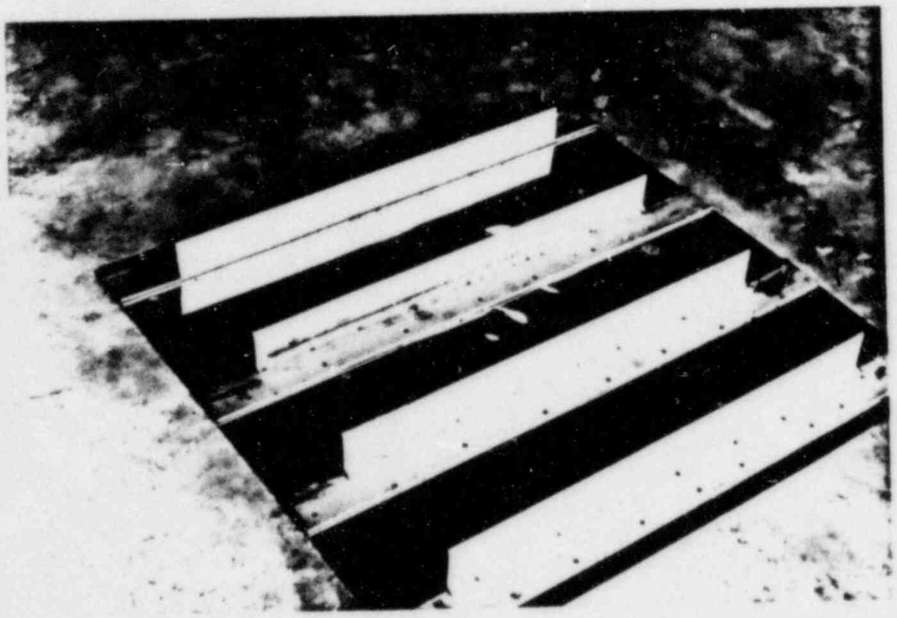


Figure I

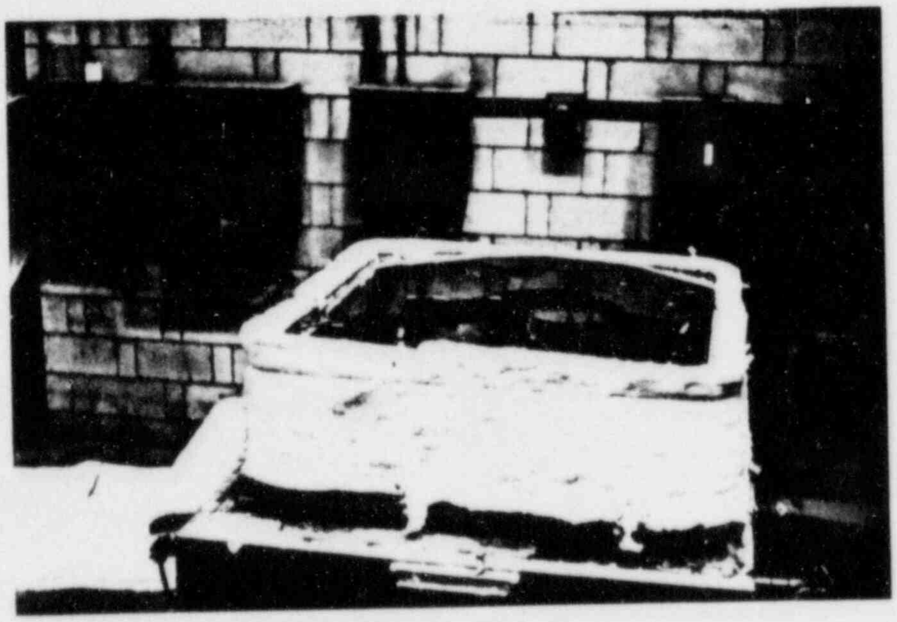


Figure II

Figure III

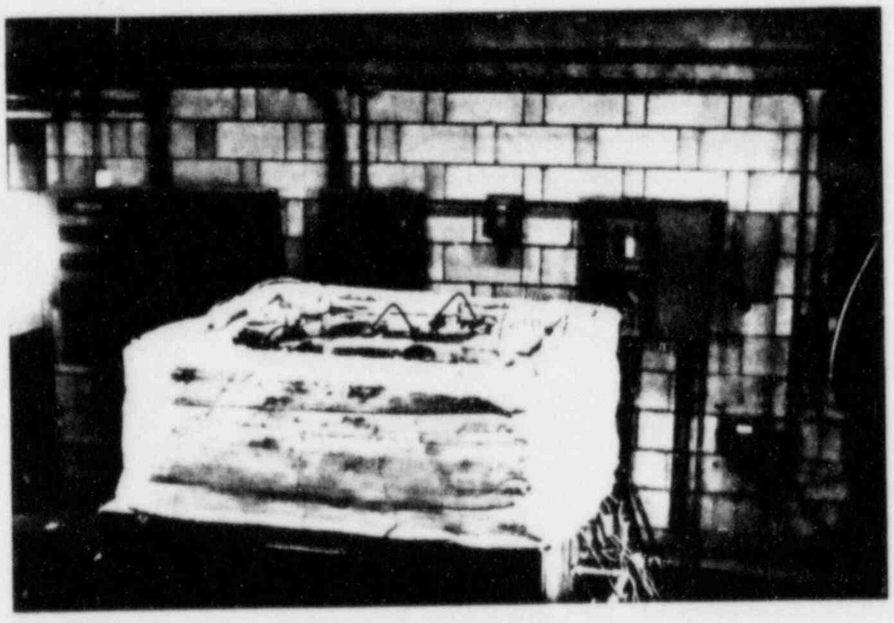


Figure IV

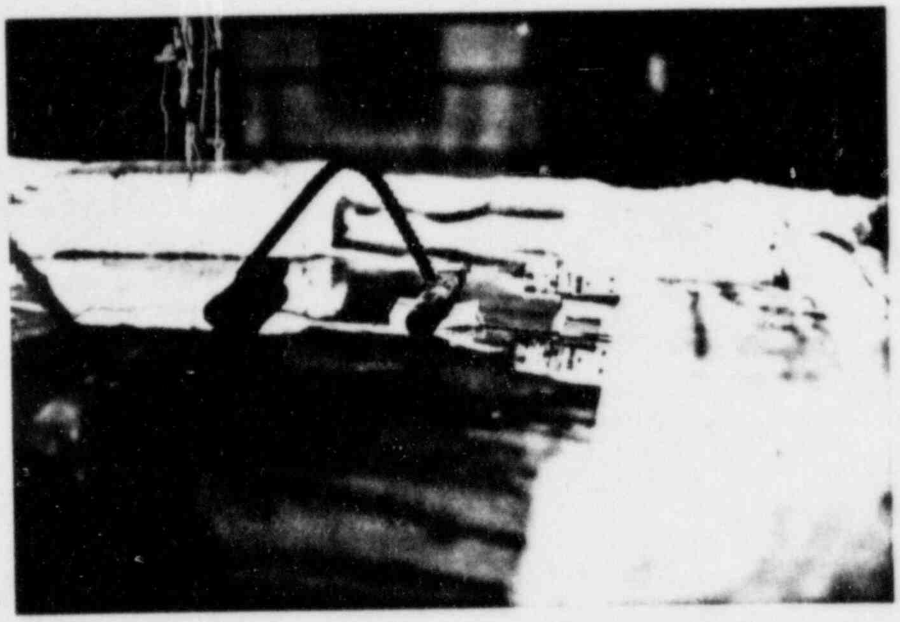


Figure V

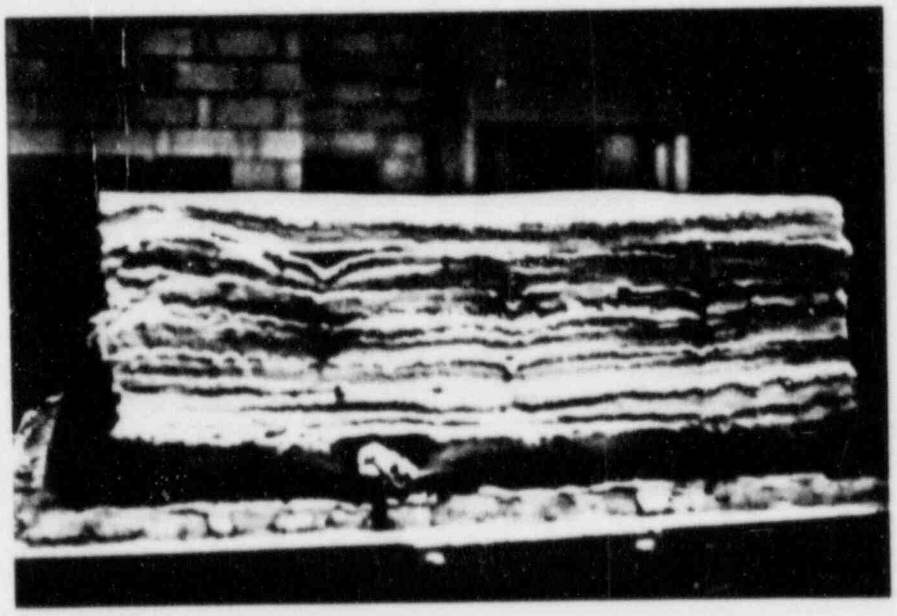


Figure VI

Figure VII

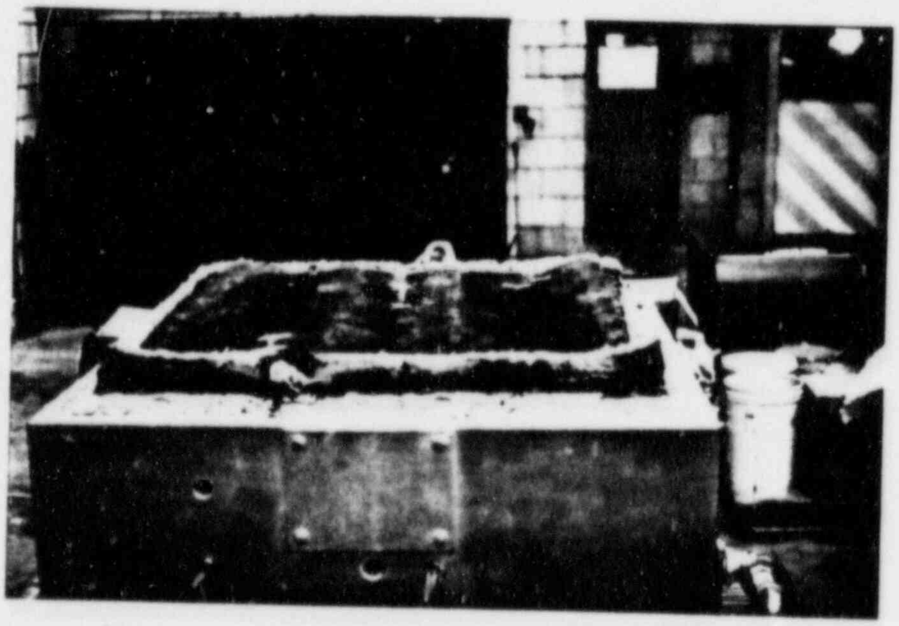


Figure VIII

Figure IX

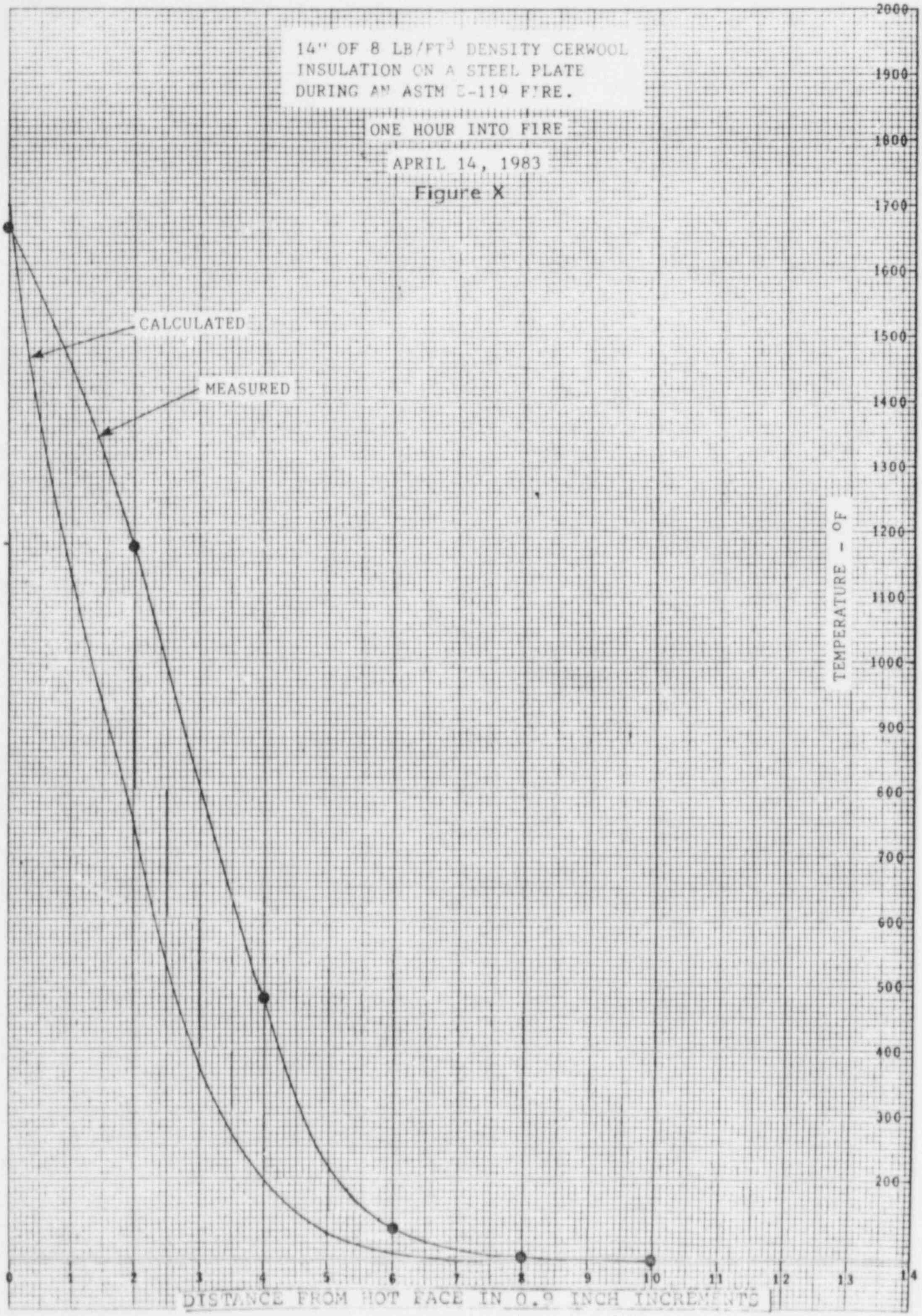

14" OF 8 LB/FT3 DENSITY CERWOOL INSULATION ON A STEEL PLATE DURING AN ASTM E-119 FIRE.
ONE HOUR INTO FIRE
APRIL 14, 1983
CALCULATED
MEASURED
TEMPERATURE - °F
2000
1900
1800
1700
1600
1500
1400
1300
1200
1100
1000
900
800
700
600
500
400
300
200
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
DISTANCE FROM HOT FACE IN 0.9 INCH INCREMENTS

Figure X

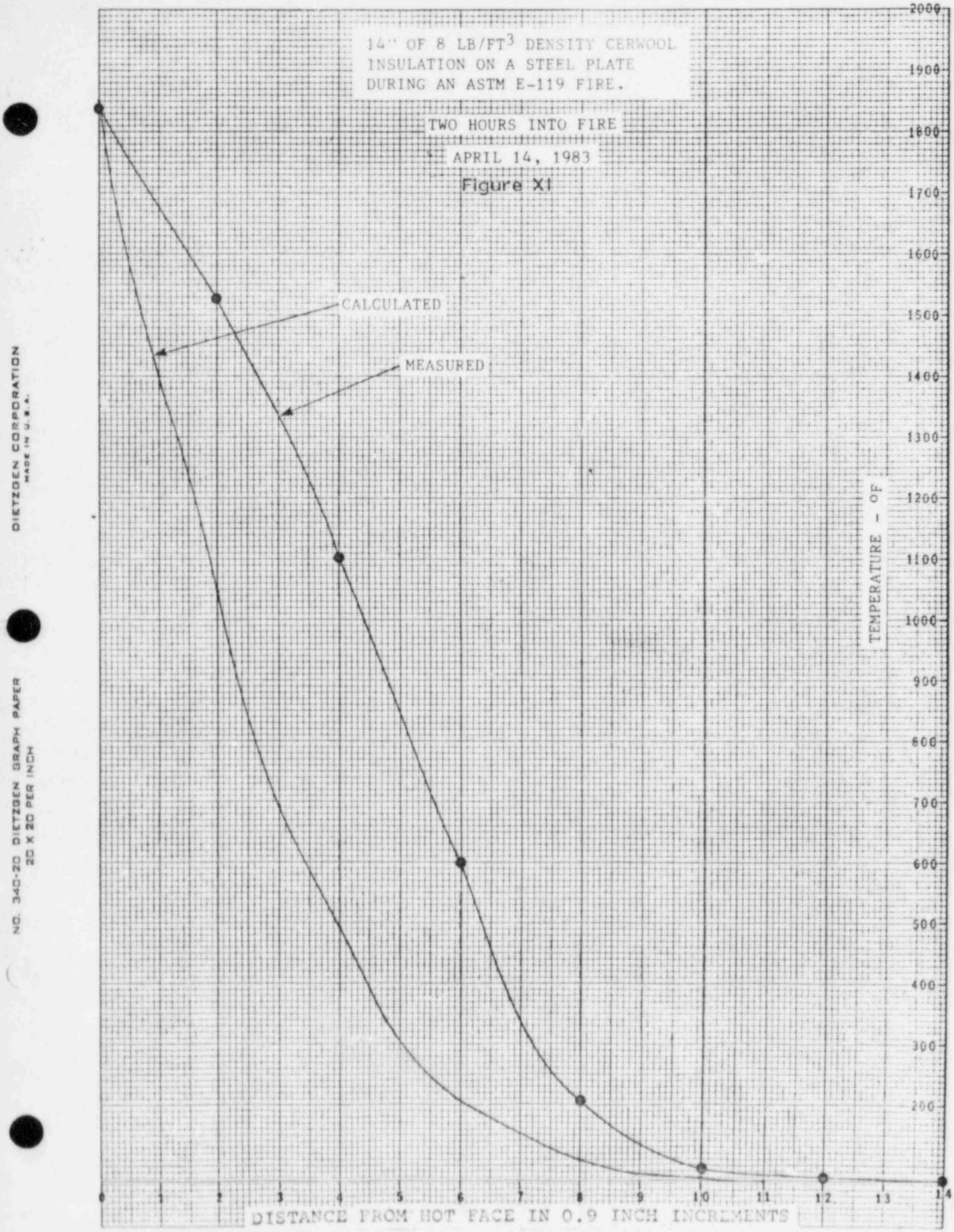

14" OF 8 LB/FT3 DENSITY CERWOOL
INSULATION ON A STEEL PLATE
DURING AN ASTM E-119 FIRE.
TWO HOURS INTO FIRE
APRIL 14, 1983
CALCULATED
MEASURED
TEMPERATURE - °F
DISTANCE FROM HOT FACE IN 0.9 INCH INCREMENTS
NO. 340-20 DIETZGEN GRAPH PAPER
20 X 20 PER INCH
DIETZGEN CORPORATION
MADE IN U.S.A.

Figure XI

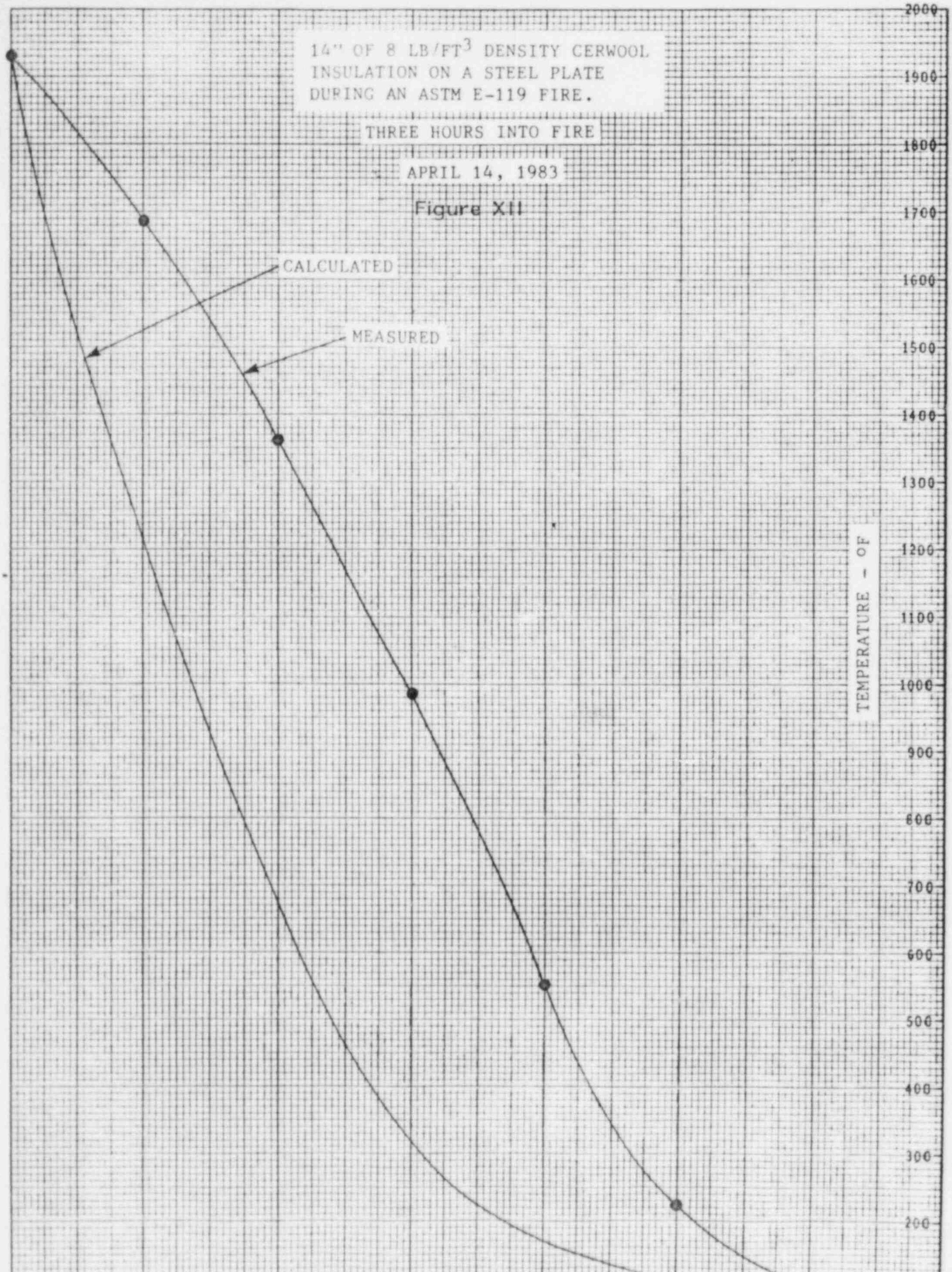

14" OF 8 LB/FT3 DENSITY CERWOOL
INSULATION ON A STEEL PLATE
DURING AN ASTM E-119 FIRE.
THREE HOURS INTO FIRE
APRIL 14, 1983
CALCULATED
MEASURED
TEMPERATURE - OF
DISTANCE FROM HOT FACE IN 0.9 INCH INCREMENTS
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
2000
1900
1800
1700
1600
1500
1400
1300
1200
1100
1000
900
800
700
600
500
400
300
200

Figure XII

# APPENDIX I

## SCHMIDT CALCULATION

For a 14" (Nominal) Thick
Blanket of 8 lb/$Ft^3$
CERWOOL

## TABLUATION

TEST REPORT No. TTR-30N

8LB/Ft² Cerwool, 7-2 Inch
Layers - Schmidt Method for a Three Hour ASTM E-119 Fire

| Plane / Time | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 7 | 10 | 1 | 2 | 3 | 4 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 min. | 75 | 75 | | | | | | | | | | | | | |
| 10 min. | 1300 | 687.5 | 75 | | | | | | | | | | | | |
| 20 min. | 1462 | 687.5 | 381 | 75 | | | | | | | | | | | |
| 30 min. | 1550 | 966 | 381 | 228 | 75 | | | | | | | | | | |
| 40 min. | 1613 | 966 | 597 | 228 | 152 | 75 | | | | | | | | | |
| 50 min. | 1661 | 1129 | 597 | 374 | 152 | 114 | 75 | | | | | | | | |
| 1:00 Hours | 1700 | 1129 | 752 | 374 | 244 | 114 | 94 | 75 | | | | | | | |
| 1:10 min. | 1735 | 1244 | 752 | 498 | 244 | 169 | 94 | 84.5 | 75 | | | | | | |
| 1:20 min. | 1765 | 1244 | 871 | 498 | 333 | 169 | 127 | 84.5 | 80 | 75 | | | | | |
| 1:30 min. | 1792 | 1331 | 871 | 602 | 333 | 230 | 127 | 103.5 | 80 | 77.5 | 75 | | | | |
| 1:40 min. | 1815 | 1331 | 966 | 602 | 416 | 230 | 167 | 103.5 | 90.5 | 77.5 | 76.2 | 75 | | | |
| 1:50 min. | 1835 | 1400 | 966 | 691 | 416 | 292 | 167 | 129 | 90.5 | 83.4 | 76.2 | 75.6 | 75 | | |
| 2:00 Hours | 1850 | 1400 | 1046 | 691 | 492 | 292 | 210 | 129 | 106 | 83.4 | 79.5 | 75.6 | 75.3 | 75 | |
| 2:10 min. | 1862 | 1454 | 1046 | 769 | 492 | 351 | 210 | 158 | 106 | 92.8 | 79.5 | 77.4 | 75.3 | 75.2 | 75 |
| 2:20 min. | 1875 | 1454 | 1112 | 769 | 560 | 351 | 254 | 158 | 125.4 | 92.8 | 85.1 | 77.4 | 76.3 | 75.2 | 75 |
| 2:30 min. | 1888 | 1500 | 1112 | 836 | 560 | 407 | 254 | 190 | 125.4 | 105.2 | 85.1 | 80.7 | 76.3 | 75.8 | 75.2 |
| 2:40 min. | 1900 | 1500 | 1168 | 836 | 621.5 | 407 | 298.5 | 190 | 147.6 | 105.2 | 93.0 | 80.7 | 78.2 | 75.8 | 75.2 |
| 2:50 min. | 1912 | 1540 | 1168 | 895 | 621.5 | 460 | 298.5 | 223 | 147.6 | 120.3 | 93.0 | 85.6 | 78.2 | 77 | 75.8 |
| 3:00 min. | 1925 | 1540 | 1217 | 895 | 678 | 460 | 342 | 223 | 172 | 120.3 | 103 | 85.6 | 81.3 | 77 | 77 |
| | 31440 | 22503 | 15003 | 9786 | 6315 | 4046 | 2643 | 1776 | 1271 | 958.4 | 770.6 | 638.6 | 540.8 | 456 | 378.2 |
| | 18 | 18 | 17 | 16 | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 |

$$(L)^2 = \frac{2\ K\Delta t}{C_p\ p}$$

$$L^2 = \frac{(2)\ (0.36)\ (10\ \text{min.})}{(0.212)(60)(8)(12)}$$

Lx = 0.07678 ft.

L = 0,9214 inch

nL = 14 x 0.9214 inches = 12.9 inches total thickness

$$\frac{98{,}525.6}{179} = 550.4$$

k = 0.36

$C_p$ = 0212

# APPENDIX II

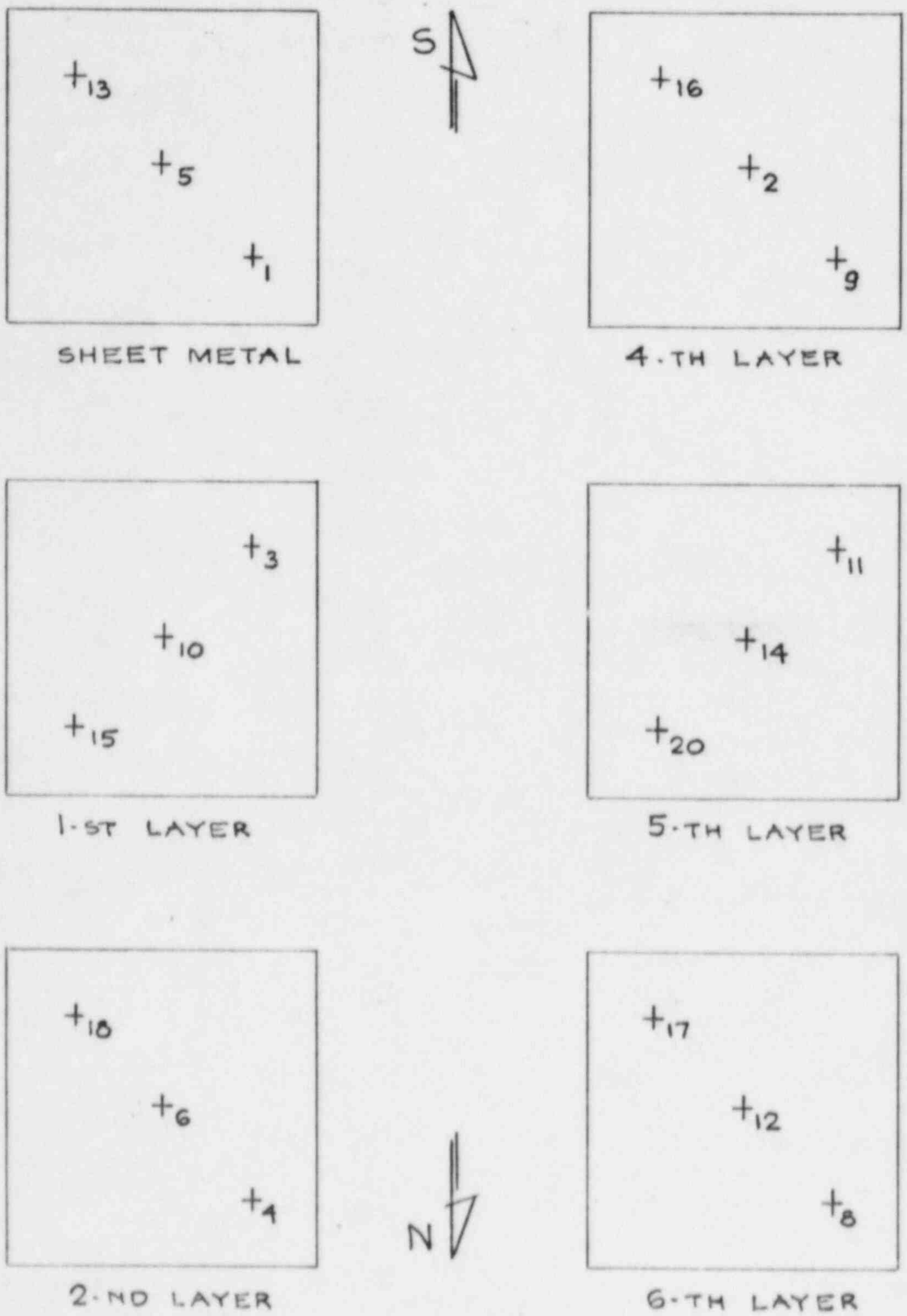
## CONSTRUCTION TECHNOLOGY LABORATORIES, FIRE RESEARCH DEPARTMENT

## TEST DATA

CONSTRUCTION TECHNOLOGY LABORATORIES
A Division of the PORTLAND CEMENT ASSOCIATION
5420 Old Orchard Road, Skokie, Illinois 60077 / Area Code 312/966-6200

Project CR5163 Sheet 1 of ____
Initials R. N Date 04-14-83
Checked ____ Date ____ Revised ____ Date ____

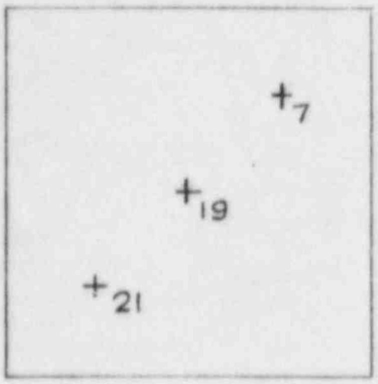
Title TRANSCO




3-RD LAYER NEXT PAGE W/ TOP SHEET METAL

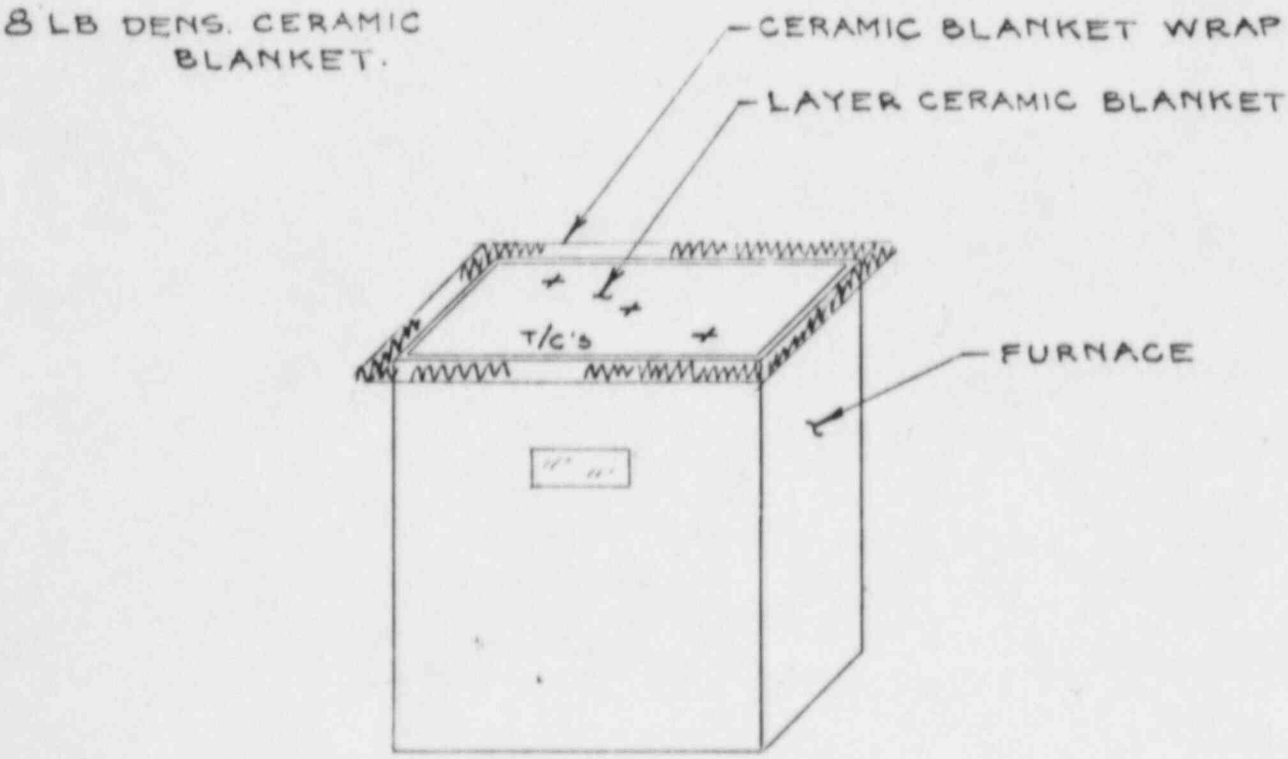
Project CR5163 Sheet 2 of 2
Initials ____ Date ____
Checked ____ Date ____ Revised ____ Date ____

Title TRANSCO




3-RD LAYER


TOP SHEET METAL COVER



TRANSCO (CR5163) - 04/14/83

THERMOCOUPLE REFERENCE CHART

| FRAME NO. | PRINT NO. | THERMOCOUPLE NO. | THERMOCOUPLE LOCATION |
|---|---|---|---|
| 11 | 1 | 1 | 1ST LAYER SHEET METAL W 1/4 PT |
| 11 | 2 | 2 | 4TH LAYER BLANKET CENTER |
| 11 | 3 | 3 | 1ST LAYER BLANKET W 1/4 PT (S) |
| 11 | 4 | 4 | 2ND LAYER BLANKET W 1/4 PT (N) |
| 11 | 5 | 5 | 1ST LAYER SHEET METAL CENTER |
| 11 | 6 | 6 | 2ND LAYER BLANKET CENTER |
| 11 | 7 | 7 | 3RD LAYER BLANKET W 1/4 PT (S) |
| 11 | 8 | 8 | 6TH LAYER BLANKET W 1/4 PT (N) |
| 11 | 9 | 9 | 4TH LAYER BLANKET W 1/4 PT (N) |
| 11 | 10 | 10 | 1ST LAYER BLANKET CENTER |
| 11 | 11 | 11 | 5TH LAYER BLANKET W 1/4 PT (N) |
| 11 | 12 | 12 | 6TH LAYER BLANKET CENTER |
| 12 | 1 | 13 | 1ST LAYER SHEET METAL E 1/4 PT |
| 12 | 2 | 14 | 5TH LAYER BLANKET CENTER |
| 12 | 3 | 15 | 2ND LAYER BLANKET E 1/4 PT (S) |
| 12 | 4 | 16 | 4TH LAYER BLANKET E 1/4 PT (S) |
| 12 | 5 | 17 | 6TH LAYER BLANKET E 1/4 PT (S) |
| 12 | 6 | 18 | 2ND LAYER BLANKET E 1/4 PT (S) |
| 12 | 7 | 19 | 3RD LAYER BLANKET CENTER |
| 12 | 8 | 20 | 5TH LAYER BLANKET E 1/4 PT (N) |
| 12 | 9 | 21 | 3RD LAYER BLANKET E 1/4 PT (N) |
| 12 | 10 | 22 | TOP SHEET METAL COVER E 1/4 PT |
| 12 | 11 | 23 | TOP SHEET METAL COVER CENTER |
| 12 | 12 | 24 | TOP SHEET METAL COVER W 1/4 PT |

TRANSCO (CR5163) - 04/14/83

FURNACE ATMOSPHERE TEMPERATURE (DEG. F)

| TEST TIME, Hr:Min | FURNACE TEMP. F | ASTM E119 TEMP. F | VARIATION FROM ASTM TEMP. F |
|---|---|---|---|
| 0:00 | 79 | 68 | 11 |
| 0:05 | 1023 | 1000 | 23 |
| 0:10 | 1258 | 1300 | -42 |
| 0:15 | 1395 | 1399 | -4 |
| 0:20 | 1471 | 1462 | 9 |
| 0:25 | 1509 | 1510 | -1 |
| 0:30 | 1550 | 1550 | 0 |
| 0:35 | 1587 | 1584 | 3 |
| 0:40 | 1617 | 1613 | 4 |
| 0:45 | 1633 | 1638 | -5 |
| 0:50 | 1662 | 1661 | 1 |
| 0:55 | 1684 | 1681 | 3 |
| 1:00 | 1689 | 1700 | -11 |
| 1:05 | 1718 | 1718 | 0 |
| 1:10 | 1738 | 1735 | 3 |
| 1:15 | 1753 | 1750 | 3 |
| 1:20 | 1769 | 1765 | 4 |
| 1:25 | 1775 | 1779 | -4 |
| 1:30 | 1791 | 1792 | -1 |
| 1:35 | 1807 | 1804 | 3 |
| 1:40 | 1815 | 1815 | -0 |
| 1:45 | 1831 | 1826 | 5 |
| 1:50 | 1840 | 1835 | 5 |
| 1:55 | 1842 | 1843 | -1 |
| 2:00 | 1848 | 1850 | -2 |
| 2:10 | 1867 | 1862 | 5 |
| 2:20 | 1874 | 1875 | -1 |
| 2:30 | 1885 | 1888 | -3 |
| 2:40 | 1905 | 1900 | 5 |
| 2:50 | 1914 | 1912 | 2 |
| 3:00 | 1930 | 1925 | 5 |
| 3:10 | 1166 | 1938 | -772 |
| 3:20 | 903 | 1950 | -1047 |

TRANSCO (CR5163) - 04/14/83

T/C TEMP. (DEG. F.)

| TEST TIME, Hr:Min | T/C NO. 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|
| 0:00 | 93 | 78 | 78 | 78 | 104 | 78 |
| 0:05 | 932 | 77 | 79 | 77 | 953 | 77 |
| 0:10 | 1203 | 77 | 140 | 78 | 1197 | 77 |
| 0:15 | 1316 | 77 | 260 | 78 | 1350 | 77 |
| 0:20 | 1392 | 77 | 409 | 79 | 1430 | 79 |
| 0:25 | 1437 | 77 | 555 | 86 | 1476 | 86 |
| 0:30 | 1492 | 77 | 757 | 102 | 1533 | 105 |
| 0:35 | 1538 | 78 | 1061 | 130 | 1570 | 142 |
| 0:40 | 1570 | 78 | 994 | 169 | 1599 | 208 |
| 0:45 | 1594 | 78 | 1018 | 219 | 1620 | 282 |
| 0:50 | 1623 | 78 | 1059 | 276 | 1649 | 357 |
| 0:55 | 1648 | 78 | 1104 | 337 | 1676 | 432 |
| 1:00 | 1653 | 79 | 1146 | 401 | 1683 | 507 |
| 1:05 | 1687 | 80 | 1185 | 468 | 1715 | 589 |
| 1:10 | 1707 | 83 | 1225 | 540 | 1735 | 693 |
| 1:15 | 1726 | 86 | 1262 | 631 | 1755 | 824 |
| 1:20 | 1743 | 90 | 1297 | 754 | 1769 | 972 |
| 1:25 | 1750 | 95 | 1329 | 932 | 1776 | 972 |
| 1:30 | 1765 | 102 | 1358 | 940 | 1790 | 961 |
| 1:35 | 1781 | 114 | 1387 | 907 | 1807 | 982 |
| 1:40 | 1793 | 128 | 1413 | 918 | 1818 | 1012 |
| 1:45 | 1805 | 145 | 1436 | 940 | 1832 | 1044 |
| 1:50 | 1817 | 164 | 1460 | 967 | 1844 | 1078 |
| 1:55 | 1818 | 185 | 1482 | 996 | 1846 | 1112 |
| 2:00 | 1827 | 208 | 1500 | 1025 | 1855 | 1149 |
| 2:10 | 1843 | 262 | 1534 | 1080 | 1873 | 1210 |
| 2:20 | 1852 | 325 | 1568 | 1130 | 1883 | 1265 |
| 2:30 | 1862 | 392 | 1598 | 1175 | 1894 | 1305 |
| 2:40 | 1884 | 458 | 1624 | 1216 | 1917 | 1340 |
| 2:50 | 1893 | 526 | 1648 | 1255 | 1927 | 1376 |
| 3:00 | 1909 | 597 | 1668 | 1291 | 1944 | 1410 |
| 3:10 | 1145 | 677 | 1507 | 1310 | 1186 | 1425 |
| 3:20 | 924 | 753 | 1323 | 1260 | 961 | 1360 |

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T/C TEMP. (DEG. F.)

| TEST TIME, Hr:Min | T/C NO. | | | | | |
|---|---|---|---|---|---|---|
| | 7 | 8 | 9 | 10 | 11 | 12 |
| 0:00 | 78 | 79 | 78 | 78 | 79 | 79 |
| 0:05 | 77 | 77 | 77 | 82 | 77 | 0 |
| 0:10 | 77 | 77 | 77 | 104 | 77 | 77 |
| 0:15 | 77 | 77 | 77 | 203 | 77 | 77 |
| 0:20 | 77 | 77 | 77 | 376 | 77 | 77 |
| 0:25 | 77 | 77 | 77 | 557 | 77 | 77 |
| 0:30 | 78 | 77 | 77 | 822 | 77 | 77 |
| 0:35 | 81 | 77 | 77 | 982 | 77 | 77 |
| 0:40 | 81 | 77 | 77 | 980 | 77 | 77 |
| 0:45 | 86 | 77 | 77 | 1029 | 77 | 78 |
| 0:50 | 96 | 77 | 77 | 1082 | 77 | 77 |
| 0:55 | 111 | 77 | 78 | 1134 | 77 | 77 |
| 1:00 | 130 | 77 | 78 | 1182 | 77 | 77 |
| 1:05 | 153 | 77 | 79 | 1226 | 77 | 77 |
| 1:10 | 180 | 77 | 80 | 1281 | 77 | 78 |
| 1:15 | 210 | 77 | 83 | 1336 | 78 | 78 |
| 1:20 | 244 | 78 | 86 | 1377 | 78 | 79 |
| 1:25 | 279 | 77 | 90 | 1406 | 79 | 78 |
| 1:30 | 317 | 78 | 94 | 1430 | 79 | 79 |
| 1:35 | 356 | 78 | 100 | 1453 | 80 | 79 |
| 1:40 | 397 | 78 | 110 | 1475 | 82 | 79 |
| 1:45 | 437 | 78 | 122 | 1496 | 83 | 80 |
| 1:50 | 479 | 78 | 134 | 1517 | 86 | 80 |
| 1:55 | 523 | 78 | 149 | 1539 | 89 | 80 |
| 2:00 | 569 | 78 | 165 | 1557 | 93 | 80 |
| 2:10 | 667 | 79 | 201 | 1589 | 103 | 81 |
| 2:20 | 765 | 80 | 241 | 1619 | 118 | 82 |
| 2:30 | 949 | 81 | 286 | 1641 | 136 | 84 |
| 2:40 | 900 | 83 | 333 | 1664 | 160 | 88 |
| 2:50 | 925 | 86 | 382 | 1687 | 189 | 96 |
| 3:00 | 965 | 91 | 432 | 1708 | 224 | 106 |
| 3:10 | 1004 | 96 | 485 | 1551 | 260 | 117 |
| 3:20 | 1024 | 104 | 542 | 1366 | 299 | 132 |

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T/C TEMP. (DEG. F.)

| TEST TIME, Hr:Min | T/C NO. 13 | 14 | 15 | 16 | 17 | 18 |
|---|---|---|---|---|---|---|
| 0:00 | 92 | 78 | 78 | 78 | 79 | 78 |
| 0:05 | 976 | 77 | 78 | 77 | 77 | 78 |
| 0:10 | 1165 | 77 | 141 | 77 | 77 | 77 |
| 0:15 | 1302 | 77 | 286 | 77 | 77 | 80 |
| 0:20 | 1398 | 77 | 463 | 77 | 77 | 83 |
| 0:25 | 1450 | 77 | 630 | 77 | 77 | 98 |
| 0:30 | 1505 | 77 | 853 | 77 | 77 | 128 |
| 0:35 | 1553 | 77 | 991 | 77 | 77 | 175 |
| 0:40 | 1587 | 77 | 1020 | 77 | 77 | 233 |
| 0:45 | 1610 | 77 | 1068 | 77 | 77 | 302 |
| 0:50 | 1637 | 77 | 1117 | 78 | 77 | 375 |
| 0:55 | 1660 | 77 | 1164 | 79 | 77 | 450 |
| 1:00 | 1666 | 77 | 1204 | 80 | 77 | 529 |
| 1:05 | 1701 | 77 | 1241 | 83 | 77 | 619 |
| 1:10 | 1722 | 78 | 1278 | 87 | 77 | 732 |
| 1:15 | 1743 | 78 | 1312 | 92 | 78 | 885 |
| 1:20 | 1758 | 79 | 1344 | 98 | 78 | 927 |
| 1:25 | 1764 | 80 | 1372 | 107 | 78 | 920 |
| 1:30 | 1776 | 81 | 1398 | 120 | 79 | 944 |
| 1:35 | 1795 | 81 | 1424 | 135 | 79 | 974 |
| 1:40 | 1805 | 82 | 1447 | 153 | 79 | 1007 |
| 1:45 | 1817 | 83 | 1469 | 174 | 79 | 1040 |
| 1:50 | 1829 | 85 | 1491 | 197 | 80 | 1071 |
| 1:55 | 1830 | 88 | 1510 | 222 | 80 | 1101 |
| 2:00 | 1836 | 92 | 1526 | 248 | 80 | 1131 |
| 2:10 | 1854 | 104 | 1557 | 304 | 81 | 1182 |
| 2:20 | 1861 | 120 | 1590 | 363 | 82 | 1229 |
| 2:30 | 0 | 142 | 1618 | 424 | 85 | 1271 |
| 2:40 | 0 | 169 | 1643 | 487 | 90 | 1309 |
| 2:50 | 0 | 202 | 1661 | 553 | 97 | 1346 |
| 3:00 | 0 | 239 | 1683 | 623 | 106 | 1381 |
| 3:10 | 33 | 280 | 497 | 699 | 118 | 1394 |
| 3:20 | 794 | 323 | 0 | 770 | 132 | 1324 |

TRANSCO (CR5163) - 04/14/83

T/C TEMP. (DEG. F.)

| TEST TIME, Hr:Min | T/C NO. | | | | | |
|---|---|---|---|---|---|---|
| | 19 | 20 | 21 | 22 | 23 | 24 |
| 0:00 | 78 | 79 | 78 | 79 | 79 | 80 |
| 0:05 | 76 | 77 | 76 | 78 | 78 | 78 |
| 0:10 | 77 | 77 | 76 | 78 | 78 | 78 |
| 0:15 | 77 | 77 | 77 | 78 | 77 | 78 |
| 0:20 | 77 | 77 | 76 | 78 | 77 | 78 |
| 0:25 | 77 | 77 | 77 | 77 | 77 | 78 |
| 0:30 | 77 | 77 | 79 | 77 | 77 | 78 |
| 0:35 | 79 | 77 | 80 | 77 | 77 | 78 |
| 0:40 | 80 | 77 | 80 | 77 | 77 | 78 |
| 0:45 | 84 | 77 | 84 | 77 | 77 | 78 |
| 0:50 | 92 | 77 | 90 | 77 | 77 | 77 |
| 0:55 | 105 | 77 | 101 | 77 | 77 | 77 |
| 1:00 | 123 | 77 | 117 | 77 | 77 | 77 |
| 1:05 | 147 | 77 | 138 | 77 | 77 | 78 |
| 1:10 | 176 | 77 | 162 | 77 | 77 | 77 |
| 1:15 | 212 | 78 | 190 | 77 | 77 | 77 |
| 1:20 | 255 | 78 | 222 | 77 | 77 | 78 |
| 1:25 | 306 | 79 | 256 | 77 | 77 | 78 |
| 1:30 | 359 | 79 | 292 | 77 | 77 | 77 |
| 1:35 | 409 | 80 | 330 | 77 | 77 | 77 |
| 1:40 | 458 | 81 | 369 | 77 | 77 | 78 |
| 1:45 | 507 | 82 | 408 | 77 | 77 | 78 |
| 1:50 | 561 | 84 | 450 | 77 | 77 | 78 |
| 1:55 | 618 | 86 | 493 | 78 | 77 | 78 |
| 2:00 | 686 | 89 | 543 | 78 | 77 | 78 |
| 2:10 | 828 | 98 | 652 | 78 | 77 | 78 |
| 2:20 | 906 | 109 | 767 | 78 | 77 | 78 |
| 2:30 | 905 | 124 | 955 | 78 | 78 | 78 |
| 2:40 | 947 | 145 | 890 | 78 | 78 | 78 |
| 2:50 | 994 | 172 | 913 | 79 | 78 | 79 |
| 3:00 | 1043 | 204 | 947 | 79 | 78 | 79 |
| 3:10 | 1093 | 236 | 985 | 79 | 78 | 80 |
| 3:20 | 1116 | 271 | 1005 | 80 | 79 | 81 |

INDEX= 2

| FRAME NO. | PRINT NO. | T/C NO. | TEMPERATURE, DEG. F | TEMPERATURE INCR., DEG. F | TIME INCR., MINUTES |
|---|---|---|---|---|---|
| 11 | 1 | 1 | 93.2 | 93.2 | 0 |
| 11 | 2 | 2 | 78.3 | 78.3 | 0 |
| 11 | 3 | 3 | 78.1 | 7[illegible].1 | 0 |
| 11 | 4 | 4 | 78.2 | 78.2 | 0 |
| 11 | 5 | 5 | 103.7 | 103.7 | 0 |
| 11 | 6 | 6 | 78.1 | 78.1 | 0 |
| 11 | 7 | 7 | 78.3 | 78.3 | 0 |
| 11 | 8 | 8 | 78.9 | 78.9 | 0 |
| 11 | 9 | 9 | 78.4 | 78.4 | 0 |
| 11 | 10 | 10 | 78.0 | 78.0 | 0 |
| 11 | 11 | 11 | 78.6 | 78.6 | 0 |
| 11 | 12 | 12 | 78.8 | 78.8 | 0 |
| 12 | 1 | 13 | 92.5 | 92.5 | 0 |
| 12 | 2 | 14 | 78.4 | 78.4 | 0 |
| 12 | 3 | 15 | 78.0 | 78.0 | 0 |
| 12 | 4 | 16 | 78.3 | 78.3 | 0 |
| 12 | 5 | 17 | 78.8 | 78.8 | 0 |
| 12 | 6 | 18 | 78.1 | 78.1 | 0 |
| 12 | 7 | 19 | 78.1 | 78.1 | 0 |
| 12 | 8 | 20 | 78.5 | 78.5 | 0 |
| 12 | 9 | 21 | 78.1 | 78.1 | 0 |
| 12 | 10 | 22 | 79.5 | 79.5 | 0 |
| 12 | 11 | 23 | 79.5 | 79.5 | 0 |
| 12 | 12 | 24 | 79.6 | 79.6 | 0 |

TEST TIME: 0:00:00
FURNACE ATMOSPHERE TEMPERATURE: 78.7 DEG. F
ASTM TEMPERATURE: 68 DEG. F
DIFFERENCE: 10.7 DEG. F

AVG TEMP. OF T/C 1-5-13= 96 F
AVG TEMP. OF T/C 3-10-15= 78 F
AVG TEMP. OF T/C 4-6-18= 78 F
AVG TEMP. OF T/C 7-19-21= 78 F
AVG TEMP. OF T/C 9-2-16= 78 F
AVG TEMP. OF T/C 11-14-20= 79 F
AVG TEMP. OF T/C 8-12-17= 79 F
AVG TEMP. OF T/C 22-23-24= 80 F

INDEX= 3

| FRAME NO. | PRINT NO. | T/C NO. | TEMPERATURE, DEG. F | TEMPERATURE INCR., DEG. F | TIME INCR., MINUTES |
|---|---|---|---|---|---|
| 11 | 1 | 1 | 931.7 | 838.5 | 5 |
| 11 | 2 | 2 | 76.7 | -1.6 | 5 |
| 11 | 3 | 3 | 79.1 | 1.1 | 5 |
| 11 | 4 | 4 | 77.1 | -1.1 | 5 |
| 11 | 5 | 5 | 953.0 | 849.3 | 5 |
| 11 | 6 | 6 | 76.7 | -1.4 | 5 |
| 11 | 7 | 7 | 76.7 | -1.6 | 5 |
| 11 | 8 | 8 | 77:3 | -1.6 | 5 |
| 11 | 9 | 9 | 76.8 | -1.6 | 5 |
| 11 | 10 | 10 | 82.4 | 4.5 | 5 |
| 11 | 11 | 11 | 77.0 | -1.6 | 5 |
| 11 | 12 | 12 | 0.0 | -78.8 | 5 |
| 12 | 1 | 13 | 975.6 | 883.1 | 5 |
| 12 | 2 | 14 | 76.7 | -1.7 | 5 |
| 12 | 3 | 15 | 78.1 | .1 | 5 |
| 12 | 4 | 16 | 76.7 | -1.6 | 5 |
| 12 | 5 | 17 | 77.0 | -1.8 | 5 |
| 12 | 6 | 18 | 77.7 | -.4 | 5 |
| 12 | 7 | 19 | 76.4 | -1.7 | 5 |
| 12 | 8 | 20 | 76.9 | -1.6 | 5 |
| 12 | 9 | 21 | 76.4 | -1.7 | 5 |
| 12 | 10 | 22 | 77.7 | -1.8 | 5 |
| 12 | 11 | 23 | 77.6 | -1.9 | 5 |
| 12 | 12 | 24 | 77.8 | -1.8 | 5 |

TEST TIME: 0:05:00
FURNACE ATMOSPHERE TEMPERATURE: 1023.5 DEG. F
ASTM TEMPERATURE: 1000 DEG. F
DIFFERENCE: 23.5 DEG. F

AVG TEMP. OF T/C 1-5-13= 953 F
AVG TEMP. OF T/C 3-10-15= 80 F
AVG TEMP. OF T/C 4-6-18= 77 F
AVG TEMP. OF T/C 7-19-21= 77 F
AVG TEMP. OF T/C 9-2-16= 77 F
AVG TEMP. OF T/C 11-14-20= 77 F
AVG TEMP. OF T/C 8-12-17= 77 F
AVG TEMP. OF T/C 22-23-24= 73 F

INDEX= 4

| FRAME NO. | PRINT NO. | T/C NO. | TEMPERATURE, DEG. F | TEMPERATURE INCR., DEG. F | TIME INCR., MINUTES |
|---|---|---|---|---|---|
| 11 | 1 | 1 | 1202.8 | 271.1 | 5 |
| 11 | 2 | 2 | 77.0 | .3 | 5 |
| 11 | 3 | 3 | 140.1 | 61.0 | 5 |
| 11 | 4 | 4 | 77.8 | .7 | 5 |
| 11 | 5 | 5 | 1196.8 | 243.8 | 5 |
| 11 | 6 | 6 | 77.2 | .5 | 5 |
| 11 | 7 | 7 | 76.8 | .1 | 5 |
| 11 | 8 | 8 | 77.3 | -.0 | 5 |
| 11 | 9 | 9 | 77.0 | .3 | 5 |
| 11 | 10 | 10 | 103.8 | 21.3 | 5 |
| 11 | 11 | 11 | 77.1 | .1 | 5 |
| 11 | 12 | 12 | 77.2 | 77.2 | 5 |
| 12 | 1 | 13 | 1165.3 | 189.7 | 5 |
| 12 | 2 | 14 | 76.8 | .1 | 5 |
| 12 | 3 | 15 | 141.3 | 63.2 | 5 |
| 12 | 4 | 16 | 76.7 | .0 | 5 |
| 12 | 5 | 17 | 77.1 | .1 | 5 |
| 12 | 6 | 18 | 77.3 | -.4 | 5 |
| 12 | 7 | 19 | 76.6 | .2 | 5 |
| 12 | 8 | 20 | 76.9 | -.0 | 5 |
| 12 | 9 | 21 | 76.5 | .0 | 5 |
| 12 | 10 | 22 | 77.7 | -.0 | 5 |
| 12 | 11 | 23 | 77.6 | -.0 | 5 |
| 12 | 12 | 24 | 77.8 | -.0 | 5 |

TEST TIME: 0:10:00
FURNACE ATMOSPHERE TEMPERATURE: 1258.5 DEG. F
ASTM TEMPERATURE: 1300 DEG. F
DIFFERENCE: -41.5 DEG. F

AVG TEMP. OF T/C 1-5-13= 1188 F
AVG TEMP. OF T/C 3-10-15= 128 F
AVG TEMP. OF T/C 4-6-18= 77 F
AVG TEMP. OF T/C 7-19-21= 77 F
AVG TEMP. OF T/C 9-2-16= 77 F
AVG TEMP. OF T/C 11-14-20= 77 F
AVG TEMP. OF T/C 8-12-17= 77 F
AVG TEMP. OF T/C 22-23-24= 78 F

INDEX= 5

| FRAME NO. | PRINT NO. | T/C NO. | TEMPERATURE, DEG. F | TEMPERATURE INCR., DEG. F | TIME INCR., MINUTES |
|---|---|---|---|---|---|
| 11 | 1 | 1 | 1315.6 | 112.8 | 5 |
| 11 | 2 | 2 | 77.2 | .2 | 5 |
| 11 | 3 | 3 | 259.6 | 119.5 | 5 |
| 11 | 4 | 4 | 77.5 | -.3 | 5 |
| 11 | 5 | 5 | 1350.1 | 153.3 | 5 |
| 11 | 6 | 6 | 77.5 | .3 | 5 |
| 11 | 7 | 7 | 76.9 | .1 | 5 |
| 11 | 8 | 8 | 77.4 | .1 | 5 |
| 11 | 9 | 9 | 77.0 | -.0 | 5 |
| 11 | 10 | 10 | 203.1 | 99.3 | 5 |
| 11 | 11 | 11 | 77.1 | -.0 | 5 |
| 11 | 12 | 12 | 77.0 | -.1 | 5 |
| 12 | 1 | 13 | 1302.4 | 137.1 | 5 |
| 12 | 2 | 14 | 76.9 | .1 | 5 |
| 12 | 3 | 15 | 286.2 | 144.8 | 5 |
| 12 | 4 | 16 | 76.8 | .1 | 5 |
| 12 | 5 | 17 | 77.1 | .0 | 5 |
| 12 | 6 | 18 | 79.8 | 2.5 | 5 |
| 12 | 7 | 19 | 76.6 | .0 | 5 |
| 12 | 8 | 20 | 76.9 | .1 | 5 |
| 12 | 9 | 21 | 76.6 | .1 | 5 |
| 12 | 10 | 22 | 77.7 | -.0 | 5 |
| 12 | 11 | 23 | 77.5 | -.1 | 5 |
| 12 | 12 | 24 | 77.8 | .0 | 5 |

TEST TIME: 0:15:00
FURNACE ATMOSPHERE TEMPERATURE: 1395.2 DEG. F
ASTM TEMPERATURE: 1399 DEG. F
DIFFERENCE: -3.8 DEG. F

AVG TEMP. OF T/C 1-5-13= 1323 F
AVG TEMP. OF T/C 3-10-15= 250 F
AVG TEMP. OF T/C 4-6-18= 78 F
AVG TEMP. OF T/C 7-19-21= 77 F
AVG TEMP. OF T/C 9-2-16= 77 F
AVG TEMP. OF T/C 11-14-20= 77 F
AVG TEMP. OF T/C 8-12-17= 77 F
AVG TEMP. OF T/C 22-23-24= 78 F

INDEX= 6

| FRAME NO. | PRINT NO. | T/C NO. | TEMPERATURE, DEG. F | TEMPERATURE INCR., DEG. F | TIME INCR., MINUTES |
|---|---|---|---|---|---|
| 11 | 1 | 1 | 1392.0 | 76.4 | 5 |
| 11 | 2 | 2 | 77.3 | .0 | 5 |
| 11 | 3 | 3 | 409.3 | 149.7 | 5 |
| 11 | 4 | 4 | 79.1 | 1.6 | 5 |
| 11 | 5 | 5 | 1430.1 | 80.0 | 5 |
| 11 | 6 | 6 | 78.8 | 1.3 | 5 |
| 11 | 7 | 7 | 77.0 | .0 | 5 |
| 11 | 8 | 8 | 77.3 | -.1 | 5 |
| 11 | 9 | 9 | 76.9 | -.1 | 5 |
| 11 | 10 | 10 | 376.5 | 173.4 | 5 |
| 11 | 11 | 11 | 77.1 | .0 | 5 |
| 11 | 12 | 12 | 77.1 | .1 | 5 |
| 12 | 1 | 13 | 1397.8 | 95.4 | 5 |
| 12 | 2 | 14 | 76.9 | -.0 | 5 |
| 12 | 3 | 15 | 463.2 | 177.1 | 5 |
| 12 | 4 | 16 | 76.9 | .1 | 5 |
| 12 | 5 | 17 | 77.0 | -.1 | 5 |
| 12 | 6 | 18 | 83.1 | 3.3 | 5 |
| 12 | 7 | 19 | 76.6 | -.1 | 5 |
| 12 | 8 | 20 | 76.8 | -.1 | 5 |
| 12 | 9 | 21 | 76.5 | -.1 | 5 |
| 12 | 10 | 22 | 77.5 | -.1 | 5 |
| 12 | 11 | 23 | 77.3 | -.2 | 5 |
| 12 | 12 | 24 | 77.6 | -.2 | 5 |

TEST TIME: 0:20:00
FURNACE ATMOSPHERE TEMPERATURE: 1470.6 DEG. F
ASTM TEMPERATURE: 1462 DEG. F
DIFFERENCE: 8.6 DEG. F

AVG TEMP. OF T/C 1-5-13= 1407 F
AVG TEMP. OF T/C 3-10-15= 416 F
AVG TEMP. OF T/C 4-6-18= 80 F
AVG TEMP. OF T/C 7-19-21= 77 F
AVG TEMP. OF T/C 9-2-16= 77 F
AVG TEMP. OF T/C 11-14-20= 77 F
AVG TEMP. OF T/C 8-12-17= 77 F
AVG TEMP. OF T/C 22-23-24= 77 F

INDEX= 7

| FRAME NO. | PRINT NO. | T/C NO. | TEMPERATURE, DEG. F | TEMPERATURE INCR., DEG. F | TIME INCR., MINUTES |
|---|---|---|---|---|---|
| 11 | 1 | 1 | 1437.4 | 45.4 | 5 |
| 11 | 2 | 2 | 77.3 | .1 | 5 |
| 11 | 3 | 3 | 555.0 | 145.7 | 5 |
| 11 | 4 | 4 | 86.1 | 7.0 | 5 |
| 11 | 5 | 5 | 1476.0 | 45.9 | 5 |
| 11 | 6 | 6 | 85.8 | 7.0 | 5 |
| 11 | 7 | 7 | 77.1 | .1 | 5 |
| 11 | 8 | 8 | 77.4 | .1 | 5 |
| 11 | 9 | 9 | 76.8 | -.1 | 5 |
| 11 | 10 | 10 | 557.0 | 180.6 | 5 |
| 11 | 11 | 11 | 77.1 | -.0 | 5 |
| 11 | 12 | 12 | 77.2 | .1 | 5 |
| 12 | 1 | 13 | 1450.2 | 52.3 | 5 |
| 12 | 2 | 14 | 76.9 | .1 | 5 |
| 12 | 3 | 15 | 630.0 | 166.7 | 5 |
| 12 | 4 | 16 | 76.8 | -.1 | 5 |
| 12 | 5 | 17 | 77.1 | .1 | 5 |
| 12 | 6 | 18 | 97.7 | 14.6 | 5 |
| 12 | 7 | 19 | 76.6 | .1 | 5 |
| 12 | 8 | 20 | 76.9 | .1 | 5 |
| 12 | 9 | 21 | 76.7 | .3 | 5 |
| 12 | 10 | 22 | 77.5 | -.1 | 5 |
| 12 | 11 | 23 | 77.3 | -.1 | 5 |
| 12 | 12 | 24 | 77.7 | .1 | 5 |

TEST TIME: 0:25:00
FURNACE ATMOSPHERE TEMPERATURE: 1508.9 DEG. F
ASTM TEMPERATURE: 1510 DEG. F
DIFFERENCE: -1.1 DEG. F

AVG TEMP. OF T/C 1-5-13= 1455 F
AVG TEMP. OF T/C 3-10-15= 581 F
AVG TEMP. OF T/C 4-6-18= 90 F
AVG TEMP. OF T/C 7-19-21= 77 F
AVG TEMP. OF T/C 9-2-16= 77 F
AVG TEMP. OF T/C 11-14-20= 77 F
AVG TEMP. OF T/C 8-12-17= 77 F
AVG TEMP. OF T/C 22-23-24= 77 F

INDEX= 8

| FRAME NO. | PRINT NO. | T/C NO. | TEMPERATURE, DEG. F | TEMPERATURE INCR., DEG. F | TIME INCR., MINUTES |
|---|---|---|---|---|---|
| 11 | 1 | 1 | 1491.8 | 54.4 | 5 |
| 11 | 2 | 2 | 77.5 | .1 | 5 |
| 11 | 3 | 3 | 756.7 | 201.8 | 5 |
| 11 | 4 | 4 | 102.3 | 16.1 | 5 |
| 11 | 5 | 5 | 1533.1 | 57.0 | 5 |
| 11 | 6 | 6 | 104.8 | 19.0 | 5 |
| 11 | 7 | 7 | 78.0 | .9 | 5 |
| 11 | 8 | 8 | 77.2 | -.2 | 5 |
| 11 | 9 | 9 | 76.7 | -.1 | 5 |
| 11 | 10 | 10 | 821.7 | 264.7 | 5 |
| 11 | 11 | 11 | 76.9 | -.2 | 5 |
| 11 | 12 | 12 | 77.1 | -.1 | 5 |
| 12 | 1 | 13 | 1505.2 | 55.0 | 5 |
| 12 | 2 | 14 | 76.9 | -.0 | 5 |
| 12 | 3 | 15 | 852.8 | 222.9 | 5 |
| 12 | 4 | 16 | 76.6 | -.1 | 5 |
| 12 | 5 | 17 | 77.0 | -.1 | 5 |
| 12 | 6 | 18 | 128.4 | 30.8 | 5 |
| 12 | 7 | 19 | 77.3 | .7 | 5 |
| 12 | 8 | 20 | 76.9 | -.0 | 5 |
| 12 | 9 | 21 | 78.6 | 1.9 | 5 |
| 12 | 10 | 22 | 77.3 | -.1 | 5 |
| 12 | 11 | 23 | 77.1 | -.2 | 5 |
| 12 | 12 | 24 | 77.6 | -.1 | 5 |

TEST TIME: 0:30:00
FURNACE ATMOSPHERE TEMPERATURE: 1550.4 DEG. F
ASTM TEMPERATURE: 1550 DEG. F
DIFFERENCE: .4 DEG. F

AVG TEMP. OF T/C 1-5-13= 1510 F
AVG TEMP. OF T/C 3-10-15= 810 F
AVG TEMP. OF T/C 4-6-18= 112 F
AVG TEMP. OF T/C 7-19-21= 78 F
AVG TEMP. OF T/C 9-2-16= 77 F
AVG TEMP. OF T/C 11-14-20= 77 F
AVG TEMP. OF T/C 8-12-17= 77 F
AVG TEMP. OF T/C 22-23-24= 77 F

INDEX= 9

| FRAME NO. | PRINT NO. | T/C NO. | TEMPERATURE, DEG. F | TEMPERATURE INCR., DEG. F | TIME INCR., MINUTES |
|---|---|---|---|---|---|
| 11 | 1 | 1 | 1537.6 | 45.8 | 5 |
| 11 | 2 | 2 | 78.1 | .7 | 5 |
| 11 | 3 | 3 | 1061.0 | 304.2 | 5 |
| 11 | 4 | 4 | 130.1 | 27.8 | 5 |
| 11 | 5 | 5 | 1569.9 | 36.8 | 5 |
| 11 | 6 | 6 | 141.9 | 37.1 | 5 |
| 11 | 7 | 7 | 80.9 | 3.0 | 5 |
| 11 | 8 | 8 | 77.3 | .0 | 5 |
| 11 | 9 | 9 | 77.0 | .3 | 5 |
| 11 | 10 | 10 | 982.4 | 160.7 | 5 |
| 11 | 11 | 11 | 77.0 | .1 | 5 |
| 11 | 12 | 12 | 77.2 | .0 | 5 |
| 12 | 1 | 13 | 1553.1 | 47.9 | 5 |
| 12 | 2 | 14 | 77.1 | .2 | 5 |
| 12 | 3 | 15 | 990.6 | 137.7 | 5 |
| 12 | 4 | 16 | 77.0 | .3 | 5 |
| 12 | 5 | 17 | 77.0 | .0 | 5 |
| 12 | 6 | 18 | 174.6 | 46.1 | 5 |
| 12 | 7 | 19 | 79.2 | 1.8 | 5 |
| 12 | 8 | 20 | 77.0 | .2 | 5 |
| 12 | 9 | 21 | 79.5 | .9 | 5 |
| 12 | 10 | 22 | 77.4 | .0 | 5 |
| 12 | 11 | 23 | 77.1 | .0 | 5 |
| 12 | 12 | 24 | 77.6 | .0 | 5 |

TEST TIME: 0:35:00
FURNACE ATMOSPHERE TEMPERATURE: 1587.1 DEG. F
ASTM TEMPERATURE: 1584 DEG. F
DIFFERENCE: 3.1 DEG. F

AVG TEMP. OF T/C 1-5-13= 1554 F
AVG TEMP. OF T/C 3-10-15= 1011 F
AVG TEMP. OF T/C 4-6-18= 149 F
AVG TEMP. OF T/C 7-19-21= 80 F
AVG TEMP. OF T/C 9-2-16= 77 F
AVG TEMP. OF T/C 11-14-20= 77 F
AVG TEMP. OF T/C 8-12-17= 77 F
AVG TEMP. OF T/C 22-23-24= 77 F

INDEX= 10

| FRAME NO. | PRINT NO. | T/C NO. | TEMPERATURE, DEG. F | TEMPERATURE INCR., DEG. F | TIME INCR., MINUTES |
|---|---|---|---|---|---|
| 11 | 1 | 1 | 1570.2 | 32.6 | 5 |
| 11 | 2 | 2 | 78.3 | .2 | 5 |
| 11 | 3 | 3 | 993.7 | -67.2 | 5 |
| 11 | 4 | 4 | 169.4 | 39.3 | 5 |
| 11 | 5 | 5 | 1598.5 | 28.6 | 5 |
| 11 | 6 | 6 | 207.6 | 65.7 | 5 |
| 11 | 7 | 7 | 81.3 | .4 | 5 |
| 11 | 8 | 8 | 77.3 | .0 | 5 |
| 11 | 9 | 9 | 77.0 | .0 | 5 |
| 11 | 10 | 10 | 979.8 | -2.6 | 5 |
| 11 | 11 | 11 | 77.0 | .0 | 5 |
| 11 | 12 | 12 | 77.4 | .2 | 5 |
| 12 | 1 | 13 | 1587.0 | 33.9 | 5 |
| 12 | 2 | 14 | 77.4 | .2 | 5 |
| 12 | 3 | 15 | 1020.4 | 29.8 | 5 |
| 12 | 4 | 16 | 77.1 | .1 | 5 |
| 12 | 5 | 17 | 77.0 | .0 | 5 |
| 12 | 6 | 18 | 233.3 | 58.8 | 5 |
| 12 | 7 | 19 | 80.1 | 1.0 | 5 |
| 12 | 8 | 20 | 77.1 | .0 | 5 |
| 12 | 9 | 21 | 79.9 | .4 | 5 |
| 12 | 10 | 22 | 77.5 | .1 | 5 |
| 12 | 11 | 23 | 77.0 | -.1 | 5 |
| 12 | 12 | 24 | 77.7 | .0 | 5 |

TEST TIME: 0:40:00
FURNACE ATMOSPHERE TEMPERATURE: 1617.4 DEG. F
ASTM TEMPERATURE: 1613 DEG. F
DIFFERENCE: 4.4 DEG. F

AVG TEMP. OF T/C 1-5-13= 1585 F
AVG TEMP. OF T/C 3-10-15= 998 F
AVG TEMP. OF T/C 4-6-18= 203 F
AVG TEMP. OF T/C 7-19-21= 80 F
AVG TEMP. OF T/C 9-2-16= 77 F
AVG TEMP. OF T/C 11-14-20= 77 F
AVG TEMP. OF T/C 8-12-17= 77 F
AVG TEMP. OF T/C 22-23-24= 77 F

INDEX= 11

| FRAME NO. | PRINT NO. | T/C NO. | TEMPERATURE, DEG. F | TEMPERATURE INCR., DEG. F | TIME INCR., MINUTES |
|---|---|---|---|---|---|
| 11 | 1 | 1 | 1594.1 | 23.9 | 5 |
| 11 | 2 | 2 | 78.3 | -.0 | 5 |
| 11 | 3 | 3 | 1017.6 | 23.8 | 5 |
| 11 | 4 | 4 | 219.0 | 49.7 | 5 |
| 11 | 5 | 5 | 1620.0 | 21.5 | 5 |
| 11 | 6 | 6 | 281.7 | 74.1 | 5 |
| 11 | 7 | 7 | 86.5 | 5.1 | 5 |
| 11 | 8 | 8 | 77.4 | .0 | 5 |
| 11 | 9 | 9 | 77.2 | .2 | 5 |
| 11 | 10 | 10 | 1028.7 | 48.9 | 5 |
| 11 | 11 | 11 | 77.3 | .3 | 5 |
| 11 | 12 | 12 | 77.5 | .1 | 5 |
| 12 | 1 | 13 | 1610.0 | 23.0 | 5 |
| 12 | 2 | 14 | 77.4 | -.0 | 5 |
| 12 | 3 | 15 | 1067.9 | 47.5 | 5 |
| 12 | 4 | 16 | 77.4 | .4 | 5 |
| 12 | 5 | 17 | 77.0 | -.0 | 5 |
| 12 | 6 | 18 | 302.1 | 68.8 | 5 |
| 12 | 7 | 19 | 84.0 | 3.9 | 5 |
| 12 | 8 | 20 | 77.1 | .0 | 5 |
| 12 | 9 | 21 | 83.9 | 4.0 | 5 |
| 12 | 10 | 22 | 77.4 | -.0 | 5 |
| 12 | 11 | 23 | 77.1 | .0 | 5 |
| 12 | 12 | 24 | 77.7 | -.0 | 5 |

TEST TIME: 0:45:00
FURNACE ATMOSPHERE TEMPERATURE: 1633.1 DEG. F
ASTM TEMPERATURE: 1638 DEG. F
DIFFERENCE: -4.9 DEG. F

AVG TEMP. OF T/C 1-5-13= 1608 F
AVG TEMP. OF T/C 3-10-15= 1038 F
AVG TEMP. OF T/C 4-6-18= 268 F
AVG TEMP. OF T/C 7-19-21= 85 F
AVG TEMP. OF T/C 9-2-16= 78 F
AVG TEMP. OF T/C 11-14-20= 77 F
AVG TEMP. OF T/C 8-12-17= 77 F
AVG TEMP. OF T/C 22-23-24= 77 F

INDEX= 12

| FRAME NO. | PRINT NO. | T/C NO. | TEMPERATURE, DEG. F | TEMPERATURE INCR., DEG. F | TIME INCR., MINUTES |
|---|---|---|---|---|---|
| 11 | 1 | 1 | 1623.1 | 29.0 | 5 |
| 11 | 2 | 2 | 78.2 | -.1 | 5 |
| 11 | 3 | 3 | 1058.9 | 41.4 | 5 |
| 11 | 4 | 4 | 276.3 | 57.2 | 5 |
| 11 | 5 | 5 | 1649.0 | 29.0 | 5 |
| 11 | 6 | 6 | 356.6 | 74.9 | 5 |
| 11 | 7 | 7 | 96.2 | 9.7 | 5 |
| 11 | 8 | 8 | 77.2 | -.1 | 5 |
| 11 | 9 | 9 | 77.2 | .0 | 5 |
| 11 | 10 | 10 | 1082.1 | 53.4 | 5 |
| 11 | 11 | 11 | 76.8 | -.4 | 5 |
| 11 | 12 | 12 | 77.2 | -.3 | 5 |
| 12 | 1 | 13 | 1636.9 | 27.0 | 5 |
| 12 | 2 | 14 | 77.4 | .1 | 5 |
| 12 | 3 | 15 | 1117.1 | 49.2 | 5 |
| 12 | 4 | 16 | 78.0 | .5 | 5 |
| 12 | 5 | 17 | 77.0 | .0 | 5 |
| 12 | 6 | 18 | 374.9 | 72.8 | 5 |
| 12 | 7 | 19 | 92.2 | 8.2 | 5 |
| 12 | 8 | 20 | 77.0 | -.1 | 5 |
| 12 | 9 | 21 | 90.2 | 6.4 | 5 |
| 12 | 10 | 22 | 77.3 | -.1 | 5 |
| 12 | 11 | 23 | 76.9 | -.2 | 5 |
| 12 | 12 | 24 | 77.5 | -.2 | 5 |

TEST TIME: 0:50:00
FURNACE ATMOSPHERE TEMPERATURE: 1661.8 DEG. F
ASTM TEMPERATURE: 1661 DEG. F
DIFFERENCE: .8 DEG. F

AVG TEMP. OF T/C 1-5-13= 1636 F
AVG TEMP. OF T/C 3-10-15= 1086 F
AVG TEMP. OF T/C 4-6-18= 336 F
AVG TEMP. OF T/C 7-19-21= 93 F
AVG TEMP. OF T/C 9-2-16= 78 F
AVG TEMP. OF T/C 11-14-20= 77 F
AVG TEMP. OF T/C 8-12-17= 77 F
AVG TEMP. OF T/C 22-23-24= 77 F

INDEX= 13

| FRAME NO. | PRINT NO. | T/C NO. | TEMPERATURE, DEG. F | TEMPERATURE INCR., DEG. F | TIME INCR., MINUTES |
|---|---|---|---|---|---|
| 11 | 1 | 1 | 1647.6 | 24.5 | 5 |
| 11 | 2 | 2 | 78.3 | .1 | 5 |
| 11 | 3 | 3 | 1104.2 | 45.3 | 5 |
| 11 | 4 | 4 | 337.4 | 61.2 | 5 |
| 11 | 5 | 5 | 1676.1 | 27.1 | 5 |
| 11 | 6 | 6 | 431.6 | 75.0 | 5 |
| 11 | 7 | 7 | 110.5 | 14.3 | 5 |
| 11 | 8 | 8 | 77.3 | .0 | 5 |
| 11 | 9 | 9 | 77.5 | .3 | 5 |
| 11 | 10 | 10 | 1134.0 | 51.9 | 5 |
| 11 | 11 | 11 | 77.1 | .3 | 5 |
| 11 | 12 | 12 | 77.4 | .2 | 5 |
| 12 | 1 | 13 | 1659.8 | 22.9 | 5 |
| 12 | 2 | 14 | 77.4 | -.1 | 5 |
| 12 | 3 | 15 | 1163.9 | 46.7 | 5 |
| 12 | 4 | 16 | 78.9 | .9 | 5 |
| 12 | 5 | 17 | 76.9 | -.1 | 5 |
| 12 | 6 | 18 | 450.2 | 75.3 | 5 |
| 12 | 7 | 19 | 105.1 | 13.0 | 5 |
| 12 | 8 | 20 | 77.0 | .0 | 5 |
| 12 | 9 | 21 | 101.3 | 11.1 | 5 |
| 12 | 10 | 22 | 77.3 | .0 | 5 |
| 12 | 11 | 23 | 77.0 | .0 | 5 |
| 12 | 12 | 24 | 77.5 | .0 | 5 |

TEST TIME: 0:55:00
FURNACE ATMOSPHERE TEMPERATURE: 1684.4 DEG. F
ASTM TEMPERATURE: 1681 DEG. F
DIFFERENCE: 3.4 DEG. F

AVG TEMP. OF T/C 1-5-13= 1661 F
AVG TEMP. OF T/C 3-10-15= 1134 F
AVG TEMP. OF T/C 4-6-18= 406 F
AVG TEMP. OF T/C 7-19-21= 106 F
AVG TEMP. OF T/C 9-2-16= 78 F
AVG TEMP. OF T/C 11-14-20= 77 F
AVG TEMP. OF T/C 8-12-17= 77 F
AVG TEMP. OF T/C 22-23-24= 77 F

INDEX= 14

| FRAME NO. | PRINT NO. | T/C NO. | TEMPERATURE, DEG. F | TEMPERATURE INCR., DEG. F | TIME INCR., MINUTES |
|---|---|---|---|---|---|
| 11 | 1 | 1 | 1653.4 | 5.8 | 5 |
| 11 | 2 | 2 | 78.8 | .5 | 5 |
| 11 | 3 | 3 | 1146.2 | 42.0 | 5 |
| 11 | 4 | 4 | 400.8 | 63.4 | 5 |
| 11 | 5 | 5 | 1682.5 | 6.4 | 5 |
| 11 | 6 | 6 | 507.0 | 75.4 | 5 |
| 11 | 7 | 7 | 129.6 | 19.0 | 5 |
| 11 | 8 | 8 | 77.2 | -.1 | 5 |
| 11 | 9 | 9 | 78.1 | .5 | 5 |
| 11 | 10 | 10 | 1181.6 | 47.6 | 5 |
| 11 | 11 | 11 | 76.6 | -.5 | 5 |
| 11 | 12 | 12 | 77.4 | -.0 | 5 |
| 12 | 1 | 13 | 1666.0 | 6.2 | 5 |
| 12 | 2 | 14 | 77.3 | -.1 | 5 |
| 12 | 3 | 15 | 1204.3 | 40.4 | 5 |
| 12 | 4 | 16 | 80.5 | 1.6 | 5 |
| 12 | 5 | 17 | 77.0 | .2 | 5 |
| 12 | 6 | 18 | 528.6 | 78.3 | 5 |
| 12 | 7 | 19 | 123.1 | 18.0 | 5 |
| 12 | 8 | 20 | 77.2 | .2 | 5 |
| 12 | 9 | 21 | 117.2 | 15.8 | 5 |
| 12 | 10 | 22 | 77.2 | -.1 | 5 |
| 12 | 11 | 23 | 76.9 | -.1 | 5 |
| 12 | 12 | 24 | 77.5 | -.0 | 5 |

TEST TIME: 1:00:00
FURNACE ATMOSPHERE TEMPERATURE: 1689.4 DEG. F
ASTM TEMPERATURE: 1700 DEG. F
DIFFERENCE: -10.6 DEG. F

AVG TEMP. OF T/C 1-5-13= 1667 F    0
AVG TEMP. OF T/C 3-10-15= 1177 F    2"
AVG TEMP. OF T/C 4-6-18= 479 F    4"
AVG TEMP. OF T/C 7-19-21= 123 F    6"
AVG TEMP. OF T/C 9-2-16= 79 F    8"
AVG TEMP. OF T/C 11-14-20= 77 F    10"
AVG TEMP. OF T/C 8-12-17= 77 F    12"
AVG TEMP. OF T/C 22-23-24= 77 F    14"

INDEX= 15

| FRAME NO. | PRINT NO. | T/C NO. | TEMPERATURE, DEG. F | TEMPERATURE INCR., DEG. F | TIME INCR., MINUTES |
|---|---|---|---|---|---|
| 11 | 1 | 1 | 1686.8 | 33.4 | 5 |
| 11 | 2 | 2 | 80.1 | 1.3 | 5 |
| 11 | 3 | 3 | 1185.0 | 38.8 | 5 |
| 11 | 4 | 4 | 467.6 | 66.8 | 5 |
| 11 | 5 | 5 | 1715.1 | 32.6 | 5 |
| 11 | 6 | 6 | 589.2 | 82.2 | 5 |
| 11 | 7 | 7 | 152.8 | 23.2 | 5 |
| 11 | 8 | 8 | 77.3 | .1 | 5 |
| 11 | 9 | 9 | 79.1 | 1.1 | 5 |
| 11 | 10 | 10 | 1226.1 | 44.5 | 5 |
| 11 | 11 | 11 | 77.3 | .7 | 5 |
| 11 | 12 | 12 | 77.5 | .1 | 5 |
| 12 | 1 | 13 | 1701.4 | 35.4 | 5 |
| 12 | 2 | 14 | 77.4 | .2 | 5 |
| 12 | 3 | 15 | 1240.8 | 36.5 | 5 |
| 12 | 4 | 16 | 83.1 | 2.7 | 5 |
| 12 | 5 | 17 | 77.2 | .2 | 5 |
| 12 | 6 | 18 | 619.3 | 90.7 | 5 |
| 12 | 7 | 19 | 147.0 | 23.8 | 5 |
| 12 | 8 | 20 | 77.4 | .2 | 5 |
| 12 | 9 | 21 | 137.6 | 20.4 | 5 |
| 12 | 10 | 22 | 77.3 | .1 | 5 |
| 12 | 11 | 23 | 77.0 | .1 | 5 |
| 12 | 12 | 24 | 77.6 | .1 | 5 |

TEST TIME: 1:05:00
FURNACE ATMOSPHERE TEMPERATURE: 1718.3 DEG. F
ASTM TEMPERATURE: 1718 DEG. F
DIFFERENCE: .3 DEG. F

AVG TEMP. OF T/C 1-5-13= 1701 F
AVG TEMP. OF T/C 3-10-15= 1217 F
AVG TEMP. OF T/C 4-6-18= 559 F
AVG TEMP. OF T/C 7-19-21= 146 F
AVG TEMP. OF T/C 9-2-16= 81 F
AVG TEMP. OF T/C 11-14-20= 77 F
AVG TEMP. OF T/C 8-12-17= 77 F
AVG TEMP. OF T/C 22-23-24= 77 F

INDEX= 16

| FRAME NO. | PRINT NO. | T/C NO. | TEMPERATURE, DEG. F | TEMPERATURE INCR., DEG. F | TIME INCR., MINUTES |
|---|---|---|---|---|---|
| 11 | 1 | 1 | 1707.3 | 20.5 | 5 |
| 11 | 2 | 2 | 82.6 | 2.5 | 5 |
| 11 | 3 | 3 | 1224.9 | 39.9 | 5 |
| 11 | 4 | 4 | 540.1 | 72.5 | 5 |
| 11 | 5 | 5 | 1735.4 | 20.3 | 5 |
| 11 | 6 | 6 | 692.7 | 103.6 | 5 |
| 11 | 7 | 7 | 179.6 | 26.8 | 5 |
| 11 | 8 | 8 | 77.2 | -.1 | 5 |
| 11 | 9 | 9 | 80.4 | 1.2 | 5 |
| 11 | 10 | 10 | 1280.6 | 54.4 | 5 |
| 11 | 11 | 11 | 77.0 | -.3 | 5 |
| 11 | 12 | 12 | 77.5 | .0 | 5 |
| 12 | 1 | 13 | 1721.8 | 20.3 | 5 |
| 12 | 2 | 14 | 77.7 | .3 | 5 |
| 12 | 3 | 15 | 1277.9 | 37.2 | 5 |
| 12 | 4 | 16 | 87.2 | 4.1 | 5 |
| 12 | 5 | 17 | 77.4 | .1 | 5 |
| 12 | 6 | 18 | 732.2 | 112.9 | 5 |
| 12 | 7 | 19 | 176.3 | 29.3 | 5 |
| 12 | 8 | 20 | 77.5 | .0 | 5 |
| 12 | 9 | 21 | 161.9 | 24.3 | 5 |
| 12 | 10 | 22 | 77.2 | -.1 | 5 |
| 12 | 11 | 23 | 76.7 | -.3 | 5 |
| 12 | 12 | 24 | 77.4 | -.2 | 5 |

TEST TIME: 1:10:00
FURNACE ATMOSPHERE TEMPERATURE: 1738.3 DEG. F
ASTM TEMPERATURE: 1735 DEG. F
DIFFERENCE: 3.3 DEG. F

AVG TEMP. OF T/C 1-5-13= 1721 F
AVG TEMP. OF T/C 3-10-15= 1261 F
AVG TEMP. OF T/C 4-6-18= 655 F
AVG TEMP. OF T/C 7-19-21= 173 F
AVG TEMP. OF T/C 9-2-16= 83 F
AVG TEMP. OF T/C 11-14-20= 77 F
AVG TEMP. OF T/C 8-12-17= 77 F
AVG TEMP. OF T/C 22-23-24= 77 F

INDEX= 17

| FRAME NO. | PRINT NO. | T/C NO. | TEMPERATURE, DEG. F | TEMPERATURE INCR., DEG. F | TIME INCR., MINUTES |
|---|---|---|---|---|---|
| 11 | 1 | 1 | 1725.9 | 18.6 | 5 |
| 11 | 2 | 2 | 86.2 | 3.6 | 5 |
| 11 | 3 | 3 | 1262.1 | 37.2 | 5 |
| 11 | 4 | 4 | 631.0 | 90.9 | 5 |
| 11 | 5 | 5 | 1755.2 | 19.9 | 5 |
| 11 | 6 | 6 | 824.0 | 131.3 | 5 |
| 11 | 7 | 7 | 210.0 | 30.4 | 5 |
| 11 | 8 | 8 | 77.3 | .1 | 5 |
| 11 | 9 | 9 | 82.7 | 2.3 | 5 |
| 11 | 10 | 10 | 1336.2 | 55.7 | 5 |
| 11 | 11 | 11 | 77.5 | .5 | 5 |
| 11 | 12 | 12 | 77.8 | .3 | 5 |
| 12 | 1 | 13 | 1743.0 | 21.2 | 5 |
| 12 | 2 | 14 | 78.2 | .5 | 5 |
| 12 | 3 | 15 | 1312.2 | 34.3 | 5 |
| 12 | 4 | 16 | 91.9 | 4.7 | 5 |
| 12 | 5 | 17 | 77.6 | .2 | 5 |
| 12 | 6 | 18 | 884.8 | 152.6 | 5 |
| 12 | 7 | 19 | 212.0 | 35.7 | 5 |
| 12 | 8 | 20 | 77.7 | .2 | 5 |
| 12 | 9 | 21 | 190.2 | 28.3 | 5 |
| 12 | 10 | 22 | 77.1 | -.0 | 5 |
| 12 | 11 | 23 | 76.8 | .1 | 5 |
| 12 | 12 | 24 | 77.4 | -.1 | 5 |

TEST TIME: 1:15:00
FURNACE ATMOSPHERE TEMPERATURE: 1753.3 DEG. F
ASTM TEMPERATURE: 1750 DEG. F
DIFFERENCE: 3.3 DEG. F

AVG TEMP. OF T/C 1-5-13= 1741 F
AVG TEMP. OF T/C 3-10-15= 1303 F
AVG TEMP. OF T/C 4-6-18= 780 F
AVG TEMP. OF T/C 7-19-21= 204 F
AVG TEMP. OF T/C 9-2-16= 87 F
AVG TEMP. OF T/C 11-14-20= 78 F
AVG TEMP. OF T/C 8-12-17= 78 F
AVG TEMP. OF T/C 22-23-24= 77 F

INDEX= 18

| FRAME NO. | PRINT NO. | T/C NO. | TEMPERATURE, DEG. F | TEMPERATURE INCR., DEG. F | TIME INCR., MINUTES |
|---|---|---|---|---|---|
| 11 | 1 | 1 | 1742.8 | 17.0 | 5 |
| 11 | 2 | 2 | 90.0 | 3.8 | 5 |
| 11 | 3 | 3 | 1297.1 | 35.0 | 5 |
| 11 | 4 | 4 | 754.1 | 123.1 | 5 |
| 11 | 5 | 5 | 1769.5 | 14.2 | 5 |
| 11 | 6 | 6 | 972.4 | 148.4 | 5 |
| 11 | 7 | 7 | 243.6 | 33.6 | 5 |
| 11 | 8 | 8 | 77.6 | .3 | 5 |
| 11 | 9 | 9 | 86.2 | 3.5 | 5 |
| 11 | 10 | 10 | 1376.5 | 40.3 | 5 |
| 11 | 11 | 11 | 78.3 | .8 | 5 |
| 11 | 12 | 12 | 78.5 | .7 | 5 |
| 12 | 1 | 13 | 1758.3 | 15.4 | 5 |
| 12 | 2 | 14 | 79.3 | 1.0 | 5 |
| 12 | 3 | 15 | 1344.4 | 32.1 | 5 |
| 12 | 4 | 16 | 98.0 | 6.2 | 5 |
| 12 | 5 | 17 | 78.2 | .6 | 5 |
| 12 | 6 | 18 | 927.1 | 42.4 | 5 |
| 12 | 7 | 19 | 254.7 | 42.7 | 5 |
| 12 | 8 | 20 | 78.3 | .6 | 5 |
| 12 | 9 | 21 | 221.5 | 31.3 | 5 |
| 12 | 10 | 22 | 77.4 | .3 | 5 |
| 12 | 11 | 23 | 77.0 | .2 | 5 |
| 12 | 12 | 24 | 77.7 | .3 | 5 |

TEST TIME: 1:20:00
FURNACE ATMOSPHERE TEMPERATURE: 1768.7 DEG. F
ASTM TEMPERATURE: 1765 DEG. F
DIFFERENCE: 3.7 DEG. F

AVG TEMP. OF T/C 1-5-13= 1757 F
AVG TEMP. OF T/C 3-10-15= 1339 F
AVG TEMP. OF T/C 4-6-18= 885 F
AVG TEMP. OF T/C 7-19-21= 240 F
AVG TEMP. OF T/C 9-2-16= 91 F
AVG TEMP. OF T/C 11-14-20= 79 F
AVG TEMP. OF T/C 8-12-17= 78 F
AVG TEMP. OF T/C 22-23-24= 77 F

INDEX= 19

| FRAME NO. | PRINT NO. | T/C NO. | TEMPERATURE, DEG. F | TEMPERATURE INCR., DEG. F | TIME INCR., MINUTES |
|---|---|---|---|---|---|
| 11 | 1 | 1 | 1750.1 | 7.3 | 5 |
| 11 | 2 | 2 | 94.5 | 4.5 | 5 |
| 11 | 3 | 3 | 1329.0 | 32.0 | 5 |
| 11 | 4 | 4 | 931.9 | 177.8 | 5 |
| 11 | 5 | 5 | 1775.8 | 6.3 | 5 |
| 11 | 6 | 6 | 972.4 | .0 | 5 |
| 11 | 7 | 7 | 279.5 | 35.9 | 5 |
| 11 | 8 | 8 | 77.5 | -.1 | 5 |
| 11 | 9 | 9 | 89.8 | 3.6 | 5 |
| 11 | 10 | 10 | 1406.2 | 29.7 | 5 |
| 11 | 11 | 11 | 78.6 | .2 | 5 |
| 11 | 12 | 12 | 78.4 | -.1 | 5 |
| 12 | 1 | 13 | 1764.4 | 6.0 | 5 |
| 12 | 2 | 14 | 79.9 | .7 | 5 |
| 12 | 3 | 15 | 1372.4 | 28.1 | 5 |
| 12 | 4 | 16 | 107.3 | 9.3 | 5 |
| 12 | 5 | 17 | 78.5 | .3 | 5 |
| 12 | 6 | 18 | 919.9 | -7.2 | 5 |
| 12 | 7 | 19 | 305.6 | 51.0 | 5 |
| 12 | 8 | 20 | 78.6 | .3 | 5 |
| 12 | 9 | 21 | 255.7 | 34.2 | 5 |
| 12 | 10 | 22 | 77.3 | -.1 | 5 |
| 12 | 11 | 23 | 77.0 | -.1 | 5 |
| 12 | 12 | 24 | 77.5 | -.1 | 5 |

TEST TIME: 1:25:00
FURNACE ATMOSPHERE TEMPERATURE: 1774.7 DEG. F
ASTM TEMPERATURE: 1779 DEG. F
DIFFERENCE: -4.3 DEG. F

AVG TEMP. OF T/C 1-5-13= 1763 F
AVG TEMP. OF T/C 3-10-15= 1369 F
AVG TEMP. OF T/C 4-6-18= 941 F
AVG TEMP. OF T/C 7-19-21= 280 F
AVG TEMP. OF T/C 9-2-16= 97 F
AVG TEMP. OF T/C 11-14-20= 79 F
AVG TEMP. OF T/C 8-12-17= 78 F
AVG TEMP. OF T/C 22-23-24= 77 F

INDEX= 20

| FRAME NO. | PRINT NO. | T/C NO. | TEMPERATURE, DEG. F | TEMPERATURE INCR., DEG. F | TIME INCR., MINUTES |
|---|---|---|---|---|---|
| 11 | 1 | 1 | 1765.2 | 15.0 | 5 |
| 11 | 2 | 2 | 102.4 | 7.9 | 5 |
| 11 | 3 | 3 | 1358.5 | 29.4 | 5 |
| 11 | 4 | 4 | 939.8 | 7.9 | 5 |
| 11 | 5 | 5 | 1789.9 | 14.2 | 5 |
| 11 | 6 | 6 | 961.0 | -11.5 | 5 |
| 11 | 7 | 7 | 317.4 | 37.9 | 5 |
| 11 | 8 | 8 | 77.8 | .3 | 5 |
| 11 | 9 | 9 | 93.5 | 3.7 | 5 |
| 11 | 10 | 10 | 1429.7 | 23.5 | 5 |
| 11 | 11 | 11 | 79.4 | .9 | 5 |
| 11 | 12 | 12 | 78.6 | .2 | 5 |
| 12 | 1 | 13 | 1778.5 | 14.1 | 5 |
| 12 | 2 | 14 | 80.6 | .6 | 5 |
| 12 | 3 | 15 | 1398.5 | 26.0 | 5 |
| 12 | 4 | 16 | 120.1 | 12.8 | 5 |
| 12 | 5 | 17 | 79.0 | .5 | 5 |
| 12 | 6 | 18 | 943.9 | 24.0 | 5 |
| 12 | 7 | 19 | 359.0 | 53.3 | 5 |
| 12 | 8 | 20 | 79.0 | .4 | 5 |
| 12 | 9 | 21 | 292.2 | 36.5 | 5 |
| 12 | 10 | 22 | 77.2 | -.1 | 5 |
| 12 | 11 | 23 | 76.9 | -.0 | 5 |
| 12 | 12 | 24 | 77.5 | -.0 | 5 |

TEST TIME: 1:30:00
FURNACE ATMOSPHERE TEMPERATURE: 1791.3 DEG. F
ASTM TEMPERATURE: 1792 DEG. F
DIFFERENCE: -.7 DEG. F

AVG TEMP. OF T/C 1-5-13= 1778 F
AVG TEMP. OF T/C 3-10-15= 1396 F
AVG TEMP. OF T/C 4-6-18= 948 F
AVG TEMP. OF T/C 7-19-21= 323 F
AVG TEMP. OF T/C 9-2-16= 105 F
AVG TEMP. OF T/C 11-14-20= 80 F
AVG TEMP. OF T/C 8-12-17= 78 F
AVG TEMP. OF T/C 22-23-24= 77 F

INDEX= 21

| FRAME NO. | PRINT NO. | T/C NO. | TEMPERATURE, DEG. F | TEMPERATURE INCR., DEG. F | TIME INCR., MINUTES |
|---|---|---|---|---|---|
| 11 | 1 | 1 | 1780.7 | 15.5 | 5 |
| 11 | 2 | 2 | 113.9 | 11.5 | 5 |
| 11 | 3 | 3 | 1386.9 | 28.4 | 5 |
| 11 | 4 | 4 | 906.6 | -33.2 | 5 |
| 11 | 5 | 5 | 1807.0 | 17.1 | 5 |
| 11 | 6 | 6 | 982.3 | 21.3 | 5 |
| 11 | 7 | 7 | 356.3 | 39.0 | 5 |
| 11 | 8 | 8 | 77.7 | -.0 | 5 |
| 11 | 9 | 9 | 100.3 | 6.8 | 5 |
| 11 | 10 | 10 | 1452.5 | 22.8 | 5 |
| 11 | 11 | 11 | 80.3 | .8 | 5 |
| 11 | 12 | 12 | 79.1 | .4 | 5 |
| 12 | 1 | 13 | 1795.2 | 16.8 | 5 |
| 12 | 2 | 14 | 80.9 | .3 | 5 |
| 12 | 3 | 15 | 1423.6 | 25.1 | 5 |
| 12 | 4 | 16 | 135.3 | 15.2 | 5 |
| 12 | 5 | 17 | 79.2 | .2 | 5 |
| 12 | 6 | 18 | 974.4 | 30.5 | 5 |
| 12 | 7 | 19 | 409.1 | 50.2 | 5 |
| 12 | 8 | 20 | 79.6 | .6 | 5 |
| 12 | 9 | 21 | 329.8 | 37.6 | 5 |
| 12 | 10 | 22 | 77.3 | .0 | 5 |
| 12 | 11 | 23 | 77.0 | .1 | 5 |
| 12 | 12 | 24 | 77.5 | -.0 | 5 |

TEST TIME: 1:35:00
FURNACE ATMOSPHERE TEMPERATURE: 1806.7 DEG. F
ASTM TEMPERATURE: 1804 DEG. F
DIFFERENCE: 2.7 DEG. F

AVG TEMP. OF T/C 1-5-13= 1794 F
AVG TEMP. OF T/C 3-10-15= 1421 F
AVG TEMP. OF T/C 4-6-18= 954 F
AVG TEMP. OF T/C 7-19-21= 365 F
AVG TEMP. OF T/C 9-2-16= 117 F
AVG TEMP. OF T/C 11-14-20= 80 F
AVG TEMP. OF T/C 8-12-17= 79 F
AVG TEMP. OF T/C 22-23-24= 77 F

INDEX= 22

| FRAME NO. | PRINT NO. | T/C NO. | TEMPERATURE, DEG. F | TEMPERATURE INCR., DEG. F | TIME INCR., MINUTES. |
|---|---|---|---|---|---|
| 11 | 1 | 1 | 1792.7 | 12.0 | 5 |
| 11 | 2 | 2 | 128.2 | 14.3 | 5 |
| 11 | 3 | 3 | 1413.0 | 26.1 | 5 |
| 11 | 4 | 4 | 917.7 | 11.1 | 5 |
| 11 | 5 | 5 | 1818.4 | 11.4 | 5 |
| 11 | 6 | 6 | 1011.8 | 29.6 | 5 |
| 11 | 7 | 7 | 396.6 | 40.3 | 5 |
| 11 | 8 | 8 | 77.9 | .1 | 5 |
| 11 | 9 | 9 | 109.9 | 9.6 | 5 |
| 11 | 10 | 10 | 1475.3 | 22.7 | 5 |
| 11 | 11 | 11 | 81.6 | 1.3 | 5 |
| 11 | 12 | 12 | 79.4 | .3 | 5 |
| 12 | 1 | 13 | 1805.2 | 9.9 | 5 |
| 12 | 2 | 14 | 81.6 | .7 | 5 |
| 12 | 3 | 15 | 1447.4 | 23.8 | 5 |
| 12 | 4 | 16 | 153.2 | 17.9 | 5 |
| 12 | 5 | 17 | 79.2 | .0 | 5 |
| 12 | 6 | 18 | 1007.2 | 32.8 | 5 |
| 12 | 7 | 19 | 458.0 | 48.9 | 5 |
| 12 | 8 | 20 | 80.6 | 1.0 | 5 |
| 12 | 9 | 21 | 368.5 | 38.7 | 5 |
| 12 | 10 | 22 | 77.3 | .0 | 5 |
| 12 | 11 | 23 | 76.9 | -.1 | 5 |
| 12 | 12 | 24 | 77.5 | .1 | 5 |

TEST TIME: 1:40:00
FURNACE ATMOSPHERE TEMPERATURE: 1814.6 DEG. F
ASTM TEMPERATURE: 1815 DEG. F
DIFFERENCE: -.4 DEG. F

AVG TEMP. OF T/C 1-5-13= 1805 F
AVG TEMP. OF T/C 3-10-15= 1445 F
AVG TEMP. OF T/C 4-6-18= 979 F
AVG TEMP. OF T/C 7-19-21= 408 F
AVG TEMP. OF T/C 9-2-16= 130 F
AVG TEMP. OF T/C 11-14-20= 81 F
AVG TEMP. OF T/C 8-12-17= 79 F
AVG TEMP. OF T/C 22-23-24= 77 F

INDEX= 23

| FRAME NO. | PRINT NO. | T/C NO. | TEMPERATURE, DEG. F | TEMPERATURE INCR., DEG. F | TIME INCR., MINUTES |
|---|---|---|---|---|---|
| 11 | 1 | 1 | 1804.6 | 11.9 | 5 |
| 11 | 2 | 2 | 144.9 | 16.6 | 5 |
| 11 | 3 | 3 | 1436.2 | 23.2 | 5 |
| 11 | 4 | 4 | 940.4 | 22.7 | 5 |
| 11 | 5 | 5 | 1831.6 | 13.1 | 5 |
| 11 | 6 | 6 | 1044.1 | 32.3 | 5 |
| 11 | 7 | 7 | 437.3 | 40.6 | 5 |
| 11 | 8 | 8 | 77.7 | -.2 | 5 |
| 11 | 9 | 9 | 121.7 | 11.8 | 5 |
| 11 | 10 | 10 | 1496.1 | 20.8 | 5 |
| 11 | 11 | 11 | 83.2 | 1.6 | 5 |
| 11 | 12 | 12 | 79.5 | .1 | 5 |
| 12 | 1 | 13 | 1817.3 | 12.1 | 5 |
| 12 | 2 | 14 | 82.6 | 1.0 | 5 |
| 12 | 3 | 15 | 1468.5 | 21.2 | 5 |
| 12 | 4 | 16 | 173.7 | 20.5 | 5 |
| 12 | 5 | 17 | 79.4 | .1 | 5 |
| 12 | 6 | 18 | 1039.7 | 32.5 | 5 |
| 12 | 7 | 19 | 507.0 | 49.0 | 5 |
| 12 | 8 | 20 | 81.7 | 1.2 | 5 |
| 12 | 9 | 21 | 408.5 | 40.0 | 5 |
| 12 | 10 | 22 | 77.4 | .1 | 5 |
| 12 | 11 | 23 | 77.1 | .2 | 5 |
| 12 | 12 | 24 | 77.6 | .1 | 5 |

TEST TIME: 1:45:00
FURNACE ATMOSPHERE TEMPERATURE: 1830.8 DEG. F
ASTM TEMPERATURE: 1826 DEG. F
DIFFERENCE: 4.8 DEG. F

AVG TEMP. OF T/C 1-5-13= 1818 F
AVG TEMP. OF T/C 3-10-15= 1467 F
AVG TEMP. OF T/C 4-6-18= 1008 F
AVG TEMP. OF T/C 7-19-21= 451 F
AVG TEMP. OF T/C 9-2-16= 147 F
AVG TEMP. OF T/C 11-14-20= 82 F
AVG TEMP. OF T/C 8-12-17= 79 F
AVG TEMP. OF T/C 22-23-24= 77 F

INDEX= 24

| FRAME NO. | PRINT NO. | T/C NO. | TEMPERATURE, DEG. F | TEMPERATURE INCR., DEG. F | TIME INCR., MINUTES |
|---|---|---|---|---|---|
| 11 | 1 | 1 | 1816.9 | 12.3 | 5 |
| 11 | 2 | 2 | 164.4 | 19.5 | 5 |
| 11 | 3 | 3 | 1459.6 | 23.4 | 5 |
| 11 | 4 | 4 | 967.5 | 27.0 | 5 |
| 11 | 5 | 5 | 1844.3 | 12.8 | 5 |
| 11 | 6 | 6 | 1077.7 | 33.5 | 5 |
| 11 | 7 | 7 | 479.3 | 42.1 | 5 |
| 11 | 8 | 8 | 77.8 | .1 | 5 |
| 11 | 9 | 9 | 134.5 | 12.7 | 5 |
| 11 | 10 | 10 | 1517.4 | 21.4 | 5 |
| 11 | 11 | 11 | 85.7 | 2.5 | 5 |
| 11 | 12 | 12 | 80.4 | .8 | 5 |
| 12 | 1 | 13 | 1829.1 | 11.8 | 5 |
| 12 | 2 | 14 | 84.6 | 2.0 | 5 |
| 12 | 3 | 15 | 1490.7 | 22.2 | 5 |
| 12 | 4 | 16 | 196.6 | 22.9 | 5 |
| 12 | 5 | 17 | 79.6 | .2 | 5 |
| 12 | 6 | 18 | 1070.9 | 31.2 | 5 |
| 12 | 7 | 19 | 560.9 | 53.9 | 5 |
| 12 | 8 | 20 | 83.6 | 1.9 | 5 |
| 12 | 9 | 21 | 450.2 | 41.8 | 5 |
| 12 | 10 | 22 | 77.4 | .0 | 5 |
| 12 | 11 | 23 | 77.1 | .0 | 5 |
| 12 | 12 | 24 | 77.6 | -.0 | 5 |

TEST TIME: 1:50:00
FURNACE ATMOSPHERE TEMPERATURE: 1839.9 DEG. F
ASTM TEMPERATURE: 1835 DEG. F
DIFFERENCE: 4.9 DEG. F

AVG TEMP. OF T/C 1-5-13= 1830 F
AVG TEMP. OF T/C 3-10-15= 1489 F
AVG TEMP. OF T/C 4-6-18= 1039 F
AVG TEMP. OF T/C 7-19-21= 497 F
AVG TEMP. OF T/C 9-2-16= 165 F
AVG TEMP. OF T/C 11-14-20= 85 F
AVG TEMP. OF T/C 8-12-17= 79 F
AVG TEMP. OF T/C 22-23-24= 77 F

INDEX= 25

| FRAME NO. | PRINT NO. | T/C NO. | TEMPERATURE, DEG. F | TEMPERATURE INCR., DEG. F | TIME INCR., MINUTES |
|---|---|---|---|---|---|
| 11 | 1 | 1 | 1818.1 | 1.2 | 5 |
| 11 | 2 | 2 | 185.2 | 20.8 | 5 |
| 11 | 3 | 3 | 1481.9 | 22.3 | 5 |
| 11 | 4 | 4 | 996.3 | 28.8 | 5 |
| 11 | 5 | 5 | 1845.6 | 1.3 | 5 |
| 11 | 6 | 6 | 1112.3 | 34.6 | 5 |
| 11 | 7 | 7 | 522.6 | 43.2 | 5 |
| 11 | 8 | 8 | 78.0 | .2 | 5 |
| 11 | 9 | 9 | 149.0 | 14.6 | 5 |
| 11 | 10 | 10 | 1538.6 | 21.2 | 5 |
| 11 | 11 | 11 | 88.8 | 3.1 | 5 |
| 11 | 12 | 12 | 80.2 | -.2 | 5 |
| 12 | 1 | 13 | 1829.6 | .6 | 5 |
| 12 | 2 | 14 | 87.9 | 3.3 | 5 |
| 12 | 3 | 15 | 1509.9 | 19.2 | 5 |
| 12 | 4 | 16 | 221.6 | 25.0 | 5 |
| 12 | 5 | 17 | 79.8 | .2 | 5 |
| 12 | 6 | 18 | 1101.5 | 30.6 | 5 |
| 12 | 7 | 19 | 618.1 | 57.1 | 5 |
| 12 | 8 | 20 | 86.2 | 2.7 | 5 |
| -12 | 9 | 21 | 493.5 | 43.2 | 5 |
| 12 | 10 | 22 | 77.5 | .1 | 5 |
| 12 | 11 | 23 | 77.2 | .1 | 5 |
| 12 | 12 | 24 | 77.7 | .1 | 5 |

TEST TIME: 1:55:00
FURNACE ATMOSPHERE TEMPERATURE: 1841.7 DEG. F
ASTM TEMPERATURE: 1843 DEG. F
DIFFERENCE: -1.3 DEG. F

AVG TEMP. OF T/C 1-5-13= 1831 F
AVG TEMP. OF T/C 3-10-15= 1510 F
AVG TEMP. OF T/C 4-6-18= 1070 F
AVG TEMP. OF T/C 7-19-21= 545 F
AVG TEMP. OF T/C 9-2-16= 185 F
AVG TEMP. OF T/C 11-14-20= 88 F
AVG TEMP. OF T/C 8-12-17= 79 F
AVG TEMP. OF T/C 22-23-24= 78 F

INDEX= 26

| FRAME NO. | PRINT NO. | T/C NO. | TEMPERATURE, DEG. F | TEMPERATURE INCR., DEG. F | TIME INCR., MINUTES |
|---|---|---|---|---|---|
| 11 | 1 | 1 | 1827.1 | 9.1 | 5 |
| 11 | 2 | 2 | 208.4 | 23.2 | 5 |
| 11 | 3 | 3 | 1500.2 | 18.3 | 5 |
| 11 | 4 | 4 | 1025.4 | 29.1 | 5 |
| 11 | 5 | 5 | 1854.9 | 9.3 | 5 |
| 11 | 6 | 6 | 1148.5 | 36.2 | 5 |
| 11 | 7 | 7 | 568.7 | 46.2 | 5 |
| 11 | 8 | 8 | 78.1 | .1 | 5 |
| 11 | 9 | 9 | 165.1 | 16.0 | 5 |
| 11 | 10 | 10 | 1557.0 | 18.4 | 5 |
| 11 | 11 | 11 | 92.7 | 3.9 | 5 |
| 11 | 12 | 12 | 80.1 | -.0 | 5 |
| 12 | 1 | 13 | 1838.0 | 8.3 | 5 |
| 12 | 2 | 14 | 92.0 | 4.1 | 5 |
| 12 | 3 | 15 | 1525.7 | 15.7 | 5 |
| 12 | 4 | 16 | 247.8 | 26.3 | 5 |
| 12 | 5 | 17 | 79.8 | .0 | 5 |
| 12 | 6 | 18 | 1130.5 | 29.1 | 5 |
| 12 | 7 | 19 | 685.9 | 67.8 | 5 |
| 12 | 8 | 20 | 89.3 | 3.1 | 5 |
| 12 | 9 | 21 | 543.2 | 49.7 | 5 |
| 12 | 10 | 22 | 77.6 | .0 | 5 |
| 12 | 11 | 23 | 77.1 | -.2 | 5 |
| 12 | 12 | 24 | 77.7 | .0 | 5 |

TEST TIME: 2:00:00
FURNACE ATMOSPHERE TEMPERATURE: 1847.7 DEG. F
ASTM TEMPERATURE: 1850 DEG. F
DIFFERENCE: -2.3 DEG. F

| | |
|---|---|
| AVG TEMP. OF T/C 1-5-13= 1840 F | 0 |
| AVG TEMP. OF T/C 3-10-15= 1528 F | 2" |
| AVG TEMP. OF T/C 4-6-18= 1101 F | 4" |
| AVG TEMP. OF T/C 7-19-21= 599 F | 6" |
| AVG TEMP. OF T/C 9-2-16= 207 F | 8" |
| AVG TEMP. OF T/C 11-14-20= 91 F | 10" |
| AVG TEMP. OF T/C 8-12-17= 79 F | 12" |
| AVG TEMP. OF T/C 22-23-24= 77 F | 14" |

| FRAME NO. | PRINT NO. | T/C NO. | TEMPERATURE, DEG. F | TEMPERATURE INCR., DEG. F | TIME INCR., MINUTES |
|---|---|---|---|---|---|
| 11 | 1 | 1 | 1828.0 | .9 | 5 |
| 11 | 2 | 2 | 233.7 | 25.3 | 5 |
| 11 | 3 | 3 | 1517.0 | 16.8 | 5 |
| 11 | 4 | 4 | 1053.4 | 28.0 | 5 |
| 11 | 5 | 5 | 1856.8 | 1.9 | 5 |
| 11 | 6 | 6 | 1180.8 | 32.3 | 5 |
| 11 | 7 | 7 | 618.1 | 49.4 | 5 |
| 11 | 8 | 8 | 78.3 | .2 | 5 |
| 11 | 9 | 9 | 182.3 | 17.3 | 5 |
| 11 | 10 | 10 | 1573.2 | 16.2 | 5 |
| 11 | 11 | 11 | 97.8 | 5.1 | 5 |
| 11 | 12 | 12 | 80.7 | .6 | 5 |
| 12 | 1 | 13 | 1837.0 | -1.0 | 5 |
| 12 | 2 | 14 | 97.2 | 5.2 | 5 |
| 12 | 3 | 15 | 1540.2 | 14.5 | 5 |
| 12 | 4 | 16 | 275.8 | 28.0 | 5 |
| 12 | 5 | 17 | 80.0 | .2 | 5 |
| 12 | 6 | 18 | 1157.5 | 26.9 | 5 |
| 12 | 7 | 19 | 748.1 | 62.3 | 5 |
| 12 | 8 | 20 | 93.1 | 3.7 | 5 |
| -12 | 9 | 21 | 595.2 | 52.0 | 5 |
| 12 | 10 | 22 | 77.5 | -.1 | 5 |
| 12 | 11 | 23 | 77.1 | -.0 | 5 |
| 12 | 12 | 24 | 77.6 | -.2 | 5 |

TEST TIME: 2:05:00
FURNACE ATMOSPHERE TEMPERATURE: 1851.0 DEG. F
ASTM TEMPERATURE: 1856 DEG. F
DIFFERENCE: -5 DEG. F

AVG TEMP. OF T/C 1-5-13= 1841 F
AVG TEMP. OF T/C 3-10-15= 1543 F
AVG TEMP. OF T/C 4-6-18= 1131 F
AVG TEMP. OF T/C 7-19-21= 654 F
AVG TEMP. OF T/C 9-2-16= 231 F
AVG TEMP. OF T/C 11-14-20= 96 F
AVG TEMP. OF T/C 8-12-17= 80 F
AVG TEMP. OF T/C 22-23-24= 77 F

INDEX= 28

| FRAME NO. | PRINT NO. | T/C NO. | TEMPERATURE, DEG. F | TEMPERATURE INCR., DEG. F | TIME INCR., MINUTES |
|---|---|---|---|---|---|
| 11 | 1 | 1 | 1843.0 | 15.0 | 5 |
| 11 | 2 | 2 | 262.2 | 28.5 | 5 |
| 11 | 3 | 3 | 1534.5 | 17.5 | 5 |
| 11 | 4 | 4 | 1079.9 | 26.5 | 5 |
| 11 | 5 | 5 | 1872.8 | 16.0 | 5 |
| 11 | 6 | 6 | 1210.1 | 29.3 | 5 |
| 11 | 7 | 7 | 667.5 | 49.4 | 5 |
| 11 | 8 | 8 | 78.7 | .4 | 5 |
| 11 | 9 | 9 | 201.1 | 18.7 | 5 |
| 11 | 10 | 10 | 1589.4 | 16.2 | 5 |
| 11 | 11 | 11 | 103.1 | 5.3 | 5 |
| 11 | 12 | 12 | 81.1 | .4 | 5 |
| 12 | 1 | 13 | 1853.9 | 17.0 | 5 |
| 12 | 2 | 14 | 103.7 | 6.5 | 5 |
| 12 | 3 | 15 | 1556.7 | 16.5 | 5 |
| 12 | 4 | 16 | 304.3 | 28.5 | 5 |
| 12 | 5 | 17 | 80.5 | .5 | 5 |
| 12 | 6 | 18 | 1182.4 | 25.0 | 5 |
| 12 | 7 | 19 | 827.7 | 79.6 | 5 |
| 12 | 8 | 20 | 97.6 | 4.5 | 5 |
| 12 | 9 | 21 | 651.7 | 56.5 | 5 |
| 12 | 10 | 22 | 77.6 | .1 | 5 |
| 12 | 11 | 23 | 77.0 | -.0 | 5 |
| 12 | 12 | 24 | 77.7 | .1 | 5 |

TEST TIME: 2:10:00
FURNACE ATMOSPHERE TEMPERATURE: 1867.1 DEG. F
ASTM TEMPERATURE: 1862 DEG. F
DIFFERENCE: 5.1 DEG. F

AVG TEMP. OF T/C 1-5-13= 1857 F
AVG TEMP. OF T/C 3-10-15= 1560 F
AVG TEMP. OF T/C 4-6-18= 1157 F
AVG TEMP. OF T/C 7-19-21= 716 F
AVG TEMP. OF T/C 9-2-16= 256 F
AVG TEMP. OF T/C 11-14-20= 101 F
AVG TEMP. OF T/C 8-12-17= 80 F
AVG TEMP. OF T/C 22-23-24= 77 F

INDEX= 29

| FRAME NO. | PRINT NO. | T/C NO. | TEMPERATURE, DEG. F | TEMPERATURE INCR., DEG. F | TIME INCR., MINUTES |
|---|---|---|---|---|---|
| 11 | 1 | 1 | 1843.7 | .7 | 5 |
| 11 | 2 | 2 | 292.3 | 30.0 | 5 |
| 11 | 3 | 3 | 1553.1 | 18.6 | 5 |
| 11 | 4 | 4 | 1105.2 | 25.3 | 5 |
| 11 | 5 | 5 | 1873.8 | 1.0 | 5 |
| 11 | 6 | 6 | 1238.4 | 28.3 | 5 |
| 11 | 7 | 7 | 720.2 | 52.7 | 5 |
| 11 | 8 | 8 | 79.4 | .7 | 5 |
| 11 | 9 | 9 | 221.2 | 20.1 | 5 |
| 11 | 10 | 10 | 1606.8 | 17.3 | 5 |
| 11 | 11 | 11 | 110.2 | 7.0 | 5 |
| 11 | 12 | 12 | 82.0 | .9 | 5 |
| 12 | 1 | 13 | 1847.3 | -6.6 | 5 |
| 12 | 2 | 14 | 110.7 | 7.0 | 5 |
| 12 | 3 | 15 | 1574.2 | 17.5 | 5 |
| 12 | 4 | 16 | 333.4 | 29.1 | 5 |
| 12 | 5 | 17 | 81.2 | .7 | 5 |
| 12 | 6 | 18 | 1206.3 | 23.8 | 5 |
| 12 | 7 | 19 | 969.3 | 141.6 | 5 |
| 12 | 8 | 20 | 102.6 | 5.0 | 5 |
| 12 | 9 | 21 | 712.3 | 60.6 | 5 |
| 12 | 10 | 22 | 77.6 | .0 | 5 |
| 12 | 11 | 23 | 77.1 | .0 | 5 |
| 12 | 12 | 24 | 77.7 | .0 | 5 |

TEST TIME: 2:15:00
FURNACE ATMOSPHERE TEMPERATURE: 1868.1 DEG. F
ASTM TEMPERATURE: 1868.5 DEG. F
DIFFERENCE: -.4 DEG. F

AVG TEMP. OF T/C 1-5-13= 1855 F
AVG TEMP. OF T/C 3-10-15= 1578 F
AVG TEMP. OF T/C 4-6-18= 1183 F
AVG TEMP. OF T/C 7-19-21= 801 F
AVG TEMP. OF T/C 9-2-16= 282 F
AVG TEMP. OF T/C 11-14-20= 108 F
AVG TEMP. OF T/C 8-12-17= 81 F
AVG TEMP. OF T/C 22-23-24= 77 F

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| FRAME NO. | PRINT NO. | T/C NO. | TEMPERATURE, DEG. F | TEMPERATURE INCR., DEG. F | TIME INCR., MINUTES |
|---|---|---|---|---|---|
| 11 | 1 | 1 | 1852.1 | 8.3 | 5 |
| 11 | 2 | 2 | 324.6 | 32.4 | 5 |
| 11 | 3 | 3 | 1568.2 | 15.1 | 5 |
| 11 | 4 | 4 | 1129.7 | 24.6 | 5 |
| 11 | 5 | 5 | 1883.1 | 9.2 | 5 |
| 11 | 6 | 6 | 1264.8 | 26.4 | 5 |
| 11 | 7 | 7 | 765.0 | 44.8 | 5 |
| 11 | 8 | 8 | 79.6 | .2 | 5 |
| 11 | 9 | 9 | 241.3 | 20.1 | 5 |
| 11 | 10 | 10 | 1619.4 | 12.6 | 5 |
| 11 | 11 | 11 | 117.6 | 7.5 | 5 |
| 11 | 12 | 12 | 82.4 | .4 | 5 |
| 12 | 1 | 13 | 1860.6 | 13.3 | 5 |
| 12 | 2 | 14 | 119.6 | 8.9 | 5 |
| 12 | 3 | 15 | 1590.3 | 16.1 | 5 |
| 12 | 4 | 16 | 363.3 | 29.9 | 5 |
| 12 | 5 | 17 | 82.1 | .8 | 5 |
| 12 | 6 | 18 | 1229.3 | 23.0 | 5 |
| 12 | 7 | 19 | 905.7 | -63.6 | 5 |
| 12 | 8 | 20 | 108.8 | 6.2 | 5 |
| 12 | 9 | 21 | 766.9 | 54.6 | 5 |
| 12 | 10 | 22 | 77.8 | .2 | 5 |
| 12 | 11 | 23 | 77.2 | .1 | 5 |
| 12 | 12 | 24 | 77.7 | .0 | 5 |

TEST TIME: 2:20:00
FURNACE ATMOSPHERE TEMPERATURE: 1874.0 DEG. F
ASTM TEMPERATURE: 1875 DEG. F
DIFFERENCE: -1 DEG. F

AVG TEMP. OF T/C 1-5-13= 1865 F
AVG TEMP. OF T/C 3-10-15= 1593 F
AVG TEMP. OF T/C 4-6-18= 1208 F
AVG TEMP. OF T/C 7-19-21= 813 F
AVG TEMP. OF T/C 9-2-16= 310 F
AVG TEMP. OF T/C 11-14-20= 115 F
AVG TEMP. OF T/C 8-12-17= 81 F
AVG TEMP. OF T/C 22-23-24= 78 F

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| FRAME NO. | PRINT NO. | T/C NO. | TEMPERATURE, DEG. F | TEMPERATURE INCR., DEG. F | TIME INCR., MINUTES |
|---|---|---|---|---|---|
| 11 | 1 | 1 | 1857.1 | 5.1 | 5 |
| 11 | 2 | 2 | 359.0 | 34.3 | 5 |
| 11 | 3 | 3 | 1582.3 | 14.1 | 5 |
| 11 | 4 | 4 | 1153.0 | 23.3 | 5 |
| 11 | 5 | 5 | 1888.4 | 5.4 | 5 |
| 11 | 6 | 6 | 1286.4 | 21.6 | 5 |
| 11 | 7 | 7 | 812.1 | 47.1 | 5 |
| 11 | 8 | 8 | 80.0 | .4 | 5 |
| 11 | 9 | 9 | 263.1 | 21.8 | 5 |
| 11 | 10 | 10 | 1631.0 | 11.6 | 5 |
| 11 | 11 | 11 | 126.6 | 9.0 | 5 |
| 11 | 12 | 12 | 83.4 | 1.0 | 5 |
| 12 | 1 | 13 | 0.0 | | |
| -1860.58951315 DDDD.D | 5 | | | | |
| 12 | 2 | 14 | 130.2 | 10.7 | 5 |
| 12 | 3 | 15 | 1602.8 | 12.5 | 5 |
| 12 | 4 | 16 | 393.4 | 30.1 | 5 |
| 12 | 5 | 17 | 83.5 | 1.4 | 5 |
| 12 | 6 | 18 | 1250.8 | 21.5 | 5 |
| 12 | 7 | 19 | 891.0 | -14.7 | 5 |
| 12 | 8 | 20 | 115.8 | 7.0 | 5 |
| 12 | 9 | 21 | 873.9 | 107.0 | 5 |
| 12 | 10 | 22 | 78.0 | .2 | 5 |
| 12 | 11 | 23 | 77.4 | .3 | 5 |
| 12 | 12 | 24 | 78.0 | .2 | 5 |

TEST TIME: 2:25:00
FURNACE ATMOSPHERE TEMPERATURE: 1879.9 DEG. F
ASTM TEMPERATURE: 1881.5 DEG. F
DIFFERENCE: -1.6 DEG. F

AVG TEMP. OF T/C 1-5-13= 1873 F
AVG TEMP. OF T/C 3-10-15= 1605 F
AVG TEMP. OF T/C 4-6-18= 1230 F
AVG TEMP. OF T/C 7-19-21= 859 F
AVG TEMP. OF T/C 9-2-16= 339 F
AVG TEMP. OF T/C 11-14-20= 124 F
AVG TEMP. OF T/C 8-12-17= 82 F
AVG TEMP. OF T/C 22-23-24= 78 F

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| FRAME NO. | PRINT NO. | T/C NO. | TEMPERATURE, DEG. F | TEMPERATURE INCR., DEG. F | TIME INCR., MINUTES |
|---|---|---|---|---|---|
| 11 | 1 | 1 | 1878.6 | 15.6 | 4 |
| 11 | 2 | 2 | 425.0 | 28.2 | 4 |
| 11 | 3 | 3 | 1610.9 | 10.8 | 4 |
| 11 | 4 | 4 | 1196.1 | 18.1 | 4 |
| 11 | 5 | 5 | 1911.5 | 16.5 | 4 |
| 11 | 6 | 6 | 1322.9 | 15.3 | 4 |
| 11 | 7 | 7 | 925.7 | -42.5 | 4 |
| 11 | 8 | 8 | 81.7 | 1.0 | 4 |
| 11 | 9 | 9 | 309.5 | 20.3 | 4 |
| 11 | 10 | 10 | 1651.5 | 8.9 | 4 |
| 11 | 11 | 11 | 147.2 | 9.5 | 4 |
| 11 | 12 | 12 | 86.3 | 1.7 | 4 |
| 12 | 1 | 13 | 0.0 | 0.0 | 4 |
| 12 | 2 | 14 | 154.7 | 11.6 | 4 |
| 12 | 3 | 15 | 1630.1 | 10.5 | 4 |
| 12 | 4 | 16 | 455.1 | 26.8 | 4 |
| 12 | 5 | 17 | 87.5 | 2.2 | 4 |
| 12 | 6 | 18 | 1290.4 | 16.5 | 4 |
| 12 | 7 | 19 | 925.1 | 18.0 | 4 |
| 12 | 8 | 20 | 133.5 | 8.4 | 4 |
| 12 | 9 | 21 | 900.8 | -65.3 | 4 |
| 12 | 10 | 22 | 78.5 | .4 | 4 |
| 12 | 11 | 23 | 78.0 | .3 | 4 |
| 12 | 12 | 24 | 78.2 | .2 | 4 |

TEST TIME: 2:35:00
FURNACE ATMOSPHERE TEMPERATURE: 1895.4 DEG. F
ASTM TEMPERATURE: 1894 DEG. F
DIFFERENCE: 1.4 DEG. F

AVG TEMP. OF T/C 1-5-= 1895 F
AVG TEMP. OF T/C 3-10-15= 1631 F
AVG TEMP. OF T/C 4-6-18= 1270 F
AVG TEMP. OF T/C 7-19-21= 917 F
AVG TEMP. OF T/C 9-2-16= 397 F
AVG TEMP. OF T/C 11-14-20= 145 F
AVG TEMP. OF T/C 8-12-17= 85 F
AVG TEMP. OF T/C 22-23-24= 78 F

| FRAME NO. | PRINT NO. | T/C NO. | TEMPERATURE, DEG. F | TEMPERATURE INCR., DEG. F | TIME INCR., MINUTES |
|---|---|---|---|---|---|
| 11 | 1 | 1 | 1883.8 | 5.2 | 5 |
| 11 | 2 | 2 | 457.6 | 32.6 | 5 |
| 11 | 3 | 3 | 1624.2 | 13.3 | 5 |
| 11 | 4 | 4 | 1216.0 | 19.9 | 5 |
| 11 | 5 | 5 | 1917.3 | 5.8 | 5 |
| 11 | 6 | 6 | 1340.1 | 17.2 | 5 |
| 11 | 7 | 7 | 900.4 | -25.3 | 5 |
| 11 | 8 | 8 | 82.8 | 1.1 | 5 |
| 11 | 9 | 9 | 333.0 | 23.6 | 5 |
| 11 | 10 | 10 | 1663.7 | 12.2 | 5 |
| 11 | 11 | 11 | 159.6 | 12.4 | 5 |
| 11 | 12 | 12 | 88.5 | 2.2 | 5 |
| 12 | 1 | 13 | 0.0 | 0.0 | 5 |
| 12 | 2 | 14 | 169.3 | 14.6 | 5 |
| 12 | 3 | 15 | 1643.1 | 13.0 | 5 |
| 12 | 4 | 16 | 486.5 | 31.4 | 5 |
| 12 | 5 | 17 | 90.1 | 2.6 | 5 |
| 12 | 6 | 18 | 1308.7 | 18.4 | 5 |
| 12 | 7 | 19 | 947.3 | 22.3 | 5 |
| 12 | 8 | 20 | 144.6 | 11.1 | 5 |
| 12 | 9 | 21 | 889.7 | -11.1 | 5 |
| 12 | 10 | 22 | 78.4 | -.0 | 5 |
| 12 | 11 | 23 | 78.0 | .1 | 5 |
| 12 | 12 | 24 | 78.2 | -.0 | 5 |

TEST TIME: 2:40:00
FURNACE ATMOSPHERE TEMPERATURE: 1905.1 DEG. F
ASTM TEMPERATURE: 1900 DEG. F
DIFFERENCE: 5.1 DEG. F

AVG TEMP. OF T/C 1-5-= 1901 F
AVG TEMP. OF T/C 3-10-15= 1644 F
AVG TEMP. OF T/C 4-6-18= 1289 F
AVG TEMP. OF T/C 7-19-21= 912 F
AVG TEMP. OF T/C 9-2-16= 426 F
AVG TEMP. OF T/C 11-14-20= 158 F
AVG TEMP. OF T/C 8-12-17= 87 F
AVG TEMP. OF T/C 22-23-24= 78 F

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| FRAME NO. | PRINT NO. | T/C NO. | TEMPERATURE, DEG. F | TEMPERATURE INCR., DEG. F | TIME INCR., MINUTES |
|---|---|---|---|---|---|
| 11 | 1 | 1 | 1884.8 | .9 | 5 |
| 11 | 2 | 2 | 491.0 | 33.4 | 5 |
| 11 | 3 | 3 | 1637.5 | 13.3 | 5 |
| 11 | 4 | 4 | 1235.7 | 19.8 | 5 |
| 11 | 5 | 5 | 1917.9 | .6 | 5 |
| 11 | 6 | 6 | 1357.8 | 17.7 | 5 |
| 11 | 7 | 7 | 908.2 | 7.8 | 5 |
| 11 | 8 | 8 | 84.3 | 1.5 | 5 |
| 11 | 9 | 9 | 357.1 | 24.1 | 5 |
| 11 | 10 | 10 | 1676.1 | 12.4 | 5 |
| 11 | 11 | 11 | 174.0 | 14.4 | 5 |
| 11 | 12 | 12 | 91.7 | 3.2 | 5 |
| 12 | 1 | 13 | 0.0 | 0.0 | 5 |
| 12 | 2 | 14 | 185.3 | 16.0 | 5 |
| 12 | 3 | 15 | 1654.1 | 11.0 | 5 |
| 12 | 4 | 16 | 519.0 | 32.5 | 5 |
| 12 | 5 | 17 | 93.3 | 3.3 | 5 |
| 12 | 6 | 18 | 1327.4 | 18.7 | 5 |
| 12 | 7 | 19 | 970.5 | 23.1 | 5 |
| 12 | 8 | 20 | 157.8 | 13.1 | 5 |
| 12 | 9 | 21 | 898.0 | 8.3 | 5 |
| 12 | 10 | 22 | 78.6 | .1 | 5 |
| 12 | 11 | 23 | 78.0 | -.0 | 5 |
| 12 | 12 | 24 | 78.2 | -.0 | 5 |

TEST TIME: 2:45:00
FURNACE ATMOSPHERE TEMPERATURE: 1904.9 DEG. F
ASTM TEMPERATURE: 1906 DEG. F
DIFFERENCE: -1.1 DEG. F

AVG TEMP. OF T/C 1-5-= 1901 F
AVG TEMP. OF T/C 3-10-15= 1656 F
AVG TEMP. OF T/C 4-6-18= 1307 F
AVG TEMP. OF T/C 7-19-21= 926 F
AVG TEMP. OF T/C 9-2-16= 456 F
AVG TEMP. OF T/C 11-14-20= 172 F
AVG TEMP. OF T/C 8-12-17= 90 F
AVG TEMP. OF T/C 22-23-24= 78 F

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| FRAME NO. | PRINT NO. | T/C NO. | TEMPERATURE, DEG. F | TEMPERATURE INCR., DEG. F | TIME INCR., MINUTES |
|---|---|---|---|---|---|
| 11 | 1 | 1 | 1893.2 | 8.4 | 5 |
| 11 | 2 | 2 | 526.0 | 35.0 | 5 |
| 11 | 3 | 3 | 1647.7 | 10.3 | 5 |
| 11 | 4 | 4 | 1255.1 | 19.4 | 5 |
| 11 | 5 | 5 | 1926.5 | 8.6 | 5 |
| 11 | 6 | 6 | 1375.6 | 17.7 | 5 |
| 11 | 7 | 7 | 925.0 | 16.8 | 5 |
| 11 | 8 | 8 | 86.2 | 1.9 | 5 |
| 11 | 9 | 9 | 381.5 | 24.5 | 5 |
| 11 | 10 | 10 | 1687.1 | 11.0 | 5 |
| 11 | 11 | 11 | 189.5 | 15.5 | 5 |
| 11 | 12 | 12 | 95.5 | 3.8 | 5 |
| 12 | 1 | 13 | 0.0 | 0.0 | 5 |
| 12 | 2 | 14 | 202.5 | 17.2 | 5 |
| 12 | 3 | 15 | 1661.3 | 7.2 | 5 |
| 12 | 4 | 16 | 553.3 | 34.3 | 5 |
| 12 | 5 | 17 | 97.2 | 3.9 | 5 |
| 12 | 6 | 18 | 1346.1 | 18.7 | 5 |
| 12 | 7 | 19 | 994.4 | 24.0 | 5 |
| 12 | 8 | 20 | 172.2 | 14.5 | 5 |
| 12 | 9 | 21 | 912.6 | 14.7 | 5 |
| 12 | 10 | 22 | 79.1 | .5 | 5 |
| 12 | 11 | 23 | 78.4 | .4 | 5 |
| 12 | 12 | 24 | 78.8 | .5 | 5 |

TEST TIME: 2:50:00
FURNACE ATMOSPHERE TEMPERATURE: 1914.4 DEG. F
ASTM TEMPERATURE: 1912 DEG. F
DIFFERENCE: 2.4 DEG. F

AVG TEMP. OF T/C 1-5-= 1910 F
AVG TEMP. OF T/C 3-10-15= 1665 F
AVG TEMP. OF T/C 4-6-18= 1326 F
AVG TEMP. OF T/C 7-19-21= 944 F
AVG TEMP. OF T/C 9-2-16= 487 F
AVG TEMP. OF T/C 11-14-20= 188 F
AVG TEMP. OF T/C 8-12-17= 93 F
AVG TEMP. OF T/C 22-23-24= 79 F

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| FRAME NO. | PRINT NO. | T/C NO. | TEMPERATURE, DEG. F | TEMPERATURE INCR., DEG. F | TIME INCR., MINUTES |
|---|---|---|---|---|---|
| 11 | 1 | 1 | 1902.2 | 9.0 | 5 |
| 11 | 2 | 2 | 562.3 | 36.4 | 5 |
| 11 | 3 | 3 | 1657.5 | 9.8 | 5 |
| 11 | 4 | 4 | 1273.3 | 18.2 | 5 |
| 11 | 5 | 5 | 1935.9 | 9.3 | 5 |
| 11 | 6 | 6 | 1392.6 | 17.1 | 5 |
| 11 | 7 | 7 | 944.5 | 19.5 | 5 |
| 11 | 8 | 8 | 88.2 | 2.0 | 5 |
| 11 | 9 | 9 | 406.5 | 25.0 | 5 |
| 11 | 10 | 10 | 1698.4 | 11.2 | 5 |
| 11 | 11 | 11 | 206.5 | 17.0 | 5 |
| 11 | 12 | 12 | 100.5 | 5.0 | 5 |
| 12 | 1 | 13 | 0.0 | 0.0 | 5 |
| 12 | 2 | 14 | 220.2 | 17.8 | 5 |
| 12 | 3 | 15 | 1672.7 | 11.4 | 5 |
| 12 | 4 | 16 | 588.3 | 35.0 | 5 |
| 12 | 5 | 17 | 101.5 | 4.2 | 5 |
| 12 | 6 | 18 | 1363.8 | 17.7 | 5 |
| 12 | 7 | 19 | 1018.9 | 24.4 | 5 |
| 12 | 8 | 20 | 187.5 | 15.3 | 5 |
| 12 | 9 | 21 | 929.4 | 16.8 | 5 |
| 12 | 10 | 22 | 79.2 | .1 | 5 |
| 12 | 11 | 23 | 78.3 | -.0 | 5 |
| 12 | 12 | 24 | 79.0 | .2 | 5 |

TEST TIME: 2:55:00
FURNACE ATMOSPHERE TEMPERATURE: 1922.1 DEG. F
ASTM TEMPERATURE: 1918.5 DEG. F
DIFFERENCE: 3.6 DEG. F

AVG TEMP. OF T/C 1-5-= 1919 F
AVG TEMP. OF T/C 3-10-15= 1676 F
AVG TEMP. OF T/C 4-6-18= 1343 F
AVG TEMP. OF T/C 7-19-21= 964 F
AVG TEMP. OF T/C 9-2-16= 519 F
AVG TEMP. OF T/C 11-14-20= 205 F
AVG TEMP. OF T/C 8-12-17= 97 F
AVG TEMP. OF T/C 22-23-24= 79 F

| FRAME NO. | PRINT NO. | T/C NO. | TEMPERATURE, DEG. F | TEMPERATURE INCR., DEG. F | TIME INCR., MINUTES |
|---|---|---|---|---|---|
| 11 | 1 | 1 | 1909.2 | 7.0 | 5 |
| 11 | 2 | 2 | 596.8 | 34.4 | 5 |
| 11 | 3 | 3 | 1668.1 | 10.5 | 5 |
| 11 | 4 | 4 | 1291.0 | 17.6 | 5 |
| 11 | 5 | 5 | 1943.9 | 8.0 | 5 |
| 11 | 6 | 6 | 1409.7 | 17.0 | 5 |
| 11 | 7 | 7 | 964.5 | 20.1 | 5 |
| 11 | 8 | 8 | 90.6 | 2.3 | 5 |
| 11 | 9 | 9 | 431.9 | 25.4 | 5 |
| 11 | 10 | 10 | 1708.3 | 9.9 | 5 |
| 11 | 11 | 11 | 223.7 | 17.2 | 5 |
| 11 | 12 | 12 | 105.7 | 5.2 | 5 |
| 12 | 1 | 13 | [illegible].0 | 0.0 | 5 |
| 12 | 2 | 14 | 239.4 | 19.1 | 5 |
| 12 | 3 | 15 | 1682.8 | 10.1 | 5 |
| 12 | 4 | 16 | 622.6 | 34.4 | 5 |
| 12 | 5 | 17 | 106.1 | 4.6 | 5 |
| 12 | 6 | 18 | 1381.1 | 17.3 | 5 |
| 12 | 7 | 19 | 1043.2 | 24.3 | 5 |
| 12 | 8 | 20 | 203.5 | 16.0 | 5 |
| 12 | 9 | 21 | 947.1 | 17.7 | 5 |
| 12 | 10 | 22 | 79.2 | .0 | 5 |
| 12 | 11 | 23 | 78.1 | -.2 | 5 |
| 12 | 12 | 24 | 79.0 | .0 | 5 |

TEST TIME: 3:00:00
FURNACE ATMOSPHERE TEMPERATURE: 1929.8 DEG. F
ASTM TEMPERATURE: 1925 DEG. F
DIFFERENCE: 4.8 DEG. F

| | |
|---|---|
| AVG TEMP. OF T/C 1-5-= 1927 F | 0 |
| AVG TEMP. OF T/C 3-10-15= 1686 F | 2" |
| AVG TEMP. OF T/C 4-6-18= 1361 F | 4" |
| AVG TEMP. OF T/C 7-19-21= 985 F | 6" |
| AVG TEMP. OF T/C 9-2-16= 550 F | 8" |
| AVG TEMP. OF T/C 11-14-20= 222 F | 10" |
| AVG TEMP. OF T/C 8-12-17= 101 F | 12" |
| AVG TEMP. OF T/C 22-23-24= 79 F | 14" |

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| FRAME NO. | PRINT NO. | T/C NO. | TEMPERATURE, DEG. F | TEMPERATURE INCR., DEG. F | TIME INCR., MINUTES |
|---|---|---|---|---|---|
| 11 | 1 | 1 | 1144.6 | -121.5 | 3 |
| 11 | 2 | 2 | 677.4 | 28.3 | 3 |
| 11 | 3 | 3 | 1506.8 | -77.4 | 3 |
| 11 | 4 | 4 | 1310.2 | -1.4 | 3 |
| 11 | 5 | 5 | 1186.4 | -119.8 | 3 |
| 11 | 6 | 6 | 1424.6 | -4.6 | 3 |
| 11 | 7 | 7 | 1004.1 | 12.7 | 3 |
| 11 | 8 | 8 | 96.4 | 2.2 | 3 |
| 11 | 9 | 9 | 485.2 | 18.2 | 3 |
| 11 | 10 | 10 | 1550.7 | -77.1 | 3 |
| 11 | 11 | 11 | 260.2 | 12.6 | 3 |
| 11 | 12 | 12 | 117.1 | 3.6 | 3 |
| 12 | 1 | 13 | 32.6 | 32.6 | 3 |
| 12 | 2 | 14 | 279.5 | 13.6 | 3 |
| 12 | 3 | 15 | 497.5 | 497.5 | 3 |
| 12 | 4 | 16 | 699.1 | 25.4 | 3 |
| 12 | 5 | 17 | 118.4 | 4.3 | 3 |
| 12 | 6 | 18 | 1393.6 | -7.1 | 3 |
| 12 | 7 | 19 | 1092.7 | 16.0 | 3 |
| 12 | 8 | 20 | 236.4 | 11.4 | 3 |
| 12 | 9 | 21 | 984.8 | 12.3 | 3 |
| 12 | 10 | 22 | 79.5 | .2 | 3 |
| 12 | 11 | 23 | 78.3 | .2 | 3 |
| 12 | 12 | 24 | 79.7 | .3 | 3 |

TEST TIME: 3:10:00
FURNACE ATMOSPHERE TEMPERATURE: 1166.2 DEG. F
ASTM TEMPERATURE: 1938 DEG. F
DIFFERENCE: -771.8 DEG. F

AVG TEMP. OF T/C 1-5-= 1165 F
AVG TEMP. OF T/C 3-10-15= 1185 F
AVG TEMP. OF T/C 4-6-18= 1376 F
AVG TEMP. OF T/C 7-19-21= 1027 F
AVG TEMP. OF T/C 9-2-16= 621 F
AVG TEMP. OF T/C 11-14-20= 259 F
AVG TEMP. OF T/C 8-12-17= 111 F
AVG TEMP. OF T/C 22-23-24= 79 F

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| FRAME NO. | PRINT NO. | T/C NO. | TEMPERATURE, DEG. F | TEMPERATURE INCR., DEG. F | TIME INCR., MINUTES |
|---|---|---|---|---|---|
| 11 | 1 | 1 | 1016.8 | -127.8 | 5 |
| 11 | 2 | 2 | 716.8 | 39.4 | 5 |
| 11 | 3 | 3 | 1406.4 | -100.4 | 5 |
| 11 | 4 | 4 | 1290.1 | -20.1 | 5 |
| 11 | 5 | 5 | 1053.6 | -132.8 | 5 |
| 11 | 6 | 6 | 1397.4 | -27.2 | 5 |
| 11 | 7 | 7 | 1018.3 | 14.3 | 5 |
| 11 | 8 | 8 | 99.8 | 3.5 | 5 |
| 11 | 9 | 9 | 512.5 | 27.3 | 5 |
| 11 | 10 | 10 | 1449.5 | -101.1 | 5 |
| 11 | 11 | 11 | 279.8 | 19.6 | 5 |
| 11 | 12 | 12 | 123.5 | 6.4 | 5 |
| 12 | 1 | 13 | 550.9 | 518.3 | 5 |
| 12 | 2 | 14 | 300.5 | 20.9 | 5 |
| 12 | 3 | 15 | 1324.6 | 827.1 | 5 |
| 12 | 4 | 16 | 734.8 | 35.7 | 5 |
| 12 | 5 | 17 | 125.1 | 6.7 | 5 |
| 12 | 6 | 18 | 1362.9 | -30.7 | 5 |
| 12 | 7 | 19 | 1109.4 | 16.7 | 5 |
| 12 | 8 | 20 | 253.6 | 17.2 | 5 |
| 12 | 9 | 21 | 999.0 | 14.2 | 5 |
| 12 | 10 | 22 | 79.4 | -.0 | 5 |
| 12 | 11 | 23 | 78.4 | .0 | 5 |
| 12 | 12 | 24 | 79.9 | .2 | 5 |

TEST TIME: 3:15:00
FURNACE ATMOSPHERE TEMPERATURE: 1009.8 DEG. F
ASTM TEMPERATURE: 1944 DEG. F
DIFFERENCE: -934.2 DEG. F

AVG TEMP. OF T/C 1-5-= 1035 F
AVG TEMP. OF T/C 3-10-15= 1393 F
AVG TEMP. OF T/C 4-6-18= 1350 F
AVG TEMP. OF T/C 7-19-21= 1042 F
AVG TEMP. OF T/C 9-2-16= 655 F
AVG TEMP. OF T/C 11-14-20= 278 F
AVG TEMP. OF T/C 8-12-17= 116 F
AVG TEMP. OF T/C 22-23-24= 79 F

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| FRAME NO. | PRINT NO. | T/C NO. | TEMPERATURE, DEG. F | TEMPERATURE INCR., DEG. F | TIME INCR., MINUTES |
|---|---|---|---|---|---|
| 11 | 1 | 1 | 924.4 | -92.4 | 5 |
| 11 | 2 | 2 | 752.9 | 36.2 | 5 |
| 11 | 3 | 3 | 1323.4 | -83.0 | 5 |
| 11 | 4 | 4 | 1260.0 | -30.1 | 5 |
| 11 | 5 | 5 | 961.0 | -92.7 | 5 |
| 11 | 6 | 6 | 1360.2 | -37.2 | 5 |
| 11 | 7 | 7 | 1024.1 | 5.7 | 5 |
| 11 | 8 | 8 | 103.9 | 4.1 | 5 |
| 11 | 9 | 9 | 542.4 | 29.9 | 5 |
| 11 | 10 | 10 | 1365.8 | -83.7 | 5 |
| 11 | 11 | 11 | 299.0 | 19.2 | 5 |
| 11 | 12 | 12 | 131.6 | 8.1 | 5 |
| 12 | 1 | 13 | 794.3 | 243.4 | 5 |
| 12 | 2 | 14 | 322.7 | 22.3 | 5 |
| 12 | 3 | 15 | 0.0 | | |
| -1324.56345091 DDDD.D | | | | | |
| | 5 | | | | |
| 12 | 4 | 16 | 769.5 | 34.8 | 5 |
| 12 | 5 | 17 | 132.3 | 7.2 | 5 |
| 12 | 6 | 18 | 1323.9 | -39.0 | 5 |
| 12 | 7 | 19 | 1115.7 | 6.3 | 5 |
| 12 | 8 | 20 | 271.2 | 17.5 | 5 |
| 12 | 9 | 21 | 1005.3 | 6.3 | 5 |
| 12 | 10 | 22 | 79.9 | .4 | 5 |
| 12 | 11 | 23 | 79.0 | .6 | 5 |
| 12 | 12 | 24 | 80.6 | .6 | 5 |

TEST TIME: 3:20:00
FURNACE ATMOSPHERE TEMPERATURE: 902.6 DEG. F
ASTM TEMPERATURE: 1950 DEG. F
DIFFERENCE: -1047.4 DEG. F

AVG TEMP. OF T/C 1-5-= 943 F
AVG TEMP. OF T/C 3-10-15= 1345 F
AVG TEMP. OF T/C 4-6-18= 1315 F
AVG TEMP. OF T/C 7-19-21= 1048 F
AVG TEMP. OF T/C 9-2-16= 688 F
AVG TEMP. OF T/C 11-14-20= 298 F
AVG TEMP. OF T/C 8-12-17= 123 F
AVG TEMP. OF T/C 22-23-24= 80 F

INDEX= 43

| FRAME NO. | PRINT NO. | T/C NO. | TEMPERATURE, DEG. F | TEMPERATURE INCR., DEG. F | TIME INCR., MINUTES |
|---|---|---|---|---|---|
| 11 | 1 | 1 | 852.0 | -72.3 | 5 |
| 11 | 2 | 2 | 803.1 | 50.2 | 5 |
| 11 | 3 | 3 | 1253.1 | -70.3 | 5 |
| 11 | 4 | 4 | 1227.0 | -33.0 | 5 |
| 11 | 5 | 5 | 888.4 | -72.6 | 5 |
| 11 | 6 | 6 | 1321.2 | -39.0 | 5 |
| 11 | 7 | 7 | 1022.1 | -2.0 | 5 |
| 11 | 8 | 8 | 108,3 | 4.4 | 5 |
| 11 | 9 | 9 | 571.8 | 29.4 | 5 |
| 11 | 10 | 10 | 1295.1 | -70.7 | 5 |
| 11 | 11 | 11 | 318.8 | 19.8 | 5 |
| 11 | 12 | 12 | 140.3 | 8.6 | 5 |
| 12 | 1 | 13 | 753.0 | -41.3 | 5 |
| 12 | 2 | 14 | 345.4 | 22.7 | 5 |
| 12 | 3 | 15 | 0.0 | 0.0 | 5 |
| 12 | 4 | 16 | 806.5 | 36.9 | 5 |
| 12 | 5 | 17 | 140.4 | 8.1 | 5 |
| 12 | 6 | 18 | 1284.5 | -39.5 | 5 |
| 12 | 7 | 19 | 1114.2 | -1.6 | 5 |
| 12 | 8 | 20 | 288.4 | 17.2 | 5 |
| 12 | 9 | 21 | 1004.5 | -.9 | 5 |
| 12 | 10 | 22 | 79.6 | -.3 | 5 |
| 12 | 11 | 23 | 79.2 | .2 | 5 |
| 12 | 12 | 24 | 80.2 | -.4 | 5 |

TEST TIME: 3:25:00
FURNACE ATMOSPHERE TEMPERATURE: 820.7 DEG. F
ASTM TEMPERATURE: 1956 DEG. F
DIFFERENCE: -1135.3 DEG. F

AVG TEMP. OF T/C 1-5-= 870 F
AVG TEMP. OF T/C 3-10-15= 1274 F
AVG TEMP. OF T/C 4-6-18= 1278 F
AVG TEMP. OF T/C 7-19-21= 1047 F
AVG TEMP. OF T/C 9-2-16= 727 F
AVG TEMP. OF T/C 11-14-20= 318 F
AVG TEMP. OF T/C 8-12-17= 130 F
AVG TEMP. OF T/C 22-23-24= 80 F

TRANSCO (CR5163) - 04/14/83

TEST COMMENTS

2:25:00 T/C #13 BURN OUT
2:30:00 T/C #13 REMOVED FROM AVG

3:00:00 BUNERS TURNED OFF. INST. LEFT RECORING

NO SMOKE OR OTHE OCCURANCES NOTED DURING FIRE TEST.
DRAFT RUN AT .08 NEG.
NO HOSE STREAM TEST RUN.

TEST REPORT No.TTR-30N

8LB/Ft² Cerwool, 7-2 Inch
Layers - Schmidt Method for a Three Hour ASTM E-119 Fire

| Plane<br>Time | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 7 | 10 | 1 | 2 | 3 | 4 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 min. | 75 | 75 | | | | | | | | | | | | | |
| 10 min. | 1300 | 687.5 | 75 | | | | | | | | | | | | |
| 20 min. | 1462 | 687.5 | 381 | 75 | | | | | | | | | | | |
| 30 min. | 1550 | 966 | 381 | 228 | 75 | | | | | | | | | | |
| 40 min. | 1613 | 966 | 597 | 228 | 152 | 75 | | | | | | | | | |
| 50 min. | 1661 | 1129 | 597 | 374 | 152 | 114 | 75 | | | | | | | | |
| 1:00 Hours | 1700 | 1129 | 752 | 374 | 244 | 114 | 94 | 75 | | | | | | | |
| 1:10 min. | 1735 | 1244 | 752 | 498 | 244 | 169 | 94 | 84.5 | 75 | | | | | | |
| 1:20 min. | 1765 | 1244 | 871 | 498 | 333 | 169 | 127 | 84.5 | 80 | 75 | | | | | |
| 1:30 min. | 1792 | 1331 | 871 | 602 | 333 | 230 | 127 | 103.5 | 80 | 77.5 | 75 | | | | |
| 1:40 min. | 1815 | 1331 | 966 | 602 | 416 | 230 | 167 | 103.5 | 90.5 | 77.5 | 76.2 | 75 | | | |
| 1:50 min. | 1835 | 1400 | 966 | 691 | 416 | 292 | 167 | 129 | 90.5 | 83.4 | 76.2 | 75.6 | 75 | | |
| 2:00 Hours | 1850 | 1400 | 1046 | 691 | 492 | 292 | 210 | 129 | 106 | 83.4 | 79.5 | 75.6 | 75.3 | 75 | |
| 2:10 min. | 1862 | 1454 | 1046 | 769 | 492 | 351 | 210 | 158 | 106 | 92.8 | 79.5 | 77.4 | 75.3 | 75.2 | 75 |
| 2:20 min. | 1875 | 1454 | 1112 | 769 | 560 | 351 | 254 | 158 | 125.4 | 92.8 | 85.1 | 77.4 | 76.3 | 75.2 | 75 |
| 2:30 min. | 1888 | 1500 | 1112 | 836 | 560 | 407 | 254 | 190 | 125.4 | 105.2 | 85.1 | 80.7 | 76.3 | 75.8 | 75.2 |
| 2:40 min. | 1900 | 1500 | 1168 | 836 | 621.5 | 407 | 298.5 | 190 | 147.6 | 105.2 | 93.0 | 80.7 | 78.2 | 75.8 | 75.2 |
| 2:50 min. | 1912 | 1540 | 1168 | 895 | 621.5 | 460 | 298.5 | 223 | 147.6 | 120.3 | 93.0 | 85.6 | 78.2 | 77 | 75.8 |
| 3:00 min. | 1925 | 1540 | 1217 | 895 | 678 | 460 | 342 | 223 | 172 | 120.3 | 103 | 85.6 | 81.3 | 77 | 77 |
| | $\frac{31440}{18}$ | $\frac{22503}{18}$ | $\frac{15003}{17}$ | $\frac{9786}{16}$ | $\frac{6315}{15}$ | $\frac{4046}{14}$ | $\frac{2643}{13}$ | $\frac{1776}{12}$ | $\frac{1271}{11}$ | $\frac{958.4}{10}$ | $\frac{770.6}{9}$ | $\frac{638.6}{8}$ | $\frac{540.8}{7}$ | $\frac{456}{6}$ | $\frac{378.2}{5}$ |

$$(L)^2 = \frac{2\ K\Delta t}{C_p\ P}$$

$$L^2 = \frac{(2)\ (0.36)\ (10\ \text{min.})}{(0.212)(60)(8)(12)}$$

Lx = 0.07678 ft.

L = 0,9214 inch

nL = 14 x 0.9214 inches = 12.9 inches total thickness

$$\frac{98,525.6}{179} = 550,4$$

k = 0.36

$C_p$ = 0212

TRANSCO INC

TEST REPORT No.: TTR-31N

TEST REPORT

AXIAL HEAT CONDUCTION OF
AN INSULATED STEEL MEMBER
IN AN ASTM E-119 FIRE TEST

TEST PERFORMED AT STREATOR, ILLINOIS
MAY 10, 1983

Test Performed By: W. D. Brown

W. D. Brown, P.E.
Mgr. Product Development
Insulation Products Division

Loren Pitts
Product and Development Engineer

## 1. INTRODUCTION

A Schmidt calculation was performed to predict the amount of insulation necessary to isolate a steel plate from the effects of a three (3) hour fire, as defined by ASTM E-119. This calculation formed the basis for TTR-30N. This calculation has been modified to predict the length of insulated support steel required to isolate a steel fabrication from the effects of a three-hour fire.

The Schmidt calculation for an infinite wall assumes heat transfer is in one direction only, perpendicular to the wall. The front face is at some temperature that may vary with time. It is assumed there are no edge losses in the infinite wall.

The Schmidt method predicted approximately 5'-5" of insulated steel would be required to isolate a steel member from the effects of a three (3) hour fire.

See TTR-30N for more background on the Schmidt method.

## 2. TEST ASSEMBLY

The test apparatus consisted of the Transco 2000°F oven, a 2" x 1½" x ¼" thick eight (8) foot long carbon steel angle, wrapped with Cer-wool, and an oven face plate made from stainless steel.

The steel oven cover had a three (3) inch square hole cut in the center of the plate. The angle iron was then placed horizontally with approximately one foot of the member extending into the oven cavity. The oven's internal dimensions measure 10" wide by 8" high by 12" deep. The oven's internals are shown in Figure I. Oven insulation consists of six (6) inches of calcium silicate.

The beam was then instrumented with two (2) thermocouples every one foot, beginning at the face of the oven and working out from the oven.

The angle iron was then wrapped with Cer-wool as shown in Figures II and III. The first two (2) feet of angle iron had approximately eight (8) inches of insulation. The second two (2) feet had approximately six (6) inches of insulation. The balance of the angle had approximately four (4) inches of insulation.

The thermocouples are connected to a gang switch. Output voltages are read by a Fluke 2100A Digital thermometer. Oven temperature is controlled by a Leeds & Northrup Electromax controller. The controller holds the temperature setpoint to +/- 10°F at 1925°F. The oven's outside dimensions are approximately 25" x 25" x 19" deep.

Figures II and III show the completed test assembly.

3. TEST PROCEDURE

At time zero, the oven was at 102°F. The switch was turned on and the oven controller was set to 1925°F. Oven temperature readings were taken every five (5) minutes. All thermocouples were read every fifteen (15) minutes.

The purpose of taking readings of the oven temperature every five (5) minutes was to determine the rate of rise in oven temperature and compare it with the ASTM E-119 curve for a three (3) hour fire.

Eighty (80) minutes into the test it was noted the oven temperature was reading 1945°F, even though the controller was set for 1925°F. The controller was then set down to 1830°F to more closely control the oven temperature to the actual temperature of 1925°F.

Ninety (90) minutes into the test it was noted the oven was hunting excessively at the setpoint. The door (which may be seen in the left of Figure III) was closed. The oven cycling decreased.

Thirty minutes into the test it was noted excess heat was coming from the steel face plate. Figure IV shows the Cer-wool, steel face plate interface at the start of the test. The plate was warping causing excess heat loss at the oven/plate interface. A loose blanket of marinite was made and placed over the top of the junction. The blanket is shown in Figure V. Figure VI shows loose fiberglass packed below the junction to shield the electrical controller from the effects of the heat leaking from the junction. Figure VII is a closeup of the junction (same view as Figure V).

4. TEST RESULTS

The results are given in Figure VIII. Figure VIII is the temperature at various distances from the oven face. The right hand side of Figure VIII includes an expanded scale to more closely see the asymptotic approach to room temperature of the temperature profile.

The calculated temperature profile was based on a room temperature of 75°F, and the room was actually close to 70°F. Consequently, 5°F was subtracted from the original calculated curve to form the curve that closely levels off at 70°F. The five (5) degree differential does not significantly affect the calculated temperatures over 150°F.

In Figure VIII the calculated curve always predicts a higher temperature profile than was actually experienced. This could be the technique, or perhaps the heat loss at the front oven face/insulation interface.

The heat loss at the insulation/oven front interface is a plausible explanation. In Figure VIII the thermocouples at the interface are approximately 300°F below the oven temperature. In dismantling the assembly, it was noted the interface thermocouples were located approximately ½" to 3/4" out from the oven. As the insulation was not tightly wrapped around the angle iron, and the opening in the plate front face was three (3) inches square, the thermocouples were almost "seeing" the inside of the oven. Because the thermocouples were reading approximately 300°F less than the oven, it appears the interface was experiencing excessive heat loss.

The calculation indicated that 5'-5" is sufficient to isolate the steel from the effects of the three-hour fire. Approximately 4'-6" was determined by experiment. Using the measured as a basis, the calculated length was in error by plus 20 percent of the measured.

Perhaps if the oven interface had been better sealed, the difference would have been significantly less.

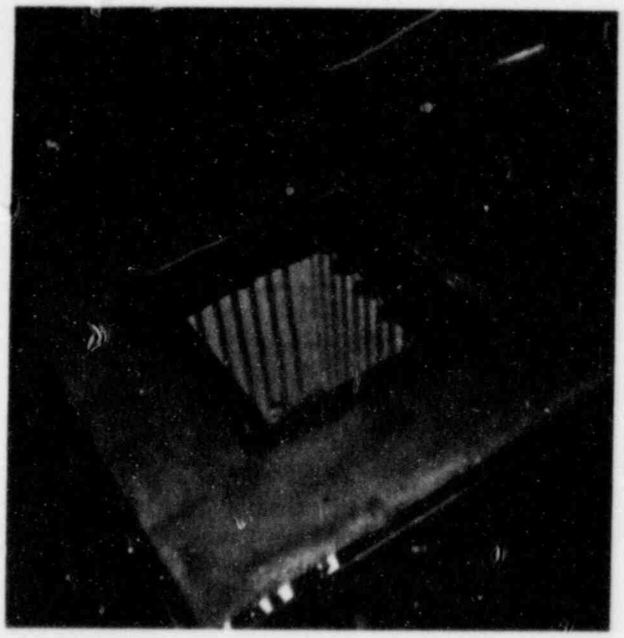
Figure IX is a comparison between the Transco oven temperature rise and that required by ASTM E-119. For experimental uses, the Transco oven temperature rise closely approaches that of the ASTM E-119 three (3) hour temperature profile.

To verify the two temperature profiles were close to each other, the total area under the two curves was determined, in degree-minutes. For the ASTM E-119 the area determined was 302,825 degree-minutes. The Transco oven had a measured area of 291,435 degree-minutes. The Transco area is within 96 percent of the ASTM E-119 area. By the area being within five percent of the ASTM E-119 temperature and time curve, the oven's response meets the requirements of ASTM E-119.

## 5. CONCLUSIONS

The Transco oven is qualified to reproduce the ASTM E-119 temperature/time curve within acceptable tolerances, for a three (3) hour duration.

To prevent a three (3) hour fire from conducting heat down the support steel to the item being supported, a minimum of 4'-6" of steel should be insulated. The steel should be insulated to such thickness so as to prevent any heat gain from the fire directly through the insulation to the steel.



OVEN INTERNAL SPACE

(Oven Laying on its Back)

FIGURE I

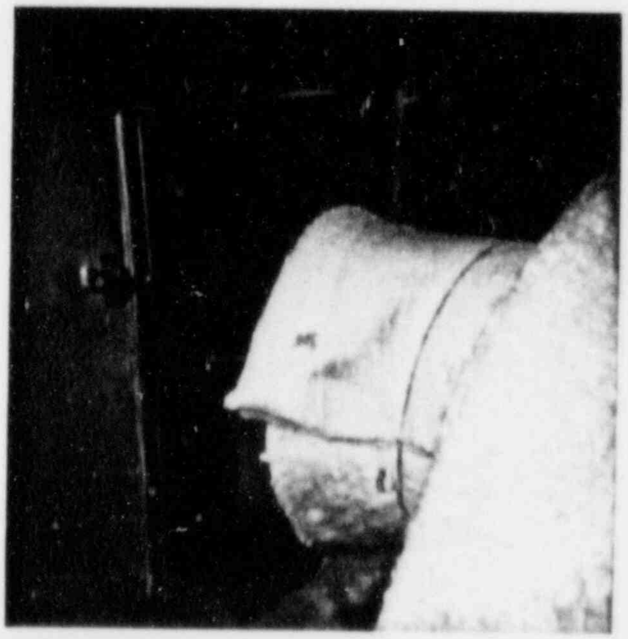
COMPLETELY WRAPPED ANGLE IRON

(Note Thermocouple Leads)

FIGURE II

COMPLETE TEST ASSEMBLY

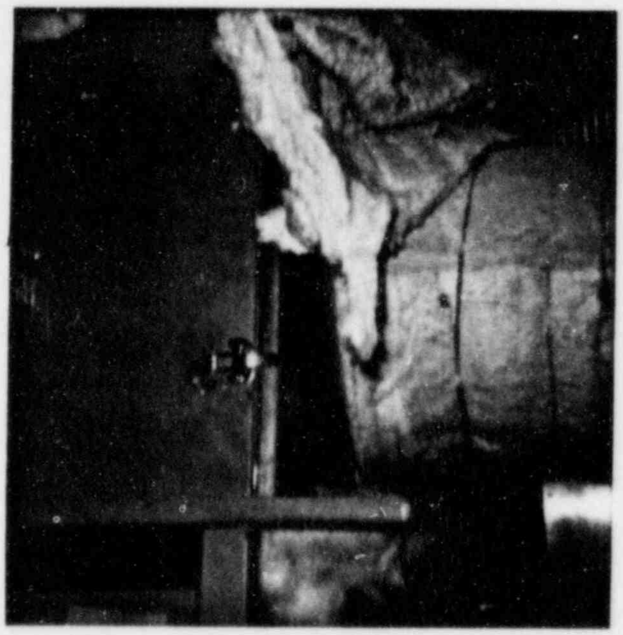
FIGURE III



OVEN/COVER PLATE INTERFACE

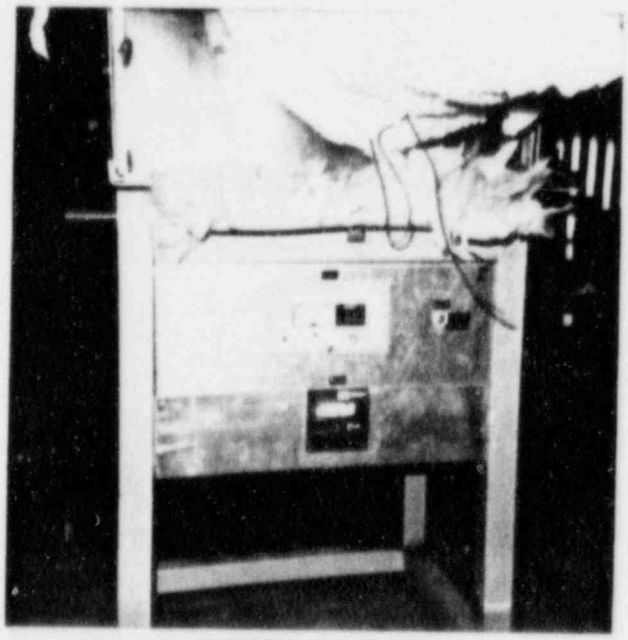
(Note Blanket Laid Back)

FIGURE IV



OVEN/COVER PLATE INTERFACE
WITH BLANKET IN PLACE

FIGURE V



BOTTOM SIDE OF
OVEN/COVER PLATE INTERFACE

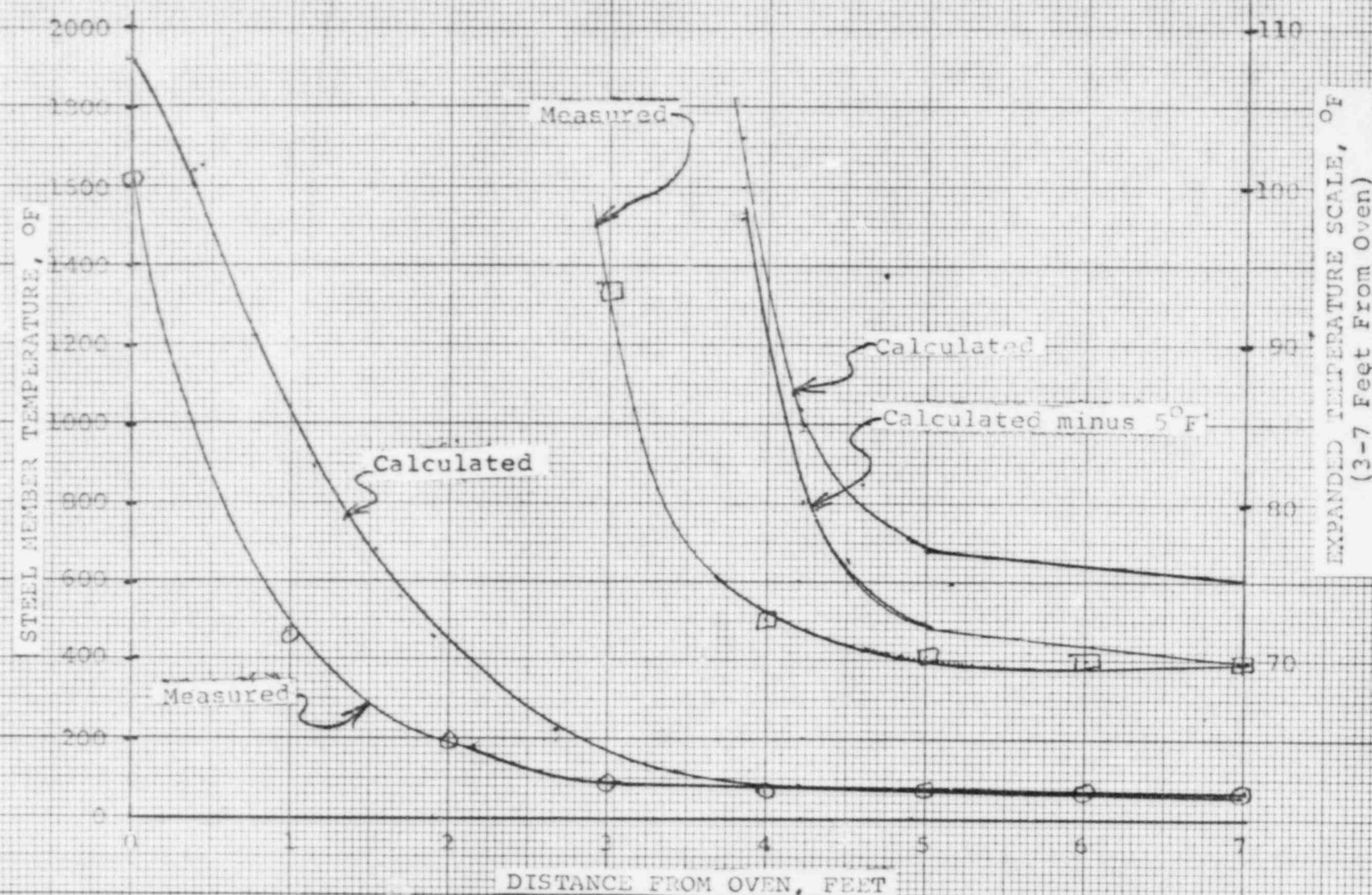
(Note Loose Fiberglass Packing to
Shield Controller From Radiant Heat)

FIGURE VI

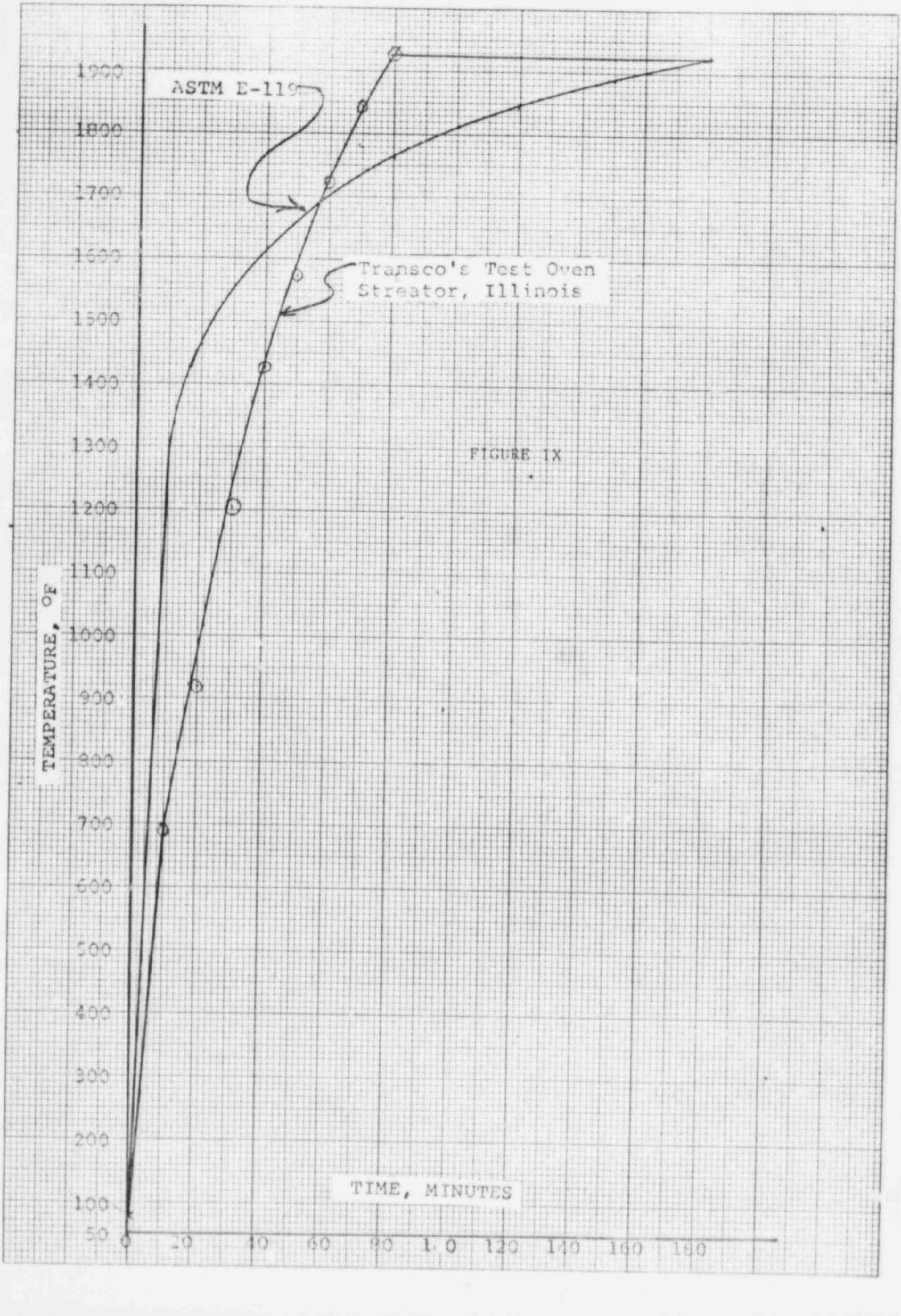
CLOSEUP OF OVEN/COVER
PLATE INTERFACE

FIGURE VII

FIGURE VIII



2000
1800
1600
1400
1200
1000
800
600
400
200
0
STEEL MEMBER TEMPERATURE, °F
0
1
2
3
4
5
6
7
DISTANCE FROM OVEN, FEET
110
100
90
80
70
EXPANDED TEMPERATURE SCALE, °F
(3-7 Feet From Oven)
Measured
Calculated
Measured
Calculated
Calculated minus 5°F



ASTM E-119
Transco's Test Oven
Streator, Illinois
TEMPERATURE, °F
1900
1800
1700
1600
1500
1400
1300
1200
1100
1000
900
800
700
600
500
400
300
200
100
50
TIME, MINUTES
0
20
40
60
80
100
120
140
160
180


FIGURE IX

## ESTIMATE OF LENGTH OF STEEL REQUIRED TO BE INSULATED, FROM DUCT, TO PREVENT STEEL FROM HEATING DUCT

The Schmidt Analysis done for the Cer-wool is based on an infinite plane, i.e., there are no edge losses. If the steel is insulated so that the fire can only "see" bare steel a certain distance away from the duct, then the insulated steel will be the same as an infinite plane with a high temperature (the portion of steel seeing the flame) front face. Only the constants in the Schmidt calculation will change. The constants being for steel, instead of Cer-wool

By the Schmidt equation:

$$L^2 = 2k\,(dT)/c_p p$$

Where:

L = Spacing between planes, feet
k = Thermal Conductivity, BTUH/Ft. - $^{o}$F
dT = Time increment between averages, Hrs.
$c_p$ = Specific Heat, BTU/Lb. - $^{o}$F
p = Density, Lbs./Ft.$^3$
n = Number of insulation spaces, no dimension

In reviewing the Schmidt Table, for all practical purposes we can assume we have 14 spaces with a temperature rise of 2$^{o}$F,

By TTR-30N, the average temperature for 14 spaces will be 550.4$^{o}$F where:

k = 28 BTUH/Ft. - $^{o}$F
p = 490 Lb./Ft.$^3$
n = 14
$c_p$ = .13 BTU/Lb. - $^{o}$F

Substituting:

$$L = (2 \times 28)(10/60)/(0.13 \times 490)^{1/2} = 0.38278 \text{ Ft.} = 4.5934 \text{ inches}$$

$$nL = (14)(4.5934 \text{ inches}) = 64.30 \text{ inches} = 5'\text{-}5''$$

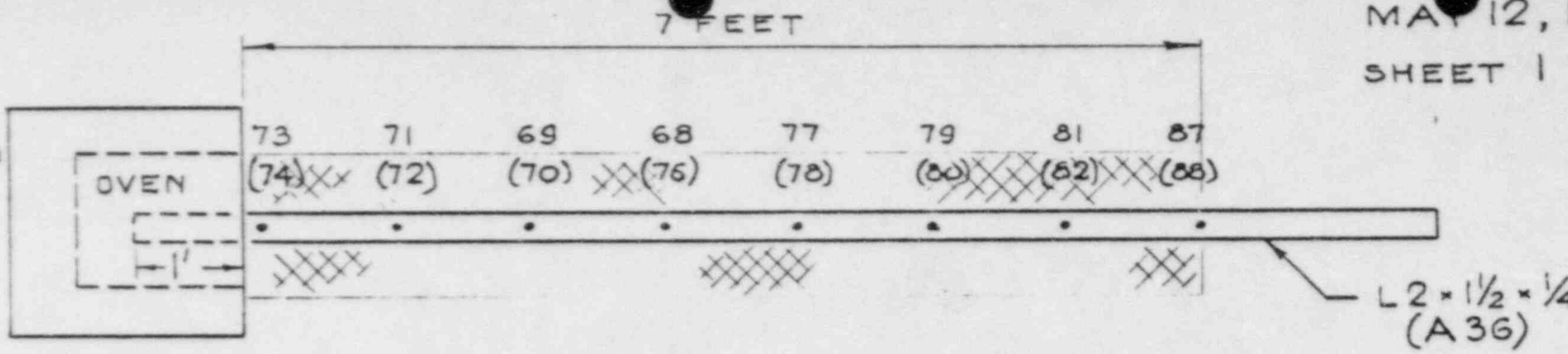
# APPENDIX

(Data on File in Transco Offices)

MAY 12, 1983



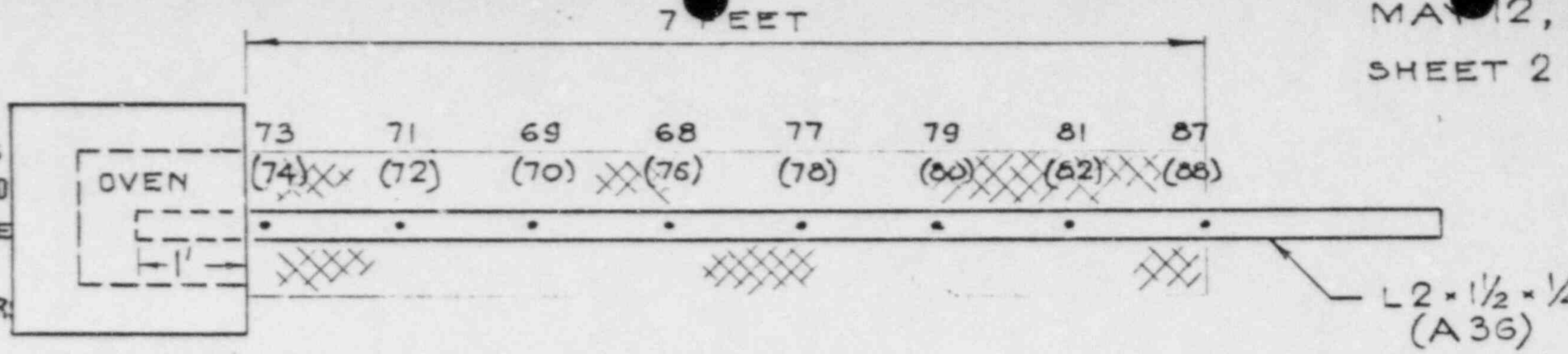
TIME 12:15 PM




THERMOCOUPLES

| (MIN) TIME | OVEN #83 | #73 | #74 | #71 | #72 | #69 | #70 | #68 | #76 | #77 | #78 | #79 | #80 | #81 | #82 | #87 | #88 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 101.7 | 83.6 | 84.0 | 70.8 | 70.8 | 69.3 | 69.4 | 68.9 | 68.9 | 68.9 | 68.9 | 68.9 | 69.1 | 69.0 | 68.9 | 68.6 | 68.6 |
| 5 | 453.0 | | | | | | | | | | | | | | | | |
| 10 | 692.2 | | | | | | | | | | | | | | | | |
| 15 | 821.5 | 297.4 | 329.1 | 72.4 | 72.4 | 69.3 | 69.5 | 68.9 | 68.9 | 68.9 | 68.8 | 68.9 | 68.9 | 68.9 | 68.9 | 68.5 | 68.7 |
| 20 | 920 | | | | | | | | | | | | | | | | |
| 25 | 947 | | | | | | | | | | | | | | | | |
| 30 | 1203 | 613.1 | 650.4 | 87.2 | 87.4 | 69.5 | 69.7 | 68.9 | 68.9 | 68.8 | 68.7 | 68.8 | 69.3 | 68.9 | 68.9 | 68.5 | 68.4 |
| 35 | 1334 | | | | | | | | | | | | | | | | |
| 40 | 1426 | | | | | | | | | | | | | | | | |
| 45 | 1502 | 892 | 926 | 124.5 | 124.5 | 70.8 | 71.1 | 68.9 | 68.9 | 68.8 | 68.8 | 68.8 | 68.9 | 68.9 | 68.9 | 68.5 | 68.4 |
| 50 | 1573 | | | | | | | | | | | | | | | | |
| 55 | 1641 | | | | | | | | | | | | | | | | |
| 60 | 1726 | 1100.7 | 1131 | 169.9 | 175.9 | 74.5 | 75.2 | 68.9 | 69.0 | 68.7 | 68.7 | 68.7 | 68.9 | 68.9 | 68.9 | 68.4 | 68.3 |
| 65 | 1788 | | | | | | | | | | | | | | | | |

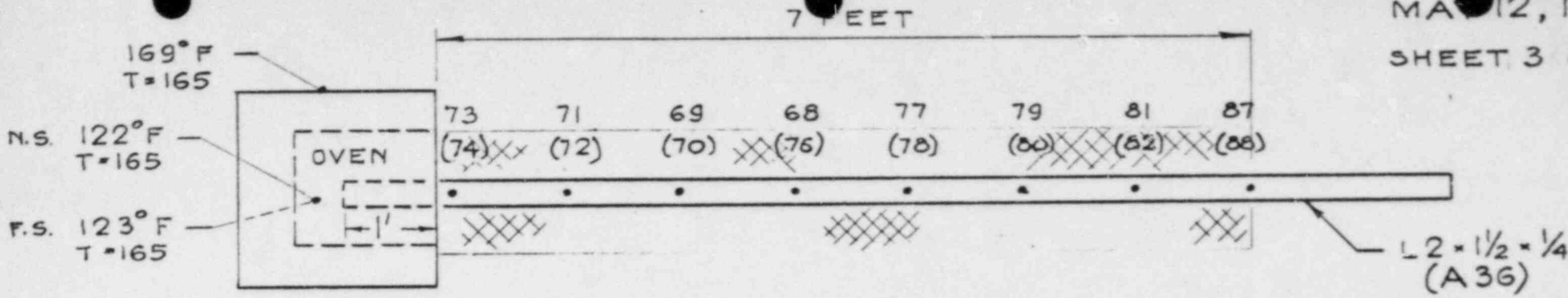
NOTE: ALL OVEN READINGS AFTER TIME=80 ARE ± 10°F DUE TO ON-OFF CYCLING OF CTLR.




THERMOCOUPLES

| (MIN) TIME | OVEN #83 | #73 | #74 | #71 | #72 | #69 | #70 | #68 | #76 | #77 | #78 | #79 | #80 | #81 | #82 | #87 | #88 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 70 | 1844 | | | | | | | | | | | | | | | | |
| 75 | 1895 | 1295 | 1333 | 222.4 | 230.2 | 82.6 | 83.5 | 69.4 | 69.6 | 68.8 | 68.9 | 68.8 | 69.1 | 68.9 | 68.9 | 68.5 | 68.4 |
| 80 | 1945 | RESET CONTROLLER @ 1835, 1825, 1833 | | | | | | | | | | | | | | | |
| 85 | 1908 | ELEMENTS IN OFF CYCLE, RAISED TO 1842, 1860 | | | | | | | | | | | | | | | |
| 90 | 1920* | 1440 | 1477 | 280.4 | 288.5 | 93.5 | 94.3 | 70.4 | 70.6 | 68.9 | 68.9 | 68.8 | 69.0 | 68.9 | 69.0 | 68.6 | 68.6 |
| 95 | 1926* | *(CYCLING 1916 – 1930) | | | | | | | | | | | | | | | |
| 100 | 1917* | RAISED TO 1870 – CYCLE DROPPING | | | | | | | | | | | | | | | |
| 105 | 1931 | 1497 | 1533 | 335 | 345 | 107.1 | 108.6 | 72.2 | 72.6 | 69.1 | 69.1 | 68.9 | 69.1 | 68.9 | 68.9 | 68.8 | 68.7 |
| 110 | 1930 | AGAIN CYCLING 1916 – 1930 | | | | | | | | | | | | | | | |
| 115 | 1924 | | | | | | | | | | | | | | | | |
| 120 | 1919 | 1536 | 1568 | 394.0 | 403.3 | 123.5 | 124.8 | 74.9 | 75.6 | 69.5 | 69.5 | 69.1 | 69.2 | 69.2 | 69.1 | 69.0 | 68.9 |
| 125 | 1913 | (RESET TO 1882) | | | | | | | | | | | | | | | |
| 130 | 1926 | (CYCLING 1922 – 1937) | | | | | | | | | | | | | | | |
| 135 | 1932 | 1561 | 1592 | 435.5 | 445.8 | 137.7 | 139.7 | 77.9 | 79.3 | 70.0 | 70.0 | 69.4 | 69.4 | 69.3 | 68.6 | 69.3 | 69.2 ** |

* SOME INCREASE DUE TO CLOSING DOOR & TO SLIGHT DRAFT ACROSS OVEN & DOWN PIPE




THERMOCOUPLES

| TIME | OVEN #83 | #73 | #74 | #71 | #72 | #69 | #70 | #68 | #76 | #77 | #78 | #79 | #80 | #81 | #82 | #87 | #88 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 140 | 1924 | | | | | | | | | | | | | | | | |
| 145 | 1929+ | | | | | | | | | | | | | | | | |
| 150 | 1929+ | 1579.8 | 1608.5 | 479.6 | 490.1 | 154.7 | 156.0 | 82.1 | 83.8 | 70.7 | 70.7 | 69.6 | 69.7 | 69.5 | 69.5 | 69.5 | 69.4 |
| 155 | 1926+ | | | | | | | | | | | | | | | | |
| 160 | 1926+ | | | | | | | | | | | | | | | | |
| 165 | 1926+ | 1592 | 1619 | 521.9 | 531.7 | 173.4 | 175.6 | 70.8 | 88.8 | 71.6 | 71.5 | 70.0 | 70.0 | 69.7 | 69.7 | 69.8 | 69.7 |
| 170 | 1925+ | | | | | | | | | | | | | | | | |
| 175 | 1925+ | | | | | | | | | | | | | | | | |
| 180 | 1925+ | 1600.6 | 1626.9 | 554.2 | 564.5 | 187.8 | 190.2 | 92.0 | 94.5 | 72.6 | 72.6 | 70.2 | 70.3 | 69.9 | 69.9 | 70.0 | 69.9 |

+ = AVERAGE TEMP. OF CYCLES.

TRANSCO INC.
TEST REPORT No.: TTR-32N

# TEST REPORT
# TEMPERATURE RESPONSE OF LAYERED MINERAL WOOL TO A THREE-HOUR ASTM E-119 FIRE TEST WITH AND WITHOUT FOIL SPACERS

TEST PERFORMED AT STREATOR, ILLINOIS
MAY 19-20, 1983


Test Performed By: W. D. Brown
W. D. Brown, P.E.
Mgr. Product Development
Insulation Products Division

Loren Pitts
Product and Development Engineer

## 1. INTRODUCTION

Thermal Diffusivity is defined as:

$$a = k/pc$$

Where:

a = Thermal Diffusivity, in $Ft.^2/Hr.$
k = Thermal Conductivity, in BTUH/Ft. - $^oF$
p = Density in $Lbs./Ft.^3$
c = Specific Heat, in BTU/Lb. - $^oF$

Thermal diffusivity is a measure of the response of an insulation to a temperature transient. The lower the thermal diffusivity, the less rapidly a material responds to a thermal transient. Because conductivity and specific heat vary with temperature, thermal diffusivity varies with temperature. Generally diffusivity increases with temperature.

In TTR-30N Cer-wool thermal diffusivity was calculated to be 0.0176 $ft.^2/hr.$, at a mean temperature of $550^oF$. TTR-30N predicted a 13-inch thickness of Cer-wool was needed to thermally isolate a steel member.

The purpose of the test was to find a material or combination of materials that would isolate a steel member from the effects of a three (3) hour fire, and would be less than 13 inches in thickness.

In Thermal Insulation, by Malloy, 1968, it was noted that mineral wool had a thermal diffusivity of between 0.01 and 0.026. In one case a diffusivity of 0.012 was reported. In an attempt to locate a material that had a lower thermal diffusivity, it was decided to test the temperature response of 8 $lb./ft.^3$ density mineral wool.

Literature reviews also indicated that highly reflective foil placed between insulation layers increased the effectiveness of the insulation. The foil introduces a thermal discontinuity which has resulted in a reduced heat transfer.

## 2. TEST APPARATUS

The test apparatus consisted of the Transco test oven at Streator, Illinois, with associated instrumentation as detailed in TTR-31N. The oven was placed on its back.

A 24-gauge stainless steel plate 24 inches square was placed on the front face of the oven. As mineral wool has a temperature limit of

1200°F, a two (2) inch thick Cer-wool layer (temperature limit 2300°F) was placed on the plate. Then five layers of mineral wool, each two (2) inches thick were stacked on the plate. All layers were approximately 24 inches square. A stainless steel plate was then placed on the top of the assembly.

Three thermocouples were placed between each layer, one at the center and two on a common 45° line on each side of the center. Due to a mixup in the test briefing, the two thermocouples on the 45° line were placed outside of the projected area of the heated portion of the oven. Three thermocouples were placed between the Cer-wool and the steel bottom plate. Three thermocouples were also placed on the top of the uppermost cover plate.

No outer wrap was used to minimize edge losses.

The foiled assembly was the same configuration, except foil was placed between the layer of Cer-wool and mineral wool. Also, foil was placed between each layer of mineral wool thereafter. There were six (6) layers of mineral wool, for the foiled assembly. Thermocouples were placed on top of the foil in all cases. The thermocouples were positioned as before, except all thermocouples were placed in the projected area of the oven heated space.

3. TEST PROCEDURE

A set of zero thermocouple readings were taken, and the oven was then turned on. The temperature controller was set for 1925°F.

Every 15 minutes, a complete set of thermocouple readings were taken, and the oven temperature was recorded every five (5) minutes for the mineral wool assembly without the foil. The assembly with the foil, had complete thermocouple readings taken every 15 minutes. Oven readings were not taken on the five minutes, as it was noted the oven was providing reproducible results.

The non-foiled assembly is shown in Figures I and II. The foiled assembly is shown in Figures III and IV.

4. TEST RESULTS

The test results are shown in Figure V. Figure V is the temperature profile after three (3) hours. The measured Cer-wool curve from T -31N plotted in Figure V is a basis for comparison. It is evident from Figure V that mineral wool has a higher thermal diffusivity than Cer-wool. No attempt to quantify the difference in thermal diffusivity was made. It is sufficient to say the mineral wool thermal diffusivity was greater than that of Cer-wool.

Because two (2) of the three (3) thermocouples in each layer were outside the projected area of the heated portion of the oven, only the center thermocouple was used to determine the layer temperature in the non-foiled test of mineral wool. The scatter of the points about the curve is indicative of the thermocouples not being exactly on center.

The mineral wool with foil curve is a significant result. The addition of foil effectively reduces the thickness of mineral wool necessary for the same temperature profile by about two (2) inches.

In fact, mineral wool with foil performs better than Cer-wool, allowing approximately one inch in thickness reduction.

Figures VI, VII, and VIII are closeups of the first and second layer of mineral wool. Figure VI is the bottom of the first layer of mineral wool. This face was in direct contact with the Cer-wool. Figure VII is the top of the same layer. Notice the decrease in burn diameter. Figure VIII is the bottom of the second layer of mineral wool. Figures VII and VIII are different, because there was a layer of foil separating the two faces.

Note in Figure VI, the outer dark ring appears to be preliminary charring of the binder. The white ring is total burnout of the binder. The dark inner ring is charring of the mineral wool fibers. There appears to be gradeation in the center circle. No explanation is readily apparent for the inner circle gradeation.

The diameter of the charred portion of the mineral wool fibers decreases with increasing distance from the front face of the oven. The diameter on the first layer of mineral wool is greater because of the large amount of transverse heat transfer in the first layer. The transverse heat transfer is caused by the temperature gradient in the horizontal plane.

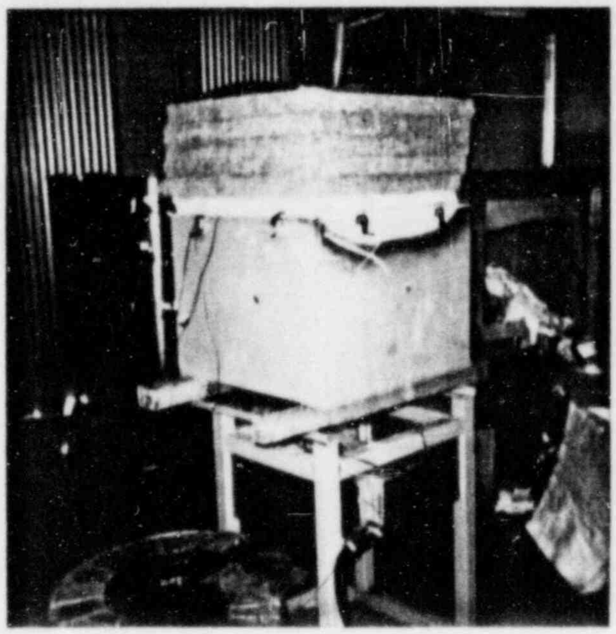
Isotherms in the mineral wool pile will approach a hemisphere with the center of the sphere being near the center of the front face of the oven.

## 5. CONCLUSIONS

Mineral wool has a thermal diffusivity greater than that of Cer-wool. Both the Cer-wool and mineral wool were eight (8) pound density material.

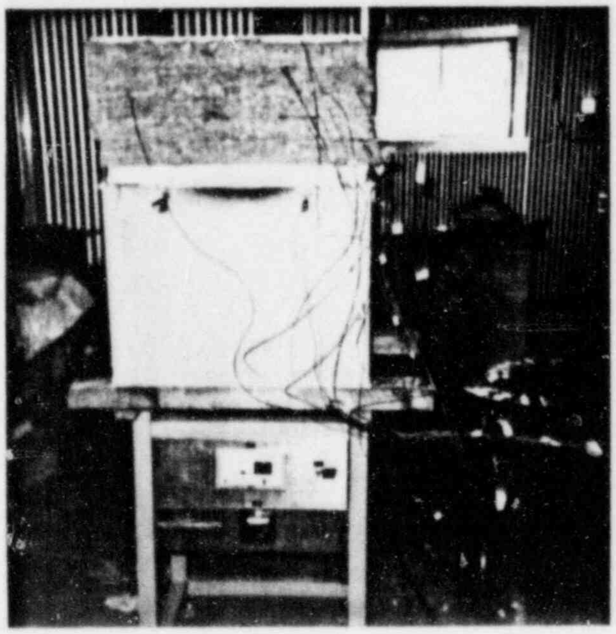
Mineral wool required approximately one inch greater thickness than Cer-wool on a 14-inch pile to produce the same temperature drop between hot and cold faces. Or, to produce equivalent temperature reductions between hot and cold faces requires approximately 7.5% more mineral wool than Cer-wool. By placement of stainless steel foil every two inches in a stack of mineral wool, a reduction of approximately 15% in thickness can be realized for the same hot and cold face temperatures.

Foil between layers of mineral wool make a significant difference in effective thermal diffusivity.



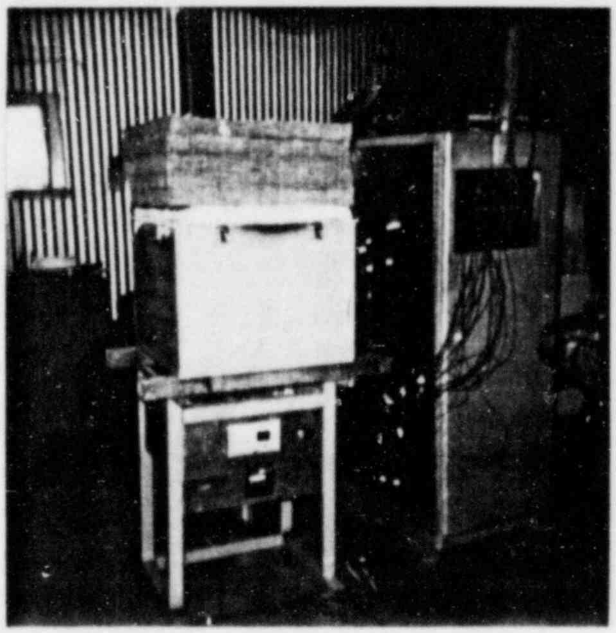
NON-FOILED MINERAL WOOL ASSEMBLY

FIGURE I



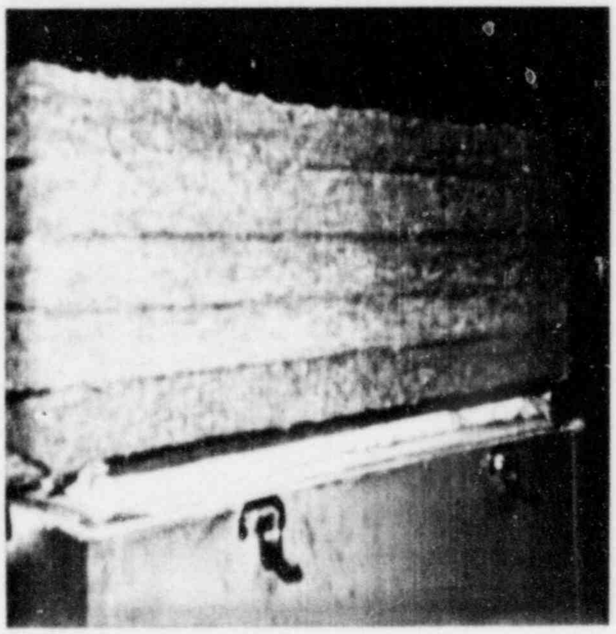
NON-FOILED MINERAL WOOL ASSEMBLY

FIGURE II



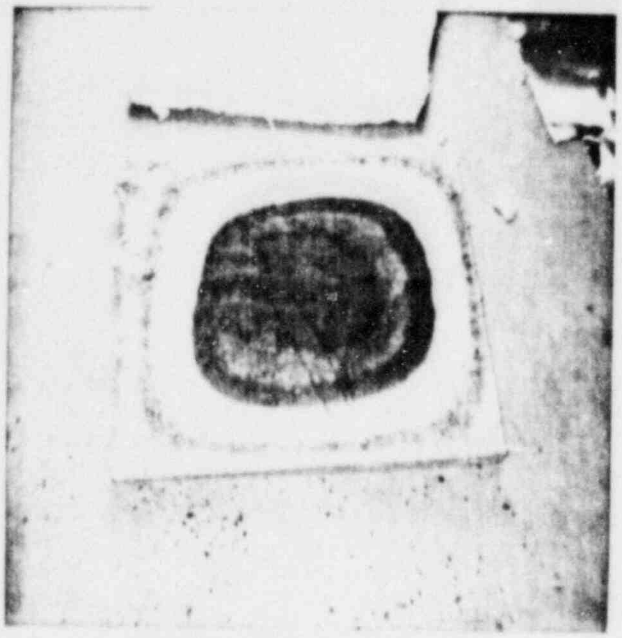
FOILED MINERAL WOOL ASSEMBLY

FIGURE III



FOILED MINERAL WOOL ASSEMBLY

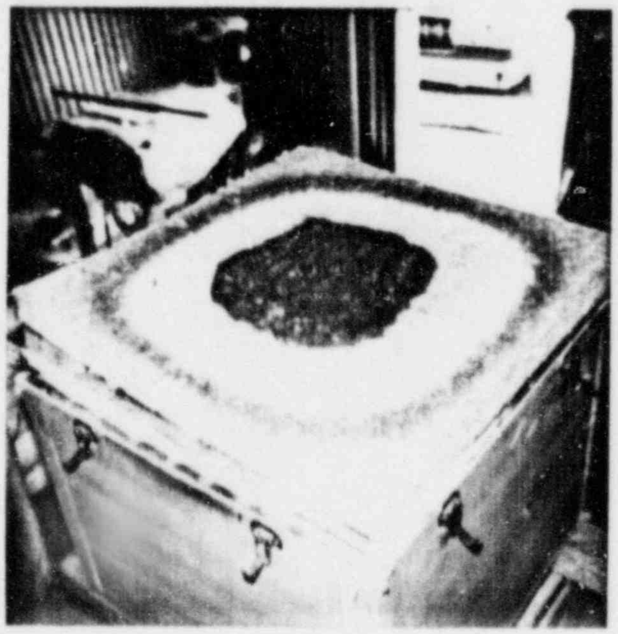
FIGURE IV



BOTTOM OF FIRST LAYER
OF MINERAL WOOL

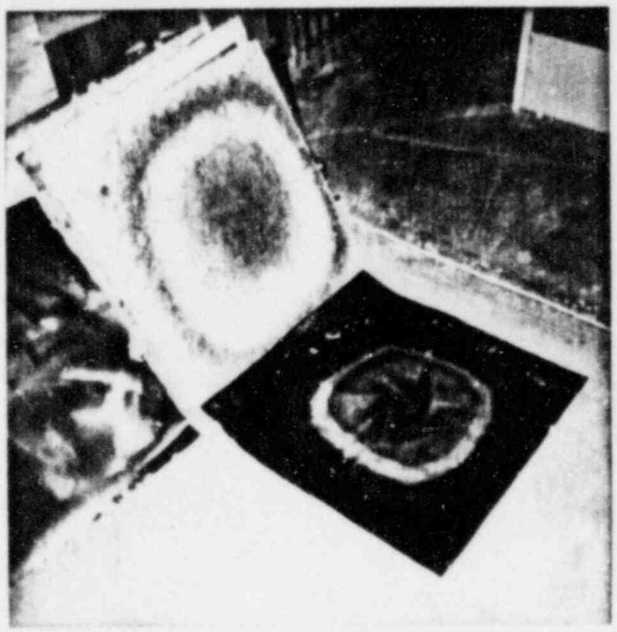
(Closest to Oven)

FIGURE VI



TOP OF FIRST LAYER
OF MINERAL WOOL

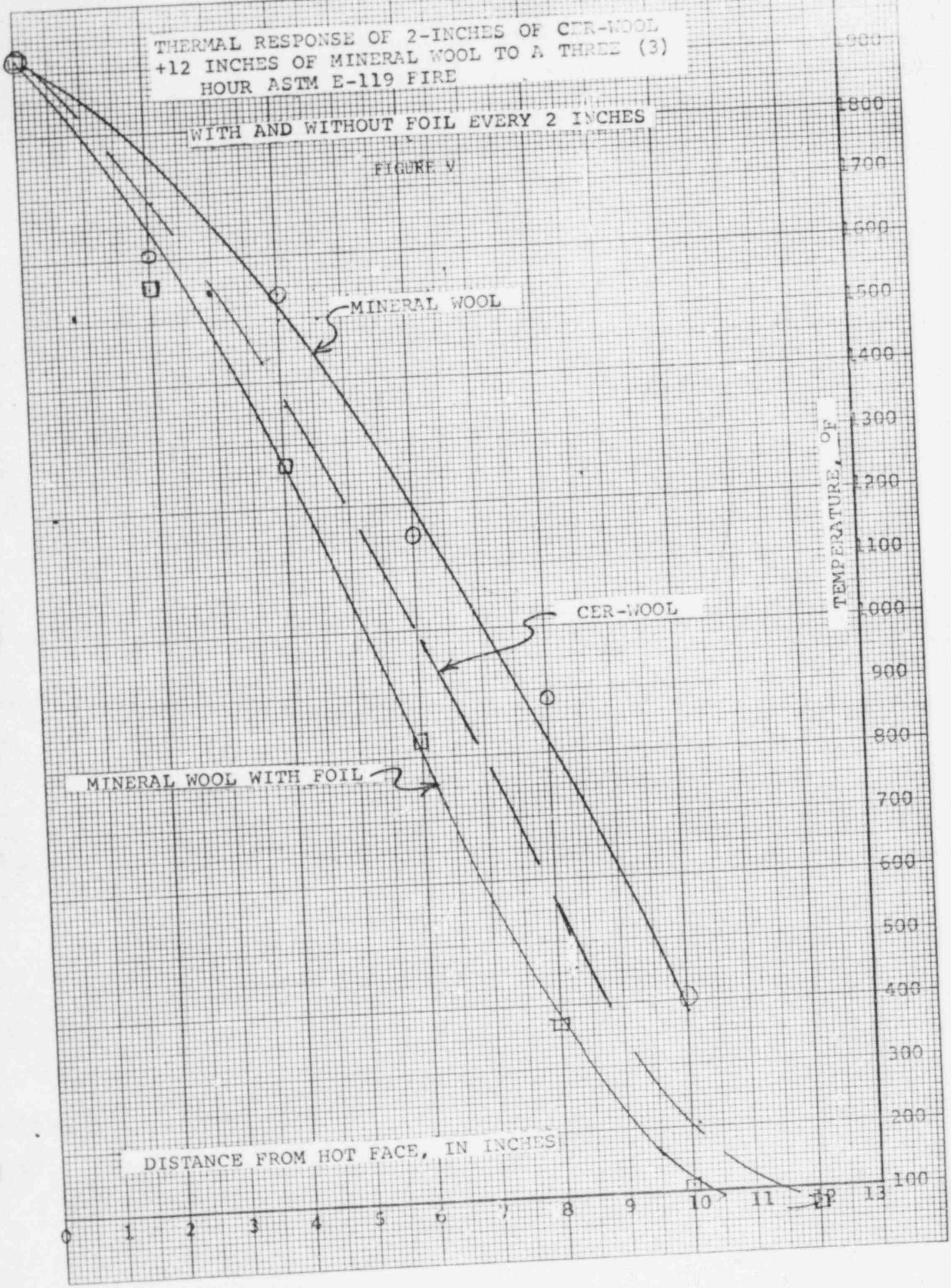
FIGURE VII



BOTTOM OF SECOND
LAYER OF MINERAL WOOL

FIGURE VIII

TEST REPORT No.: TTR-32N



APPENDIX

(Data on File in Transco Offices)

Ref. Sketch DB

DESC. 1-2" Cerwool - 5 - 2" Mineral Wool - Foil Between

| TIME | 83 Oven Temp. °F | THERMOCOUPLE TEMPERATURES | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 68 | 69 | 70 | 71 | 72 | 73 | 74 | 75 | 76 | 77 | 78 | 79 | 80 | 81 | 82 | 83 | 85 | 86 | 87 | 88 | 89 |
| 0 | 109 | 104.2 | 1043 | 104.4 | 79.4 | 79.1 | 79.3 | 65.6 | 65.7 | 65.6 | 63.5 | 63.6 | 63.5 | 63.7 | 63.7 | 63.7 | 64.0 | 64.1 | 63.9 | 66.0 | 65.0 | 66.0 |
| 15 | 1060 | 1071 | 1066 | 1070 | 181 | 155 | 206 | 67.1 | 67.3 | 67.3 | 63.7 | 63.8 | 63.7 | 63.7 | 63.9 | 63.8 | 64.2 | 64.0 | 64.0 | 66.6 | 66.4 | 66.8 |
| 30 | 1474 | 1472 | 1475 | 1473 | 577 | 516 | 636 | 79.1 | 81.2 | 79.6 | 64.1 | 64.1 | 64.1 | 63.9 | 64.0 | 63.9 | 64.4 | 64.3 | 64.2 | 67.2 | 67.0 | 67.1 |
| 45 | 1806 | 1806 | 1812 | 1804 | 1012 | 968 | 1053 | 1313 | 141.2 | 134.5 | 65.7 | 65.7 | 65.5 | 64.0 | 64.5 | 64.0 | 64.7 | 64.6 | 64.5 | 67.7 | 67.5 | 67.6 |
| 1925 @ 53 min. | | | | | | | | | | | | | | | | | | | | | | |
| 60 | 1923 | 1913 | 1921 | 1909 | 1257 | 1227 | 1281 | 330 | 370 | 349 | 74.7 | 74.4 | 73.8 | 64.6 | 64.4 | 64.3 | 64.9 | 64.7 | 64.7 | 68.3 | 68.0 | 68.2 |
| 1:15 | 1925 | 1921 | 1927 | 1916 | 1361 | 1345 | 1371 | 588 | 658 | 628 | 101 | 99.3 | 97.4 | 65.2 | 65.4 | 65.3 | 65.1 | 65.2 | 64.7 | 68.7 | 68.5 | 68.7 |
| 1:30 | 1925 | 1922 | 1931 | 1925 | 1430 | 1431 | 1436 | 926 | 976 | 954 | 317.5 | 190.8 | 287 | 79.5 | 79.5 | 80.3 | 66.2 | 66.1 | 66.0 | 69.5 | 69.2 | 69.4 |
| 2:00 | 1925 | 1918 | 1929 | 1928 | 1439 | 1448 | 1447 | 1011 | 1053 | 1033 | 444 | 417 | 413 | 100 | 100 | 102 | 67.6 | 67.7 | 67.6 | 70.2 | 69.9 | 70.0 |
| 2:15 | 1925 | 1920 | 1920 | 1918 | 1450 | 1464 | 1457 | 1092 | 1128 | 1109 | 567 | 540 | 530 | 142 | 143 | 147 | 71.4 | 71.6 | 71.7 | 71.0 | 70.6 | 70.8 |
| 2:30 | 1925 | 1930 | 1931 | 1926 | 1468 | 1490 | 1475 | 1160 | 1190 | 1170 | 684 | 656 | 642 | 204 | 206 | 211 | 79.0 | 80.4 | 80.0 | 71.6 | 71.5 | 71.6 |
| 2:45 | 1925 | 1920 | 1928 | 1929 | 1504 | 1528 | 1511 | 1213 | 1236 | 1220 | 771 | 749 | 731 | 276 | 283 | 285 | 90.0 | 91.0 | 91.9 | 72.4 | 72.4 | 72.2 |
| 3:00 | 1925 | 1922 | 1923 | 1917 | 1546 | 1571 | 1552 | 1262 | 1278 | 1265 | 842 | 827 | 806 | 362 | 370 | 376 | 107 | 111 | 113 | 72.0 | 74.2 | 74.0 |

Ref. Sketch
DESC. 2" Cerwool + 10" Min Wool



DB
May 19, 1983

| TIME (Min) | Oven Temp. °F (#83) | THERMOCOUPLE TEMPERATURES (°F) 71 | 72 | 73 | 69 | 70 | 74 | 76 | 77 | 78 | 89 | 90 | 91 | 79 | 80 | 75 | 81 | 82 | 87 | Amb. 99 | Top Surface 88/98 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 66.1 | 66.6 | 66.5 | 67.1 | 66.4 | 67.0 | 67.1 | 67.0 | 66.8 | 66.9 | 66.8 | 67.5 | 67.5 | 66.9 | 67.1 | 67.2 | 67.5 | 67.7 | 67.9 | 64.7 | 68.6/68. |
| 5 | 476 | | | | | | | | | | | | | | | | | | | | |
| 10 | 785 | | | | /Loc? | | | | | | | | | | | | | | | | |
| 15 | 986 | 598.7 | 975.9 | 418.9 | 196 | 91.6 | 81.2 | 67.3 | 67.6 | 67.3 | 67.1 | 67.4 | 67.5 | 67.2 | 67.2 | 67.3 | 67.6 | 67.8 | 66.5 | 66.3 | 68.2/68.3 |
| 20 | 1147 | | | | | | | | | | | | | | | | | | | | |
| 25 | 1284 | | | | | | | | | | | | | | | | | | | | |
| 30 | 1407 | 1055 | 1380 | 859 | 655 | 294 | 225 | 71.9 | 86.5 | 71.1 | 68.0 | 67.8 | 67.8 | 67.5 | 66.9 | 67.4 | 67.6 | 67.8 | 67.5 | 70.4 | 63.7/69.5 |
| 35 | 1519 | | | | | | | | | | | | | | | | | | | | |
| 40 | 1621 | | | | | | | | | | | | | | | | | | | | |
| 45 | 1718 | 1420 | 1696 | 1211 | 1132 | 646.4 | 548.6 | 105.8 | 287.2 | 96.0 | 77.8 | 71.0 | 70.3 | 68.9 | 68.5 | 68.2 | 67.9 | 68.2 | 67.8 | 71.0 | 68.0/68 |
| 50 | 1809 | | | | | | | | | | | | | | | | | | | | |
| 55 | 1897 | | | | /error | | | | | | | | | | | | | | | | |
| 60 | 1925 | 1712 | 1900 | 1518 | 1430 | 1086 | 973 | 274 | 797 | 193.8 | 106.7 | 87.1 | 82.5 | 75. | 72.6 | 71.6 | 69.4 | 69.0 | 68.3 | 66.6 | 69.3/69.7 |
| 65 | 1935 | | | | | | | | | | | | | | | | | | | | |
| 70 | 1925 ±8 | | | | | | | | | | | | | | | | | | | | |
| 75 | " | 1777 | 1910 | 1633 | 1549 | 1325 | 1227 | 710 | 1049 | 582 | 265 | 116.4 | 109.1 | 99.6 | 90.6 | 87.5 | 70.6 | 72.3 | 69.4 | 67.7 | 70.0/70.0 |
| 80 | " | (Closed Door) | | | | | | | | | | | | | | | | | | | |
| 85 | " | | | | | | | | | | | | | | | | | | | | |
| 90 | " | 1800 | 1922 | 1675 | 1607 | 1417 | 1322 | 943 | 1174 | 889 | 531 | 265 | 213 | 122 | 114.3 | 109.4 | 78.9 | 84.1 | 73.2 | 67.3 | 72.4/71.9 |

Ref. Sketch
DESC. 2" Cerwool + 10" Min Wool



DB
May 19, 1983

| TIME (Min) | Oven Temp. °F (#83) | THERMOCOUPLE TEMPERATURES (°F) 71 | 72 | 73 | 69 | 70 | 74 | 76 | 77 | 78 | 89 | 90 | 91 | 79 | 80 | 75 | 81 | 82 | 87 | Amb. 99 | Top Surface 88/98 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 95 | 1925 ± 8 | | | | | | | | | | | | | | | | | | | | |
| 100 | " | | | | | | | | | | | | | | | | | | | | |
| 105 | " | 1820 | 1920 | 1707 | 1651 | 1478 | 1390 | 1080 | 1267 | 1059 | 745 | 515 | 435 | 188.6 | 133.6 | 1258 | 95.0 | 100.7 | 83.2 | 65.7 | 78.5/74.7 |
| 110 | " | | | | | | | | | | | | | | | | | | | | |
| 115 | " | | | | | | | | | | | | | | | | | | | | |
| 120 | " | 1833 | 1918 | 1732 | 1673 | 15230 | 1437 | 1152 | 1323 | 1189 | 908.1 | 736 | 667 | 323.7 | 228.2 | 214.6 | 106.5 | 111.0 | 94.1 | 66.6 | 95.2/80.0 |
| 125 | " | | | | | | | | | | | | | | | | | | | | |
| 130 | " | | | | | | | | | | | | | | | | | | | | |
| 135 | " | 1837 | 1917 | 1755 | 1698 | 1559 | 1479 | 1205 | 1355 | 1331 | 1003 | 914 | 852 | 507.8 | 384 | 383 | 115.5 | 118.9 | 104.1 | 65.3 | 92.8/82.2 |
| 140 | " | | | | | | | | | | | | | | | | | | | | |
| 145 | " | | | | | | | | | | | | | | | | | | | | |
| 150 | " | 1843 | 1922 | 1739 | 1719 | 1584 | 1500 | 1252 | 1410 | 1402 | 1087 | 1039 | 962 | 689 | 566 | 582 | 121.5 | 153.7 | 111.1 | 66.6 | 96.8/84.8 |
| 155 | " | | | | | | | | | | | | | | | | | | | | |
| 160 | " | | | | | | | | | | | | | | | | | | | | |
| 165 | " | 1847 | 1922 | 1745 | 1742 | 1597 | 1515 | 1276 | 1482 | 1477 | 1169 | 1105 | 1030 | 832 | 743 | 784 | 182.7 | 249.2 | 134.6 | 66.3 | 99.3/ |
| 170 | " | | | | | | | | | | | | | | | | | | | | |
| 175 | " | | | | | | | | | | | | | | | | | | | | |
| 180 | " | 1848 | 1926 | 1747 | 1760 | 1605 | 1527 | 1305 | 1537 | 1532 | 1251 | 1149 | 1065 | 947 | 884 | 942 | 312 | 403 | 232 | 66.2 | 126/ |

TRANSCO INC.
TEST REPORT No.: TTR-33N

# TEST REPORT
# TEMPERATURE RESPONSE OF LAYERED CER-WOOL TO A THREE-HOUR ASTM E-119 FIRE TEST WITH AND WITHOUT FOIL BETWEEN LAYERS

TEST PERFORMED AT STREATOR, ILLINOIS
MAY 24-25, 1983

Test Performed By: W. D. Brown
W. D. Brown, P.E.
Mgr. Product Development
Insulation Products Division

Loren Pitts
Product and Development Engineer

## 1. INTRODUCTION

Transco TTR-30N was performed in an approximately three foot cubed gas-fired floor furnace, at Construction Technology Laboratories in Skokie, Illinois. The temperature/time curve of the oven matches that of ASTM E-119.

Transco's recently upgraded oven at Streator, Illinois produces a temperature/time curve nearly equal to that of Construction Technology Laboratories's gas-fired furnace. However, the Transco oven is approximately eight (8) inches by ten (10) inches by twelve (12) inches deep. TTR-31N and TTR-32N were conducted on the Transco, Streator, Illinois oven.

The first purpose of this test is to determine if a thick wall of Cer-wool responds identically to an ASTM E-119 temperature/time curve as produced by both ovens. In other words, are the Transco oven tests comparable with Construction Technology Laboratories oven tests.

TTR-32N was conducted on a simulated mineral wool wall. TTR-32N results indicated that foils placed every two (2) inches in a thick mineral wool wall resulted in a 15 percent reduction in material thickness required to produce an 1850°F temperature drop.

The second purpose of this test is to determine if foil placed between two (2) inch layers of Cer-wool will result in an equivalent reduction in required insulation thickness.

## 2. TEST APPARATUS

The test apparatus consisted of the Transco test oven at Streator, Illinois with associated instrumentation.

The oven was rotated onto its back. A 24-gauge stainless steel plate 24 inches square was placed over the eight (8) by ten (10) inch front oven face. Seven (7) layers of two (2) inch thick eight (8) pound density Cer-wool was placed on top of the stainless steel plate. All layers were approximately 24 inches square. A stainless steel plate was then placed on top of the assembly.

Three (3) thermocouples were placed between each layer; one at the center and two on a common 45° line on each side of the center. Great care was taken to place all three thermocouples in the projected area of the oven.

The foiled assembly was the same configuration, except foil was placed between each layer of Cer-wool. The thermocouples were mounted on top of the foil. There was no foil on the top of the Cer-wool pile, just a stainless steel cover sheet.

Figure I shows a typical Cer-wool assembly. In this case, the foiled assembly is shown.

3. TEST PROCEDURE

A set of zero temperature readings were taken, and the oven was then turned on. The temperature controller was set for 1925°F.

Every 15 minutes, a complete set of thermocouple readings were taken. The readings were continued for a full three-hour period. At the end of three hours the oven was turned off, and the insulation and steel plates were removed from the oven face.

The oven was allowed to cool overnight between the non-foiled and the foiled Cer-wool tests.

The same Cer-wool blankets were used for both tests.

4. TEST RESULTS

The results are shown in Figure II. The first purpose of the test was to see if a thick wall of Cer-wool responds identically to an ASTM E-119 temperature/time transient produced by both Construction Technology Laboratories's furnace, and Transco's oven.

Transco's oven produced a slightly lower temperature curve, on the order of 60°F lower, than the Construction Technology Laboratories furnace curve.

The two curves are not identical. The thickness is on the order of 0.3 to 0.4 of an inch difference for equivalent temperatures. However, for experimental purposes the curves are essentially the same. The area on the Transco oven temperature/time curve was approximately five (5) percent less than the ASTM E-119 curve. Hence, it is logical the temperature profile of the Transco oven should be lower than the Construction Technology Laboratories temperature profile.

The second purpose of the test of Cer-wool was to determine if the foil placed between the Cer-wool layers will affect the same change in required thickness as the foils between the mineral wool did in TTR-32N. Approximately a two (2) inch reduction in insulation thickness was realized by the insertion of foil between the layers of mineral wool.

A review of Figure II indicates a thickness reduction on the order of three quarters of an inch will be realized by the insertion of foil every two inches in a 14-inch stack. It appears foil does not make as significant a difference with Cer-wool as it does with mineral wool.

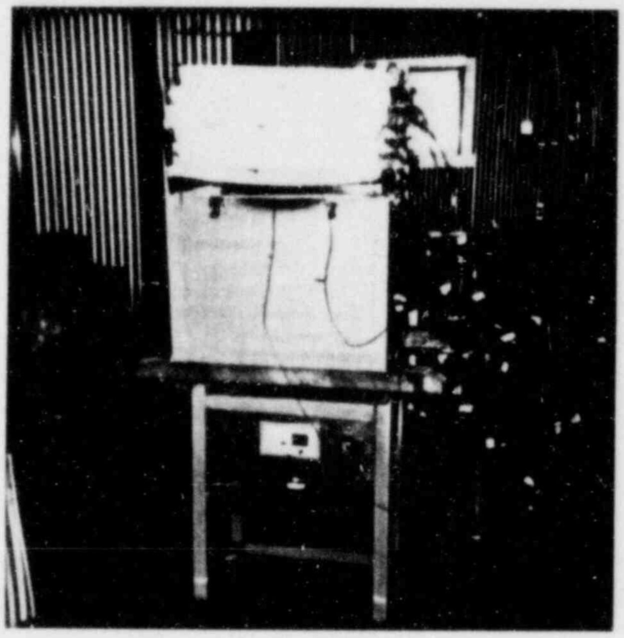
On a fourteen (14) inch thick stack, a reduction of 0.8 inches is a six (6) percent thickness reduction. Whereas the mineral wool experienced a reduction of two (2) inches, or fourteen (14) percent.

5. CONCLUSION

The Transco oven at Streator, Illinois can be used to predict the results of a thick wall of insulation's response to an ASTM E-119 temperature/time transient. The results compare within experimental limits with the larger gas-fired furnace at Construction Technology Laboratories in Skokie, Illinois.

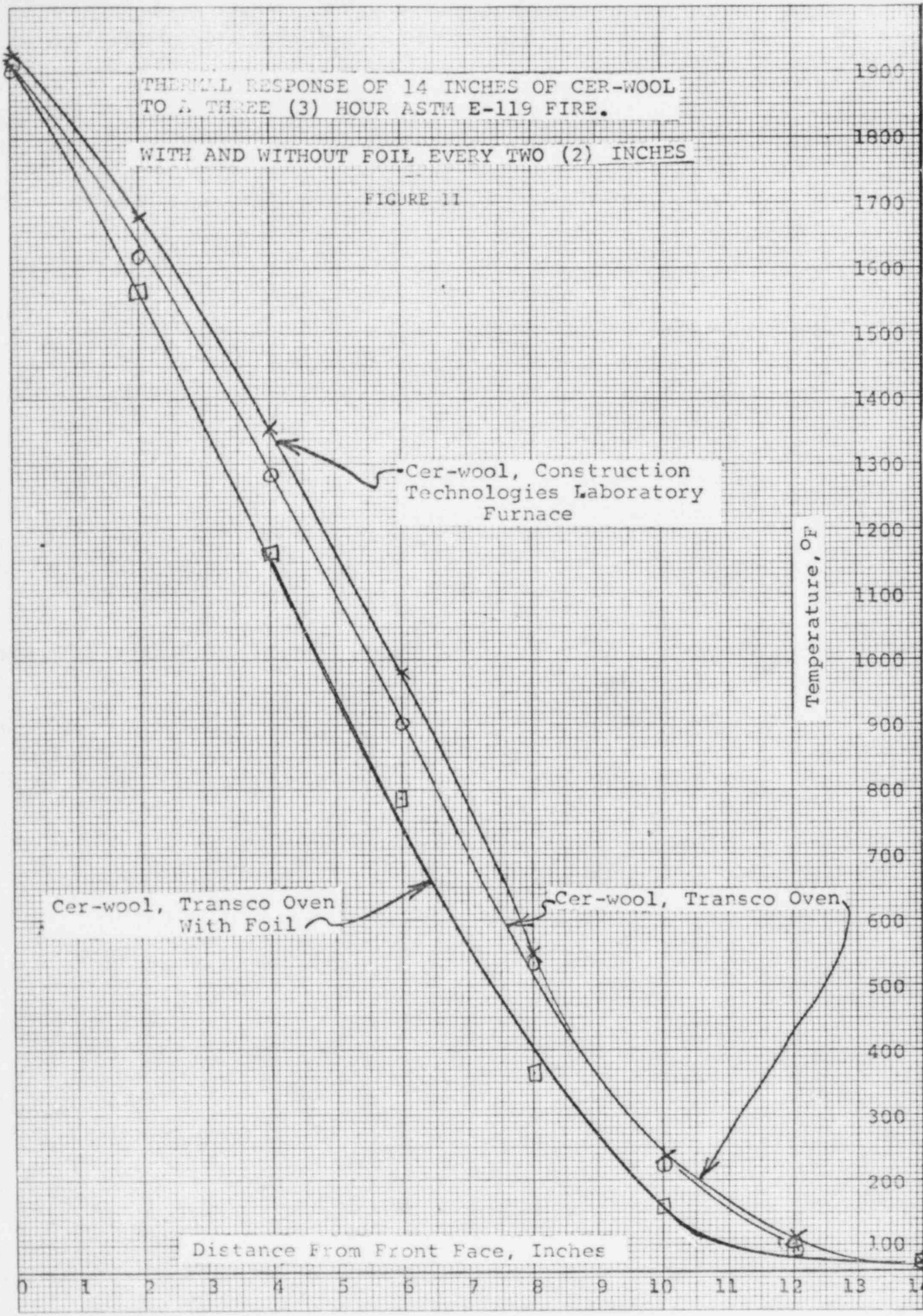
The use of foil between layers of Cer-wool does reduce the heat transfer through a thick wall of Cer-wool. For mineral wool, the reduction was on the order of 15 percent, for one foil every two (2) inches. For Cer-wool the reduction was only on the order of six (6) percent. Hence, the effectiveness of the foil seems to be dependent upon the type of insulation the foil is separating.

Foil insertion does not make a significant difference in a thick wall of Cer-wool.



TYPICAL CER-WOOL ASSEMBLY

FIGURE I


THERMAL RESPONSE OF 14 INCHES OF CER-WOOL
TO A THREE (3) HOUR ASTM E-119 FIRE.
WITH AND WITHOUT FOIL EVERY TWO (2) INCHES
FIGURE 11
Cer-wool, Construction Technologies Laboratory Furnace
Cer-wool, Transco Oven
Cer-wool, Transco Oven With Foil
Temperature, °F
1900
1800
1700
1600
1500
1400
1300
1200
1100
1000
900
800
700
600
500
400
300
200
100
Distance From Front Face, Inches
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14

APPENDIX

(Data on File in Transco Offices)

DESC. 14" Cer-Wool w/Foil Every 2" (8#/$f_t^3$)  May 25, 1983

| TIME (Min) | Oven Temp. | THERMACOUPLE | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 0 | | | 2" | | | 4" | | | 6" | | | 8" | | | 10" | | | 12" | |
| | °F | 68 | 69 | 70 | 71 | 72 | 73 | 74 | 75 | 76 | 77 | 78 | 79 | 80 | 81 | 82 | 84 | 85 | 86 | 87 | 88 | 89 |
| 0 | 67.9 | 69.0 | 69.1 | 69.4 | 69.9 | 70.0 | 70.0 | 70.2 | 69.3 | 69.3 | 68.4 | 68.4 | 68.3 | 68.2 | 67.8 | 68.0 | 67.9 | 68.9 | 68.3 | 70.9 | 70.7 | - |
| 15 | 1081 | 940 | 948 | 958 | 164 | 153 | 140 | 70.4 | 69.8 | 69.6 | 68.5 | 68.6 | 68.6 | 68.7 | 68.5 | 68.6 | 69.2 | 69.2 | 68.9 | 71.6 | 71.6 | 71.9 |
| 30 | 1465 | 1382 | 1388 | 1372 | 546 | 537 | 486 | 77.5 | 88.5 | 85.1 | 68.9 | 69.1 | 68.9 | 69.8 | 68.9 | 69.0 | 69.8 | - | 69.4 | 72.4 | 72.3 | 72.5 |
| 45 | 1746 | 1694 | 1687 | 1678 | 928 | 947 | 925 | 117.4 | 188 | 173 | 72.8 | 73.4 | 72.8 | 70.0 | 69.2 | 69.3 | 70.4 | 70.1 | 70.0 | 72.9 | 72.8 | 72.9 |
| @ 56 MM. | | | | | | | | | | | | | | | | | | | | | | |
| 60 | 1925 | 1916 | 1897 | 1884 | 1244 | 1265 | 1244 | 253 | 447 | 421 | 95.0 | 98.0 | 95.3 | 70.4 | 71.2 | 70.1 | 70.8 | 70.6 | 70.5 | 73.2 | 73.2 | 73.3 |
| 75 | " | 1915 | 1899 | 1903 | 1380 | 1401 | 1364 | 492 | 717 | 703 | 177 | 188 | 180 | 73.2 | 72.9 | 72.8 | 71.4 | 71.3 | 71.1 | 73.6 | 73.5 | 73.7 |
| 90 | " | 1915 | 1907 | 1906 | 1442 | 1463 | 1427 | 666 | 869 | 864 | 307 | 324 | 317 | 82.5 | 83.2 | 82.0 | 72.1 | 72.0 | 71.9 | 73.9 | 73.9 | 74.0 |
| 105 | " | 1914 | 1907 | 1908 | 1480 | 1500 | 1465 | 786 | 967 | 966 | 439 | 457 | 457 | 106 | 109 | 106 | 78.4 | 74.5 | 74.2 | 74.3 | 74.3 | 74.4 |
| 120 | " | 1916 | 1901 | 1906 | 1506 | 1526 | 1492 | 867 | 1035 | 1034 | 546 | 562 | 568 | 146 | 154 | 149 | 80.4 | 80.8 | 80.3 | 75.1 | 75.1 | 75.0 |
| 135 | " | 1919 | 1903 | 1903 | 1526 | 1546 | 1512 | 920 | 1081 | 1081 | 624 | 638 | 648 | 195 | 208 | 201 | 91.3 | 72 | 91.5 | 76.3 | 76.6 | 76.3 |
| 150 | " | 1918 | 1911 | 1913 | 1540 | 1560 | 1527 | 963 | 1119 | 1119 | 691 | 602 | 714 | 252 | 269 | 262 | 110 | 112 | 111 | 78.9 | 79.7 | 78.7 |
| 165 | " | 1910 | 1910 | 1914 | 1551 | 1572 | 1538 | 994 | 1145 | 1146 | 740 | 750 | 763 | 324 | 316 | 317 | 133 | 135 | 134 | 83.0 | 85.9 | 82.7 |
| 180 | " | 1922 | 1913 | 1916 | 1560 | 1581 | 1547 | 1020 | 1167 | 1168 | 779 | 787 | 802 | 352 | 375 | 366 | 161 | 162 | 161 | 88.8 | 91.3 | 88.4 |

| 90 | 14" 91 | 92 | 99 | 98 |
|---|---|---|---|---|
| 77.1 | 77.0 | 77.1 | 75 | 172.8 |
| 78.7 | 78.6 | 78.7 | 75.3 | 94.0 |
| 78.2 | 78.2 | 78.1 | 82.0 | 142 |
| 78.1 | 77.9 | 77.9 | 99.3 | 209.5 |
| 78.3 | 78.2 | 78.2 | 129.5 | 261.1 |
| 78.5 | 78.4 | 78.5 | 237 | 265 |
| 78.9 | 78.8 | 78.7 | 262 | 406 |
| 79.2 | 79.1 | 79.2 | 307 | 427 |
| 79.5 | 79.5 | 79.5 | 339 | 444 |
| 79.8 | 79.8 | 79.9 | 361 | 456 |
| 80.5 | 80.5 | 80.7 | 380 | 469 |
| 80.7 | 80.7 | 80.8 | 393 | 469 |
| 81.2 | 81.3 | 81.4 | 403 | 476 |

93 Amb <u>14" - Cerwool -7 - 2" Layers Calibration Pile</u>

 May 25, 1983

| TIME (Min) | Oven Temp. °F 83 | 68 | 69 | 70 | 71 | 72 | 73 | 74 | 75 | 76 | 77 | 78 | 79 | 80 | 81 | 82 | 84 | 85 | 86 | 87 | 88 | 89 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 68.4 | | | | | | | | | | | | | | | | | | | | | | |
| 0 | 113 | 96.4 | 94.3 | 95.6 | 71.8 | 71.5 | 71.6 | 67.1 | 67.1 | 67.0 | 67.3 | 67.3 | 67.3 | 67.0 | 66.6 | 65.6 | 67.1 | 67.0 | 67.0 | 66.7 | 66.8 | 66.8 |
| 66.8 | | | | | | | | | | | | | | | | | | | | | | |
| 15 | 977 | 768 | 754 | 791 | 136 | 136 | 141 | 68.6 | 68.3 | 68.3 | 66.9 | 66.8 | 67.0 | 67.0 | 67.1 | 60.3 | 66.9 | 66.7 | 66.7 | 66.8 | 66.3 | 66.6 |
| 67.6 | | | | | | | | | | | | | | | | | | | | | | |
| 30 | 1406 | 1258 | 1244 | 1265 | 478 | 496 | 492 | 864 | 82.3 | 84.1 | 67.3 | 67.3 | 67.3 | 67.0 | 66.9 | 66.9 | 66.9 | 66.7 | 66.7 | 66.6 | 66.6 | 66.6 |
| 67.6 | | | | | | | | | | | | | | | | | | | | | | |
| 45 | 1701 | 1597 | 1581 | 1587 | 887 | 913 | 893 | 189 | 169 | 178 | 71.1 | 71.5 | 71.6 | 67.2 | 67.1 | 68.4 | 66.9 | 66.6 | 66.8 | 66.6 | 66.6 | 66.6 |
| 67.8 | | | | | | | | | | | | | | | | | | | | | | |
| 60 | 1960 | 1880 | 1869 | 1857 | 1282 | 1305 | 1288 | 477 | 440 | 457 | 98.7 | 101.5 | 98.0 | 68.0 | 67.9 | 67.9 | 66.9 | 66.8 | 66.7 | 66.8 | 66.8 | 66.8 |
| 67.6 | | | | | | | | | | | | | | | | | | | | | | |
| 75 | 1925 | 1883 | 1873 | 1856 | 1424 | 1443 | 1426 | 768 | 738 | 750 | 185 | 194 | 184 | 72.7 | 71.7 | 73.1 | 67.1 | 67.3 | 67.0 | 66.9 | 66.9 | 66.8 |
| 68.0 | | | | | | | | | | | | | | | | | | | | | | |
| 90 | 1922 | 1883 | 1875 | 1862 | 1489 | 1506 | 1500 | 962 | 937 | 946 | 347 | 358 | 346 | 93.1 | 91.1 | 94.3 | 68.0 | 67.9 | 67.9 | 67.2 | 67.2 | 67.1 |
| 68.4 | | | | | | | | | | | | | | | | | | | | | | |
| 105 | 1925 | 1894 | 1878 | 1871 | 1531 | 1547 | 1532 | 1075 | 1054 | 1063 | 516 | 527 | 514 | 150 | 143 | 149 | 72.4 | 71.9 | 72.6 | 67.6 | 67.6 | 67.4 |
| 68.6 | | | | | | | | | | | | | | | | | | | | | | |
| 120 | - | 1897 | 1883 | 1868 | 1556 | 1572 | 1557 | 1146 | 1126 | 1135 | 635 | 645 | 633 | 227 | 218 | 227 | 83.5 | 82.2 | 84.3 | 68.6 | 68.6 | 68.5 |
| 68.9 | | | | | | | | | | | | | | | | | | | | | | |
| 135 | - | 1895 | 1881 | 1877 | 1573 | 1588 | 1574 | 1196 | 1178 | 1186 | 728 | 738 | 726 | 319 | 304 | 314 | 106 | 106 | 108 | 71 | 71.7 | 71.3 |
| 69.2 | | | | | | | | | | | | | | | | | | | | | | |
| 150 | - | 1902 | 1889 | 1875 | 1589 | 1604 | 1591 | 1235 | 1218 | 1225 | 801 | 809 | 799 | | 388 | 399 | 141 | 136 | 143 | 76.9 | 77.7 | 76.9 |
| 69.1 | | | | | | | | | | | | | | | | | | | | | | |
| 165 | - | 1903 | 1893 | 1880 | 1601 | 1616 | 1603 | 1265 | 1249 | 1256 | 857 | 866 | 855 | 478 | 461 | 471 | 181 | 174 | 184 | 86.2 | 87.3 | 86.3 |
| 180 | - | 1895 | 1891 | 1925 | 1610 | 1625 | 1612 | 1290 | 1274 | 1281 | 903 | 911 | 901 | 544 | 526 | 536 | 230 | 221 | 233 | 101 | 103 | 101 |

| 90 | 91 | 92 | 97 | 98 | 99 |
|---|---|---|---|---|---|
| 66.1 | 66.2 | 66.1 | 76.3 | 71.4 | 68.3 |
| 66.8 | 66.3 | 66.6 | 66.4 | 66.5 | 66.4 |
| 66.6 | 66.7 | 66.7 | 173 | 83.8 | 68.6 |
| 67.0 | 67.1 | 67.2 | 323 | 133 | 72.6 |
| 67.4 | 67.4 | 67.4 | 525 | 280 | 92 |
| 67.8 | 67.8 | 67.8 | 603 | 448 | 142 |
| 68.2 | 68.2 | 68.2 | 644 | 563 | 223 |
| 68.7 | 68.7 | 68.7 | 677 | 640 | 310 |
| 69.2 | 69.2 | 69.2 | 701 | 692 | 376 |
| 69.9 | 69.9 | 69.9 | 718 | 731 | 434 |
| 70.9 | 70.6 | 70.6 | 735 | 759 | 477 |
| 71.4 | 71.6 | 71.3 | 748 | 780 | 509 |
| 72.4 | 72.6 | 72.5 | 757 | 798 | 537 |

TRANSCO PRODUCTS INC.

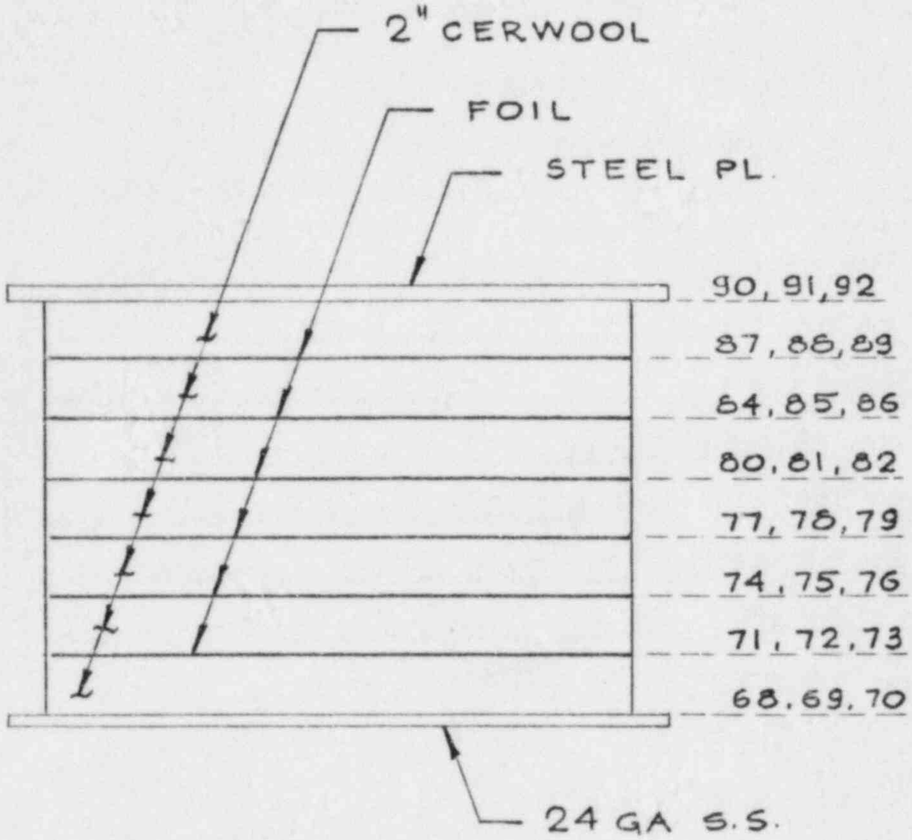
DEPT. ______ JOB NO. ______ SHEET ______

FILE NO. ______ DATE ______

SUBJECT: CERWOOL & FOIL

BY ______

CHKD. ______



TRANSCO INC.
TEST REPORT No.: TTR-34N

TEST REPORT
TEMPERATURE RESPONSE OF A
CER-WOOL/MICROTHERM ASSEMBLY TO A
THREE-HOUR ASTM E-119 FIRE TEST

TEST PERFORMED AT STREATOR, ILLINOIS
JUNE 10, 1983

Test Performed By: W. D. Brown

W. D. Brown, P.E.
Mgr. Product Development
Insulation Products Division

Loren Pitts
Product and Development Engineer

1. INTRODUCTION

A series of tests has been performed to determine the amounts of insulation necessary to isolate a metal body from the effects of a three (3) hour fire, as defined by ASTM E-119.

It has been noted in test reports TTR-30N through TTR-33N that approximately 13 inches of eight (8) lb./ft.$^3$ density Cer-wool will isolate a fire from a steel surface. Adding foil every two (2) inches between the layers of Cer-wool insulation reduces the 13 inches to 12 inches.

As the purpose of these tests is to develop a fire-resistant wrap that is useable in congested areas, it is important that a minimum thickness insulation be developed. A potential candidate is Microtherm as manufactured by Micropore International, Ltd. Microtherm has a high specific heat, low conductivity, and high density (nominally 12-20 lb./ft.$^3$). Microtherm has physical characteristics that should yield a low thermal diffusivity (thermal conductivity divided by specific heat and density), thus its response to a transient should be slow.

In reviewing the literature it was noted that insulation thermal conductivities and specific heats for varying temperatures are generally not available. Microtherm does have known properties that indicate it has good transient response characteristics.

Microtherm does reach an equilibrium concentration of moisture with humid air. Normal Microtherm will contain about three (3) percent by weight moisture. Hydrophobic Microtherm will contain about 0.5 percent by weight moisture. When heated suddenly, conventional Microtherm will pass the steam (water vapor) from the hot face to the cold face. If the Microtherm is not in a sealed container the steam will exit the insulation and diffuse in the air. In the case of an outer surface being exposed to fire, the moisture will be driven into the interior, or to the body being protected. The steam will stop at the first impermeable barrier, and condense at 212$^{\circ}$F. The heat of condensation will be then transmitted to the body being protected by the insulation.

To minimize the steam vapor effect for this test, two precautions are taken. The first is to use Hydrophobic Microtherm so that the amount of moisture available to handle is minimized. Secondly, a foil barrier is placed near the cool surface to prevent water vapor migration to the steel surface that is being protected from the fire effects.

Microtherm also has an upper temperature limitation of 1742$^{\circ}$F for conventional, or 1922$^{\circ}$F for high-temperature insulation. As the Microtherm installation is for a once-only application, the conventional Microtherm is recommended. Further, to maintain the Microtherm's geometric shape, an outer wrap of Cer-wool will be provided to protect the Microtherm from deformation by the stainless steel lagging. The Cer-wool outer wrap will reduce the temperature seen by the Microtherm to within its temperature limits also. The Microtherm is normally encapsulated in a fiberglass cloth that loses its strength at 1200°F. The Cer-wool outer wrap will hold the Microtherm in place during the fire, even though the cloth may deteriorate.

Figure I shows Microtherm that was placed directly behind the steel plate, with no Cer-wool barrier. The material maintained its integrity until it was physically removed from the oven face, and placed on the floor (from another test). Hence, even though the temperature of the glass cloth was exceeded, the cloth maintained its shape until it was disturbed.

The purpose of the test is to determine the ability of two (2) inches of Cer-wool and four and one-half (4½) inches of standard, Hydrophobic Microtherm to isolate a steel body from the effects of a three-hour ASTM E-119 fire.

2. TEST APPARATUS

The test apparatus consisted of the Transco test oven at Streator, Illinois with associated instrumentation.

The oven was rotated onto its back. A 24-gauge stainless steel plate 24 inches square was placed over the eight (8) by ten (10) inch front oven face. One layer of Cer-wool (8 lb./ft.$^3$) two (2) inches thick was placed on top of the plate. Nine (9) layers of Hydrophobic standard temperature Microtherm each 1/2" thick, were placed over the Cer-wool. Between the seventh and eighth layers of Microtherm a layer of 0.002" thick stainless steel was inserted.

Three (3) thermocouples were placed on a 45° line through the center of the oven face, in various horizontal planes. Care was taken to maintain the three (3) thermocouples (two on each side of the one in the exact center) within the projected area of the open oven. A set of three thermocouples were placed at the following locations:

1. Between the steel plate and the Cer-wool layer;
2. Between the Cer-wool and the first layer of Microtherm (+2");
3. Between the second and third layers of Microtherm (+3");
4. Between the fourth and fifth layers of Microtherm (+4");
5. Between the sixth and seventh layers of Microtherm (+5");
6. Between the seventh and eighth layers of Microtherm (+5.5");
7. Between the top layer of Microtherm (ninth) and the steel plate (+6.5").

The Microtherm used for the test was slotted Microtherm. The slots were aligned in the same direction and offset on successive layers. Each piece of Microtherm was 2' x 3' wide. The offsetting may be seen in Figure III.

Figures II and III are the test apparatus completely assembled. The thermocouple leads may be seen in Figure III. A weight was placed on the center of the stack of Microtherm to remove any air spaces between the Microtherm layers and the steel plates.

## 3. TEST PROCEDURE

After completing the assembling of the test apparatus, a set of zero temperature readings were taken. The oven was then turned on, and the temperature controller was set for 1925°F.

Every fifteen minutes a complete set of thermocouple readings were taken. The readings were continued for a full three-hour period. At the end of three hours the oven was turned off, and the insulation and steel plates were removed from the oven face.

There is a heat soaking effect that occurs with the Calcium Silicate insulation in the oven wall. Consequently the oven temperature will rise to 1925°F, with the controller set for 1850°F. The controller will hunt about the 1850°F setting (± 8°F). The oven temperature will gradually decrease over a 20-minute period to something on the order of 1910°F. The controller must then be reset to say 1865°F, and the oven temperature will rise to 1925°F again (± 8°F). The oven initially reaches 1925°F approximately eighty (80) minutes into the test. The oven temperature stabilizes approximately 120 minutes to 130 minutes into the test.

Even though readings are taken every fifteen minutes, the oven is normally checked every ten minutes in the 80-130 minute time to assure the 1925°F oven temperature is maintained.

## 4. TEST RESULTS

The test results are shown in Figure IV. The temperature profile shows that at the end of three (3) hours the cold face of the insulation was beginning to increase in temperature. From the data sheets, the cold face temperature increased from 83°F to 89°F at the end of the three-hour test.

As there was no calculation performed, there is no theoretical temperature profile to compare the measured temperature profile with. The intent of the test was to determine the amount of Microtherm, in a Cer-wool/Microtherm sandwich, necessary to isolate a metal structure from the results of a three (3) hour ASTM E-119 fire. It appears from the graph that two (2) inches of Cer-wool and four and one-half (4½) inches of Microtherm will effectively isolate a steel structure from the effects of a three (3) hour fire.

To compare the effectiveness of the Cer-wool/Microtherm sandwich with Cer-wool only, the Cer-wool only curve was placed in Figure IV. To obtain a comparative thickness, the thickness required to maintain the cold face temperature at 100°F was chosen for a reference point. Six (6) inches of the Cer-wool/Microtherm sandwich is equivalent to approximately twelve (12) inches of Cer-wool. In other words, a 50% thickness reduction can be realized with the Cer-wool/Microtherm sandwich.

Figure V is a closeup of the oven/steel place interface. A minor amount of heat leakage can be seen, as orange traces. The orange is actual line of sight into the oven interior. Perhaps if the seal at the oven/steel plate interface were better, the rate of oven cycling would have been less. The oven cycling was on the order of 3/4 of a minute for a +8°F to -8°F range.

Figure VI is the bottom of the first and second layers of Microtherm, after the ASTM E-119 temperature curve. Figure VII is the top of the first and second layers of Microtherm. In both pictures, the first layer is laying on the floor, the second layer is inclined.

Note in Figure VI the very distinct projection of the oven face onto the bottom of the first layer. Note on the top of the first layer, the oven projected area image is gone and only the larger discolored area is noticeable (Figure VII).

Of interest in both Figure VII, the top of the second layer, and in Figure VIII, the bottom of the third layer, is the small dark spot in the center of the burn area. Comparing this emerging dark spot, with the full dark spot on the bottom of the fourth layer, it appears that the cloth goes through a burn discoloration, then a whitening, as temperature increases. Reviewing the temperature profile in Figure IV, and remembering the layers were 1/2" thick, the bottom of the third layer where the burn disappears reached a maximum temperature of about 1200°F.

The full burning effect is occurring near the bottom of the fourth layer. By Figure IV, this corresponds to a maximum temperature of about 900°F. The top of the fifth layer of Microtherm, in Figure IX, appears to have the discoloration beginning. The discoloration apparently begins (by Figure IV) near 350°F.

The cloth that wraps the Microtherm is rated to 1200°F, which is the temperature at which the darkening disappeared.

Each slat of Microtherm is about 2.75" wide. From the preceding, the dark ring occurs at about 900°F. It appears the 900°F ring occured at about seven (7) inches from the edge of the 10 inch wide oven face, on the bottom face of the first layer of Microtherm.

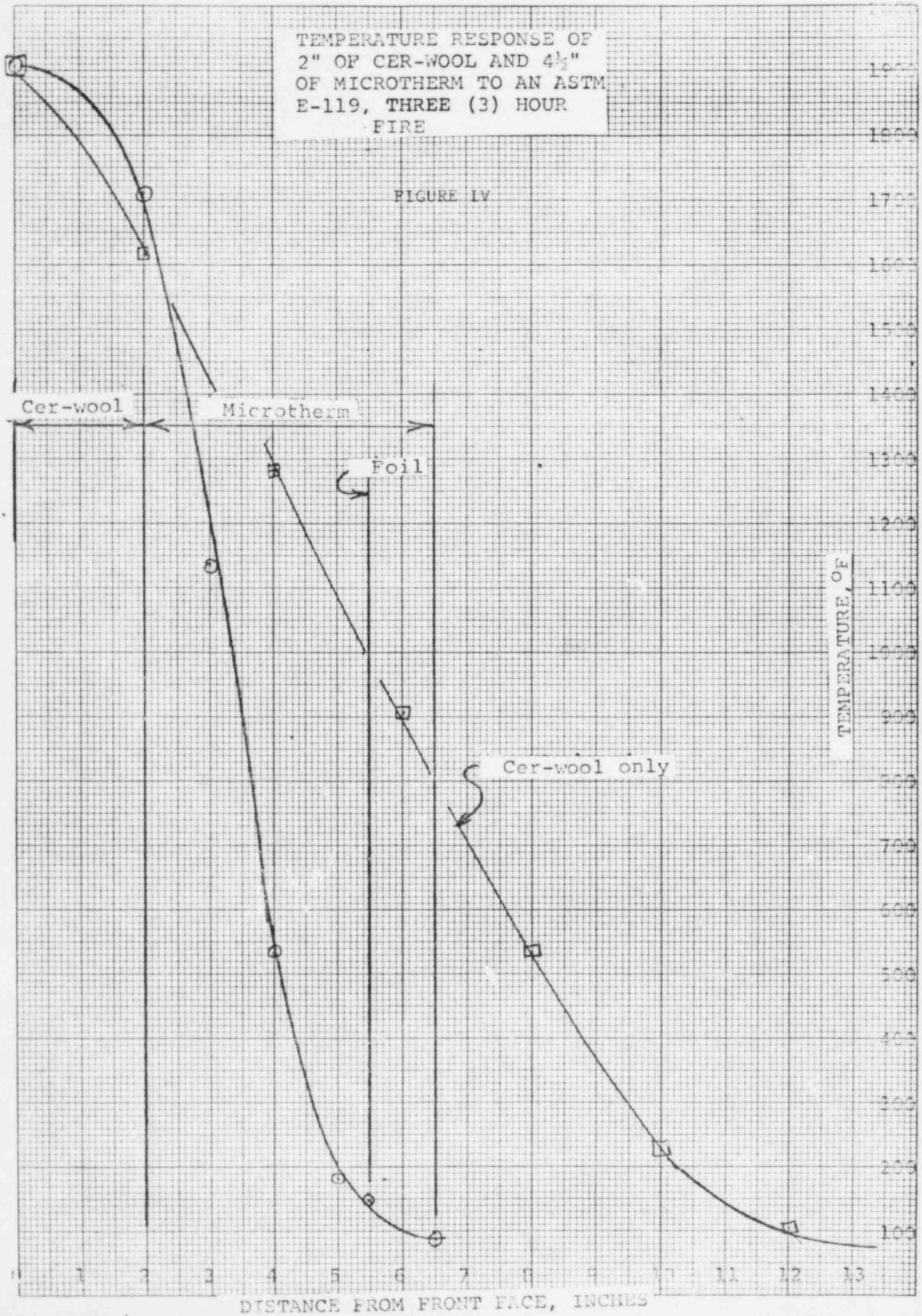
Knowing the burn patterns, one can review other stacks of Microtherm and discern peak temperatures reached.

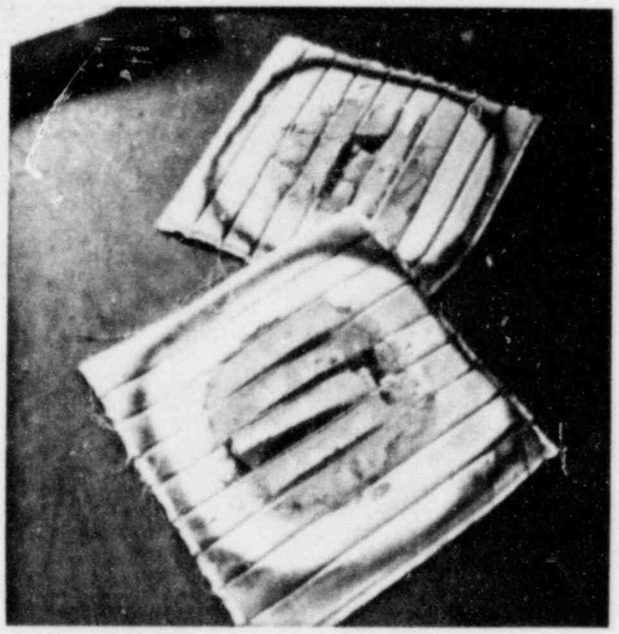
5. CONCLUSION

From the test results, Figure IV, a Cer-wool/Microtherm sandwich will effectively isolate the steel structure from the effects of a three (3) hour fire. A 2 inch thickness of 8 lb. density Cer-wool, with 4½ inches of Microtherm is sufficient.

The outer cloth wrapping on Microtherm begins to discolor at about 350°F, fully discolors at about 900°F, and whitens, showing little burn damage to the eye at about 1200°F.

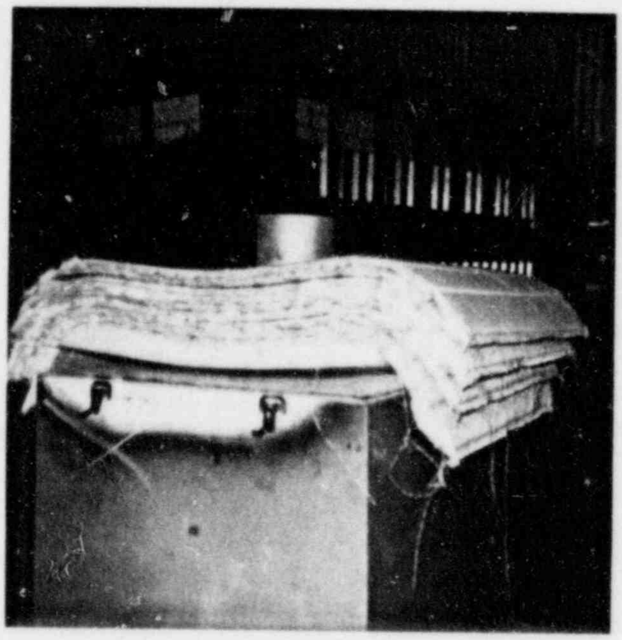
From Figure IV, two inches of Cer-wool and four inches of Microtherm will result in a steel face temperature of 100°F.


TEMPERATURE RESPONSE OF
2" OF CER-WOOL AND 4½"
OF MICROTHERM TO AN ASTM
E-119, THREE (3) HOUR
FIRE
FIGURE IV
Cer-wool
Microtherm
Foil
Cer-wool only
TEMPERATURE, °F
1700
1300
1200
1100
1000
900
700
600
500
200
100
0
1
2
3
4
5
6
7
8
10
11
12
13
DISTANCE FROM FRONT FACE, INCHES



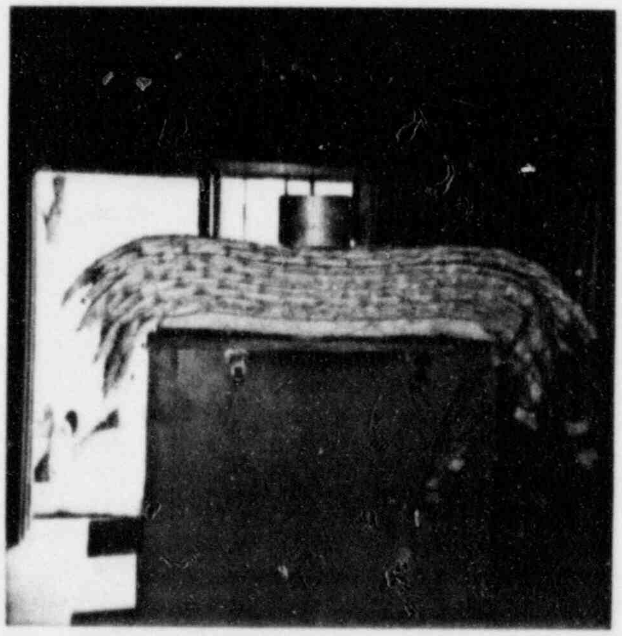
CONVENTIONAL MICROTHERM
ISOLATED FROM A THREE (3) HOUR
FIRE BY A STEEL PLATE

FIGURE I



COMPLETED TEST APPARATUS

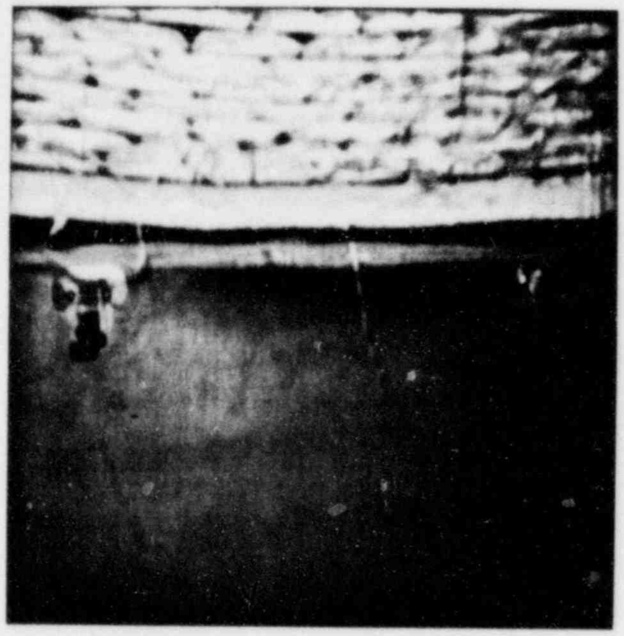
FIGURE II



COMPLETED TEST APPARATUS

(Note Thermocouple Leads
and Staggering of Slots)

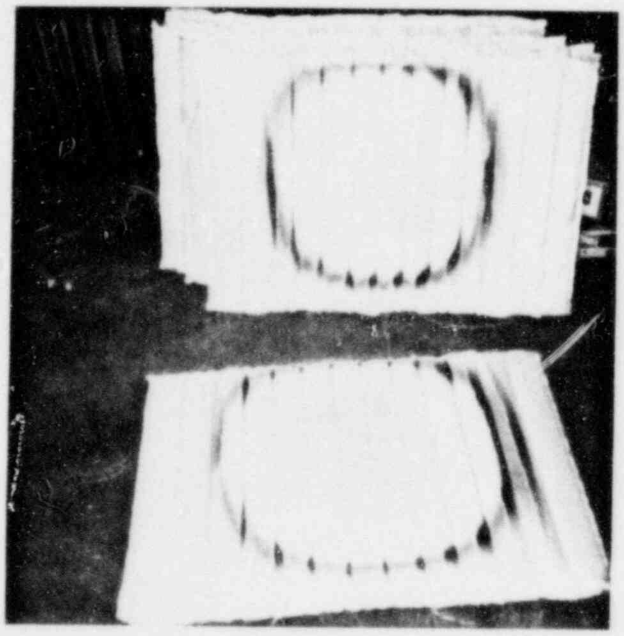
FIGURE III



HEAT LEAKAGE FROM OVEN

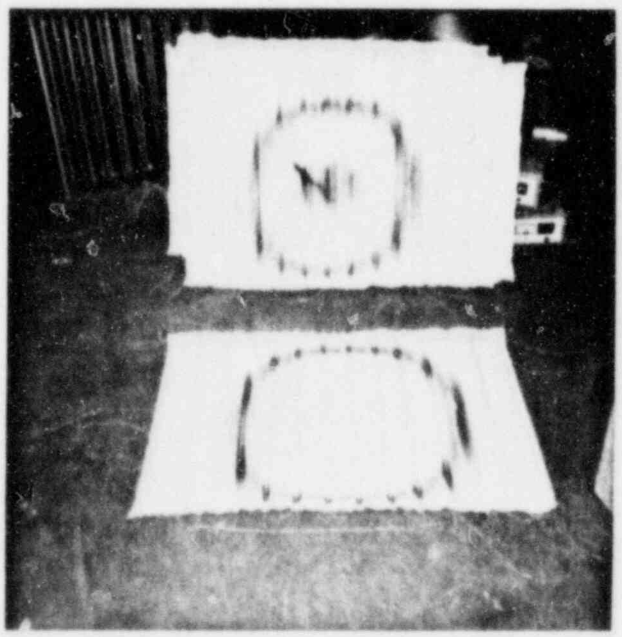
FIGURE V

TRANSCO INC.
TEST REPORT No.: TTR-34N



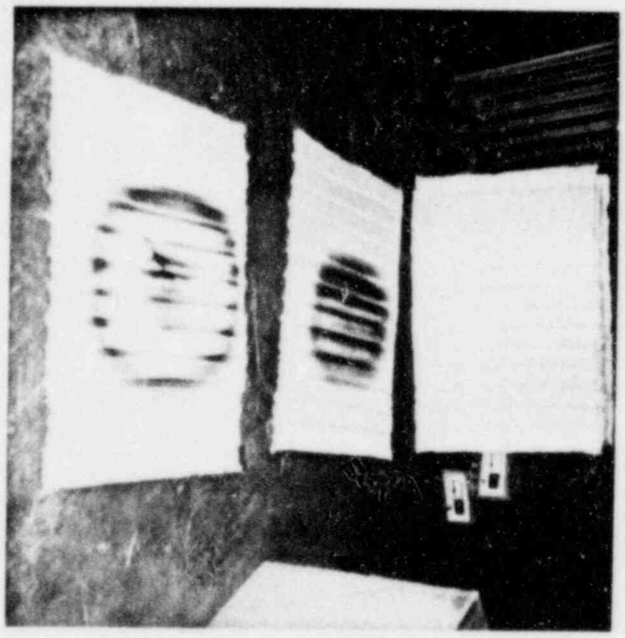
BOTTOM OF MICROTHERM
LAYERS ONE AND TWO

FIGURE VI



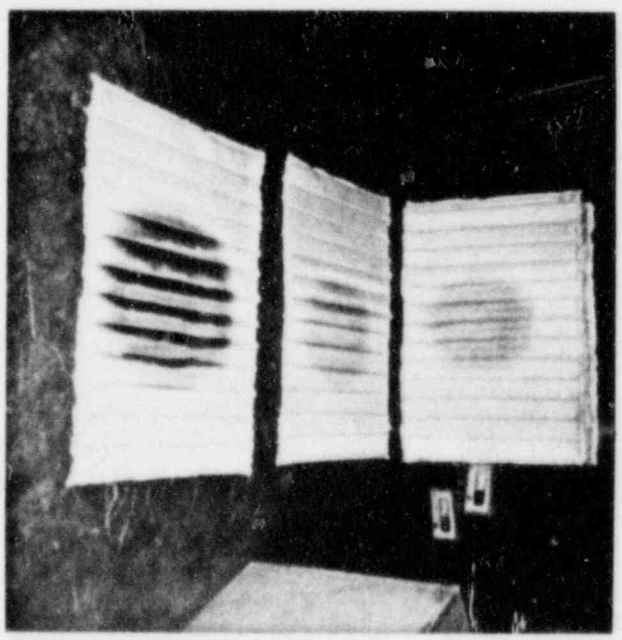
TOP OF MICROTHERM
LAYERS ONE AND TWO

FIGURE VII



BOTTOM OF THIRD, FOURTH, AND
FIFTH MICROTHERM LAYERS

FIGURE VIII



TOP OF THIRD, FOURTH, AND
FIFTH MICROTHERM LAYERS

FIGURE IX

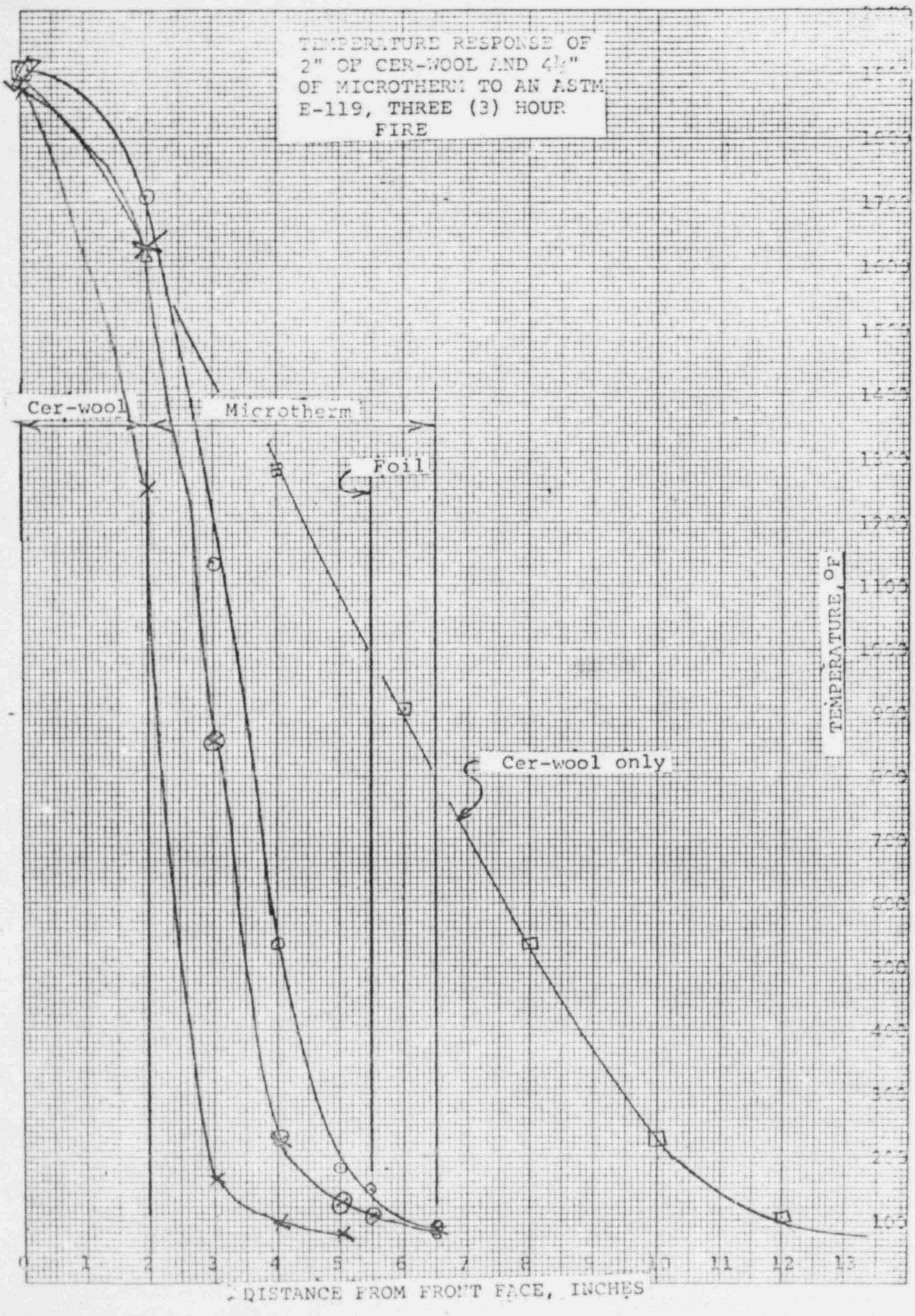
# APPENDIX

(Data at Transco Offices)

2" Cerwool + 9 - 1/2" Hydophobic Microtherm

WDB June 10, 1983

| TIME MM | Oven Temp. | 68 | 69 | 70 | 71 | 72 | 73 | 74 | 75 | 76 | 77 | 78 | 79 | 80 | 81 | 82 | 84 | 85 | 86 | 87 | 88 | 89 | 93 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 107 | 100 | 101 | 99 | 83 | 83.5 | 83.5 | 77.9 | 77.4 | 77.0 | 76.2 | 75.9 | 76.6 | 76.1 | 76.9 | 76.6 | 76.0 | 75.9 | 76.3 | 76.6 | 76.6 | 75.0 | 79 |
| 15 | 965 | 734 | 756 | 778 | 101 | 112 | 106 | 79 | 78 | 78 | 76 | 76 | 66 | 65 | 77 | 77 | 77 | 76 | 76 | 78 | 78 | 77 | 80 |
| 30 | 1386 | 1204 | 1243 | 1284 | 301 | 332 | 329 | 86 | 86 | 86 | 77 | 77 | 77 | 77 | 77 | 77 | 77 | 77 | 77 | 80 | 79 | 78 | 81 |
| 45 | 1701 | 1572 | 1619 | 1628 | 727 | 740 | 782 | 109 | 113 | 111 | 80 | 80 | 80 | 77 | 77 | 77 | 77 | 77 | 77 | 80 | 80 | 79 | 80 |
| 60 | 1915 | 1852 | 1883 | 1875 | 1253 | 1223 | 1290 | 156 | 173 | 164 | 94 | 94 | 93 | 79 | 79 | 79 | 78 | 78 | 78 | 81 | 81 | 80 | 80 |
| 15 | 1925 | 1864 | 1898 | 1886 | 1465 | 1453 | 1490 | 320 | 369 | 318 | 117 | 117 | 115 | 86 | 85 | 86 | 80 | 80 | 80 | 82 | 82 | 81 | 80 |
| 30 | 1925 | 1875 | 1897 | 1898 | 1541 | 1533 | 1559 | 513 | 527 | 486 | 134 | 133 | 132 | 99 | 95 | 99 | 87 | 86 | 85 | 83 | 82 | 82 | 82 |
| 45 | 1925 | 1881 | 1900 | 1913 | 1590 | 1581 | 1607 | 704 | 754 | 658 | 160 | 160 | 153 | 114 | 111 | 114 | 98 | 96 | 95 | 83 | 83 | 83 | 82 |
| 60 | 1925 | 1880 | 1901 | 2214 | 1625 | 1616 | 1642 | 857 | 893 | 808 | 231 | 232 | 215 | 129 | 125 | 128 | 113 | 111 | 109 | 84 | 85 | 84 | 83 |
| 15 | 1925 | 1891 | 1915 | 2266 | 1650 | 1642 | 1666 | 930 | 967 | 897 | 296 | 298 | 276 | 137 | 134 | 137 | 124 | 121 | 120 | 85 | 86 | 85 | 83 |
| 30 | 1925 | 1892 | 1907 | 2240 | 1676 | 1673 | 1691 | 1019 | 1064 | 1012 | 385 | 388 | 358 | 146 | 143 | 147 | 134 | 131 | 130 | 87.0 | 87 | 86 | 83 |
| 45 | 1925 | 1885 | 1915 | 2222 | 1690 | 1687 | 1710 | 1075 | 1120 | 1063 | 467 | 471 | 437 | 157 | 153 | 160 | 143 | 140 | 139 | 88 | 88 | 87 | 83 |
| 60 | 1925 | 1893 | 1911 | 2183 | 1700 | 1698 | 1735 | 1128 | 1168 | 1110 | 541 | 546 | 513 | 184 | 172 | 186 | 152 | 149 | 146 | 89 | 90 | 88 | 83 |



TEMPERATURE RESPONSE OF
2" OF CER-WOOL AND 4½"
OF MICROTHERM TO AN ASTM
E-119, THREE (3) HOUR
FIRE
Cer-wool
Microtherm
Foil
Cer-wool only
TEMPERATURE, °F
0 1 2 3 4 5 6 7 8 9 10 11 12 13
DISTANCE FROM FRONT FACE, INCHES