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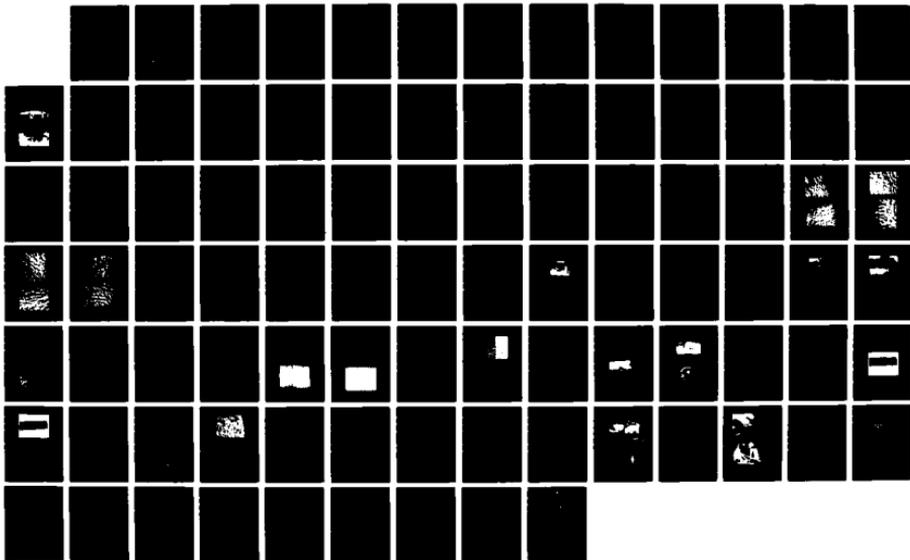
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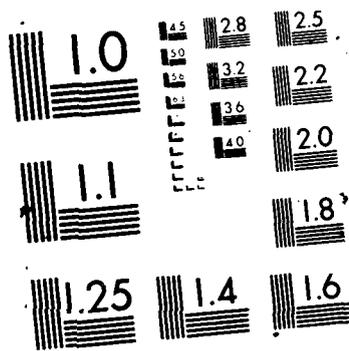
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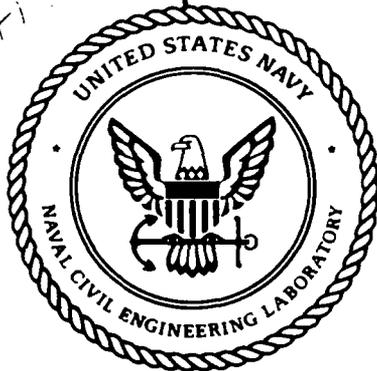
Users Guide for POLYURETHANE FOAM ROOFING

By

K. Coultrap, Coultrap Consulting Services, Inc.,
R.L. Alumbaugh, and E.F. Humm, NCEL

April 1987

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Key...

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K.H. Coultrap, R.L. Alumbaugh, and E.F. Humm
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Sprayed polyurethane foam (PUF) roofing materials have been used in the private sector for 15 to 20 years and in the Navy for about 12 years. However, until very recently, there has not been a great deal of criteria available for their proper selection, application and maintenance. The purpose of this Guide is to provide information necessary for anyone working with PUF roofing to make knowledgeable decisions concerning their use. The Guide is intended to be a valuable source of information for planners and estimators, designers, and construction and maintenance personnel. Information is presented on PUF, certain elastomeric coating materials, why they should be used, when and where they can or cannot be used, and how to use them properly. The Guide also presents information on foam and coating material selection procedures, standardized maintenance procedures, and a comparison of PUF and other systems including their relative costs.

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INTRODUCTION

There are many relatively new roofing systems and products currently on the market. They are the result of much research and today's Space-Age technology. Among them are sprayed-in-place polyurethane foam (PUF) roofing systems. Fundamentally, the systems are composites of sprayed lightweight rigid PUF insulation and liquid applied protective coatings or membranes. These systems provide a method for obtaining excellent insulation and waterproofing qualities over various types of roof substrates in construction.

Polyurethane foam roofing systems have been in use in the private sector for 15 to 20 years and have been used both experimentally and in practice by the Navy for about 12 years. These systems, however, have not been trouble free largely because they have been misunderstood, improperly specified with respect to materials and more generally misapplied.

When PUF roof systems were first introduced, they were often promoted by overly aggressive sales personnel as the panacea to solve all roofing problems. The systems were frequently installed in situations that were improper or too severe for the protective coating materials available and there was a lack of recognition that creation of a PUF roofing system is in effect an on site manufacturing process. This makes the process subject to various factors in the environment where the application takes place. The inability to control the environment is probably the one greatest detriment to use of these systems. Accordingly, in addition to proper specifications and materials, it is essential that the contractor makes application under the best conditions possible and that he uses good procedures.

In practice PUF is spray applied to the roof deck or substrate as a liquid mixture which reacts chemically and immediately expands from 20 to 30 times its original liquid volume to form a cellular mass that hardens and becomes a lightweight solid insulation. A unique feature of sprayed PUF is that it is self-adhering to all known roof deck materials and when applied to clean, dry, properly prepared surfaces will develop adhesive strength that equals or exceeds the cohesive strength of the PUF itself.

The surface of PUF exposed to weather will degrade due to the effect of ultra violet light in sunlight causing the surface to become friable which in turn makes the exposed surface further susceptible to deterioration by moisture and wind erosion. Therefore, it is essential that the PUF be protected by a suitable coating system. If the PUF is coated with a protective coating that is not designed for application over foam the coating will fail prematurely and lead to early failure of the total PUF roofing system.

Experience has shown that PUF roofing systems have been specified and successfully used over every type of roof deck substrate in all climatic environments of the world, including areas subject to hail,

over buildings which house coolers or freezers, over laundries (high humidity areas), and in tropical, subtropical and desert areas where roofs are exposed to intense solar radiation and/or high humidity. Special building constructions and environments require precautions and procedures which must be followed as outlined.

Sprayed PUF roofing systems, properly designed, applied and maintained, with possible interim recoating after eight to twelve years, should provide at least 20-year service lives.

The purpose of this Guide is to provide information necessary for anyone working with PUF roofing systems to make correct decisions concerning their use. The Guide is intended to be a valuable source of information on PUF roof systems for designers, construction and maintenance personnel, planners, estimators and others who desire background information on the technology. The Guide provides information on PUF and certain elastomeric coating materials, why they should be used, when and where they can or cannot be used and how to use them properly. In addition, the Guide provides information on foam and coating material selection procedures, standardized maintenance procedures and a comparison of PUF and other roofing systems including their relative costs.

PLANNING CONSIDERATIONS

Why Use PUF For Roofs?

Spray-on-in-place PUF roofing systems offer a unique method for insulating and waterproofing roof deck constructions simultaneously. A combination of sprayed rigid foam insulation, which is self-adhering to the roof deck, and liquid application of protective coating provides a monolithic roof covering free of seams or joints.

The systems are lightweight, applicable to virtually all types of roof decks, easy to apply, offer rapid rates of production and are generally economically competitive with other types of roofing systems. Additional features are that the foam component is self-flashing, which eliminates expensive and complicated metal flashings, is highly water resistant, although not waterproof, and offers the best insulating efficiency per unit of thickness all commercial roof insulating materials.

Where To Use PUF For Roofs

Climate. PUF roofing systems are adaptable to all climate conditions for use if care is taken to select and specify the proper materials with respect to the environment involved. The choice of systems, which is dictated primarily by the protective elastomeric coating selected, is more restricted in cold, damp, windy geographical areas and more attention must be given to controlling the conditions of application. Special techniques may be required such as the use of a "tent" or "air structure" on the roof deck and/or "wind barriers" or "wind screens" may be required. The period during the year when application can be made may be restricted to short periods of time in more severe climates and the best results will be obtained by scheduling application in the drier season.

Type Of Roof Substrate. A primary factor for the application of any sprayed-in-place PUF roofing system is that the roof deck substrate be clean, dry, and adhere well to the building structure. Otherwise the foam when sprayed to the selected substrate may be subjected to movement that will destroy the adhesion of the foam and ultimately cause blistering or fracturing of the composite foam and coating system.

PUF roofing systems can be successfully applied over properly prepared:

- Metal Decks
- Concrete Decks
- Wooden Decks
- Existing Weathered Roof Covering Systems
- Insulation Boards and Insulating Fill Materials

Slope Of Roof Deck. PUF roof systems can be applied to roof decks of any slope and when applied by contractors with proper skills can be used to create slopes to drain where none exists in the roof structure. Although these systems are applied to dead level roof decks, it is always advisable to avoid water ponding by creating slopes with the foam or certain other materials prior to foam application. Minimum slopes of 1/8-inch to 1/4-inch to the foot are recommended and NAVFAC now recommends 1/2-inch per foot for new construction. Where ponding water cannot be eliminated or is a problem, a high quality impermeable coating must be used to protect the foam.

These roofing systems are excellent for use on domes, roof decks with other curvatures and special configurations and have been used successfully on many aesthetic roof deck structures. In some cases sprayed PUF systems offer the only practical solution to waterproofing and insulating such roof decks. (see Figures 1 & 2).

Type Of Construction. PUF roof systems can be used for new and remedial roof constructions for industrial, commercial, residential and many special use structures. The use of these systems for remedial roofing is of particular interest in that application can often be made without resorting to costly tear-off of existing roof coverings plus preserving the life of dry insulating materials that are frequently present in conventional built-up roof (BUR) constructions. It must be emphasized that the existing BUR and insulation must be dry.



Figure 1. Pyramidal roof.



Figure 2. Domed roof.

Another feature of applying these systems to existing buildings that are occupied and in use is the opportunity to provide significant improvement in roofing insulation without interfering with the internal operations of the structure. Typically PUF roof systems applications are clean, free from objectionable odors, quiet and are frequently accomplished with little or no disturbance to the occupants. Also, special requirements such as the application of a vapor retarder can be achieved on the exterior side of the roof deck construction.

When To Use PUF Roofing Systems

Conventional Roofing Systems. The use of conventional systems, such as single ply sheet membranes, liquid applied coating membranes, special metal constructions, or hot mopped rolled roofing (BUR) may be of advantage with respect to cost and/or performance where little or no insulation is required and waterproofing is the only concern. Also, certain of these systems are best for use in high roof traffic applications or under conditions of high hail incidence, heavy snow and ice loads. Some BUR and single ply membrane constructions should be considered if water ponding is unavoidable or if the roof covering is constantly wet as is the case in some industrial applications or in some geographical areas with high rainfall.

General limitations of conventional roofing systems as may apply to one or the other of the systems selected are roof slope limits, high cost, heavy weight loading of the roof structure, fire hazards, lack of aesthetics, and broken joint construction. The difficulty of application to curved surfaces or irregular shapes as well as various styles of metal roof decks and the inability to obtain high insulation efficiency may also cause limits.

PUF Roofing Systems. Advantages in the use of these systems are in their light weight and good strength/weight ratios. They are composed of monolithic seamless materials which provide laminar adhesion to all types of roof deck substrates wherein the PUF component seals and fills all cracks, openings, splits and small holes or other imperfections as the liquid mixture expands and sets to form the finished foam. In addition, they can be applied to all slopes, are self-flashing, can be tapered in application to provide slopes to drain, easy to maintain and repair, adaptable to special roof deck configurations, offer the best in insulation efficiency per unit of thickness, provide excellent wind tear-off resistance and many systems are available that meet Navy/DOD fire safety criteria.

Disadvantages in the use of PUF roof systems are high dependence upon applicator skill in obtaining level surfaces and uniform insulation thickness, the need for good substrate preparation and the requirement that application be made under favorable environmental conditions. To this may be added the cost of recoating the protective membrane periodically, although, this factor is becoming less of a problem with ongoing development of coating systems. PUF systems are also generally more susceptible to damage by mechanical impact and high traffic use as well as water ponding conditions than BUR systems. Special consideration must be given to selection of the system when it is to be used in areas having extreme climates.

Cost Considerations

The primary cost variables in conjunction with conventional BUR roofing systems are based on the number of plies specified, the type and amount of insulation desired and whether the finished roof surface is smooth or treated with a flood coat and gravel. Single ply roof systems will also vary in cost with respect to the type and amount of insulation used but differ from BUR types of roofing in that the systems may be loose laid and ballasted with gravel or rock, adhered mechanically or with adhesives, and may be constructed with adhesive, solvent or heat welded seams. The variations indicated in the latter case as well as choice of several different generic types of single ply material available together with the flashings and/or counter flashings required with any of the above systems offer a range of installed cost of less than \$1.00 per square foot to more than \$4.00 per square foot.

The primary cost variables in conjunction with PUF roofing systems are based on the foam insulation thickness desired and the generic type and dry film mil thickness (DFT) of elastomeric protective coating selected. Due to the self-flashing nature of these systems, such costs are not normally a consideration.

Properly specified protective coating systems used over the sprayed-inplace foam at a thickness of not less than one inch and up to about three inches in thickness provide a range of installed cost of \$1.50 per square foot to less than \$4.00 per square foot.

Other cost considerations involve comparison of long range maintenance costs and factors dealing with energy savings. Experience and recent surveys have shown that properly specified and installed PUF roofing systems offer excellent cost advantages in this regard.

DESIGN CONSIDERATIONS

Design Requirements

Once the decision has been made to use a PUF roofing system there are a number of important items that must be considered to ensure that the system selected and the specifications created are proper for the application to be made. It is essential that the specifications limit the materials to be used to those that have been selected, with respect to both quality and amounts, and include quality control provisions for the installation.

Fundamentals to be considered are the following.

- The type of substrates that are involved in the application, which will usually be different for new construction as opposed to remedial or reroofing projects.

- Climatic conditions at the project site determine what type of elastomeric protective coating should be used. These conditions will also control the choice of spray foam system selected with respect to extremes in either hot or cold temperatures or if a higher density foam is required to provide above average compressive strength for snow loading, as an example.
- A high moisture vapor condition will determine whether the protective coating should be permeable (breathable) or nonpermeable (non-breathing) and whether vapor retarder protection is required over the roof deck surface underneath the installed PUF roofing system.
- The minimum thickness of foam must be determined to meet insulation requirements, if any, or it may be necessary to calculate variable thicknesses of foam if it is intended that slopes to drain are to be created. It is recommended that no less than one inch of foam be installed or specified in any application with the exception of termination points at roof edges, flashings, cants, equipment mountings, etc.
Experience dictates that a maximum "R" value of 6.25 per inch of foam applied should be used for insulation or energy related calculations.
- Frequently, it is important to specify special items in conjunction with the applied protective coating such as traffic pads or mineral granules, spread into the final wet application of coating. This helps reduce or eliminate damage from foot traffic in high use areas around roof entries and roof mounted equipment which requires frequent servicing. Mineral granules imbedded in the overall roof surface will also provide improved protection against hail, bird pecking and other mechanical impact. Also, granules generally improve overall appearance and in special cases, where aesthetics are important or desired, can serve as a base for color coat applications between materials otherwise incompatible. An example of the latter is the use of an acrylic coating over a silicone rubber elastomer. (See Figure 1)
- Proper flashing details must be selected and specified such as those included in this Guide. (see Figures 3 to 21)
- The insulation efficiency of urethane foam applied to a roof deck construction serves to put the roof deck to sleep thermally and reduces the roof deck temperature to the inside ambient operating temperature of the building for all practical purposes. Thereby expansion and contraction of the roof deck is greatly reduced, minimizing or eliminating the need for expansion joints that would be required from a thermal standpoint. However, expansion joints should be provided where structural movement can be expected, such as where substrate material changes occur or where the intersections of L or T shaped roof decks change direction.

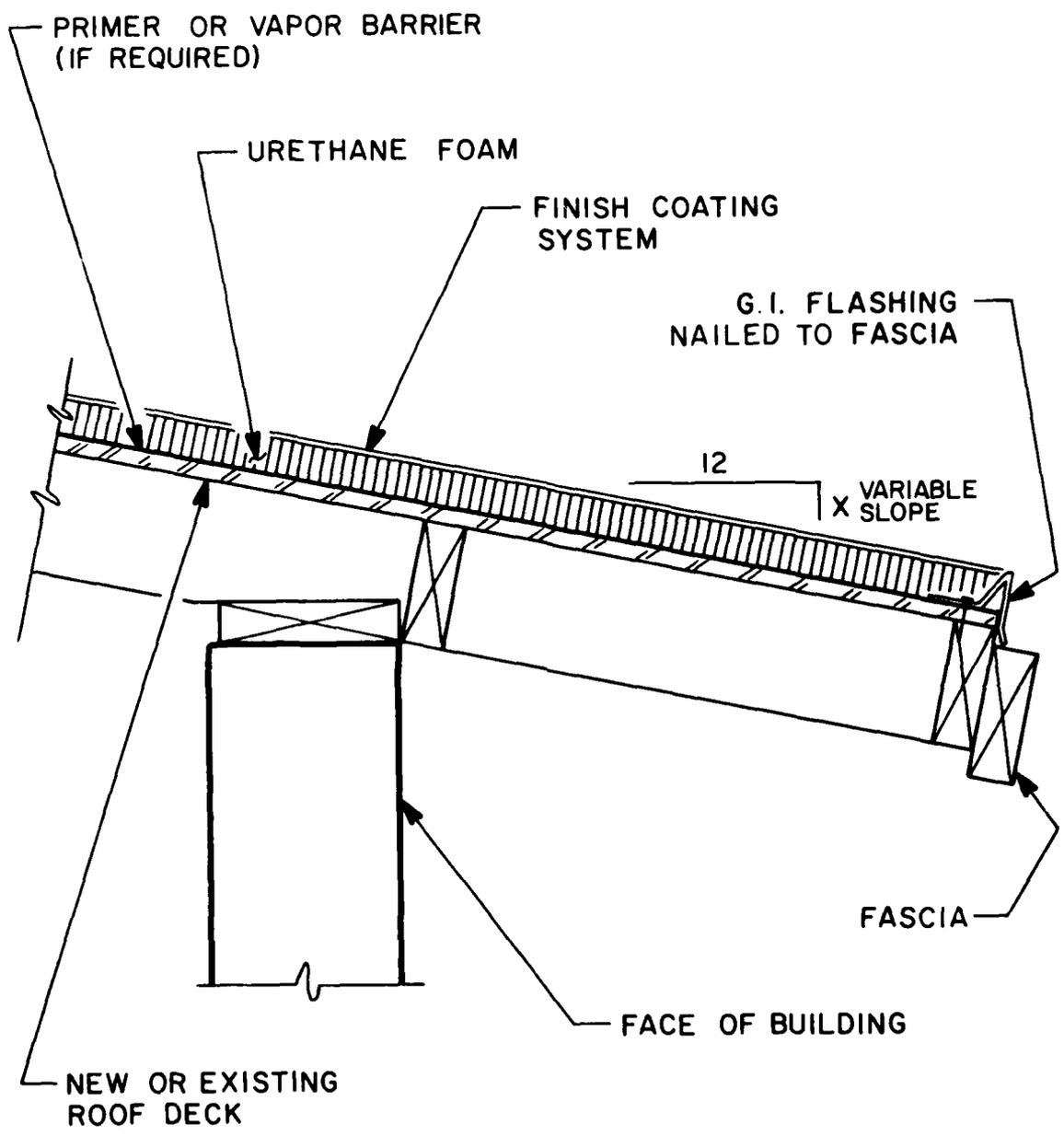


Figure 3. Sloped roof eave detail.

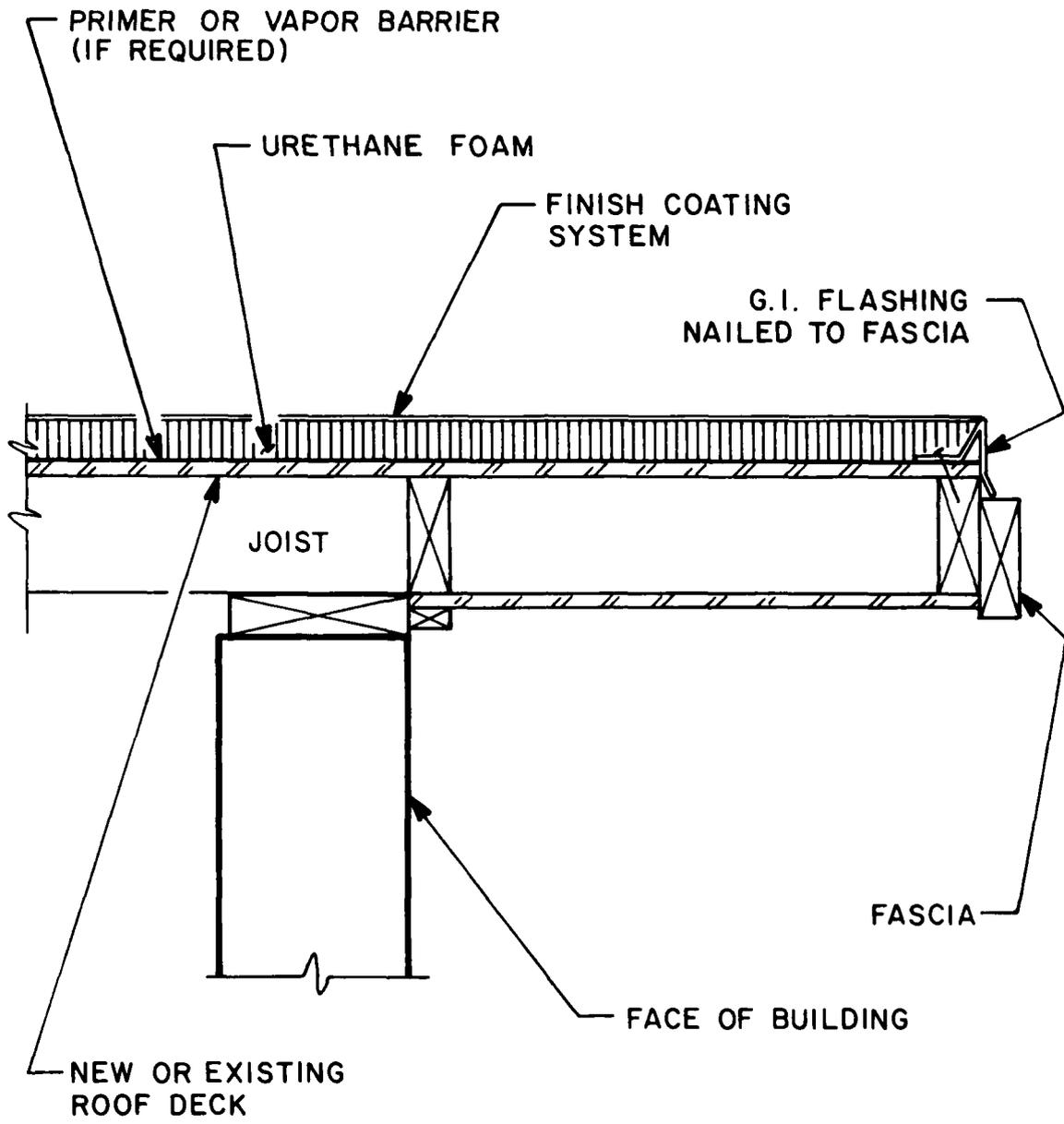


Figure 4. Flat roof eave detail.

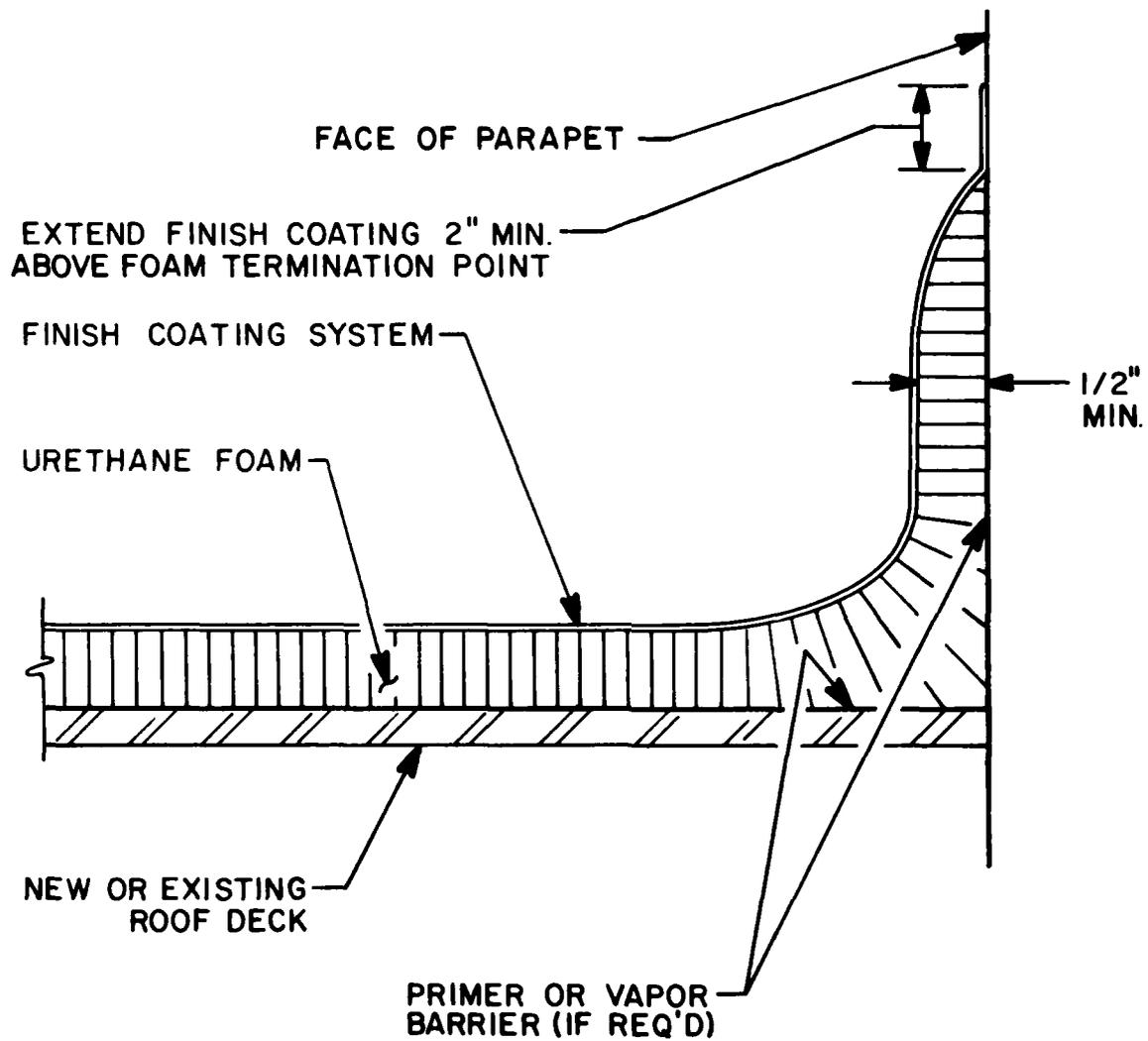


Figure 5. Self flashing at parapet wall.

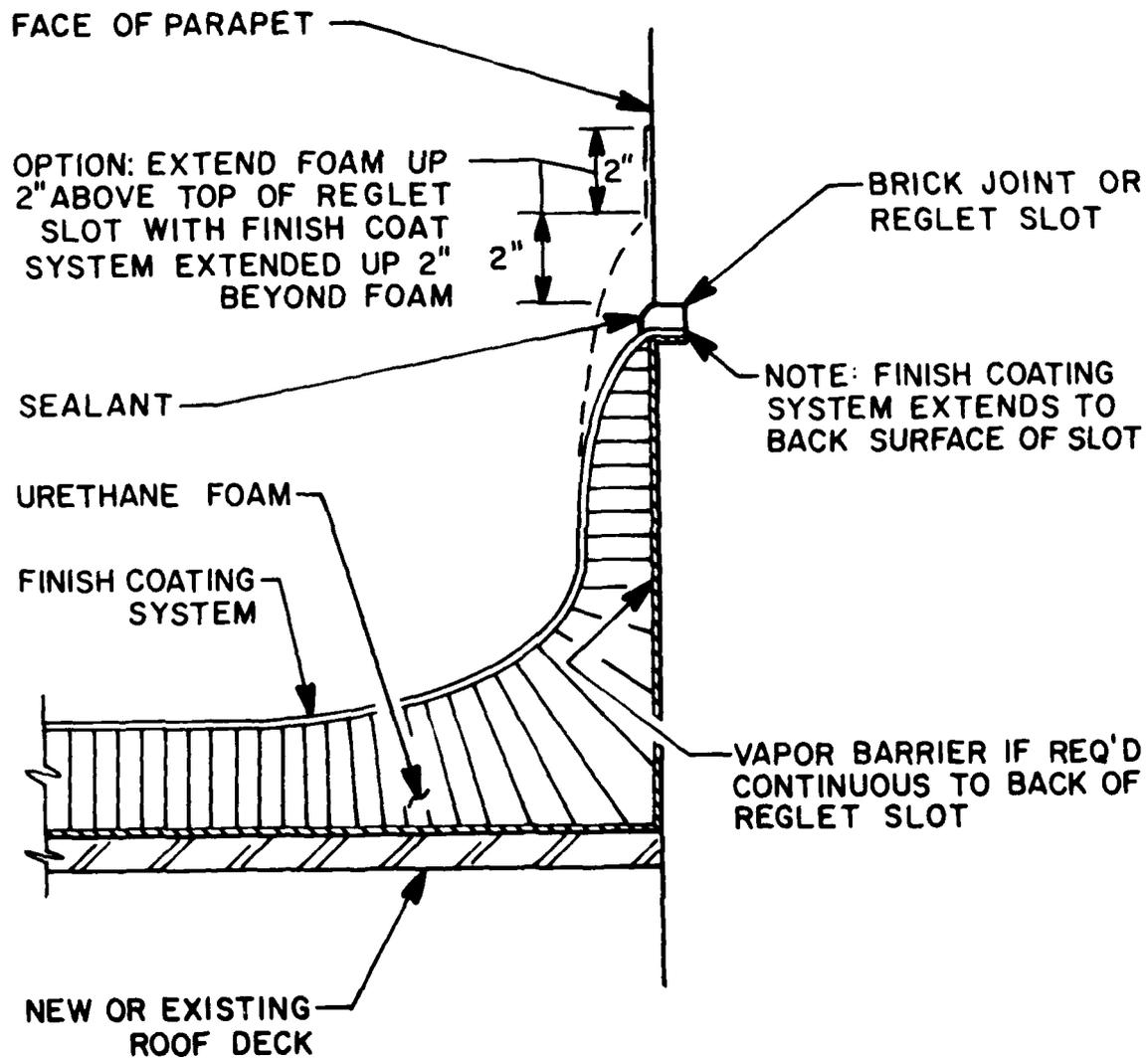


Figure 6. Reglet flashing at parapet.

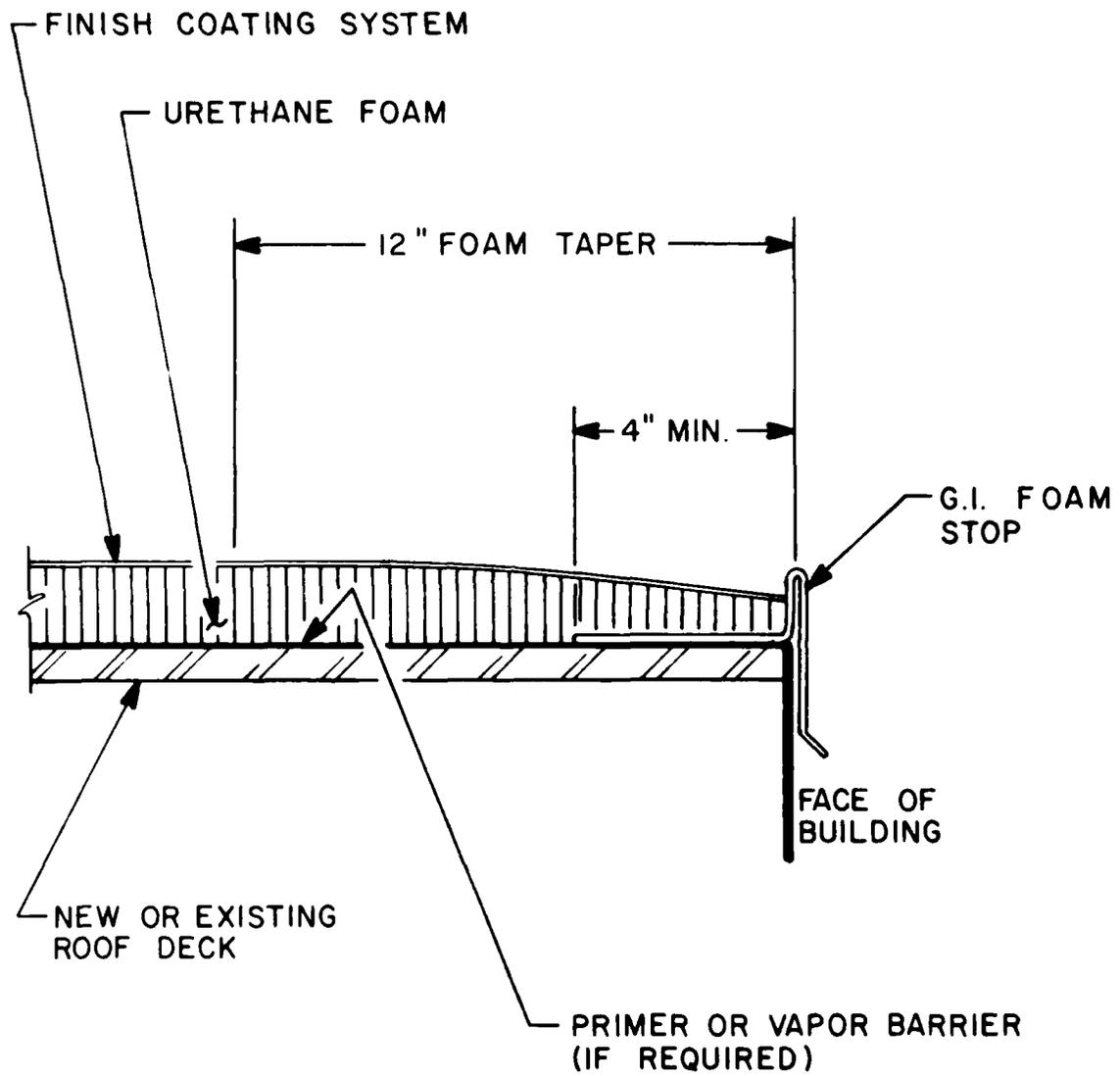


Figure 7. Foamstop detail.

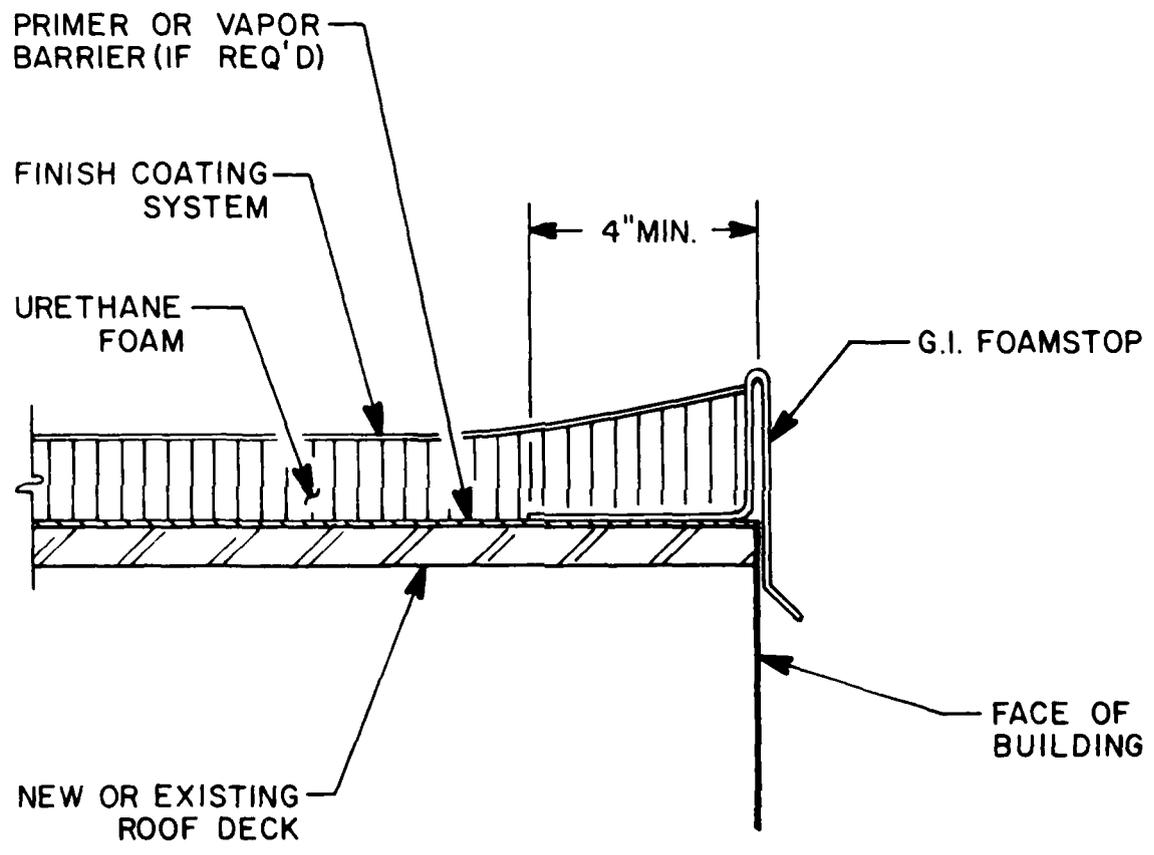


Figure 8. Foamstop detail.

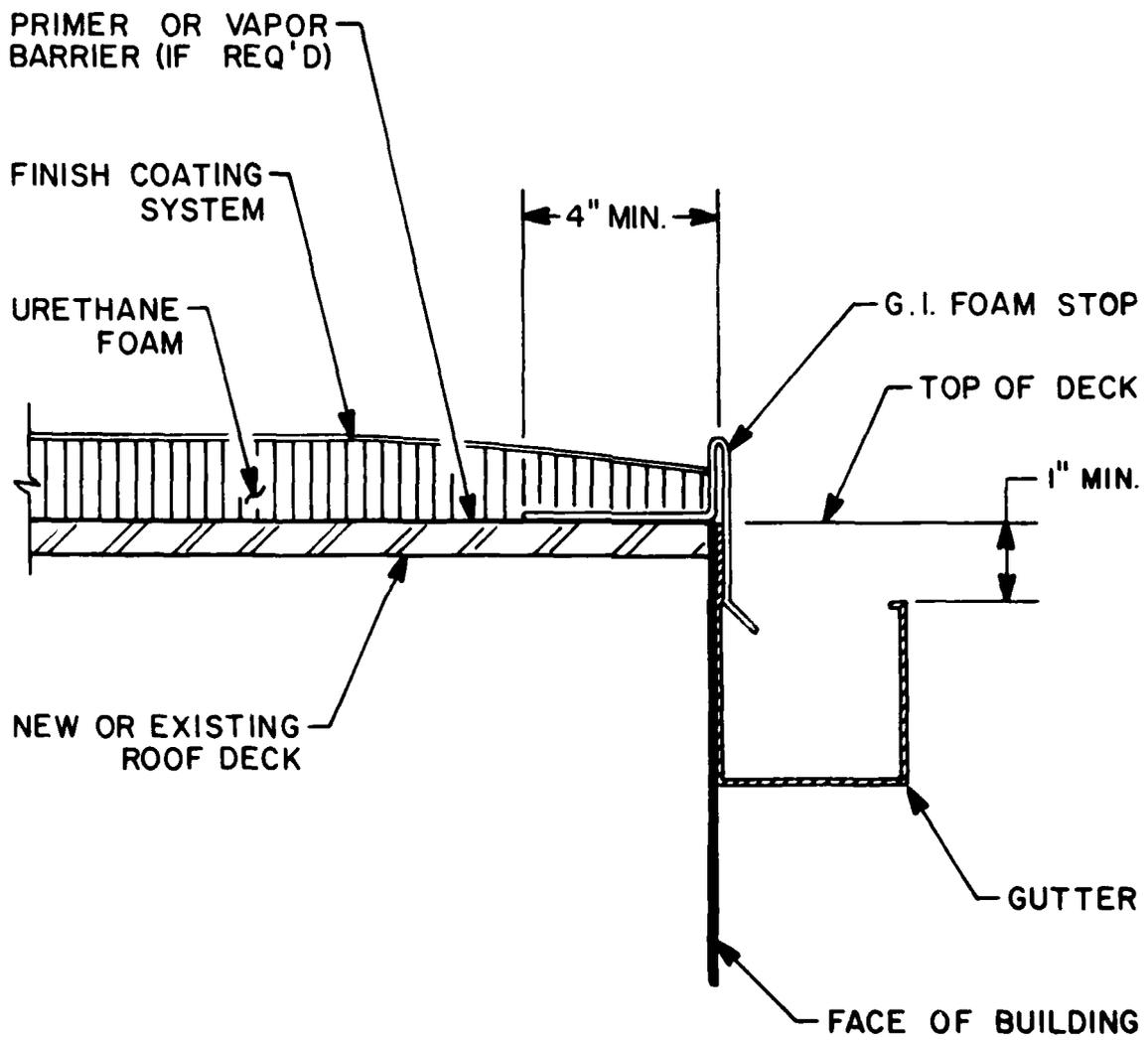
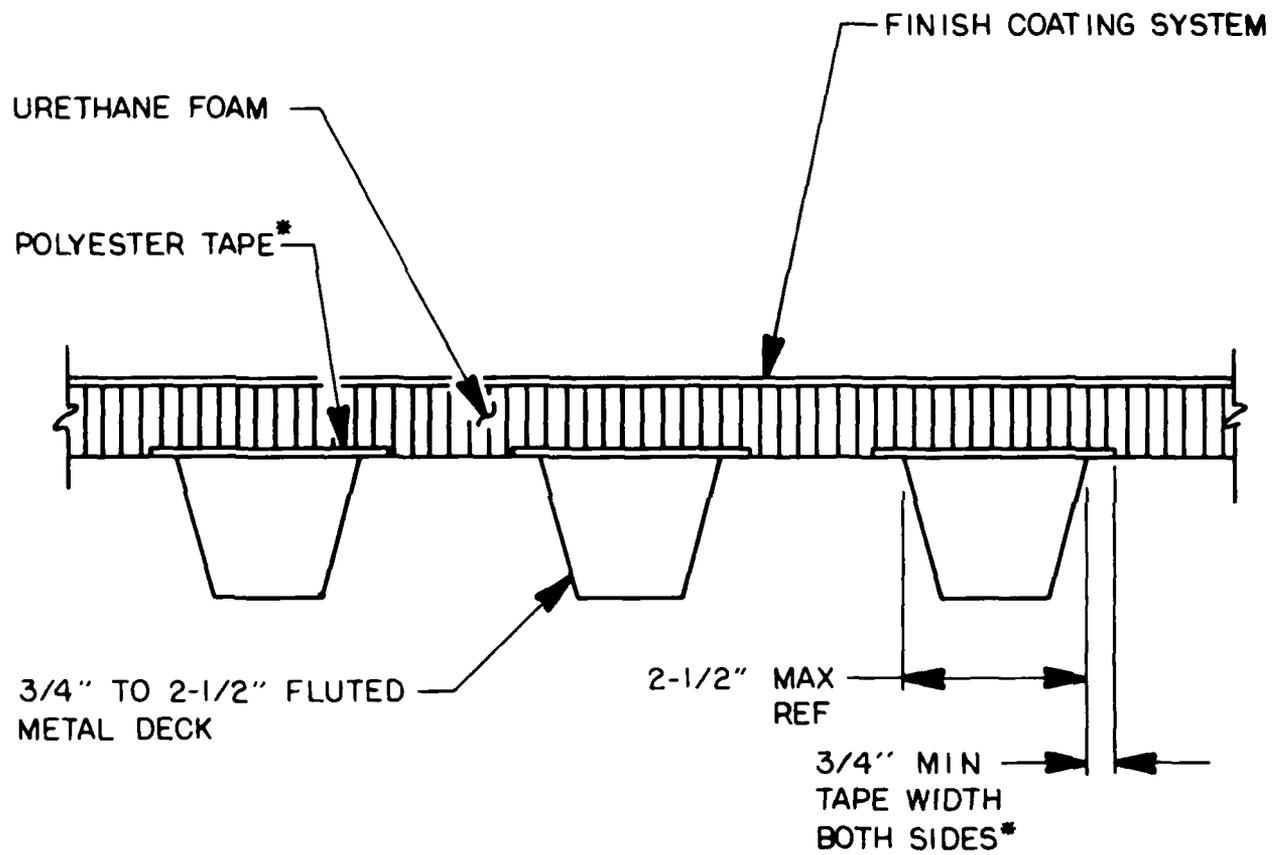


Figure 9. Gutter detail.



* TAPE WIDTH MUST EXCEED FLUTE WIDTH BY 1-1/2"

Figure 10. Metal pan decking detail.

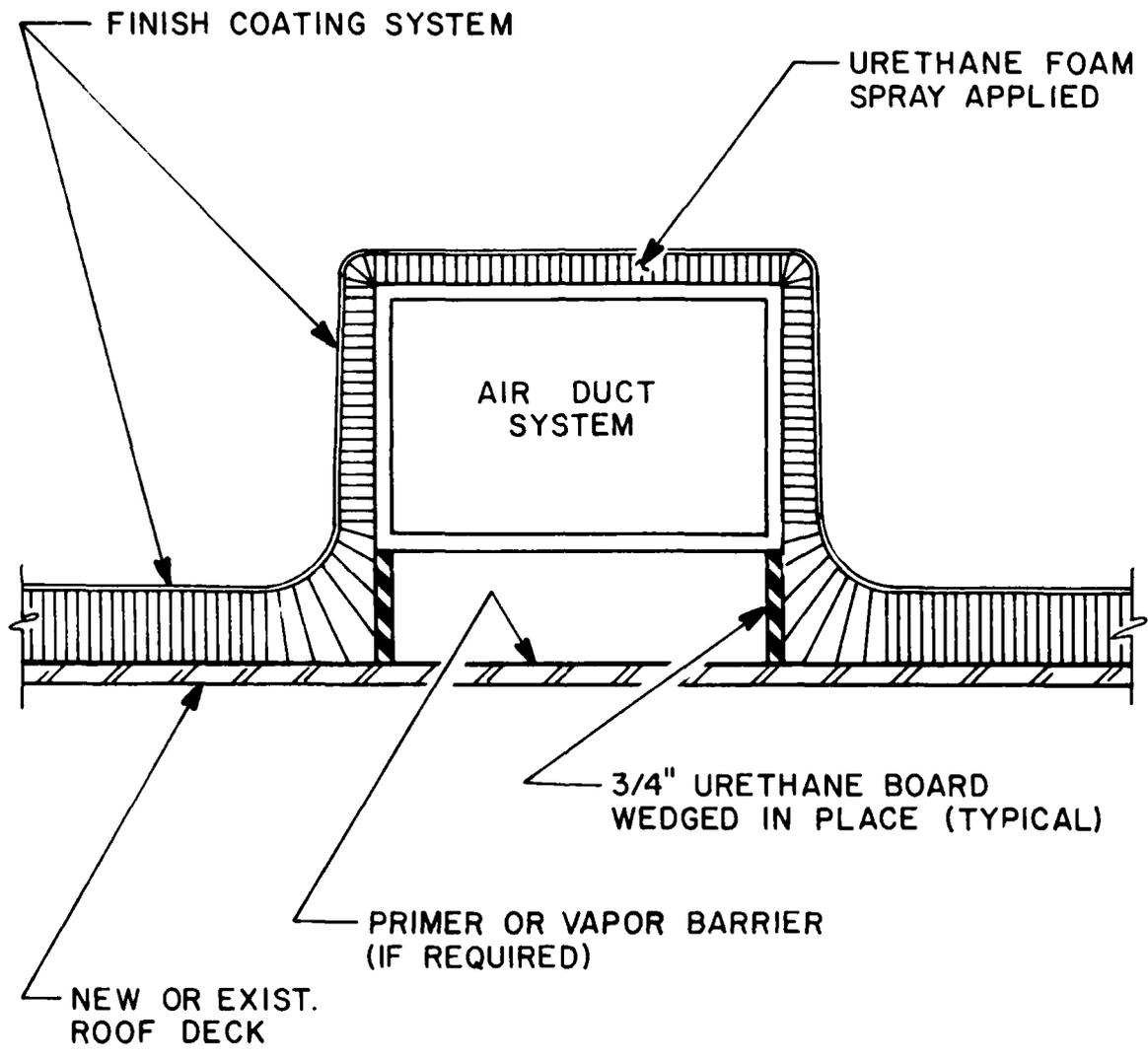


Figure 11. Surface mounted A/C duct.

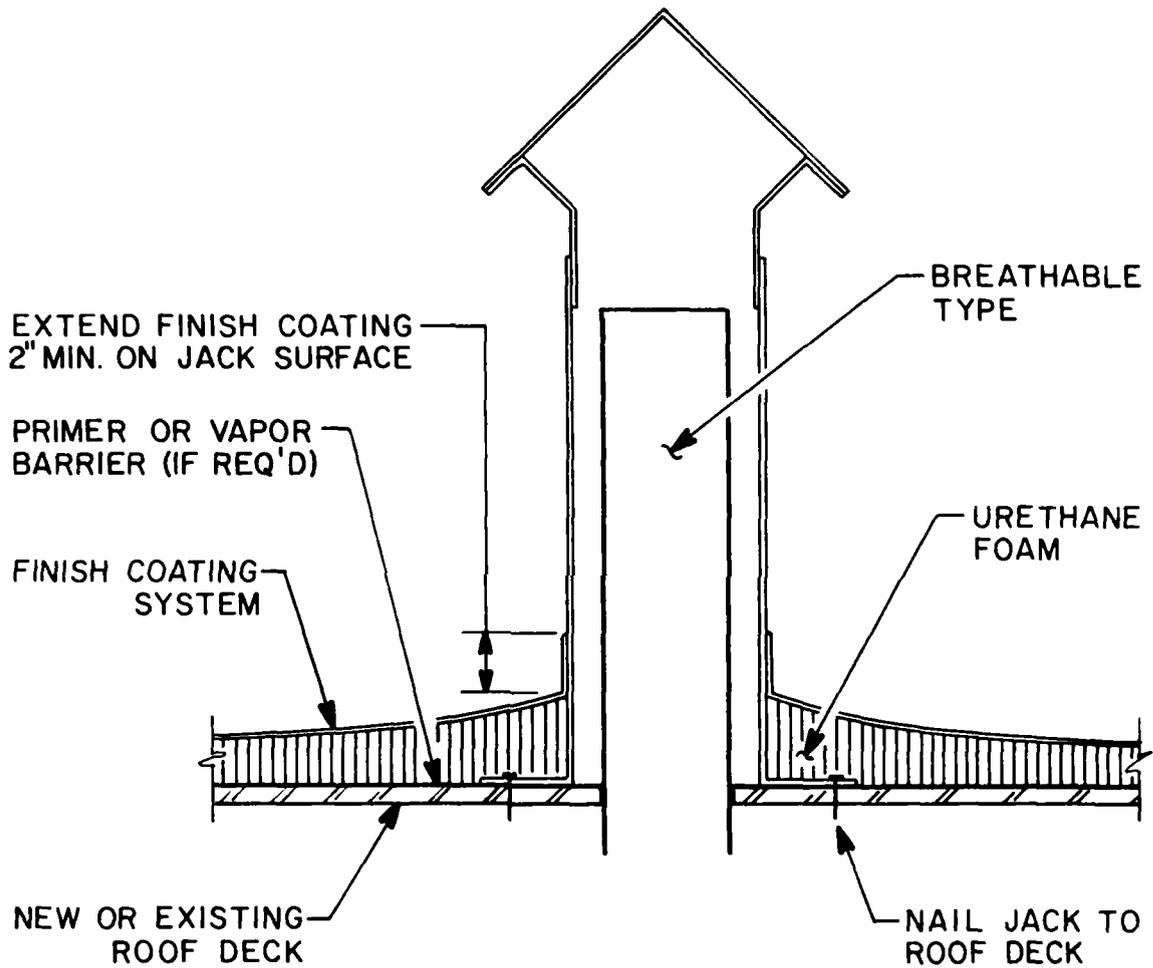


Figure 12. Pressure relief vent detail.

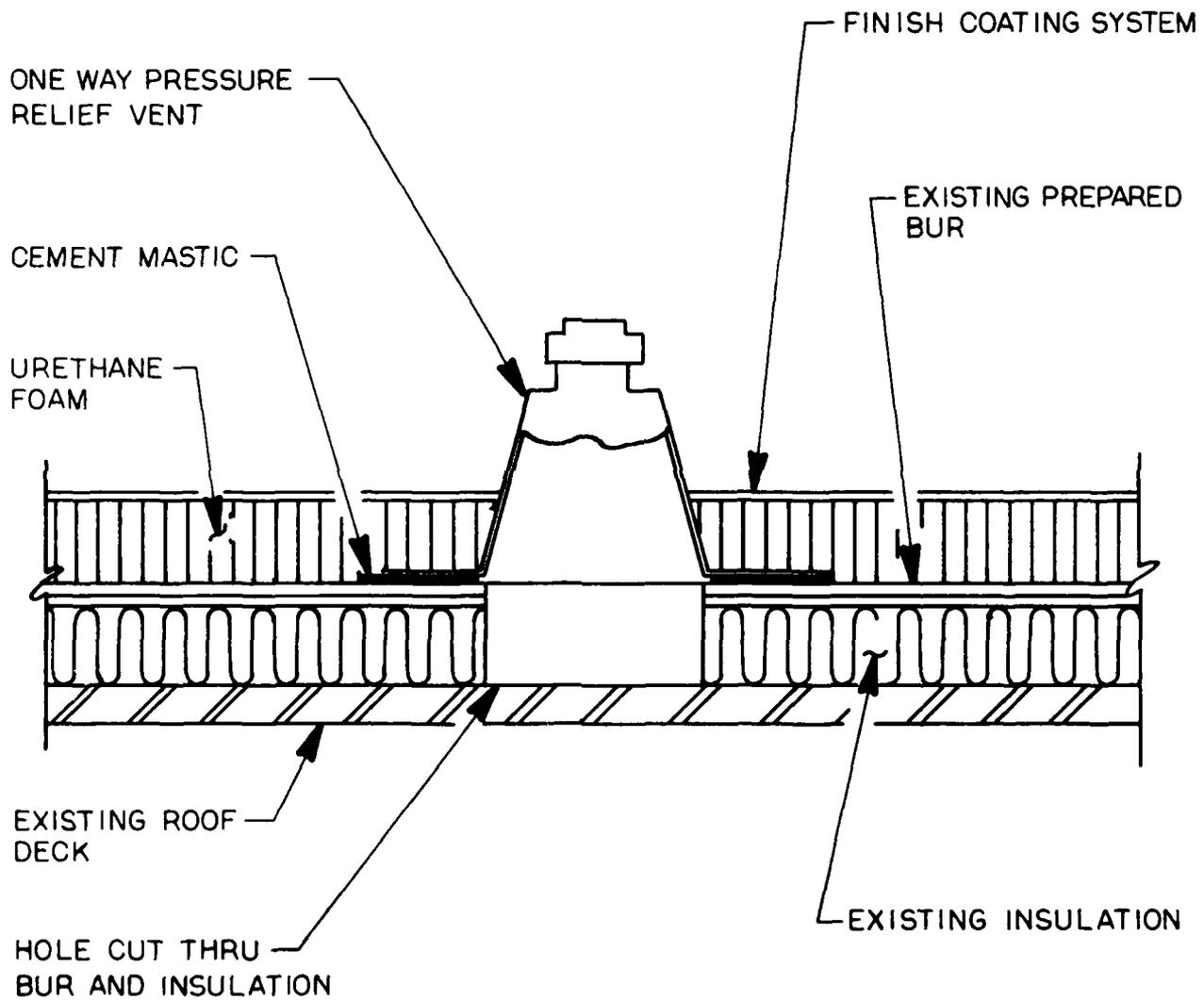


Figure 13. Moisture/pressure vent detail.

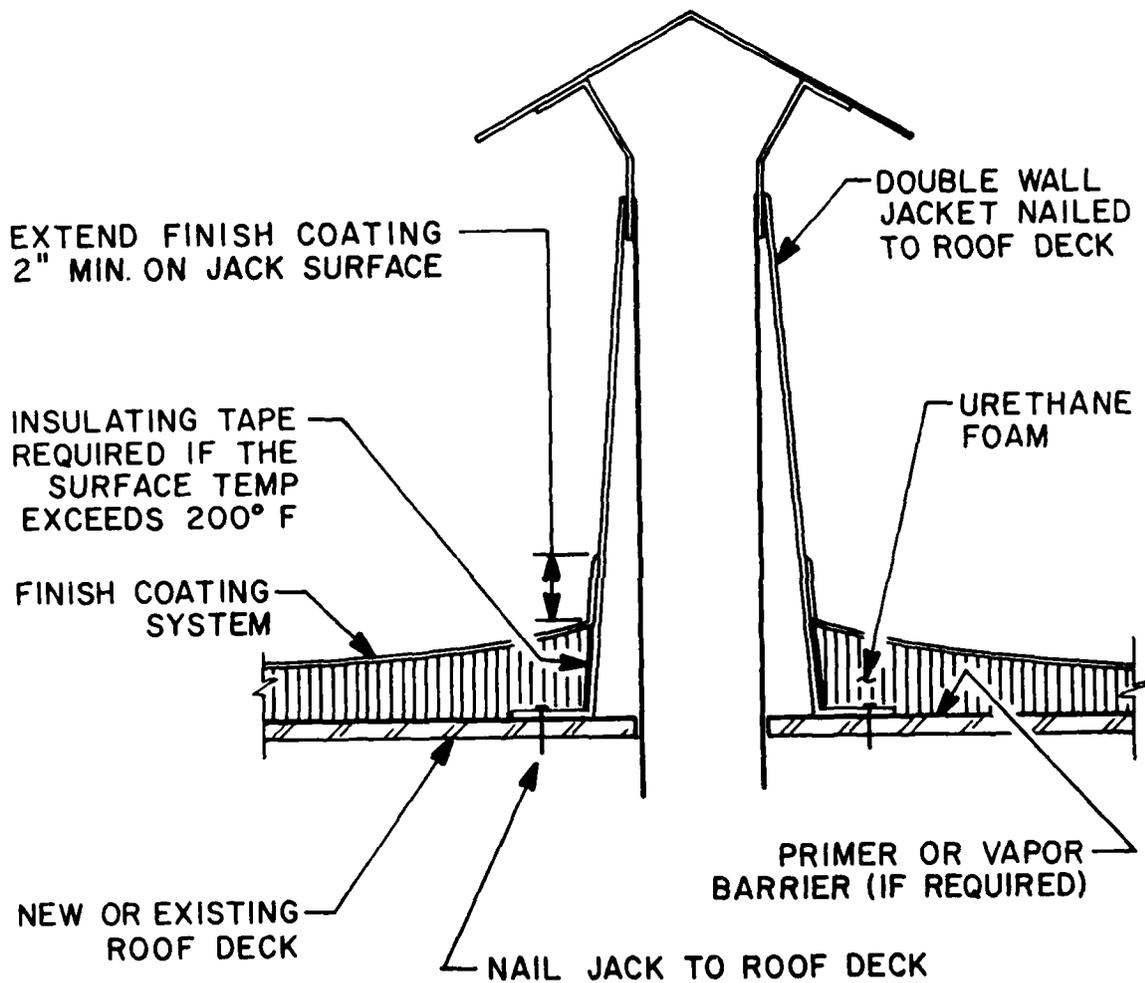


Figure 14. Heat vent jack detail.

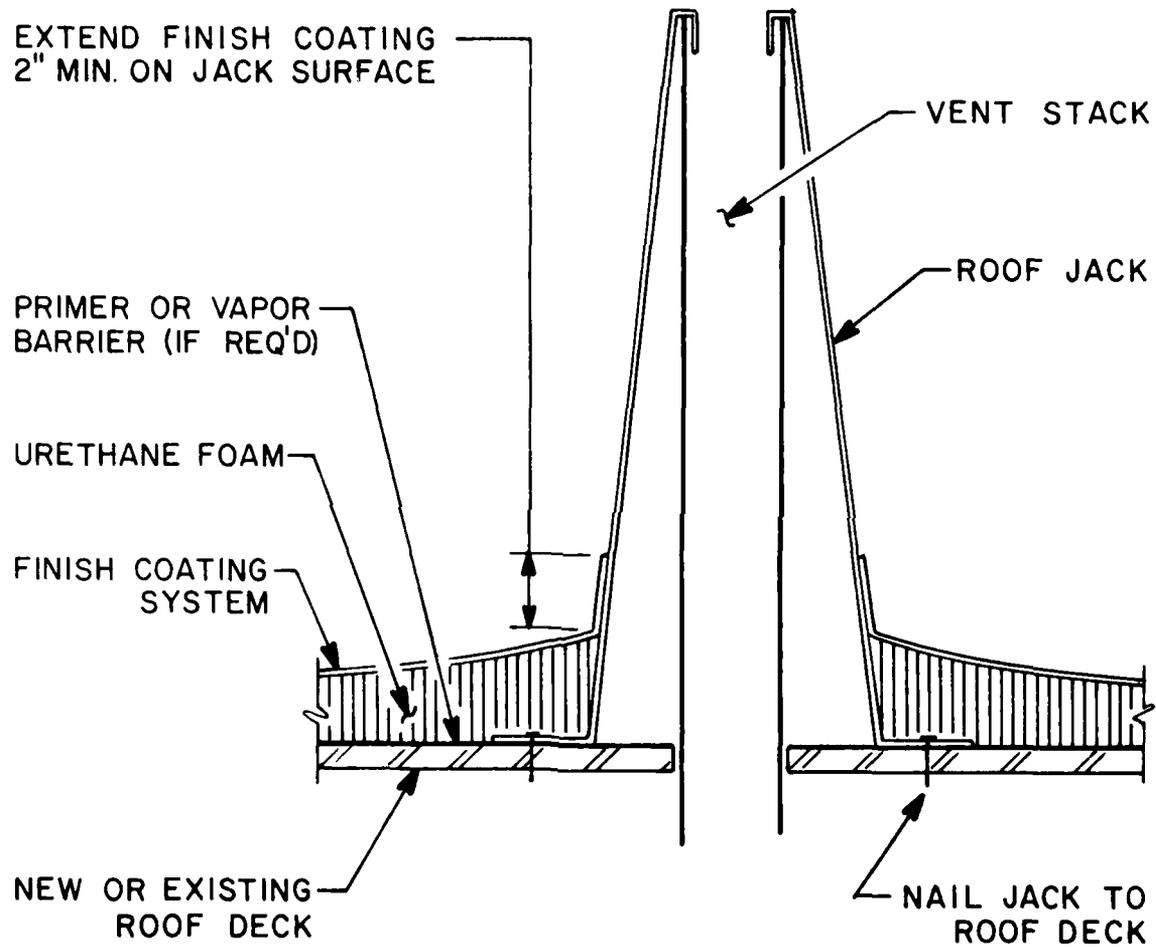


Figure 15. Roof jack detail.

EXTEND FINISH COATING 2" MIN.
ABOVE FOAM TERMINATION POINT

PRIMER OR VAPOR
BARRIER (IF REQ'D)

URETHANE FOAM
SPRAY APPLIED

FINISH COATING
SYSTEM

NEW OR EXISTING
ROOF DECK

VENT OR
PIPE

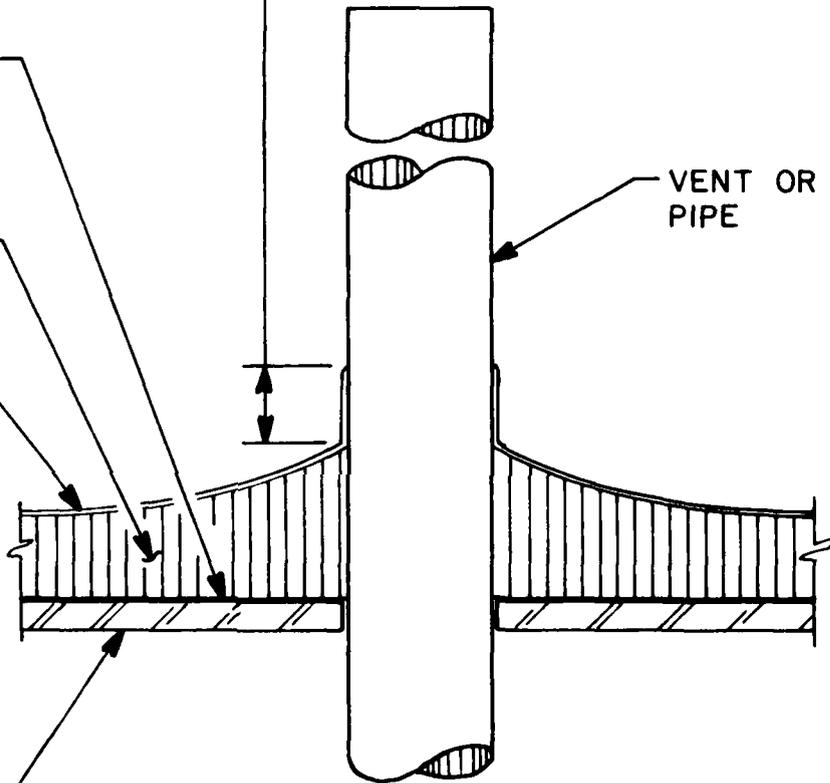


Figure 16. Self flashing around pipe/vent.

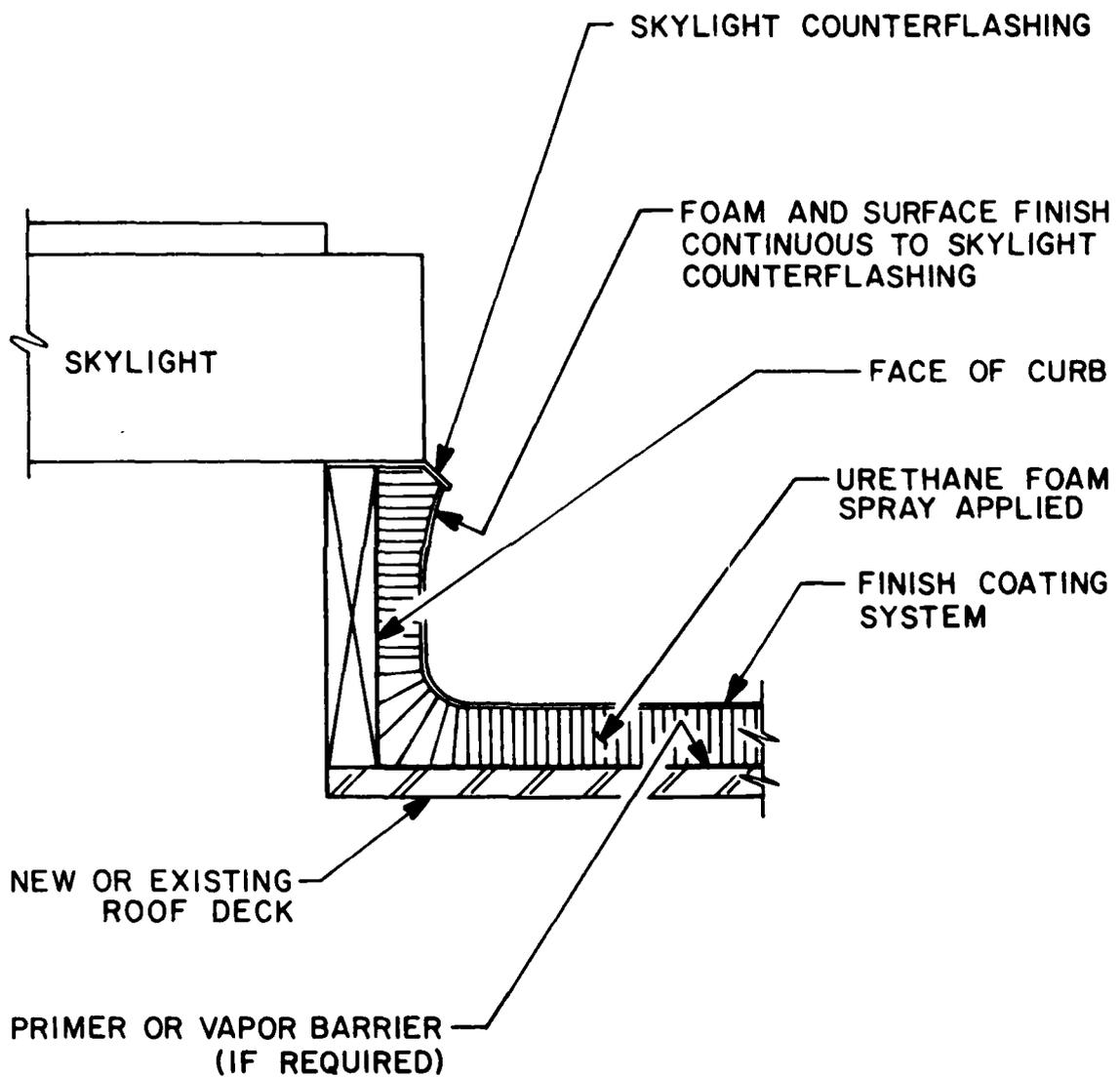


Figure 17. Skylight curb detail.

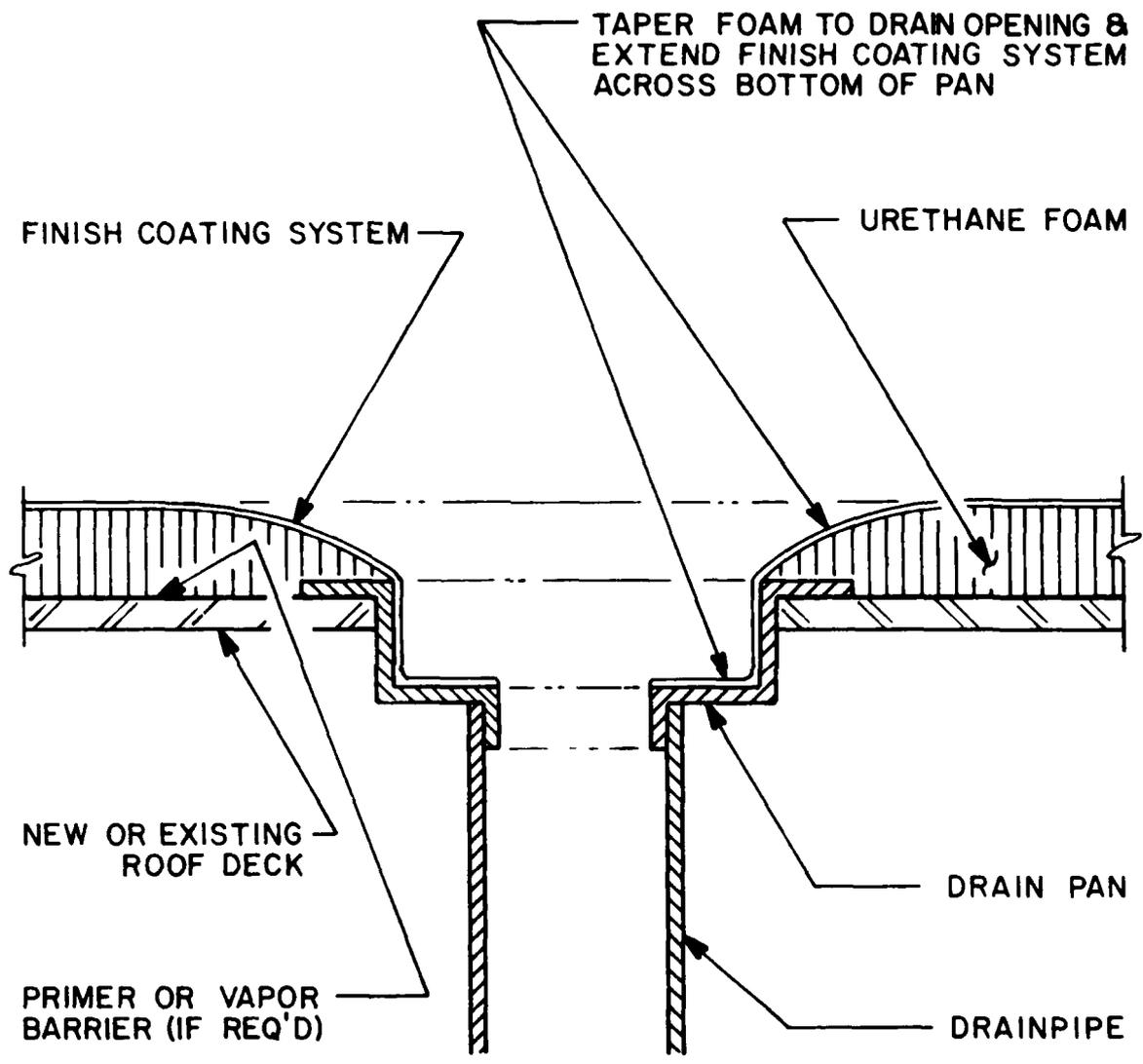


Figure 18. Pan type roof drain.

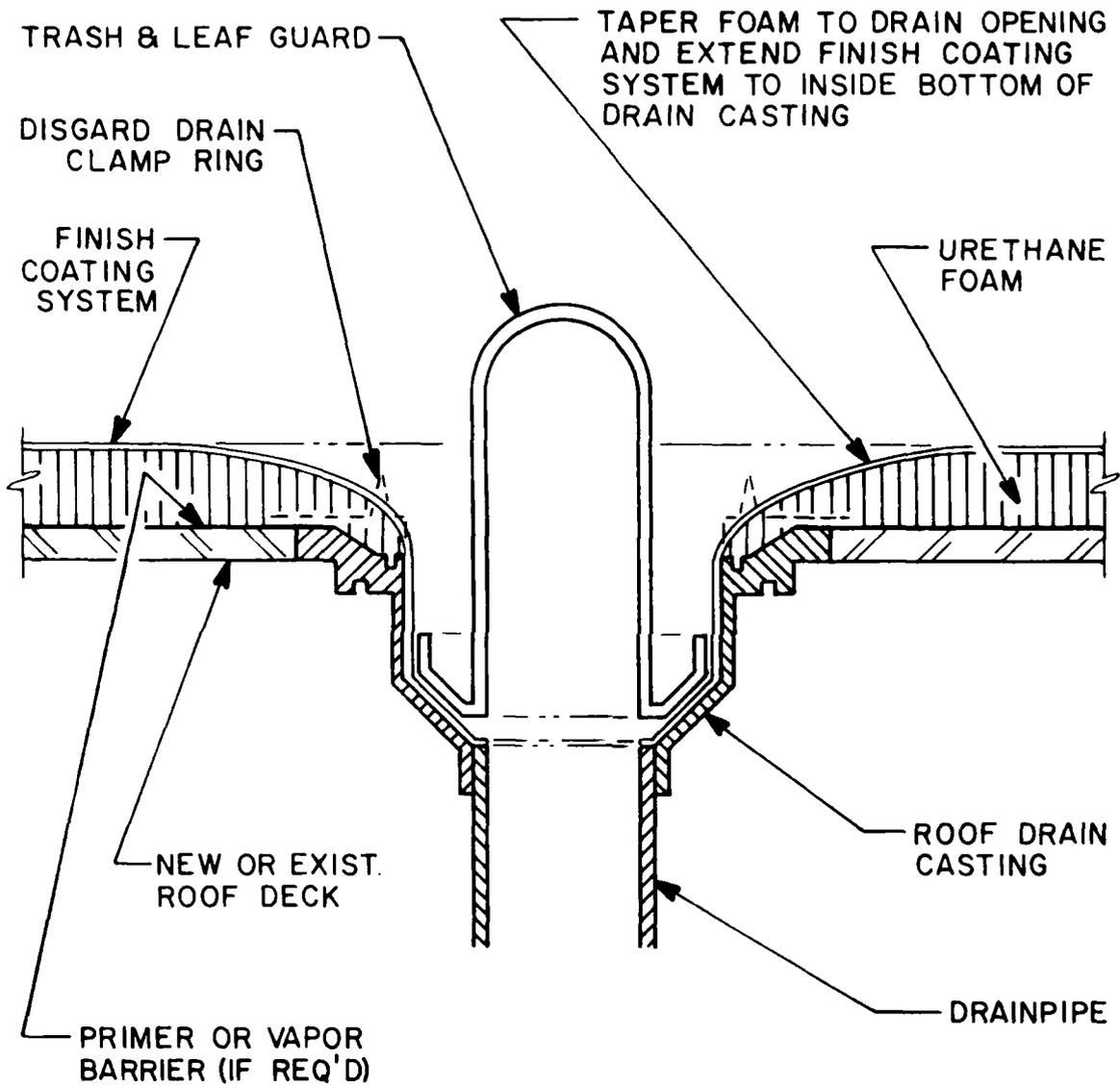


Figure 19. Typical roof drain.

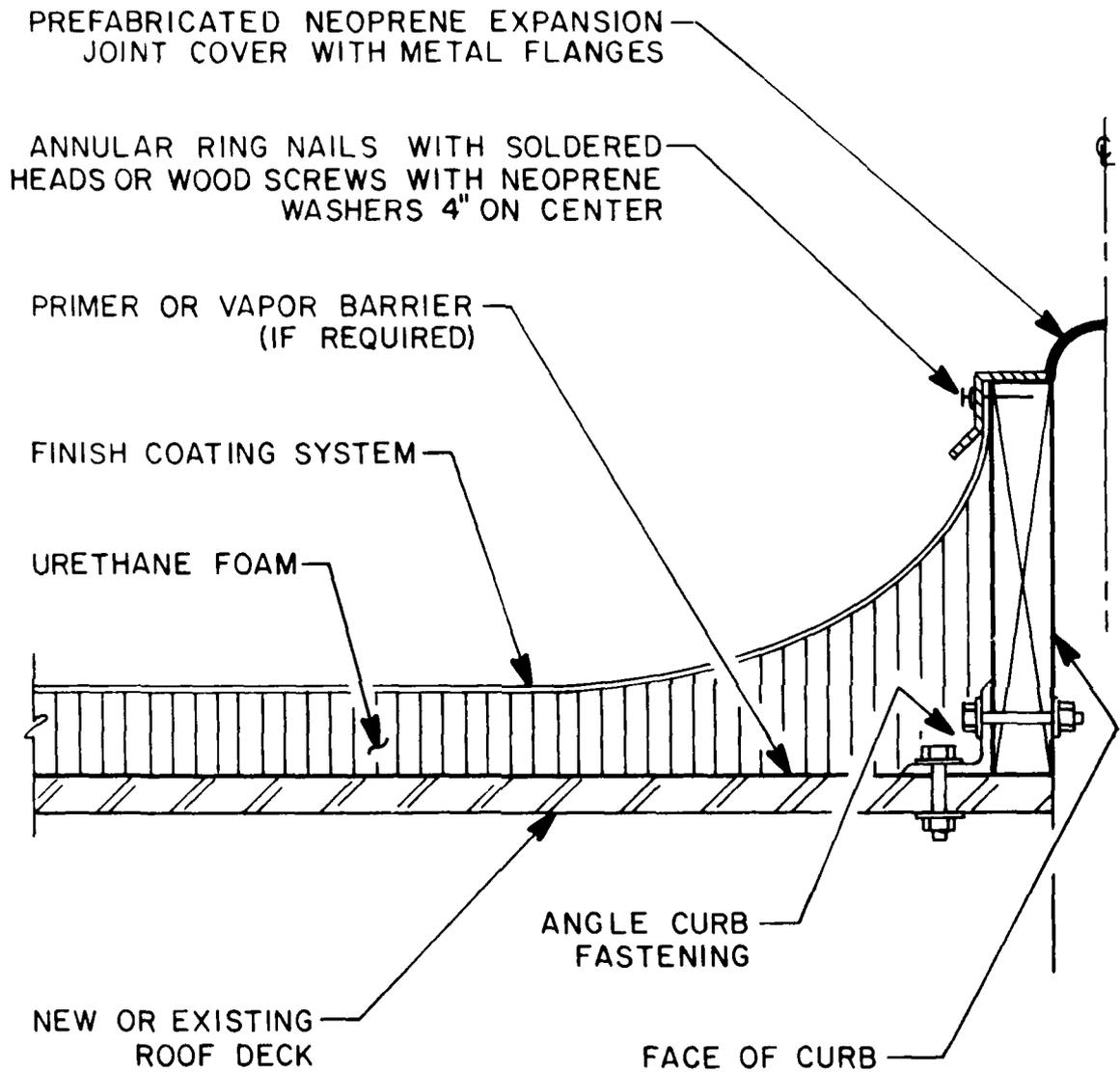
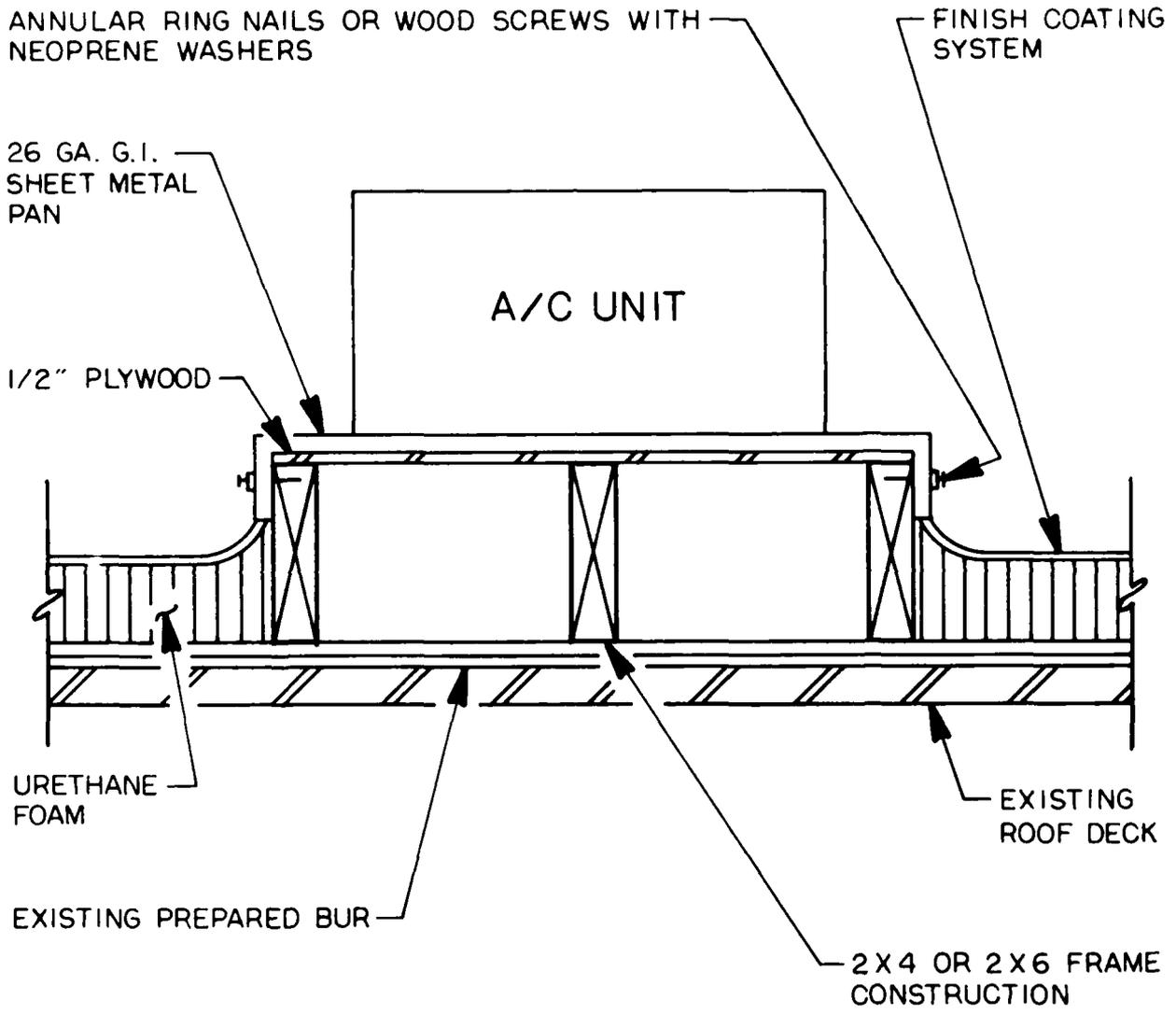


Figure 20. Expansion joint detail.



(LENGTH AND WIDTH OF PAD
SIZED TO A/C UNIT)

Figure 21. A/C pad detail.

- Although the more important design considerations with respect to PUF roofing systems are presented in the Guide, it is suggested that NAVFAC DESIGN MANUAL DM-1.5 on "Roofing and Waterproofing" be consulted for other information of interest.

Fire Safety Requirements

Extensive research and development has been conducted on PUF roofing systems over the past 15 - 20 years with respect to both external and internal fire exposure. Many adverse comments have been made about the flammability and fire safety of PUF roofing systems and many horror stories have been disseminated about potential fire problems with these materials. In actual fact, very few problems have occurred with fire on these systems particularly where proper fire-classified systems have been employed. NCEL has always maintained that PUF roofing systems should meet the same fire safety requirements as any other roofing system. That is, the PUF roof systems should be required to meet Underwriters' Laboratory (UL) or Factory Mutual (FM) requirements.

Criteria in this area are provided by two sources. The first is the Department of Defense Construction Criteria Manual, DOD 4270.1M and the second is NAVFAC Design Manual DM-8. For combustible or metal roof decks, DOD 4270.1M requires that "the entire roof construction assembly, including the insulation, be either Underwriters' Laboratories (UL) fire [classified] or Factory Mutual approved for Class I roof deck construction." That is, either a classification in accordance with UL 790 for exterior fire exposure and UL Subject 1256 for internal fire exposure or a FM Class I classification is required. The UL Subject 1256 or FM Class I is not required if the insulation is installed above poured concrete or poured gypsum roof decks, nominal 2-inch-thick tongue-and-groove wood plank roof decks, or over precast roof deck panels or planks which are FM approved as noncombustible roof deck construction. In such cases, only a UL 790 classification for exterior fire exposure is required.

NAVFAC DM-8 is more specific with requirements for both roof coverings and roof deck assemblies. Section 7 gives the following requirements:

1. Roof Coverings. All roof coverings shall be [classified] by Underwriters Laboratories, Inc. UL Building Materials Directory lists three classes (A, B and C) of acceptable roof coverings based upon Test Methods for Fire Resistance of Roof Covering Materials, UL 790 [for exterior fire exposure]. Class C roof coverings shall be restricted to housing and small, insignificant buildings with light exposure.

2. Roof Deck Assemblies. Roof deck assemblies are composed of decking with materials (adhesive, vapor retarder, insulation and roof surfacing) added in layers to the deck. They may contribute significantly to the spread of fire beneath the roof deck when exposed to an interior fire. Assemblies acceptable from an interior fire exposure standpoint [shall meet the requirements for] Class I in the FM Approval Guide [or] a Fire [classification for Deck Assemblies] in the UL Building Materials Directory. Roof deck assemblies shall be of acceptable type when used in buildings that are not fully sprinklered [i.e., acceptable roof deck assemblies shall have either a FM Class I listing or an UL Roof Deck Construction Classification].

In addition, section 2.1d of DM-8 includes the following:

d. Roof Exposure. "When a combustible exposed building roof is below the top of the exposing building, the exposed roof may receive sufficient radiant heat to be set on fire. A burning brand, large enough to cause pilot ignition, may also fall on the (lower level) roof (from the upper level roof). For such a case, the exposed building roof covering shall [meet the requirements for] either Factory Mutual approved or [classification by] Underwriters' Laboratories [Inc.] as a Class A [built-up or prepared roof covering material]."

Neither these or other DOD or Navy criteria require a particular flamespread rating for roofs. However, most civilian Building Codes require use of a Class II foam (a flamespread of 75 or less per UL 723, ASTM E-84). NCEL believes this to be a reasonable requirement.

SPECIFICATION CONSIDERATIONS

Foam Requirements

Polyurethane foams are complex polymeric materials formed by the chemical reaction between a liquid isocyanate and a liquid polyol (an alcohol containing material). It is common practice within the industry to identify the isocyanate material as the "A" component and the polyol or resin as the "B" component. However manufacturers also use selected code numbers in combination with part "A" and part "B" designations. These two components also contain other ingredients which are of importance in obtaining foams of acceptable quality and physical properties. These include fluoro-carbon blowing agents (R-11), cell-stabilizers or surfactants, fire retardant agents, catalysts, and in some special cases, fillers.

The two components are generally sprayed in a mixed ratio of "one-to-one" by volume. As the "A" and "B" components react heat is produced causing the R-11 to vaporize and form cells in the reacting mass as it changes from a liquid to a solid state. It is the gaseous R-11 contained in closed cells formed in the finished foam that provides the excellent insulating efficiency obtained and the amount of R-11 in the formulation that basically determines the final foam density.

Foam Properties. There are a number of physical characteristics of a foam that contribute to good foam performance. However, the most important of these are the density and the compressive strength. The density of the foam determines the yield, that is, the number of square feet of coverage per pound of foam and hence the cost of the foam per square foot. The density also affects the compressive strength of the foam.

The compressive strength of the foam is possibly even more important because this property is one of the factors that determines the impact strength of the foam and how easily the protective coating and the foam can be damaged under compressive loads on the system in use. Generally, the higher the compressive strength, the more resistant the foam roof is to mechanical damage from foot traffic, dropped tools, etc. Sprayed PUF used in roofing systems should have a density of 2.5 to 3.5 pounds per cubic foot and a MINIMUM compressive strength of 40 psi.

Other Considerations. Two important aspects of the applied foam which should be controlled by the specifications are the foam thickness and the foam surface texture.

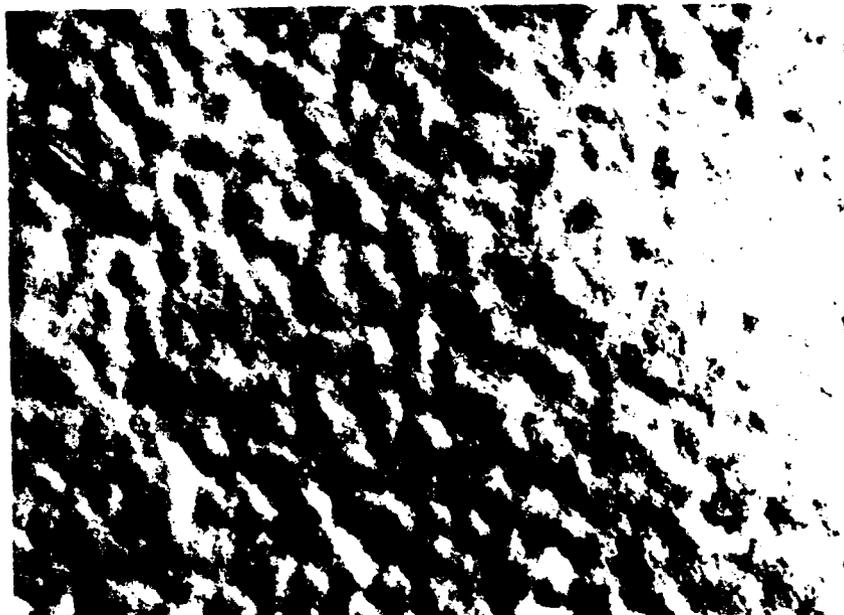
The mixed components of the foam formulation sprayed onto a roof deck or other substrate as a liquid expands 20 to 30 times its original volume depending upon its ultimate density. As the foam rises and sets into a solid, a skin forms on the surface. Each application made to obtain a final specified foam thickness is commonly called a pass or lift and each of the passes will in turn form its own skin. The thickness of each lift is dependent on the skill of the applicator and the metered output of the spray equipment. Optimum pass thicknesses should be from 1/2 to 1-inch. Very thin passes should be avoided in general and should be limited to feathering out or tapering of the foam at termination points, due to the skin formation which may develop stresses that can cause the foam to disbond from the substrate or at the pass lines. Further, in certain applications that may require foam thicknesses approaching 4-inches or more the foam applicator or mechanic may tend to make repeated passes in a short period of time. Caution should be exercised in this regard as the heat generated by the chemical reaction between the "A" and "B" components will be cumulative, due to the insulative nature of the foam, and become so great as to cause scorching in the body of the foam. In some cases the foam may smolder and in the extreme catch fire and burn. The alternative is to permit the applied foam to cool down for suitable periods of time before adding more material when the foam thickness exceeds 2-1/2 to 3-inches. One of the best visual indicators of a good foam application is the appearance of the surface profile or texture. Terms used to describe the foam surface texture are given below:

- Smooth
- Orange Peel
- Coarse Orange Peel
- Verge of Popcorn
- Popcorn
- Treebark
- Pinholes or Blowholes
- Rippling

Photographic standards for these surface textures are described and shown in Figures 22 to 29.

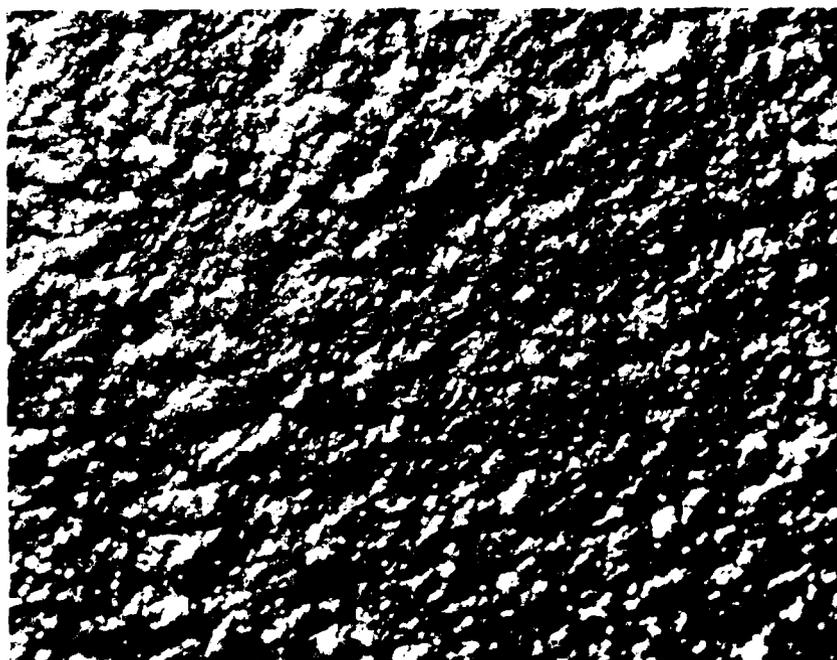
Acceptable surface textures range from "smooth" to "coarse orange peel". "Verge of popcorn" is marginally acceptable. All of the others described, i.e., "popcorn," "treebark," "pinholes," or "blowholes," and "rippling" are not acceptable and should be avoided. The photographic standards are to be used as a reference when checking the surface texture of freshly sprayed foam to determine if the surface is acceptable for coating application.

Surface texture of sprayed foam is a function of many variables, but there are three principal contributing factors: (1) equipment adjustment, (2) environmental effects, and (3) applicator skill. These factors are discussed in more detail in Section V of the Guide.



1"

Figure 22. Smooth foam surface.



1"

Figure 23. Orange peel foam surface.

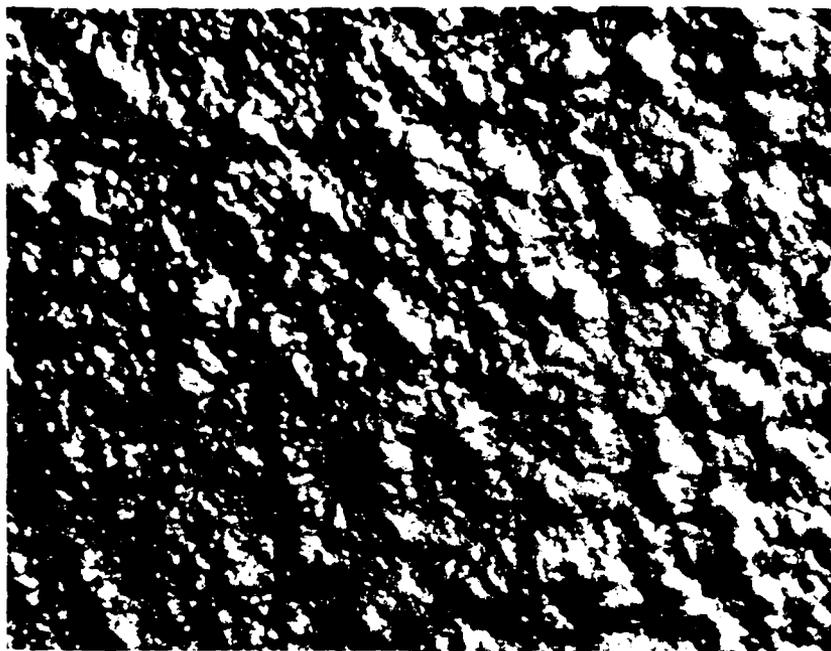


Figure 24. Coarse orange peel foam surface.



Figure 25. Verge of popcorn foam surface.

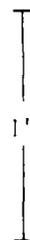


Figure 26. Popcorn foam surface.

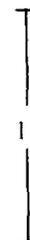


Figure 27. Treebark foam surface.

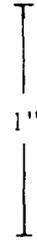
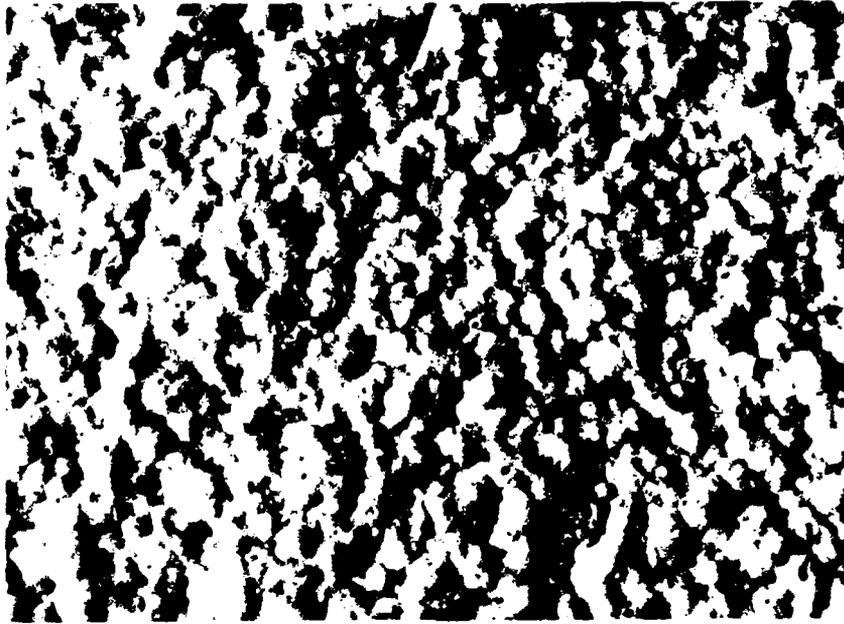


Figure 28. Pinholes or blowholes in foam surface.

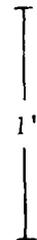
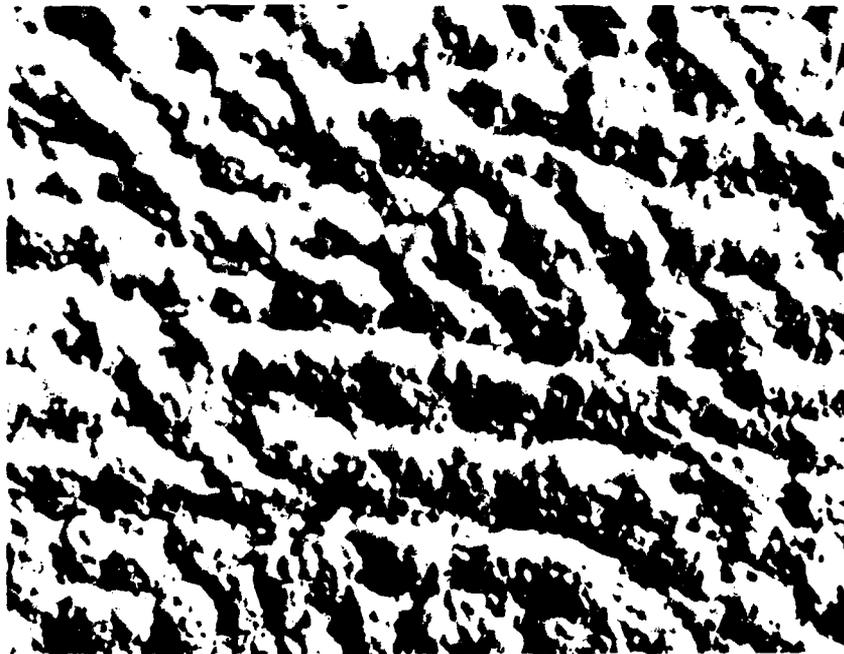


Figure 29. Rippling in foam surface.

Foam Specifications. NFGS-07545 entitled "Sprayed Polyurethane Foam (PUF) For Roofing Systems" provides essential information and requirements for specifying the sprayed foam used in the roofing system and should be consulted for the preparation and writing of specifications.

Coating Requirements

The protective coating material selected for use in a PUF roofing system is one of the most important factors responsible for the satisfactory, long term performance of the system. The coating system must serve multiple functions in protecting the underlying sprayed foam and should be selected from those coatings which have been specifically designed for, and have a proven history of satisfactory performance when used over foam. Any other coating material must be considered experimental.

Historically, a high percentage of premature failures of PUF roofing systems have been traced to a malfunction of the protective coating.

Coating Properties. Based on extensive testing both in the laboratory and in the field, it has been determined that protective coatings for use over sprayed foam must:

- Be elastomeric (i.e., stretch and recover)
- Be resistant to solar degradation and in turn protect the foam from ultraviolet (U.V.) light degradation by the sun
- Be waterproof
- Adhere sufficiently to the foam to resist delamination due to moisture, wind uplift and other mechanical forces
- Be tough enough to withstand physical abuse such as foot traffic, dropped tools and hail impact
- Have necessary fire resistance when tested in combination with the foam

Coating Types. There are several different generic types of elastomeric coatings that are available and that have performed satisfactorily on sprayed PUF roofing systems. In addition to the different generic types of coating materials, there is an important subdivision or classification that places a coating into one of two categories, (1) permeable or (2) impermeable with respect to moisture vapor transmission (MVT). These categories are also commonly referred to as "breathable" and "non-breathable".

Permeable coatings are those that permit passage of certain amounts of moisture vapor through the film, which will vary with the dry film thickness (DFT), but do not permit entry of liquid moisture (water). Impermeable coatings retard the passage of moisture vapor through the coating film, except at very low levels, and are also impervious to liquid moisture or what is sometimes referred to as "hydraulic" effects.

In the industry, coatings that have a perm rating, at a given DFT, above 1 perm are considered to be permeable while those with a perm rating below 1 perm are said to be impermeable. Obviously, there is very little difference in the permeability of a coating having a perm rating of 1.1 and another with a rating of 0.9 perm. However, the first is considered to be permeable while the second is not. Typically, the spread would be greater than the above example, but in certain building applications or environments the choice would not be critical. However, when a coating is required to protect the foam and the structure from a strong moisture vapor drive, such as a refrigerated cold storage building, an impermeable coating with a very low perm rating should be used.

Coating Selections - Permeable Types

Acrylics. Acrylics are single-component, water-based elastomeric coatings that cure by evaporation of water in the formulation. Because they are water-based total film coalescence is not obtained until the applied coating is completely dried. Therefore, if they are subjected to dew, rainfall or other moisture prematurely the coating may be re-emulsified with a resultant loss of film properties or loss of applied coating by wash-off. Newer materials are available that tend to minimize wash-off problems. Also, acrylic coatings are subject to freezing when applied at low temperatures which may destroy the quality of the coating. However, when acrylics are properly dried they have good properties, are generally lower in cost than other coating types and perform very well in environments that have low or moderate humidity. Acrylic coatings should not be subjected to severe water ponding conditions and should be limited to use in warm or moderate climate areas. They should not be applied in severely cold climates where freezing can occur prior to film coalescence.

Single-Component Silicones. The single-component silicones cure by reacting with moisture in the atmosphere (humidity) following evaporation of solvent(s) in the coating formulation. These coatings exhibit low toughness and elongation, are occasionally subject to bird pecking damage and are more easily damaged than other coating types. The silicone coatings have some surface tackiness and tend to hold static electric charges which contribute to dirt retention. Mineral granules are frequently imbedded into the finished coating surface which improves resistance to bird pecking and virtually eliminates the dirt retention problem. The problems described are minimized by the fact that silicone coated roofs weather extremely well with little or no change in original coating film properties or thickness and there are many silicone/PUF roofs that are in excellent condition after more than 10 years of service. The silicone type coatings are the most permeable to MVT and rarely, if ever, exhibit blistering caused by water vapor.

Two-Component Silicones. The two-component silicone coatings cure by chemical reaction of the components in the formulation and do not rely on atmospheric moisture. This type coating requires plural component spray equipment for application because of a rapid chemical reaction between the two components once they are mixed. The proportions in which the two components are mixed must be closely controlled and the ratio

should be checked periodically during the course of the application. The two-component silicones have the same problems as described for single component silicones but also offer the same excellent service and performance.

Single-Component Urethanes. Single-component urethane elastomeric coatings are also called moisture-curing urethanes because they cure by reaction with atmospheric moisture following solvent evaporation. These materials are quite tough and have good tensile properties. However, they generally do not weather well, due to their aromatic chemical structure, and are usually used in combination with Hypalon or aliphatic urethane top coats. Moisture-curing aliphatic topcoats are now available that weather better than the aromatic basecoats. In some cases, the single-component urethanes are highly pigmented with aluminum flakes or are used with mineral granules imbedded in the surface to improve weathering performance. It should be noted that the use of a Hypalon top coat will greatly reduce the permeability of these coating and, in fact, may make the system impermeable.

Two-Component Urethanes. These coatings cure by chemical reaction of the components in the formulation and do not rely on atmospheric moisture. They can be aromatic, aliphatic or specially modified in their chemical make-up.

Aromatic urethanes are generally used as base coats for the aliphatic materials and these combination systems are characterized by excellent toughness and high tensile properties, and weather extremely well.

The two-component urethanes are available in two different versions referred to as "standard cure" or "fast cure". The "standard cure" materials are slower setting and have a cure time of 4 to 8 hours. They can generally be batch mixed and sprayed with a standard airless spray unit. The "fast cure" materials are very fast setting and cure in 1 to 60 minutes. These materials must be sprayed with plural component spray equipment. The rapid set and cure features offer the advantage of being able to cover the foam and be unaffected by almost immediate rainfall. It should be noted that "fast cure" materials have been on the market a relatively short time and thus do not have an established performance record as do the "standard cure" coatings.

Coating Selections - Impermeable Types

Butyl Rubber. The most common butyl rubber coatings are two-component materials and are available in "standard cure" or "fast cure" versions. The "standard cure" materials can be batch mixed and sprayed with a standard airless spray unit. However, in contrast with the "standard cure" urethanes these materials have a shorter cure time and limited pot life of 1-1/2 to 2-1/2 hours or less depending upon ambient temperature and the type catalyst used. The "fast cure" materials are very fast setting and cure in 1 to 60 minutes. These materials must also be sprayed with plural component spray equipment.

Butyl rubber elastomer coatings have the lowest perm rating in comparison to the other coatings used in PUF roofing systems and are especially recommended in applications where there is a strong moisture vapor drive from the exterior top-side of the roof toward the inside of

the building, such as roofs over coolers, freezers, etc. These coatings are also highly recommended for unusually wet conditions and unavoidable water ponding situations.

Butyl rubber coatings are not particularly tough and do not weather well, therefore, they should be topcoated with tougher or more weatherable coatings. Hypalons, urethanes and acrylics are frequently used for these purposes.

Hypalons. The Hypalons are a registered trademark of E.I. Dupont de Nemours Co. and are based on chlorosulfonated polyethylene rubbers. They are generally fast drying, single-component materials that cure by solvent evaporation. They have excellent fire retardancy, chemical resistance, weathering properties and low permeability.

Hypalons were frequently used in combination with Neoprene base coats in the early stages of the urethane roofing industry. However, due to relatively poor performance, Hypalons are now used primarily as a total coating system or as top-coats over butyl rubbers or moisture-cured urethanes, if at all. Hypalon coatings are difficult to apply on a pin-hole free basis due to their low volume solids and high solvent content. Also, they require multiple coat application to build sufficient film thickness. Additional disadvantages are that although they weather well, they chalk heavily and tend to show loss of flexibility as they age. Hypalon coatings are of limited interest in today's market.

Modified Urethanes. These are urethanes which are specially formulated with various nonreactive resin plasticizers, synthetic hydrocarbons, refined oils, tar or asphalt. The modifications are typically used to obtain or improve specific properties such as impermeability or as a means to lower cost. Due to the variety of modifications possible, physical properties vary widely.

The modified urethanes are also available as single-component and two-component formulations. Certain of the modified urethanes are relatively new in the market and should be regarded as experimental coatings.

Selection of Generic Type

The two-component urethane coatings and single or two-component silicones all have a well established history of performance and are frequently the coatings recommended. However, high quality acrylics also perform very well in proper environments and applications. In fact a recent survey cited acrylic coated PUF roof systems approaching 10 years in age in very good condition that had not been recoated. While there are a number of high performance acrylics on the market (i.e., those that are 100 percent acrylic elastomers), new acrylics and blends containing acrylics are continually being introduced and care must be exercised in their selection. Although the urethanes and the silicones are higher in cost than the acrylics, they generally can be expected to provide longer lasting protection to the foam without the cost of recoating.

The butyl rubbers, Hypalons and certain modified urethanes tend to be used in speciality applications in combination with the other coatings and should be given careful consideration when being specified.

Other Considerations

Thickness. A frequent cause of failure of protective coatings that may have otherwise been properly selected and applied is the lack of adequate dry film thickness (DFT). Due to accumulated experience, the Navy recommends that the minimum DFT of all elastomeric coating systems be 30 mils (0.030 inch). Thirty dry mils is the minimum coating thickness acceptable on the peaks or high points of the surface texture of the foam not in the valleys or low points. It is not an average of all values, it is the minimum DFT allowed. Some manufacturers recommend less than 30 mils DFT while others recommend more than 30 mils. The Navy recommends that only those specifications for more than 30 mils DFT be followed. It is particularly recommended that silicones have 30 mils DFT minimum, and urethanes or acrylics 40 mils DFT minimum. In extremely humid climates urethanes should be specified at 45 mils minimum DFT.

Roof Slope. The selection of a coating system is guided by the slope of the roof deck to the extent that the following coatings should be used only for applications with positive drainage and no water ponding conditions.

- Acrylics
- Silicones

Cost. The cost of the coating system should not take precedence over the physical properties or performance attributes required in selection of the coating system. Frequently, failures of PUF roofing systems are created as a result of economic considerations being given priority over performance.

Coating Specifications. NFGS-07540 entitled "Fluid-Applied Elastomeric Roof Coating Over Polyurethane Foam (PUF)" provides essential information and requirements for specifying the protective coating materials generally recommended for use by the Navy. Accordingly, this document should be consulted for the preparation and writing of specifications. Also, consult the expanded coating selection chart included in this users guide in Appendix A.

CONSTRUCTION CONSIDERATIONS

The time and effort spent in planning, selection of the PUF roofing system, and creating the best of specifications will all be lost unless close attention is paid to good installation procedures and practices. Since the spraying of polyurethane foam insulation involves the manufacture of a roof system on the job site, the process is subject to various environmental factors. As was mentioned at the outset, the inability to control environmental conditions is probably the one greatest disadvantage of PUF roofing systems. However, through proper knowledge there is much that can be done to assure satisfactory foam roof construction. This section of the Guide provides essential and valuable information in that regard.

Equipment Requirements

Fortunately, properly operated commercial spray equipment for application of both foam and coating materials provides excellent control over ratios of materials, temperatures, and pressures. Therefore, one important aspect is to insure that the equipment used by the contractor is well maintained and running properly.

Foam Equipment. Modern spray foam systems are generally supplied as two-component materials which can be properly metered through the equipment on a "one-to-one" basis by volume. For the best application, the manufacturer's recommendations for operation and maintenance of the equipment should be closely followed. The contractor should not be allowed to vary the density in the field by changing formulation ratios in the spray equipment, because proper formulation ratio is essential to obtain other required properties of the applied foam. Although slight variations in density will result from mechanical tolerances of the equipment, foam formulations generally provide proper results as long as the ratio accuracy of the "A" and "B" components is within $\pm 2\%$ by volume.

Coating Equipment. Spray equipment for application of coatings is usually simpler in design and operation than foam equipment. However, the advent of two-component, fast cure coating systems has created the need for plural component equipment capability or equipment for pre-mixing of materials prior to being fed to a single component airless spray gun. These equipment variations involve ratio metering of coating components that may differ from simple "one-to-one" ratios, therefore, it is essential that the contractor uses the correct equipment and follows the recommendations of both coating and equipment manufacturers.

Application Requirements - Surface Preparation

Any roof deck or roofing surface on which urethane foam is to be sprayed must be securely fastened to the substrate to preclude wind uplift or tear off. Surfaces to which foam is to be sprayed must also be clean and dry. A nominally clean surface is one that is free of loose rust, scale, grease, or other contaminants. A dry surface is one that is free of visible moisture. A moisture meter such as that shown in Figure 30 may be calibrated to verify surface dryness. For example, it can be established that a given reading with such a meter indicates acceptable dryness.

Application Requirements - New Roof Decks

Metal Surfaces. Metal surfaces having loose scale or rust must be cleaned in accordance with Steel Structure Painting Council Bulletin SP-63 Commercial Blast Cleaning. If free of rust or loose scale, the surface may be cleaned by use of air jet, vacuum equipment or with a hand or power broom to remove loose dirt. Grease, oil or other obvious contaminants must be removed by use of a proper chemical solvent.

If a fluted metal roof deck is employed, the flutes can be covered with polyester tape, PUF board stock may also be cut and wedged into the flutes or other suitable methods may be used for covering or filling of

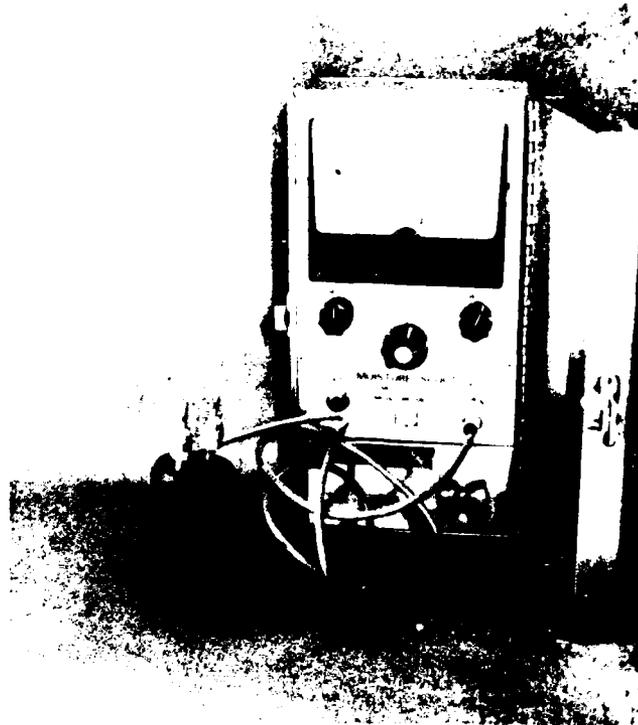


Figure 30. Moisture meter.

the flutes. In addition, any application of sprayed foam to fluted or other metal decks must comply with correct fire safety criteria, such as those specified in DOD Construction Criteria Manual 4270.1M and/or DM-8, Fire Protection Engineering.

Priming of surfaces with weathered or chalking paint may be required as well as galvanized metal surfaces. In such cases, the recommendation of the foam or coatings manufacturers should be followed.

Concrete Surfaces-Precast, Prestressed. Sprayed foam generally adheres well to clean dry concrete surfaces. Form oil, other oil, grease, and form release agents must be removed by the proper chemical solvent. Loose dirt may be removed by air jet, vacuum equipment or brooming. If washing with water is used, the surface must then be thoroughly dried prior to foam application.

Concrete decks may have joints or irregular surfaces that require remedial procedures prior to foam application. Joint openings of more than 1/4-inch between mating panels of beams should be taped prior to foam application. Similarly, mating edges of precast or prestressed single and twin tee beams offset in their level plane more than 1/2-inch may require special treatment.

In some cases, priming may be required prior to foam application. This will depend on the actual job conditions and the recommendation of the foam manufacturer. The preferred primer for concrete surfaces is a low-viscosity, catalyzed epoxy material. Asphaltic primers are not recommended for use.

Concrete Surfaces-Structural Poured-In-Place. Most aspects of substrate preparation (including priming) are the same for structural concrete decks as for precast or prestressed decks.

Wood float or trowelled surfaces which are clean and dry are generally acceptable substrates for sprayed foam.

Due to water of hydration that is present in concrete, it is generally recommended that poured concrete decks be permitted to cure for 28 days prior to foam application.

Concrete Surfaces-Lightweight Fill (Perlite, Vermiculite). Particular attention must be paid to the moisture content of the lightweight fill to be sure that it has dried sufficiently prior to foam application. Contaminants should be removed as recommended for other concrete decks.

Loose granular surfaces must be hardened, such as by use of a low viscosity, catalyzed epoxy primer which will penetrate and harden the surface. The surface should be relatively smooth and firm.

Wood Surfaces-Plywood. All untreated and unpainted wood surfaces should be primed with a good grade exterior primer recommended for the purpose in order to minimize problems with moisture absorption and eliminate potential foam adhesion problems. Primer should be applied in accordance with the manufacturer's recommendations. Plywood joints in excess of 1/4-inch should be taped or filled with a suitable caulk sealant prior to foam application. The deck must be dry and free of loose dirt, grease, oil and other contaminants prior to application of primer or foam.

All contaminants on the primed surface must be removed by a method that does not remove previously applied primer. Loose dirt can be removed by use of air jet, vacuum equipment, hand or power broom. Grease, or other contaminants may require removal by use of special solvents. No washing should be permitted.

Wood Surfaces-Tongue and Groove (T&G) Decking, Sheathing, Planking. When T&G decking, sheathing or planking is to be foamed, a plywood or other sheathing overlay may be required due to potential shrinkage cracking from drying and aging of the deck. When overlay materials are used they should be nailed on maximum 12-inch centers with properly sized annular grooved nails. Where the overlay is plywood, all the previous recommendations for plywood wood surfaces apply. In some cases, a non-wood overlay or masonite may be employed requiring special priming. In any event, all standards of a clean, dry deck should apply.

Application Requirements - Existing Built-Up Roofing.

The replacement or repair of an existing roofing system is a many faceted problem. Each roof must be examined to determine the degree of deterioration, extent of any wet insulation, type of materials used, soundness of the roof structure and any existing drainage problems. The existing membrane should be mechanically secure and the surface should be clean and dry. Consideration must be given to these items before specific recommendations can be made regarding partial or complete removal of the existing builtup membrane and installation of a sprayed foam roofing system. Although sprayed foam has been used successfully

for partial repair applications to other roofing systems, such use can introduce a question of divided responsibility for the roofing system should subsequent leaks occur.

Gravel Surfaces. Prior to foam application, all existing non-embedded gravel or slag surfacing material should be removed by means of stiff bristle street broom or powered mechanical sweeper. It is also common practice to use power vacuuming equipment in combination with sweeping to remove all loose dirt, dust or gravel particles.

CAUTION

Care should be taken not to accumulate large amounts of gravel or slag in any one place that might overload the roof deck structure.

Areas where cold application materials may have been previously applied should be examined. Where present in excessive amounts, such as mounds or puddles, these materials should be removed down to existing roofing felts. No washing of the roof should be permitted. All blisters should be cut and repaired or removed back to where the roof felts are firmly adhered. If insulation materials are present and in a wet or spongy condition such areas should be removed and the roof deck permitted to dry. Any loose felts should be secured or removed to provide a firmly adhered base for the foam application.

It should be determined that proper flashing with sprayed foam can be made to existing vents, skylights, flashings, drains, scuppers and other openings or penetrations. Supporting members of roof-mounted equipment such as air conditioning, evaporative coolers, fans and ducts should be examined to assure that they can be properly flashed with sprayed foam. Any changes required should be completed before beginning the foam application. Existing low areas where water ponds and areas with obviously poor drainage to thru-wall scuppers, drains or roof edges should be considered for correction by tapering or sloping the sprayed foam.

Smooth Surfaces. With the exception of the gravel or slag removal defined above, all other items described should be given the same consideration and treatment.

Priming. Existing built-up roof surfaces which are properly prepared, clean and dry do not normally require priming, however, if priming is desired the foam manufacturer's recommendation should be followed with the exception that asphaltic primers are not recommended for use.

Vapor Retarders. In certain types of building construction there is moisture vapor drive from the inside to the outside of the building. In colder geographical areas where buildings are heated through major periods of the year, it is advisable and generally recommended that a vapor retarder be installed at the roof deck surface. Where PUF roofing systems are installed over existing built-up roof coverings, the mopped

roofing felts in-place generally serve to provide the vapor retarder needed. In new construction where wood and concrete decks are employed, butyl rubber coatings applied at the proper DFT provide excellent vapor retarder protection. In the case of metal decks, the main deck areas serve as the vapor barrier, however, butyl rubber tape or other suitable materials should be applied over seams or joints in the deck.

It should be noted that where a butyl rubber coating is applied to the roof deck surface for vapor drive protection, the installed coating also serves as an excellent primer base for the foam application which follows.

The application of PUF roofing systems should not be attempted during periods of inclement weather conditions unless specific procedures or aids, such as tenting or air structures, are employed to insure that the existing conditions do not interfere with proper application. Generally, the weather conditions for application of the foam are more stringent than those required for the coating application.

Foam Application

Moisture Limitations. One of the most fundamental requirements in the successful application of sprayed urethane foam is that the foam be applied to a dry surface. This point should never be compromised. It is important to recognize that the surfaces involved include the foam previously applied which is to receive additional foam, as well as the originally prepared roof deck or substrate.

Moisture present on the surface will react with the isocyanate "A" component of the foam formulation. Any moisture that reacts with the isocyanate component steals this material from the formulation intended to create the urethane polymer and therefore in extreme cases can be the cause for an off-ratio foam in favor of excess polyol or "B" component. 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. The latter condition usually leads to blister formation or delamination at some later point in time.

The following rules should be applied to preclude problems with moisture.

- No foam application should be permitted in the presence of rainfall, mist, fog, snow or visible moisture on the surface.
- Moisture conditions of surfaces suspected to be improper should be checked with a moisture meter, such as shown in Figure 30.
- No foam application should be permitted when moisture meter readings are in excess of a predetermined amount, such as ten percent (10%).
- No foam application should be permitted if the dew point is less than 5°F above the surface temperature of application, as measured by a surface pyrometer, such as shown in Figure 31.

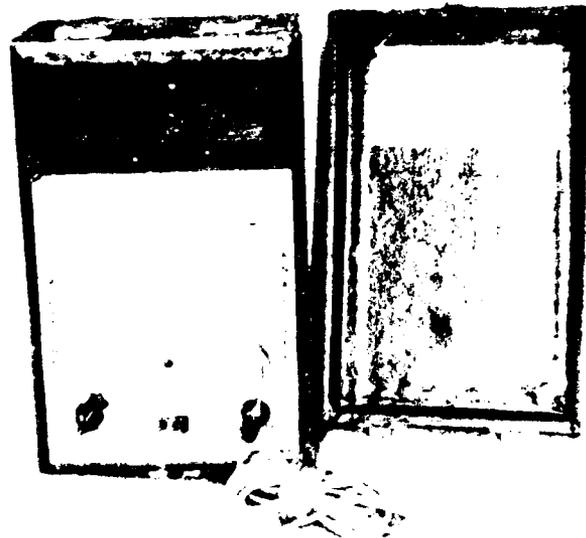


Figure 31. Pyrometer.

One practice that usually results in good foam application and one that is generally required by NAVFAC Guide Specifications is to apply all foam, in a given area, to the desired thickness on a "same day" basis. On large jobs, of course, this is impossible. Under such conditions it is better to complete one section of the roof than to apply part of the foam thickness required over a large area, for completion perhaps a day or two later. The former situation will require that lead edges of foam be tied in at a later time. When such is the case, it is very important to take moisture meter readings at the lead edge of the existing foam surface to be sure that the foam surface is dry.

Urethane foam has a low heat capacity and foam surfaces that become wet or damp will not dry as rapidly as adjacent unfoamed roof deck surfaces. Often the roof 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 occurs most frequently between foam passes and is often caused by moisture present on existing foam surfaces at the time of foam application. The effects on foam applied on a wet surface are shown in Figure 32.

Temperature Limitations. Extremes of temperature where surfaces for application of sprayed foam are either too cold or too hot can affect foam quality with respect to physical properties as well as surface texture and adhesion. It is important to understand these effects and be able to recognize them when such conditions exist.

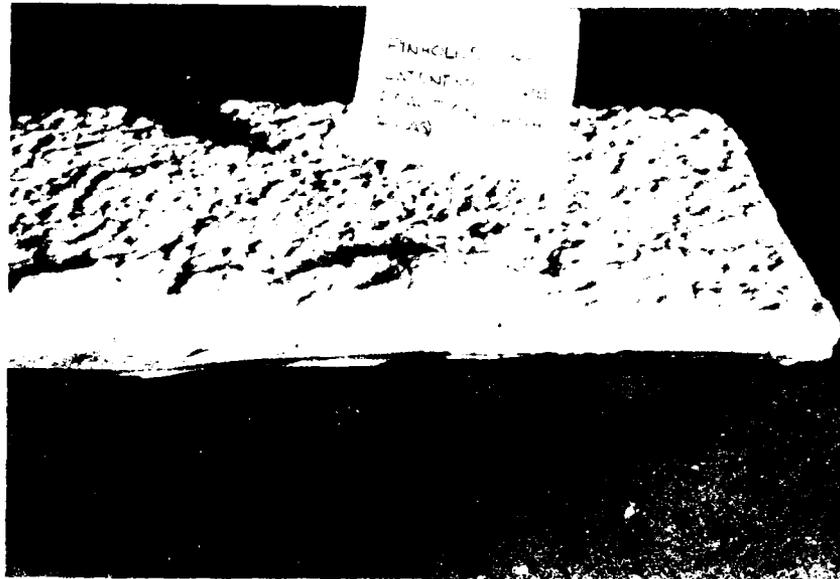
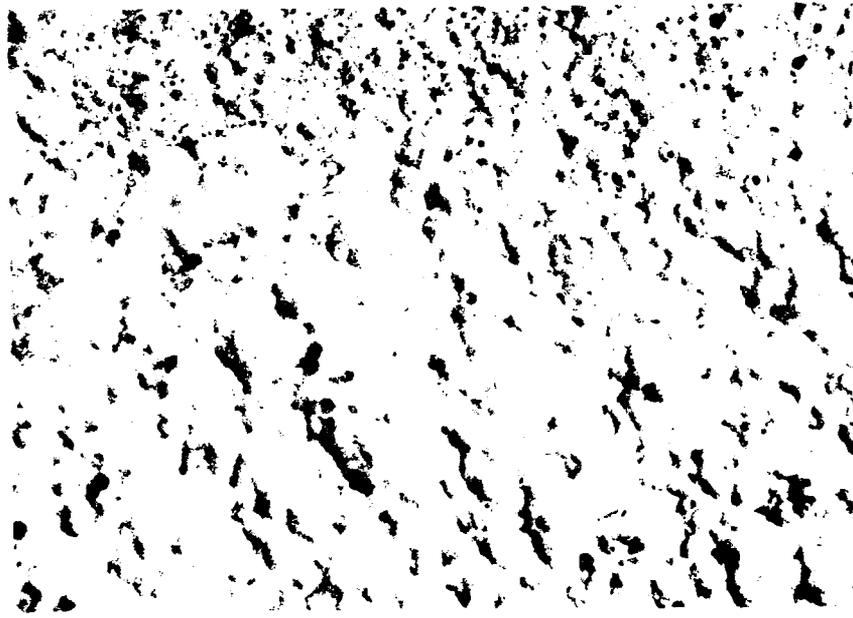


Figure 32. Foam application over wet surface.

In the case of cold surfaces, the exothermic or chemical heat which is required for proper reaction and formation of the foam can be lost or absorbed by a roof deck that is too cold. A surface that is colder than that recommended by the foam manufacturer for foam application constitutes a heat sink. Aside from the possibility of a cold surface being damp, surfaces that are below 50°F to 60°F create a heat sink with spray foam systems that rely totally on a R-11 fluorocarbon blowing agent for cellulation. The difficulty encountered 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. A heat sink can steal or drain off this heat to the extent that no foaming takes place initially when the mixed foam formulation is sprayed on the deck or surface. In such case the mixed and sprayed chemicals react very slowly resulting in a thin film on the roof surface. When this occurs to a substantial degree, a smooth thick skin or rind will form between the surface of application and the foam applied above it. This layer of material will exhibit little or no cellulation and will be friable, hard and brittle. Usually, the condition described will affect adhesion and can cause foam blistering and delamination at a later time. This condition may develop when the roof deck temperature drops to about 60°F, depending upon the foam formulation, and it may be necessary to halt foam application until the condition is corrected.

It is important to note that this effect usually predominates on the original roof deck surface of foam application in contrast to application over previously properly applied foam. The foam in place, being an insulator, creates no heat sink so subsequent passes of sprayed foam are not affected.



1"

Figure 33. Foam application over cold surface.



1"

Figure 34. Foam application over hot surface.

The key to watch for is less than normal foam rise on first pass application and/or evidence of a wet-looking slow reacting, liquid film at the surface. The effect of this very slow reaction is illustrated in Figure 33.

In some geographical areas, roof deck surface temperatures may be so hot that a special foam formulation is required. Two effects visually observed are (1) an increase in foam density due to 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 34.

Strange as it may seem, the foam surface texture can vary from smooth to verge of popcorn, depending upon the temperature level at the surface to be foamed. It is difficult to be specific about hot surfaces, due to formulation variables. 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. 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 hours. The principal adjustment is to select a foam system formulated for a longer cream time in combination with some reduction of material temperature in the spray equipment.

Wind Limitations. Wind tends to be the most variable factor at all times. In general, practical experience has shown that foam should not be sprayed when wind speeds exceed 12 miles per hour unless some form of windshield is used. Depending upon foam formulation cream times in combination with severe wind conditions the surface texture quality of the foam can be affected. A so-called "wind on water" effect which produces rippling of the foam surface is frequently observed. An illustration of rippling is shown in Figure 29.

Another important aspect of severe wind conditions is the potential damage that might occur due to uncontrolled foam overspray being deposited on vehicles, adjacent buildings or items not scheduled for foam application. Due to the adhesive nature of foam, overspray is very difficult to remove and should be controlled to the extent possible. Obviously, some relief can be obtained from overspray problems by proper masking protection, however, masking is mainly effective in controlling and protecting terminal points of foam application around roof mounted equipment, building parapet walls, etc.

Other Environmental Factors. Modern spray foam material systems are formulated to provide different speeds of reaction at some given or expected surface temperature upon which the foam will be applied. This is the "cream time" which has been referred to previously. The cream time is 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 and deposited on the surface of spray foam application. For example, contractors frequently refer to a 4-second, 6-second or 8-second foam. These rates of the cream time can be changed to some extent by the control of material temperatures in the spray equipment. However, it is the responsibility of the contractor to select the version of a foam system with an appropriate cream time for

*Cream time is the time measured in seconds at a given temperature of application for the A and B components to begin to react after being mixed through the spraygun.

the environment and/or the time of the year where the foam application is to be made. Evidence of 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 experience difficulty in obtaining a smooth or orange peel surface. Typically, the texture of the foam will tend to coarse orange peel and beyond, depending upon the conditions. A foam with a faster or shorter cream time will not be quite as sensitive to wind velocities that may be present, as discussed above under Wind Limitations. However, the benefit indicated is marginal. It is better to use a foam system that fits the proper temperature conditions 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. As a consequence, more spray passes will be required to obtain the desired foam thickness. Also, the spray passes may be thinner than desired which should be avoided. A cream time that is too long will also present problems when the foam is sprayed on vertical surfaces, such as parapet walls, flashings and cants. The effect will be for the evolving foam to run or sag, which tends to lead to treebark or rough textures in extreme cases. When foam is applied to vertical surfaces it should foam at a rate that causes the foam to rise straight out with no visible slump or sag. The rippling effect of wind, previously described, is an effect of long cream time.

Coating Application

In the application of PUF roofing systems the primary surface of application of the protective coating is to the sprayed-in-place foam. Therefore, the surface preparation steps required for the foam application do not affect the coating application, except those surfaces adjacent to the various points where the foam is terminated, such as flashings, parapet wall areas above cants, roof mounted equipment, etc.. These surfaces are normally coated as part of the finishing operation work and if clean and dry present no problems with today's coating materials.

A general rule with respect to weather considerations is that if environmental conditions are satisfactory for the application of sprayed foam, they are satisfactory for the application of coatings.

Special Application Considerations for Foam

It is important to recognize that the applied spray foam insulation is the base for the ultimate application of a protective coating system. The quality of the finished system is highly dependent upon the proper application and properties of the in-place foam.

Proper application of sprayed foam requires a highly skilled and trained operator. Equipment and materials available in the modern technology can provide satisfactory results, but it is the ability and willingness of the contractor to exercise proper controls over various job site related factors that frequently accounts for the difference between success and failure. For this reason, it is imperative at the outset that the contractor has the proper equipment and materials at the

job site and that he knows and understands acceptable conditions for good foam application. The minimum quality level acceptable should be established with the contractor before the foam application is started.

Equipment Adjustments. For purposes of this discussion it is assumed that all equipment is operating properly and that material component ratios are correct. It is also assumed that the equipment is of the type that has variable controls for adjusting material pressures and temperatures.

Based on the above assumptions, the correct temperature and pressure of the materials contribute most significantly to a proper spray pattern. A full and proper spray pattern enables the spray applicator to make passes of mixed material that rises steadily and uniformly 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 and/or ridges. The overall effect is a popcorn or, in an extreme case, 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 be reacting too fast to permit leveling 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 how to adjust for them.

Applicator Skills. 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. It cannot be emphasized too strongly that foam application should be suspended immediately if the results being obtained cast doubt on the skill of the applicator. It is far better to prevent bad application than to try to correct such conditions after the foam is in place.

Spray Foam Equipment and Material Problems. Consideration was given above to foam surface texture quality factors independent of equipment malfunction and improper materials or mixtures. This discussion is intended to aid in recognizing problems caused by materials being off ratio and/or due to materials being too old, out of shelf life, or reacting improperly. The effects of the latter problems can usually be discerned through improper foam surface texture, color or where the foam is soft and spongy or hard and brittle. In certain situations the surface of the foam may also exhibit blow holes and/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 on a constant basis. However, short term blockage of materials in the spray gun or momentary metering pump cavitation problems may escape detection by the applicator which will result in deposit of poor quality foam in relatively small areas. At times an operator will see a short break in the spray pattern and decide that nothing is wrong and will proceed with the work. However, if it is observed that there are constant fluctuations in the

spray pattern or the appearance of the foam being applied is abnormal, the work should be stopped until the cause is determined and corrected.

If the materials being sprayed are too old or have deteriorated due to chemical shelf life, early detection by observance of poor foam quality is normally possible. In the event of such an occurrence, no job site remedy is usually available and the material(s) should be removed from the job site and replaced. It is obvious that the latter problem can be avoided if it is determined, prior to application, that the materials are within the shelf life recommendations of the supplier and that they 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 excesses 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, such as shown in Figure 35, will exhibit one or more of the following effects:

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

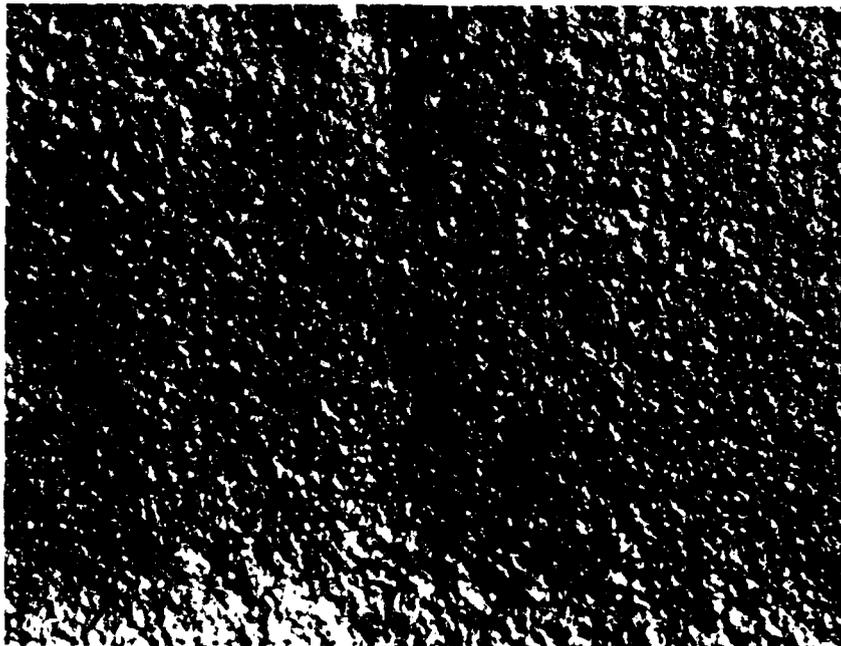


Figure 35. Isocyanate rich surface.

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

Excess Polyol or "B" Component. The effects of foam applied which is off ratio or misproportioned with respect to the polyol component will be one or more of the following:

- Light in color
- Slow and/or insufficient rise
- Soft and spongy
- Improper cell structure
- Highly mottled or coarse orange peel surface texture
- Blow holes or pinholes

Foam of the type described will not have normal strength properties, density or insulation value. Such foam will also be susceptible to high water absorption and should be removed. In fact a simple test is to cut a small piece of the foam and immerse it in water and observe whether it exhibits immediate water absorption. No coating over this type foam should be permitted. Figure 36 shows a typical resin-rich surface (excess polyol).

Aged or Improper Materials. The effects of using foam materials which have exceeded shelf life, have been stored improperly, have been improperly formulated, have lost R-11 blowing agent, or have moisture

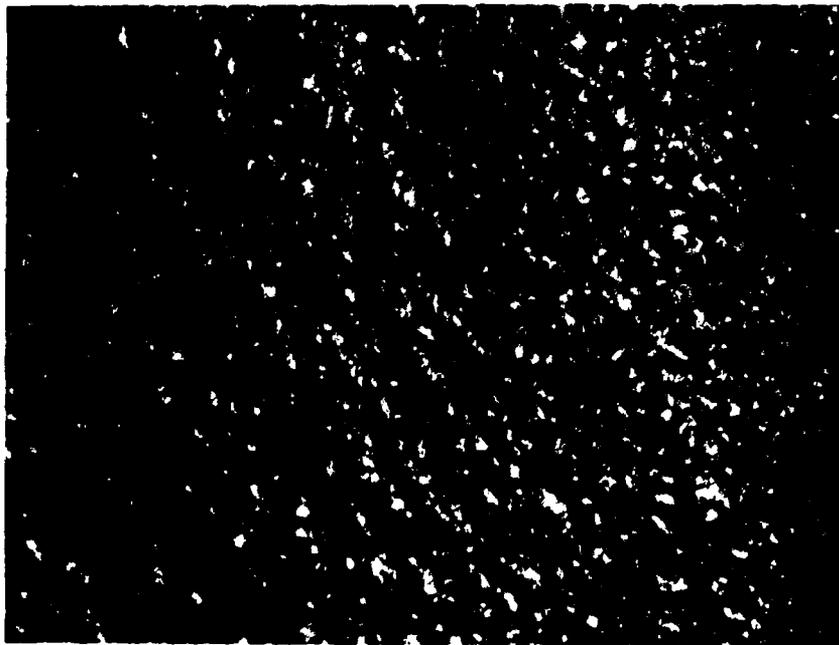


Figure 36. Resin rich surface.

contamination are described below. Fortunately, such problems are infrequent and when they do occur there is no mistaking their effects.

When these factors are present, it is highly unlikely that any good foam will be obtained. The applicator cannot make equipment adjustments to improve it. The obvious effects 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
- Foam that is undercured
- Poor physical properties

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

Foam Thickness Measurement. Foam thickness should be continually monitored as application proceeds in order to assure that specified foam thickness is achieved for insulation requirements, for creating proper slopes, or for elimination of low areas. The most satisfactory and easiest method is to use a thin or small diameter probe, such as a needle, wire or small knife blade. Either the probe can be pre-marked for thickness or a separate rule can be used to measure the thickness from a gauge mark on the probe or from where it is held by a "thumb nail" on the probe after it is removed from the foam. Since the foam will be sealed with a coating, use of a thin probe will cause no problems. Use of welding rods, nails or other large diameter objects as probes should not be permitted because the larger holes are not likely to be sealed by the coating and may become sources for water penetration.

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 aid in overcoming special problems. In some situations, a combination of using a transit level and a probe is desirable. Readings with a transit level can be made from distances of two hundred feet or more, depending upon the quality of the instrument.

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

Foam Skin Sunlight Degradation. Ultraviolet (UV) light from the sun degrades urethane foam which has not been protected with coating. The longer the exposure, the more severe the degradation of the surface will be, as shown in Figure 37. Specifications tend to vary in describing



Figure 37. UV degradation of foam.

periods of time that are permitted for exposure before coating or between subsequent spray passes in the foam application. However, it is important to understand the conditions that create a basis for acceptance or rejection.

Generally, it can be stated that lower density foams undergo more rapid surface degradation than higher density foams. It is also important to consider the extent of UV exposure with respect to time. It is obvious that the condition is more likely to be a problem in geographical areas of high solar exposure than in areas where there is more cloud cover and fewer days of sunshine. The primary concern is that the degraded foam surface does not adversely affect adhesion of subsequently applied foam or coating.

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

The best and recommended way to prevent degradation of foam is to schedule the work to make "same day" application of full foam thickness where multiple passes of foam are required, the same as was discussed previously in dealing with moisture interference. The first or base coat of protective coating should be applied that same day if at all possible. When this is not possible, 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.

If surface UV degradation is present in a small area to the extent 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. In the case where foam is ready for coating, a light pass of foam should be applied to the scarfed or sanded surface to reseal the surface and provide a proper coating base. Where larger areas are involved, the degraded foam must be mechanically removed, as described above, the surface clean of all loose material, the clean dry surface primed with a primer recommended by the foam manufacturer, and at least an additional 1/2-inch of new foam applied.

Coating Considerations

Samples of sprayed foam have been immersed in water for various periods of time with little evidence of water absorption. However, tests such as these do not include moisture vapor drive conditions caused by pressure and temperature differentials that exist on opposite sides of the roof deck. Typical sprayed foam is fairly water resistant but should not be considered as waterproof in and of itself. An elastomeric protective coating, usually applied as a liquid, is required for true waterproofing, as well as control of moisture vapor, and for protection against UV degradation from sunlight. Although there are other ways to protect sprayed foam in roofing applications, this Guide deals only with liquid applied elastomeric protective coating systems.

Proper application of the coating system is equally as important as proper foam application, since both are needed for a complete roofing system. However, once a good quality foam is in-place, the coating application is relatively easy and proceeds rapidly.

The personnel involved in the coating application must know and understand the factors that result in quality coating application, such as proper adjustment of the spray equipment to obtain correct spray patterns, control of coating thickness, etc. Although the equipment used for application of coatings is usually less complex than that used for foam and easier to adjust, it is just as important.

Coating Thickness. The thickness of a given coating can be determined either as it is being applied (wet) or after it has cured (dry). Wet film measurement is sometimes preferred because no repair of a cut-out sample is required as in the case of a measurement after the coating has cured. If wet film measurement indicates the coating is too thin, the contractor merely adds more. A dry film measurement consists of taking a small cut of the cured coating (unfortunately also including some of the foam) and using a special instrument to measure the dry film thickness (DFT). Any deficiency in thickness must then be corrected and the small cut sample area repaired. Frequently, if monitoring of the wet film thickness is not done, at the time of application, improper coating thickness is not discovered until the project is completed and the contractor has moved off the job site. Therefore, a combination of both wet and dry film measurements is recommended, as the coating application proceeds.

The thickness of coatings is measured in mils, with one mil equal to one thousandth of an inch (0.001-inch). Figure 38 shows a wet film gauge, and Figures 39 and 40 show typical dry film thickness gauges. An optical comparator type gauge like that shown in Figure 39 is usually preferred since foam on the back of a coating sample tends to interfere with the accuracy of the mechanical type gauge unless it is carefully removed from the sample specimen.

For any given rate of application of coating, such as 2 gallons per 100 square feet, the final dry film thickness in mils is a function of the percent solids by volume (also called "volume solids"). The rate of application and the volume solids are supplied by the manufacturer of the coating.

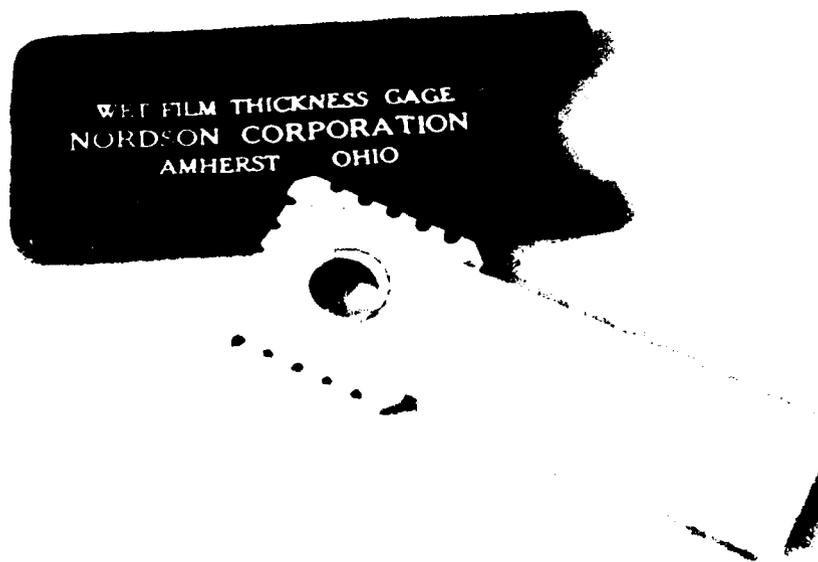


Figure 38. Wet film gauge.



Figure 39. Peak dry film thickness gauge.

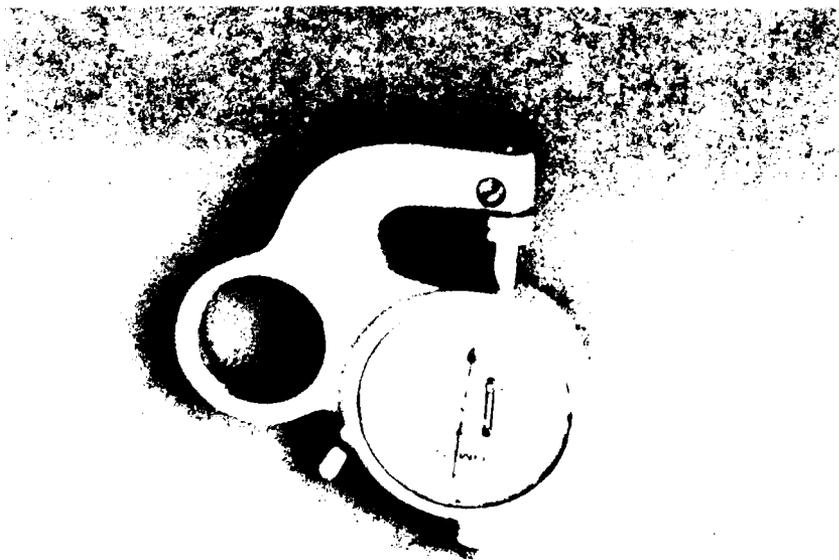


Figure 40. Ames dry film thickness gauge.

Two equations involving volume solids are shown below.

$$\% \text{ volume solids} \times 0.16 = \text{dry mils/gal/100 sq. ft.} \quad (1)$$

$$\frac{100 \times \text{dry mils}}{\% \text{ volume solids}} = \text{wet mils} \quad (2)$$

Example (1): Assume that the specifications call for the coating to be applied at approximately 2 gal/100 sq. ft. using a two-coat application; also assume that the volume solids is 60%. Using Equation (1)

$$60\% \times 0.16 = 9.6 \text{ dry mils/gal/100 sq. ft.}$$

Then for each one gallon of coating applied, the dry mil thickness should be 9.6 or 9.5 mils; for 2 gallons of coating, the DFT would be 19 mils.

Equation (2) provides the equivalent wet film mil thickness.

$$\frac{100 \times 9.5}{60} = 15.8 \text{ or } 16 \text{ mils (wet)/coat for each coat, then,}$$

the wet film thickness should be 16 mils.

Example (2): Assume that the specifications call for a total DFT of 30 mils, applied in two coats and assume that the volume solids is 55%. Only Equation (2) is needed.

$$\frac{100 \times 30}{55} = 54.5 \text{ wet mils (total)}$$

Since the coating is to be applied in two coats, the wet film thickness per coat is 27 - 28 mils.

It is important to note that even though the applicator sprays the specified amount of coating in terms of gallons per 100 square feet, he will have to spray more material to compensate for overspray losses and foam surface texture. The applicator must be aware that the intent of the specifications is to provide a coating of a specified thickness and not just to spray a specified volume of material.

Coating Coverage. Obtaining proper protective coating thickness and coverage is highly dependent upon the surface texture and/or profile of spray applied foam. Therefore, it is important for the applicator to recognize that the actual surface being coated varies with respect to the surface profile of the foam. Often the contractor may meet a prescribed rate of coating application in terms of a certain number of gallons per square (100 sq. ft.), but may not have applied an adequate amount of coating to obtain proper DFT. A specification that states gallon per square coverage with no reference to DFT is prescriptive.

This type of specification is risky and should be avoided. A specification that gives a suggested rate of coating application, but requires specific minimum DFT of the coating is referred to as a performance specification and is the preferred type of specification.

Table 1 below provides a guide for the amount of additional coating required, over the various acceptable foam surface textures, in terms of the percentage of volume (number of gallons) beyond the theoretical amount recommended by the manufacturer or required by the specifications.

TABLE 1

Additional Elastomeric Coating Required
For Various Foam Surface Textures

Smooth	5 %
Orange Peel	10 %
Coarse Orange Peel	25 %
Verge of Popcorn	50 %

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 end result is a coating film of non-uniform thickness, which will usually lead to premature failure.

In addition to uneven thickness of a coating, noted above, 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. In such instances the problem can usually be corrected by brush or roller application of additional coating, which can be worked down into small voids, crevices and pinholes. Suitable caulk sealants can also be used to make corrections. Such corrective procedures should be limited to relatively small areas and not be permitted as major corrective action for a poor or improper coating application.

The best assurance of uniform coating application, assuming proper spray techniques are employed, is to control the original foam application to assure acceptable surface texture through good inspection. As noted earlier, "smooth," "orange peel," and "coarse orange peel" surfaces are acceptable while "verge-of popcorn" is marginally acceptable. However, "popcorn," "treebark," "pinholes," or "blowholes," and "rippling" are not acceptable and the foam should be removed and the area refoamed.

In terms of coating application technique, a good practice to follow in obtaining uniform coating coverage is to apply alternate coats of material in contrasting colors, such as white top coat over gray base coat and to apply alternate coats in a cross-hatch or so-called "north-south," "eastwest" fashion. The latter procedures are frequently written into specifications. Figures 41 through 48 show appearance of coating sprayed over foam with various surface textures.

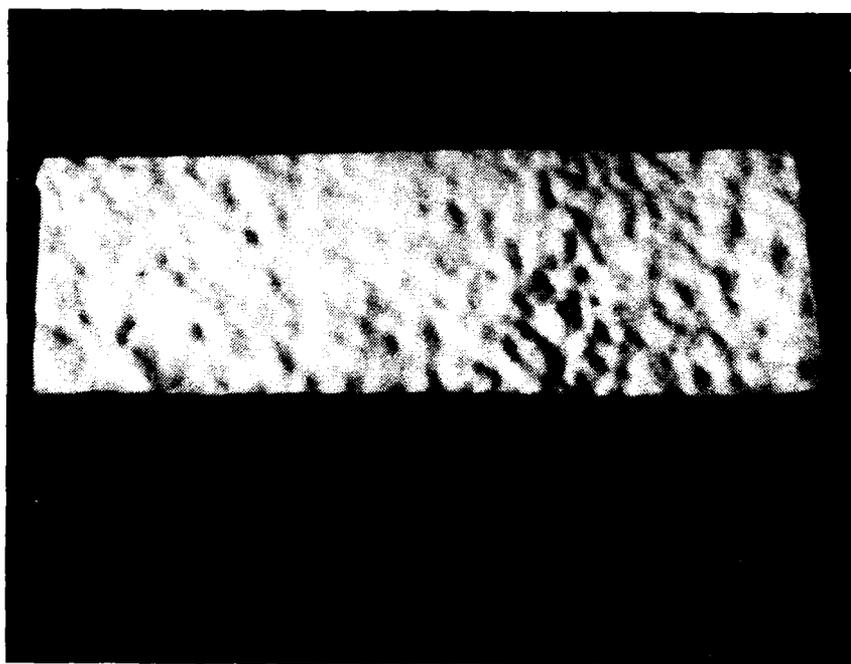


Figure 41. Coating over smooth/orange peel.

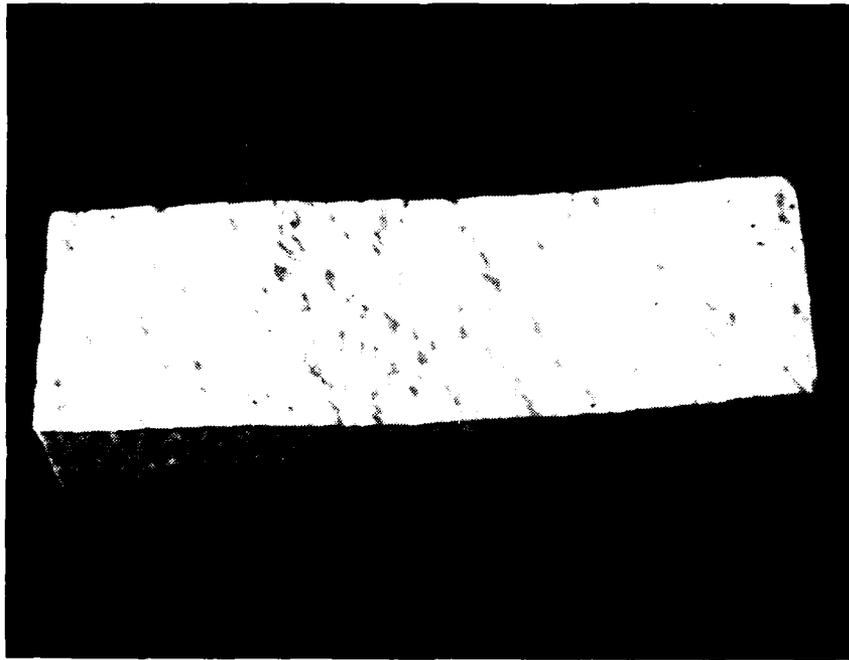


Figure 42. Coating over orange peel.

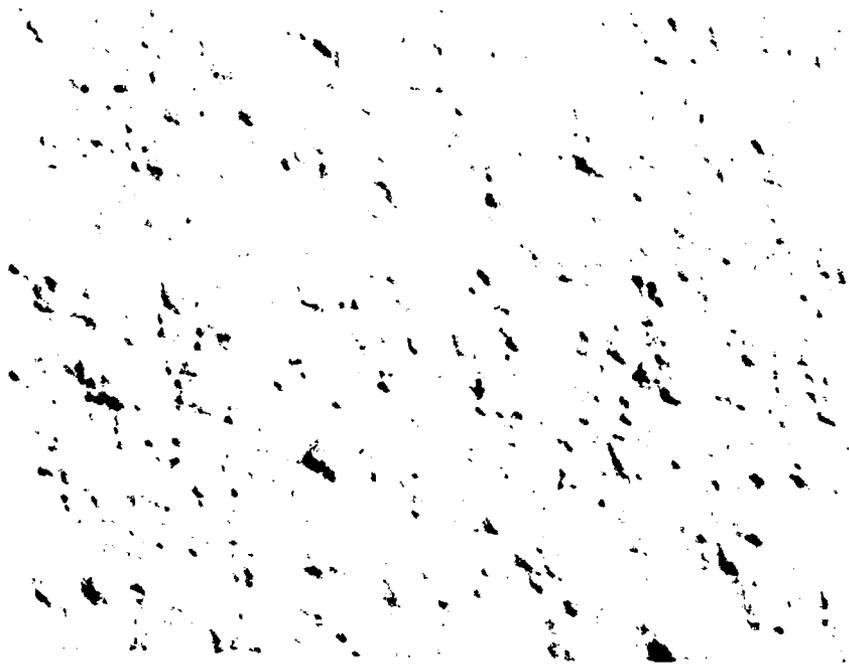


Figure 43. Coating over coarse orange peel.

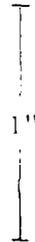
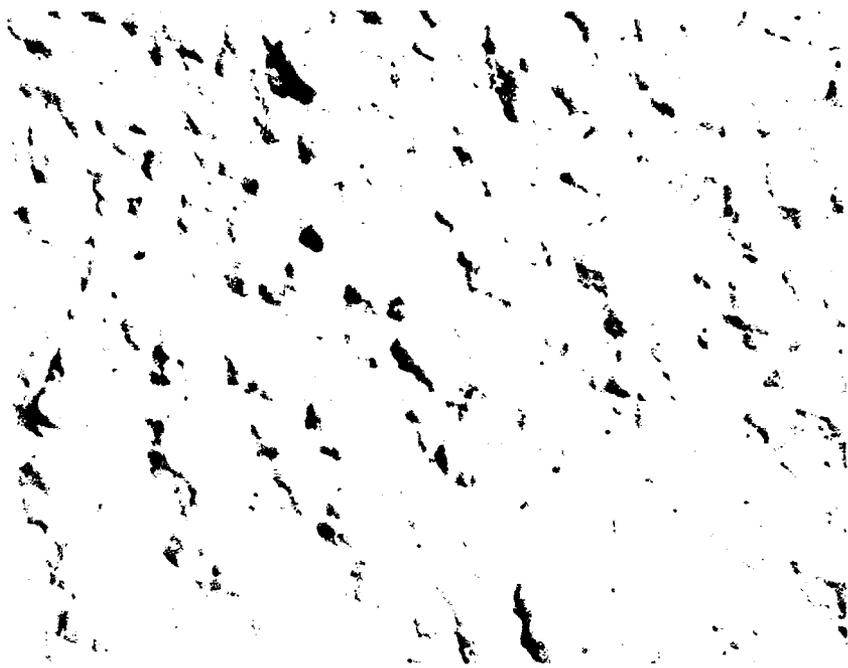


Figure 44. Coating over verge of popcorn.

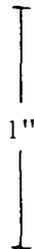
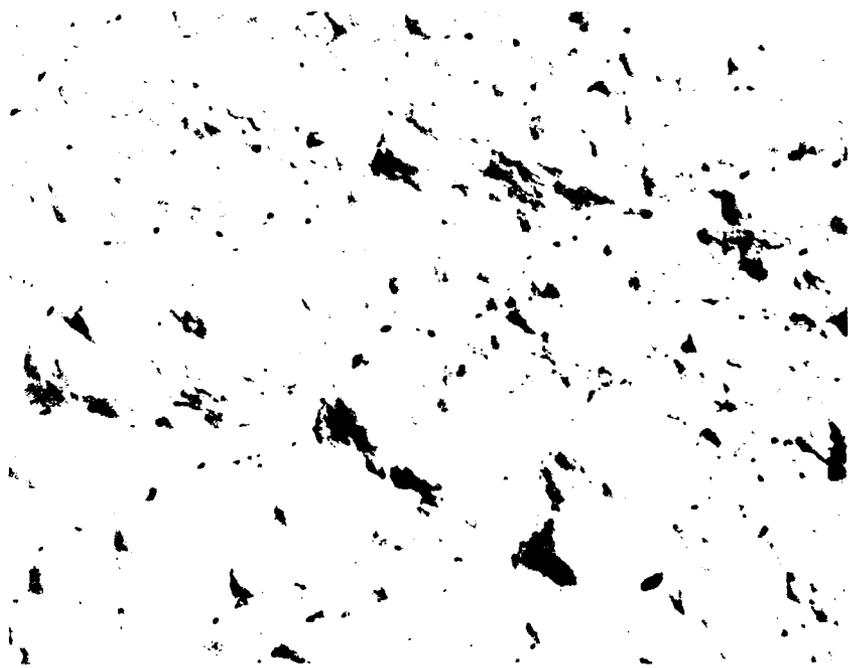
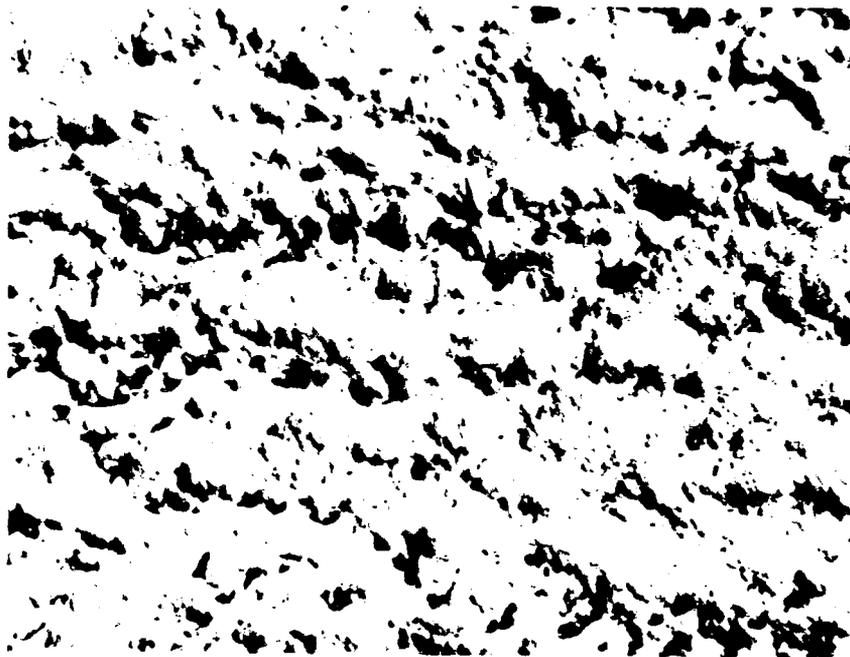
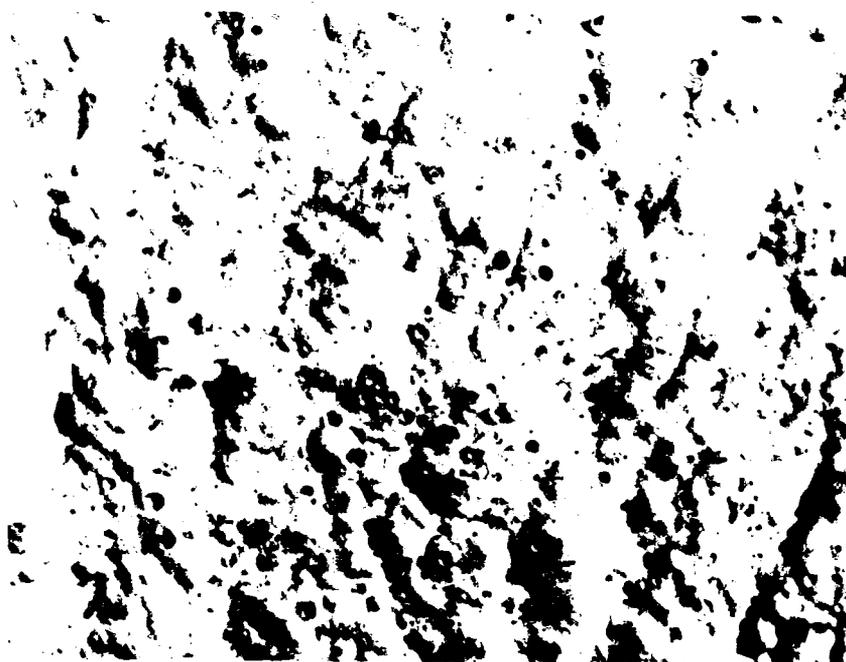


Figure 45. Coating over popcorn.



1"

Figure 46. Coating over treebark.



1"

Figure 47. Pinholes in coating.

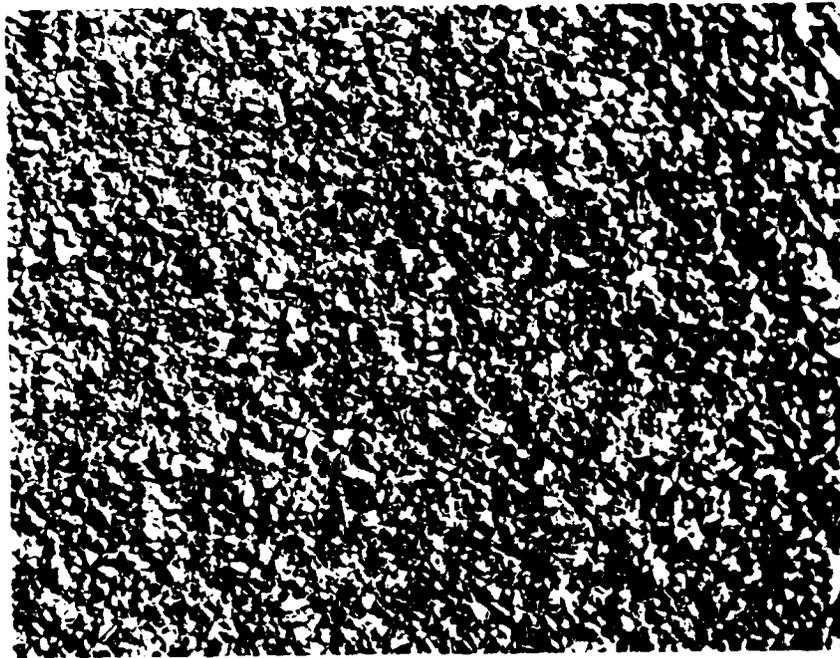


Figure 48. Granules over coating.

Coating Defects. In order to obtain the best possible protection of applied urethane foam in roofing systems by the coating material selected, assuming proper film thickness and coverage, it is important to avoid certain defects that can lead to premature failure of the protective coating. Defects that sometimes appear in the coating system are 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, such as shown in Figure 47. Although it may appear that holes in the foam are covered initially 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 closure of the hole that is formed in the coating so that the defect remains. In some instances application of additional coating will close the pinhole; normally, however, continued application of coating only serves to magnify the pinhole condition.

The ability to cover pinholes in the foam or a previous coating with pinholes will depend to some extent on the nature of the coating material itself.

Factors such as viscosity, volume solids, solvent content, and thixotropy are important. Again, the best solution is to prevent the occurrence of surface defects in the foam through rigid inspection at the time of application.

- Blistering (Loss of Adhesion). Blistering can be caused by factors which do not relate directly to coating application. These factors concern such things as MVT and the choice of breathing or nonbreathing coatings. In this discussion, it is assumed that correct technical design decisions have been made and attention is directed to problems that must be considered at the time of coating application. As with good foam application, a properly clean, dry surface is required to obtain good coating application. Anything that interferes with these elements can serve to 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 at a later time, leaving the foam unprotected. Other factors that can cause lack of adhesion are a UV degraded foam surface and excessive foam overspray on the foam surface. Excessive overspray which creates an irregular surface that prevents uniform contact of the coating with the overall surface can serve to 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 surface texture conditions, 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 non-uniform in thickness, which creates uneven stresses in the coating as it dries or cures. This factor in combination with temperatures that may be too hot or cold can serve to cause cracking of the applied coating. In some instances where foam texture is very bad, puddling of the coating will take place so that as the coating dries or cures, shrinkage cracks, crazing, or crow's feet tend to develop. The latter effect will usually be observed to some degree where coating puddles form due to excessive application rates. Normally, puddling is most frequent adjacent to vertical surfaces such as parapet walls, cants, vent pipes and equipment flashings. Short of puddling, the coating may tend to slump, sag or run on vertical surfaces which creates non-uniform coating thickness, leading to the problems previously described.

Temperature Limitations. It is difficult to be specific about the effects of temperature on an applied coating as it dries or cures, in view of the vast number of coating formulation variables and types of coating available. Coating manufacturers' recommendations should be carefully followed as to permissible ranges of temperature for coating application.

Generally, aqueous or water based systems are more sensitive to cold temperatures, whereas organic solvent systems are more troublesome under hot conditions. In extreme conditions of cold temperatures, an aqueous coating may freeze before it is properly dried. A freezing or near freezing condition is normally accompanied by cracking and crazing. Also, the quality of the coating will be severely affected, if not ruined, when freezing occurs before drying is complete, because the coating will not coalesce properly.

Hot temperatures with organic solvent coating systems tend to develop pinholes rather than cracking or crazing, due to rapid solvent loss at the wet coating surface in combination with "skinning." When premature skinning occurs, solvent still contained in the body of the wet coating below the surface must escape and will drive through the surface and cause pinholes or blow holes.

Contractor Selection Procedures. The importance of contractor knowledge and applicator skills is emphasized in the Guide. Once a PUF roofing system has been selected and the material specifications established, perhaps, the most critical factor in the successful completion of the project resides in the selection of the contractor to perform the work. All too often contracting firms are awarded contracts on a "low dollar" or "low bid" basis without sufficient attention being paid to technical qualifications and experience.

In more recent years, the major coating manufacturers have instituted so-called "qualified applicator" programs to assure the successful use of their coatings in conjunction with certain selected foam material systems. This approach has become more and more important with the evolution of long term (10-year) warranties. Generally, these programs are excellent in that the coating manufacturer enjoins the contractor on a contractual basis that provides for financial responsibility, training, and takes the experience factor into consideration. Further, the coating manufacturer, in cooperation with various foam suppliers, provides certification for fire testing and other physical properties required. Most of the qualified applicator programs also provide standards for quality control monitoring of the installation and post inspection upon completion of the project for purposes of issuing a warranty to the building owner. The update of NFGS-07540 includes a "qualified applicator" requirement.

In the absence of a program such as has been described, it is strongly recommended that specifications for a given project be written to require certification of experience for every "man on the gun" that must apply the particular materials included in the PUF roofing system selected. Many contracts require certified references of the man on the gun to show a minimum of 3 years experience with respect to foam application and 2 years of coating application experience. Also, it is normally required that the applicator of the coating give evidence and certify to training or experience with the coating material specified.

OPERATION AND MAINTENANCE CONSIDERATIONS

Inspection Procedures

Quality control monitoring and proper inspection during the installation of a PUF roofing system will serve to provide for a good roof initially. However, it is equally as important to monitor the condition of the roofing system through proper inspection at frequent or scheduled time intervals to discover damage to the roof or small imperfections that can be corrected with minimal maintenance, etc. No roof covering system can or should be expected to give good long term performance without some attention and maintenance. Too frequently, roofs are out of sight and out of mind until a leak develops. A roof system has to endure all types of chemical and physical stress problems in a given environment. The response to these problems is normally thought of as "aging." Most problems begin in a small way and if left undetected develop into more extensive and expensive need for repairs or, in the extreme, roof replacement.

A good procedure to follow is to perform inspections at least once a year and/or immediately following severe weather occurrences, extraordinary maintenance or work on roof mounted equipment. A historical record of inspections should be kept on file with notations as to the conditions found, repairs required, and whether any repairs required are covered by warranty. In normal practice, failure to report repairs or faults covered by a warranty or to correct nonwarranted damage will lead to cancellation of the warranty by the coating manufacturer or other warrantor.

Items which should be checked, noted and scheduled for correction during an inspection of a PUF roofing system include the following:

- All roof drains and through wall scuppers should be checked to see that they are open and free of debris.
- The complete roof should be checked for accumulated debris such as leaves, tree branches and foreign objects thrown or left on the roof.
- A walk-over of the roof should be made to examine for cracks, punctures, penetrations, coating blisters, foam blisters, or delamination of either foam or coating. The roof surface should also be carefully examined for any unusual signs of wear, erosion or flaking of the coated surface.
- Flashings around drains, equipment, roof vents, stacks, hatches, along roof edges and parapet walls should be examined for cracks or loss of adhesion of either foam or coating.
- On occasion, PUF roofing systems have been subject to "bird pecking" problems. Most frequently, the problem occurs where birds roost along roof edges and high points on the roof. Therefore, these areas should be routinely included in the inspection.

- Expansion joints, if existing, should be inspected along curbing details to insure that no structural movement has taken place outside the expansion joint area resulting in cracks in the foam and coating system.
- Peripheral items that are not a direct part of the foam and coating system that should be checked during an inspection are integrity of metal cap flashings on parapet walls, the masonry parapet walls themselves to see that they are free from structural cracks that might permit water entry into the building or behind the applied PUF roof system, and seals or caulk joints on sky-light units.

Maintenance Procedures

Experience has shown that when a PUF roofing system has been properly selected and installed the maintenance required under normal circumstances is minor and very simple to perform over a period of many years. Also, there is no doubt that a regular inspection and maintenance program that serves to correct defects or damage as it occurs can extend the life of the roof and eliminate the need for recoating several years. There are now many PUF roofs in existence that are approaching 15 years in age that have been properly maintained which are leak free and show no signs of need for recoating or replacement.

It is important to note that maintenance procedures of any type should be conducted using materials that are similar and compatible with those materials involved in the PUF roofing system being serviced. Predominately, the greatest concern deals with caulk sealants and the particular elastomeric protective coating. However, any foam repairs needed should be made with a foam of proper density and fire rating classification. Except in the case of temporary emergency repairs, the use of asphaltic, bitumen, or coal tar based mastics and plastic type patching materials should be avoided.

For purposes of this Guide, maintenance procedures are divided into three types or categories as follows.

Type I - Minor Repairs. This type of repair is normally conducted during routine or annual inspections or if a small defect is discovered or caused during roof equipment servicing activities. Type I repairs should be limited to those that do not require use of foam materials. This type of repair can be effected with the use of a compatible caulk sealant, small amount of coating material and granules, if used originally.

The defects in this category are small cuts, fractures, punctures, penetrations, cracks, gouges, and scuffs limited to 1 to 1-1/2-inches in width or less. Length may be variable and does not impose a restriction for this type of repair. Depth may be variable. Isolated defects in the coating such as cracking, flaking, spalling, and blisters may also be considered as Type I repairs.

The procedure for repairs is as follows.

- Inspect the area to be repaired for water, dirt or contamination. Dry off the area if wet and/or clean away granules (if any) dirt or contamination over and around repair area.
- Using a serrated or razor knife, trim exposed foam in any fracture to obtain a clean dry foam surface to the depth of penetration. Typically, 1/8inch to 1/4inch slices are adequate to clean up the penetration.
- Fill the prepared area with caulk sealant that is compatible with the coating system, and trowel smooth over the filled area extending onto the surrounding surface.
- If applicable, granules can be sprinkled onto the wet caulked surface and patted lightly to obtain imbedment. If coating is to be applied, the caulk sealant must be permitted to set or cure sufficiently to allow brush application of coating for completion of repair.
- If coating only is required, a sufficiently large area should be dried and/or cleaned off to permit tying-in of new coating application to existing coating in surrounding area. It is recommended that at least two separate brush coats of the proper coating be applied, allowing sufficient curing or drying time between coats. Minimum DFT of the new coating should be 30 mils.

Type II - Moderate Repairs. On occasion an inspection will reveal isolated areas of poor quality foam, wet foam, foam blisters, foam delamination, or mechanically damaged areas that are too large to be treated as Type I repairs and that cannot be corrected by caulking or recoating. Such areas require removal and replacement of foam. If these areas are limited and not larger than about 2 square feet in size, they can be repaired fairly easily without the use of spray foam or coating equipment.

Foam replacement can be made by use of proper density pour foam, (that can be hand mixed), canned froth foam, and in limited instances rigid PUF board stock. The coating replacement can be accomplished by use of either brush or roller. Overcoating of larger areas included in Type II repairs with caulk sealant is not recommended.

The procedure for repairs is as follows.

- Using a serrated or razor knife cut away distressed foam and coated area back to the point where foam is clean, dry and/or firmly adhered to a minimum depth of 1/2-inch, as shown in Figure 49.
- Bevel cut the foam edge at approximately a 45 degree angle around the perimeter of the opening to the depth of the penetration, as shown in Figure 50.



Figure 49. Old foam cut out.



Figure 50. Edge cut beveling.

Special Note: Frequently, foam blisters and delamination of foam do not occur at the roof deck surface, but will be found to be due to loss of adhesion at laminate spray pass lines. This was caused by presence of moisture, contamination or UV degradation that existed at one given surface level of the foam where multiple foam passes were used to obtain the desired or specified foam thickness during the original foam application. Often, removal of a foam blister or delaminated foam will reveal a smooth skin surface. Normally, it is not necessary to remove foam beyond this depth, however, the surface skin should be scarified with a stiff wire brush or cut away before foaming in the repair opening.

- Brush back loose granules, if any, dirt, dust or other debris from around repair opening.
- Gradually introduce foaming mixture into the prepared area by pouring material onto the beveled cut foam edge in order to wet out the cut surface as completely as possible, then distribute remaining material evenly over the bottom of the repair opening.
- Permit the foam to rise and set, so that the repair opening is completely filled. Allow in-place foam to cure for a minimum of 1/2-hour. Larger repairs may require slightly longer to dissipate heat in the foam and for the foam to become firm enough for cutting and trimming.
- If repair area is underfilled a second or third application of foam may be required to completely fill the void. If a second or third application or pour is required, pour(s) can be made as soon as the foam is tack free (4 - 5 minutes) without waiting for the 1/2-hour or longer cure period that is required when foaming is completed.

Note. Depending upon the cream time of the foaming mixture used for repair, it is sometimes helpful, in filling out the void, to semimold or back pressure the foam by placing a small piece of polyethylene wrapped plywood over the foam, holding it in place physically or by use of weights, until foam reaction is complete. This technique works best with pour foams that have 40 - 45 second cream times as opposed to canned froth foam which reacts very rapidly.

- Once foam in the filled void is cured or firm, trim away excess foam with a serrated knife or hand saw to nominal level of adjacent foam surface, then grind, rasp or sand smooth. See Figures 51 and 52.
- Remove all foam dust and/or bits of foam debris from repair area and after permitting the foam to cure for, at least, one hour, proceed with new coating application and addition of granules, if required. See Figure 53.



Figure 51. New foam patch trimming.



Figure 52. Cut foam finishing.



Figure 53. Sanded foam - coating finish.

- In working over the cut and sanded surfaces of foam as described in this procedure, it is strongly recommended that at least three brush or rolled coats of new coating be applied to obtain 35 to 40 mils DFT. It is especially important that the first coat be worked thoroughly into the cut and open cells of the foam surface to compensate for the fact that no skin exists, as is the case with a normally applied spray foam.
- Repairs using foam board stock should only be made if other foam materials, described above, are not available. Also, such repairs should be done strictly with rigid PUF board stock of proper density. No dissimilar materials such as polystyrene type boards should be used.
- In the event that board stock is used, the board should be slightly thicker than depth of foam in the repair area and must be cut and shaped to conform as closely as possible to the opening being repaired. It is usually easier to effect a better repair if a square or rectangular opening is used without beveling either the edge of the board or the foam around the repair opening.
- Once a good fit of the board is obtained the edges of both the board and the opening should be buttered with caulk sealant along with "dabs" or "ribbons" of caulking being placed in a fairly uniform fashion on the deck surface in the repair opening, to provide adhesion to the roof deck. See Figure 54.

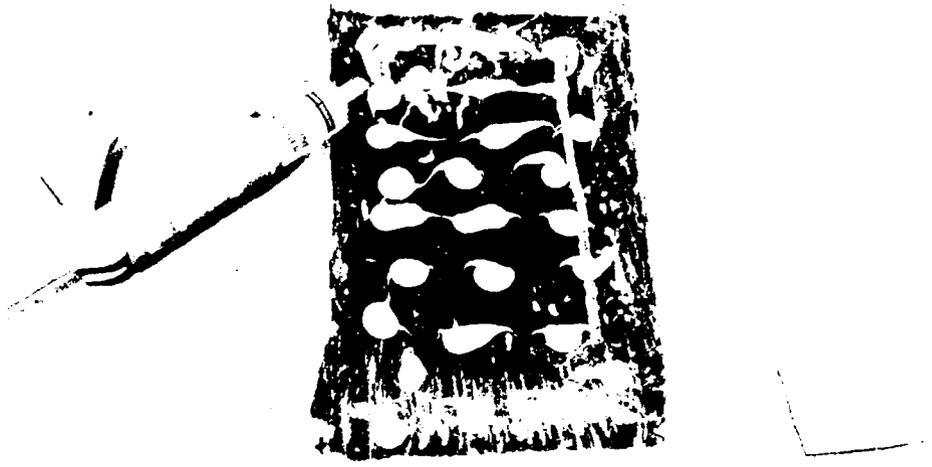


Figure 54. Patch using boardstock.

Caution. Only water resistant caulk sealants such as silicones, urethanes or butyls should be employed for board stock repairs. Acrylic or putty type sealants are not recommended for use, due to lower strength and possible susceptibility to water.

- Lay prepared board into the repair opening and press firmly into place. Permit caulking to set and cure, after which time the surface can be ground, rasped or sanded smooth in preparation for coating, as previously described.

Type III - Major Repairs. Experience has shown that major repairs which include extensive foam replacement and recoating work should not be attempted as a part of maintenance procedures in most cases. Rather, a contractor should be employed who has proper equipment and skills.

In terms of long-term preventive maintenance for a PUF roof of good quality that has been properly maintained, the primary factor is the need for recoating in a period of 6 to 12 years, depending upon the coating system involved. In general, the acrylics have shorter life, and the urethane and silicone type coatings will tend to have a longer life.

It is important that recoating be undertaken when the existing coating begins to show signs of deterioration due to weathering but is mostly intact and well bonded. The delay of recoating will lead to more serious problems and premature failure of the roof system. In extreme cases, complete coating removal and replacement along with extensive foam replacement may be necessary. Many PUF roofing systems are lost due to failure of observing these precautions.

It is recommended that NAVFAC MO113, Inspection, Repair and Maintenance of Roofing Systems, Chapter 6, (Spray Applied Polyurethane Foam Roofing Systems) be consulted for other information of interest with respect to maintenance and repairs.

Other Considerations

Safety. During application of PUF roofing systems, the Navy requires the following unless in conflict with a manufacturer's recommendations or other requirements of a recognized legal authority, in which case, those requirements take precedence:

- Wear cannister-type or fresh air supply masks when applying foam and coating materials or when handling hazardous liquid materials. Respiratory protective devices shall be as recommended by OSHA 1910.134 and approved by the Mining Enforcement and Safety Administration or be acceptable to the U.S. Department of Labor for the specific contaminant to which a person is exposed. Instruct personnel required to use respiratory protective devices in their use. Maintain such equipment and inspect regularly.
- Use eye and face protection during foam and coating application. Face protective equipment shall meet the requirements of ANSI Z87.1.
- Wear protective clothing and gloves during foam and coating application. Skin areas not covered by clothing shall be protected by suitable protective creams.
- When opening "A" (isocyanate) foam component material drums, do not inhale vapors. Decontaminate empty non-returnable "A" component drums by filling with water and allowing to stand for 48 hours or more with bung removed. Under no circumstances should these drums be sealed, stopped or closed in any manner.
- When opening "B" (polyol) foam component material drums, begin by partially unscrewing the smaller 3/4-inch bung cap to gradually vent the drum, of pressure that may be present from R-11 in the material. Pressure develops in "B" component drums when the material temperature begins to rise above 72°F.
- Head protective equipment (hard hats) shall be worn by all personnel when working or present in areas where there is possible danger of head injuries from impact, flying or falling objects, electrical shock and burns. Helmets for protection against impact and penetration by falling and flying objects shall meet requirements of ANSI Z891.1-1969. Helmets for protection against electrical shock and burns shall meet the requirements of ANSI Z89.2-1971.

Material Handling and Storage. The materials and containers in use during PUF roofing systems applications should always be handled in accordance with the recommendations of the manufacturers. All liquids should be stored in airtight containers and kept closed except when removing materials for use.

Equipment or containers containing remains of dissimilar materials or products should not be used.

Materials delivered to the job site should be in manufacturer's standard commercial containers; these must be unopened and undamaged and bear the following legible information:

- Name of manufacturer
- Name of contents/product code
- Net weight of contents
- Lot or batch number
- Storage temperature limits
- Shelf life expiration date
- Mixing instructions/proportions of components
- Safety information and instructions
- Disposal information

Where materials are specified by an applicable document, labeling shall include the referenced specification numbers and material designation, such as type and class of contents, as applicable.

Materials should be delivered in sufficient quantities to allow work to continue without interruption. Stored material containers should be protected from damage and the weather. Also stored material contained at the job site should be placed on pallets and covered with a tarpaulin, not polyethylene, with all sides of the tarp tied to the bottom of the pallets. PUF component containers must be tightly sealed and stored at temperatures between 50 and 80 degrees F. Do not expose PUF "B" component containers, or others that contain R-11 fluorocarbon, to direct sunlight for periods of time sufficient to cause the contents to exceed 80°F. Higher temperatures will cause pressure to build in the containers and in an extreme case could lead to rupture of the container(s). Materials that have been exposed to moisture or that exceed shelf life limits should not be used and should be immediately removed from the job site.

Do not dilute primers or other coating materials unless required and/or recommended by the manufacturer. If thinning is to be done, only solvents recommended by the manufacturer shall be used. Do not use cleaning solvents for thinning primers or other coating materials.

Personnel Training. One of the more difficult aspects in the development of PUF roofing systems and their application has been and continues to be the proper training and education of the contractor and those persons responsible for inspection and quality control monitoring. Various equipment, foam, and coating suppliers provide information of value and frequently sponsor seminars and workshops for training and educational purposes. Contact with such suppliers is highly recommended when specific information is required.

On a broader scale, there are two organizations that should be considered for educational and training purposes and the source for important information. They are as follows:

Polyurethane Foam Contractors Division (PFCD) Society of Plastics Industry, Inc. (Spi)
1025 Connecticut Ave. N.W., Suite 409
Washington, D.C. 20036
Tel: (202)822-6700, 1-800-523-6154

The Roofing Industry Educational Institute (RIEI) 6851 South Holly Circle Suite 100 Englewood, Colorado 80112
Tel: (303) 770-0613

Both PFCD/SPI and RIEI publish documents from time to time and maintain libraries of these documents that are available at reasonable cost. These organizations are also invaluable sources for references to other literature.

Finally, it is important to note that the Navy has done research, sponsored and produced criteria, reports, various guides, some of which have been referenced in this Guide and continues to contribute to the development of the industry with items such as this Users Guide. Also, the Navy is conducting ongoing research.

REGULATIONS/STANDARDS/POLICY

All Navy information covering Regulations, Standards, and policy is contained in DOD and Navy Design manuals, Maintenance Manuals, and Guide Specifications. These include the following documents:

DOD 4270.1M	- Fire Safety Requirements
NAVFAC DM-1.5	- Design Considerations
NAVFAC DM-8	- Fire Safety Requirements
NFGS - 07540	- Guide Specification for Coatings
NFGS - 07545	- Guide Specification for PUF

These following documents are listed in more detail along with NCEL reports covering investigations of polyurethane foam roofing systems.

1. Department of Defense, "Construction Criteria Manual", DoD 4270.1M, Chapter 13, Aug 1984.
2. Department of the Navy, Naval Facilities Engineering Command Design Manual, NAVFAC DM-1.5, "Roofing and Waterproofing, Section 7, Sprayed Polyurethane Foam (in draft).
3. Department of the Navy, Naval Facilities Engineering Command Design Manual, NAVFAC DM-8, "Fire Protection Engineering", Apr 1981.
4. Department of the Army, the Navy, and the Air Force Technical Manual, "Inspection, Maintenance and Repair of Roofing System," (Army TM5617, NAVFAC MO-113, Air Force AFM 9131 and Marine Corps MCO P11014.9), Chapter 6, Spray Applied Polyurethane Foam Roofing Systems (in draft).

5. Department of the Navy, Naval Facilities Engineering Command Guide Specifications, NFGS-07545 (July 1984), "Sprayed Polyurethane Foam (PUF) for Roofing Systems."
6. Department of the Navy, Naval Facilities Engineering Command Guide Specifications, NFGS-07540 (Sept 1985), "Fluid-Applied Elastomeric Coatings over Polyurethane Foam (PUF)."
7. Naval Civil Engineering Laboratory. Technical Note N-1450: Experimental polyurethane foam roofing systems, by J.R. Keeton, R.L. Alumbaugh, and E.F. Humm. Port Hueneme, Calif., Aug 1976.
8. _____. Technical Note N-1496: Investigation of spray-applied polyurethane foam roofing systems, by R.L. Alumbaugh and J.R. Keeton. Port Hueneme, Calif., Jul 1977.
9. _____. Purchase Order Report - P.O. No. 79-MR-461, Principles of urethane foam roof application, by Keith H. Coultrap. Coultrap Consulting Services, Inc., Jun 1980.
10. _____. Technical Note N-1643: Thermal conductivity of weathered polyurethane roofing, by D.A. Zarate and R.L. Alumbaugh. Port Hueneme, Calif., Sep 1982.
11. _____. Technical Note N-1656: Experimental polyurethane foam roof systems - II, by R.L. Alumbaugh, J.R. Keeton, and E.F. Humm. Port Hueneme, Calif., Jan 1983.
12. _____. Technical Note N-1683: Underwriters Laboratories fire tests of sprayed polyurethane foam applied directly to metal roof decks, by R.L. Alumbaugh and S.R. Conklin. Port Hueneme, Calif., Dec 1983.
13. _____. Technical Note N-1691: Preliminary guidelines for maintenance of polyurethane foam roofing systems, by R.L. Alumbaugh, S.R. Conklin, and D.A. Zarate. Port Hueneme, Calif., Mar 1984.
14. _____. Technical Note N-1742: Experimental polyurethane foam (PUF) roofing systems - III: Naval Station, Roosevelt Roads, Puerto Rico, and Naval Facilities, Cape Hatteras, North Carolina, by S.R. Conklin, D.A. Zarate, and R.L. Alumbaugh. Port Hueneme, Calif., Jan 1986.

APPENDIX
Coating Selection Guide Chart

Coating Selection Guide Chart

COATING DESCRIPTION	PERFORMANCE FEATURES	RECOMMENDED APPLICATIONS	*RELATIVE COST/ML (THICKNESS)/SQ. FT.
Acrylics	Single component, water based. The fact that they are water based allows for easy application and clean-up. Excellent resistance to weathering. High permeability.	Use on slopes 1/2:12 or greater. Do not use in areas with relative humidity averaging 80-85 percent annually. Good color selection availability.	0.65
Butyl Rubber	Two component, solvent based. Available in "standard cure" or "fast cure". Does not weather well. Good vapor retarders. Lowest permeability of any coatings for PUF.	Low slope or near level roofs with unavoidable ponding water or wet conditions. Require topcoating with other type coatings such as Hypalons, urethanes or acrylics on external weathering applications. Vapor retarders for roofs over coolers, freezers, etc.	1.45
Hypalons	Single component, solvent based. Low film foaming solids thereby requiring multiple coats for building dry film thickness. Good chemical resistance and weathering properties. Low permeability.	Top-coating material for butyl rubber and moisture-cure urethanes to provide good fire retardancy and weathering. Good color selection. Can be used as total coating system on 1/2:12 slopes or greater.	1.80

COATING DESCRIPTION	PERFORMANCE FEATURES	RECOMMENDED APPLICATIONS	*RELATIVE COST/ML (THICKNESS)/SQ. FT.
Silicones, Moisture Cured	Single component, solvent based. Low tensile and elongation properties, however, age extremely well. Tends to soil and hold static electric charges, but can be improved with use of mineral granules imbedded into surface. Withstands temperature extremes well. Highest permeability.	Use on slopes 1/2:12 or greater. Excellent for use in all geographic areas. Limited color selection. However, the use of acrylic cover coats applied over imbedded mineral granules can overcome this limitation.	1.00
Silicones, Catalyzed	Two component, solvent based Low tensile and elongation properties, however, age extremely well. Tends to soil and hold static electric charges, but can be improved with use of mineral granules imbedded into surface. Withstands temperature extremes well. Highest permeability.	Use on slopes 1/2:12 or greater. Excellent for use in all geographic areas. Limited color selection. However, the use of acrylic cover coats applied over imbedded mineral granules can overcome this limitation.	1.20
Urethanes, Moisture Cured	Single component, solvent based. High tensile and elongation properties. Moderate aging resistance, due to aromatic chemical structure. Medium permeability.	Use on slopes 1/4:12 or greater. Can be used in most geographical areas if topcoated with aliphatic urethanes, Hypalons or pigmented with aluminum flakes or mineral granules. Hypalon topcoat will further reduce permeability. Good color selection.	0.85

COATING DESCRIPTION	PERFORMANCE FEATURES	RECOMMENDED APPLICATIONS	*RELATIVE COST/ML (THICKNESS)/SQ. FT.
Urethanes, Catalyzed	Two component, solvent based. Can be aromatic or aliphatic in chemical structure. If aromatic, are generally used with aliphatic urethane top-coat. High tensile and elongation properties. Combination of aromatics and aliphatics provide excellent weathering. Available in "standard cure" or "fast cure." Medium permeability.	Use on roofs of any slope. "Fast cure" types cannot be used with mineral granules. Can be used in most geographical areas. Good color selection.	0.90 - 1.20
Urethanes, Modified	Available in both single and two component systems, solvent based. Tensile and elongation properties vary with type. Aging resistance varies with type as does permeability.	Use on slopes vary with type. Geographical use varies with type. May be useful where specific properties are required. Generally considered experimental.	0.75

*Compared to moisture cure, one component, silicones.

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