MAINTENANCE OF SPRAYED POLYURETHANE FOAM (PUF) ROOFING SYSTEMS

R.L. ALUMBAUGH, S.R. CONKLIN and D.A. ZARATE
Naval Civil Engineering Laboratory
Port Hueneme, Calif.

The use of polyurethane foam (PUF) roofing systems has increased over the past decade, not only in the private sector but also at Naval shore bases. As with any new material, problems have occurred (Reference 1). When these roofing systems first were introduced, mistakes were made in their specification and application. Frequently, the roofs were installed and forgotten (i.e., there was no inspection and preventive maintenance program). Both of these factors led to many problems and a consequent high rate of failure.

PUF degrades when exposed to sunlight and must be protected by a suitable elastomeric coating system. If the elastomeric coating is too thin, is subjected to excessive mechanical damage, or has weathered excessively, it tends to spall or flake from the substrate, exposing the foam. When this happens, the surface must be recoated as soon as possible. If this is not done, the roofing system deteriorates and eventually fails as a result of ultraviolet (UV) degradation and water absorption into the degraded foam.

At some point in time, generally eight to 12 years after application, the elastomeric coating systems will weather (age) to the point where maintenance is required to provide continued protection to the foam. When properly applied and protected, PUF roofing systems should perform well for a minimum of 20 years. With the high-quality elastomeric coating systems that are currently available, it should be possible to obtain 20 years of service with only one recoating.

There are no standardized procedures for maintaining PUF roofing systems. The actual procedures employed are determined by the knowledge and ingenuity of the individual contractor. The objective of this research is to: (1) investigate existing maintenance procedures for PUF roofs; (2) develop new maintenance procedures, materials, and methods for PUF roofs; and (3) standardize the best procedures for Navy use. A detailed account of this work is presented in Reference 2.

SCOPE OF WORK

A study of roof maintenance procedures used by contractors indicated that the most frequent method of foam repair is to broom the coated PUF roof, air blow to remove dirt and deteriorated coating, and recoat with a suitable coating. A more radical procedure consists of complete removal and reapplication of the PUF roofing system. This is only necessary when the existing PUF is so badly degraded that it no longer serves its proper function as a roofing system.

In between these two extremes, there are several other possible procedures. Procedures investigated in this study include the following:

1. Broom and recoat with a suitable elastomeric coating* system.
2. Broom, prime, and recoat with a suitable elastomeric coating* system.
3. Broom, apply a new lift of foam, and coat with a suitable elastomeric coating system.
4. Broom, prime, apply a new lift of foam, and coat with a suitable coating system.
5. Shave or sand to remove bad coating and foam until only good-quality foam remains. Blow off or vacuum all dust, and coat with a suitable elastomeric coating system or prime and coat with a suitable coating system.
6. Shave or sand to remove bad coating and foam until only good-quality foam remains. Blow off or vacuum all dust, apply a new lift of foam, and coat with a suitable elastomeric coating system; or prime, apply a new lift of foam, and coat with a suitable elastomeric coating system.

All of these procedures were investigated to disclose their limitations and to determine which are most effective under different prevailing roof conditions.

In addition to the maintenance procedures mentioned above, localized roof repairs may be required for areas up to 10 ft^2 where poor-quality or water-saturated foam needs replacement. This type of repair is easily accomplished by removing the bad foam and replacing it with new foam applied either by a foam spray unit or by using single- or two-package "canned" foam units.

EXPERIMENTAL INVESTIGATIONS

Research directed toward development or selection of optimum maintenance methods for PUF roofing systems was conducted both in the laboratory and in the field. The work was carried out in four phases.

Phase 1 — Maintenance of 12 Coated PUF Test Panels That Had Failed

Twelve PUF roofing system panels from another portion of the NCEL roof research program were used. Four of the systems described in Reference 3, and exposed at each of the

* *In selecting a suitable elastomeric coating system, consideration must be given to the possibility of some moisture in the old foam, and to the permeability of the new coating. If moisture is present in the foam, a permeable coating should be used to prevent blistering that might occur if an impermeable coating (a vapor retarder) is used.*

three NCEL experimental weathering sites†, had either failed or were nearing failure after varying periods of exposure.

As with many other systems, proper surface preparation is the most important consideration in the maintenance of PUF roofing systems. If a deteriorated PUF roof surface is improperly prepared, it is highly unlikely that any maintenance procedure will be effective. The procedures for cleaning the PUF coatings, or otherwise preparing the PUF roof surfaces listed above were investigated. These procedures involved equipment for brooming, shaving, and sanding a degraded PUF roof surface. The sander is a heavy-duty, electrical disk sander. The shaver is a 24-inch foam plane for shaving foam applied between studs in a wall.

The procedures and materials used for maintaining the 12 deteriorated systems and their system numbers are given in Table 1. The reconditioned PUF roofing systems were coated or recoated with a two-component (catalyzed) urethane elastomer applied in two coats.

The experimentally maintained PUF panels of Phase 1 have been exposed at the Port Hueneme site for about five years. Samples were cut from these specimens for adhesion testing after they had been exposed for about two years, and approximately on an annual basis thereafter (*Table 2*). The performance of each of the treatments was also rated on an annual basis *(Table 1)*. After 4 years of weathering, additional small samples were cut from samples 7F-1 and 8F-1. During the maintenance procedure both were sanded to good-quality bare foam, 8F-1 was primed, and both were refoamed. These samples were taken to determine if use of a primer improved bonding of the new foam to the old foam *(Table 3)*.

Phase 2 — Maintenance of 12 Coated and Eight Uncoated PUF Test Panels

To provide additional weathered PUF surfaces on which to perform maintenance experiments, three ½″×4′×8′ plywood panels were sprayed with 1½ inches of PUF. The foam was coated with TT-P-95, a chlorinated rubber paint, and the samples weathered at one of the NCEL exposure sites for about two years.

This particular coating was selected because it had been used unsuccessfully on PUF roofs at several Naval activities before it was recognized that elastomeric coatings are required to accommodate the large expansions and contractions experienced by PUF roofs. The rigid coatings applied over PUF roofs at field activities had failed within six months to two years after application.

Each of the three 4′×8′ weathered panels were cut into four equal 2′×4′ sections. The TT-P-95 coating showed mudcracking, crazing, flaking, and line cracking. In addition, foam had been spray-applied to eight 2′ × 4′ plywood panels that had been allowed to weather uncoated until the foam surfaces had degraded. These eight uncoated panels were used in surface preparation studies involving sanding. In all, 20 test panels were used.

All six of the experimental maintenance procedures were included in this phase of the investigation. Actual procedures used on each system are given in Table 1. Brooming was accomplished with a rattan pushbroom, brushing with GI brushes, and sanding with a disk sander. The coating system used with this group of panels was an acrylic latex elastomer applied in two coats.

Following surface conditioning, all loose foam material and dust were removed by blowing the surface with an air hose. Duplicate panels of each of the maintenance systems were prepared, and all panels have been exposed at the Port Hueneme site for about four years. A small section of each of the duplicate panels was removed periodically and returned to the laboratory to determine performance characteristics. Systems were inspected and rated, and physical properties, such as coating and foam adhesion over unprimed and primed surfaces, were all determined annually. These characteristics are described in Reference 3.

Phase 3 — Test and Evaluation of Repair Methods for Small Areas of PUF Roof Systems

Often only small areas of a foam roof (i.e., 1 to 10 ft^2) require maintenance. These usually occur when there is some deficiency in foam quality caused by: (1) the two components of the foam being off ratio when dispensed, (2) the foam sustaining mechanical damage following application, or (3) the foam becoming wet. In such cases, it is generally necessary to remove the affected foam down to the roof deck, refoam, and coat the newly foamed patch. When PUF spray equipment is available, patching of small areas presents few problems. However, if proper equipment and trained personnel are not available, other procedures must be used.

Repairs using conventional foam equipment are described in Reference 4, where approximately 15 to 20 ft^2 of spongy foam was removed from test roofs at NRC Clifton, N.J., replaced with new foam, and coated. This provided a monolithic roofing system that has performed the same as a new roofing system.

When PUF spray equipment is not available, other sources of PUF, such as canned foam or foam boardstock, must be used. Canned foam is available in two forms: (1) single-component (one can), where the foam reacts with atmospheric moisture to cure; and (2) two-component (two cans), in which the components react to cure. The single-component foam must cure for about 24 hours before it can be sanded. The two-component foam cures sufficiently in one to two hours to be sanded.

Both single- and two-component canned foams were investigated at the NRC Clifton test site. Additional tests were conducted at NCEL. The NCEL tests involved the two-component canned foam and either PUF or polystyrene foam insulation board cut to the approximate size of the foam removed from the roof. The shaped boardstock was then set into four or five beads of caulking material applied to the roof deck. The area between the boardstock and the adjacent foam was caulked, and the surface of the foam was protected with a proper caulking material or coating. The use of both canned foam and foam insulation boardstock for patching is shown in Figure 1.

† *NCEL has experimental weathering sites at the following locations: (1) Port Hueneme, Calif. (marine weather); (2) China Lake, Calif. (desert site); and (3) Pickel Meadows, Calif. (cold weather site).*

Phase 4 — Maintenance Coating of Aged PUF System Test Panels

Concern has been expressed that silicone coatings are difficult to recoat because the new silicone coating may not adhere well to the old silicone coating. To determine the validity of this concern, two 2′×4′ experimental panels coated with a single-component, moisture-cured silicone were returned to NCEL for an additional maintenance operation. One of these panels had been exposed at the China Lake site, while the second had been exposed at the Pickel Meadows site. Both were in excellent condition after eight years of exposure.

Each of two panels was divided in half. Four different surface treatments were tried, one on each half of the panel, prior to recoating with new silicone coating. These surface treatments are described in Table 4.

Small samples were cut from these panels to determine the adhesion of the new coating to the old coating before the systems were exposed and again after six months of weathering at Port Hueneme.

RESULTS AND DISCUSSION

This paper presents results of a five-year laboratory and small-scale field study to develop preliminary guidelines for maintaining foam roofs.

Phase 1

The condition of the 12 weathered systems in this phase varied. For all practical purposes, no two systems were in the same condition. Results of the inspection of these systems for performance during five years of weathering are given in Table 1.

The three methods used in this phase for preparation of the surfaces were brooming, sanding, and shaving. Brooming was relatively effective only on system 1F-1, but was not effective for surfaces that have a moderate percentage of flaked coating, such as systems 1F-2 and 2F-1.

Not as much of the original urethane coating had spalled from the foam of system 1F-1 as from systems 1F-2 and 2F-1. As a result, system 1F-1 was rated good after five years' exposure while system 1F-2 had failed and system 2F-1 was rated poor. System 1F-2 had absorbed water after one year of exposure. The slightly better performance of system 2F-1 over system 1F-2 is attributed in part to the use of a primer, which improves the adhesion of the new coating to the old coating. Compare adhesive properties for systems 2F-1 and 1F-2 in Table 2.

The foam plane did not have sufficient cutting ability to remove these coatings, particularly the moisture-cured urethanes. Although these coatings had deteriorated, the remaining portion was still quite tough. The disk sander was used to partially sand the most deteriorated portions of systems 3F-1, 3F-2, 3F-3, 4F-1, and 4F-2. While the disk sander did a relatively good job, it is not effective in removing deteriorated tough coatings, such as the urethanes.

After five years of weathering, systems 3F-1 and 3F-2 were providing good to very good protection to the PUF panels. Less than 10 percent of the old weathered coating had spalled before this maintenance was performed. Where there were breaks in the original coating, the new coating generally bridged over the transition from foam to old coating. However, there was minor cracking which was more prevalent on system 3F-1 than on system 3F-2. The third system in this group, system 3F-3, had failed after five years of weathering. There were many interface areas of old coating to foam, and the maintenance coating was cracking around these areas.

System 4F-1 is providing good protection to the PUF after five years' exposure. The old weathered coating had no more than 10 percent spalled areas, which had been sanded to remove degraded coating and foam. This caused some cracking of the maintenance coating where it had originally bridged these transition areas between sanded foam and old coating. System 4F-2, on the other hand, had more than 40 percent spalling of the original weathered coating which had been sanded lightly to good-quality foam. There were relatively few breaks in the maintenance coating where it had been applied over areas of transition from sanded foam to good-quality coating. System 4F-2 was rated very good after five years' exposure.

A comparison of the adhesive characteristics of systems 3F and 4F *(Table 2)* does not show a clear-cut advantage for using or not using a primer. The reason for this is believed to be the variability of the primed substrate, both sanded foam and weathered coating.

Systems 5F-1 through 8F-1 required complete removal of old deteriorated coating and foam using the disk sanders. As mentioned above, the residual urethane elastomeric coatings (systems 5F-1 and 6F-1) were very tough and abrasion-resistant. Removal with a disk sander was time consuming, and the material tended to gum up the disk sanders. The weathered butyl-hypalon systems (systems 7F-1 and 8F-1) were not quite as difficult to remove because they were less abrasion resistant.

Systems 5F-1 and 6F-1 both performed well, providing complete protection to the sanded foam substrate for up to five years *(Table 1)*. The catalyzed urethane elastomer bonded very well to the sanded foam surface except for a few blisters between the sanded foam surface and the new coating. The primer in system 6F-1 appeared to have minimized blistering and provided a definite improvement in coating adhesion to the sanded foam surface *(Table 2)*. Coating application to a sanded or scarfed foam surface, whether primed or not, is generally not recommended. However, these results suggest that such a procedure would be acceptable in small, isolated areas. When small areas are sanded to provide a smoother surface, the sanded areas should be primed, and at least 35 to 40 total dry mils of coating should be applied.

Systems 7F-1 and 8F-1 also have performed well for five years' exposure. These two systems, sanded foam surfaces that were refoamed and the new foam coated, were similar except for the primer applied to the sanded foam of system 8F-1. Because of the new foam and the catalyzed urethane coating, these two systems would be expected to perform well. They were included to determine if priming the sanded foam surface is advantageous before refoaming. Data in Table 3 for these two systems show that the adhesion of new foam to old foam is improved by using a primer.

Phase 2

The objective of this phase of the work was to determine whether or not it is advantageous to prime before coating or foaming over old weathered coatings or over sanded foam surfaces *(Table 1)*.

Two types of brooming were investigated. In the first, systems 9F-1 and 9F-2 and 10F-1 and 10F-2, the rattan push broom did a very effective job at cleaning dirt, chalk, loose coating, and deteriorated foam from the panels. The second treatment, brushing with GI brushes, was used on the remainder of the weathered TT-P-95 panels, including panels 11F-1 and 11F-2 through 14F-1 and 14F-2. Brushing was not nearly as effective as the rattan push broom.

The weathered, uncoated foam panels were easily and efficiently cleaned of degraded foam using the disk sander (systems 15F-1 and 15F-2 through 18F-1 and 18F-2).

The second panel of each series (i.e., 9F-2, 10F-2, etc.) was returned to NCEL on a periodic basis and a small section cut off for adhesion testing. The series has been exposed for about four years. The coating on systems whose surfaces were prepared for recoating by brooming or brushing (i.e., systems 9F-1 to 12F-2) showed very slight cracking where the new coating bridged over cracks in the original coating or where the original coating had flaked from the foam. However, this was not serious, and all of the systems in this series were providing excellent protection.

An elastomeric coating applied over a sanded foam surface is more easily compressed into the foam than a coating applied over a foam surface with a skin. The skin tends to make the foam surface more rigid. Thus, a coating applied over a sanded foam surface may be more easily damaged. For this reason, sanding the foam followed by an extra heavy coating should be used only in small, isolated areas.

The effect of a butyl primer on the adhesion of new coating applied to a weathered coating surface or to a sanded foam surface is shown in Table 2, The data show lower adhesive values for the primed surfaces than for the unprimed surfaces, the reverse of that found when using the urethane primer in Phase 1. While the differences in adhesive values for primed and unprimed surfaces were substantial after one year of exposure, they appear to lessen with additional exposure. This suggests that the problem may involve retention of solvents in the butyl primer during the initial exposure period.

Application of the butyl primer over a brushed, weathered coating and over a sanded foam surface prior to refoaming increased the adhesion of new foam to those surfaces *(Table 3)*. The reason for this is not clear since the butyl primer did not enhance adhesion of the acrylic elastomer coating. However, use of a primer appears desirable because of the lower incidence of blistering when a coating is applied over a sanded foam surface, the better adhesion of neN foam to old when using the butyl primer, and overall improved adhesion with the urethane primer.

Phase 3

This phase of the investigation deals with maintenance of small areas of a PUF roof. During annual inspections, very small defects can be corrected with caulking material carried by the inspector. During the annual inspections at the NRC Clifton test site (References 4, 5), it was a relatively simple matter to remove small degraded coating/foam areas and repair them on the spot with either silicone or acrylic caulk. Such a procedure often prevents small problems from becoming large roof defects.

If a defect 1 ft^2 or larger is found at any time, it is necessary to use maintenance procedures that incorporate other materials for foam and coating replacement. "Canned" foams and precut foam insulation boardstock were investigated for this purpose.

The single-component foam did not perform acceptably. Although this froth foam filled the voids relatively well, the cell structure was very irregular, resulting in extremely poor physical characteristics. This caused the applied coating to spall within 1 year, and the foam had to be replaced. Although there are better quality single-component foams available, these materials require a curing time of about 24 hours before they can be shaped or coated.

The two-component canned foams expanded and filled the voids well, but also produced a very rough surface that had to be shaped. This froth foam cures within one to two hours and provides a better quality foam with better cell structure. Because of the short curing time, the two-component foams can be shaped with a disk sander within two hours of application.

If the canned foam is not available, PUF or polystyrene foam boardstock insulation is an acceptable alternative. Boards are adhered to the roof deck with caulking material, shaped if required, and then waterproofed or protected from the environment with either a suitable coating or caulking material.

Of the three methods mentioned, NCEL believes that the two-component canned foams provide a better patch than either single-component canned foam or foam boardstock.

Shaping the foam gives a sanded or cut foam surface without the normal foam skin, and its coating is more easily damaged than over a skinned surface. Coating applied over a sanded foam surface should be applied in multiple coats to form a minimum dry film thickness of 35 to 40 mils. As a result, NCEL favors the use of caulking materials for patching.

New, small, foam spray machines are currently available for small foam roof repairs. These machines have small canisters of the two foam components and require only a 110-volt power source and low-pressure, low-volume compressed air (1 cfm). They provide the best maintenance procedure, because the two-component foam used is the same quality as in the original roof.

Phase 4

Results of research to determine the adhesion of new silicone coatings over weathered silicone coatings are presented in Table 4. The single-component silicones were applied over weathered silicones that had received one of four different surface treatments: (1) broomed, (2) washed with water, (3) washed with moderate, 100+ psi pressure water blasting, and (4) washed with detergent. The adhesion data in Table 4 suggest that brooming is normally an adequate surface preparation, because there is not much difference in the adhesion between the coatings applied over the four surface treatments. However, in certain heavy industrial atmospheres oily substances may be deposited on the roof, and washing with detergent may be required to properly prepare the surface. Failure was normally adhesive between the new and old coating. This is not considered serious because the adhesion of the new to old coating appears to increase with time. While there have been some problems in the past with the adhesion of the single-component, moisture-cured silicone to foam, a new base coat of this material that incorporates an adhesion promoter is now available.

FINDINGS AND CONCLUSIONS

1. A PUF roofing system can be easily maintained using methods and materials described in this report.
2. A strong inspection and maintenance program can extend the time before recoating as much as five additional years.
3. When removing small areas of poor-quality, wet, or degraded foam, the areas should be refoamed with conventional foaming equipment. If this equipment is not available, repairs can be made using two-component canned foam or foam boardstock. Any voids between new and old foam should be caulked, and the new foam surface protected with an appropriate caulk or 35 to 40 mils of elastomeric coating.
4. If spalling of weathered elastomeric coating is distributed uniformly over less than 10 percent of the roof, the roof generally can be satisfactorily recoated. In such cases, a tiecoat of primer recommended by the coating manufacturer should be applied before recoating. While the primer may or may not enhance adhesion of the new coating to the weathered coating, depending on the primer employed, it does appear to improve the overall performance of the coating.
5. New sprayed PUF applied over an existing coated foam system that was primed, has performed very well in these studies. While such a procedure is not applicable in all cases, it can be used. Each application should be considered individually.
6. Coating a sanded foam surface generally is not recommended. However, coating small, isolated areas of approximately 5 to 10 ft^2 appears to present no problem as long as the area is not a high traffic area and the coating is at least 35 to 40 mils thick.
7. When refoaming over an existing coated foam roof, the roofing system should be thoroughly inspected for roof defects using a nuclear survey or other specialized inspection technique to ensure that it is dry. Any wet or degraded areas should be removed, allowed to dry, and refoamed. Weathered surfaces should be cleaned and primed prior to refoaming. Additional foam should not be applied over an impermeable coating or over a silicone-coated foam roof.

REFERENCES

[1] K.H. Coultrap. principles of urethane foam roof application, Civil Engineering Laboratory, Purchase Order Report PO 79-MR-461. Tempe, Ariz., Coultrap Consulting Services, Inc., June 1980.

[2] R.L. Alumbaugh, S.R. Conklin, and D.A. Zarate. Preliminary guidelines for maintenance of polyurethane foam (PUF) roofing systems, Naval Civil Engineering Laboratory, Technical Note N-1691, Port Hueneme, Calif., March 1984.

[3] R.L. Alumbaugh and J.R. Keeton. Investigation of spray-applied polyurethane foam roofing systems — I, Civil Engineering Laboratory, Technical note N-1496. Port Hueneme, Calif., July 1977.

[4] J.R. Keeton, R.L. Alumbaugh, and E.F. Humm. Experimental polyurethane foam roofing systems, Civil Engineering Laboratory, Technical Note N-1450. Port Hueneme, Calif., August 1976.

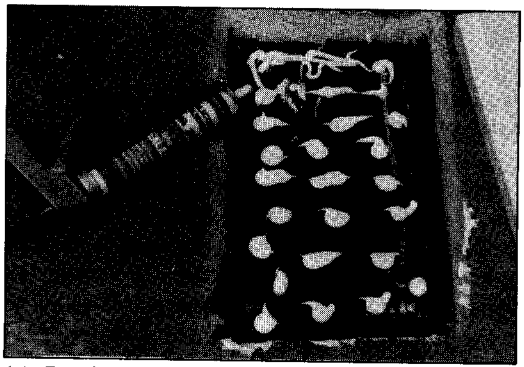
[5] R.L. Alumbaugh, J.R. Keeton, and E.F. Humm. Experimental polyurethane foam roofing systems — II, Naval Civil Engineering Laboratory, Technical Note N-1656. Port Hueneme, Calif., January 1983.

(a) Edge of cut is beveled and all debris is removed.

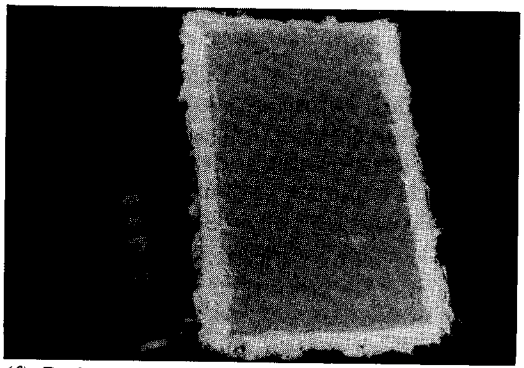
(b) PUF is patched with canned foam.

(c) Rough foam surface is smoothed with a disc sander.

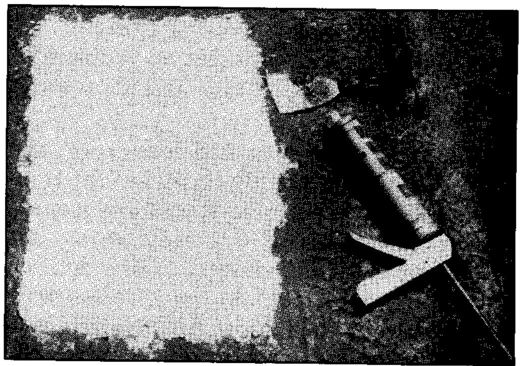
(d) Sanded foam surface is protected with coating or caulking and, where required, roofing granules.



(e) Patch using boardstock is adhered to the roof deck with caulking material.



(f) Perimeter of patch is caulked.



(g) Foam patch is protected with caulking material.

Figure 1 *Patching polyurethane foam (PUF) roofs with canned foam or with foam boardstock*

System Number	Description of Maintenance Procedure	Primer	New Foam Density (lb/ft³)	Performance Ratings on Weathering[a]					
				4 Mo	1 Yr	2 Yr	3 Yr	4 Yr	5 Yr
			Phase I[b]						
1F-1	Broom panel and coat	none	none	VG-G	VG-G	VG-G	VG-G	G	G
1F-2		none	none	G	P-F	F	F	F	F
2F-1	Broom panel, prime, and coat	urethane	none	E	VG	G	G	G	P
3F-1	Broom panel, sand some portions, and coat	none	none	E-VG	VG	VG-G	VG-G	VG-G	VG-G
3F-2		none	none	VG	VG	VG	VG	VG	VG
3F-3		none	none	VG	VG-G	G	G	P	F
4F-1	Broom panel, sand some portions, prime, and coat	urethane	none	VG	VG	VG	VG	VG-G	G
4F-2		urethane	none	VG	VG	VG	VG	VG	VG
5F-1	Broom, sand entire panel, and coat	none	none	E	E	E	E	E	E
6F-1	Broom, sand entire panel, prime, and coat	urethane	none	E	E	E	E	E	E
7F-1	Broom, sand entire panel, foam, and coat	none	3	E	E	E	E	E	E
8F-1	Broom, sand entire panel, prime, foam, and coat	urethane	3	E	E	E	E	E	E
			Phase II[c]						
9F-1	Broom panel and coat	none	none	E	E	E	E	E	—
10F-1	Broom panel, prime, and coat	butyl	none	E	E	E	E	E	—
11F-1	Brush panel and coat	none	none	E	E	E	E	E	—
12F-1	Brush panel, prime, and coat	butyl	none	E	E	E	E	E	—
13F-1	Brush panel, foam, and coat	none	3	E	E	E	E	E	—
14F-1	Brush panel, prime, foam, and coat	butyl	3	E	E	E	E	E	—
15F-1	Sand entire panel and coat	none	none	E	E	E	E	E	—
16F-1	Sand entire panel, prime, and coat	butyl	none	E	E	E	E	E	—
17F-1	Sand entire panel, foam, and coat	none	3	E	E	E	E	E	—
18F-1	Sand entire panel, prime, foam, and coat	butyl	3	E	E	E	E	E	—

[a]Performance ratings were assigned as follows:
E = Èxcellent. The system is performing without any noticeable deterioration.
VG = Very Good. Only very minor deterioration of the system.
G = Good. Although the maintained PUF systems show deterioration, it is not serious.
P = Poor. System deterioration is serious. Remedial action will be required in the near future.
F = Failed. Deterioration of the system has advanced to the point of requiring immediate maintenance.

[b]Topcoat for Phase I consisted of two coats of a catalyzed urethane. Both the black basecoat and the oyster white topcoat were applied at the rate of 1½ gal/sq (30 mils dry film thickness).

[c]Topcoat for Phase II consisted of two coats of an acrylic latex elastomer applied at the rate of 1½ gal/sq/coat (35 mils total dry film thickness).

Table 1 Performance ratings for polyurethane foam (PUF) maintenance systems

System Number	Primer	Adhesive Properties for Approximate Exposure Times of— 1 Year Stress (kg/cm²)	1 Year Failure[a] Mode	2 Years Stress (kg/cm²)	2 Years Failure[a] Mode	3 Years Stress (kg/cm²)	3 Years Failure[a] Mode	4 Years Stress (kg/cm²)	4 Years Failure[a] Mode
				Phase I					
1F-1	no	—	—	24.0	4	9.6	7	10.9	7
1F-2	no	—	—	12.3	6	11.1	4	11.1	5/7
2F-1	urethane	—	—	18.9	5/8	17.5	2	15.6	2/8
3F-1	no	—	—	28.3	8	17.5	7/4	15.7	4/8
3F-2	no	—	—	14.6	8	13.4	8/7	15.4	8
3F-3	no	—	—	18.7	8/5	8.6	7/4	7.1	7
4F-1	urethane	—	—	19.0	8	17.2	7/8	13.3	7/8
4F-2	urethane	—	—	21.7	3	13.7	7/8	14.0	7
5F-1	no	—	—	17.7	8	13.1	7/8	11.0	7/8
6F-1	urethane	—	—	18.2	8	17.4	8	15.9	4/8
				Phase II					
9F-2	no	26.0	8	42.8	8	15.6	8	11.5	8
10F-2	butyl	20.0	8/3	36.3	8/9	12.0	8/2	9.3	8
11F-2	no	25.4	8	30.2	8	20.6	8	11.5	8
12F-2	butyl	13.8	3	18.1	3	11.6	6/8	7.0	8/7
15F-2	no	14.2	8	30.2	8	15.1	8/6	13.1	8
16F-2	butyl	13.2	8/6	15.0	8/6	14.0	8/6	11.7	8/6

[a]Failure modes were:
1. Adhesive failure of probe to new coating.
2. Adhesive failure of new coating to primer.
3. Adhesive failure of primer to old coating.
4. Adhesive failure of new coating to old coating.
5. Adhesive failure of old coating to foam.
6. Cohesive failure of old coating.
7. Cohesive failure of new coating.
8. Cohesive failure in foam.
9. Adhesive failure of primer to old foam (in areas where old coating spalled from foam).

Table 2 *Adhesive properties of coatings on polyurethane foam (PUF) maintenance panels*

System Number	Weathered Foam Treatment	Primer Type	Adhesive Properties for Exposure Times of— 2.5 Years Stress (kg/cm²)	2.5 Years Mode[a]	4 Years Stress (kg/cm²)	4 Years Mode[a]
		Phase I				
7F-1	Broomed, sanded, and foamed	none	—	—	1.55	1
8F-1	Broomed, sanded, primed, and foamed	urethane	—	—	1.83	1
		Phase II				
13F-2	Brushed and foamed	none	1.59	1	2.53	1
14F-2	Brushed, primed, and foamed	butyl	1/88	2/3/4/5	3.10	2/4
17F-2	Sanded and foamed	none	1.29	1	2.68	2/1
18F-2	Sanded, primed, and foamed	butyl	2.41	5	2.97	4/2

[a]Principal mode of failure.
1. Adhesive failure of new foam to old foam.
2. Adhesive/cohesive failure with old foam.
3. Adhesive failure of primer to old foam.
4. Adhesive failure of new foam to primer.
5. Adhesive/cohesive failure within new foam.
6. Bond of old foam to primed plywood.

Table 3 *Adhesion of new foam to old foam—with and without primer*

System Number[b]	Surface Treatment	Adhesive Properties for Exposure Times of— Initially: Stress (kg/cm^2)	Initially: Mode[c]	6 Months: Stress (kg/cm^2)	6 Months: Mode[c]	Original Coating System
19F-1	Thoroughly broomed to remove adhered dirt	5.5	2	8.9	2/1	Silicone exposed at China Lake, Calif., for 8 years. System in excellent condition.
19F-2	Thoroughly broomed, washed with water, and dried completely	6.2	1/2	7.4	2/1	Silicone exposed at China Lake, Calif., for 8 years. System in excellent condition.
20F-1	Washed with a pressurized water (~100 psi) spray and dried completely	7	2/1	8.6	2	Silicone exposed at Pickel Meadows, Calif., for 8 years. System in excellent condition.
20F-2	Washed and scrubbed with trisodium phosphate detergent, rinsed with clean water, and dried completely	6	2/1	7	2/1	Silicone exposed at Pickel Meadows, Calif., for 8 years. System in excellent condition.

[a]The recoat system consists of two coats of moisture curing Silicone applied at 1 gal/sq/coat.
[b]Systems 19F-1 and 19F-2 and 20F-1 and 20F-2, respectively, were each applied to one-half of the panel.
[c]Predominant modes of failure in tension were:
1. Adhesive failure of probe to new coating.
2. Adhesive failure of new coating to old coating.

Table 4 Adhesion of new silicone coating to weathered silicone (phase 5)[a]