AD-A128 767 THERMAL CONDUCTIVITY OF WEATHERED POLYURETHANE FOAM ROOFING(U) NAVAL CIVIL ENGINEERING LAB PORT HUENEME CA D A ZARATE ET AL. SEP 82 NCEL-TN-1643 1/1

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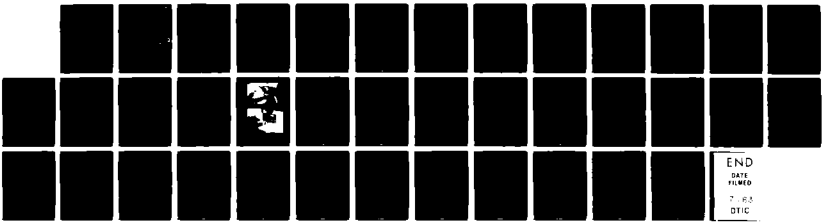

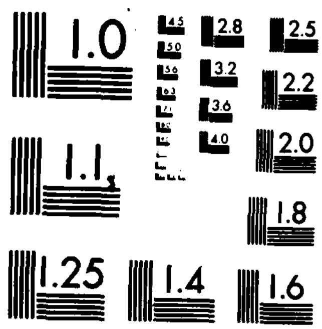


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ADA 128 767

TN NO: N-1643

TECHNICAL NOTE

TITLE: THERMAL CONDUCTIVITY OF WEATHERED POLYURETHANE FOAM ROOFING

AUTHOR: D. A. Zarate and R. L. Alumbaugh, Ph D

DATE: September 1982

SPONSOR: Chief of Naval Material

PROGRAM NO: S0371-01-112B







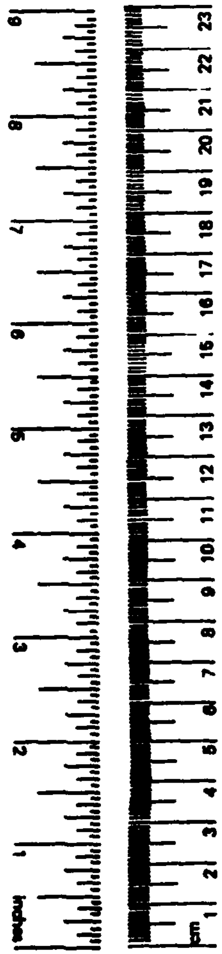
NAVAL CIVIL ENGINEERING LABORATORY
PORT HUENEME, CALIFORNIA 93043

# METRIC CONVERSION FACTORS

### Approximate Conversions to Metric Measures

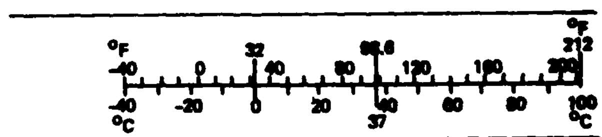
| Symbol | When You Know | Multiply by | To Find | Symbol |
|---|---|---|---|---|
| | | **LENGTH** | | |
| in | inches | *2.5 | centimeters | cm |
| ft | feet | 30 | centimeters | cm |
| yd | yards | 0.9 | meters | m |
| mi | miles | 1.6 | kilometers | km |
| | | **AREA** | | |
| $in^2$ | square inches | 6.5 | square centimeters | $cm^2$ |
| $ft^2$ | square feet | 0.09 | square meters | $m^2$ |
| $yd^2$ | square yards | 0.8 | square meters | $m^2$ |
| $mi^2$ | square miles | 2.6 | square kilometers | $km^2$ |
| | acres | 0.4 | hectares | ha |
| | | **MASS (weight)** | | |
| oz | ounces | 28 | grams | g |
| lb | pounds | 0.45 | kilograms | kg |
| | short tons (2,000 lb) | 0.9 | tonnes | t |
| | | **VOLUME** | | |
| tsp | teaspoons | 5 | milliliters | ml |
| Tbsp | tablespoons | 15 | milliliters | ml |
| fl oz | fluid ounces | 30 | milliliters | ml |
| c | cups | 0.24 | liters | l |
| pt | pints | 0.47 | liters | l |
| qt | quarts | 0.95 | liters | l |
| gal | gallons | 3.8 | liters | l |
| $ft^3$ | cubic feet | 0.03 | cubic meters | $m^3$ |
| $yd^3$ | cubic yards | 0.76 | cubic meters | $m^3$ |
| | | **TEMPERATURE (exact)** | | |
| °F | Fahrenheit temperature | 5/9 (after subtracting 32) | Celsius temperature | °C |

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.




### Approximate Conversions from Metric Measures

| Symbol | When You Know | Multiply by | To Find | Symbol |
|---|---|---|---|---|
| | | **LENGTH** | | |
| mm | millimeters | 0.04 | inches | in |
| cm | centimeters | 0.4 | inches | in |
| m | meters | 3.3 | feet | ft |
| m | meters | 1.1 | yards | yd |
| km | kilometers | 0.6 | miles | mi |
| | | **AREA** | | |
| $cm^2$ | square centimeters | 0.16 | square inches | $in^2$ |
| $m^2$ | square meters | 1.2 | square yards | $yd^2$ |
| $km^2$ | square kilometers | 0.4 | square miles | $mi^2$ |
| ha | hectares (10,000 $m^2$) | 2.5 | acres | |
| | | **MASS (weight)** | | |
| g | grams | 0.035 | ounces | oz |
| kg | kilograms | 2.2 | pounds | lb |
| t | tonnes (1,000 kg) | 1.1 | short tons | |
| | | **VOLUME** | | |
| ml | milliliters | 0.03 | fluid ounces | fl oz |
| l | liters | 2.1 | pints | pt |
| l | liters | 1.06 | quarts | qt |
| l | liters | 0.26 | gallons | gal |
| $m^3$ | cubic meters | 35 | cubic feet | $ft^3$ |
| $m^3$ | cubic meters | 1.3 | cubic yards | $yd^3$ |
| | | **TEMPERATURE (exact)** | | |
| °C | Celsius temperature | 9/5 (then add 32) | Fahrenheit temperature | °F |



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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

| REPORT DOCUMENTATION PAGE | | READ INSTRUCTIONS BEFORE COMPLETING FORM |
|---|---|---|
| 1. REPORT NUMBER<br>TN-1643 | 2. GOVT ACCESSION NO.<br>DN987069 | 3. RECIPIENT'S CATALOG NUMBER<br>AD-A128 767 |
| 4. TITLE (and Subtitle)<br>THERMAL CONDUCTIVITY OF WEATHERED POLYURETHANE FOAM ROOFING | | 5. TYPE OF REPORT & PERIOD COVERED<br>Final; Jan 1971 – Nov 1981<br>6. PERFORMING ORG. REPORT NUMBER |
| 7. AUTHOR(s)<br>D. A. Zarate and R. L. Alumbaugh, Ph D | | 8. CONTRACT OR GRANT NUMBER(s) |
| 9. PERFORMING ORGANIZATION NAME AND ADDRESS<br>NAVAL CIVIL ENGINEERING LABORATORY<br>Port Hueneme, California 93043 | | 10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS<br>64710N;<br>S0371-01-112B |
| 11. CONTROLLING OFFICE NAME AND ADDRESS<br>Chief of Naval Material<br>Washington, DC 20360 | | 12. REPORT DATE<br>September 1982<br>13. NUMBER OF PAGES<br>33 |
| 14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office) | | 15. SECURITY CLASS. (of this report)<br>Unclassified<br>15a. DECLASSIFICATION DOWNGRADING SCHEDULE |

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

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

18. SUPPLEMENTARY NOTES

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

Roofs, energy conservation, insulation, polyurethane foam, thermal conductivity, thermal resistance.

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

An investigation of the decay in the thermal conductivity of polyurethane foam (PUF) with time is presented. The polyurethane foams studied included samples removed from sprayed PUF roofing systems on structures at Guam, Marianas Islands; Subic Bay, Republic of the Phillipines; Denver, Colorado; Clifton, New Jersey; and Port Hueneme, California. Thermal conductivity results closely agree with those predicted for a foam aged at 25°C in a controlled atmosphere. Results also indicate that the foam can provide good insulation characteristics in spite of poor application.

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Naval Civil Engineering Laboratory
THERMAL CONDUCTIVITY OF WEATHERED POLY-URETHANE FOAM ROOFING (Final), by D. A. Zarate and R. L. Alumbaugh, Ph D
TN-1643 33 pp illus September 1982 Unclassified

1. Energy conservation 2. Insulation I. S0371-01-112B

An investigation of the decay in the thermal conductivity of polyurethane foam (PUF) with time is presented. The polyurethane foams studied included samples removed from sprayed PUF roofing systems on structures at Guam, Marianas Islands; Subic Bay, Republic of the Phillipines; Denver, Colorado; Clifton, New Jersey; and Port Hueneme, California. Thermal conductivity results closely agree with those predicted for a foam aged at 25°C in a controlled atmosphere. Results also indicate that the foam can provide good insulation characteristics in spite of poor application.

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## INTRODUCTION

Polyurethane foam (PUF) is produced by the spontaneous and exothermic reaction between a polyol and a polyisocyanate. The reacting components are foamed by the presence of a blowing agent, generally $CFCl_3$ (trichlorofluoromethane), which is vaporized by reaction exotherm. The installation of PUF as insulation in a sprayed PUF roof system is well-established, and its use is increasing. When properly formulated and applied, such a system has excellent weather (Ref 1, 2, and 3) and fire retardant properties (Ref 4, 5).

One of the primary reasons for the increasing use of PUF is its low thermal conductivity property which is one of the lowest available. Conversely, PUF's high thermal resistance is one of the highest available. Lining refrigerators almost exclusively with PUF further establishes PUF's credibility as an excellent insulating material.

When applied properly on roofs and protected with suitable elastomeric coatings, PUF roofing systems have excellent stability and weathering properties as well as low maintenance requirements. In the field, aging characteristics of the thermal conductivity have not been well established. Interest in this aspect is based on the increasing use of PUF roofing systems at Naval Shore Bases. The increased use of all types of insulation is based on the need to reduce overall consumption of energy. The aging characteristics of the thermal conductivity of PUF in such a roofing system is important in order to establish this material as a viable alternative to conventional insulation materials.

## BACKGROUND

The thermal conductivity (k) of a material is a measure of the material's ability to transfer - or inhibit the transfer - of heat. The k-value is conventionally reported in Btu/(hr)($ft^2$)(°F/in.) and all values for k given in this report will be listed in these units. The better a material is able to inhibit the transfer of heat, the lower is its thermal conductivity or k-value. Note that the thermal conductivity is given for 1 inch of material. The insulating ability for materials of thicknesses other than 1 inch (usually greater than 1 inch) is the thermal resistivity or R. The thermal resistivity is the reciprocal of the thermal conductivity (1/k) times the thickness: the higher the R-value, the better the insulation.

A literature survey revealed very little information on the thermal conductivity of sprayed PUF used in the construction industry. Some results were reported by European and Russian researchers, but these were not immediately available. Some excellent theoretical treatments and laboratory aging studies have been reported on the aging characteristics of thermal conductivity in PUF.

Norton (Ref 6) presented an excellent theoretical treatment of the change in thermal conductivity with time supported by some laboratory work. The change in thermal conductivity was addressed by considering the thermal conductivities of individual components ($CFCl_3$, polymer, air) and the diffusion coefficients of the gases through the polymer (PUF). While this work was directed toward the use of PUF in refrigeration, its use as insulation is equally pertinent to foam in PUF roofing systems.

Using 2.2 pcf (pounds-per-cubic foot) density foam with all cells filled with $CFCl_3$, the experimentally determined k-value was 0.100 (6).

The thermal conductivity contribution of $CFCl_3$ is 0.057 at 1 atmosphere and 25°C. Subtracting 0.057 from the k-value determined for PUF (0.100) gives the polymer contribution as 0.043. Taking the polymer contribution and adding it to the thermal conductivity for air (0.176) suggests that the maximum attainable k-value for this foam is 0.219. This latter value assumes complete displacement of $CFCl_3$ by air but no intrusion of water or water vapor.

From experimental data and application of Fick's law for diffusion of matter in solids and the Fourier equation upon which Fick's law is based, Norton in Reference 6 determined the diffusion constants for $CFCl_3$, nitrogen, and oxygen to be $2.25 \times 10^{-9}$, $6.27 \times 10^{-8}$ and $1.12 \times 10^{-7}$ $cm^2/sec$, respectively.

With these values, Norton predicted that it would require 50 years for a 12x12x1-inch PUF sample to reach its maximum (air-filled only) thermal conductivity and 200 years for a 12x12x2-inch PUF sample to reach its maximum. At 50 years, the predicted k-value for the 2-inch-thick PUF is 0.19. These predictions were for a 2.2-pcf-density PUF, 12x12 inches and 1 or 2 inches thick, all sides exposed to the air at 25°C (77°F) and without the intrusion of water or water vapor.

In Reference 7, Ball, Hurd, and Walker compared existing and new aging data with Norton's theoretical treatment of the change in thermal conductivity with time. The experimental results agreed remarkably well with the theoretical. Based on their experiments, Ball et al. also predicted that the maximum thermal conductivity of the PUF aged at room temperature would be achieved after approximately 100 to 200 years. It should be emphasized that all of the predicted values are based on aging under ambient laboratory conditions with no consideration given to the effects of exposure to exterior weather conditions.

## SCOPE OF WORK

The objective of this work was to evaluate samples of sprayed PUF roofing systems that had been exposed to various climatic conditions for varying periods of time. Particular emphasis was placed on obtaining roof samples that were 5 or more years of age. This was done in order to collect data on the thermal conductivity of materials that have undergone long-term aging under actual field conditions. The disadvantage of such an approach is that it is not always possible to obtain all pertinent data such as coating or foam types, manufacturer, installation date, or conditions. In spite of this, sufficient data were generally obtained on each sample to make the thermal conductivity data useful.

Aged PUF roof samples were obtained from roofs at: (1) the Naval Reserve Center, Clifton, New Jersey; (2) the U. S. Bureau of Reclamation, Denver, Colorado (one sample from a roof; other samples were from foam roofing that had been sprayed on concrete panels cast on the ground); (3) Naval Station, Guam, Marianas Islands; (4) Naval Base, Subic Bay, Republic of the Philippines; and (5) Naval Civil Engineering Laboratory (NCEL), Port Hueneme, California. In each case, an attempt was made to obtain samples at least 1 foot square in size (Figure 1). However, on occasion, the adhesion of the PUF to the roof deck was so great that it was not possible to obtain this size without some breakage. Once the sample was cut and pried from the roof, it was wrapped in a plastic bag to prevent any loss or gain of moisture, if present, and shipped to NCEL for testing. The samples ranged in age from 1 to 11 years.

## EXPERIMENTAL

Once the samples were received at NCEL, they were prepared for testing and their thermal conductivity determined as soon as possible. Sample preparation consisted of squaring the edges and top and bottom surfaces with a band saw. It was necessary to have the top and bottom surfaces flat and parallel. A belt sander was used to achieve this requirement after cutting. The thermal conductivity of the prepared samples was determined using a thermal conductivity analyzer, Model 88 from Anacon, Inc. (Figure 2). Each time k-values were determined, the Model 88 was calibrated using a National Bureau of Standards fiberglass insulation standard. The Model 88 accepts samples from 4 x 4 inches to 8 x 8 in., square or rectangular, and 0.62 to 2.20 inches thick. By definition, the k-value is for a sample 1 inch thick, and the Model 88 automatically determines the k-value for a 1 inch thick sample.

## RESULTS AND DISCUSSION

Test results are presented in Table 1 and are grouped according to geographical location. The sprayed foam roof samples tested were coated with various generic types of coating systems. In addition, part of the coating systems were permeable or "breathing." Permeable coatings allow more rapid diffusion of water vapor or air through the coating system. Impermeable coatings are vapor retarders which, as the name implies, may severely retard but do not prevent the diffusion of water vapor or air through the coating.

Permeability of coatings is generally determined in accordance with ASTM standard method E-96. The unit of permeability (or permeance) is 1 perm-inch (or 1 perm) which is equivalent to 1 gr/hr x ft$^2$ inches of mercury inches of thickness (or 1 perm is equivalent to 1 gr/hr x ft$^2$ inches of mercury). Within the industry, an arbitrary cutoff point has been established as 1 perm. With this arbitrary standard, coating systems having a perm rating >1 are considered permeable while those with perm ratings <1 are considered impermeable.

The first set of results listed in Table 1 are for samples obtained from the Clifton, New Jersey, test site. These roofs were sprayed in October 1973, and the samples taken in October 1978. All of these are CPR Upjohn's #485-2 PUF, 2-pound density, with good small cell structure.

The lowest two readings are from foams coated with a permeable over an impermeable coating. These samples - 4b and 5a - have a total coating thickness of 45 mils (k = 0.139) and 10 mils (k = 0.138), respectively.

The highest three samples are 2a, 2b, and 1a and are coated with permeable coatings. For 2a, 2b, and 1a, respectively, the total coating thicknesses are 7 mils (k = 0.172), 20 mils (k = 0.176), and 20 mils (k = 0.178).

Except for 3a, all foam samples from this area that were coated with an impermeable coating have lower, therefore, better k-values than those coated with a permeable coating. All of the samples are 5 years old and were approximately 2 inches thick on the roof. The predicted 5-year k-value for a 2.2-pcf-density PUF, 12 x 12 x 2-inch slab, aged at 25°C (77°F) is 0.148 (Ref 6). From Table 2, the overall average k-value of these samples is 0.158 which is closer to the predicted k-value of 0.158 for a 12 x 12 x 1-inch slab. However, the k-value for the samples with an impermeable coating averages 0.146, and those with a permeable coating average 0.170. This shows a strong correlation between samples with impermeable coatings aged at Clifton, New Nersey, and samples without coatings aged under controlled laboratory conditions.

The perm ratings of permeable coatings (2 to 3 perms) is close to, or equivalent to, that of PUF (approximately 2 perms). A permeable coating allows the foam to breathe and release excessive water vapor. Impermeable coatings (perm ratings <1) retard the entrance or release of excessive water vapor and to some extent retard the passage of air as well. Excessive moisture could also be liquid water that has intruded through breaks in the coating. Water vapor or air, once past the coating, would diffuse at a faster rate into the foam (low concentration of air and water) rather than back out into the atmosphere (high concentration of air and water). The diffusion rate could be increased by the presence of a strong "moisture drive."

A moisture drive exists when there are warm temperatures and high humidity on one side of a partition or roof and cooler temperatures with lower humidity on the other. This effectively "drives" or forces moisture from the warmer side to the cooler side in an effort to equilibrate. Moisture drives exist in areas such as the South Pacific and Eastern Seaboard where buildings are generally air conditioned during warm weather.

The climatic conditions in Clifton can vary from around 38°C (100°F) and 70% relative humidity to 10°C (50°F) and 50% relative humidity daily in the summer and from around 18°C (65°F) and 70% relative humidity to -18°C (0°F) and 50% relative humidity daily in the winter.

Because of the moisture drive in this area, permeable coatings would allow the k-value of PUF to increase at a greater rate than those with impermeable coatings. Due to the greater rate at which water vapor and air pass through the permeable coating, the k-value of the PUF would tend to increase more rapidly than with an impermeable coating and results bear this out.

In areas with a moisture drive, results indicate that an impermeable coating may help keep the k-value from increasing faster than that found under controlled laboratory conditions. Results also show that, in spite of the harsher conditions found at Clifton, the k-values of PUF with impermeable coatings agree very well with those predicted for PUF aged at 25°C under controlled atmospheric conditions.

The next set of results listed in Table 1 is for samples of Systems 6 through 12 and was obtained from the Denver, Colorado, test site. Sample 12 was sprayed on a roof deck while the rest were sprayed over concrete panels located on the ground; Samples 6 and 7 are about 10-1/2 years old and have a good small cell structure. Samples 8 and 9 are almost 10 years old (9-3/4) and in general show a good small cell structure; Sample 8 appears to have been exposed for a few days before being coated (the coating easily peeled off and the surface was sun burnt) while Sample 9 has a 1/4-inch-deep gouge in the center of the sample. Samples 10 and 11 are about 4 years old (4-1/3) with a rather coarse and large cell structure. At least 50% of the cells are larger than a pinhead and perhaps 10% to 20% are twice that size with a small percentage (less than 10%) of small cells. Sample 12 is about 6-1/2 years old with about 10% large cells and more than 50% small cells.

The two lowest thermal conductivity readings are from Samples 8 and 9; Sample 8 (k = 0.170) was coated with 15 mils of a permeable coating and Sample 9 (k = 0.169) was coated with 7 mils of an impermeable coating. Both are almost 10 years old. Sample 9 has an extemely irregular surface with the coating degrading and exposing the foam. If a coating, especially an impermeable one, is to be effective, it must cover the foam surface entirely and be applied at the proper thickness; 7 mils is only about one-third the <u>minimum</u> acceptable thickness. This and the gouge in the surface of Sample 9 may explain the similar k-values of Samples 8 and 9.

The k-values of the rest of the samples range from approximately 0.19 to 0.20. The disparity of these values with the age of the samples may be explained by the lack of proper thickness in the coatings, by larger cell structures, and by the fact that the concrete slab on which the foam was applied was directly on the ground. This may have contributed to more rapid diffusion of moisture vapor into the foam. In comparing the foam characteristics and the k-value of Sample 9 to that of Samples 10, 11, and 12, the only apparent difference that could make the k-value of Sample 9 lower is the cell structure. The difference is even more apparent when Sample 8 is compared with Sample 9.

The next set of results listed in Table 1 was obtained from roof samples at Subic Bay in the Philippines and from Guam. These samples illustrate some adverse effects on PUF roofs caused by poor application of either the PUF, the coatings, or both.

The first three samples (13 to 15, which had k-values = 0.18 to 0.19) were coated with an exterior house paint, not a coating formulated for protecting PUF or even for use on roofs. The samples are about 6 years old. They show signs of severe checking and cracking with about 10% to 20% of the coating flaking from the foam surface; the paint is also very brittle. Samples 13 and 15 appear to have been applied over a wet surface as indicated by the poor quality of foam surface adjacent to the deck.

Sample 16 was coated with 10 mils of a permeable coating and is approximately 4 years old. The bottom of the foam adjacent to the roof deck was wet, and the coating was alligatoring in low spots but was continuous over a rough foam surface. The coating was, therefore, still protecting the foam from the sun and intrusion of water; the k-value of the foam was about 0.16.

Sample 17 was in good condition and was about 5 years old. It has the same coating as on Sample 16; the foam has a k-value of 0.17.

Internally, beyond both surfaces, these samples had a good cellular structure. This may have been fortuitous since all of the k-values are less than 0.20. These roofs will probably continue to render fairly good insulating service.

Sample 18 from Guam is coated with an asphalt-based coating of unknown permeability. The system was about 5 years of age with a badly deteriorated surface and some patching of the coating.

Sample 19 from Guam was taken from a PUF roof that had been maintained, (i.e., a second layer of foam was sprayed over an existing PUF roof in which both the coating and the foam had degraded). The original coating over the foam was a paint (not meant for roof surfacing) while the second layer or new foam had a permeable silicone coating. No k-value could be determined for the first (bottom) foam layer because of its small size. The second layer had a value of nearly 0.26. This higher k-value may have been due in part to entrapped moisture in the first layer migrating into the second. However, the most significant cause for this higher k-value may be the poor foam cell structure. Approximately 50% of the sample had large (1/8 to 1/2 inch across) cell[illegible]r voids while the remainder had normal, uniform, small cells.

Sample 20a from Guam was 10 years old, had a good cell str[illegible]ure, and a reasonably good k-value. The surface had been maintained [illegible]., a second coating applied after the original coating had degraded s[illegible]what).

The last set of results listed in Table 1 are for samples [illegible]ned from roofs at NCEL, Port Hueneme, California. All of the build[illegible] un north and south except for a flat roof where Sample 29a was take[illegible]. All samples were cut in July 1981. For ease of discussion, the samples are relisted in Table 3 in order of increasing k-value.

Considering Samples 21b, 21a$_1$, and 21a$_2$, 28b, and 28a as 5-year-old samples, the overall average k-value is 0.139 ± 0.010 and the average thickness is 2.20 ± 0.21 inches. The average k-value of the two 2-inch samples is 0.146 ± 0.013. Reference 6 indicated that the 5-year predicted k-value for a 2.2 pcf density foam, 12 x 12 x 2 inches, aged under controlled conditions is 0.148. The experimental results agree very well with the predicted values (see Tables 4 and 5).

All the 7-year-old samples with impermeable coatings have an average k-value and thickness of 0.159 and 1.75 inches, respectively; with permeable coatings it is 0.170 and 1.69 inches respectively. Overall it is 0.164 and 1.72 inches, respectively.

Interpolating the 5- and 10- year predicted k-values to a 7-year sample, the k-values are 0.165 and 0.150 for a 1- and a 2-inch-thick 12x12-inch slab, respectively (Ref 6). The overall average k-value for the 7-year samples (k = 0.164 ± 0.020) at NCEL agrees more closely with the predicted 1-inch-thick sample value. The samples with an impermeable coating are only slightly lower (k = 0.159 ± 0.018). Taking only the 2-inch-thick 7-year-old-samples into consideration, the average k-value for samples with an impermeable coating is 0.144 ± 0.004, and for those with a permeable coating the k-value is 0.148 ± 0.012. These latter values agree very well with the predicted value of 0.150 for a 2 inch thick sample and indicate that thickness plays a significant role in the thermal conductivity aging characteristics of PUF.

The climatic conditions at NCEL can vary from about 35°C (95°F) to 7°C (45°F) daily in the summer and from around 25°C (77°F) to 1°C (34°F) in the winter. The average relative humidity percentage remains fairly constant at approximately 70% due to the proximity of the ocean. The relative humidity percentage can vary from a low of about 60% to a high of about 80%. Lows of 15% to 20% relative humidity are infrequent and occur on days when hot, dry winds blow through the area.

The basic function of all coatings used on PUF is to protect the foam from sunlight (especially ultraviolet light), moisture, and consequent degradation. The permeable and impermeable coatings are rated on their ability to keep water vapor from passing through the coating film.

The k-value of water vapor at 25°C (77°F) and 1 atmosphere is 0.123, and for liquid water is 4.20.* The k-value at the same conditions for air is 0.176, that for $CFCl_3$ is 0.057, and polymer can be taken to be 0.043 to 0.061 for a foam 2.0 to 3.0-lb/cu ft density respectively. With these values it is seen that foam filled with air (theoretical maximum k-value = 0.219 to 0.237) will have a higher k-value than if filled with water vapor only (theoretical maximum k-value = 0.166 to 0.184). In areas where a moisture drive might exist, results indicate that an impermeable coating may be better than a permeable coating.

At NCEL Port Hueneme, there is no strong evidence to indicate that impermeable coatings are much better than permeable coatings in keeping the k-value of PUF low with aging. Also, the climatic conditions at Port Hueneme are not as harsh or as severe as those found at Clifton. This suggests that the permeability of the coatings may not be a significant factor in the aging of thermal conductivity in PUF in areas such as Port Hueneme or where a moisture drive might not exist or be very strong.

Since the k-values of aged samples are fairly close to predicted values, this implies a predictability of the thermal conductivity of PUF in spite of varying temperatures and climates.

In Table 6 all samples are listed according to increasing k-value. With one exception, all samples had k-values $\leq$0.20. The exception was a poor quality foam exhibiting large voids in the cellular structure. In Table 2, the average for all samples is shown to be 0.163 ± 0.022. In Reference 9 a k-value equal to 0.16 has been established as a design value for a 1.5 pcf density PUF. The experimental values given in this report provide a firm basis for the use of 0.16 as a design k-value for 2.0 to 3.0 lb/cu ft density PUF. The experimental values also show that, even though the k-value does decay, PUF remains equal to or better than the next best material, extruded Styrofoam®, which maintains a k-value of 0.20 (Ref 10).

The overall PUF and coating quality was found to be best in the NCEL and Clifton samples, followed by the Denver samples and, finally, the Guam and Subic Bay samples. From the standpoint of temperature fluctuations, the harshest environments would be those found at Clifton and Denver followed by NCEL, then Guam and Subic Bay.

A point borne out by Table 6 is that all samples below k = 0.164, except for one from Subic Bay, are from NCEL or Clifton. This may in part be due to the better foam quality and in part to the samples being cut from PUF sprayed on roofs rather than on panels as at Denver.

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*Interpolated and converted from Cal/(sec)($cm^2$)(°C/cm) values given in Reference 8 by dividing by $3.445 \times 10^{-4}$. The conversion factor given in Reference 6 can also be multiplied by the conversion factor given in Reference 8 if results are also multiplied by 12 to convert from °F/ft to °F/in.

It is also noticed that most of the samples below 0.164 from Clifton have an impermeable coating. Comparing the averages of the samples from NCEL and Clifton in Table 2, the samples with permeable coatings from NCEL (k = 0.153) have a significantly better k-value than those from Clifton (k = 0.170). The samples with impermeable coatings are about the same when age is considered and when compared to the predicted values (Ref 6) for a PUF aged at 25°C (77°F). This indicates that impermeable coatings help to maintain a low thermal conductivity in PUF and even keep the aging to a point similar to that where the permeability of the coating does not play a significant role. Comparison of the NCEL and Clifton averages suggests again that impermeable coatings may be better than permeable coatings where a moisture drive exists; in other areas where a stong moisture drive does not exist, they may not exhibit a significant effect on the aging of the thermal conductivity. Figure 3 compares graphically the k-values reported here according to age and coating type (permeable or impermeable).

A comparison of the averages of the Clifton and the 7-year-old NCEL samples to those predicted values in Reference 6 show good agreement between those samples with impermeable coatings and the 2-inch-thick predicted samples. This suggests that the k-value for PUF roofing systems in the field may be predicted for those with impermeable coatings. For PUF roofing systems with permeable coatings in areas such as Clifton, k-values may be predicted by adding 0.03 to those predicted for PUF with impermeable coatings. In areas such as NCEL Port Hueneme, predicted k-values for systems with impermeable coatings may be used for systems with permeable coatings.

This predictability implies that varying climatic conditions may not be significant if the PUF is properly coated with an impermeable coating. This is in spite of the large daily and yearly changes in temperature, humidity, rain, snow, or other weather conditions to which the PUF roofing systems may be subjected.

Factors not specifically considered which may play a part in the thermal conductivity aging characteristics are foam thickness, percentage of open cells, cell structure and size, foam density, cell orientation, and surface skins.

## FINDINGS AND CONCLUSIONS

The following findings and conclusions are presented on the basis of the data contained in the report on the thermal conductivity of PUF roofing specimens aged from 1 to 10-1/2 years.

1. Impermeable coatings help to maintain a low thermal conductivity factor in PUF better than permeable coatings. In areas where a strong moisture drive exists, this becomes even more pronounced. In areas where a moisture drive does not exist or is weak, the effect on aging by the type of coating used appears insignificant.

2. Good agreement exists between PUF samples aged in the field under harsh climatic conditions with an impermeable coating and predicted k-values for PUF samples with no coating aged in the laboratory at 25°C (77°F) under controlled atmospheric conditions. This implies a predictability to the life of a PUF system in the field if the foam and coating are properly applied and maintain .

Another major factor in maintaining a low thermal conductivity with time is the thickness; i.e., the thicker the PUF, the longer it takes for the thermal conductivity to increase. This is also noted in the predicted values for 2-inch and 1-inch-thick 12x12-inch slabs Reference 6. The predicted time for the 2-inch-thick sample to reach its theoretical maximum is approximately 200 years, and for the 1-inch-thick sample it is approximately 50 years. Even though the 2-inch sample is only twice as thick as the 1-inch sample, it may require four times as long to achieve its maximum. This is, of course, theoretical at this time.

3. A k-value of 0.16 may be established as a design value for 2.0- to 3.0-pcf-density PUF.

4. In spite of poor application and maintenance, it has been shown that a PUF roofing system can still provide good service with respect to k-value decay. However, such decay occurs more rapidly with foam roof systems that are improperly applied and maintained, than with those that are properly applied and maintained.

5. In spite of the decay in k-value, PUF is equal to or better than the next best material (extruded Styrofoam®) for maintaining a low k-value.

## RECOMMENDATIONS

1. Polyurethane foam should be applied to achieve a uniform small cell structure and as smooth a surface texture as possible in order to obtain the best thermal conductivity properties.

2. A coating should be used that has been formulated for protecting PUF from the sunlight and weather. Where a significant moisture drive exists, an impermeable coating is recommended.

3. Protective coatings should be applied to their proper minimum film thickness (generally manufacturer's recommended thickness). A thin coating thickness may result in premature exposure of the foam to the sun and degradation and the possible intrusion of water.

4. In harsh environments it is even more important to maintain the coating in the PUF system at the proper minimum film thickness.

## ACKNOWLEDGMENTS

The authors wish to express their appreciation to Ms. Nathalie Milliken and Mr. Valente Hernandez for sampling the roofs at NCEL; to Mr. Bernard V. Jones, U.S. Bureau of Reclamation, Denver, Colorado, for supplying the samples from the Denver site; to Mr. Charles Schembri, U.S. Navy Public Works Center, Subic Bay, R. P., for sending samples; and to the Navy Public Works Center, Guam, Marianas Islands, for supplying samples.

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Figure 1. Taking a PUF sample from a roof.

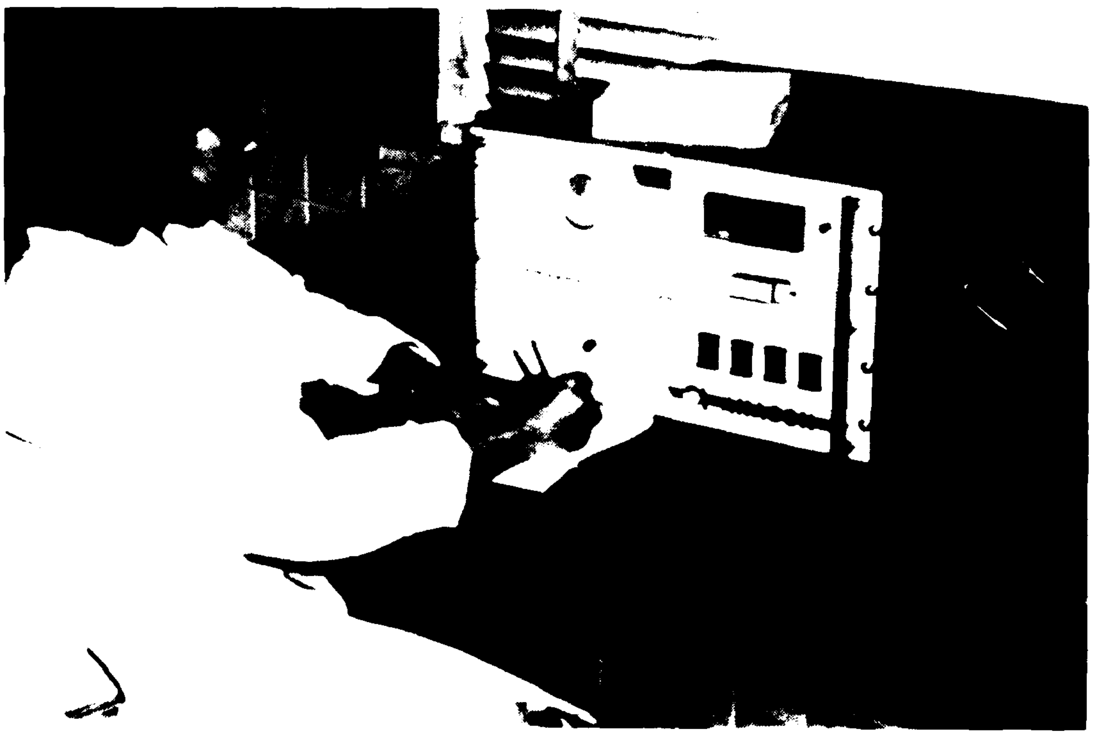

Figure 2. Determining thermal conductivity on the Model 88
Thermal Conductivity Analyzer from Anacon, Inc.

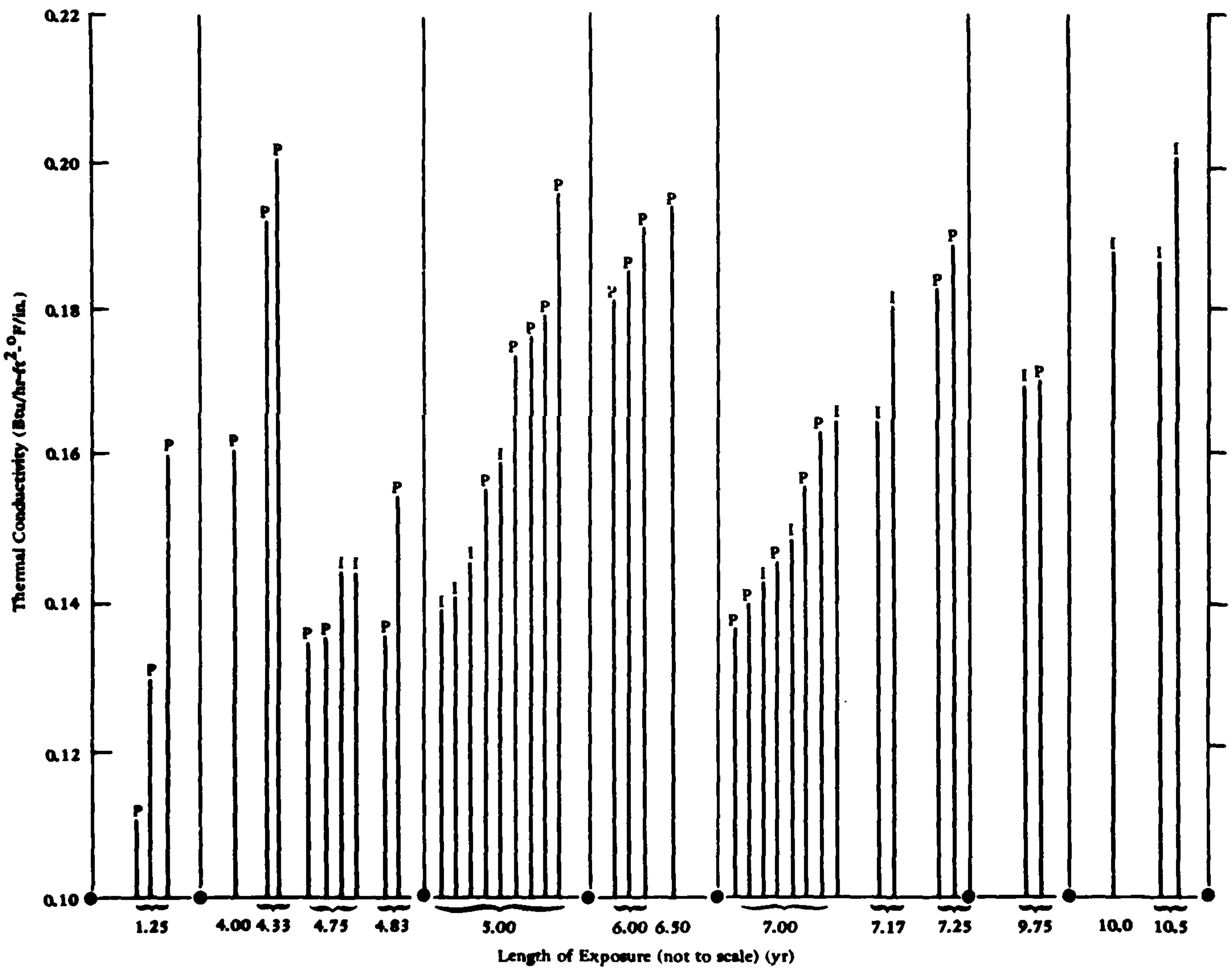


Figure 3. Comparison of retained k-value on the basis of coating type (permeable versus impermeable).

Table 1. Thermal Conductivity (k) of Polyurethane Foam Samples From Weathered PUF Roof Systems

| Sample No.[a] | Roof Coating/Foam Description System | Age (yr) | Foam Density (pcf) and Quality | Coating Thickness (mils)[b] | | | | Foam Thickness (in.) | | Thermal Conductivity (Btu/hr-ft$^2$-°F/in.) | | Comments |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | First Coat | Second Coat | Third Coat | Total | Roof (Avg) | Sample | Individual Sample | Average | |
| Samples from Clifton Test Roofs[c] | | | | | | | | | | | | |
| $1a_1$ | General Electric Silicone with Granules/CPR Upjohn 480-2.0 | 5 | 2.0/good, uniform cell structure | 10 (P) | 10 (P) | -- | 20 (P) | 2.0 | 1.32 | 0.181 | 0.178 | Coating and foam in good condition |
| $1a_2$ | | 5 | 2.0/good, uniform cell structure | 10 (P) | 10 (P) | -- | 20 (P) | 2.0 | 1.46 | 0.175 | | |
| $1b_1$ | General Electric Silicone w/o Granules/CPR Upjohn 480-2.0 | 5 | 2.0/good, uniform cell structure | 15 (P) | 5 (P) | -- | 20 (P) | 2.0 | 1.37 | 0.156 | 0.156 | Coating and foam in good condition |
| $1b_2$ | | 5 | 2.0/good, uniform cell structure | 15 (P) | 5 (P) | -- | 20 (P) | 2.0 | 1.35 | 0.156 | | |
| $2a_1$ | Dow Corning Silicone/CPR Upjohn 480-2.0 | 5 | 2.0/good, uniform cell structure | 7 (P) | -- | -- | 7 (P) | 1.75 | 1.09 | 0.181 | 0.175 | Coating very thin but foam in good condition |
| $2a_2$ | | 5 | 2.0/good, uniform cell structure | 7 (P) | -- | -- | 7 (P) | 1.75 | 1.09 | 0.169 | | |
| $2b_1$ | Dow Corning Silicone/CPR Upjohn 480-2.0 | 5 | 2.0/good, uniform cell structure | 10 (P) | 10 (P) | -- | 20 (P) | 2.25 | 1.57 | 0.188 | 0.1755 | Coating and foam in good condition. |
| $2b_2$ | | 5 | 2.0/good, uniform cell structures | 10 (P) | 10 (P) | -- | 20 (P) | 2.25 | 1.58 | 0.171 | | |
| $3a_1$ | U.S. Polymeric Butyl-Hypalon base + Dow Corning Silicone w/granules topcoat/CPR Upjohn 480-2.0 | 5 | 2.0/good, uniform cell structure | 10 (I) | -- | 5 (I) | 15 (I) | 2.25 | 1.42 | 0.160 | 0.1575 | Butyl-Hypalon damaged by hail and overcoated with Dow Corning silicone. Silicone did not bridge cracks in Butyl-Hypalon. Most of Hypalon coating flaked from Butyl before silicone applied. |
| $3a_2$ | | 5 | 2.0/good, uniform cell structure | 10 (I) | -- | 5 (P) | 15 (I) | 2.25 | 1.58 | 0.155 | | |

continued

Table 1. Continued

| Sample No.[a] | Roof Coating/Foam Description System | Age (yr) | Foam Density (pcf) and Quality | Coating Thickness (mils)[b] | | | | Foam Thickness (in.) | | Thermal Conductivity (Btu/hr-ft$^2$-°F/in.) | | Comments |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | First Coat | Second Coat | Third Coat | Total | Roof (Avg) | Sample | Individual Sample | Average | |
| $4a_1$ | Monolar Mastic Base + Carboline Rooflex 145/155 topcoat/CPR Upjohn 480-2.0 | 5 | 2.0/good, uniform cell structure | 15 (I) | 20 (P) | 20 (P) | 55 (I) | 2.0 | 1.37 | 0.148 | 0.147 | Monolar damaged by hail and overcoated with Rooflex. Rooflex bridged cracks in monolar but exhibited pinholes through coating to foam. Foam in good condition. |
| $4a_2$ | | 5 | 2.0/good, uniform cell structure | 15 (I) | 20 (P) | 20 (P) | 55 (I) | 2.0 | 1.37 | 0.146 | | |
| $4b_1$ | Monolar Mastic Base + Carboline Rooflex 145/155 topcoat/CPR Upjohn 480-2.0 | 5 | 2.0/good, uniform cell structure | 20 (I) | 10 (P) | 15 (P) | 45 (I) | 2.25 | 1.50 | 0.143 | 0.139 | Monolar damaged by hail and overcoated with Rooflex. Rooflex bridged cracks in monolar but exhibited pinholes through coating to foam. Foam in good condition. |
| $4b_2$ | | 5 | 2.0/good, uniform cell structure | 20 (I) | 10 (P) | 15 (P) | 45 (I) | 2.25 | 1.48 | 0.135 | | |
| $5a_1$ | United Coatings Butyl-Hypalon Base + Irathane 300/394 w/granules/CPR Upjohn 480-2.0 | 5 | 2.0/good, uniform cell structure | 5 (I) | -- | 10 (P) | 15 (I) | 2.25 | 1.51 | 0.144 | 0.1405 | Butyl-Hypalon damaged by hail and overcoated with Irathane and granules. Irathane did not bridge cracks in Butyl-Hypalon. Foam in good condition. |
| $5a_2$ | | 5 | 2.0/good, uniform cell structure | 5 (I) | -- | 10 (P) | 15 (I) | 2.25 | 1.48 | 0.137 | | |
| Samples from U.S. Bureau of Reclamation, Denver, Colorado | | | | | | | | | | | | |
| 6 | General Electric Silicone/PPG Foam | 10-1/2 | 2.0/good, uniform cell structure | 12 (P) | -- | -- | 12 (P) | 1.50 | 1.12 | 0.202 | | |
| 7 | United Butyl-Hypalon/PPG Foam | 10-1/2 | 2.0/good, uniform cell structure | 3 (I) | -- | -- | 3 (I) | 1.50 | 1.08 | 0.191 | | Coating extremely thin because of chalking and corrosion. Damaged by hail. Foam has been exposed to weather. |
| 8 | Dow Corning Silicone/North American Foam | 9-3/4 | 2.0/good cell structure, irregular surfaces, top sunburnt | 15 (P) | -- | -- | 15 (P) | 2.00 | 1.57 | 0.170 | | Foam beneath surface has deteriorated. Irregular surface. |

continued

Table 1. Continued

| Sample No.[a] | Roof Coating/Foam Description System | Age (yr) | Foam Density (pcf) and Quality | Coating Thickness (mils)[b] | | | | Foam Thickness (in.) | | Thermal Conductivity (Btu/hr-ft$^2$-°F/in.) | | Comments |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | First Coat | Second Coat | Third Coat | Total | Roof (Avg) | Sample | Individual Sample | Average | |
| 9 | Gaco-SBR base Hypalon topcoat/North American Foam | 9-3/4 | 2.0/good cell structure, some larger holes (~10%) | 2 (I) | 5 (I) | -- | 7 (I) | 1.50 | 1.15 | 0.169 | | Coating thin because of chalking and erosion. Extremely irregular surface, coating cratered and foam exposed. |
| 10 | Dow Corning Silicone/ United Foam | 4-1/3 | 2.0/good, uniform cell structure | 10 (P) | 10 (P) | -- | 20 (P) | 2.00 | 1.54 | 0.189 | | |
| 11 | Carboline Rooflex/ United Foam | 4-1/3 | 2.0/good, uniform cell structure, ~10% medium holes | 150 (P) | 20 (P) | 5 (P) | 175 (P) | 2.00 | 1.56 | 0.198 | | Coating excessively thick |
| 12 | General Electric Silicone/Witco Foam | 6-1/2 | 2.0/good, uniform cell structure | 10 (P) | 10 (P) | -- | 20 (P) | 2.25 | 1.67 | 0.194 | | Sample from roof deck |
| Samples from U.S. Naval Base, Subic Bay, R.P. | | | | | | | | | | | | |
| 13 | TT-P-19 Latex paint/ (foam type unknown) | 6 | unknown/foam quality fair, irregular cell structure: 10%-20% large cells | 15 (P) | -- | -- | 15 (P) | 1.25 | 0.77 | 0.186 | | Coating checking, cracking, and flaking. Approximately 10% flaked off. Coating brittle. Sample from Ship Repair Facility (SRF) roof. |
| 14 | TT-P-19 Latex paint/ (foam type unknown) | 6 | unknown, fairly uniform cell structure ~10% large cells | 15 (P) | -- | -- | 15 (P) | 1.25 | 0.65 | 0.182 | | Coating checking, cracking, and flaking severely. Sample from Ship Repair Facility (SRF) roof. |
| 15 | TT-P-19 Latex paint/ (foam type unknown) | 6 | unknown, fair cell structure, foam applied over wet surface 20%-30% large cells | -- | -- | -- | -- (P) | 1.75 | 1.26 | 0.189 | | Coating badly deteriorated. Appears to have aluminum asphalt patch over poor coating. No coating thickness determined. Irregular sample from SRF roof. |
| $16a_1$ | Gaco A-5400 acrylic/ Foam Systems FSC 26 Foam | 4 | 2.0/good, uniform cell structure. Foam wet on one surface corner | 10 (P) | -- | -- | 10 (P) | 2.00 | 1.37 | 0.168 | 0.161 | Coating applied over rough surface and is alligatoring in low spots. Coating is continuous. |
| $16a_2$ | | 4 | | 10 (P) | -- | -- | 10 (P) | 2.00 | 1.62 | 0.154 | | |

continued

Table 1. Continued

| Sample No.[a] | Roof Coating/Foam Description System | Age (yr) | Foam Density (pcf) and Quality | Coating Thickness (mils)[b] | | | | Foam Thickness (in.) | | Thermal Conductivity (Btu/hr-ft$^2$-°F/in.) | | Comments |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | First Coat | Second Coat | Third Coat | Total | Roof (Avg) | Sample | Individual Sample | Average | |
| 17 | Gaco A-5400 acrylic/ Foam Systems FSC 26 Foam | 5 | 2.0/good, uniform cell structure. *Foam dry* | 15 (P) | -- | -- | 15 (P) | 1.5 | 1.06 | 0.173 | | Coating in good condition. |
| Samples from U.S. Naval Station, Guam, M.I. | | | | | | | | | | | | |
| 18 | Uniflex Aluminum/CPR Upjohn 425 foam | 5 | 2.0/fair cell structure and uniformity | 5 (P) | -- | -- | 5 (P) | 1.25 | 0.66 | 0.195 | | Badly deteriorated coating - some patching. |
| 19 | Dow Corning w/granules over Witco Foam over TT-P-19/PPG Foam | 4-1/3 | 2.0/3.0; 50% fair cell structure, the rest composed of large open areas from 1/8" to 1" across | 12 (P) | -- | -- | 12 (P) | 1.00 | 0.56 | 0.259 | | PPG Foam not run sample too small. TT-P-19 PPG Foam surface degraded. Values are for Witco foam layer. |
| $20a_1$ | Gaco Neoprene-Hypalon over unknown existing coating/CPR 425 foam | 10 | 2.0/good, uniform cell structure. | -- | -- | -- | -- | 2.0 | 1.40 | 0.185 | 0.1885 | Foam may have been uncoated for some time before Neoprene-Hypalon applied. |
| $20a_2$ | | 10 | 2.0/good, uniform cell structure | -- | -- | -- | -- | 1.75 | 1.25 | 0.192 | | |
| Samples from NCEL, Port Hueneme, California | | | | | | | | | | | | |
| $21a_1$ | Irathane 300/394 Urethane/CPR Upjohn 485-2.0 | 4-3/4 | 2.0/good, uniform cell structure. | 10 (P) | 10 (P) | -- | 20 (P) | 2.25 | 1.58 | 0.130 | 0.135 | Coating is chalking to point where base coat starting to show. Coating flexible and in condition otherwise. |
| $21a_2$ | | 4-3/4 | 2.0/good, uniform cell structure | 10 (P) | 10 (P) | -- | 20 (P) | 2.25 | 1.58 | 0.140 | | |
| 21b | Irathane 300/394 Urethane/CPR Upjohn 485-3.0 | 4-3/4 | 3.0/good, uniform cell structure | 6 (P) | 6 (P) | -- | 12 (P) | 2.50 | 1.76 | 0.134 | | Same as Sample $21a_2$ |
| 21c | Irathane 300/157 Urethane/Hypalon CPR Upjohn 485-2.0 | 4-3/4 | 2.0/good, uniform cell structure | 5 (P) | 4 (I) | -- | 9 (I) | 2.00 | 1.17 | 0.144 | | Topcoat chalking heavily with pin holes to base coat. Coating flexible in good condition. |
| 21d | Irathane 300/157 Urethane/Hypalon CPR Upjohn 485-3.0 | 4-3/4 | 3.0/good, uniform cell structure | 8 (P) | 6 (I) | -- | 14 (I) | 2.25 | 1.35 | 0.144 | | Very rough foam surface. Coating same as Sample 22a. |

continued

Table 1. Continued

| Sample No.[a] | Roof Coating/Foam Description System | Age (yr) | Foam Density (pcf) and Quality | Coating Thickness (mils)[b] | | | | Foam Thickness (in.) | | Thermal Conductivity (Btu/hr-ft$^2$-°F/in.) | | Comments |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | First Coat | Second Coat | Third Coat | Total | Roof (Avg) | Sample | Individual Sample | Average | |
| $22a_1$ | Monolar Mastic Hypalon/CPR Upjohn 485-2.5 | 7 | 2.5/good, uniform cell structure. | 14 (I) | -- | -- | 14 (I) | 2.00 | 1.33 | 0.140 | 0.142 | Very rough surface. Coating eroded, exposing foam in some cases. Coating flexible and in good condition otherwise. |
| $22a_2$ | | 7 | 2.5/good, uniform cell structure | 14 (I) | -- | -- | 14 (I) | 2.00 | 1.27 | 0.145 | | |
| 22b | Monolar Mastic Hypalon/CPR Upjohn 485-2.5 | 7 | 2.5/good, uniform cell structure. | 11 (I) | -- | -- | 11 (I) | 2.00 | 1.22 | 0.148 | | Same as Sample 23a |
| $23a_1$ | Diathon Acrylic/CPR Upjohn 485-2.5 | 7-1/4 | 2.5/good, uniform cell structure | 25 (P) | -- | -- | 25 (P) | 1.25 | 0.79 | 0.180 | 0.188 | Very rough foam surface. Coating eroded, exposing foam in some cases. Coating moderately flexible and in only fair condition. |
| $23a_2$ | | 7-1/4 | 2.5/good, uniform cell structure | 25 (P) | -- | -- | 25 (P) | 1.25 | 0.58 | 0.196 | | |
| $23b_1$ | Diathon Acrylic/CPR Upjohn 485-2.5 | 7-1/4 | 2.5/good, uniform cell structure | 20 (P) | -- | -- | 20 (P) | 1.75 | 1.04 | 0.199 | 0.183 | Coating condition same as Sample 24a. Some liquid water observed in foam. |
| $23b_2$ | | 7-1/4 | 2.5/good, uniform cell structure | 20 (P) | -- | -- | 20 (P) | 1.75 | 0.81 | 0.167 | | |
| $24a_1$ | United Coatings Butyl-Hypalon/CPR Upjohn 485-2.5 | 7-1/6 | 2.5/good, uniform cell structure | 29 (I) | 15 (I) | -- | 44 (I) | 1.50 | 1.02 | 0.181 | 0.182 | Coating exhibiting heavy chalking. Topcoating eroding, exposing base coat. Coating flexible and in good condition. |
| $24a_2$ | | 7-1/6 | 2.5/good, uniform cell structure | 29 (I) | 15 (I) | -- | 44 (I) | 1.50 | 0.93 | 0.184 | | |
| 24b | United Coatings Butyl-Hypalon/CPR Upjohn 485-2.5 | 7-1/6 | 2.5/good, uniform cell structure | 15 (I) | 9 (I) | -- | 24 (I) | 2.25 | 1.66 | 0.165 | | Same as Sample 25a. |
| 25a | General Electric Silicone with Granules/CPR Upjohn 485-2.5 | 7 | 2.5/good, uniform cell structure | 7.5 (P) | 7.5 (P) | -- | 15.0 (P) | 1.75 | 1.48 | 0.164 | | Coating does not present any obvious indication of wearing out, still flexible and in good condition. |
| 25b | General Electric Silicone with Granules/CPR Upjohn 485-2.5 | 7 | 2.5/good, uniform cell structure | 11 (P) | 11 (P) | -- | 22 (P) | 1.75 | 1.39 | 0.146 | | Same as Sample 25a. |

continued

Table 1. Continued

| Sample No.[a] | Roof Coating/Foam Description System | Age (yr) | Foam Density (pcf) and Quality | Coating Thickness (mils)[b] | | | | Foam Thickness (in.) | | Thermal Conductivity (Btu/hr-ft$^2$-°F/in.) | | Comments |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | First Coat | Second Coat | Third Coat | Total | Roof (Avg) | Sample | Individual Sample | Average | |
| 25c | General Electric Silicone w/o Granules/CPR Upjohn 485-2.5 | 7 | 2.5/good, uniform cell structure | 9.5 (P) | 9.5 (P) | -- | 19.0 (P) | 2.00 | 1.65 | 0.157 | | Same as Sample 25a except that dirt is more obvious. |
| 25d | General Electric Silicone w/o Granules/CPR Upjohn 485-2.5 | 7 | 2.5/good, uniform cell structure | 7.5 (P) | 7.5 (P) | -- | 15.0 (P) | 2.00 | 1.53 | 0.140 | | Same as Sample 25a. |
| 26a | Gaco N-118 Neoprene + N-10 Hypalon/CPR Upjohn 485-2.5 | 7 | 2.5/good, uniform cell structure | 8 (I) | 8 (I) | -- | 16 (I) | 1.50 | 1.37 | 0.137 | | Heavy chalking of top coat; base coat showing through. Overall coating is flexible and in good condition. |
| $26b_1$ | Gaco N-118 Neoprene + N-10 Hypalon/CPR Upjohn 485-2.5 | 7 | 2.5/good, uniform cell structure | 10 (I) | 8 (I) | -- | 18 (I) | 1.50 | 0.90 | 0.162 | 0.167 | Same as Sample 26a, except that topcoat is cratered. |
| $26b_2$ | | 7 | 2.5/good, uniform cell structure | 10 (I) | 8 (I) | -- | 18 (I) | 1.50 | 0.56 | 0.172 | | |
| 27a | Rapid Roof with Granules/ CPR Upjohn 480-2.5 | 1-1/4 | 2.5/good, uniform cell structure | 25 (P) | 30 (P) | -- | 55 (P) | 2.25 | 2.08 | 0.111 | | Coating in good condition. |
| 27b | Rapid Roof with Granules/ CPR Upjohn 480-2.5 | 1-1/4 | 2.5/good, uniform cell structure | 28 (P) | 29 (P) | -- | 57 (P) | 2.00 | 1.74 | 0.129 | | Coating in good condition. |
| 28a | Rooflex 155/CPR Upjohn 485-2.5 | 4-5/6 | 2.5/good, uniform cell structure. Foam surface sun-burnt | 36 (P) | -- (P) | -- | 36 (P) | 2.00 | 1.89 | 0.155 | | Coating cratered, flexible, and in good condition. Foam surface sunburnt. |
| 28b | Rooflex 155/CPR Upjohn 485-2.5 | 4-5/6 | 2.5/good, uniform cell structure | 30 (P) | -- (P) | -- | 30 (P) | 2.00 | 1.88 | 0.136 | | Coating cratered, breaks easily. Some areas worn through to foam; fair condition. |

continued

Table 1. Continued

| Sample No.[a] | Roof Coating/Foam Description System | Age (yr) | Foam Density (pcf) and Quality | Coating Thickness (mils)[b] | | | | Foam Thickness (in.) | | Thermal Conductivity (Btu/hr-ft$^2$-°F/in.) | | Comments |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | First Coat | Second Coat | Third Coat | Total | Roof (Avg) | Sample | Individual Sample | Average | |
| $29a_1$ | Foam Systems Acrylflex/ FSC-26-3.0 | 1-1/4 | 3.0/good, uniform cell structure | 16 (P) | 10 (P) | -- | 26 (P) | 1.50 | 0.82 | 0.157 | 0.160 | Coating, although maintaining some flexibility, is almost brittle; breaks easily; fair condition. |
| $29a_2$ | | 1-1/4 | 3.0/good, uniform cell structure | 16 (P) | 10 (P) | -- | 26 (P) | 1.50 | 0.70 | 0.162 | | |

[a]The number refers to a building (roof) or panel where a sample was taken, the letter following the number refers to sample taken from a different area. Numbers (if any) refer to the specimens cut out of the sample when more than one specimen was cut and tested from a given sample.

[b]P = permeable; I = impermeable.

[c]Sample numbers for Samples 1 through 5 are the same as those given systems in Reference 1.

## Table 2. Average k-Values and Ages of PUF Samples

| Area | PUF With Permeable Coatings | | | PUF With Impermeable Coatings | | | Overall Averages | | |
|---|---|---|---|---|---|---|---|---|---|
| | Average k-Value (Btu/hr-ft²-°F/in.) | Average Age (yr) | Number of Samples | Average k-Value (Btu/hr-ft²-°F/in.) | Average Age (yr) | Number of Samples | k-Value (Btu/hr-ft²-°F/in.) | Age (yr) | Number of Samples |
| [illegible] | 0.170 ± 0.010 | 5.0 | 8 | 0.146 ± 0.008 | 5.0 | 8 | 0.158 ± 0.015 | 5.0 | 16 |
| Denver | 0.191 ± 0.012 | 7.1 ± 2.9 | 5 | 0.180 ± 0.016 | 10.1 ± 0.5 | 2 | 0.188 ± 0.013 | 8.0 ± 2.8 | 7 |
| [illegible] Bay | 0.175 ± 0.013 | 5.2 ± 1.0 | 6 | --- | --- | --- | 0.175 ± 0.013 | 5.2 ± 1.09 | 6 |
| Guam | 0.195 | [illegible] | 1 | --- | --- | --- | 0.191 ± 0.005 | 8.3 ± 2.9 | 3[a] |
| NCEL | 0.153 ± 0.024 | 5.0 ± 2.4 | [illegible] | 0.156 ± 0.017 | 6.6 ± 0.9 | 11 | 0.154 ± 0.021 | 5.7 ± 2.1 | 28 |
| Total | 0.164 ± 0.023 | 5.8 ± [illegible] | 37 | 0.156 ± 0.017 | 7.[illegible] ± 3.0 | 21 | 0.163 ± 0.022 | 5.8 ± 2.1 | 60[a] |

[a]Total averages include two samples of an unknown type of coating from Guam but do not include Sample 19, also from Guam

## Table 3. Thermal Conductivity k-Values of NCEL Samples in Increasing Order

| Sample Number | Coating Thickness (mils)[a] | Coating[b] | Foam Density (pcf) | Foam Thickness (in.) | | Thermal Conductivity | | Roof age (yrs) |
|---|---|---|---|---|---|---|---|---|
| | | | | Roof (avg) | Sample | Individual | Average | |
| 27a | 25/30:55 | P | 2.5 | 2.25 | 2.08 | 0.111 | | 1-1/4 |
| 27b | 28/29:57 | P | 2.5 | 2.00 | 1.74 | 0.129 | | 1-1/4 |
| 21b | 6/6:12 | P | 2.0 | 2.50 | 1.76 | 0.134 | | 4-3/4 |
| 21a$_1$<br>21a$_2$ | 10/10:20 | P | 2.0 | 2.25<br>2.25 | 1.58<br>1.58 | 0.130<br>0.140 | 0.135 | 4-3/4 |
| 28b | 30:30 | P | 2.5 | 2.00 | 1.88 | 0.136 | | 4-5/6 |
| 26a | 8/8:16 | I | 2.5 | 1.50 | 1.37 | 0.137 | | 7 |
| 25d | 7.5/7.5:15 | P | 2.5 | 2.00 | 1.53 | 0.140 | | 7 |
| 22a$_1$<br>22a$_2$ | 14:14 | I | 2.5 | 2.00<br>2.00 | 1.33<br>1.27 | 0.140<br>0.145 | 0.1425 | 7 |
| 21d | 8/6:14 | P/I | 2.0 | 2.25 | 1.35 | 0.144 | | 4-3/4 |
| 21c | 5/4:9 | P/I | 2.0 | 2.00 | 1.17 | 0.144 | | 4-3/4 |
| 25b | 11/11:22 | P | 2.5 | 1.75 | 1.39 | 0.146 | | 7 |
| 22b | 11:11 | I | 2.5 | 2.00 | 1.22 | 0.148 | | 7 |
| 28a | 36:36 | P | 2.5 | 2.00 | 1.89 | 0.155 | | 4-5/6 |
| 25c | 9.5/9.5:19 | P | 2.5 | 2.00 | 1.65 | 0.157 | | 7 |
| 29a$_1$<br>29a$_2$ | 16/10:26 | P | 3.0 | 1.50<br>1.50 | 0.82<br>0.70 | 0.157<br>0.162 | 0.1595 | 1-1/4 |
| 25a | 7.5/7.5:15 | P | 2.5 | 1.75 | 1.48 | 0.164 | | [illegible] |
| 24b | 15/9:24 | I | 2.5 | 2.25 | 1.66 | 0.165 | | [illegible] |
| 26b$_1$<br>26b$_2$ | 10/8:18 | I | 2.5 | 1.50<br>1.50 | 0.90<br>0.56 | 0.162<br>0.172 | 0.167 | |
| 24a$_1$<br>24a$_2$ | 29/15:44 | I | 2.5 | 1.50<br>1.50 | 1.02<br>0.93 | 0.181<br>0.184 | 0.1[illegible] | [illegible] |
| 23b$_1$<br>23b$_2$ | 20:20 | P | 2.5 | 1.75<br>1.75 | 1.04<br>0.81 | 0.199<br>0.167 | 0.183 | [illegible] |
| 23a$_1$<br>23a$_2$ | 25:25 | P | 2.5 | 1.25<br>1.25 | 0.79<br>0.58 | 0.180<br>0.196 | 0.188 | [illegible] |

[a] First coat/second coat:total

[b] P = permeable; I = Impermeable

Table 4. k-Values for a 2.2 pcf PUF

| Age of Samples (yr) | Predicted[a] k-Value for Following Foam Thicknesses | |
|---|---|---|
| | 1 in. | 2 in. |
| 5 | 0.158 | 0.148 |
| 7 | 0.165 | 0.150 |
| 10 | 0.175 | 0.154 |

[a]From Reference 6. Samples are 12 x 12 x 1 or 2 inches, aged at 25°C (77°F), under controlled atmospheric conditions with all sides exposed.

Table 5. Actual Average k-Values for NCEL Field-Aged PUF Samples

| Coating Type | 5-Year Old Sample | | 7-Year Old Samples | |
|---|---|---|---|---|
| | PUF Thickness (in.) | Average k-Value | PUF Thickness (in.) | Average k-Value |
| Permeable | 2.20 ± 0.21<br>2.0 only | 0.139 ± 0.010<br>0.145 ± 0.013 | 1.69 ± 0.29<br>2.0 only | 0.169 ± 0.022<br>0.148 ± 0.012 |
| Impermeable | 2.12 ± 0.18<br>2.0 only | 0.144<br>0.144 | 1.75 ± 0.31<br>2.0 only | 0.159 ± 0.018<br>0.144 ± 0.004 |
| Overall | 2.18 ± 0.010<br>2.0 only | 0.140 ± 0.008<br>0.145 ± 0.010 | 1.72 ± 0.29<br>2.0 only | 0.164 ± 0.020<br>0.146 ± 0.007 |

Table 6. k-Values of all Samples in Increasing Order

| Area[a] | Sample Number | Coating Thickness (mil)[b] | Coating[c] | Foam Density (pcf) | Foam Thickness (in.) | | Thermal Conductivity | | Roof (age) (yr) |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | Roof (avg) | k-Sample | Individual | Average | |
| N | 27a | 25/30/-:55 | P | 2.5 | 2.25 | 2.08 | 0.111 | | 1-1/4 |
| N | 27b | 28/29/-:57 | P | 2.5 | 2.00 | 1.74 | 0.129 | | 1-1/4 |
| N | 21b | 6/6/-:12 | P | 2.0 | 2.50 | 1.76 | 0.134 | | 4-3/4 |
| N | $21a_1$ | 10/10/-:20 | P | 2.0 | 2.25 | 1.58 | 0.130 | 0.135 | 4-3/4 |
| N | $21a_2$ | 10/10/-:20 | P | 2.0 | 2.25 | 1.58 | 0.140 | | 4-3/4 |
| N | 28b | 30/-/-:30 | P | 2.5 | 2.00 | 1.88 | 0.136 | | 4-5/6 |
| N | 26a | 8/8:16 | I | 2.5 | 1.50 | 1.37 | 0.137 | | 7 |
| C | $4b_1$ | 20/10/15:45 | I/P/P | 2.0 | 2.25 | 1.50 | 0.143 | 0.139 | 5 |
| C | $4b_2$ | 20/10/15:45 | I/P/P | 2.0 | 2.25 | 1.48 | 0.135 | | 5 |
| N | 25d | 7.5/7.5:15 | P | 2.5 | 2.00 | 1.53 | 0.140 | | 7 |
| C | $5a_1$ | 5/10/-:15 | I/P | 2.0 | 2.25 | 1.51 | 0.144 | 0.1405 | 5 |
| C | $5a_2$ | 5/10/-:15 | I/P | 2.0 | 2.25 | 1.48 | 0.137 | | 5 |
| N | $22a_1$ | 14/-/-:14 | I | 2.5 | 2.00 | 1.33 | 0.140 | 0.1425 | 7 |
| N | $22a_2$ | 14/-/-:14 | I | 2.5 | 2.00 | 1.27 | 0.145 | | 7 |
| N | 21d | 8/6/-:14 | P/I | 2.0 | 2.25 | 1.35 | 0.144 | | 4-3/4 |
| N | 21c | 5/4/-:9 | P/I | 2.0 | 2.00 | 1.17 | 0.144 | | 4-3/4 |
| N | 25b | 11/11/-:22 | P | 2.5 | 1.75 | 1.39 | 0.146 | | 7 |
| C | $4a_1$ | 15/20/20:55 | I/P/P | 2.0 | 2.00 | 1.37 | 0.148 | 0.147 | 5 |
| C | $4a_2$ | 15/20/20:55 | I/P/P | 2.0 | 2.00 | 1.37 | 0.146 | | 5 |
| N | 22b | 11/-/-:11 | I | 2.5 | 2.00 | 1.22 | 0.148 | | 7 |
| N | 28a | 36/-/-:36 | P | 2.5 | 2.00 | 1.89 | 0.155 | | 4-5/6 |
| C | $1b_1$ | 15/5/-:55 | P | 2.0 | 2.00 | 1.37 | 0.156 | 0.156 | 5 |
| C | $1b_2$ | 15/5/-:55 | P | 2.0 | 2.00 | 1.35 | 0.156 | | 5 |
| N | 25c | 9.5/9.5/-:19 | P | 2.5 | 2.00 | 1.65 | 0.157 | | 7 |
| C | $3a_1$ | 10/5/-:15 | I/P | 2.0 | 2.25 | 1.42 | 0.160 | 0.1575 | 5 |
| C | $3a_2$ | 10/5/-:15 | I/P | 2.0 | 2.25 | 1.58 | 0.155 | | 5 |
| N | $29a_1$ | 16/10/-:26 | P | 3.0 | 1.50 | 0.82 | 0.157 | 0.1595 | 1-1/4 |
| N | $29a_2$ | 16/10/-:26 | P | 3.0 | 1.50 | 0.70 | 0.162 | | 1-1/4 |

continued

Table 6. Continued

| Area[a] | Sample Number | Coating Thickness (mil)[b] | Coating[c] | Foam Density (pcf) | Foam Thickness (in.) | | Thermal Conductivity | | Roof (age) (yr) |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | Roof (avg) | k-Sample | Individual | Average | |
| C | $16a_1$ | 10/-/-:26 | P | 2.0 | 2.00 | 1.37 | 0.168 | 0.161 | 4 |
| C | $16a_2$ | 10/-/-:26 | P | 2.0 | 2.00 | 1.62 | 0.154 | | 4 |
| N | 25a | 7.5/7.5/-:15 | P | 2.5 | 1.75 | 1.48 | 0.164 | | 7 |
| N | 24b | 15/9/-:24 | I | 2.5 | 2.25 | 1.66 | 0.165 | | 7-1/6 |
| N | $26b_1$ | 10/8/-:18 | I | 2.5 | 1.50 | 0.90 | 0.162 | 0.167 | 7 |
| N | $26b_2$ | 10/8/-:18 | I | 2.5 | 1.50 | 0.56 | 0.172 | | 7 |
| D | 9 | 2/5/-:7 | I | 2.0 | 1.50 | 1.15 | 0.169 | | 9-3/4 |
| D | 8 | 15/-/-:7 | P | 2.0 | 2.00 | 1.57 | 0.170 | | 9-3/4 |
| C | $2a_1$ | 7/-/-:7 | P | 2.0 | 1.75 | 1.09 | 0.175 | 0.172 | 5 |
| C | $2a_2$ | 7/-/-:7 | P | 2.0 | 1.75 | 1.09 | 0.169 | | 5 |
| S | 17 | 15/-/-:15 | P | 2.0 | 1.50 | 1.06 | 0.173 | | 5 |
| C | $2b_1$ | 10/10/-:20 | P | 2.0 | 2.25 | 1.57 | 0.180 | 0.1755 | 5 |
| C | $2b_2$ | 10/10/-:20 | P | 2.0 | 2.25 | 1.58 | 0.171 | | 5 |
| C | $1a_1$ | 10/10/-:20 | P | 2.0 | 2.00 | 1.32 | 0.181 | 0.178 | 5 |
| C | $1a_2$ | 10/10/-:20 | P | 2.0 | 2.00 | 1.46 | 0.175 | | 5 |
| S | 14 | 15/-/-:15 | P | (?) | 1.25 | 0.65 | 0.182 | | 6 |
| N | $24a_1$ | 29/15/-:44 | I | 2.5 | 1.50 | 1.02 | 0.181 | 0.1825 | 7-1/6 |
| N | $24a_2$ | 29/15/-:44 | I | 2.5 | 1.50 | 0.93 | 0.184 | | 7-1/6 |
| N | $23b_1$ | 20/-/-:20 | P | 2.5 | 1.75 | 1.04 | 0.199 | 0.183 | 7-1/4 |
| N | $23b_2$ | 20/-/-:20 | P | 2.5 | 1.75 | 0.81 | 0.167 | | 7-1/4 |
| S | 13 | 15/-/-:15 | P | (?) | 1.25 | 0.77 | 0.186 | | 6 |
| N | $23a_1$ | 25/-/-:25 | P | 2.5 | 1.25 | 0.79 | 0.180 | 0.188 | 7-1/4 |
| N | $23a_2$ | 25/-/-:25 | P | 2.5 | 1.25 | 0.58 | 0.196 | | 7-1/4 |
| G | $20a_1$ | -/-/-:- | P | 2.0 | 2.00 | 1.40 | 0.185 | 0.1885 | 10 |
| G | $20a_2$ | -/-/-:- | P | 2.0 | 1.75 | 1.25 | 0.192 | | 10 |
| S | 15 | -/-/-:- | P | (?) | 1.75 | 1.26 | 0.189 | | 6 |
| D | 10 | 10/10/-:20 | P | 2.0 | 2.00 | 1.54 | 0.189 | | 4-1/3 |

continued

Table 6. Continued

| Area[a] | Sample Number | Coating Thickness[b] (mil) | Coating[c] | Foam Density (pcf) | Foam Thickness (in.) Roof (avg) | Foam Thickness (in.) k-Sample | Thermal Conductivity Individual | Thermal Conductivity Average | Roof (age) (yr) |
|---|---|---|---|---|---|---|---|---|---|
| C | $16a_1$ | 10/-/-:26 | P | 2.0 | 2.00 | 1.37 | 0.168 | 0.161 | 4 |
| C | $16a_2$ | 10/-/-:26 | P | 2.0 | 2.00 | 1.62 | 0.154 | | 4 |
| N | 25a | 7.5/7.5/-:15 | P | 2.5 | 1.75 | 1.48 | 0.164 | | 7 |
| N | 24b | 15/9/-:24 | I | 2.5 | 2.25 | 1.66 | 0.165 | | 7-1/6 |
| N | $26b_1$ | 10/8/-:18 | I | 2.5 | 1.50 | 0.90 | 0.162 | 0.167 | 7 |
| N | $26b_2$ | 10/8/-:18 | I | 2.5 | 1.50 | 0.56 | 0.172 | | 7 |
| D | 9 | 2/5/-:7 | I | 2.0 | 1.50 | 1.15 | 0.169 | | 9-3/4 |
| D | 8 | 15/-/-:7 | P | 2.0 | 2.00 | 1.57 | 0.170 | | 9-3/4 |
| C | $2a_1$ | 7/-/-:7 | P | 2.0 | 1.75 | 1.09 | 0.175 | 0.172 | 5 |
| C | $2a_2$ | 7/-/-:7 | P | 2.0 | 1.75 | 1.09 | 0.169 | | 5 |
| S | 17 | 15/-/-:15 | P | 2.0 | 1.50 | 1.06 | 0.173 | | 5 |
| C | $2b_1$ | 10/10/-:20 | P | 2.0 | 2.25 | 1.57 | 0.180 | 0.1755 | 5 |
| C | $2b_2$ | 10/10/-:20 | P | 2.0 | 2.25 | 1.58 | 0.171 | | 5 |
| C | $1a_1$ | 10/10/-:20 | P | 2.0 | 2.00 | 1.32 | 0.181 | 0.178 | 5 |
| C | $1a_2$ | 10/10/-:20 | P | 2.0 | 2.00 | 1.46 | 0.175 | | 5 |
| S | 14 | 15/-/-:15 | P | (?) | 1.25 | 0.65 | 0.182 | | 6 |
| N | $24a_1$ | 29/15:44 | I | 2.5 | 1.50 | 1.02 | 0.181 | 0.1825 | 7-1/6 |
| N | $24a_2$ | 29/15:44 | I | 2.5 | 1.50 | 0.93 | 0.184 | | 7-1/6 |
| N | $23b_1$ | 20/-/:20 | P | 2.5 | 1.75 | 1.04 | 0.199 | 0.183 | 7-1/4 |
| N | $23b_2$ | 20/-/:20 | P | 2.5 | 1.75 | 0.81 | 0.167 | | 7-1/4 |
| S | 13 | 15/-/-:15 | P | (?) | 1.25 | 0.77 | 0.186 | | 6 |
| N | $23a_1$ | 25/-/-:25 | P | 2.5 | 1.25 | 0.79 | 0.180 | 0.188 | 7-1/4 |
| N | $23a_2$ | 25/-/-:25 | P | 2.5 | 1.25 | 0.58 | 0.196 | | 7-1/4 |
| G | $20a_1$ | -/-/-:- | P | 2.0 | 2.00 | 1.40 | 0.185 | 0.1885 | 10 |
| G | $20a_2$ | -/-/-:- | P | 2.0 | 1.75 | 1.25 | 0.192 | | 10 |
| S | 15 | -/-/-:- | P | (?) | 1.75 | 1.26 | 0.189 | | 6 |
| D | 10 | 10/10/-:20 | P | 2.0 | 2.00 | 1.54 | 0.189 | | 4-1/3 |

continued

Table 6. Continued

| Area[a] | Sample Number | Coating Thickness (mil)[b] | Coating[c] | Foam Density (pcf) | Foam Thickness (in.) | | Thermal Conductivity | | Roof (age) (yr) |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | Roof (avg) | k-Sample | Individual | Average | |
| D | 7 | 3/-/-:3 | I | 2.0 | 1.50 | 1.08 | 0.191 | | 10-1/2 |
| D | 12 | 10/10/-:20 | P | 2.0 | 2.00 | 1.67 | 0.194 | | 6-1/2 |
| G | 18 | 5/-/-:5 | P | 2.0 | 1.25 | 0.66 | 0.195 | | 5 |
| D | 11 | 150/20/5:175 | P | 2.0 | 2.00 | 1.56 | 0.198 | | 4-1/3 |
| D | 6 | 12/-/-:12 | P | 2.0 | 1.50 | 1.12 | 0.202 | | 10-1/2 |
| G | 19 | 12/-/-:12 | P | 2.0/3.0 | 1.00 | 0.56 | 0.259 | | 4-1/3 |

[a]N = NCEL, Port Hueneme, C = Clifton, S = Subic Bay; D = Denver; G = Guam

[b]First coat/second coat/third coat: total - Dashes indicate further coatings were not used

[c]P = permeable; I = impermeable

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NAS CO, Guantanamo Bay Cuba; Code 114, Alameda CA; Code 183 (Fac. Plan BR MGR); Code 18700, Brunswick ME; Code 18U (ENS P.J. Hickey), Corpus Christi TX; Code 6234 (G. Trask), Point Mugu CA; Code 70, Atlanta, Marietta GA; Code 8E, Patuxent Riv., MD; Dir of Engrng. PWD, Corpus Christi, TX; Dir. Maint. Control Div., Key West FL; Dir. Util. Div., Bermuda; Grover, PWD, Patuxent River, MD; Lakehurst, NJ; Lead. Chief. Petty Offr. PW/Self Help Div, Beeville TX; OIC, CBU 417, Oak Harbor WA; PW (J. Maguire), Corpus Christi TX; PWD - Engr Div Dir, Millington, TN; PWD - Engr Div, Gtmo, Cuba; PWD - Engr Div, Oak Harbor, WA; PWD Maint. Cont. Dir., Fallon NV; PWD Maint. Div., New Orleans, Belle Chasse LA; PWD, Code 1821H (Pfankuch) Miramar, SD CA; PWD, Maintenance Control Dir., Bermuda; PWD, Willow Grove PA; PWO Belle Chasse, LA; PWO Chase Field Beeville, TX; PWO Key West FL; PWO Lakehurst, NJ; PWO Sigonella Sicily; PWO Whiting Fld, Milton FL; PWO, Cubi Point, R.P.; PWO, Dallas TX; PWO, Glenview IL; PWO, Kingsville TX; PWO, Millington TN; PWO, Miramar, San Diego CA; PWO., Moffett Field CA
NAVFACENGCOM CONTRACTS ROICC Key West FL
NAS SCE Norfolk, VA; SCE Norfolk, VA; SCE, Barbers Point HI; Security Offr, Alameda CA
NASDC-WDC T. Fry, Manassas VA
NATL BUREAU OF STANDARDS B-348 BR (Dr. Campbell), Washington DC
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NAVACT PWO, London UK
NAVACTDET PWO, Holy Lock UK
NAVAEROSPREGMEDCEN SCE, Pensacola FL
NAVAIRDEVCEN Chmielewski, Warminster, PA; Code 813, Warminster PA; PWD, Engr Div Mgr, Warminster, PA
NAVAIRPROPTESTCEN CO, Trenton, NJ
NAVAVIONICFAC PW Div Indianapolis, IN; PWD Deputy Dir. D/701, Indianapolis, IN
NAVAVNWPNSFAC Wpns Offr, St. Mawgan, England
NAVCHAPGRU Engineering Officer, Code 60 Williamsburg, VA
NAVCOASTSYSCEN CO, Panama City FL; Code 423 Panama City, FL; Code 715 (J Quirk) Panama City, FL; Code 715 (J. Mittleman) Panama City, FL; Library Panama City, FL; PWO Panama City, FL
NAVCOMMAREAMSTRSTA Code W-60, Elec Engr, Wahiawa, HI; PWO, Norfolk VA; SCE Unit 1 Naples Italy; SCE, Wahiawa HI
NAVCOMMSTA Code 401 Nea Makri, Greece; PWD - Maint Control Div, Diego Garcia Is.; PWO, Exmouth, Australia; SCE Balkoa, Panama Canal
NAVCONSTRACEN Curriculum/Instr. Stds Offr, Gulfport MS
NAVEDTRAPRODEVCEN Technical Library, Pensacola, FL
NAVEDUTRACEN Engr Dept (Code 42) Newport, RI
NAVENVIRHLTHCEN CO, NAVSTA Norfolk, VA
NAVEODTECHCEN Code 605, Indian Head MD
NAVFAC PWO, Brawdy Wales UK; PWO, Centerville Bch, Ferndale CA; PWO, Point Sur, Big Sur CA; SCE
NAVFACENGCOM Code 03T (Essoglou) Alexandria, VA; Code 043 Alexandria, VA; Code 044 Alexandria, VA; Code 0453 (D. Potter) Alexandria, VA; Code 046; Code 0461D (V M Spaulding) Alexandria, VA; Code 04A1 Alexandria, VA; Code 04B3 Alexandria, VA; Code 051A Alexandria, VA; Code 09M54, Technical Library, Alexandria, VA; Code 100 Alexandria, VA; Code 1002B (J. Leimanis) Alexandria, VA; Code 1113, Alexandria, VA; Code 111A Alexandria, VA
NAVFACENGCOM CONTRACTS ROICC, Yap; ROICC Code 495 Portsmouth VA
NAVFACENGCOM code 08T Alexandria, VA
NAVFACENGCOM - CHES DIV. Code 101 Wash, DC; Code 403 Washington DC; Code 405 Wash, DC; Code 407 (D Scheesele) Washington, DC; Code FPO-1C Washington DC; Contracts, ROICC, Annapolis MD; FPO-1 Washington, DC; FPO-1EA5 Washington DC; Library, Washington, D.C.
NAVFACENGCOM - LANT DIV. Code 111, Norfolk, VA; Code 403, Norfolk, VA; Eur. BR Deputy Dir, Naples Italy; Library, Norfolk, VA; RDT&ELO 102A, Norfolk, VA
NAVFACENGCOM - NORTH DIV. CO; Code 04 Philadelphia, PA; Code 09P Philadelphia PA; Code 1028, RDT&ELO, Philadelphia PA; Code 111 Philadelphia, PA; Code 4012/AB (A. Bianchi) Philadelphia, PA; Library, Philadelphia, PA; ROICC, Contracts, Crane IN
NAVFACENGCOM - PAC DIV. (Kyi) Code 101, Pearl Harbor, HI; CODE 09P PEARL HARBOR HI; Code 2011 Pearl Harbor, HI; Code 402, RDT&E, Pearl Harbor HI; Commander, Pearl Harbor, HI; Library, Pearl Harbor, HI

NAVFACENGCOM - SOUTH DIV. Code 403, Gaddy, Charleston, SC; Code 405 Charleston, SC; Code 411 Soil Mech & Paving BR Charleston, SC; Code 90, RDT&ELO, Charleston SC; Library, Charleston, SC
NAVFACENGCOM - WEST DIV. 102; AROICC, Contracts, Twentynine Palms CA; Code 04B San Bruno, CA
NAVFACENGCOM CONTRACTS Contracts, AROICC, Lemoore CA
NAVFACENGCOM - WEST DIV. Library, San Bruno, CA; O9P/20 San Bruno, CA; RDT&ELO Code 2011 San Bruno, CA
NAVFACENGCOM CONTRACTS AROICC MCAS El Toro; AROICC, NAVSTA Brooklyn, NY; AROICC, Point Mugu CA; AROICC, Quantico, VA; Colts Neck, NJ; Dir, Eng. Div., Exmouth, Australia; Eng Div dir, Southwest Pac, Manila, PI; NAS, Jacksonville, FL; OICC, Southwest Pac, Manila, PI; OICC-ROICC, NAS Oceana, Virginia Beach, VA; OICC/ROICC, Balboa Panama Canal; ROICC AF Guam; ROICC, Diego Garcia Island; ROICC, Keflavik, Iceland; ROICC, NAS, Corpus Christi, TX; ROICC, Pacific, San Bruno CA; ROICC-OICC-SPA, Norfolk, VA
NAVHOSP PWD - Engr Div, Beaufort, SC
NAVMAG PWD - Engr Div, Guam; SCE, Guam; SCE, Subic Bay, R.P.
NAVOCEANO Code 3432 (J. DePalma), Bay St. Louis MS; Library Bay St. Louis, MS
NAVOCEANSYSCEN Code 4473 Bayside Library, San Diego, CA; Code 4473B (Tech Lib) San Diego, CA; Code 5221 (R.Jones) San Diego Ca; Code 523 (Hurley), San Diego, CA; Code 6700, San Diego, CA; Code 811 San Diego, CA
NAVORDMISTESTFAC PWD - Engr Dir, White Sands, NM
NAVORDSTA PWD - Dir, Engr Div, Indian Head, MD; PWO, Louisville KY
NAVPETOFF Code 30, Alexandria VA
NAVPETRES Director, Washington DC
NAVPHIBASE CO, ACB 2 Norfolk, VA; Code S3T, Norfolk VA; Harbor Clearance Unit Two, Little Creek, VA
NAVFACENGCOM CONTRACTS OICC/ROICC, Norfolk, VA
NAVPHIBASE SCE Coronado, SD,CA
NAVRADRECFAC PWO, Kami Seya Japan
NAVREGMEDCEN Code 3041, Memphis, Millington TN; PWD - Engr Div, Camp Lejeune, NC; PWO, Camp Lejeune, NC; SCE Newport RI; PWO Portsmouth, VA
NAVREGMEDCEN PWO, Okinawa, Japan
NAVREGMEDCEN SCE; SCE San Diego, CA; SCE, Camp Pendleton CA; SCE, Guam; SCE, Oakland CA
NAVREGMEDCEN SCE, Yokosuka, Japan
NAVSCOLCECOFF C35 Port Hueneme, CA; CO, Code C44A Port Hueneme, CA
NAVSCSOL PWO, Athens GA
NAVSEASYSCOM Code 0325, Program Mgr, Washington, DC; Code 05E1, Wash, DC; Code PMS 395 A 3, Washington, DC; SEA 04E (L Kess) Washington, DC; SEA05E1, Washington, D.C.
NAVSECGRUACT Facil. Off., Galeta Is. Panama Canal; PWO, Adak AK; PWO, Edzell Scotland; PWO, Puerto Rico; PWO, Torri Sta, Okinawa
NAVSECSTA PWD - Engr Div, Wash., DC
NAVSHIPREPFAC SCE Subic Bay
NAVSHIPYD Bremerton, WA (Carr Inlet Acoustic Range); Code 134, Pearl Harbor, HI; Code 202.4, Long Beach CA; Code 202.5 (Library) Puget Sound, Bremerton WA; Code 380, Portsmouth, VA; Code 382.3, Pearl Harbor, HI; Code 400, Puget Sound; Code 440 Portsmouth NH; Code 440, Norfolk; Code 440, Puget Sound, Bremerton WA; Code 453 (Util. Supr), Vallejo CA; Commander, Philadelphia, PA; L.D. Vivian; Library, Portsmouth NH; PW Dept, Long Beach, CA; PWD (Code 420) Dir Portsmouth, VA; PWD (Code 450-HD) Portsmouth, VA; PWD (Code 453-HD) SHPO 03, Portsmouth, VA; PWD (Code 457-HD) Shop 07, Portsmouth, VA; PWD (Code 460) Portsmouth, VA; PWO, Bremerton, WA; PWO, Mare Is.; PWO, Puget Sound; SCE, Pearl Harbor HI; Tech Library, Vallejo, CA
NAVSTA Adak, AK; CO Roosevelt Roads P.R. Puerto Rico; CO, Brooklyn NY; Code 4, 12 Marine Corps Dist, Treasure Is., San Francisco CA; Dir Engr Div, PWD, Mayport FL; Dir Mech Engr 37WC93 Norfolk, VA; Engr. Dir., Rota Spain; Long Beach, CA; Maint. Cont. Div., Guantanamo Bay Cuba; Maint. Div. Dir/Code 531, Rodman Panama Canal; PWD (LTJG.P.M. Motolenich), Puerto Rico; PWD - Engr Dept, Adak, AK; PWD - Engr Div, Midway Is.; PWO, Guantanamo Bay Cuba; PWO, Keflavik Iceland; PWO, Mayport FL
NAVFACENGCOM CONTRACTS ROICC Rota Spain
NAVSTA SCE, Guam; SCE, Pearl Harbor HI; SCE, San Diego CA; SCE, Subic Bay, R.P.; Utilities Engr Off. Rota Spain
NAVSUBASE Code 23 (Slowey) Bremerton, WA; ENS S. Dove, Groton, CT
NAVSUPPACT CO, Naples, Italy; PWO Naples Italy
NAVSUPPFAC PWD - Maint. Control Div, Thurmont, MD
NAVSURFWPNCEN PWO, White Oak, Silver Spring, MD
NAVTECHTRACEN SCE, Pensacola FL
NAVTELCOMMCOM Code 53, Washington, DC
NAVWPNCEN Code 2636 China Lake; Code 3803 China Lake, CA; PWO (Code 266) China Lake, CA; ROICC (Code 702), China Lake CA

NAVWPNSTA (Clebak) Colts Neck, NJ; Code 092, Colts Neck NJ; Code 092, Concord CA; Code 092A, Seal Beach, CA; Maint. Control Dir., Yorktown VA
NAVWPNSTA PW Office Yorktown, VA
NAVWPNSTA PWD - Maint. Control Div., Concord, CA; PWD - Supr Gen Engr, Seal Beach, CA; PWO, Charleston, SC; PWO, Seal Beach CA
NAVWPNSUPPCEN Code 09 Crane IN
NCBU 405 OIC, San Diego, CA
NCTC Const. Elec. School, Port Hueneme, CA
NCBC Code 10 Davisville, RI; Code 15, Port Hueneme CA; Code 155, Port Hueneme CA; Code 156, Port Hueneme, CA; Code 25111 Port Hueneme, CA; Code 400, Gulfport MS; Code 430 (PW Engrng) Gulfport, MS; Code 470.2, Gulfport, MS; NEESA Code 252 (P Winters) Port Hueneme, CA; PWO (Code 80) Port Hueneme, CA; PWO, Davisville RI; PWO, Gulfport, MS
NCBU 411 OIC, Norfolk VA
NCR 20, Code R70; 20, Commander
NMCB 74, CO; FIVE, Operations Dept; Forty, CO; THREE, Operations Off.
NOAA (Dr. T. Mc Guinness) Rockville, MD; Library Rockville, MD
NORDA Code 440 (Ocean Rsch Off) Bay St. Louis MS
NRL Code 5800 Washington, DC; Code 8441 (R.A. Skop), Washington DC
NROTC J.W. Stephenson, UC, Berkeley, CA
NSC Code 54.1 Norfolk, VA
NSD SCE, Subic Bay, R.P.
NSWSES Code 0150 Port Hueneme, CA
NTC OICC, CBU-401, Great Lakes IL
NUSC Code 131 New London, CT; Code 5202 (S. Schady) New London, CT; Code EA123 (R.S. Munn), New London CT; Code SB 331 (Brown), Newport RI; Code TA131 (G. De la Cruz), New London CT
OFFICE SECRETARY OF DEFENSE OASD (MRA&L) Dir. of Energy, Pentagon, Washington, DC
ONR Central Regional Office, Boston, MA; Code 221, Arlington VA; Code 485 (Silva) Arlington, VA; Code 700F Arlington VA
PACMISRANFAC HI Area Bkg Sands, PWO Kekaha, Kauai, HI
PHIBCB 1 P&E, San Diego, CA; 1, CSWC D Wellington, San Diego, CA
PMTC Pat. Counsel, Point Mugu CA
PWC CO Norfolk, VA; CO, (Code 10), Oakland, CA; CO, Great Lakes IL; CO, Pearl Harbor HI; Code 10, Great Lakes, IL; Code 105 Oakland, CA; Code 110, Great Lakes, IL; Code 110, Oakland, CA; Code 120, Oakland CA; Code 120C, (Library) San Diego, CA; Code 128, Guam; Code 154, Great Lakes, IL; Code 200, Great Lakes IL; Code 200, Guam; Code 400, Great Lakes, IL; Commanding Officer, Subic Bay; Code 400, Pearl Harbor, HI; Code 400, San Diego, CA; Code 420, Great Lakes, IL; Code 420, Oakland, CA; Code 424, Norfolk, VA; Code 500 Norfolk, VA; Code 505A Oakland, CA; Code 600, Great Lakes, IL; Code 610, San Diego Ca; Code 700, Great Lakes, IL; Code 700, San Diego, CA; Library, Pensacola, FL; Library, Guam; Library, Norfolk, VA; Library, Oakland, CA; Library, Pearl Harbor, HI; Library, Subic Bay, R.P.; Util Dept (R Pascua) Pearl Harbor, HI; Utilities Officer, Guam
SPCC PWO (Code 120) Mechanicsburg PA
SUPANX PWO, Williamsburg VA
TVA Smelser, Knoxville, Tenn.; Solar Group, Arnold, Knoxville, TN
UCT ONE OIC, Norfolk, VA
UCT TWO OIC, Port Hueneme CA
U.S. MERCHANT MARINE ACADEMY Kings Point, NY (Reprint Custodian)
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USAF SCHOOL OF AEROSPACE MEDICINE Hyperbaric Medicine Div, Brooks AFB, TX
USCG (Smith), Washington, DC; G-EOE-4 (T Dowd), Washington, DC; G-MMT-4/82 (J Spencer)
USDA Forest Products Lab. Madison WI; Forest Service Reg 3 (R. Brown) Albuquerque, NM; Forest Service, Bowers, Atlanta, GA
USNA Ch. Mech. Engr. Dept Annapolis MD; Civil Engr Dept (R. Erchyl) Annapolis MD; ENGRNG Div, PWD, Annapolis MD; Energy-Environ Study Grp, Annapolis, MD; Environ. Prot. R&D Prog. (J. Williams), Annapolis MD; Mech. Engr. Dept. (C. Wu), Annapolis MD; NAVSYSENGR Dept. Annapolis, MD; PWO Annapolis MD
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