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THE TECHNICAL VIABILITY OF ALTERNATIVE BLOWING AGENTS IN POLYISOCYANURATE ROOF INSULATION

Part 4. In-situ Thermal Aging and Performance in Different Roof Systems*

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ABSTRACT (Number 26B)

This paper presents a progress report on field thermal performance measurements on a set of private industry-produced, experimental polyisocyanurate laminate board stock foams blown with CFC-11, HCFC-123, HCFC-141b, 50/50, and 65/35 blends of HCFC-123/HCFC-141b. These boards have been observed for almost 300 days of roof field exposure in East Tennessee.

The field data are used to derive an empirical model which can be used to predict effective diffusion coefficients for the air components into the foam cells. These diffusion coefficients are compared with those developed from steady state laboratory measurements of thin sliced samples from the same batch of experimental boards.

The relative performance of test specimens of HCFC-141b under a black and under a white membrane are reported. The aging of the HCFC-141b blown foam under the white membrane occurred more slowly during cold weather, but accelerated after the winter season, resulting in no significant resistivity difference after 280 days of exposure from September 1989 until May 1990.

The field data analysis suggests that the percent increase in k over that of the foam blown with CFC-11 is, after one year of aging, 5.5% for HCFC-123 and 11.7% for HCFC-141b. This leads to the same ordering as derived from the laboratory thin-slicing analysis report in Part 3 of this session.

Additional plans are described for further thermal and mechanical property measurements to be conducted on two ORNL roof field testers. After the first year of this three-year study, there has been no indication that thermal performance differences are serious enough to suggest that any or all of the HCFC alternate blowing agents would not be technically viable in polyisocyanurate roof insulations.

THE TECHNICAL VIABILITY OF ALTERNATIVE BLOWING AGENTS IN POLYISOCYANURATE ROOF INSULATION

Part 4. In-situ Thermal Aging and Performance in Different Roof Systems

INTRODUCTION

Rigid board polyisocyanurate foam insulations prepared with CFC-11, HCFC-123, HCFC-141b, and two blends of HCFC-123 and HCFC-141b have been installed in roof test panels in an outdoor facility at Oak Ridge National Laboratory. Roof panels with the unblended blowing agents have been in place since September 1989 and panels with the blends were installed in February 1990. The thermal performance of all panels is being continuously monitored. In addition, a second array of roof panels has been installed recently in a new apparatus to examine the behavior of roof systems with these same insulations for a range of construction conditions. The project is sponsored by the Society of the Plastics Industry (SPI) - Polyurethane Division, the Polyisocyanurate Insulation Manufacturers Association (PIMA), the National Roofing Contractors Association (NRCA), the U.S. Department of Energy (DOE), and the U.S. Environmental Protection Agency (EPA). The project has been under the direction of a Steering Committee with representatives from each of the sponsors and Oak Ridge National Laboratory. The purpose of the project is to determine if the performance of polyisocyanurate roof insulation foam boards blown with alternate agents differs from boards blown with CFC-11. This report describes progress after the first year of observation.

EXPERIMENTAL PLAN FOR THERMAL TESTING

Six specimens, each 4 feet by 4 feet in area, were selected for testing. Each consists of a metal deck section, two layers of 1.5-inch thick polyisocyanurate foam insulation, and a 45 mil reinforced ethylene propylene diene terpolymer (EPDM) single ply membrane. The central 2 feet by 2 feet area of each specimen is used for thermal measurements with the 1 foot perimeter acting as a guard. Specimens are mounted in pairs side by side in three 4 feet by 8 feet test panels as shown in Figure 1. The perimeter pieces of insulation in addition to being a thermal guard will be used for periodic yet to-be-determined material properties testing. Two layers of insulation were used. A single layer would not have allowed adequate instrumentation to be used. Two layers provide simultaneous thermal performance measurements at two different mean temperatures. In the summer, the top board has a much higher mean temperature than the bottom, and in winter the bottom board has a higher mean temperature than the top. In this paper only the combination performance of the top and bottom boards of each alternative is reported. Insulation board joints are not staggered in the test specimens because this would prevent easy removal for inspection and laboratory testing.

Five of the specimens are assembled with insulations made with the five blowing agents; CFC-11, HCFC-123, HCFC-141b, a 50/50 blend of HCFC-123 and HCFC-141b, and a 65/35 blend of HCFC-123 and HCFC-141b and all are under similar black EPDM membranes. A sixth specimen is blown with HCFC-141b and is under a white EPDM membrane. All foams were produced on the same production line by a single PIMA member. This strategy allows meaningful direct performance comparisons between each of the foams with alternative blowing agents and the foam with CFC-11. The use of the black and white coverings over one insulation type provides a comparison of performance under two different environments since the white membrane typically is 20 to 60 degrees fahrenheit cooler each day.

The center 2 feet region of each specimen is used for thermal measurements. A two inch square heat flux transducer (HyCal BI-7) is mounted between the two layers of insulation in the center of the measuring region as shown in Figure 2. Copper-Constantan 30 gage thermocouples, all cut from the same spool to reduce relative errors, are placed at each boundary. Prior to mounting the center pieces were taken to the Building Material Properties Laboratory at ORNL where initial values for the steady-state thermal conductivity were measured in accordance with ASTM C518 procedures and the (Refs) embedded heat flux transducers were calibrated. After each six months of field exposure this process is to be repeated. The procedure used in the laboratory is described in another paper in this session (Ref. 1).

THE ROOF THERMAL RESEARCH APPARATUS

The outdoor thermal performance testing is being carried out with the Roof Thermal Research Apparatus (RTRA). The RTRA, shown in Figure 3, has been described previously (Ref. 2). Briefly, it is a 10 feet by 28 feet conditioned building 9 feet high that can accommodate two 4 feet by 8 feet removable test specimens on either side of a fixed center section. The RTRA has a complete weather station for continuous monitoring of ambient conditions as well as solar and infrared radiation. This information as well as data from thermocouples, heat flux transducers, and moisture probes attached to test panels is recorded continuously at one minute intervals and averaged over an hour before storage on a computer disk. Computer disk capacity is sufficient so that one disk holds all the data from any single experiment from the RTRA, some of which have lasted as long as two years.

Analysis of RTRA data is on a week by week basis. Seven days of data is sufficiently long to contain enough diurnal fluctuation to characterize the time of year and short enough not to be affected by seasonal drifts. Figure 4 shows the outside air temperature and building air temperature for a week in April 1990. As expected the diurnal variations show very clearly. Note that on the fourth day a warm front abruptly moved through the area resulting in a sharp increase in the mean outdoor temperature. Also note that the indoor temperature, controlled by a through-the-wall heat pump, fluctuates because of outdoor changes. Neither of these effects upsets the measurements of thermal performance because the analysis procedure used in this study is a dynamic method and these "extra" transient effects are taken into account.

Figure 5 shows the variation in both the solar radiation intensity and the background sky radiation intensity. The former, measured with a pyranometer, records the incident radiation in the visible portion of the spectrum. Thus, the big peaks during daylight hours, are sharply reduced during periods of cloud cover, and zero is read during night hours. The background sky radiation is measured with a pyrgiometer which only records radiation in the infrared (heat radiation). This sky radiation is only slightly influenced by sunlight and is primarily a measure of the temperature of the sky. Thus, it exhibits a slow seasonal variation, being larger in the summer than in the winter. Both these quantities are important in an analysis of the thermal energy balance of a roof system. Figure 6 is plot of the hourly temperatures recorded by thermocouples placed at different depths in the insulation as indicated in Figure 2. As one would expect, the fluctuations induced by radiation and convection heating of the surface are dampened toward the interior. The lack of any significant time lag in the temperature peaks at different depths indicates that thermal storage effects are negligible for these materials. The vertical gradient of temperature shown in Figure 6 will result in a heat flow across the system. This is shown in Figure 7 which is a plot of the hourly output of a heat flux transducer located in the center of the insulation stack as shown in Figure 2. Note that fluctuations in heat flux follow fluctuations in temperatures, including sharp changes caused by cloud cover, shown in Figure 6. Also note that the heat flux will reverse directions, being out of the building (negative sign) during the evening and into the building during the day (positive sign).

As mentioned previously, one specimen is HCFC-141b covered by a white membrane. The purpose is to provide a comparison of performance of the same material under different temperature regimes. Figure 8 shows the surface temperatures of these two membranes during the same week in April 1989. As one would expect, the differences in daytime peak temperatures is quite dramatic. In Figure 9 this same data is plotted as a difference and compared to the difference in surface temperature between the black EPDM over HCFC-141b and a black EPDM over HCFC-123. First note that the difference in peak temperatures for the two different colored membranes readily reaches 60 degrees during daylight hours. Also note that the night time difference in temperature for these two systems is very near zero. This suggests that even though they have quite different optical reflectances in the visible portion of the spectrum, their reflectances in the infrared are nearly the same. Also note that there are non-zero differences in the surface temperatures of the two similar membranes over different insulations. This is probably due to these two panels being on different ends of the RTRA where slight differences in wind speed and direction can result in slight differences in surface temperature.

THERMAL PERFORMANCE CALCULATIONS

The principal RTRA results that characterize the thermal performance of roof systems have been obtained using the computer program PROPOR (Properties - Oak Ridge). PROPOR is a non-linear regression theory program that combines solutions of the fundamental heat transfer equations with least squares analysis techniques. It was developed by J. V. Beck (Ref. 3) and modified for estimating the thermal conductivity and specific heat of building materials from transient temperature and heat flux data.

PROPOR is preferred over other available procedures, e.g., the "averaging technique" (Ref. 2). It gives thermal conductivity as a function of temperature, it provides useful results over a wide range of weather conditions, it includes estimates of uncertainty, (Ref. 4) and it is the only means to estimate the specific heat of building materials from in situ data (this feature is not used in this project because the specific heat of light weight insulations does not have a significant effect on thermal performance).

PROPOR, being a statistical tool, operates on a fixed data set. For light weight roof systems an adequate set size is one week, or 168 hourly data points for each input parameter. While PROPOR has several output modes, in this study the output consists of the thermal conductivity and the slope of the thermal conductivity versus temperature curve at the mean temperature of the sample for each week of data. For each specimen, independent calculations are carried out for the top board, the bottom board, and both boards combined (since each of these configurations have a different mean temperature each week).

THERMAL TEST RESULTS

Measured weekly R-values collected for a 40-week period from September 1989 until May 1990 are shown in Figure 10 for the combined two-board test systems containing CFC-11, HCFC-123, and HCFC-141b boards under the black EPDM. These values represent the actual R-value for each week reported at the combined mean board insulation temperature experienced during that week. The top set of data represent the CFC-11 boards, the middle, HCFC-123, and the lower HCFC-141b. The relative performance of all three boards remains the same for the entire measurement period. These data show decreasing R-value over time. A slight rise in R-value occurred between the age of 150 and 250 days. This period represents the winter season with low mean insulation temperatures and, the actual resistivity is inversely related to temperature in this range of mean insulation temperatures.

Measured weekly R-values collected for a 20-week period from January 1990 until May 1990 are shown in Figure 11 for the HCFC blends. These boards were not exposed to the same (temperature/time) conditions as the other three boards, so the relative comparison to CFC-11 is a bit misleading. The slight rise in R-value, shown in Figure 10 for the non-blends does not occur for the blends because these boards were installed after the period of cold temperatures, which occurred in December 1989. The mean temperatures of the 50/50 and 65/35 blend (HCFC-123/HCFC-141b) boards' were higher during their initial aging period than that of the exposure for the CFC-11 boards.

The temperature effect can be eliminated by normalizing the R-values using the R-value temperature relationship developed by steady state laboratory measurements of the test specimens prior to installation on top of the RTRA (Ref. 1). The R-values shown in Figure 12 are normalized to an insulation temperature of 75°F. The R-value versus temperature relationship was obtained by fitting a non-linear equation to 5 steady state measurements at different mean temperatures of each of the 5 different boards prior to field installation. The resulting R (75°F) for each of these boards was subtracted from the non-linear equation. This left an adjustment factor as a function of mean insulation temperature. This relationship was then used to convert the weekly R-values at the mean weekly insulation temperatures to R-values at 75°F. This procedure assumes that the shape of the R-value versus mean insulation temperature remains the same for the entire testing period.

The aging caused by oxygen and nitrogen diffusion into the polyisocyanurate foam is more clearly depicted in the presentation of temperature-normalized R-values. The slicing study examination of diffusion coefficients, described by Ref. 1, suggests that the initial predominant aging effect is caused by the air component diffusion into the cells in boards with 1.5-in. thickness for at least the first 365 days.

The data sets shown in Figure 12 illustrate much more of a linear relationship between R-value and age for this measurement period. This observed relationship can be used to derive the effective air component diffusion coefficients for field-installed foams. Using the empirical equation described in Ref. 1 results in k described by an exponential dependence in diffusion coefficient (D_1), time (t), and thickness (h).

$$k = k_1 \exp \{(D_1 t)^{1/2}/h\} \qquad (1)$$

where k_1 is the initial thermal conductivity,

$$\ln k = \ln k_1 + (D_1 t)^{1/2}/h \qquad (2)$$

$$Y = A + BX \qquad (3)$$

where
$A = \ln k_1$,
$Y = \ln k$
$X = t^{1/2}/h$
$B = D_1^{1/2}$
k_1 = initial k of specimen
D_1 = effective diffusion coefficient for air components into the foam, cm^2s.

Therefore, the weekly measured normalized k values for the test specimens with a thickness (h) as a function of aging time (t), and a plot of Y (ln k) versus X ($t^{1/2}/h$) should yield a straight line with slope B ($D_1^{1/2}$). A least squares fit of the measured field data yields a straight line represented by Eq. 3 with an intercept of ln k_1 and a slope of $D_1^{1/2}$.

Figures 13, 14, and 15 show the increase of field measured k (75°F) (plotted in the same form as the laboratory slicing data reported in Ref. 1) as a function of $\text{time}^{0.5}$/thickness ($\text{days}^{1/2}$/mm) for the two-board combination of the CFC-11, HCFC-123, HCFC-141b under black EPDM, and 141b under the white EPDM, respectively. The field data base size could easily be tripled for each board type by using weekly data points of the top and bottom boards as well as the combination. However, the linear fit leads to reasonably high R^2 for each case using just the combinations (.85,.92; .97,.97 for CFC-11, HCFC-123, HCFC-141b under black EPDM, and HCFC-141b under white, respectively). The R^2 value is a statistic that measures the proportion of total variation about the regression line. R^2 values can take values as high as 1 when the data can be reproduced exactly by the regression equation.

The resulting effective air component diffusion coefficients and the initial k values obtained from the field data are shown in Tables 1 and 2 and compared with the values derived from the slicing analysis, aged at 75°F and 150°F (Ref. 1).

Table 1. Effective diffusion coefficients derived from RTRA data and slicing tests in laboratory, 10^{-8} cm^2/sec for the air components, D_1.

	CFC-11 Black EPDM	HCFC-123 Black EPDM	HCFC-141b Black EPDM	HCFC-141b White EPDM
RTRA Data	2.21	1.96	2.58	4.02
Steady-State Lab (75°F)	1.52	1.64	1.51	1.51
% Difference	+45%	+20%	+71%	+166%
Steady State Lab (150°F)	10.78	6.81	3.33	3.33
% Difference	-80%	-71%	-23%	21%

The effective air diffusion coefficients appear to be higher in the faced field specimens than laboratory measurements on the unfaced sliced specimens conditioned at 75°F by 20 to 71% for those specimens under the black membrane. The same HCFC-141b boards under a white membrane lead to a surprisingly higher value than that under the black membrane. The air diffusion appears to be lower in the field specimens under the black membrane than in laboratory specimens condition at 150°F by 20 to 80%. However, the diffusion coefficient derived from the HCFC-141b boards under the white membrane is actually 21% higher than even the diffusion coefficient derived at 150°F conditioned samples.

The field-derived air component effective diffusion coefficients obtained by the HCFC-141b specimens under the white EPDM are suspect since the diffusion rate ordinarily increases with increased temperature. The mean specimen temperature under the black membrane was 77°F and under the white membrane 70°F. This observation, however, does raise the possibility that average temperature is not the only variable driving the foam board initial aging effect.

Figure 16 shows the normalized R-values at 75°F for the HCFC-141b under the black and white EPDM. After an unexplained anomalous reading in the second week, the HCFC-141b under the white membrane aged much more slowly throughout the winter season up until about 200 days of age. After that, it appears as if the HCFC-141b specimen under the white EPDM aging accelerated such that the R-value in May 1990, 340 days of age are within 2% of the HCFC-141b specimen under the black EPDM.

Table 2 displays the values of k_1 derived from the faced insulation board field data compared to the k_1 derived from the laboratory slicing analyses on unfaced specimens. The percent differences between the CFC-11, HCFC-123, and HCFC-141b field specimens under the black EPDM yield k_1-values which agree quite well with the slicing analyses when compared to the sliced samples aged at 75°F. The k_1 predictions are within $\pm 3\%$ between the field and laboratory slicing analyses derived values. The mean temperature of the field-installed test specimens from December 1989 until May 1990 was around 77°F. The values of k_1 can be used to compare the initial impact of the alternate blowing agents before any aging occurs. The field data results suggest that the percent increase in k over that of the other non-blended blown boards with CFC-11 is 6.4% for HCFC-123 and 9.6% for HCFC-141b. This is the same ordering as estimated by the slicing tests (Ref. 1).

The long-term (5+ years) prediction of the thermal resistivity of the specimens cannot be made confidently with less than one year's worth of continuous field data from the 1.5-in. thick faced boards. After approximately one year, the diffusion of the blowing agents should dominate the aging effect. Data collected after one year should begin to provide some insight into the effective blowing agent diffusion in these full-thickness boards.

Table 2. Initial k_1 (75°F) derived from field data (Btu·in./h·ft^2·°F).

		k_1		
	CFC-11 Black EPDM	HCFC-123 Black EPDM	HCFC-141b Black EPDM	HCFC-141b White EPDM
Field data	0.1231	0.1310	0.1349	0.125
Steady state lab (75°F)	0.1206	0.1317	0.1393	0.1393
% Difference	+2%	-0.5%	-3%	-10.2%
Steady state lab (150°F)	0.1260	0.1374	0.1503	0.1317
% Difference	-23%	-4.7%	-10.2%	-5.1%

Table 3. Predicted thermal resistivity at 75°F for faced 1.5-inch thick prototypical foam boards using field data compared to unfaced slicing analysis values conditioned at 75°F and at 150°F, for an age of one year (365 days).

R-Value h·ft^2·°F/Btu·in.

	CFC-11 Black EPDM	HCFC-123 Black EPDM	HCFC-141b Black EPDM	HCFC-141b White EPDM
Field data	6.58	6.24	5.89	6.01
Steady state (75°F)	6.81	6.59	6.08	6.08
% Difference	-3.4%	-5.3%	-3.1%	-1.1%
Steady state (150°F)	6.12	5.87	5.64	5.64
% Difference	+7.5%	+6.3%	+4.4%	+6.5%

Using the regression fits of the field data for all four test specimens shown by the line in Figures 13, 14, and 15, the predicted thermal resistivity at 75°F for the faced 1.5-in. thick experimental foam boards can be made at a one-year aging time. Table 3 contains these aged field resistivity predictions and compares them to the unfaced 1.5-in. thick boards aged at 75°F and 150°F derived from the slicing analyses. The field data derived predictions are 1 to 5.3% less than slicing analyses predictions for unfaced boards at 75°F and 4.4% to 7.5% above the resistivity prediction for the slicing analysis derived samples at 150°F. The faced field-installed boards appear to be aging after one year somewhere between that which can be predicted by conditions at 75 and 150°F. It is important to recall that the field exposure of these experimental boards has not yet seen a full summer season.

A crosscheck of the RTRA measurement of resistivity and steady state measurements of the exact same specimens taken on the Building Materials Properties Laboratory thin screen heater (Ref. 1) is shown in Table 4. The RTRA two-foot assemblies' k value was measured prior to installation (60-80 days of age and after 240 days of exposure at age 330-340). The resistivity steady-state laboratory measurements of resistivity are compared to in-situ data derived from linear regression of each of three test specimens: CFC-11, HCFC-123, and HCFC-141b under black membranes.

Table 4. Crosscheck of in-situ RTRA resistance measurements compared to laboratory steady state measurements using the thin screen tester. Resistivity (h·ft^{2}·°F/Btu·in.)

	CFC-11	HCFC-123	HCFC-141b black
Initial Measurement 60-80 days			
Field data	7.45	7.03	6.75
Steady state laboratory	7.81	7.41	6.94
% Difference	-4.6%	-5.1%	-2.7%
330-340 days			
Field data	6.65	6.29	5.95
Steady-state laboratory	7.194	6.67	6.37
% Difference	-7.6%	-5.7%	-6.6%

Analysis of the RTRA data yields resistive values on the average of 4.1% lower than the laboratory measurements taken before any exposure. The RTRA data gives resistivity values on the average, of 6.6% lower after the first periodic check of field resistivity data with laboratory resistivity data. The first periodic check with steady state laboratory measurements were conducted a little less than one year since these boards were produced. The observations suggest about a 5% offset or a °.2 to °.6 h·ft^2·°F/Btu·in. lower in-situ resistivity than that measured by steady state means in the laboratory. This offset is of concern, but within the confidence intervals of both measuring devices. In light of the typical difficulty in making precise field measurements, it is remarkable the difference is so small. However, it is important to note that the emphasis of this overall project is to determine the relative differences between an experimental laminate board blown with CFC-11 compared to experimental prototypes blown with HCFC alternatives.

EVALUATION OF MECHANICAL PROPERTIES

To evaluate the mechanical properties of insulation products, a special apparatus was constructed. The Roof Mechanical Properties Research Apparatus (RMPRA), shown in Figures 17 and 18, permits full-scale roof application using various types of application techniques.

Roof application subjects insulation to rather severe conditions, such as exposure to hot asphalt, solvent-bearing adhesives, and high compressive concentrated loads from application equipment. Roof application on the RMPRA will allow evaluation of the susceptibility of insulation blown with the various agents to the rigors of roof application.

Physical Characteristics of the Apparatus

The RMPRA has a plan dimension of 32 feet by 72 feet. It is a one-story structure built predominantly below grade with the roof platform at about 5 feet above grade. The apparatus is equipped with heating and cooling equipment that will maintain an interior temperature of approximately 75°F. The below grade portion of the structure will also be used to study energy flow through typical residential basement wall constructions. The roof deck is designed for typical commercial construction with a 20 pounds per square foot live load. Half of the structure is designed for a roof covering load of 10 pounds per square foot, while the other half is designed for 19 pounds per square foot. The deck is 22 gauge galvanized steel, 1-1/2" deep, wide rib. The deck is supported by steel joists spaced at 6'-3" on center which span 30'-8".

Roof System Description

The roof deck is divided in half by a wooden control curb. Half of the roof will have a built-up membrane system, while the other half will have an EPDM system. Each type of roof system will incorporate all five insulation products. Each system will utilize two layers of insulation, with each layer being 1-1/2" thick. A portion of the roof will utilize insulation boards with perforated facers. Figure 19 is a schematic showing the position of the different roof systems which will be installed on the RMPRA.

BUR System

The built-up roof (BUR) system will have two variations. Half of the BUR system will be fully adhered directly to the insulation with hot asphalt. The other half of the BUR system will utilize a vented base sheet that will be spot mopped with asphalt.

EPDM System

The EPDM system will have two variations. Half of the EPDM system will be fully adhered with adhesive directly to the insulation. The other half of the EPDM system will be mechanically attached to the insulation with screws and plates (the membrane will be loose, except at the fastener locations).

Tests During Application

During roof application, a number of tests will be conducted:

- A four-wheel cart loaded with insulation will make five passes over the insulation to determine damage susceptibility.
- During application of asphalt (which will have a maximum temperature of approximately 460°F), susceptibility to high temperatures will be observed. Test cuts will also be taken to augment the evaluation.

- After BUR application, a loaded BUR aggregate spreader will make five passes over the membrane. Test cuts will be taken to assess potential insulation damage.
- After laying a portion of the EPDM, a loaded ballast buggy (a device used to spread aggregate over the membrane) will make five passes over the membrane. The membrane will be removed and insulation damage assessed. The membrane will be repositioned and ballast applied over the membrane. The buggy will make two additional passes over the aggregate. The membrane will be removed and the insulation again assessed for damage. The ballast buggy will have a wheel load of approximately 300 pounds.
- After fully adhering the EPDM, a loaded ballast buggy will make five passes over the membrane. Test cuts will be taken to assess damage caused by the adhesive and the buggy.

Near the completion of the test period (1 to 2 years), additional test cuts will be taken to determine if further deterioration has occurred over time.

Long-Term Thermal Testing

Six insulation boards containing heat flux transducers and thermocouples will be installed during application. These will permit monitoring of the thermal performance and temperature of the CFC-11, HCFC-123, and HCFC-141b boards throughout the RMPRA test period. The data collected will provide a valuable comparison of results with those obtained from the RTRA and laboratory testing. The particular focus will be to determine aging differences of the foam boards encapsulated with asphalt (BUR system) and coated on one side with adhesive (EPDM system), versus foam boards in the RTRA which do not have any encapsulant.

DISCUSSION AND CONCLUSIONS

This paper presents a progress report on field thermal performance measurements taken on a set of private industry-produced, experimental polyisocyanurate laminate board stock foams blown with CFC-11, HCFC-123, HCFC-141b, and 50/50 and 65/35 blends of HCFC-123/HCFC-141b. These boards have been observed for almost 300 days of field roof exposure. The field data are used to derive an empirical model which can be used to predict effective diffusion coefficients for the air components into the foam cells. These diffusion coefficients are compared with those developed from steady state laboratory measurements of thin sliced samples from the same batch of experimental boards.

The relative performance of a test specimen of HCFC-141b is reported under a black and under a white membrane. The aging of the 141b blown foam under the white membrane aged more slowly during cold weather than when placed under a black membrane, but accelerated aging occurred under the white EPDM after the winter season resulting in less than 2% resistivity difference after 280 days of exposure from September 1989 until May 1990.

The field data analysis suggests that the percent increase in k over that of the foam blown with CFC-11 is, after one year of aging, 5.5% for HCFC-123 and 11.7% for HCFC-141b. This leads to the same ordering as derived from the laboratory thin slicing analysis report in Part 3 of this session. Additional thermal and mechanical property measurements will be conducted on the two ORNL roof field testers.

At the time of this writing, roof application on the RMPRA is scheduled for the last week in June, 1990. It is envisioned that work on the RMPRA will allow evaluation of damage susceptibility of the insulation products blown with the various alternatives. It is imperative to have an insulation that can withstand the rugged nature of roof application, otherwise, problems with the insulation can be detrimental to the roof membrane and lead to premature roof failure. The results of this work should assist in selection of an alternative blowing agent that can be used to produce polyisocyanurate roof insulation that provides a suitable substrate for various types of roof membranes.

After the first year of the three-year study, there has been no indication that thermal performance differences are serious enough to suggest that any or all of the HCFC alternative blowing agents would not be technically viable in polyisocyanurate roof insulation.

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5. "Environmental Acoustics," PCN:01-040686-10, ASTM 1989 Annual Book of Standards, Vol. 4.06, Thermal Insulation, American Society for Testing and Materials, Philadelphia, 1989.

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NOMENCLATURE

A	constant in Eq. 3 (1n k_1)
B	slope in Eq. 3 ($D^{1/2}$), cm^2/s
D_1	effective diffusion coefficient for air components into the foam cm^2/s
h	thickness, ft, in., cm, or mm
k	thermal conductivity, Btu.in./h.ft^2.°F
k	(75°F) thermal conductivity at 75°F
k_1	initial thermal conductivity, Btu.in./hr.ft^2.°F
R	thermal resistivity, h.ft^2.°F/Btu.in.
t	aging time, days or seconds
X	variable in Eq. 3 ($t^{1/2}/h$)
Y	variable in Eq. 3 (ln k)

Symbols

CFC	chlorofluorocarbon
EPDM	ethylene propylene diene terpolymer
HCFC	halogenated chlorofluorocarbon
HFT	heat flux transducer
NRCA	National Roofing Contractors Association
PIMA	Polyisocyanurate Insulation Manufacturers Association
PIR	polyisocyanurate
RMPRA	Roof Mechanical Properties Research Apparatus
RTRA	Roof Thermal Research Apparatus

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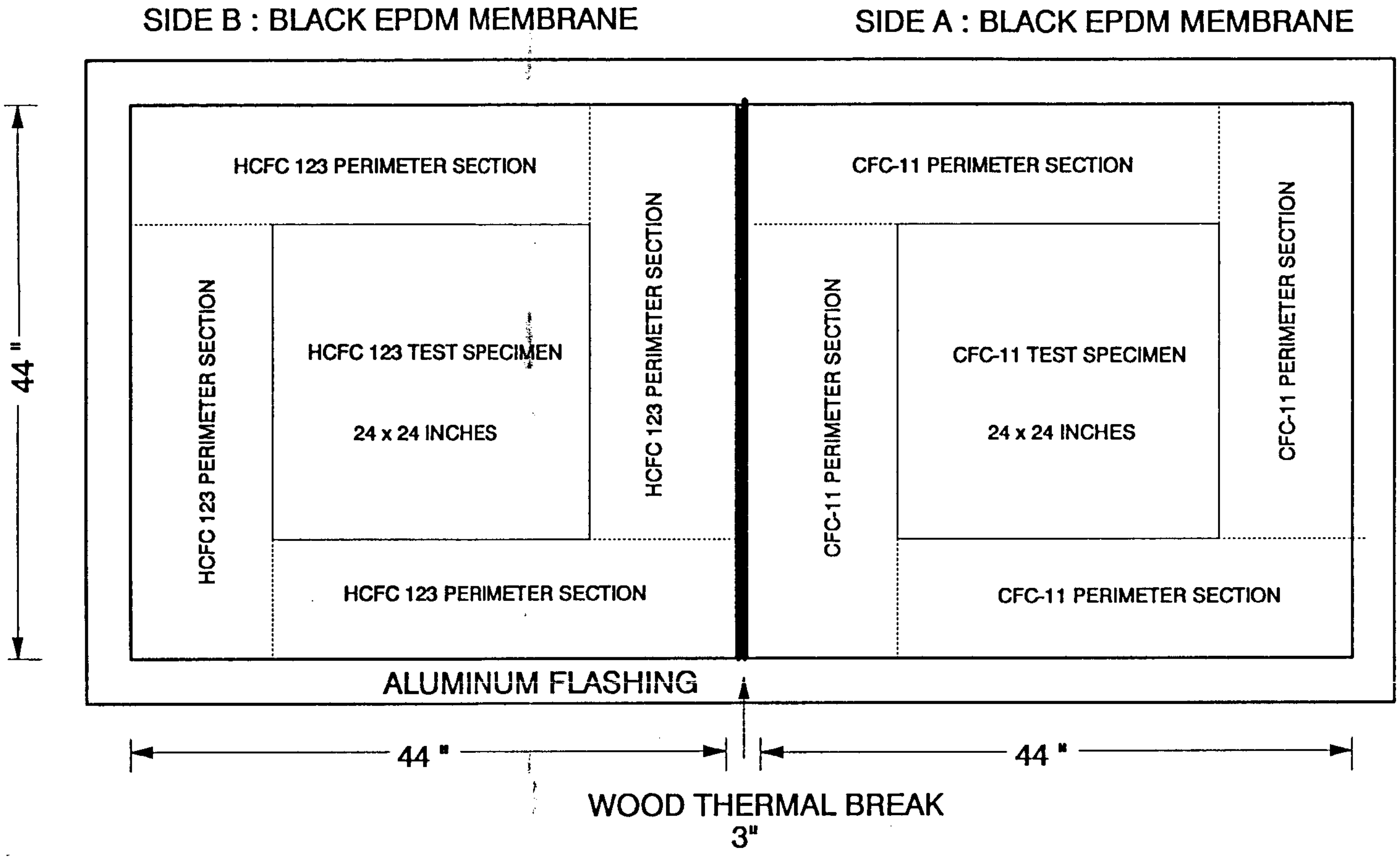
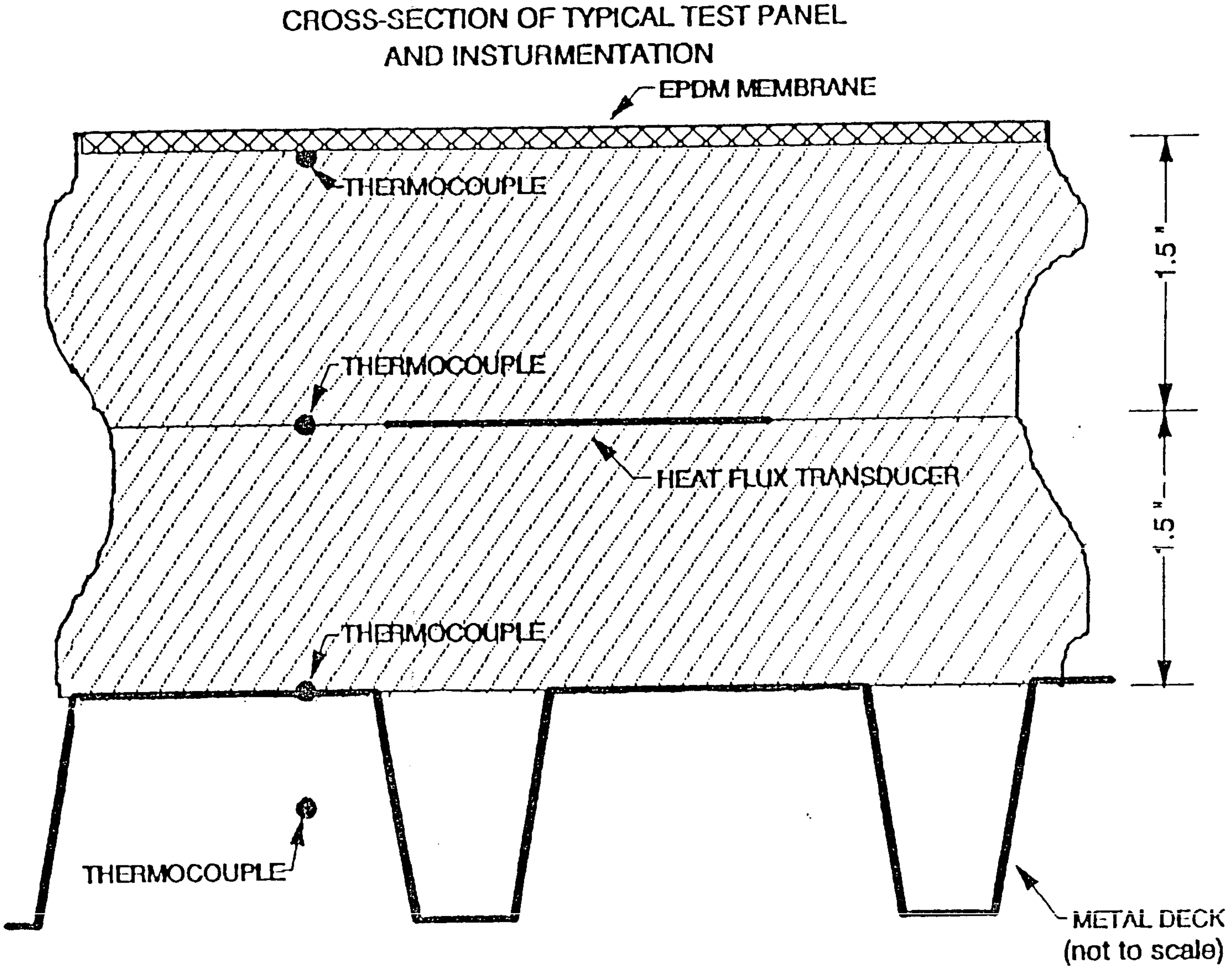


Top View of CFC-11 vs. HCFC 123 Panel

- EPDM MEMBRANE IS MECHANICALLY ATTACHED TO ALUMINUM FLASHING
- HCFC 123 and CFC-11 are NOMINALLY 1.5" THICK BY 2 LAYERS TOTAL 3.0"
- ALL TEST PIECES REST ON METAL DECK

Figure 1. Typical board layout in one of the panels.



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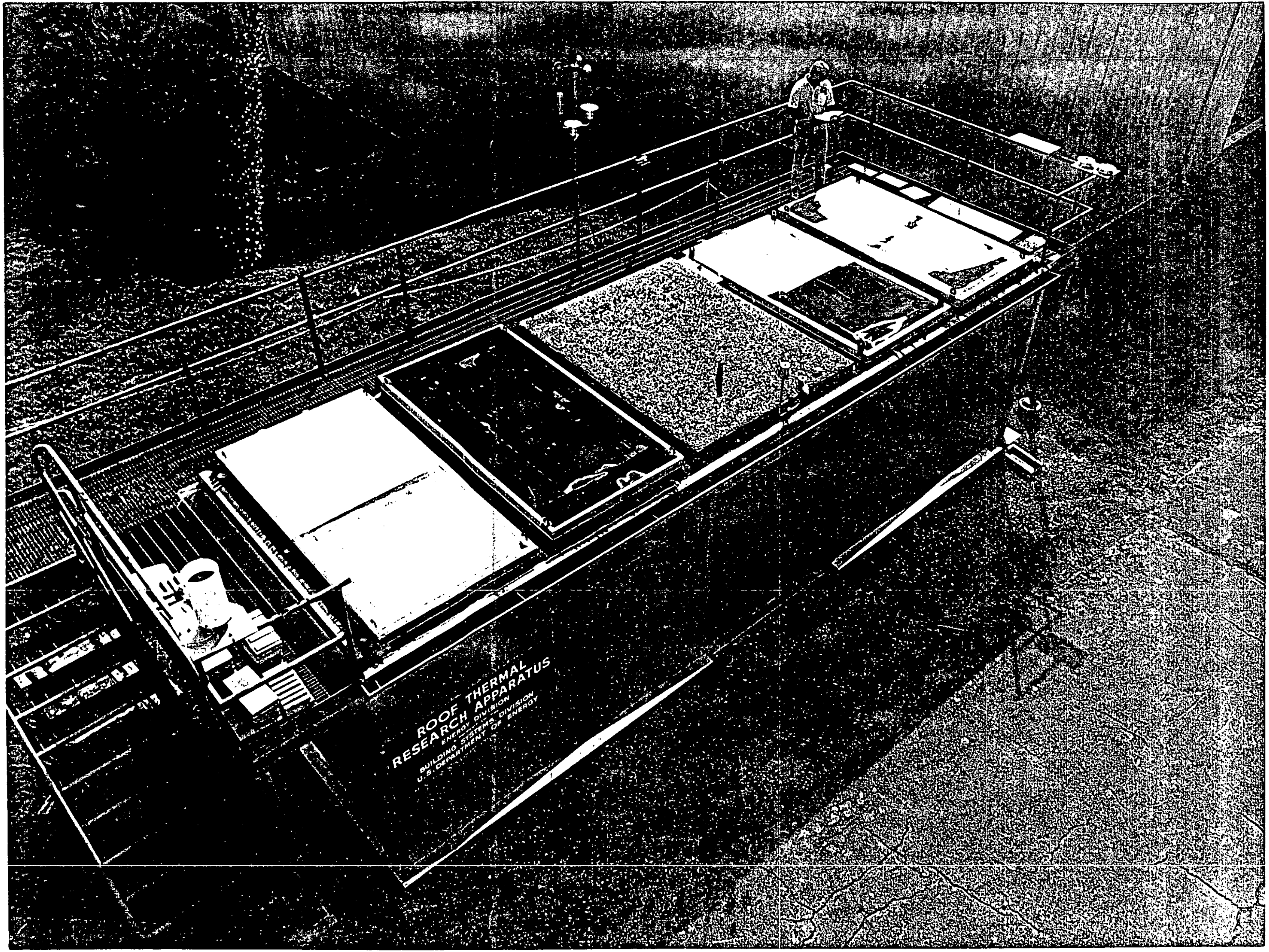

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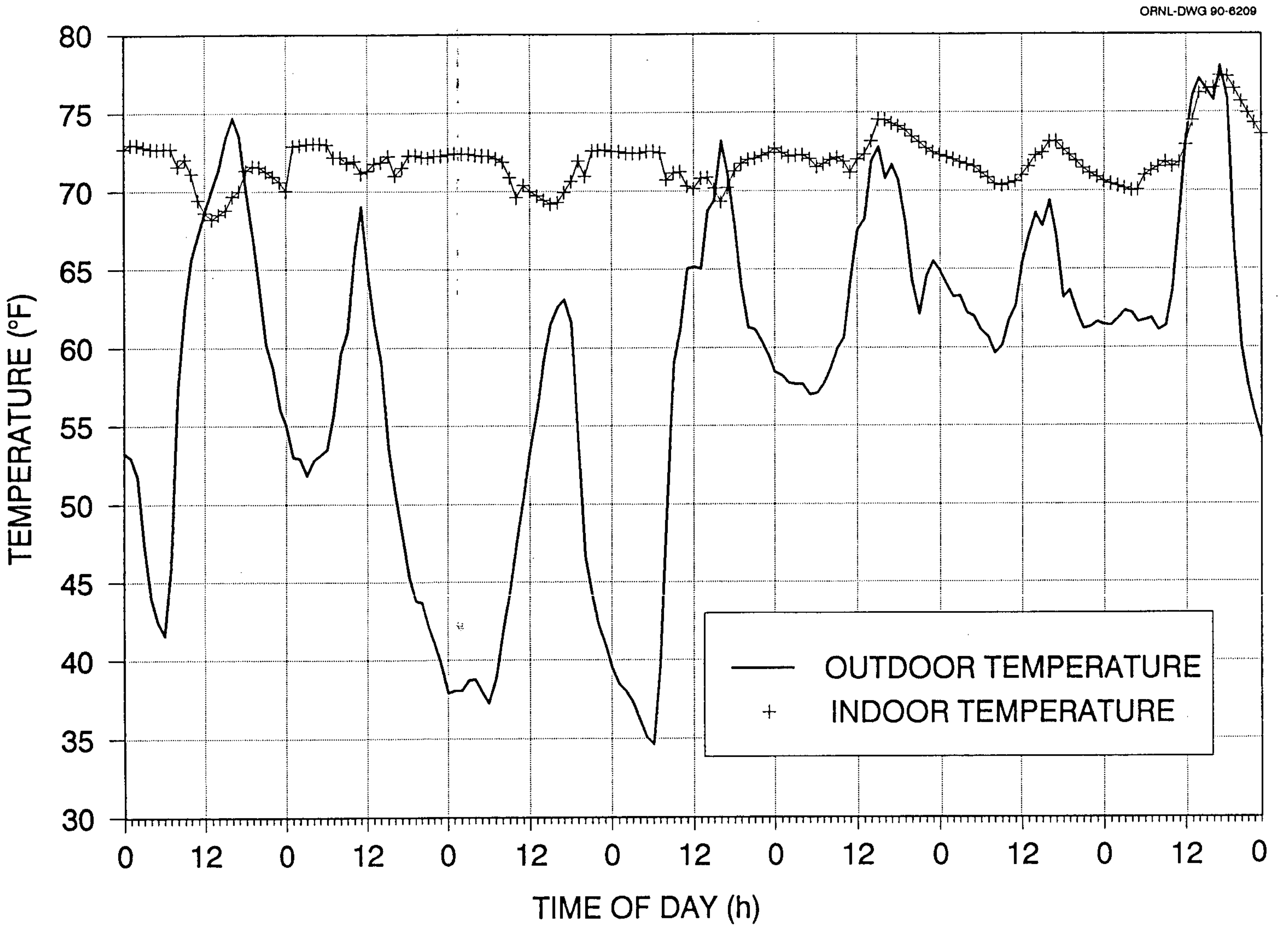

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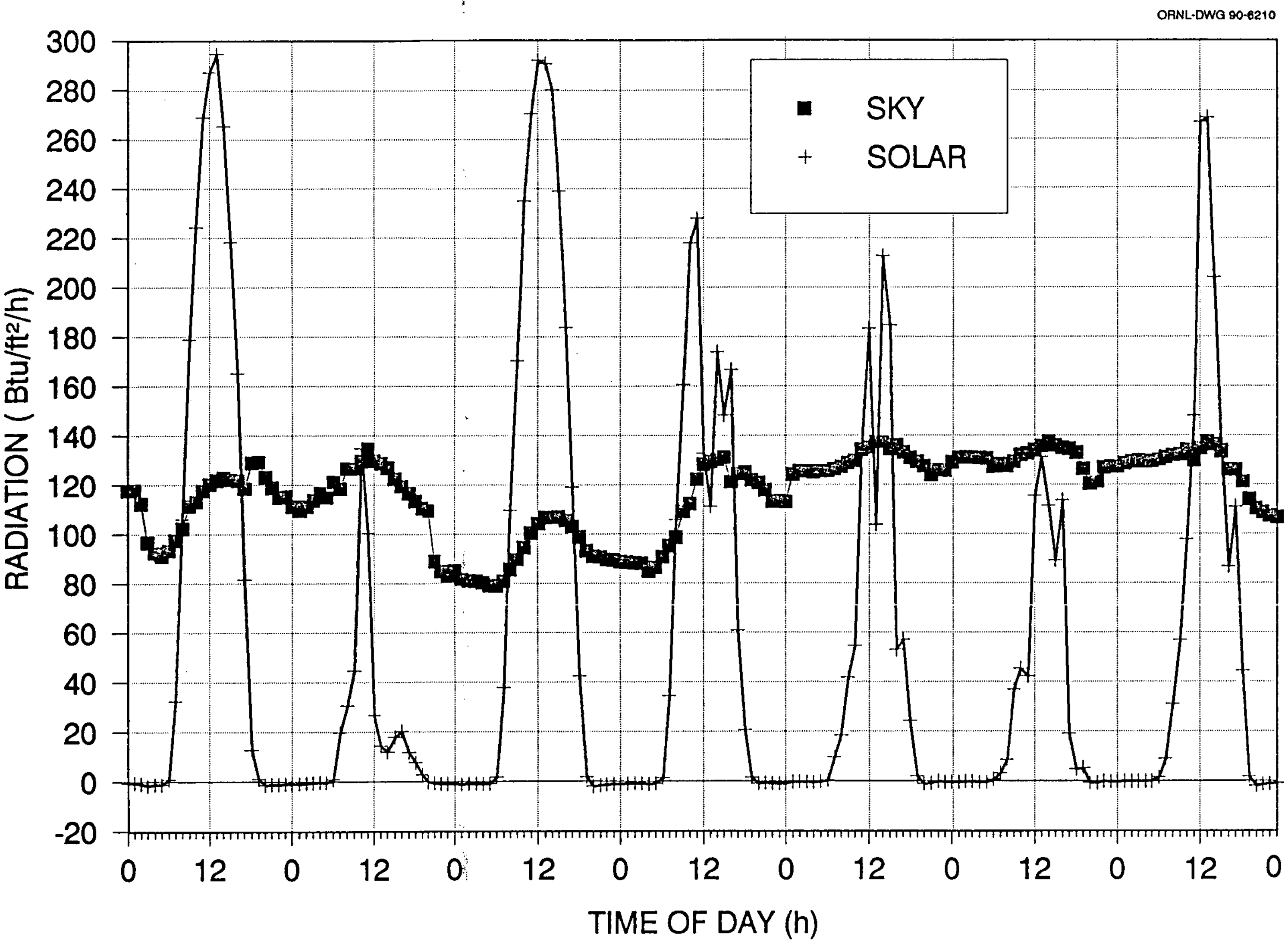

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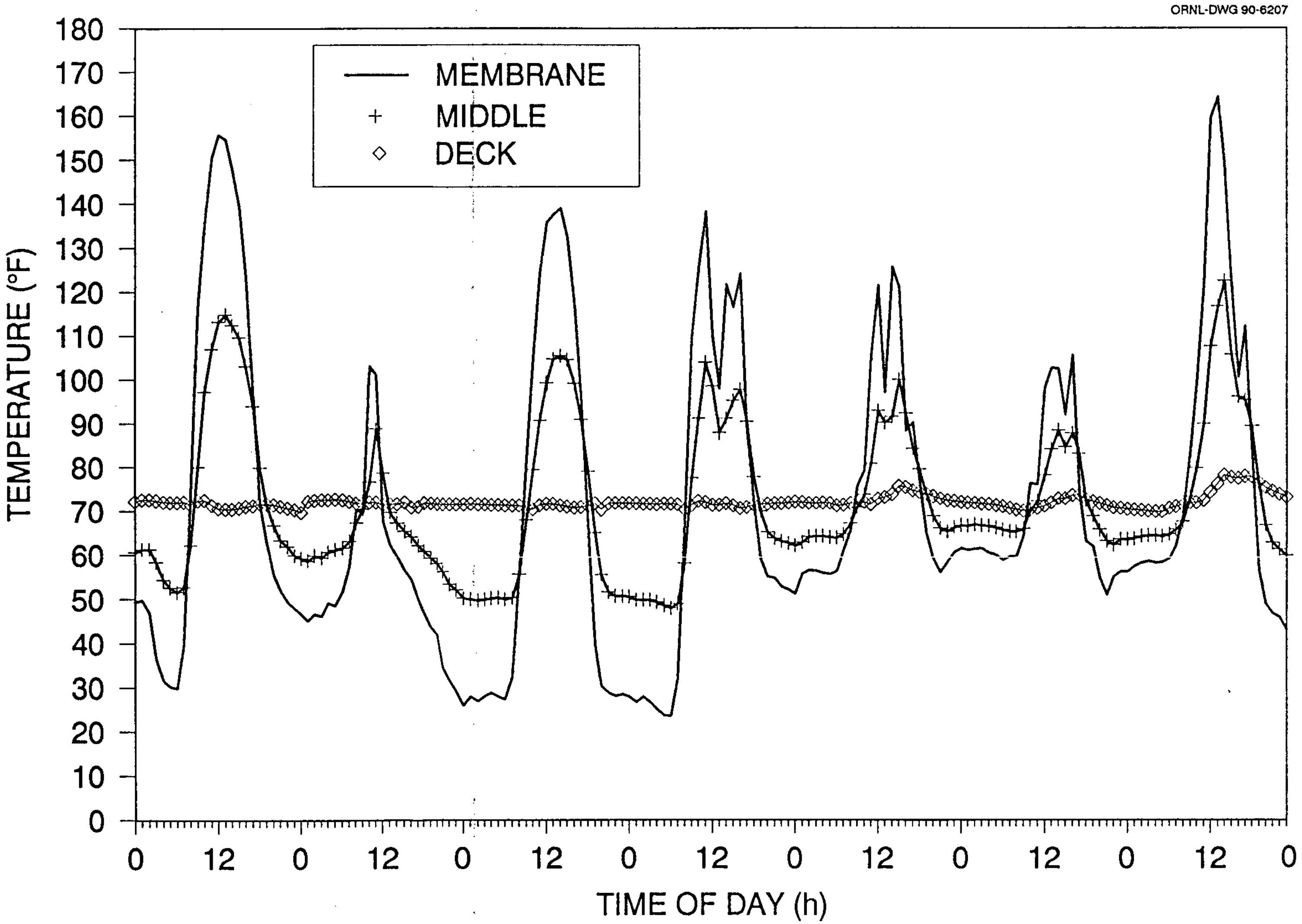

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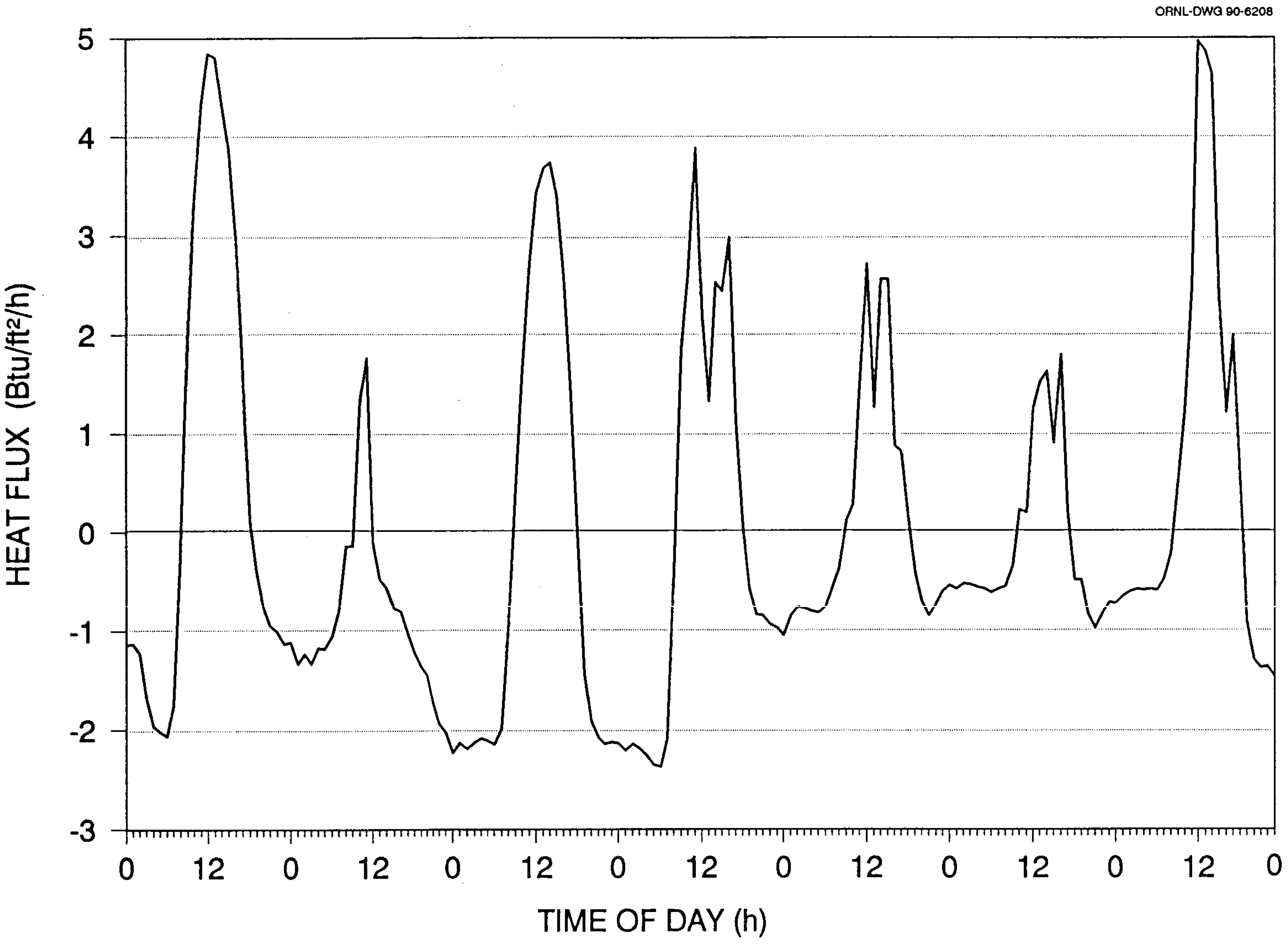

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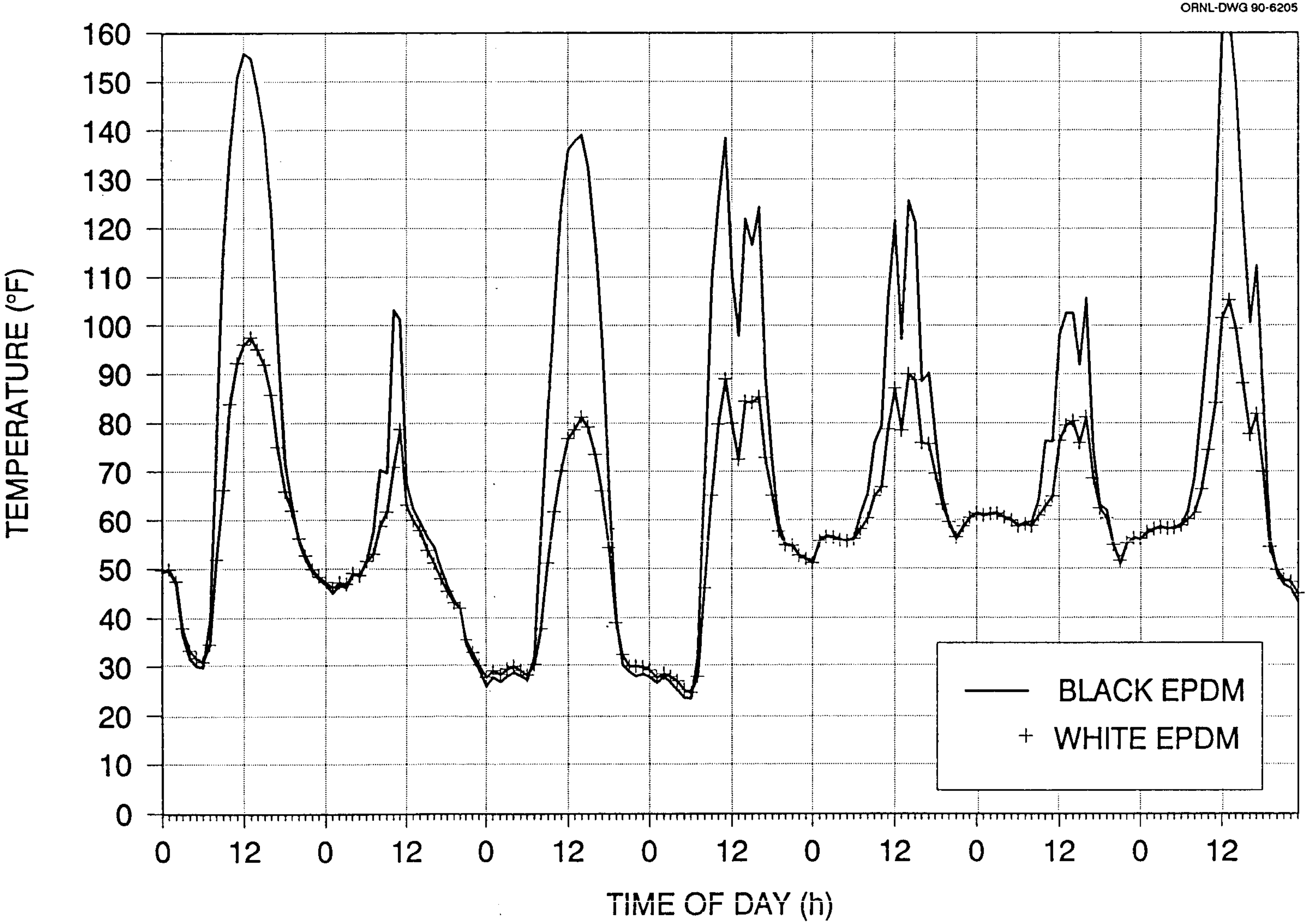

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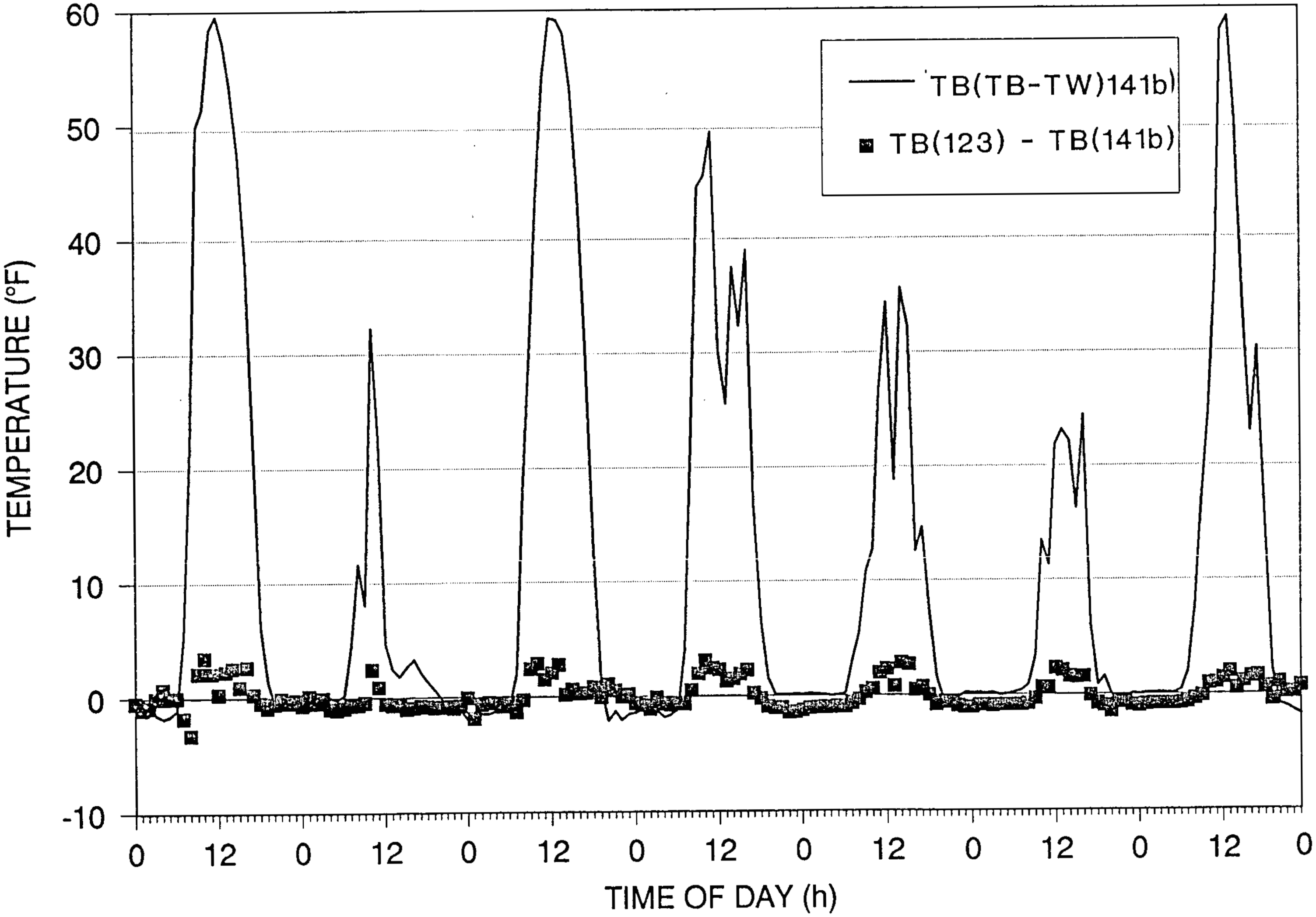

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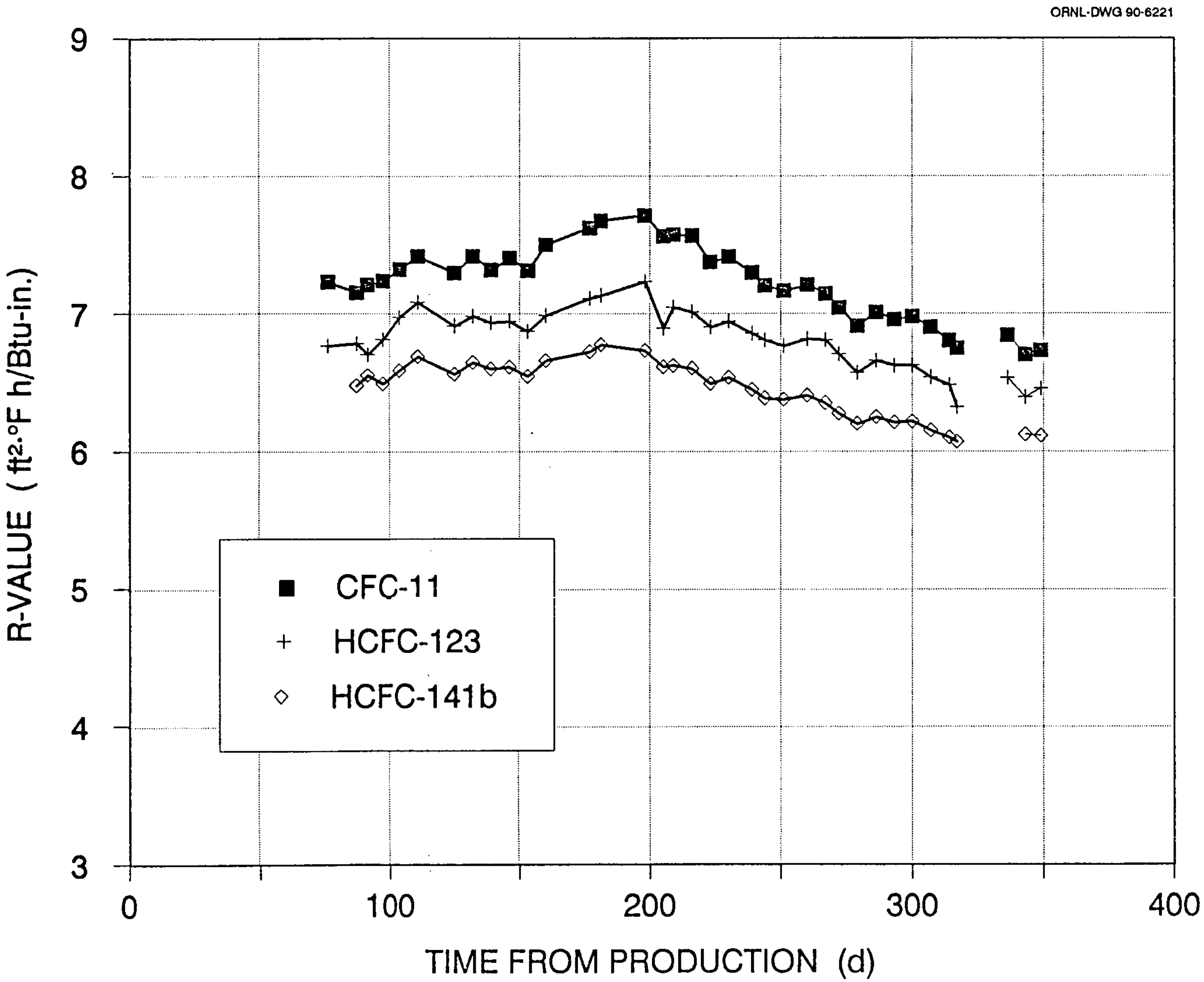

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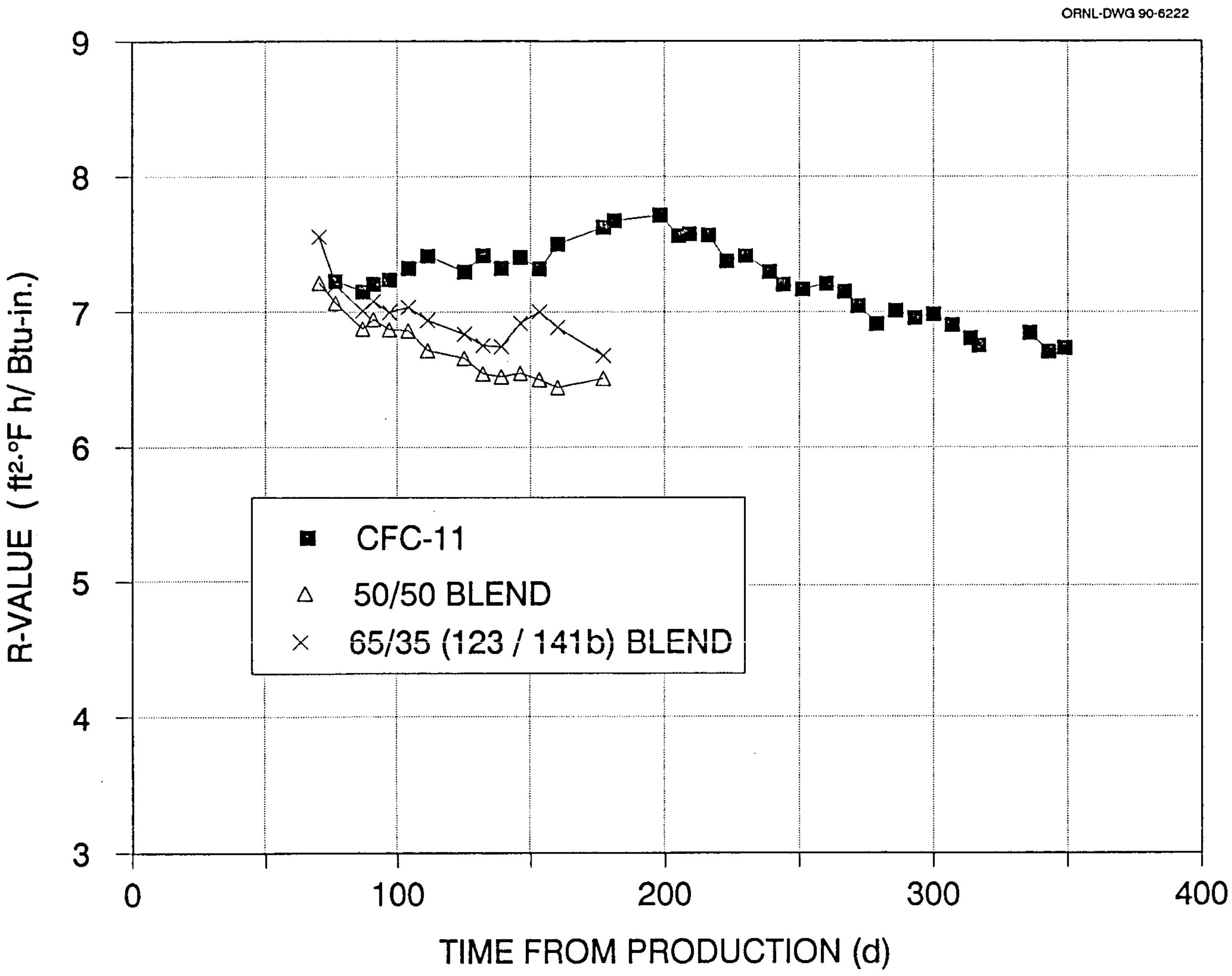

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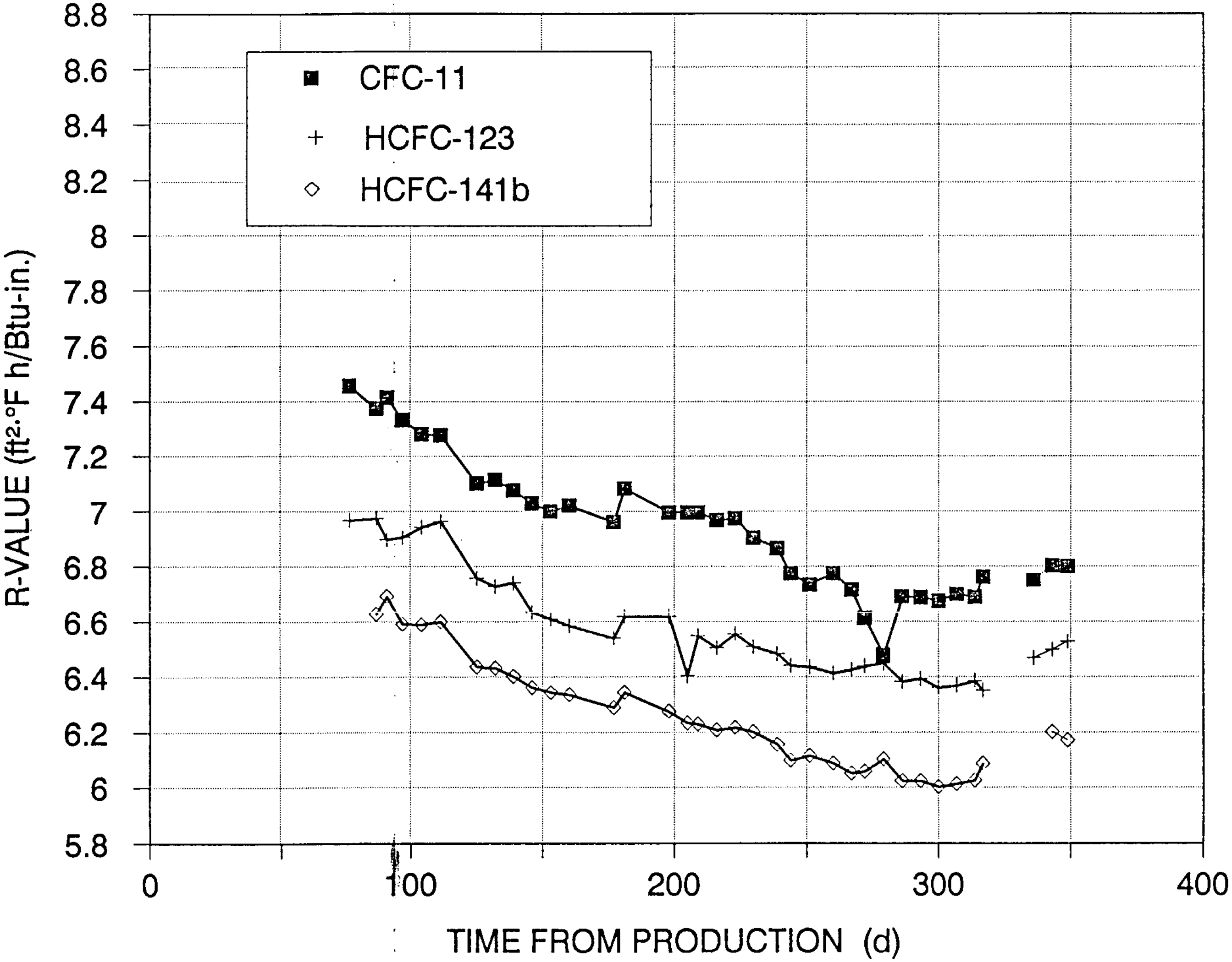

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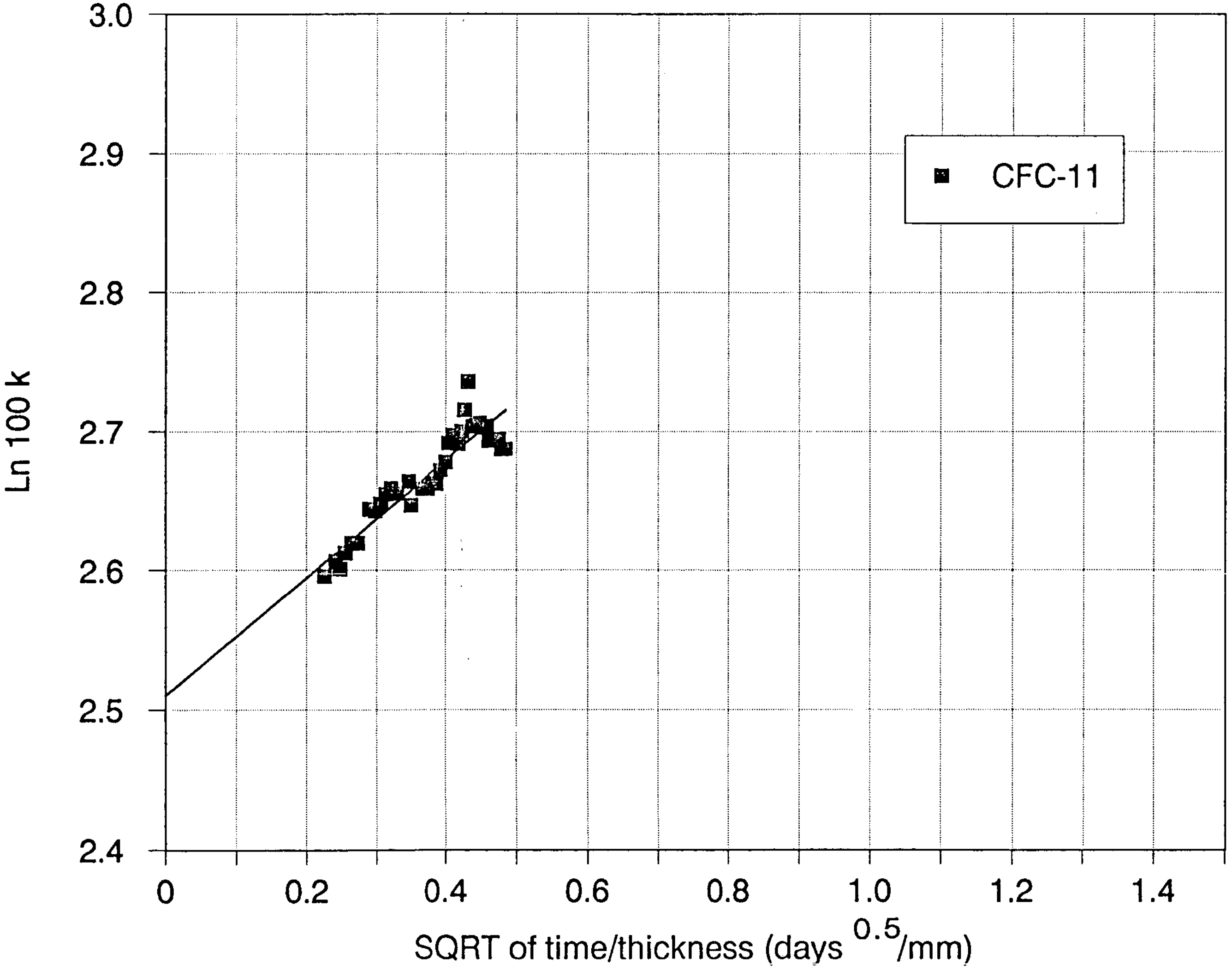

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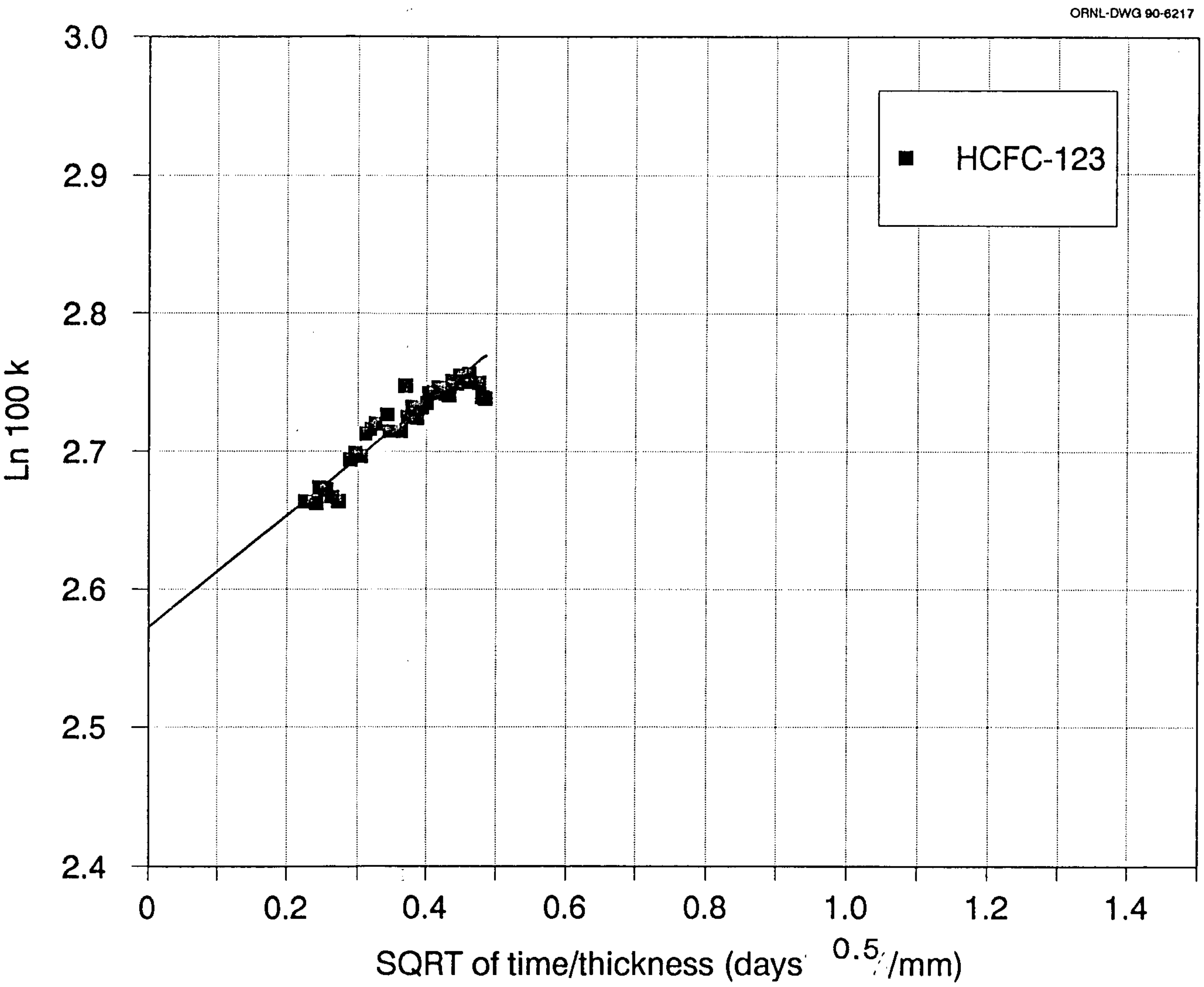

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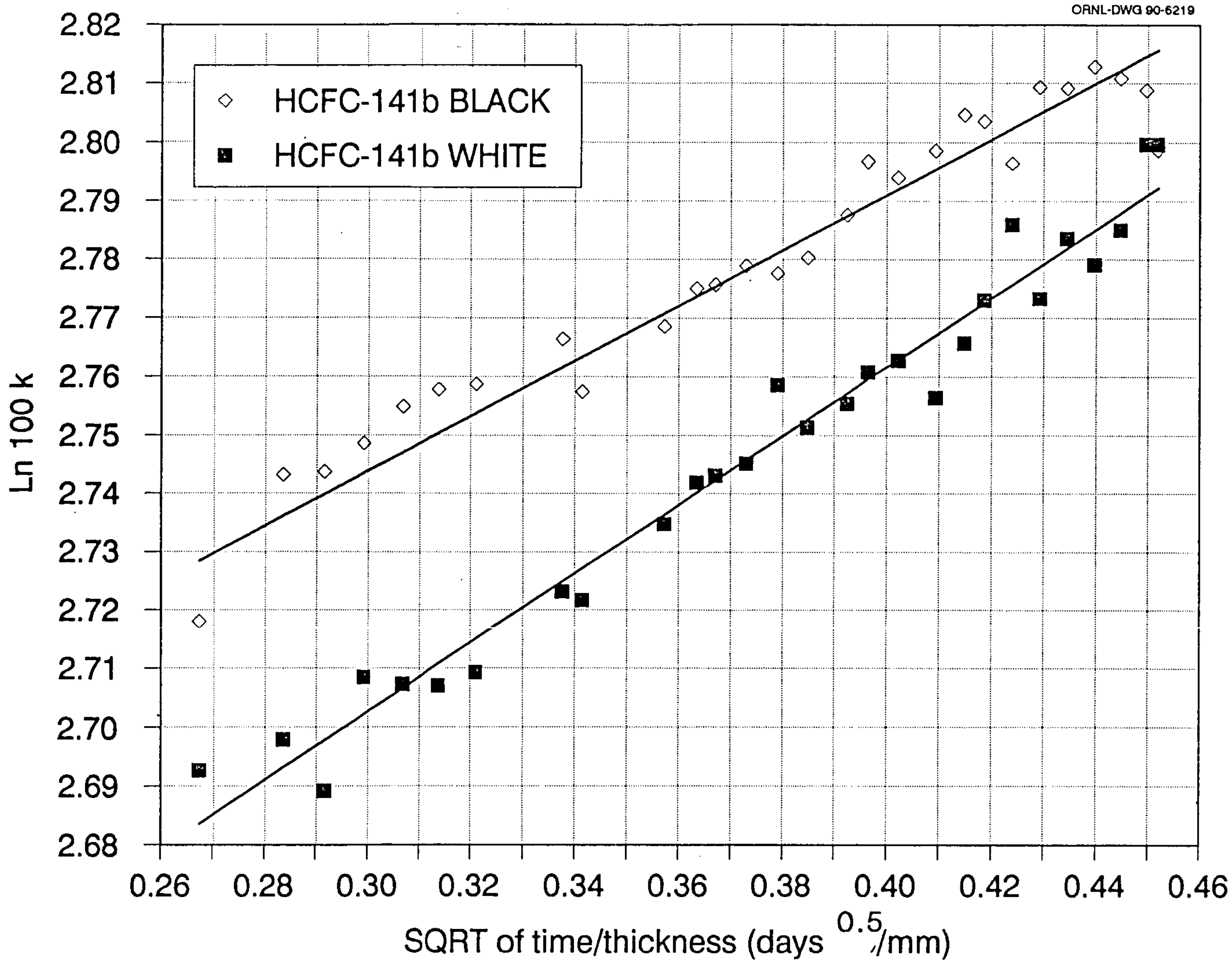

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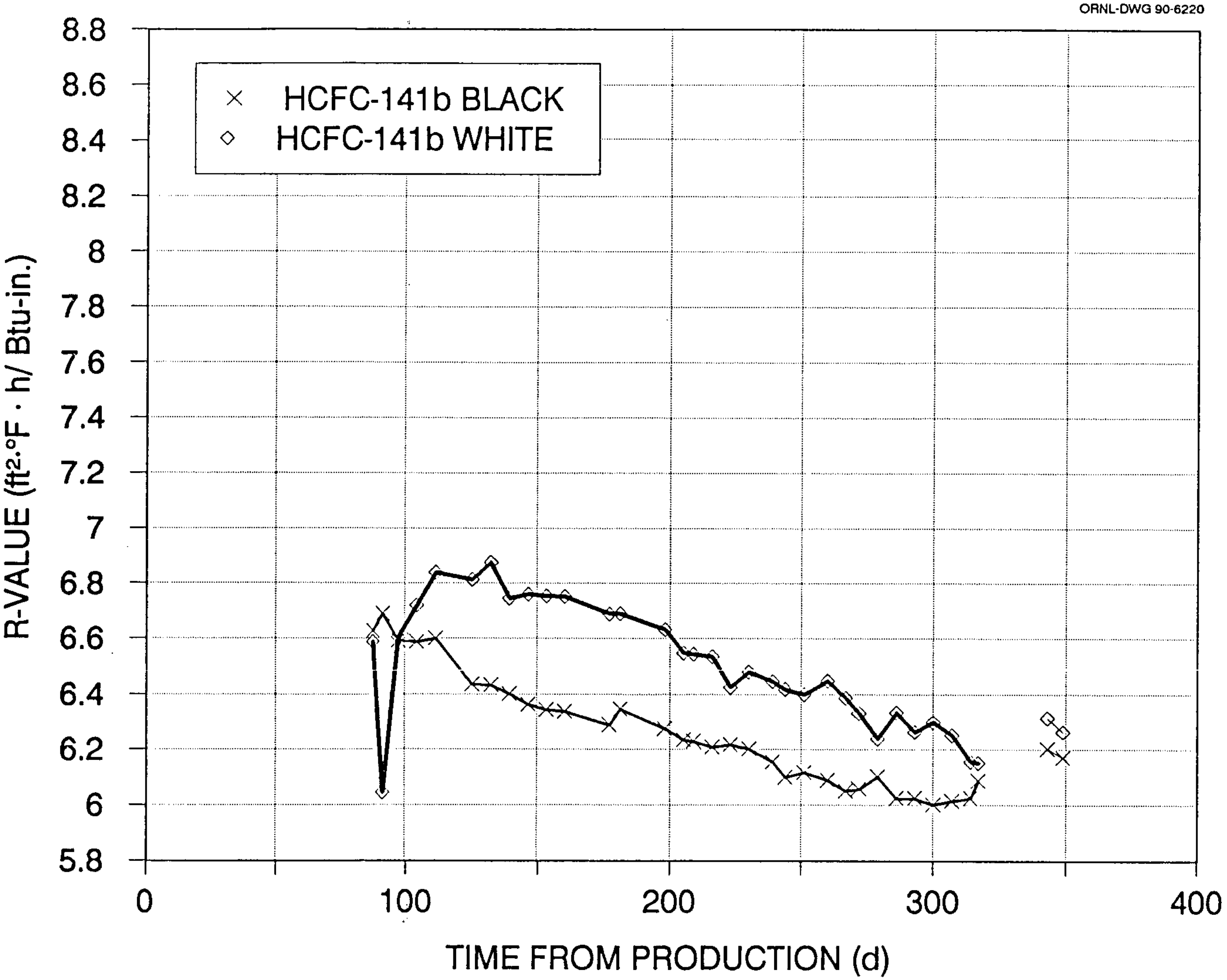

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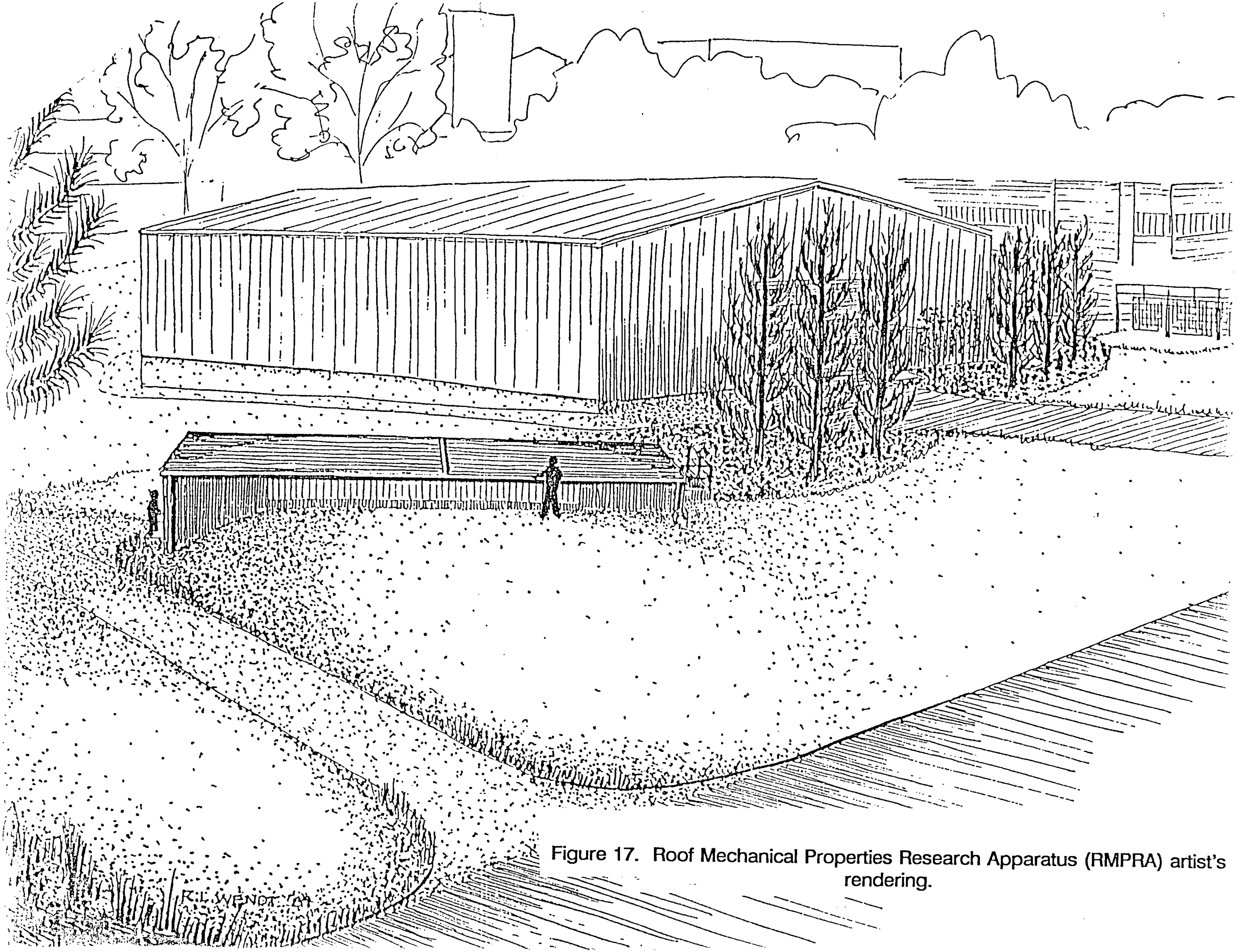

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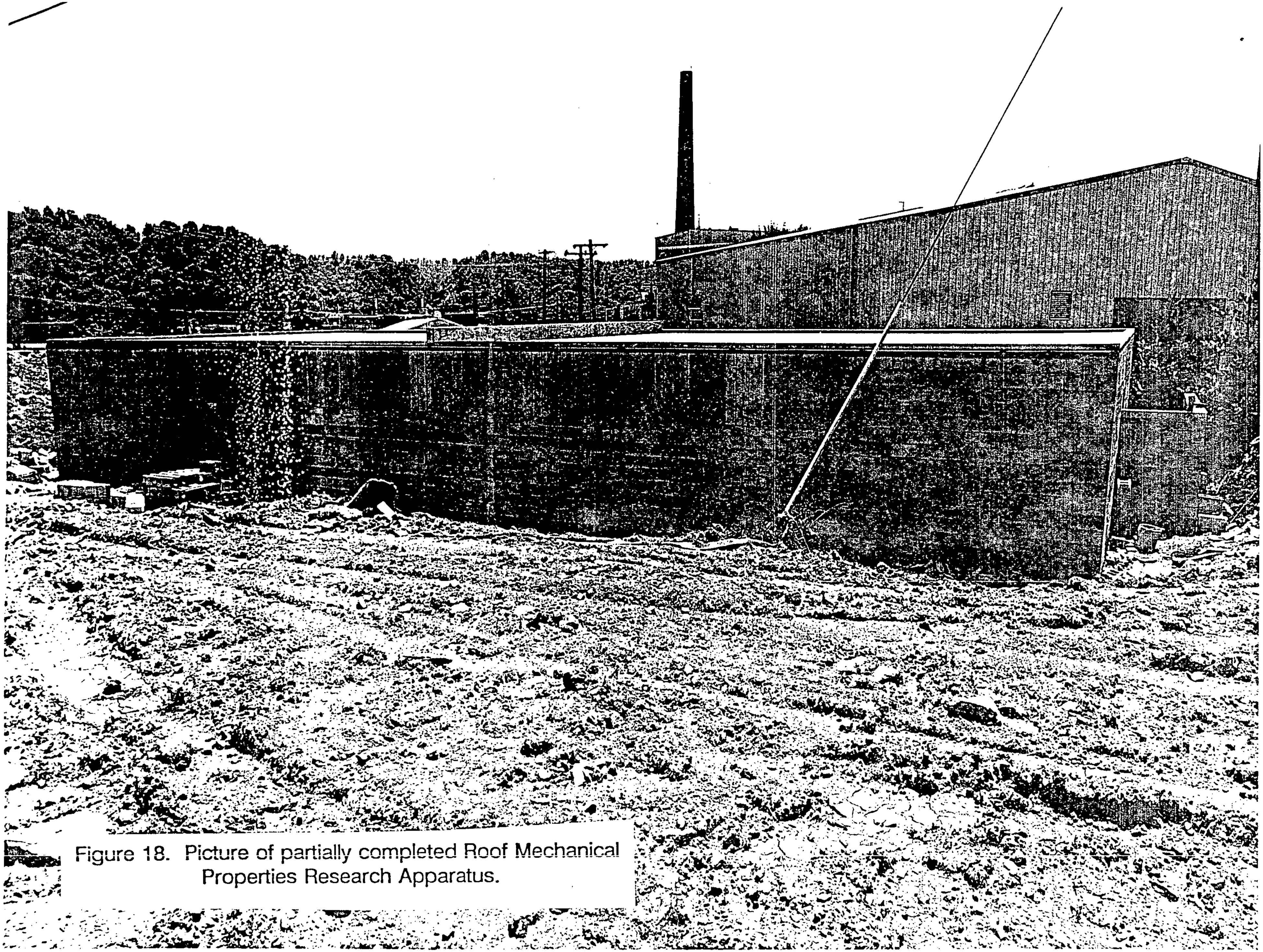

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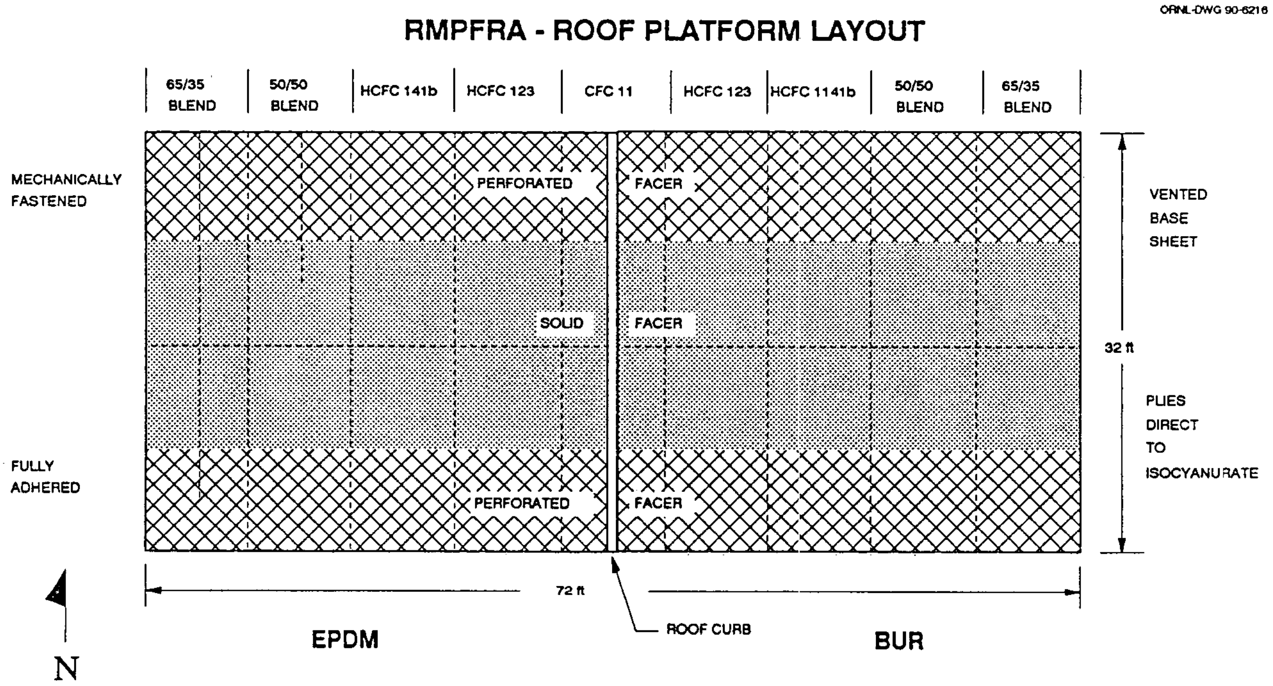

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