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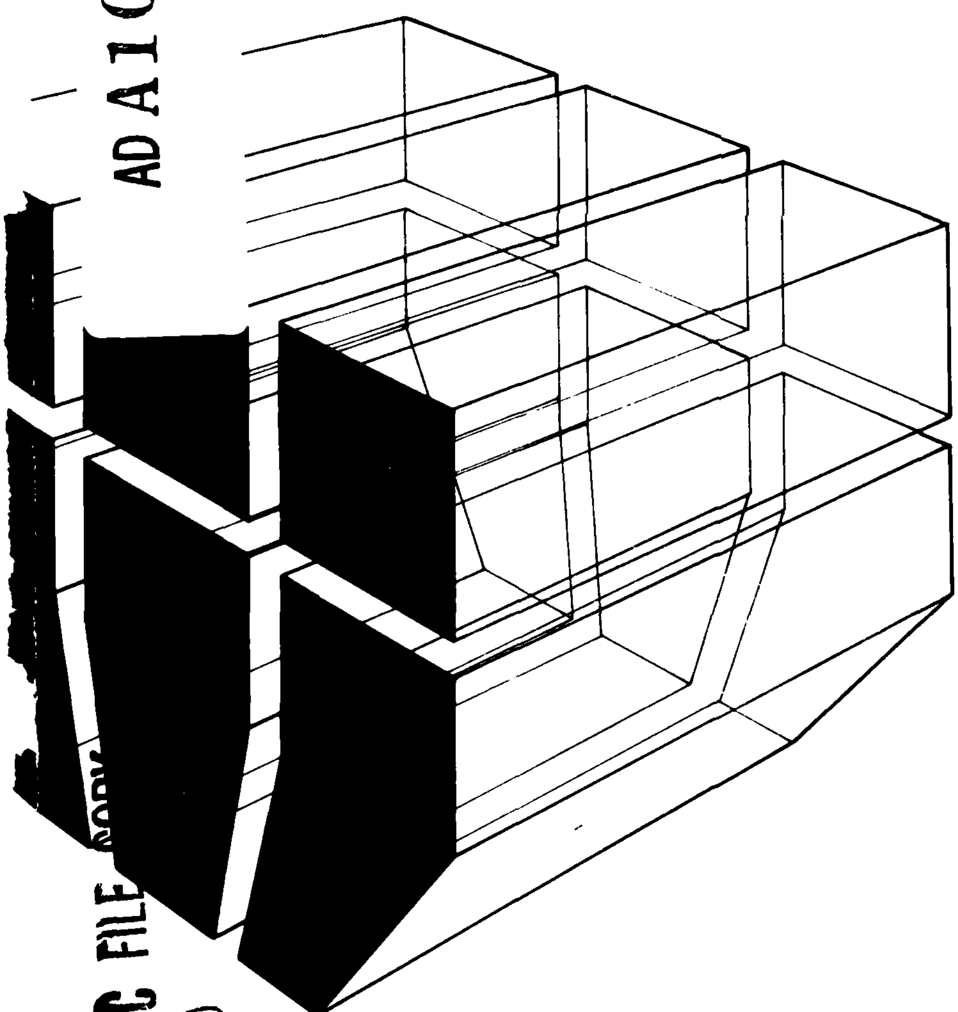
TECHNICAL REPORT M-297
November 1981
New Roofing Concepts in the Military Construction Process

EVALUATION OF SPRAYED POLYURETHANE FOAM ROOFING AND PROTECTIVE COATINGS



by
Myer J. Rosenfield

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This report documents a study to evaluate sprayed polyurethane foam (PUF) roofing and protective coatings for use in reroofing at Army installations. Manufacturers, field applications, and literature were surveyed to identify advantages and disadvantages associated with the use of these systems.

It was found that the service life of this type of roof system depends on the skill of the applicator and the capability of the coating material to resist the effects of climate and weather.

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PUF can be used as an alternative to conventional built-up roofing (BUR) for new roofs, or to replace failed roofs. However, because these systems are relatively new (and long-term durability statistics are not available), they should only be used on carefully selected Army roofs. New construction is limited to the use of silicone-coated PUF over concrete roof decks, as required by Corps of Engineers Guide Specification (CEGS)-07540.

FOREWORD

This investigation was performed for the Directorate of Military Programs, Office of the Chief of Engineers (OCE), under Project 4A762731AT41, "Military Facilities Engineering Technology"; Task A, "Military Construction"; Work Unit 044, "New Roofing Concepts in the Military Construction Process." The OCE Technical Monitor is Marvin Beck, DAEN-MPO-B.

This study was performed by the Engineering and Materials Division (EM), U.S. Army Construction Engineering Research Laboratory (CERL). Dr. R. Quattrone is Chief of EM.

Appreciation is expressed to Dr. Robert L. Alumbaugh of the U.S. Navy Civil Engineering Laboratory, and Mr. Bernard V. Jones of the U.S. Bureau of Reclamation for their contributions to and review of the technical content of this report.

Figures 2 through 25 are official U.S. Navy photographs.

COL Louis J. Circeo is Commander and Director of CERL, and Dr. L. R. Shaffer is Technical Director.

CONTENTS

TABLES

FIGURES

FIGURES (con't)

EVALUATION OF SPRAYED POLYURETHANE FOAM ROOFING AND PROTECTIVE COATINGS

1 INTRODUCTION

Background

Most Army facilities use conventional roofing systems, such as built-up roofing (BUR), that are expensive and complicated to construct. Often, these systems are comparatively short-lived, resulting in high life-cycle roofing costs that are difficult for already overburdened Army operation and maintenance budgets to absorb. Therefore, the Directorate of Military Programs has asked the U.S. Army Construction Engineering Research Laboratory (CERL) to identify alternative, easy-to-install roofing systems that can improve the performance of Army roofing while reducing life-cycle costs.

Objective

The overall objectives of CERL's roofing studies are to: (1) evaluate innovative roofing systems and materials to determine alternatives to BUR systems, (2) provide a means to improve Army roof performance and reduce life-cycle costs, and (3) develop guide specifications for selected alternative systems.

The specific objective of this report is to document an investigation into the use of one alternative system, polyurethane foam (PUF) with a suitable elastomeric coating.

Approach

This investigation is being conducted in the following steps:

1. Survey of literature, manufacturers, and field applications to identify advantages and disadvantages associated with the use of PUF roofing systems.

2. Construction of PUF roofing systems at selected Army installations.

3. Evaluation of the design, construction, and post-construction performance of the test roofs over 2 years.

4. Determination of the suitability of PUF for use in Army roofing systems and the subsequent revisions to existing Corps of Engineers Guide Specification (CEGS)-07540.

This report documents step 1, above.

Mode of Technology Transfer

If the results of this study show that PUF roofing systems can be used at Army installations, CEGS-07540, *Elastomeric Roofing, Fluid-Applied,* will be revised to include application on decks other than concrete and use of coatings other than silicone.

2 INSTALLATION OF FOAM ROOFING ON VARIOUS SUBSTRATES

Criteria for Foam Application

Fire Safety

Regardless of the roof deck being covered, sprayed PUF roofing systems should be designated Class A, B, or C by Underwriters' Laboratories (UL) Standard 790.[1] In addition, combustible roof decks, including metal decks, are required to have a UL roof deck construction classification or a Factory Mutual (FM) Class I classification. These requirements are included in Department of Defense (DOD) *Construction Criteria Manual* DOD 4270.1-M.[2] Note that this manual lists 2-in. (51-mm) tongue-and-groove wooden decking as a noncombustible roof deck.

Wind Resistance

The roofing system should adhere tightly to the substrate. A minimum adhesion of 95 percent is recommended.[3]

Weather Resistance

Foamed urethanes are susceptible to damage by sunlight and water (freeze-thaw) and must be coated to prevent deterioration.

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[1] *Tests for Fire Resistance of Roof Covering Materials,* UL Standard 790 (Underwriters' Laboratories [UL], 1978).

[2] *Construction Criteria Manual,* DOD 4270.1-M (Department of Defense, October 1972).

[3] W. C. Cullen and W. J. Rossiter, *Guidelines for Selection of and Use of Foam Polyurethane Roofing Systems,* NBS Technical Note 778 (National Bureau of Standards, May 1973).

Strength

The foam should be strong enough to resist the effect of compressive forces resulting from hail, foot traffic, or other causes. Until recently, the industry recommended application of foam in the range of 2 pcf (32 kg/m³), without considering compressive strength. Current recommendations are for foam with a minimum compressive strength of 40 psi (27.6 N/cm²), which is obtained with foam in the range of 2-1/2 to 3 pcf (40 to 48 kg/m³). The relationship between density and compressive strength of foam is given in Figure 1.[4]

Dimensional Stability

Movements under service conditions must not be so large that the foam will tend to separate from the substrate or delaminate between lifts.

[4] *Properties of Rigid Urethane Foams* (Elastomer Chemicals Department, E. I. DuPont de Nemours and Co., n.d.).

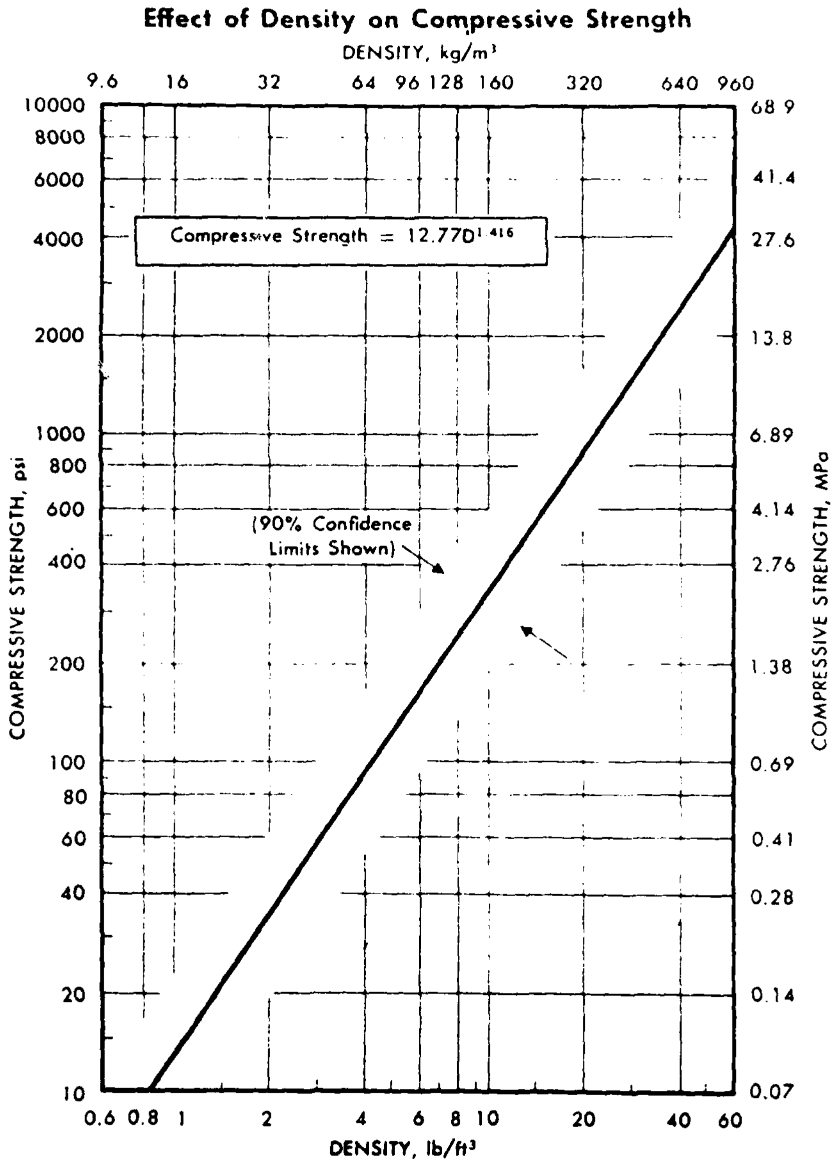

Figure 1. The relationship between density and compressive strength of foam.

Insulation

Insulation values must meet the requirements of DOD 4270.1-M (U-value of 0.05 or R-value of 20).

Drainage

Foam should be installed with a minimum slope of 1:100, and the surface should be flat enough that only small, shallow pools of water (bird baths) will remain after a rain.

Cell Structure

The foam should have a uniform structure, of which 90 percent consists of small spherical closed cells. This structure is necessary to provide the required insulation value and to prevent absorption of water.

Surface

The foam surface should be as smooth as possible so that the coating, when applied, will cover properly and uniformly. Foam surfaces commonly termed "smooth" (Figure 2), "orange peel" (Figures 3 and 4), and "verge of popcorn" (Figure 5) are acceptable. "Popcorn" (Figure 6) or "tree bark" (Figure 7) surfaces are not acceptable and should not be coated. The normal surface texture to be expected is "orange peel."

Vapor Retarder

Installation of a vapor retarder between the substrate and the foam depends on the environment in the building. Moisture flowing through the roof must be analyzed carefully to see whether there will be a significant quantity moving from the building into the foam, and whether it will subsequently condense or freeze within the foam or beneath the coating. Conditions that normally suggest a vapor retarder for a BUR also suggest one for a foam roof system. If the analysis reveals that a vapor retarder is needed, three types are available: built-up, made of felt and hot asphalt; sheet-applied, of impervious elastomeric membrane; or fluid-applied, of materials such as butyl rubber, neoprene rubber, and chlorosulfonated polyethylene. The type of roof deck often indicates the best vapor retarder to use.

Application to Concrete Roof Decks

Until recently, installing PUF roofing on concrete roof decks was the only method rated Class A by UL. Because the Corps of Engineers requires that all roofs meet Class A requirements, regardless of material used, CEGS-07540 (formerly CE-220.13) is limited to application of foam over structural concrete decks in new construction.[5] Application to metal roofs is a retrofit, and is beyond the scope of CEGS-07540.

If the deck is clean and dry, free of all form oil, form-release agents, or other grease or oil, then the foam can be applied directly to the deck. Although wood float or trowelled finishes may be foamed directly, CEGS-07540 requires a broomed finish so that a better bond may be attained. Decks which cannot be cleaned of residual oil or grease, or which contain remnants of old asphalt vapor retarders, may need to be primed. The various foam manufacturers state the conditions under which primers must be used before foam is applied. Many even specify and offer a particular primer for use with their foam. Cutback asphalt, such as American Society for Testing and Materials [ASTM] D 41,[6] should dry from 2 to 4 weeks before foaming. Otherwise, the heat of reaction of the foam will cause the primer to lose its bond to the concrete, and the foam will ultimately float off. Some asphalt primers have a high paraffin content, which affects bonding of anything applied on them. A primer recommended by the foam manufacturer should be used.

Lightweight concrete and poured-in-place gypsum are not satisfactory substrates for application of foam because: (1) their cohesive strength is much less than the adhesive bond strength between the surface and the foam, and (2) there is a tendency to apply the foam before the substrate is thoroughly dry. The moisture will cause severe problems since it tends to evaporate. CEGS-07540 specifically prohibits foam application to lightweight concrete.

Application to Wood Roof Decks

Roofs consisting of sprayed PUF applied to wood decks are designated either Class B or Class C by UL. This does not mean that only wood decks are classified Class B or C; noncombustible decks may also bear these ratings. Details may be found in UL's *Building Materials Directory*.[7] Wood deck constructions tested by UL consist of foam applied to plywood of various thicknesses, but at least 3/8 in. (10 mm).

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[5] *Elastomeric Roofing, Fluid Applied*, CEGS-07540 (Department of the Army [DA], Office of the Chief of Engineers [OCE], April 1980).

[6] *Asphalt Primer Used in Roofing, Damp-Proofing and Waterproofing*, ASTM D 41-78 (American Society for Testing and Materials [ASTM], 27 May 1980).

[7] *Building Materials Directory* (UL, January 1980).

Figure 2. Smooth foam surface

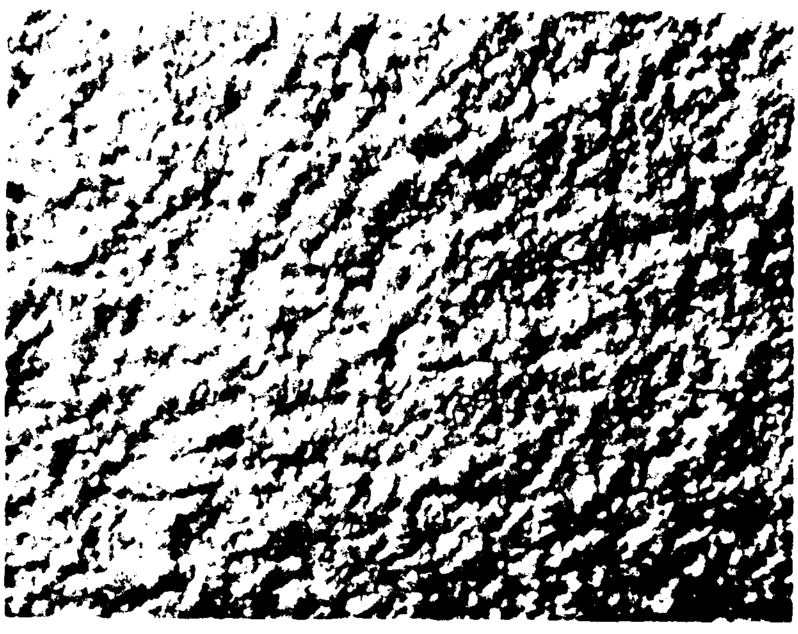

Figure 3. Orange peel foam surface

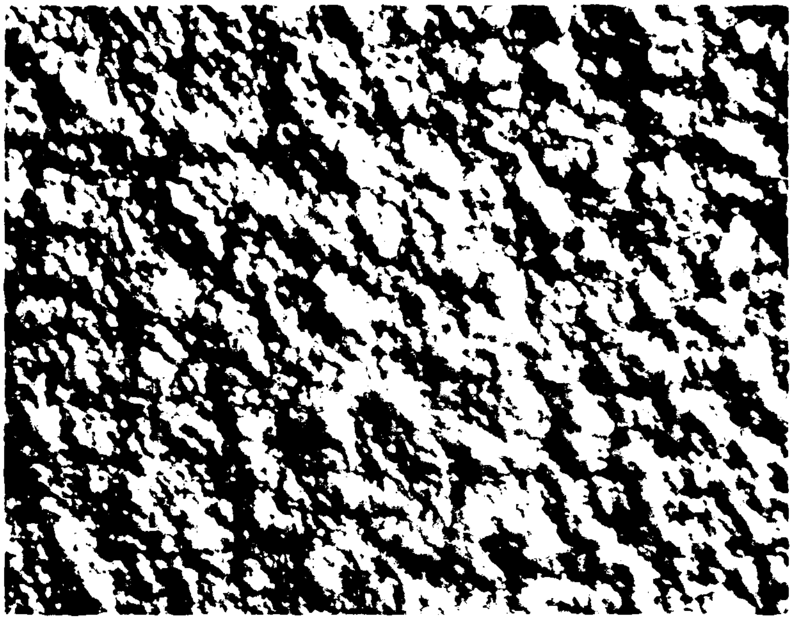

Figure 4. Coarse orange peel foam surface.

Figure 5. Verge of popcorn foam surface.

Figure 6. Popcorn foam surface.

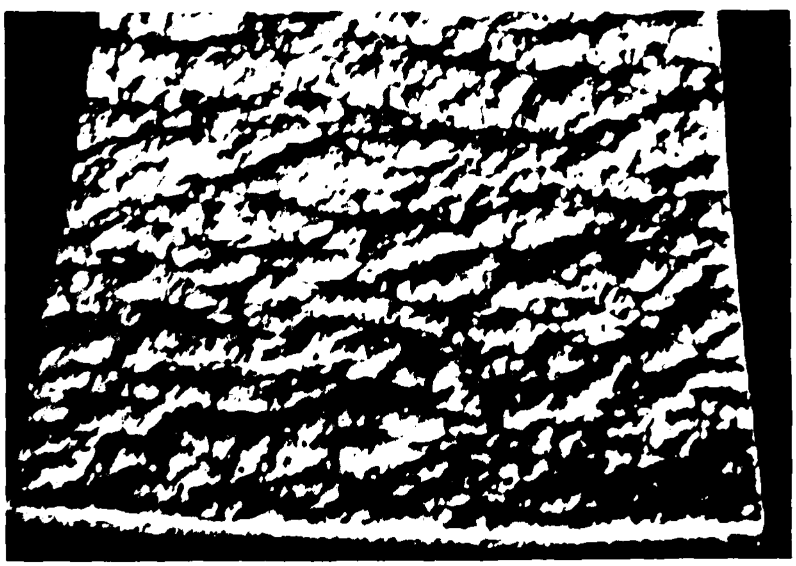

Figure 7. Treebark foam surface.

Although foam may be applied to tongue and groove decking, sheathing, or planking, it is advisable to overlay the deck with plywood to eliminate future problems caused by potential shrinkage cracking from drying or aging. The plywood must be firmly nailed to the deck and primed according to the foam manufacturer's recommendations. Joints larger than 1/4 in. (6 mm) should be caulked or taped before foaming.

It is unlikely that foamed roofing will be applied to wood decks on any Army buildings because this construction will not meet UL Class A requirements.

Application to Steel Roofs

For several years, the U.S. Navy Civil Engineering Laboratory (CEL) has been applying PUF roofing directly to steel roofs of Butler Rib-type buildings. Realizing that this construction may meet UL Class A requirements, CEL asked that UL perform its tests in accordance with UL 790 and UL Subject 1256, "Outline of the Proposed Investigation for Roof Deck Constructions." Results of these tests indicate that this construction does meet Class A requirements.[8] Although a limited number of foams and coatings were actually tested (two foams and two coatings, for a total of four different systems), the way is now open to perform similar tests on other combinations of foams and coatings. UL has listed this construction as Roof Deck Construction No. 136.[9] At least six different foams and eight different coating systems are now classified as meeting this construction. Systems listed under Roof Deck Construction No. 136 meet the fire safety requirements of DOD 4270.1-M.

The surface to be coated should be clean and dry, free of all rust, loose scale and paint, grease, oil, or other foreign matter. Priming may be required; if so, it should be performed according to the recommendations of the foam manufacturer or installer.

Application to Fluted Steel Roof Decks

Application of PUF directly to fluted steel roof decks does not now meet either UL Class A or FM Class I requirements. UL Roof Deck Constructions Nos. 74 and 82 have been tested for wind uplift and meet Class 90 criteria, but have not been investigated for fire resistance. No. 74 is direct application of foam to the deck, with foam filling the flutes. No. 82 is with formed shapes of foam placed in the flutes before sprayed foam is applied. This construction is not authorized for Army use because the Class A criterion is not met. To meet Class A requirements, a thermal barrier must first be mechanically fastened to the deck, and the foam applied to the barrier. A satisfactory barrier is 1-in.-thick (25-mm) perlite board, or 1/2-in.-thick (13-mm) waterproofed gypsum board. A vapor retarder may or may not be required between the thermal barrier and the foam.

Advantages and Disadvantages

CERL Technical Report M-263 describes the advantages and disadvantages of foamed-in-place roofing systems; these points are summarized below.[10]

Advantages

1. Insulation capability. Polyurethane foams are the best insulating materials now available for use in construction. Since they are good insulators, they can prevent excessive thermal movement in metal buildings when applied on top of existing roof systems and on exterior surfaces.

2. Ease of application and repair. Polyurethane foams are multicomponent systems that are applied with a special spray apparatus. Two layers (lifts) are recommended to ensure an adequate seal. Damaged areas are easily repaired by removing affected sections and refoaming. However, the skill of the operator and weather conditions are extremely important.

3. Ease of coverage. Since the foam forms a homogeneous layer, it can be used to bridge cracks and irregularities in the substrate. The foamed-in-place system is also self-flashing and will seal readily at parapet walls and around projections.

4. Lightweight. Because foam systems are much lighter than conventional BUR systems, various densities and thicknesses of foam can be applied to meet many requirements for insulation, impact resistance, or roof traffic. However, care must be exercised to prevent disbonding when applying different density foams over one another.

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[8] *Fire Tests of Polyurethane Foam Roof Deck Construction on Steel Decks*, Report CR 79.004 (Civil Engineering Laboratory, Naval Construction Battalion Center, December 1978).

[9] "Construction No. 136," *Building Materials Directory* (UL, January 1980).

[10] E. Marvin, et al., *Evaluation of Alternative Reroofing Systems*, Interim Report M-263/ADA071578 (U.S. Army Construction Engineering Research Laboratory, June 1979).

5. Direct application to suitably prepared existing roof. A weathered or damaged roof can, in effect, be stabilized by foam application, within certain limitations.

Disadvantages

1. Susceptibility to ultraviolet (UV) radiation and weather degradation. After curing, foamed-in-place systems must have a suitable elastomeric coating, such as acrylics, silicone rubbers, butyl/Hypalons,* Hypalon mastics, catalized urethanes, and other weather- and UV-resistant coatings. In addition, these systems must be kept coated throughout the life of the roof to prevent UV- or weather-induced degradation.

2. Low compressive and tensile strength. A completed foam roof is subject to damage from hail and foot traffic; in some areas, birds and rodents also can cause damage.

3. Preparation. To ensure proper adhesion, substrates must be thoroughly prepared to receive foamed-in-place systems. Such preparation includes removal of any loose or flaking section of an existing roof. Foam cannot be mechanically fastened, and will not adhere to dirty, wet, or oily surfaces.

4. Flammability. Since foams are organic, they will burn; however, the full extent of the fire hazard they represent has not yet been resolved. In particular, the direct application of foam over fluted metal decks in habitable buildings is actively being researched but has not yet been approved. Foam roofs may be placed over metal decks if a suitable fire barrier is provided between the deck and the foam layer. Direct application of foam to prefabricated steel, Butler Rib-type buildings is now designated by UL as Class A, and thus meets the requirements of DOD 4270.1-M.

5. Overspray. Foam should not be applied when wind speeds are above 12 mph (19.2 km/hr) unless wind screens are used. All spray operations should be suspended when wind speeds exceed 20 to 25 mph (32 to 40 km/hr). The influence of excessive wind during spraying can: (1) make it difficult to control foam surface texture and, to a lesser extent, foam thickness, and (2) cause an overspray which can damage adjacent vehicles or buildings. However, foam overspray is no more a problem than overspray from a paint spray operation.

6. Irregular surfaces. Foaming systems do not generally provide an even roof surface. The result is a surface which can contain small depressions (bird baths) and other irregularities where water tends to pond after rain storms. To minimize this effect and other difficulties, such as overspray, skilled foaming system operators are required.

Proper Application Procedures

Questions related to foam quality, surface texture, equipment and materials, application, exposure to sunlight, and thickness measurement have been discussed by Coultrap in a recent report.[11] The remainder of this chapter consists of material from his report.

Foam Quality

Once the substrate or surface has been correctly prepared, proper inspection will frequently be a determining factor in the success or failure of a urethane foam roof application. Many factors must be considered and observed to assure application of high quality foam. It is also important to recognize that the foam insulation applied is the base for the ultimate application of a protective coating system. Thus, the quality of the finished system depends primarily on the proper application and properties of the in-place foam.

Proper application of sprayed foam requires a highly skilled and trained operator. Of course, equipment and materials available with modern technology can provide satisfactory results. But the contractor's ability and willingness to exercise proper controls over various factors at the job site frequently are the difference between success and failure. Therefore, from the outset the contractor must have the proper equipment and materials at the job site, and must understand conditions necessary for good foam application. The minimum acceptable levels of quality should be established with the contractor before the foam application is started.

Surface Texture and Quality

One of the best visual indicators of a good foam application is the appearance of the surface profile or texture. Surface texture of sprayed foam is a function of many variables, but there are three principal con-

*Hypalon is a registered trademark of E. I. DuPont de Nemours & Co.

[11]Keith H. Coultrap, *Principles of Urethane Foam Roof Application*, PO No. 79-MR-461 (Civil Engineering Laboratory, Naval Construction Battalion Center, June 1980).

tributing factors: (1) equipment adjustments, (2) environmental effects, and (3) applicator skills.

Terms used to describe foam surface texture and quality are listed below:

Smooth – see Figure 2
Orange peel – see Figure 3
Coarse orange peel – see Figure 4
Verge of popcorn – see Figure 5
Popcorn – see Figure 6
Treebark – see Figure 7
Pinholes or blowholes – see Figure 8
Rippling – see Figure 9

In this discussion, it is assumed that all equipment is operating properly and that material ratios are correct. It is also assumed that the equipment has variable controls for adjusting material pressures and temperatures.

Equipment Adjustments. Given the above assumptions, the correct temperature and pressure of the materials contribute most significantly to proper spray pattern. A full and proper spray pattern allows the spray applicator to make uniform passes of mixed material that rises steadily as it is applied to the advancing foam front. For a given pressure, materials that are too cold will cause a rather narrow spray pattern which drives into the rising deposited foam and causes dimples, holes, roughness, or ridges. The overall effect is a popcorn or, in an extreme case, a treebark foam surface. If the temperature is only slightly low, adjustments of the material pressure or the spray gun valving rod can correct the pattern.

If the materials are too hot, the foam deposited will react too fast to permit levelling, and a "verge of popcorn" surface will tend to develop, even though the spray pattern is full.

Part of the training of a skilled foam applicator is to recognize spray pattern problems and to adjust for them. The symptoms listed above should help one recognize the causes of foam with improper texture.

Environmental Factors. Modern spray foam material systems have been formulated to provide different speeds of reaction at some given or expected temperature of the surface upon which the foam will be applied. This factor is called the "cream time," measured in seconds of time at a given temperature of application that the "A" and "B" components will begin to react or foam after being mixed through the spray gun. For example, contractors frequently refer to a 4-second, 6-second, or 8-second foam. These rates of reaction (cream times) can be changed to some degree by material temperatures, but it is the responsibility of the contractor to select a system with an appropriate "cream time" for the environment where the foam is to be applied. Selection of an improper cream time can usually be judged by certain surface texture factors. If the cream time is too short and the environmental conditions are too warm, the applicator will have difficulty obtaining a smooth or orange peel surface. Typically, the texture will be coarse orange peel and beyond, depending on the conditions. A foam with a faster or shorter cream time will not be quite as sensitive to winds during application; however, the benefit is marginal. It is better to use a foam system that is proper for the temperature, and to limit the application to acceptable wind conditions.

When the cream time is too long, the surface texture of the foam may be very smooth, but the surface skin may be quite dense, and the density of the foam may be affected. Consequently, more spray passes will be required to obtain the desired foam thickness. A long cream time will also present problems when the foam is sprayed on vertical surfaces, such as parapet walls, flashings, and cants. The material will run or sag before proper foaming begins, which tends to lead to treebark in extreme cases. When foam is applied to vertical surfaces, it should foam straight out with no visible slump or sag. Foam with a long cream time is more susceptible to wind effects on the surface, and in extreme cases, a ridging or rippling effect will occur, much the same as that from wind on water.

Aside from temperature, winds often create a most difficult situation. As indicated above, wind not only affects the surface texture of applied foam but also causes overspray, which is a serious problem. Overspray can damage surfaces not intended to be sprayed, such as other buildings, vehicles, and equipment, and excessive overspray deposited on foam already in place causes an irregular surface which interferes with subsequent foam or coating application. Practical experience has shown that foam should not be sprayed when wind speeds are over 12 mph (19 km/hr) without some form of windshield, and should not be sprayed at all when wind speed is over 25 mph (40 km/hr). It is important to evaluate damage that might be caused by overspray combined with the surface texture quality of the foam being applied. Some relief can be obtained from overspray problems by proper masking protection, but it is essential that the quality of the foam applied under windy conditions be carefully controlled. Rippling

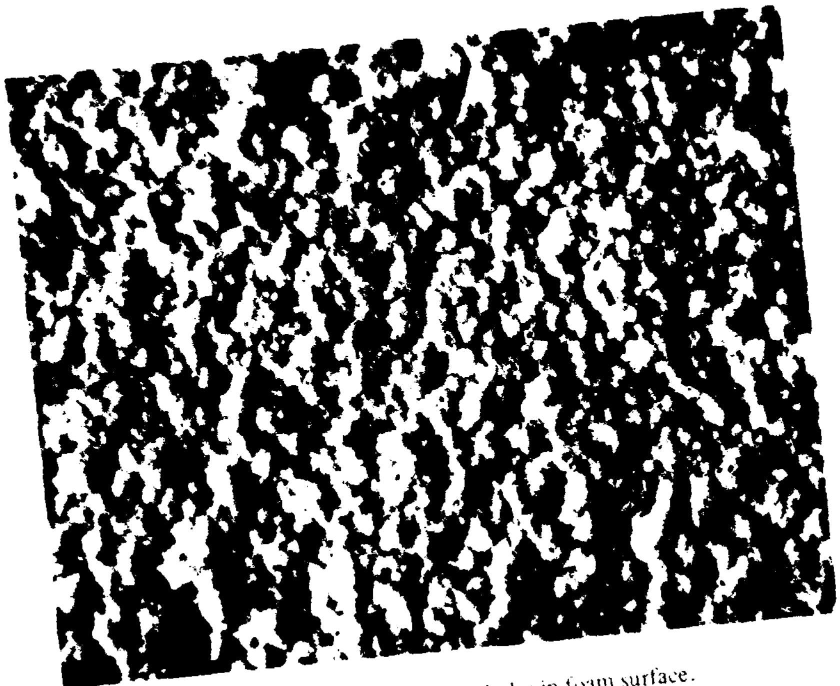

Figure 8. Pinholes or blowholes in foam surface.

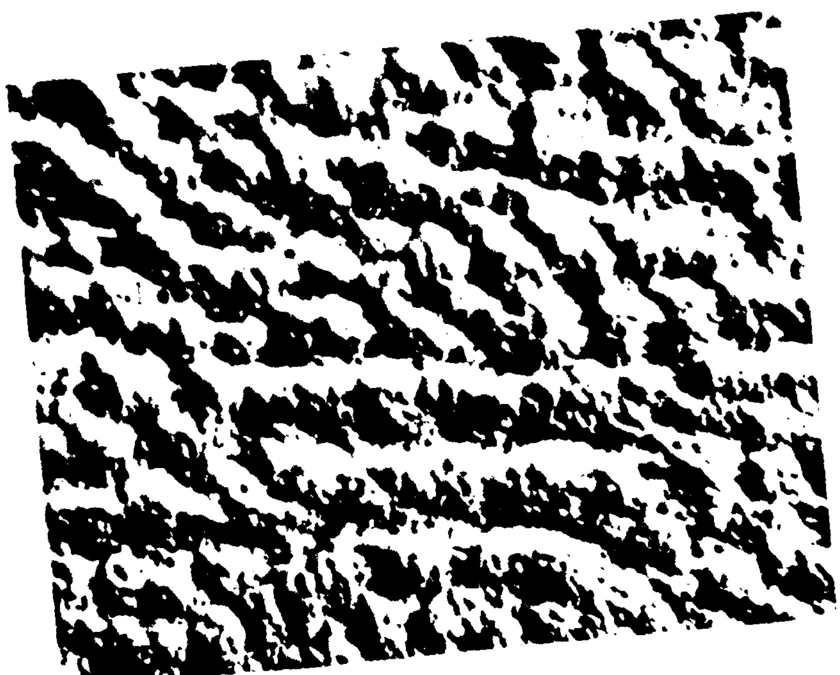

Figure 9. Rippling in foam surface.

(Figure 9) can result from spraying at excessive wind speeds.

Applicator Skills. Given proper materials, equipment, and conditions of application, the skill of the applicator of the foam is one of the most important factors in determining the surface texture and uniformity of foam thickness. It is important to determine as soon as possible after foam application begins that the applicator possesses the skills and experience to make a proper application. These skills must include the knowledge of proper adjustments to the equipment, the foam material being used, and the limits that environmental factors may impose. The applicator must also be willing to follow proper procedures.

It cannot be emphasized too strongly that foam application should be stopped immediately if the results indicate that the applicator is not skilled. *It is far better to prevent bad application than to correct such conditions after the foam is in place.* One can soon tell how competent the applicator is by observing whether the foam passes are applied to a uniform thickness of 1/2 in. to 3/4 in. (13 to 19 mm) per pass, and whether the surface texture of the foam exhibits an acceptable "smooth" or "orange peel" finish. Application should also be judged by the uniformity of foam applied to transition points of flashings, cants, roof edges, equipment mountings, etc. A good applicator will properly overlap the spray pattern, which results in a uniform planar level of the foam, free of "ridging" or "rippling" (sometimes referred to as a "wash board" effect).

It is vital that the acceptable level of foam quality be established with the applicator(s) during the early stages of work.

Spray Foam Equipment and Material Problems

This discussion focuses on problems caused by materials which are off-ratio, too old, out of shelf life, or which react improperly. These problems usually cause improper foam surface texture or color, or make foam soft and spongy or hard and brittle. In certain situations, the surface of the foam may also exhibit blow holes or pinholes.

With modern spray foam equipment, the applicator will not be able to develop a consistently proper spray pattern through the spray gun if the metering or proportioning pumps seriously malfunction, or if materials are not supplied to the proportioning pumps constantly. In addition, the applicator may not notice short-term blockage of materials in the spray gun or momentary metering pump cavitation problems; thus, poor quality foam will be deposited in relatively small areas. At times, an operator will see a short break in the spray pattern, decide that nothing is wrong, and proceed with the work. However, if constant fluctuations are observed in the spray pattern, or if the appearance of the foam being applied is abnormal, the work should be stopped until the cause is determined.

Early detection of poor foam quality can provide an indication that the materials being sprayed are too old or have deteriorated because their chemical shelf life has expired. These materials usually should be replaced. Obviously, the problem can be avoided if it is determined, before application, that the materials are within the shelf life recommendations of the supplier, and have been stored properly on the job site.

Excess Isocyanate or "A" Component. The effects of foam applied which is off-ratio or misproportioned with respect to the isocyanate component are more difficult to discover unless the condition is extreme. In fact, foam applied with slight excess of isocyanate is not as seriously affected as when there is excess polyol, because in the former case, the polyol is totally reacted. The more extreme condition of excess isocyanate (Figure 10) will produce one or more of the following effects:

– Dark color
– Smooth hard surface
– Irregular glassy cell structure
– Friable and/or brittle foam
– Improper density
– Improper rise.

Such foam should be removed and replaced because normal physical properties will not be obtained. No coating over this type of foam should be permitted.

Excess Polyol or "B" Component. Foam which is off-ratio or misproportioned with respect to the polyol component will have one or more of the following characteristics:

– Light color
– Slow or insufficient rise
– Softness and sponginess
– Improper cell structure
– Highly mottled or coarse orange peel surface texture
– Blow holes or pinholes.

Such foam will not have normal properties of strength,

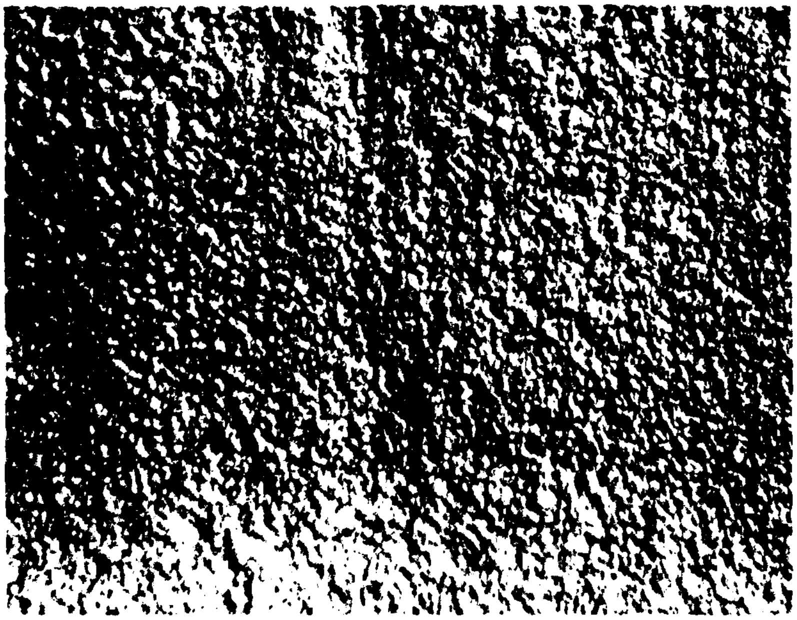

Figure 10. Isocyanate-rich surface

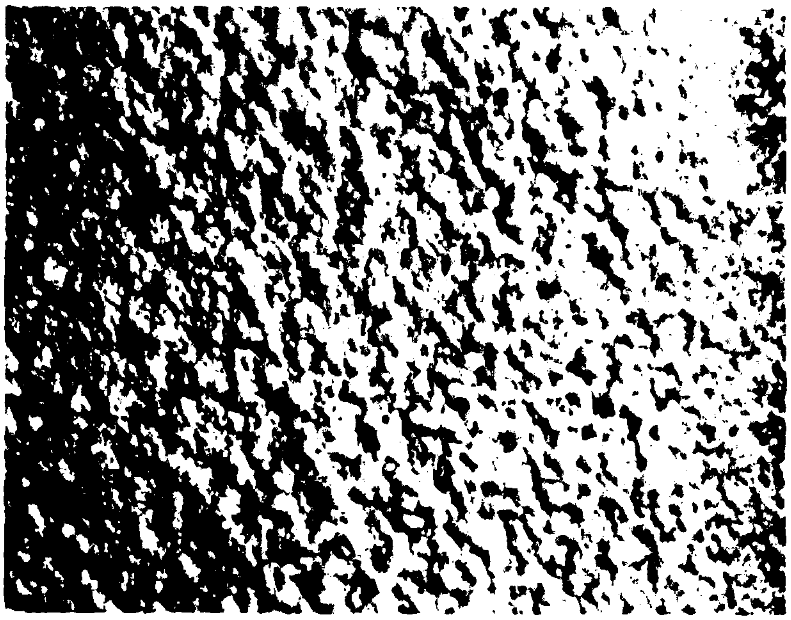

Figure 11. Resin-rich surface

density, or insulation value. It should be removed and replaced; coating over this foam should not be permitted. Figure 11 shows a typical resin-rich surface (excess polyol).

Aged or Improper Materials. Fortunately, problems with aged or improper materials are infrequent, and when they do occur there is no mistaking their effects. It is highly unlikely that any good foam will be obtained; moreover, the applicator cannot make adjustments to improve the quality. The effects of using foam materials which are aged (beyond shelf life), have been stored improperly, have been improperly formulated, have lost blowing agent, or have moisture contamination are one or more of the following:

- Slow rise or reaction
- Poor cell structure
- Improper color
- Blow holes or pinholes
- Improper density
- Frequent clogging of spray foam equipment
- Poor spray pattern
- Friable foam
- Foam which is slow to cure
- Poor physical properties.

No coating application should be permitted on such poor quality foam. It is essential that all such materials applied be removed and the area refoamed.

Application of Foam Over Improper Surfaces

Various surface conditions, primarily caused by the weather, can lead to problems with foam. It is important to recognize that the surfaces involved include foam previously applied which is to receive additional foam, as well as the originally prepared roof deck or substrate. It is assumed in this discussion that the roof deck or substrate is secure and clean.

Damp or Wet Surfaces. For successful application, urethane foam must be sprayed on a dry surface; this point should never be compromised. Moisture will react with the isocyanate component of the foam formulation. Any moisture that reacts with the isocyanate component steals isocyanate from the formulation intended to create the urethane polymer and therefore, in extreme cases, can cause an off-ratio foam in favor of excess polyol. Such a foam will have improper physical properties, especially at the foam surface interface where the reaction occurs, and will affect the adhesive and/or cohesive strength of the foam. This usually leads to blister formation at some later time.

When water or moisture reacts with the isocyanate component, a by-product of the reaction is the formation of CO_2 (carbon dioxide) gas. This gassing causes the foam surface to exhibit high porosity where the reaction occurs. The severity of the condition described varies with the amount of moisture, but porosity does provide a way to visually check whether moisture was present when the foam was sprayed. Surface effects of foaming on a wet surface are shown in Figure 12.

The following rules should be applied to prevent problems with moisture:

1. No foam application should be permitted in the presence of rainfall, mist, fog, snow, or visible moisture.

2. Moisture conditions of surfaces suspected to be improper should be checked with a moisture meter, such as that in Figure 13. No foam application should be permitted where moisture meter readings are more than a predetermined amount, such as 10 percent.

3. No foam application should be permitted if the dew point is less than 5°F (3°C) above the surface temperature of application, as measured by a surface pyrometer such as that in Figure 14.

One practice that usually results in good foam application is applying all foam, in a given area, to the desired thickness on the same day. On large jobs, of course, it is impossible to apply all of the foam to the desired thickness in one day. Rather than trying to apply some foam over a large area, it is better to complete one section of the roof. Thus, the lead edges of the foam must be tied in later. When this has to be done, it is very important to take moisture meter readings at the existing foam surface lead edge to be sure that conditions are proper.

Urethane foam has a low heat capacity; therefore, foam surfaces that become wet or damp will usually be slower to dry than the adjacent unfoamed roof deck. Often the deck surface will be dry enough for application of foam before existing applied foam reaches the same dry condition. Usually, the contractor will leave such an area open during the course of a day's work to permit drying and tie in the existing lead edge at the end of the day. Experience has shown that blistering in urethane foam roof systems is often caused by moisture on surfaces at the time of foam application.

Surfaces That Are Too Cold. Surfaces that are colder

Figure 12. [illegible]

Figure 13. [illegible]

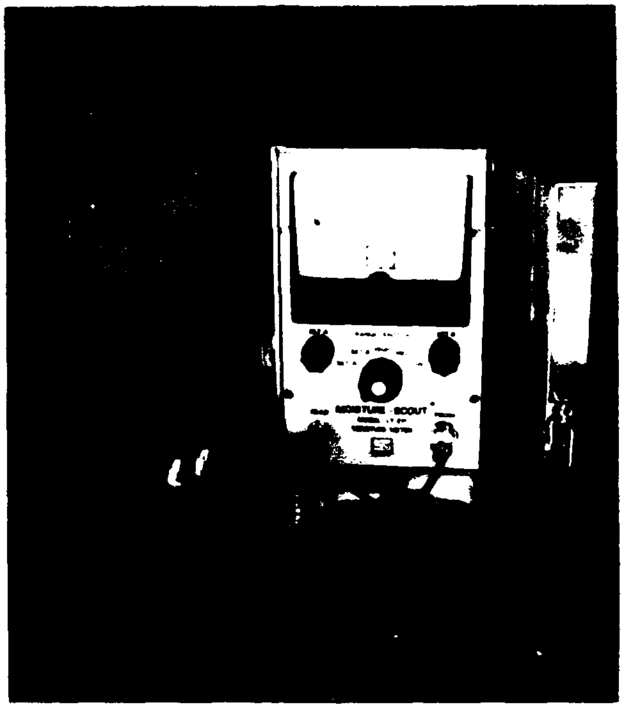

Figure 14. Pyrometer.

than the temperature recommended by the foam supplier usually constitute a heat sink, which causes a problem with spray foam systems that rely totally on R-11 blowing agent for cellulation. The difficulty is that the exothermic heat generated in the formation of the urethane polymer is required to vaporize the R-11, which has a boiling point of approximately 75°F (24°C). A heat sink can steal or drain off this heat so that there is no foaming initially, and the mixed and sprayed chemicals, reacting very slowly, form a thin film on the surface.

Eventually, a smooth thick skin or rind can form between the surface of application and the foam above it. This layer of material exhibits little or no cellulation and is friable, hard, and brittle. Usually, the condition described affects adhesion and can cause foam blistering later. This condition may develop when the roof deck temperature drops to about 60°F (16°C), and foam application may have to stop.

It is important to note that this effect usually occurs when foam is sprayed on the original roof deck surface rather than on previously applied foam, which is an insulator and creates no heat sink. Subsequent passes of sprayed foam are trouble free if the foam surface is properly dry.

The key to watch for is less than normal foam rise on first pass application, or evidence of a wet-looking liquid film at the surface. The effect of this very slow reaction is illustrated in Figure 15.

Unfortunately, cold conditions for application of foam are often accompanied by moisture problems. However, there are some situations in which cold conditions prevail alone at temperatures of approximately 35°F (2°C) or higher. Material, equipment, and procedures are available to allow foam application at temperatures above 35°C (2°C), but the only practical way to apply foam at lower temperatures is to use heated space enclosures.

Although conventional foam systems have a nominal lower limit of 60°F (16°C) for surface temperature, some manufacturers provide specially catalyzed foam systems having a short cream time and producing enough chemical heat or exotherm to permit application down to about 50°F (10°C). However, at surface temperatures between 35°F (2°C) and 50°F (10°C), a different technique must be used to avoid the problem.

The usual approach is to employ a "froth" spray foam. This requires a special adaptation of the spray foam equipment which permits controlled injection of

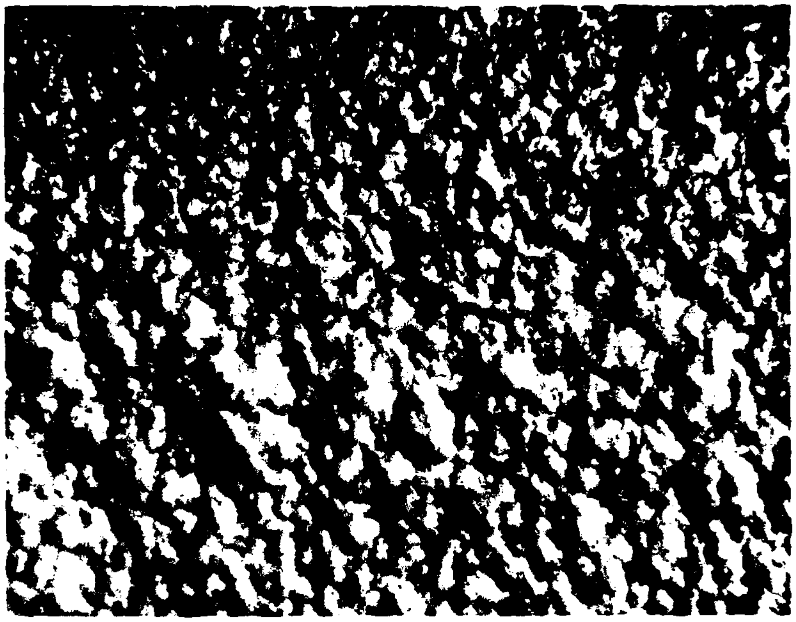

Figure 15. Foam application over cold surface.

small amounts of fluorocarbon blowing agent R-12, which has a boiling point of about −20°F (−29°C), and a special foam system that will react properly with the R-12 material. The mixed foam composition pre-expands, or froths, as it leaves the spray gun and is applied to the cold surface. The froth composition blocks or insulates the cold surface (heat sink) long enough to permit the chemical heat or exotherm generated to vaporize the R-11 blowing agent contained in the system, thereby providing a proper foam rise.

Another technique can be used successfully when it is sunny but moderately cold: a black or dark primer can be applied to the roof deck. This can increase the roof deck temperature by as much as 20°F (11°C) above the temperature that would exist otherwise, given surrounding environmental conditions. The higher deck temperature also helps provide a dry surface.

Other methods of raising roof deck temperatures are used occasionally, such as under-deck heating with space heaters and top heating with electric insulating blankets. However, these methods are of limited and questionable practical value.

Surfaces That Are Too Hot. In some geographical areas, roof deck surface temperatures may be so hot that a special foam formulation is required. The two effects visually observed are: (1) an increase in foam density caused by loss of R-11 blowing agent, and (2) blow holes or pinholes in the foam. Effects of applying foam to surfaces which are too hot are shown in Figure 16.

Strange as it may seem, the foam surface texture can vary from smooth to verge of popcorn, depending on the temperature level at the surface to be foamed. Because of formulation variables, it is difficult to be specific about hot surfaces. Except when the contractor uses a foam with a totally improper cream time, the problem is not normally severe at roof deck temperatures up to 120°F (49°C). In climates where surface condensation is not a problem, a solution is to limit spray foam application to early morning, late afternoon, or late evening. The principal adjustment is to select a foam system with a longer cream time in combination with some reduction of material temperature in the spray equipment.

Foam Skin Sunlight Degradation

UV light from the sun degrades urethane foam which has not been protected with coating. The longer the exposure, the more severe the degradation (Figure 17). Specifications tend to vary in describing periods of time that are permitted for exposure before coating. However, it is important to understand the conditions that create a basis for accepting or rejecting foam with UV degradation.

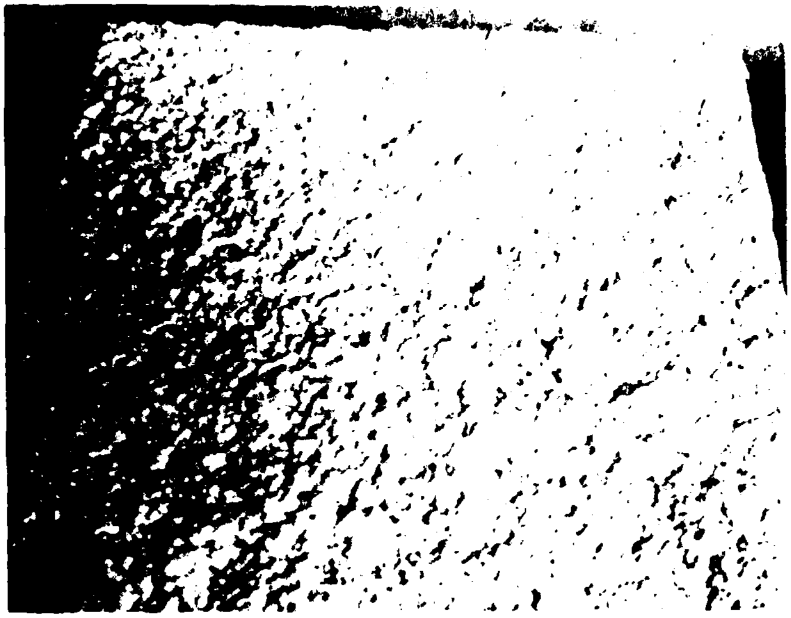

Figure 16. Foam application over hot surface.

Figure 17. UV degradation of foam

Generally, lower density foams undergo more rapid surface deterioration than higher density foams. In addition, the extent of UV exposure with respect to time should be considered. Obviously, the condition is more likely to be a problem in geographical areas of high solar exposure than in areas with more cloud cover and fewer days of sunshine. The primary concern is that the degraded foam surface does not adversely affect the adhesion of subsequently applied foam or coating.

Effects of UV degradation are easy to observe. First, the surface will darken. As the condition progresses, the surface will show evidence of dusting or friability, and will eventually become burnt orange and show evidence of erosion. Normally, there will be no harmful effects of UV degradation within a period of 3 days (72 hours). However, once this time has passed, foam surfaces should be examined for the effects described.

The best way to prevent degradation of foam is to make "same day" application of full foam thickness where multiple passes of foam are required, and to apply the first coat of protective coating that same day. As stated above, *the foam must be coated within 72 hours.* If the foam remains uncoated for even one day, the surface should be examined to be certain that objectionable degradation has not occurred and that the surface is dry before spray application is resumed. The degradation rate will be reduced when work is interrupted by rain or cloudiness, but special attention must be given to assure surface dryness before work is resumed.

If there is enough surface UV degradation that dusting or friability is observed, the foam surface should be thoroughly brushed with a stiff bristle broom, mechanically scarfed or sanded, and cleaned of loose material before further application of foam or coating is permitted. If the foam is ready for coating, a light pass of foam should be applied to the prepared surface to reseal it and provide a proper coating base.

Foam Thickness Measurement

As application proceeds, foam thickness should be continually monitored to assure that the specified foam thickness is achieved to meet insulation requirements, to create proper slope, or to eliminate low areas. The most satisfactory and easiest method is to use a thin or small diameter probe, such as a needle, thin wire, or small knife blade. Either the probe can be premarked for thickness or a separate rule can be used to indicate thickness. Since the foam will be sealed with a coating, use of a thin probe will cause no problems. Welding rods, nails, or large diameter objects should not be used as probes because the larger holes, not likely to be sealed by the coating, may allow water to penetrate.

A very accurate but tedious method of measuring foam thickness involves use of a "transit level." The instrument can be placed at any convenient location on the roof structure and, by using a surveyor's rod, foam thickness can be determined on slope lines and low areas relative to points of reference such as drain receivers, roof edges, and equipment mountings. In certain cases, preliminary reference points may be marked, before foam application begins, to help overcome special problems. In some situations, a combination of the transit level method and a probe is desirable. Readings with a transit level can be made from distances of 200 ft (61 m) or more, depending on the quality of the instrument.

Screed blocks made from foam or string lines should not be allowed to monitor foam thickness because they are not very accurate and usually interfere with foam application. They may also give a false indication because of accumulation of foam overspray.

3 COATINGS USED ON SPRAYED FOAM

Criteria for Coatings

Cullen and Rossiter have summarized the prime functions of coatings applied to sprayed PUF roofing: to shield the foam from ultraviolet radiation, to keep the foam dry, and to protect the foam from abrasion and impact.[12] UV radiation causes the foam to photo-oxidize rapidly, developing a characteristic yellowish or brownish color; this may take a few hours to several days. The rate of deterioration varies considerably with different foams. Further exposure causes the foam surface to degrade, become friable, and turn to powder. As the degraded foam is physically removed, more foam degrades. The effect is progressive, and given enough time, the foam will deteriorate completely.

Although the foam is resistant to penetration by water, the surface can absorb some moisture and may retain for a long time much of what it absorbs, even

[12] W. C. Cullen and W. J. Rossiter, *Guidelines for Selection of and Use of Foam Polyurethane Roofing Systems*, NBS Technical Note 778 (National Bureau of Standards, May 1973).

though the surface appears dry. The importance of this characteristic is discussed by Jones.[13] Such absorbed moisture from rain or dew can be an unsuspected course of problems in applying subsequent layers of foam or in applying coatings that are adversely affected by moisture. Absorbed moisture may also contribute to blistering when a vapor barrier coating is used. Crushed foam (e.g., from heavy foot traffic) becomes sponge-like and can absorb large amounts of water very easily.

To fulfill its intended function, a protective system must first be compatible with the foam urethane. Upon exposure, the system also must possess and retain certain characteristics for some time:

1. Adhesiveness to urethane in order to remain in place under conditions of exposure, e.g., wind, temperature, humidity.

2. Impact resistance from hail, falling objects, and the like.

3. Adequate resistance to temperature change, e.g., good flexibility at low temperature, no flow at high temperature.

4. Abrasion resistance to foot traffic, water and sand erosion, and the like.

5. Resistance to deterioration from water in liquid and vapor states.

6. Weather resistance, e.g., sun, rain, dew, wind.

7. Maintainability, i.e., ease of repair if damaged, and capability of weathered surface to accept and retain additional coating when recoating becomes necessary.

8. Durability, i.e., the capability of the coating or system to remain within acceptable performance levels over some time.

9. Strength and elasticity, i.e., strong enough and elastic enough to accommodate normal movements in the substrate without rupture.

In addition to the above, fire safety is very important. The same fire safety criterion as for the foam application applies to the coating; foam and coating must always be considered as one system.

The coating can also be selected to provide a breathable membrane or a moisture vapor retarder, depending on the construction or use of the particular building to which the system is applied. For example, a cold storage or freezer storage area would require that the top coating on the foam be a vapor retarder, to prevent moisture from penetrating the foam and condensing or freezing on the cold surface. Conversely, a kitchen, laundry, indoor swimming pool, shower room, etc., would require a vapor retarder between the roof deck and the foam, and a breathable membrane as a top coating.

Coatings may be protected by broadcasting ceramic granules into the top coat while still wet. These are usually applied at the rate of 50 lbs/100 sq ft (2.5 kg/m^2). In some cases, granules are required for Class A, B, or C fire ratings, as listed in the UL *Building Materials Directory*.[14] Applying granules to vapor-retardant coatings such as butyl or Hypalon may not be advisable; this may increase the permeability of the membrane where the thickness is reduced because of penetration by the granule particles.

Available Coatings

Coatings for sprayed PUF roofing may be classified in various ways. For the purposes of this report, two basic classifications will be considered: permeable and impermeable, as applied to water vapor transmission properties.

Impermeable coatings may be described as having a permeance of 1.0 perms or less. All coatings having a permeance of more than 1.0 perms may be described as permeable. Coatings within these classifications are listed below.

Impermeable:
- Some acrylics
- Butyl
- Chlorosulfonated polyethylene (Hypalon)
- Certain proprietary synthetic rubbers
- Some urethanes
- Vinyl

Permeable:
- Some acrylics
- Silicone
- Some urethanes.

[13] B. V. Jones, *Laboratory and Field Investigations of New Materials for Roof Construction*, REC-ERC-76-4 (U.S. Department of the Interior, Bureau of Reclamation, April 1976).

[14] *Building Materials Directory* (UL, January 1980).

Some system manufacturers provide a combination coating such as butyl/Hypalon or urethane/Hypalon. The latter may be classified either way, depending on the perm rating of the applied system. The classification given is based on a film thickness of 20 mil (0.51 mm) unless otherwise noted in Tables 1 and 2.

Coatings investigated are listed in Tables 1 and 2 based on water vapor transmission properties. The tables are limited to coatings listed in the January 1980 edition of the UL *Building Materials Directory*. This information was not actually used in the evaluation but is provided for technical reference.

A simple calculation is used to determine the rate of application of the coating that will yield the film thickness recommended by the manufacturer. One gal (3.8 L) of 100 percent solids material applied to 100 sq ft (9.29 m^2) of roof surface will result in a membrane 16-mil (0.41-mm) thick. Multiplying by the percent solids by volume (as provided by the manufacturer) gives the final dry film thickness. To determine the application rate needed, divide the desired dry film thickness by the theoretical thickness for 1 gal (3.8 L) of the material being used, and the rate in gallons per 100 sq ft (9.29 m^2) will result. Expressed mathematically:

$$\frac{\text{desired dry film thickness in mils} \times 100}{16 \times \text{percent solids by volume}}$$

$$= \text{application rate gal/100 sq ft}$$

Advantages and Disadvantages

CERL Interim Report M-263 discusses the advantages and disadvantages of liquid-applied membranes for foamed-in-place systems.[15] A summary is provided below.

Advantages

1. Easy to apply. The coating is applied as a liquid with either a spray gun, roller, or squeegee. Since the liquid flows somewhat, it can fill crevices and cover small irregularities in the foam surface.

2. Self-flashing. The homogeneous membrane is self-flashing and can be applied continuously from horizontal to vertical surfaces.

3. Extensible. The elastomeric materials used can elongate, then return to their original shape. This quality accommodates limited structural movement, though not as much as allowed by sheet-applied systems. Most elastomerics also offer low-temperature flexibility and maintain their integrity at lower temperatures than bitumen-based materials.

4. Easy to repair and maintain. Fluid-applied coatings are generally repaired by reapplying the coating with a spray gun, roller, or squeegee.

5. Compound variety. Various compounds and materials can be selected to meet special requirements such as compatibility with an underlying material or use in a chemically hostile atmosphere.

6. Color variety. Liquid-applied coatings are easily colored with pigments. In addition, color keying each layer of a multilayered coating system can aid inspection and quality assurance.

Disadvantages

1. Workmanship dependent. Measurement of the wet thickness is difficult, and in the case of multicoat applications it can be difficult to assure complete coverage. However, this problem can be minimized by using different colored layers.

2. Limited elongation. While liquid coatings exhibit some elastic properties, they generally cannot accommodate larger cracks in the substrate to which they are applied. Neither can they tolerate irreversible compression of the foam (such as that caused by heavy foot or equipment traffic or severe hail), unless they are specifically engineered for severe conditions.

3. Highly flammable solvent-based systems. Some liquid-applied coatings present a substantial fire risk during installation; therefore, adequate safety and ventilation measures must be observed. There is also a risk of toxicity with some systems if installing crews are not protected from fumes and from contact with the components during application.

4. Lack of exposure performance data and design criteria older than 10 years.

Proper Application Procedures

Questions related to coating coverage, coating defects, granule application, and application in severe environments have been discussed by Coultrap in a

[15] E. Marvin, et al., *Evaluation of Alternative Reroofing Systems*, Interim Report M-263/ADA071578 (U.S. Army Construction Engineering Research Laboratory, June 1979).

Table 1
Impermeable Coatings

Type	Manufacturer	Trade Name	Solvent	Cure	Percent Solids by *Volume*	Film Thickness, *mils*	Primer Required	Tensile Strength, psi	Elong., Percent	Impact Resist., lb-in.	Weather meter, Hours
Acrylic	Deer-0	Foam Cap W248	Water	Evap	40	20	No	320	350	NA†	3500
Acrylic	Deer-0	Foam Cap W282	Water	Evap	51	20	No	320	350	NA	3500
Butyl	Matcote	Poly-R	Flammable	Catalyst	46	20	No	NA	NA	NA	NA
Butyl	Plas-Chem	Chem-Elast 5501	Flammable	Catalyst	46	15	Optional	600	250	NA	NA
Butyl	United Coatings	Elastron 858	Flammable	Catalyst	46	30	No	NA	NA	NA	NA
Hypalon	Childers	Encacel V	Flammable	Evap	33	30	Optional	128	900	98	10,000
Hypalon	Foam Systems	Lo Perm 2	Flammable	Evap	30	30	No	850	200	NA	NA
Hypalon	Futura	Elastobond 850	Flammable	Evap	30	24-30	No	800	250	NA	NA
Hypalon	H.B. Fuller	Monolar	Flammable	Evap	30	30	No	340	560	98	1000
Hypalon	Neogard	Hypalon "M"	Flammable	Evap	33	30	No	500	250	NA	350
Hypalon	Neogard	Hypalon 7300	Flammable	Evap	33	6	No	450	300	NA	2000
Hypalon	Plas-Chem	Chem-Elast 5011	Flammable	Evap	25	20-30	No	900	150	NA	NA
Hypalon	Plas-Chem	Chem-Elast 5011				4-12	No				
Hypalon	United Coatings	Elasto-Mir Hypalon 35	Flammable	Evap	26	6	No	1100	450	NA	NA
Urethane	Futura	Futura Flex 500	Flammable	Catalyst	72	28-40	No	1600	300	NA	2000
Urethane	Futura	Futura Flex 550	Flammable	Catalyst	65	8-10		200	200	NA	3000
Urethane	United Coatings	Elastall FR Fast Cure Aluminum	Flammable	Catalyst	90	30	No	350	500	70	3000
Urethane	United Coatings	Elastall FR Fast Cure Tan	Flammable	Catalyst	90	30	No	290	500	70	5000
Vinyl	Plas-Chem	Chem-Elast 1522	Flammable	Evap	25	20	Yes	1200	150	216	NA
Proprietary Rubber	Foam Systems	Lo Perm 1	Flammable	Evap	42	20-40	No	400	250	NA	NA
Proprietary Rubber	Futura	Elastobond 875	Flammable	Evap	36	25-30	No	800	375	NA	3000

*Test specimen thickness, 35 mil.
**Granule requirement is for UL Class A listing.
†NA = Information not available from manufacturer.

Table I
Impermeable Coatings

Percent Solids by Volume	Film Thickness, mils	Primer Required	*Tensile Strength, psi*	*Elong., Percent*	*Impact Resist., lb-in.*	*Weatherometer, Hours*	Permeance, Perms	Positive Drainage Required	Foam Exposure Limit, Hrs.	Total Cure Time, Days	Remarks
40	20	No	320	350	NA†	3500	0.50*	Yes	8	7	Granules Required**
51	20	No	320	350	NA	3500	0.50*	Yes	8	7	Granules Optional
46	20	No	NA	NA	NA	NA	NA	Yes	8	several weeks	
46	15	Optional	600	250	NA	NA	0.02	No	NA	NA	Requires 5011 Top Coat
46	30	No	NA	NA	NA	NA	0.02	NA	72	21	Requires Elastomit 35 Top Coat
33	30	Optional	128	900	98	10,000	0.02	Yes	24	1	
30	30	No	850	200	NA	NA	0.35	Yes	72	NA	
30	24-30	No	800	250	NA	NA	0.15	Yes	72	2	
30	30	No	340	560	98	1000	0.06	Yes	72	2	
33	30	No	500	250	NA	350	0.1*	No	72	3	
33	6	No	450	300	NA	2000	0.1*	No		3	Top Coat for Permalon
25	20-30	No	900	150	NA	NA	0.4	NA	NA	NA	When Used Alone
	4-12	No									Top Coat for 5501
26	6	No	1100	450	NA	NA	<1	NA		NA	Top Coat for *Elastron 858*
72	28-40	No	1600	300	NA	2000	0.65	Yes	72	1.5	Requires Flex 550 Top Coat
65	8-10		200	200	NA	3000	0.48	Yes		1.5	Top Coat for Flex 500
90	30	No	350	500	70	3000	0.36	No	72	2	
90	30	No	290	500	70	5000	0.44	No	72	2	
25	20	Yes	1200	150	216	NA	0.8	NA	NA	NA	
42	20-40	No	400	250	NA	NA	0.14	Yes	72	NA	
36	25-30	No	800	375	NA	3000	0.11	Yes	72	2	

Table 2
Permeable Coatings

Type	Manufacturer	Trade Name	Solvent	Cure	Percent Solids by Volume	Film Thickness, mils	Primer Required	Tensile Strength, psi	Elong., Percent	Impact Resist., lb-in.	Weatherometer, Hours
Acrylic	Anchor	Sun Shield 790A	Water	Evap	60	30	No	330	172	160	500
Acrylic	Conklin	Rapid Roof	Water	Evap	55	20	Optional	88	300	160	2000
Acrylic	Foam Systems	Acryflex	Water	Evap	67	32	No	300	250	NA†	NA
Acrylic	H.B. Fuller	Duralar	Water	Evap	53	25	No	250	190	98	1000
Acrylic	Futura	Acro Bond 440/442	Water	Evap	60	30	No	300	150	NA	3000
Acrylic	Gaco Western	Gacoflex A54	Water	Evap	56	28	**	250	300	NA	NA
Acrylic	Plas-Chem	Chem-Elast 5226	Water	Evap	50	20	No	200	300	NA	NA
Acrylic	United Coatings	Diathon	Water	Evap	60	20	No	250	280	70	8000
Acrylic	VIP	VIP-4000	Water	Evap	53	25	No	NA	150	98	2000
Silicone	Dow-Corning	3-5000	None	Moisture	58	15	No	360	200	98	4000
Silicone	General Electric	SCM 3300	Flammable	Catalyst	66	20	No	500	100	24	4000
Urethane	E.R.A.	H.E.R. 202	Flammable	Evap	80	36	No	250	800	NA	1500
Urethane	Foam Systems	Ureflex 100	Flammable	Catalyst	73	24	No	3000	450	NA	NA
Urethane	Foam Systems	Ureflex 200	Flammable	Catalyst	62	30	No	2800	200	NA	NA
Urethane	Neogard	Permalon FR	None	Moisture	100	30	No	300	500	NA	2000
Urethane/Hypalon	Irathane	Weatherflex	Flammable	Catalyst	50	20	No	1600	400	NA	6500
Urethane	3M	Scotch Clad 5762/5796	Flammable	Moisture	70	25	No	400	180	NA	350

*Granule requirement is for UL Class A listing.
**Primer required if water will pond.
†NA = Information not available from manufacturer.

Table 2
Permeable Coatings

Percent Solids by Volume	Film Thickness, mils	Primer Required	Tensile Strength, psi	Elong., Percent	Impact Resist., lb-in.	Weathero-meter, Hours	Permeance, Perms	Positive Drainage Required	Foam Exposure Limit, Hrs.	Total Cure Time, Days	Remarks
60	30	No	330	172	160	500	1.35	Yes	48	30	
55	20	Optional	88	300	160	2000	4.9	Yes	24	1	Granules Required*
67	32	No	300	250	NA†	NA	3.0	Yes	48	2	
53	25	No	250	190	98	1000	1.8	Yes	72		Granules Optional
60	30	No	300	150	NA	3000	2.8	Yes	72	2	
56	28	**	250	300	NA	NA	2.73	Yes	72	3	Granules Optional
50	20	No	200	300	NA	NA	2.8	Yes	NA	2 hrs	
60	20	No	250	280	70	8000	3.0	No	72	10 hrs	Granules Optional
53	25	No	NA	150	98	2000	NA	No	48	NA	
58	15	No	360	200	98	4000	2.9	Yes	72	6 hrs	Granules Optional
66	20	No	500	100	24	4000	NA	Yes	24	1 hr	Granules Optional
80	36	No	250	800	NA	1500	3.75	Yes	24	2	Granules Required
73	24	No	3000	450	NA	NA	5.0	Yes	36	36 hrs	
62	30	No	2800	200	NA	NA	NA	Yes	48	2	
100	30	No	300	500	NA	2000	2.5	No	72	3	Requires 7300 Top Coat. Granules Required*
50	20	No	1600	400	NA	6500	3.0	Yes	72	1	Granules Optional
70	25	No	400	180	NA	350	3.2	Yes	48	16 hrs	Granules Required

recent report.[16] The remainder of this chapter is taken from his report.

Coating Coverage

Obtaining proper protective coating thickness and coverage depends primarily on the surface texture and profile of spray-applied urethane foam. Therefore, it is important for responsible personnel to recognize that the actual surface area being coated, within given dimensions, varies with the surface profile of the foam. Often, the contractor may meet the rate of coating application required by the specifications, especially where a certain number of gallons per square* is required, but may not have applied enough coating to provide sufficient dry film thickness. If the foam surface texture is "coarse orange peel" or worse, the coating applied will tend to be too thin on the high points and may actually "puddle" in the low areas. Obviously, the result is a coating that lacks uniform thickness, which will usually lead to premature failure in service.

Application of coating over rough foam surfaces often creates other problems, such as pinholes, voids (or "holidays"), and cracking. Occasionally, small areas of marginal coating coverage may be found on an otherwise acceptable application. This problem can usually be corrected by brush or roller application of additional coating, which can be worked down into small voids, crevices, and pinholes. Such procedures should be limited to relatively small areas and should not be permitted as a major corrective action. The best assurance of uniform coating application, assuming proper spray techniques are employed, is to use good inspection to control the original foam application and ensure acceptable surface texture.

To obtain proper coverage, a good technique is to apply alternate coats of material in a cross-hatch or so-called "north-south," "east-west" fashion. The latter procedure is frequently written into specifications. Figures 18 through 23 show coating sprayed over foam with various surface textures.

Coating Defects

The coating material selected must provide the best possible protection of applied urethane foam in roofing systems. Even with proper film thickness and coverage, it is important to avoid certain defects that can lead to premature failure of the protective coating: pinholing, blistering (lack of adhesion), and cracking.

Pinholing. Liquid coatings tend to flow into pinholes, blowholes, and crevices in the foam surface and later create pinholes in the coating (Figure 24). Although it may appear that holes in the foam are covered as the coating is sprayed in place, air trapped in the holes by the wet coating often pressures through the coating as it begins to dry or cure. The surface tension and/or viscosity of the coating then prevents the hole from closing, so the defect remains. In some instances, application of additional coating will close the pinhole; normally, however, continued application of coating will only magnify the pinhole condition.

The characteristics of the coating material itself will determine to some extent whether pinholes can be covered. Factors such as viscosity, volume solids, solvent content, and thixotropy of various coatings account for the differences in ability to cover defects in the foam surface. The best solution to the problem is to prevent, through rigid inspection, the occurrence of surface defects in the applied foam.

In addition, it is important to understand that certain coatings are prone to pinhole development, although recent coating advances have eliminated most of the problem. *Generally, coatings that are low in volume solids and high in solvent content, particularly organic solvents, are sensitive to pinhole formation. This type of coating must be applied in thinner coats to prevent pinholes, so more coats will be needed to obtain desired film thickness.*

Coatings with high solvent content and low volume solids applied in thick, wet films tend to dry first at the surface, leaving wet coating below. Depending on air temperatures and solar conditions at the coating surface, solvent can be forced through the partially dried surface skin, causing pinholes. Usually, the only solution is for the contractor to adjust the application technique. In certain instances, application may have to be done during periods of the day when surface drying can be minimized. Invariably the cause can be traced to excessive wet film thickness.

Once pinholes are present in an applied coating system, it is extremely difficult to correct the situation. Marginal problems can usually be corrected by screeding a compatible caulk sealant into pinholes or voids with a putty knife, permitting the sealant to set up, and then applying additional coating over the repaired areas. It is not recommended that this procedure be

[16] Keith H. Coultrap, *Principles of Urethane Foam Roof Application*, PO No. 79-MR-461 (Civil Engineering Laboratory, Naval Construction Battalion Center, June 1980)

*In roofing, one square = 100 sq ft.

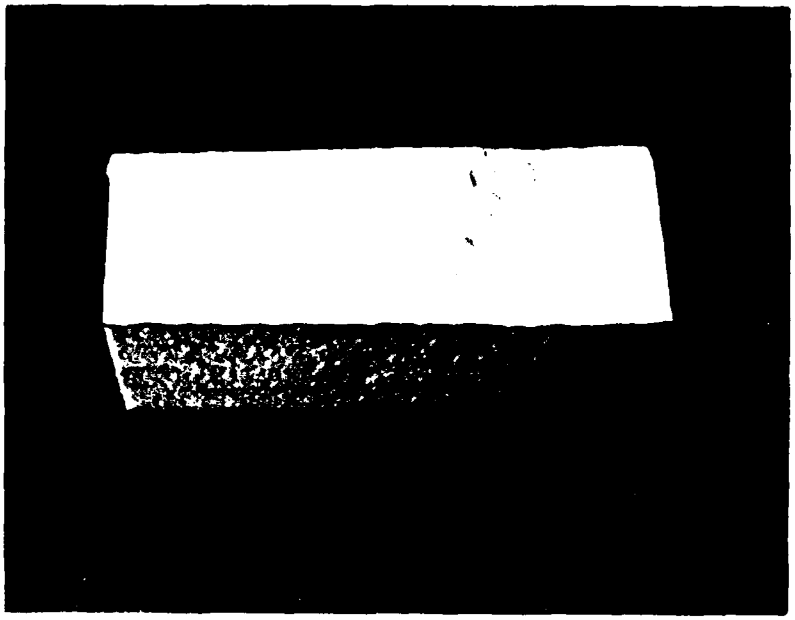

Figure 18. Coating over smooth orange peel.

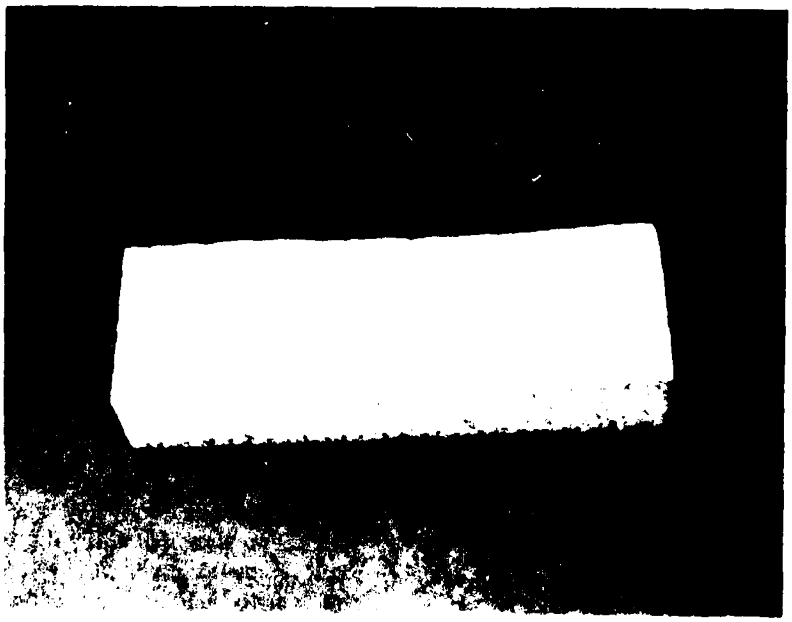

Figure 19. [illegible]

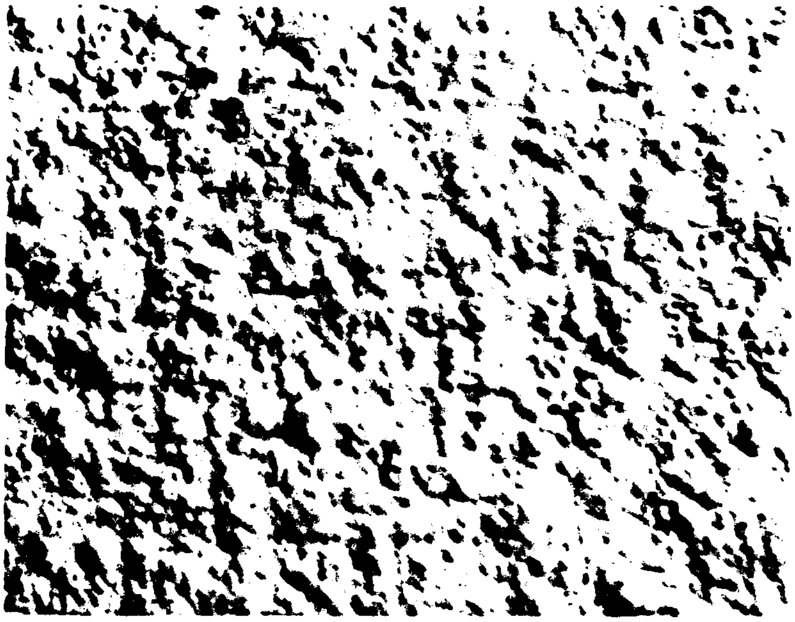

Figure 20. Coating over coarse orange peel.

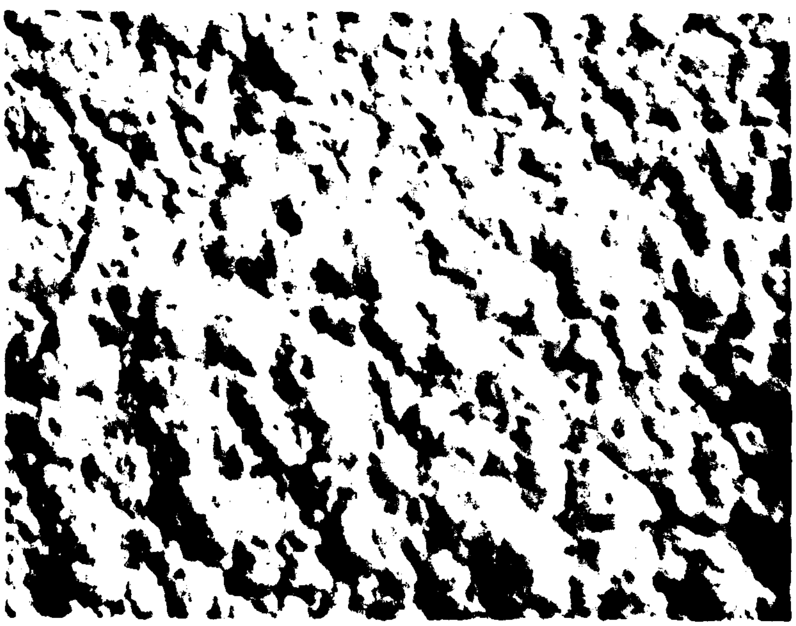

Figure 21. Coating over verge of popcorn.

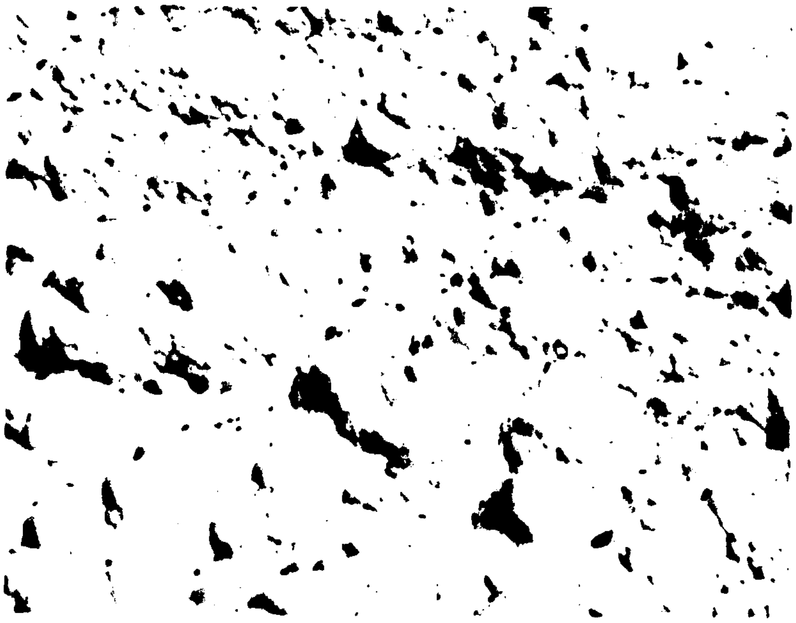

Figure 22. Coating over popcorn.

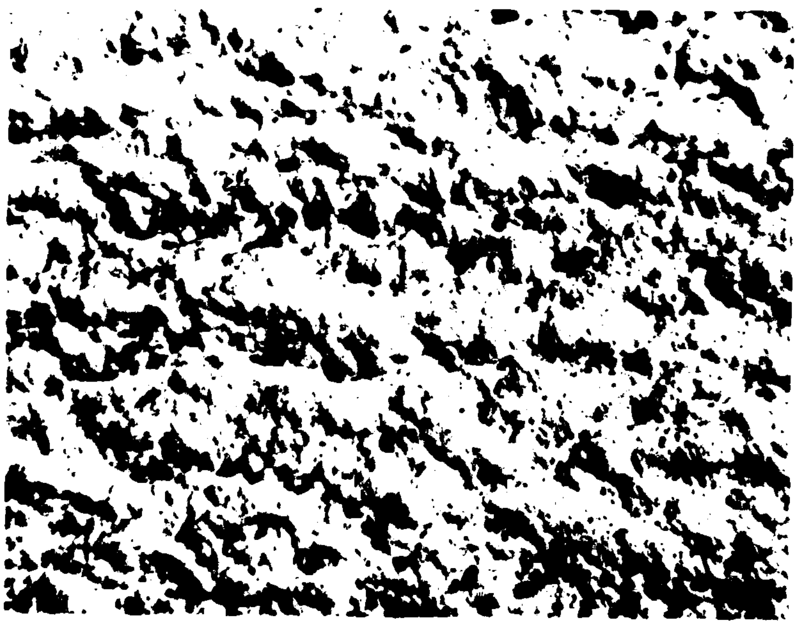

Figure 23. Coating over treebark.

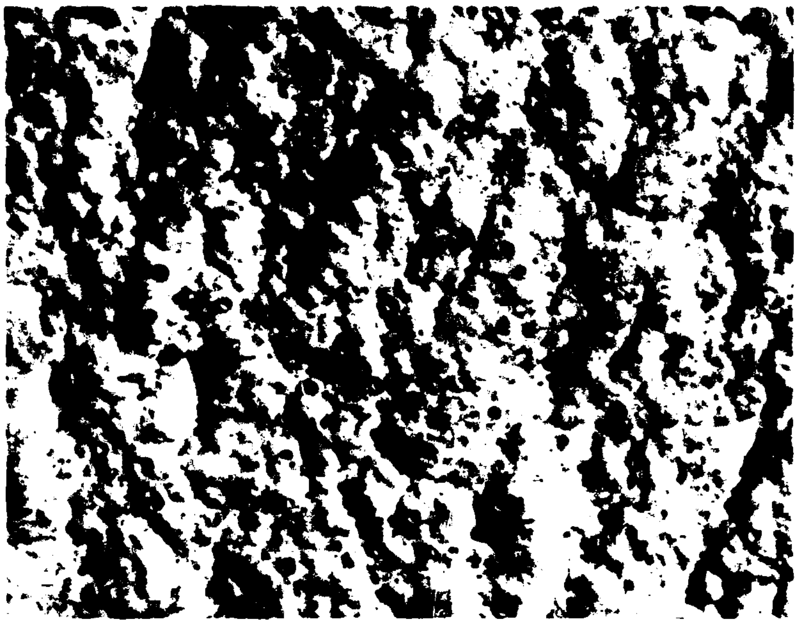

Figure 24. Pinholes in coating.

permitted or used on a major scale. In any case, elimination of pinholes is important to prevent water entry into the foam. Also, since pinholes do not contain coating, the foam becomes subject to deterioration by sunlight. Eventually, this condition can undermine the coating system and lead to complete failure.

Blistering (Loss of Adhesion). Blisters can be caused by factors which do not relate directly to coating application: vapor transmission and choice of breathing or nonbreathing coatings, for example. This discussion assumes that correct technical design decisions have been made, and focuses on problems that must be considered at the time of coating application. As with good foam application, a properly cleaned, dry, sound surface is required to obtain good coating application. Anything that interferes with these elements can create poor adhesion of the coating, which will lead to formation of blisters or to conditions that might permit the coating to be stripped off the foam surface later, leaving the foam unprotected.

Aside from obvious contamination such as dirt, grease, oil, and solvent spills, one of the most frequent causes of poor coating adhesion is deterioration of the applied foam surface because of sunlight. Excessive exposure of the foam surface to sunlight causes a breakdown of the surface, creating dusting or friability. Coating over such a foam surface can result in little or no bond of the coating to the foam. As mentioned above, a dry foam surface is generally most desirable. However, it is important to point out that some of the newer aqueous or water-based coating systems can tolerate a small amount of dampness on the surface of coating application. The best procedure is to check the manufacturer's recommendations for the coating system being applied. However, no application of any coating should be permitted over obviously wet surfaces.

One additional condition that can cause adhesion problems with the coating is excessive foam overspray on the foam surface. Excessive overspray creates an irregular surface that prevents uniform contact of the coating on the surface and can cause "bridging" of the coating between small nodules of foam overspray.

Cracking. Coating cracks, crazing, "crow's feet," and "mud checking" at the time of coating application are predominantly due to poor foam texture, excess wet film thickness or "puddling," improper temperatures, and exposure of the applied coating to excessive moisture before the coating is properly dried or cured.

Coating applied over coarse foam surfaces is usually not uniform in thickness, which creates uneven stresses in the coating as it dries or cures. This factor, combined with temperatures that may be too hot or cold, can cause cracking of the applied coating. In some instances where foam texture is very bad, puddling of the coating also takes place so that as the coating dries or cures, shrinkage cracks, crazing, or "crow's feet" tend to develop. The latter effect usually will be observed to some degree where coating puddles form because of excessive application rates. Normally, puddling is most frequent next to vertical surfaces such as parapet walls, cants, vent pipes, and equipment flashings. Short of puddling, the coating may tend to slump or run on vertical surfaces, which creates nonuniform coating thickness, leading to the problems previously described.

Temperature. Because there are many coating variables, it is difficult to be specific about the effects of temperature on an applied coating as it dries or cures. Generally, aqueous or water-base systems are more sensitive to cold temperatures, whereas organic solvent systems are more troublesome under hot conditions. In extreme cold, an aqueous coating may freeze before it is properly dried. With freezing or near-freezing conditions, there is normally cracking and crazing. Also, the quality of the coating will be severely affected if freezing occurs before drying is complete, because the coating will not coalesce properly.

Hot temperatures with organic solvent coating systems tend to produce pinholes rather than cracking or crazing for the reasons explained in **Pinholing**. However, because of shrinkage caused by rapid drying at the coating surface, hot temperatures with aqueous coating systems can lead to any of the cracking effects mentioned above. Deposit of moisture on an applied coating that is not thoroughly dry or cured is usually detrimental to any coating and will, in many instances, cause cracking. Aqueous-based coatings are more susceptible to moisture; in some cases they can be diluted, and in extreme situations can be washed off the coated surface.

Aside from the obvious problems caused by poor foam texture or coating application techniques, the coating manufacturer's recommendations should be consulted to determine proper limits on drying or cure time, temperature, and moisture.

Granule Application

In recent years, mineral granules spread into the final wet application of coating have been used to: (1) reduce damage from foot traffic and other mechanical exposures, (2) increase hail resistance, (3) provide walkway surfaces around equipment, (4) improve overall appearance, (5) provide a broad range of colors, (6) serve as a base for color coat applications between materials otherwise incompatible, and (7) reduce bird pecking.

Certain coatings are more vulnerable to foot traffic and other mechanical damage, but granules imbedded in the final wet coat harden the surface. Another benefit has been increased resistance to hail damage in some situations. Granules have also been applied in limited areas for walkways and around equipment installations where frequent servicing is required. This use of granules has decreased damage to urethane roofs in such service-related areas. The finished appearance of roof systems visible on various building designs is another valuable aspect of granule applications. Granules, in this instance, eliminate flash marks from spraying of both foam and coatings, and thereby provide a smoother, more uniform appearance to the finished roof surface.

Granules can be selected in a broad range of colors; in addition, when a selected coating is available only in a limited number of colors, imbedded granules can provide a base for application of a color coat material. Granules can also serve as a base or buffer for color coat applications between coating materials that would otherwise be incompatible. For example, silicone rubber coatings are usually white or gray, and other coatings may not adhere to them; imbedded granules provide a base for applying a color coat material, such as an acrylic.

Overall Roof Application. When granules are spread over the entire roof system, they are usually applied to the final wet coating. The method used is to alternately apply coating and granules as the work proceeds across the roof. After an area is coated, the granules are spread leaving a clean, wet, lead edge of coating so that the next area of coating application can be tied in without spraying coating onto the granules in place.

Limited Service Areas. Granules used in creating walkways and service areas around equipment are normally placed into a coat of material applied in addition to the specified coating system. Service areas are usually marked with chalk lines to identify limits of additional wet coating application, which can be done by brush, roller, or spraying using a "picture framing" technique. Granules are spread into the wet opening and left until the coating has thoroughly dried or cured. Then, loose, nonembedded granules are swept up and discarded.

It is important to note that loose granules in limited service area applications should not be left to spread out over an otherwise nongranular coated roof system.

Foot traffic on loose granules can abrade the rest of the roof, which can cause penetration and wear of the coating system. This can be particularly severe when walkways or service areas are violated, as often happens.

In some limited cases, granules can be hand-applied, but most contractors use specially designed spray equipment — usually modified sand blasting equipment. This must typically be operated at relatively low air pressures to give the operator good control over the spread of granules. Excessively high pressure of the sprayed granule stream should be avoided to prevent penetration of existing dried or cured coating, and to keep the granules from bouncing off the surface and falling, uncontrolled, to the roof. Another effect of high pressure in the granule spray stream is that the granules may tend to "tumble" in wet coating, which leads to poor appearance and a generally poor application. The desired effect is for the granules to lose almost all their velocity out of the spray nozzle and "free fall" into the wet coating.

In a good application, the granules are spread evenly and provide close to 100 percent saturation of the coated surface. Care should be taken to prevent voids, or "shiners," as they are called in the trade. Obviously, it is important that granules be applied to the wet coating material to obtain proper bonding.

Normal applications of granules are in the range of 40 to 50 lb/100 sq ft of surface (2 to 2.5 kg/m^2). Figure 25 shows a properly granulated surface.

Application in Severe Environments

As with many construction-related activities, severe weather can cause serious problems during construction of urethane foam roof systems. This discussion suggests special precautions that may be necessary to cope with various environmental problems. It should be noted that, in general, accommodations made to permit satisfactory application of foam will also allow successful coating application. Therefore, most comments in this section are directed to foam application problems.

Four basic environmental factors, alone or in combination, can affect application: (1) moisture and/or humidity, (2) heat, (3) cold, and (4) wind.

Moisture and/or Humidity. In geographical areas where rainfall or snow is more or less constant at certain times of the year, the best results will be obtained by scheduling roofing work in the drier season. When this is impractical or impossible, methods are available to reduce the weather effects during roof construction. Temporary protection — a "tent" or similar structure — can be prepared and moved from point to point as the roofing progresses. The tenting material can be canvas or plastic film. Some "air structures" have been used in

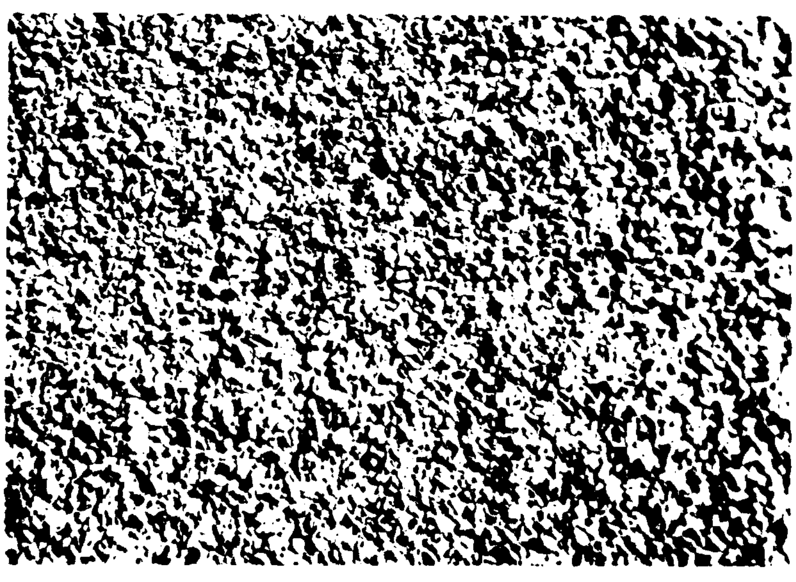

Figure 25. Granules over coating.

very severe situations, such as in construction of the foam roof over the Superdome in New Orleans, LA. Air structures have been made commercially, but some contractors have built a structure by heat-sealing plastic film together into an inflatable cover. Some form of simple anchoring device, such as a sand-filled fire hose, has been used to create a continuous seal around the bottom edge. Relatively little air pressure is required for inflation, which normally can be provided with a simple squirrel cage blower. Such an air structure is simple to move and can be made into various shapes, depending on the pattern selected. Air structures have two major disadvantages: they are subject to wind limits based on design and inflation pressure, and contractor personnel spraying foam or coating within such a structure usually need fresh air masks.

The factor of high humidity in itself is not usually a problem if the roof deck surface temperature is at least 5°F (3°C) above the dew point. When cold temperatures and high humidity are present together, either a structure must be used, or the temperature of the roof deck raised in some way. As emphasized before, the roof deck must be dry if a good sprayed foam roof system is to be constructed.

Heat. Application problems caused by high heat have been discussed in **Temperature**.

Wind. Wind tends to be the most variable factor at all times. The practical limit of wind speed is about 12 mph (19 km/hr), without special precautions to avoid adverse effects on applied product quality and overspray. Because of the variability of winds, structures such as those discussed above can be justified only under very special conditions. Obviously, if a structure is erected for other environmental reasons, it also provides relief from wind. The most successful approach to wind control has been the use of portable windscreens. These are usually a "picture frame" or partition-type construction built from common lumber and then covered with fine mesh window screen, burlap, or netting. The screens break the wind and still permit enough air passage to prevent a solid barrier to the wind, which would require heavy construction and anchoring.

For stability and wind protection from two directions, it is often convenient to erect the windscreen in an ell-type configuration. Such a screen can be hinged at the corner for easier handling and movement. It is also possible, of course, to have a three- or four-sided construction if necessary. Usually, windscreens can be anchored with sandbags, full 5 gal (19 L) material containers, or other small, heavy objects that are readily available. Although the wind speeds that can be tolerated will depend on the sturdiness of the windscreen, velocities beyond 25 mph (40 km/hr) are not acceptable under any circumstances.

4 DISCUSSIONS WITH OTHER GOVERNMENT AGENCIES

Discussions were held with researchers at CEL, Naval Construction Battalion Center, Port Hueneme, CA, and the Engineering and Research Center, Bureau of Reclamation (BUREC), Denver, CO. Both agencies have reported the results of several years' experience with PUF roofing and various coatings.[17] The following summaries of these discussions indicate that the two agencies do not completely agree about the performance of the various coating materials.

Naval Construction Battalion Center

The leaders now used are the catalyzed urethanes, the silicones, and the acrylics. Of these, the high quality catalyzed urethanes are perhaps best, followed by the silicones, which have a slight edge over the acrylics. These are followed by combination butyl and Hypalon, or Hypalon only, with the neoprenes in last place. The neoprenes are too costly because they are labor-intensive; many thin coats are needed for adequate coverage. Asphalt products should be avoided because they tend to crack and flake off.

The catalyzed urethanes are extremely tough when fully cured. Most can be batch mixed before application; however, a few products require mixing at the time of application and thus must be applied with mixing-type spray equipment.

There are two silicone products on the market. One of these is a single component material, which makes it easier to apply. It cures by exposure to atmospheric moisture. The other, a fast reacting catalytically cured material, requires plural component equipment, similar

[17] B. V. Jones, *Laboratory and Field Investigations of New Materials for Roof Construction*, REC-ERC-76-4 (U.S. Department of the Interior, Bureau of Reclamation, April 1976). J. R. Keeton, R. L. Alumbaugh and E. F. Humm, *Experimental Polyurethane Foam Roofing Systems*, Technical Note N-1450 (Civil Engineering Laboratory, Naval Construction Battalion Center, August 1976); R. L. Alumbaugh and J. R. Keeton, *Investigation of Spray-Applied Polyurethane Foam Reroofing Systems*, Technical Note N-1496 (Civil Engineering Laboratory, Naval Construction Battalion Center, July 1977).

to the catalyzed urethanes. The two silicones are essentially equal in performance. Acrylics are water suspensions and cure by coalescing of the film as the water evaporates, leaving the film behind. The silicones are slightly tougher than the acrylics, but are less tough than the catalyzed urethanes.

Several factors are critical to a satisfactory installation of a sprayed PUF roof system: proper preparation of the substrate, proper ambient conditions during and after spraying, proper physical and mechanical properties of the foam itself. A minimum of 40 psi (27.6 N/cm^2) compressive strength is critical for resistance to damage from impact such as foot traffic and hailstone impact.

Bureau of Reclamation

Based on weathering characteristics of the materials, coatings for PUF can be rated as follows:

Coatings	Weathering	Impact Resistance
Silicones	Excellent	Fair to good
Acrylics	Good	Good to very good
Hypalon	Fair to good	Good
Urethane	Poor to very good	Good to excellent

In the above ranking, fewer samples of acrylics have been exposed for shorter periods of time than other generic types. Impact damage ranking is based on laboratory tests (dropping ball) and field observation of hail and other mechanical damage. The materials are discussed below.

Based on experiences with accelerated aging, natural aging, and 10 years of construction, the silicones have the best weathering characteristics, with the two types about equal in this respect. Mechanically, the silicones rate about average, with the single-component slightly above and the two-component slightly below.

Acrylics have good toughness and other physical properties, and are easy to apply. Since they are water emulsions, there is no tendency to pollute. They are well above average in all weathering resistance characteristics except brittle temperature stability and aging. The glass transition temperature, originally very low, tends to increase with age. In one test series, United Coatings' Diathon increased in glass transition temperature (T_g) from 3°F (−16°C) to 25°F (−3°C) after 1500 hours of accelerated weathering, equivalent to about 18 months of natural weathering. In the same test series, behavior of acrylic coatings manufactured by other companies ranged from no perceptible T_g change to unacceptably high T_g (over 40°F [4.4°C]) before weathering. Glass transition temperatures were determined on a Perkin-Elmer Differential Scanning Calorimeter, in accordance with ASTM D 3418.[18] The glass transition temperature may not coincide with the brittle impact temperature, which may be higher, but the trend should be equivalent.

A difference was noted between 15-mil (0.38-mm) and 30-mil (0.76-mm) Diathon coatings in both laboratory tests and outdoor aging. Thicker samples survived impact better than the thinner ones. The effect of thickness on glass transition temperature has not yet been studied. The coatings must be applied in several thin coats, each about 10-mil (0.25-mm) dry thickness. After 30 mil (0.76 mm), additional thickness adds very little aging resistance.

Granules added to the Diathon, embedded before the material gels, tend to hide hail damage rather than prevent it. One actual installation was made with four coatings: Diathon with granules, Diathon without granules, and Dow-Corning silicone and General Electric (GE) silicone, each without granules. This outdoor exposure test has been in service for several years. The uncoated Diathon has noticeable hail damage, the GE very slight damage, and the Dow-Corning none. Damage is not visible on the Diathon with granules. In laboratory low-temperature impact tests, damage that could not be seen on the granule-coated surface was found by peeling the coating from the foam and examining the back of the coating. Based on these tests, and the observations of Diathon performance in the field, it was concluded that there is as much chance that the granules are hiding damage as that they are preventing it.

The early urethanes all seemed to weather more poorly than the silicones, acrylics or Hypalons, although catalyzed urethanes weathered better than the single-component ones. Urethanes may deteriorate from the surface down, usually by chalking, or the entire thickness may deteriorate by hydrolysis. Their use is questionable in highly humid areas unless the product can be subjected to rigid control testing for hydrolysis resistance before application. These deteriorations may be the weak point in total aging of urethanes, as the glass transition temperature is for acrylics. Toughness is good to outstanding. The less ex-

[18] *Standard Test Method for Transition Temperatures of Polymers by Thermal Analysis*, ASTM D 3418 (ASTM, 1975).

pensive single component urethanes have low strength but high elongation, and coats from 30-mil (0.76-mm) to 40-mil (1.02-mm) dry thickness are necessary. The more costly catalyzed urethanes have higher strengths and higher modulus values, and some have excellent weathering resistance. However, an exact relationship between cost and performance cannot be established.

Aluminum flake pigment has been found very effective in resisting the aging of very thin (10 to 15 mil [0.25 to 0.38 mm]) coatings of urethane. The aluminum has a tendency to block the UV attack. The only product tested to date is 3M Company's Scotch Clad. (Another on the market is United Coatings' Elastall FR Fast Cure Aluminum.) The type of flake and its quantity, and the characteristics of the vehicle are critical. Aluminum must be flake, not granule, and the vehicle and application method must promote plating of the flakes. This has not yet been studied. It is known that the flakes tend to overlap as the vehicle cures.[19] This results in a layer that is uniform in opaqueness, and that resists the passage of light and moisture. The characteristics of the urethane itself may influence the results. If the gray aluminum color is objectionable, colored or natural granules may be added. These will protect the coating from sunlight, but are not entirely reliable. There are always invisible voids in the application.

Most of the coatings discussed above are permeable to water vapor. The butyls and Hypalons are nearly impermeable, and vapor flow must be carefully analyzed before either material is specified. The BUREC has specified butyl as a primer and vapor retarder under the foam on top of the substrate, rather than the normal felt and asphalt vapor retarder. However, in the past 10 years, BUREC has not encountered one situation which required a highly impermeable vapor retarder to be used with a breathing coating. It should be emphasized, however, that the usual environment for BUREC structures (because of the organization's mission) is relatively dry.

The glass transition temperatures of butyls and Hypalons (like those of the acrylics) increase with age. These materials are suitable mainly for warm climates and can be used in humid locations. The flow of water vapor must always be analyzed to avoid trapping moisture in the foam.

[19] W. H. Matson, *Federation Series on Coatings Technology, Unit Ten, Black and Metallic Pigments* (Federation of Societies for Paint Technology, January 1969), pp 29-37.

The BUREC believes that a good coating for foam consists of urethane as a base coat for toughness, with silicone as a finish coat for weather resistance. It is important to consider the chemical compatibility of the two materials. Laboratory tests and field construction experience to date have been satisfactory. However, it is expensive to provide adequate amounts of each material.

The discrepancies in results from testing by the two agencies may be caused in part by differences between the climates where the samples were exposed and where the coatings are intended to be used. The U.S. Navy CEL used sites in California at the Pacific seashore, the high desert at 2440-ft (745-m) elevation, and a mountain area at 7000-ft (2140-m) elevation.[20] The BUREC outdoor exposure site was at Denver, CO, just east of the ramparts of the Rocky Mountains at an elevation of about 5500 ft (1680 m).[21] No thorough qualitative or quantitative comparison of the effects of these climates has been published yet.

5 RESULTS OF SITE VISITS

Site visits were conducted to observe existing PUF roofs and to observe and photograph the sequence of operations in the installation of such a roof. A total of 10 sites were visited. Two completed sites were described in CERL Interim Report M-263;[22] seven completed roofs and the one being installed were visited for the preparation of this report. Characteristics of these roofs are given in Table 3.

Site Descriptions

Site 1 had been completed about 5 weeks before the visit. Although no deterioration had yet occurred, the surface of the United Coatings' Diathon material was tacky to the soles of shoes. The original roof on this building was a standard four-ply BUR with gravel surface. It was badly blistered and had several leaks. In preparation for foaming, the gravel was removed and

[20] R. L. Alumbaugh and J. R. Keeton, *Investigation of Spray-Applied Polyurethane Foam Reroofing Systems*, Technical Note N-1496 (Civil Engineering Laboratory, Naval Construction Battalion Center, July 1977).

[21] B. V. Jones, *Laboratory and Field Investigations of New Materials for Roof Construction*, REC-ERC-76-4 (U.S. Department of the Interior, Bureau of Reclamation, April 1976).

[22] E. Marvin, et al., *Evaluation of Alternative Reroofing Systems*, Interim Report M-263/ADA071578 (U.S. Army Construction Engineering Research Laboratory, June 1979).

Table 3
Foamed Roofs Inspected

Site	Location	Owner	Date Installed	Foam Density, pcf (kg/m^3)	Coating Type	Coating Mfr	Coating Trade Name	Coating Thickness, mils (mm)	Date Visited
1	Indianapolis, IN	Crestview Nursing Home	May 80	2.5 (40)	Acrylic	United	Diathon	28 (0.71)	25 Jun 80
2	Indianapolis, IN	Standard Grocery Stores Warehouse	In Progress	2.5 (40)	Butyl/ Hypalon	Plas-Chem	Chem-Elast 5501/5011	36 (0.92)	25 Jun 80
3	Melvin, IL	Volunteer Fire Dept.	Oct 78	3 (48)	Acrylic	Conklin	Rapid-Roof	27 (0.69)	8 Jul 80
4	Colfax, IL	AW Dynamometer	Spring 79	2 (32)	Acrylic	Conklin	Rapid-Roof	12 (0.31)	8 Jul 80
5	Bloomington, IL	City of Bloomington	Aug 76	2 (32)	Acrylic	VIP	VIP-4000	17 (0.43)	6 Aug 80
6	Bloomington, IL	Eastland Shop Ctr	Fall 79	2 (32)	Urethane	Gaco-Western	U66	20 (0.51)	6 Aug 80
7	Mendota, IL	Black Bros.	Nov 79	2 (32)	Acrylic	Conklin	Rapid-Roof	20 (0.51)	6 Aug 80
8	Mendota, IL	FS Services	Jun 75	2 (32)	Acrylic	United	Diathon	20 (0.51)	6 Aug 80

the blisters cut and nailed back. No primer was used because the mechanical sweeping for gravel removal also removed all loose dust and dirt from the surface. One inch (25 mm) of 2.5 pcf (40 kg/m^3) foam was sprayed over the swept surface, and was covered with two coats of United Coatings' Diathon for a total dry thickness of 28 to 30 mil (0.71 to 0.76 mm). Texture of the foam surface varied from smooth to verge of popcorn, with no evident pattern to the difference. In many cases, it seemed that the two textures came in sequence during the same sweep of the spray gun. While walking on the roof, it became evident that there were many blisters in the foam itself, most of them along or near one side only. The contractor had no explanation for this. Foam was sprayed directly over the base flashing and up to the top of the parapet. Recent rains had left several shallow ponds on the surface; the foam application was uneven and drainage was poor. Figure 26 shows the variation in foam surface. Figure 27 shows the ponding caused by the uneven application of the foam.

Site 2 was being installed at the time of the visit. This is a large complex under one roof, totaling 400,000 sq ft (37 200 m^2). Much of this had already been completed. At the time of the visit, 130,000 sq ft (12 100 m^2) were being reroofed. The old roof was a four-ply BUR with gravel surface and was prepared for foaming in the same way as Site 1. The area being foamed was above the cold storage and freezer sections, so the surface coating used also will act as a vapor retarder. This coating consists of a butyl base coat (Chem-Elast 5501) with a Hypalon topcoat (Chem-Elast 5011), the products of Plas-Chem Coatings. Application of the foam was very uneven and recent rains had left many ponds, most of which were on foam that had not yet been coated. This foam was already 6 days old. The contractor stated that the surface had not yet deteriorated, but other investigations have determined that this is questionable. References to Tables 1 and 2 indicate that the maximum time recommended by any coating manufacturer for foam to remain uncoated is 72 hours. Figure 28 shows water ponded on the uncoated foam. The contractor had problems mixing and applying the butyl base coat. The ratio of resin to catalyst is 20:1, which makes it impractical to use a mixing gun. The normal quantity for mixing is 5 gal (18.9 L). Because of the large area to be covered, the contractor had to mix batches of about 30 gal (114 L), starting the next mix as the one being used was close to being consumed. This size batch reduced the pot life of the mix from 1-1/2 hours to about 45 minutes, which could cause the mix to gel before it was consumed. On this job, two sets of hoses were plugged this way and had to be scrapped.

Site 3 was completed during October 1978. The original roof was a BUR, smooth-surfaced with no

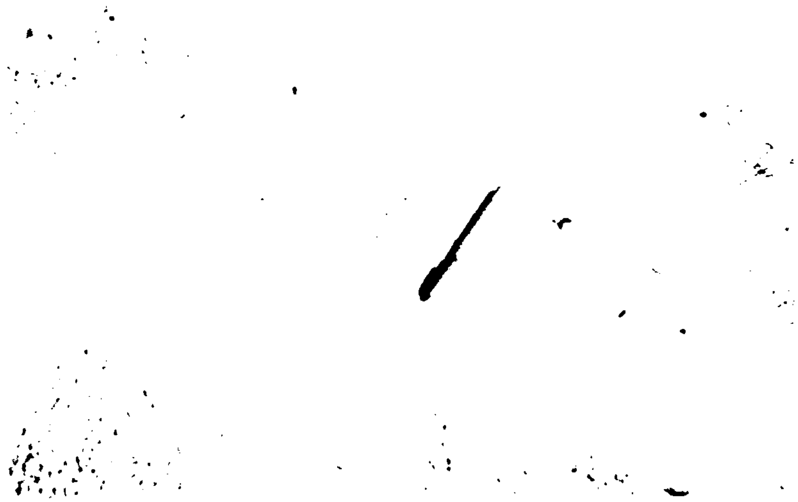

Figure 26. Variation in foam surface texture

Figure 27. Ponded water on roof

Figure 28. Ponded water on uncoated foam.

gravel. It was swept before foaming. No primer was used. One inch (25 mm) of 3 pcf (48 kg/m^2) foam was installed and covered with two coats of Conklin Rapid-Roof for a dry thickness of 27 mil (0.69 mm), followed by one coat of Conklin Show Coat at about 1-mil (0.02-mm) dry thickness. This combination is not listed in the UL *Building Materials Directory*. The Show Coat has two purposes: it provides a bright white heat-reflective surface, and eliminates the tacky feel of the Rapid-Roof which may persist for a long time. The foam had an uneven surface with much variation in surface texture. There were many spots where water tended to pond; these were dry, but were evident from the dirt patterns left behind. Figure 29 shows the variation in foam surface texture. Figure 30 shows the dirt pattern remaining after evaporation of ponded water.

Site 4 was completed in the spring of 1979. The original roof was a BUR, smooth-surfaced with no gravel. It was swept before foaming. No primer was used. One inch (25 mm) of 2 pcf (32 kg/m^3) foam was installed and covered with one coat of Conklin Rapid-Roof for a dry thickness of 12 mil (0.31 mm). A second coat of the same thickness was applied over a portion of the roof. There was clear evidence of widespread ponding, visible because of dirt residue (Figure 31). Some deterioration was already evident because of the insufficient coating thickness (Figure 32). Some damage from an unknown missile was observed (Figure 33). At the junction with the wall of a higher bay the foam had separated from the wall, there was no counterflashing, and the owner mentioned that there were leaks at that location. The foam varied greatly in surface texture, from smooth to rough apparently in the same pass of the gun (Figure 34). Some parts of the surface had popcorn texture, which had not been corrected before coating (Figure 35).

Site 5 was originally a standard BUR with aggregate surface. In August 1976, all loose gravel, dirt, and dust were removed and 1 in. (25 mm) of 2 pcf (32 kg/m^3) foam was applied. No primer was used on the old BUR. Two gallons per square (409 ml/m^2) of VIP-4000 was applied. At 53 percent solids content (see Table 2), this calculates to a dry film thickness of 17 mil (0.43 mm). The company's literature recommends at least a 25 mil (0.64 mm) dry film thickness. The application of the foam was extremely uneven; the many ponds and puddles provided ample evidence of recent rains.

The coating had failed less than 2 years after it had been applied (Figure 36). Moisture had penetrated through the coating and had affected the foam. The coating had completely separated from the foam at the high points. It had lost its flexibility within 6 months and turned brittle at temperatures of about 20°F (−7°C). Some patching was performed in the spring of 1978 where the foam had failed. The foam and old BUR in those areas were completely removed down to the concrete deck. The deck was primed, and new

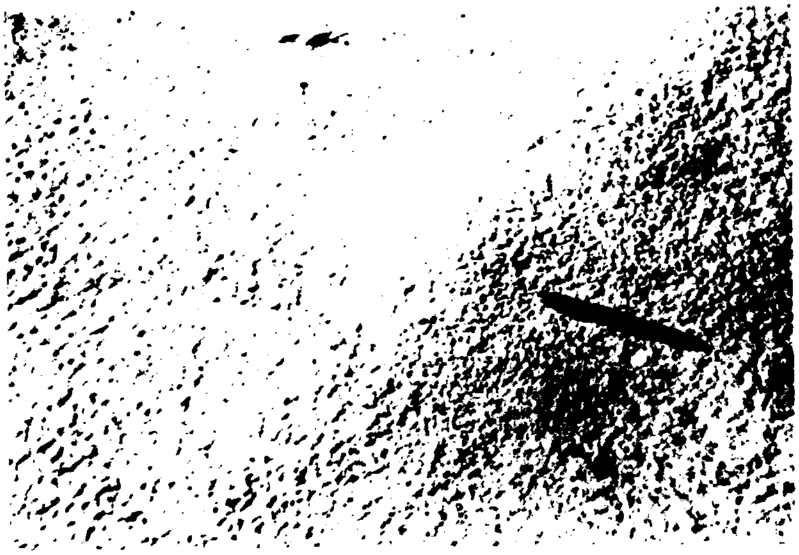

Figure 29. Variation in foam surface texture.

Figure 30. Spots where water had ponded.

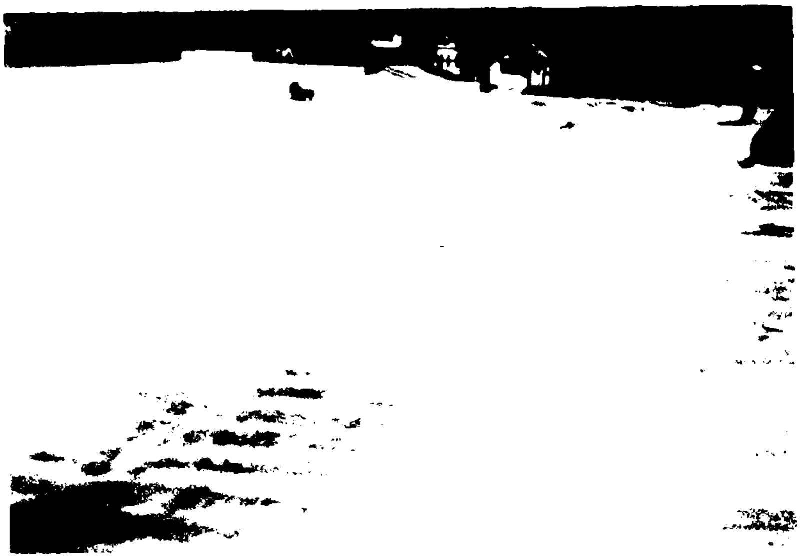

Figure 31. View of roof showing dirt in valley.

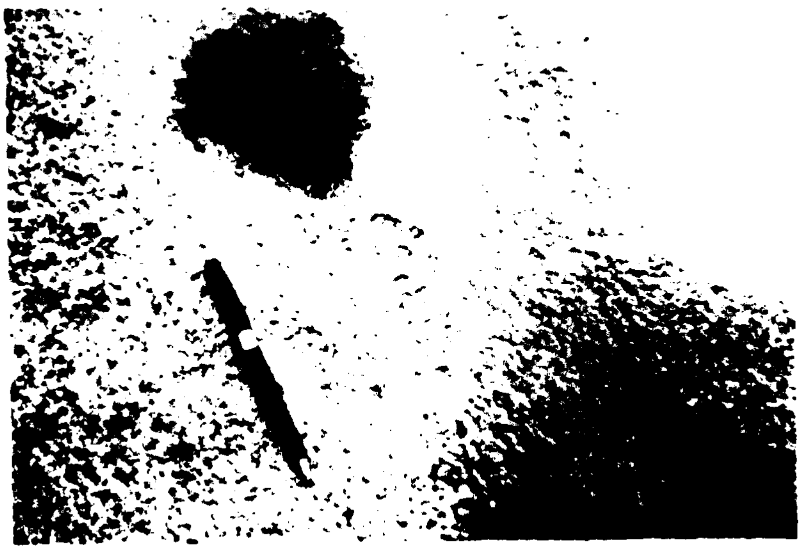

Figure 32. Deterioration of coating due to insufficient thickness.

Figure 33. Damage to coating from unknown missile.

Figure 34. Variation in foam surface texture.

Figure 35. Popcorn surface of foam.

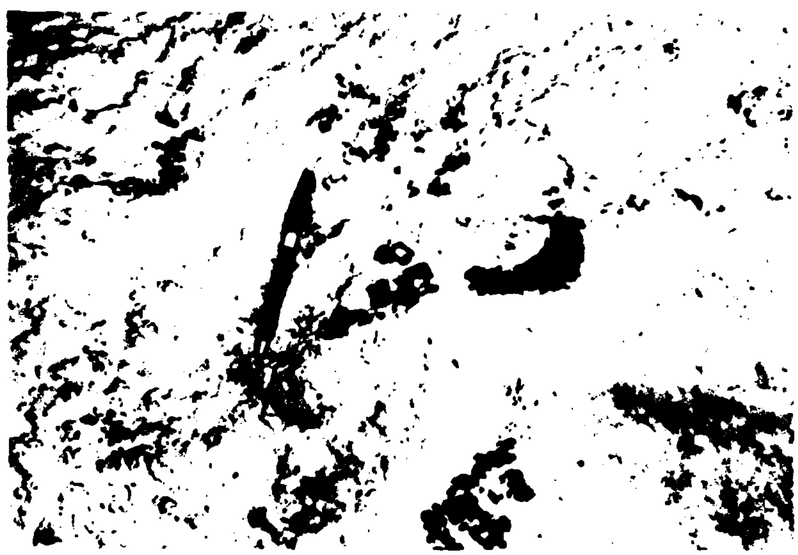

Figure 36. Failure of VIP-4000 coating.

foam was applied. The coating used was aluminized urethane AB-175 made by Performance Polymers applied to a dry film thickness of 20 to 25 mil (0.51 to 0.64 mm). This coating is not UL listed. It has completely failed, becoming disbonded from the foam (Figure 37) and has lost its elastomeric properties.

In other areas, as much of the VIP coating as possible was scraped off the existing foam. The Performance Polymers material was then applied; it completely disbonded from both the foam and the VIP coating in low places where water had ponded (Figure 38).

Two days before the site visit, some further recoating had been done using Gaco Western U66 urethane. Some cracks had formed in the foam under the original VIP coating. It was observed that the Gaco Western material did not bridge these cracks (Figure 39).

Site 6, an enclosed shopping mall, was composed of many retail stores of varying sizes. On one store, a leaky flashing of an existing BUR, at its junction with a second-story wall, had been repaired in 1972 by foaming and coating with an acrylic latex paint. This failed in 3 years. The loose paint was brushed off and United Coatings' Diathon was applied. After 5 years, it is still in good condition, but is on a vertical surface and water cannot accumulate on it.

The roof of another store was repaired during the late fall of 1979; a power broom and compressed air were used to remove loose aggregate and dirt from the existing BUR. One inch of 2 pcf (32 kg/m^3) density foam was applied and coated with Gaco Western U66. Ponding has not affected this material, but it was applied less than 1 year before the site visit. One part of this roof is continually ponded because water leaks from an air-conditioning cooling tower (Figure 40). Another case of ponding was solved by cutting a drainage trench in the foam itself and recoating (Figure 41). A nearby area was foamed at about the same time with 1-1/2 pcf (24 kg/m^3) density foam and also coated with Gaco Western U66. This failed almost immediately, probably because the foam was too weak to support foot traffic. Foot marks are plainly visible and the breaks in the coating all occur at these marks (Figure 42).

All foam observed at Sites 5 and 6 was very uneven in quality and surface, with many high and low places.

Site 7 was completed during November 1979. The original roof was a two-ply BUR from which loose gravel was removed; 1 in. (25 mm) of 2 pcf (32 kg/m^3) density foam was applied. The foam surface was more uniform in smoothness and texture than that observed at Sites 5 and 6. Conklin Rapid-Roof was applied, and part of this was covered with Gaco Western U66 by mistake. The U66 appears to adhere satisfactorily to the Rapid-Roof, but application was performed only 9 months before the site visit.

Site 8 was completed in the summer of 1975. Although performed long before the UL certification, the construction corresponds to UL Construction No. 136.[23] One inch (25 mm) of 2 pcf (32 kg/m^3) density foam was applied directly to the sloping roof of a prefabricated steel building. The roof slopes at a ratio of one vertical to three horizontal, shedding all water. The foam was coated with 20 to 25 mil (0.51 to 0.63 mm) of United Coatings' Diathon. Much hail damage was noted during the summer of 1979 (Figure 43). In most cases, the coating is cracked, but in some it is gone completely, leaving small holes in the coating and depressions in the foam. Foam under and around these areas is saturated with water, which covers the surface when pressed (Figure 44). One such area had a growth of algae about 6-in. (152-mm) wide by 30-in. (760-mm) long (Figure 45).

Summary of Site Visits

Several of the conditions observed in both the foam and coating appeared to be the result of poor application techniques. Site 5 appeared to exhibit deficiencies in both application and material. All the sites installed before 1980 indicated that regular inspection and maintenance are needed because rapid deterioration sets in once the coating is damaged.

6 CONCLUSIONS

These conclusions are based on a few site visits in the Middle West and discussions with roofing contractors, building owners, and technical personnel at CEL and BUREC.

1. Application of foam roofing (directly to decks) that meets UL Class A requirements is limited to cast-in-place structural concrete decks and sloped steel roofs typically used for Butler-type buildings; fluted metal roof decking is not included. Foam can only be applied over fluted metal roof decks if a thermal bar-

[23] "Construction No. 136," *Building Materials Directory* (UL, January 1980).

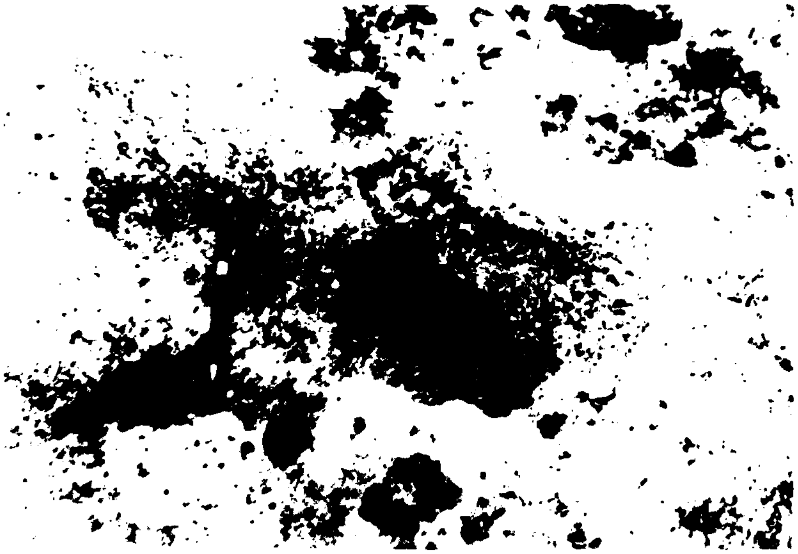

Figure 37. Failure of performance polymer coating where refoamed.

Figure 38. Delamination of performance polymer coating from VIP-4000.

Figure 39. Gaco Western U66, 2 days old, not bridging crack in foam.

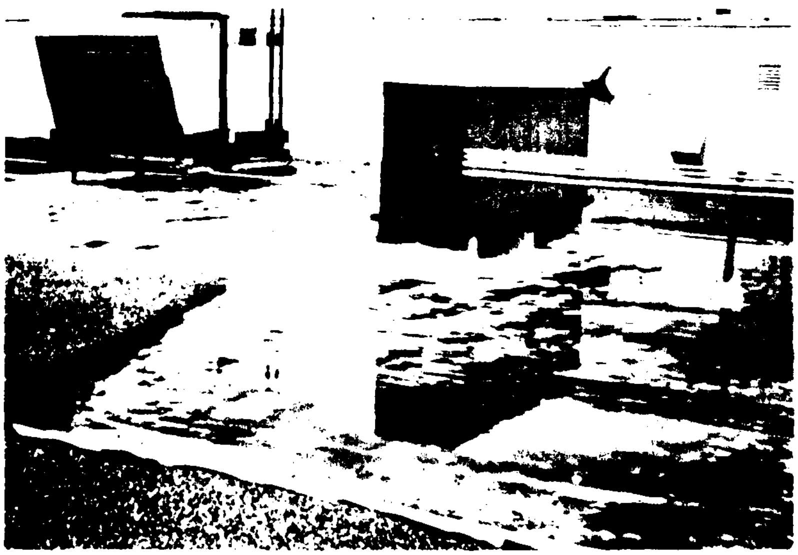

Figure 40. Ponded water from leak in cooling tower

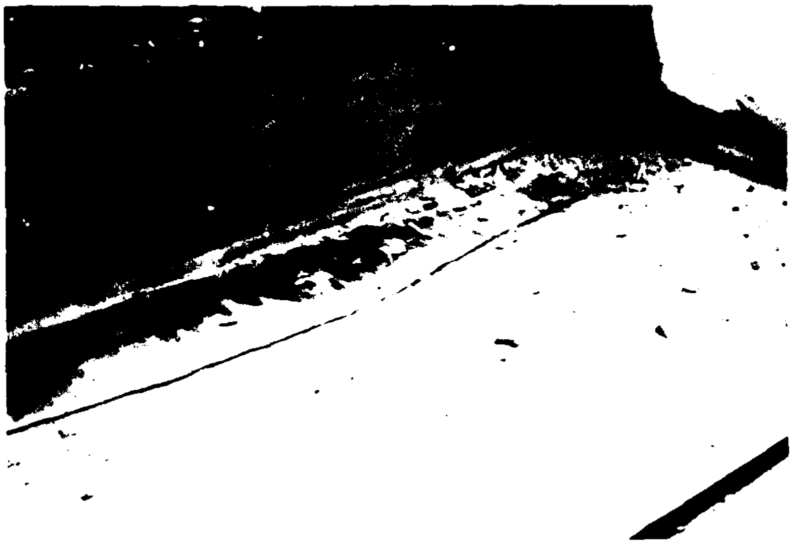

Figure 41. Pond drained by cutting trough in foam.

Figure 42. Footprints visible on 1-1/2 pcf foam.

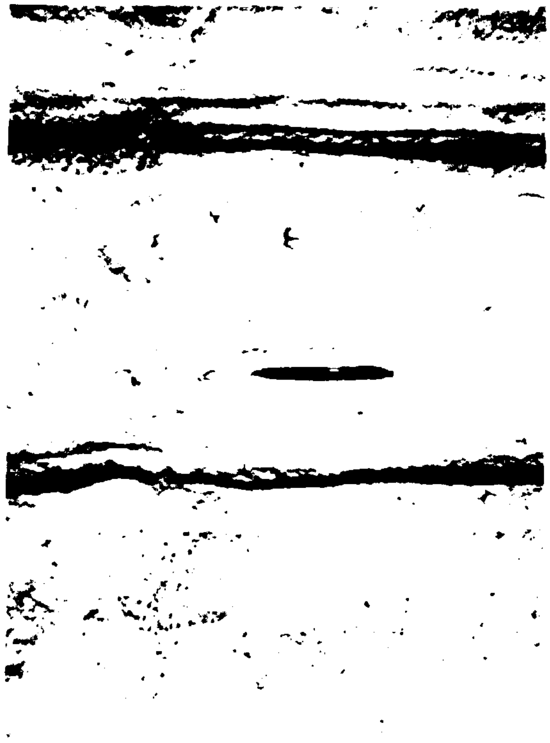

Figure 43. Hail damage to Diathon coating.

Figure 44. Saturated foam under Diathon coating.

Figure 45. Algae growing on sloped roof.

rier is first mechanically fastened to the deck and the foam applied to this barrier. Foam must always be applied so that water will drain from its surface.

2. Because of their different needs, Government agencies disagree about the type of coating to be used. It was found that silicones and catalyzed (two-component) urethanes have the best service record of all coatings for general use. One of the acrylics (Diathon) has improved hail resistance if the film thickness is increased from the manufacturer's recommended 20 mils (0.51 mm) to 30 mils (0.76 mm).

3. The direction of water vapor flow must be studied carefully when designing and selecting materials for a foam roof application. As with any roof system, foam roofs above kitchens, laundries, and indoor swimming pools, and similar services require a vapor barrier between the roof deck and the foam to prevent migration of moisture into the foam from the building interior. Conversely, roofs above cold storage facilities such as meat lockers, refrigerated rooms, or freezers require a vapor barrier above the foam to prevent atmospheric moisture from penetrating the foam and condensing or freezing at the deck-to-foam interface.

4. Although many coating materials have been rated for Class A application by UL, experience has shown that they do not all have a service life long enough to be economically justifiable. Some fail within 2 years after installation, requiring extensive treatment of the foam surface before the foam can be recoated.

5. To prevent workmen from crushing the foam and fracturing the coating, a minimum of 40 psi (27.6 N/cm^2) compressive strength is critical.

6. Application of granules to the coating in some cases results in a tendency to hide hail damage rather than prevent it. On the other hand, granules add mechanical strength to the coating and help prevent solar degradation.

7. CEGS-07540, *Elastomeric Roofing, Fluid-Applied*, for new construction, should be retained in its present form. However, the application of the system directly to sloped roofs or prefabricated steel Butler-type buildings should be permitted for retrofit purposes.

8. Because of the highly sensitive nature of foam materials, users should be prepared to take special precautions with regard to temperature, moisture, wind, and control of mechanical devices used for application.

9. Coatings other than silicone should be permitted for experimental installation only, with each application requiring special authorization from the Major Command or the Office of the Chief of Engineers.

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First Coast Guard District
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82 Air Base Group/DE
Williams AFB

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Rocky Mountain Arsenal

HQ US Army Facilities Engineer Activity, Korea
ATTN: EAFE-E-ST

US Army Engineer Division Pacific Ocean
ATTN: PODED-T

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