10.00

NATIONAL BUREAU OF STANDARDS REPORT

8382

EVALUATION OF NEW ROOFING SYSTEMS ON GUAM, M.I.

by

William C. Cullen

NBS

U.S. DEPARTMENT OF COMMERCE

NATIONAL BUREAU OF STANDARDS

THE NATIONAL BUREAU OF STANDARDS

The National Bureau of Standards is a principal focal point in the Federal Government for assuring maximum application of the physical and engineering sciences to the advancement of technology in industry and commerce. Its responsibilities include development and maintenance of the national standards of measurement, and the provisions of means for making measurements consistent with those standards; determination of physical constants and properties of materials; development of methods for testing materials, mechanisms, and structures, and making such tests as may be necessary, particularly for government agencies; cooperation in the establishment of standard practices for incorporation in codes and specifications; advisory service to government agencies on scientific and technical problems; invention and development of devices to serve special needs of the Government; assistance to industry, business, and consumers in the development and acceptance of commercial standards and simplified trade practice recommendations; administration of programs in cooperation with United States business groups and standards organizations for the development of international standards of practice; and maintenance of a clearinghouse for the collection and dissemination of scientific, technical, and engineering information. The scope of the Bureau's activities is suggested in the following listing of its four Institutes and their organizational units.

Institute for Basic Standards. Electricity. Metrology. Heat. Radiation Physics. Mechanics. Applied Mathematics. Atomic Physics. Physical Chemistry. Laboratory Astrophysics.* Radio Standards Laboratory: Radio Standards Physics; Radio Standards Engineering.** Office of Standard Reference Data.

Institute for Materials Research. Analytical Chemistry. Polymers. Metallurgy. Inorganic Materials. Reactor Radiations. Cryogenics.** Office of Standard Reference Materials.

Central Radio Propagation Laboratory.** Ionosphere Research and Propagation. Troposphere and Space Telecommunications. Radio Systems. Upper Atmosphere and Space Physics.

Institute for Applied Technology. Textiles and Apparel Technology Center. Building Research. Industrial Equipment. Information Technology. Performance Test Development. Instrumentation. Transport Systems. Office of Technical Services. Office of Weights and Measures. Office of Engineering Standards. Office of Industrial Services.

---

* NBS Group, Joint Institute for Laboratory Astrophysics at the University of Colorado.
** Located at Boulder, Colorado.

NATIONAL BUREAU OF STANDARDS REPORT

NBS PROJECT		NBS REPORT
1004-12-10447	30 June 1964	8382

EVALUATION OF NEW ROOFING SYSTEMS ON GUAM, M.I.

by

William C. Cullen
Organic Building Materials Section
Building Research Division

Sponsored by

Office of the Chief of Engineers
Department of the Air Force
Bureau of Yards and Docks

IMPORTANT NOTICE

NBS

U.S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS

CONTENTS

EVALUATION OF NEW ROOFING SYSTEMS ON GUAM, M.I.

1. INTRODUCTION

It is well known that the intensity of solar radiation, the high temperatures, and the very high humidities generally associated with tropical areas accelerate the degradation of most organic building materials. Bituminous roofings are no exception as confirmed by their early deterioration in tropical areas. The many premature failures of such systems experienced in these areas have resulted in abnormally high maintenance and replacement costs. The need for improvement in roofing performance was recognized by the construction agencies of the Defense Department and an evaluation program of new roofing systems was proposed by the members of Task 30 of Department of Defense Project 32 in February 1963. In this connection, the National Bureau of Standards was requested to provide technical assistance in the selection of the roofing systems, in the conduction of the tests, and in the methods of evaluation. The National Bureau of Standards portion of the program was conducted as a task under Project 10447, "Performance of Roofings", Tri-Service Engineering Investigation of Building Construction and Equipment, NBS.

The selection of 7 new roofing systems was based on data developed under the project in both simulated service tests conducted in the laboratory and outdoor exposures during field service. "On-site" observations were made by the author of test installations on Guam Island during the period of 8 April to 15 April 1964.

In 1954 the National Bureau of Standards actively participated in a similar program to evaluate various types of roofing materials on Guam Island under the sponsorship of the Bureau of Yards and Docks, U. S. Navy. This program also included "on-site" inspections by the author.

This report summarizes the results of the 1954 evaluation program based on the "on-site" inspections in 1954 and 1964, as well as on the inspection data furnished periodically by the Bureau of Yards and Docks. The test exposures included in the 1964 evaluation program are also described. Further, the report includes our observations, opinions and recommendations regarding the past and future performance of specific roofing systems under evaluation.

2. LOCAL CLIMATOLOGICAL DATA, GUAM, PACIFIC

Guam is the largest and southernmost of the Mariana Islands. It lies at about 13.5° N., 145°E. with the Philippine Sea to the west and the Pacific Ocean to the east. The Island is 28 miles long, 4 to 8 miles wide, and is oriented NNE - SSW.

The climate of Guam is almost uniformly warm and humid throughout the year. Afternoon temperatures are typically in the middle or high eighties and nighttime temperatures typically fall to the low seventies or high sixties. Relative humidity commonly ranges from around 65-75 percent in the afternoon to 85-100 percent at night. Though temperature and humidity vary only slightly throughout the year, rainfall and wind conditions vary markedly, and it is these latter variations that really define the seasons.

There are two primary seasons and two secondary seasons on Guam. The primary seasons are the 4-month dry season, which extends from January through April, and the 4-month rainy season which extends from mid-July to mid-November. The secondary seasons are May to mid-July and mid-November through December. These are transitional seasons that may be either rainy or dry depending upon the nature of the particular year.

The mean annual rainfall on Guam ranges from around 95 inches on the windward (east) side of the higher mountains to about 80 inches along the coast of the western side of the southern half of the Island. On the average, about 15 percent of the annual rainfall occurs during the dry season and 55 percent during the rainy season.

At all times of the year the dominant winds on Guam are the trade winds which blow from the northeast or east. The trades are strongest and most constant during the dry season, when windspeeds of 15-25 m.p.h. are very common. During the rainy season there is often a breakdown of the trades and on some days the weather may be dominated by moving storm systems that bring heavy showers or steady, and sometimes torrential, rain. Most of the storms of the rainy season are simply rainstorms, associated with definite but still very mild storm systems. Occasionally, however, there are typhoons, and these bring not only tremendous rains, but also violent winds.

3. ROOFING MATERIAL EVALUATION PROGRAM 1954

3.1 History

The post-war construction period on Guam saw the evolvement of many problems in building construction. Not the least of the problems was the attainment of an effective, economical, and durable roof system for permanent structures. Initially, a smooth-surfaced, built-up roof insulated from the deck was selected. This selection was based on the best engineering knowledge available at that time and on previous experience in other areas. However, many premature failures occurred in these systems which resulted in enormous repair, maintenance, and replacement costs. This experience precipitated a program, the purpose of which was to evaluate other roofing materials for possible use in lieu of the built-up roof system.

In May 1954, a series of tests were initiated on some 46 roofing materials on permanent buildings at the Dependent Housing Area, Naval Communication Station, Finegayen, Guam. The program was conducted by the Materials Testing and Evaluation Division, Public Works Center, OICC, Guam, with technical assistance provided by the Building Technology Division, National Bureau of Standards.

The installation of the materials was conducted under the supervision of the Public Works Center personnel who also carried out the periodic examinations. "On-the-roof" inspections were made by the author in October 1954 and again in April 1964.

3.2 Roof Systems

3.2.1 Roof Exposures.

The roof decks selected for the test installations were on new concrete block, two-storey, semi-detached homes, as illustrated in Figure 1. The poured-in-place concrete slab was about 13.5 squares in area and varied in thickness from 7-1/2 inches at the ridge to 4-1/2 inches at the eave which provided for a slight slope. The decks were smooth, clean, and essentially dry prior to the application of the test systems.

3.2.2 Roofing Materials.

Forty-six roofing materials were evaluated in the program. For various reasons, we have not attempted to enumerate the materials included. However, for convenience we have placed each material into one of five general classes.

3.2.2.1 Class I. Mastics. (12 Materials)

The mastics were heavy-bodied materials consisting of organic solids thinned to a workable consistency with a volatile organic solvent. The coatings generally contained added stabilizers such as asbestos fibers, fine mineral matter, and pigments such as aluminum powder. The organic solids included asphalt, fatty-acid pitch, chlorinated rubbers, and various resins. The spreading rate of these compounds varied from approximately 20 to 100 sq. ft. per gallon.

3.2.2.2 Class II. Paints. (12 Materials)

The paints were relatively thin-bodied coatings consisting of organic materials and pigments dispersed in volatile and non-volatile vehicles. The coatings of this class were applied by brush and roller at a spreading rate which varied from 100 to 300 sq. ft. per gallon. Included in this group were aluminum and other light colored paints, enamels, and lacquers.

3.2.2.3 Class III. Emulsions. (6 Materials)

The emulsions were heavy-bodied materials consisting of dispersions of various organic solids as asphalt and coal-tar pitch in water. The compounds included both the chemical and clay type emulsions which contained pigments, stabilizers, and emulsifiers. The spreading rates for this class varied from 50 to 100 sq. ft. per gallon.

3.2.2.4 Class IV. Reinforced Membranes. (8 Systems)

The reinforced membranes consisted of either a single-ply or multiple-plies of a reinforcing medium (glass, asbestos, organic or metallic) adhered to the deck and embedded in a hot- or cold-applied bituminous material (asphalt, coal-tar pitch, etc.) or other organic compounds (epoxy, etc.). The membranes were either left smooth or were surfaced with a manufactured coral aggregate.

3.2.2.5 Class V. Miscellaneous. (8 Materials)

The miscellaneous materials consisted of cement water paints, silicone preparations, floor hardeners, linseed oils, and other slab treatments not covered by the preceeding classifications. The materials were applied by various techniques at spreading rates dictated by the properties of the materials.

3.3 Evaluation

The application of each material was supervised by the Public Works Center personnel and periodic examinations were made on at least an annual basis for the exposure period of 10 years. Each roofing material was rated on a numerical system based on its performance in the following categories:

a. General Appearance
b. Waterproofing Qualities
c. Physical Integrity
   (1) blistering
   (2) cracking
   (3) flaking
   (4) alligatoring
   (5) checking
d. Appearance
   (1) color change
   (2) fading
   (3) chalking

The test of a given material was discontinued and was considered a failure when the numerical rating of the elements rated approached zero.

A record was also kept by taking photographs of each material initially and at the time of the periodic examination.

3.4 Results

The results are given in tabular form and are expressed as a percentage failure of the total candidates in each group in relation to exposure time.

3.4.1 Class I - Mastics. (12 Materials)

Years Exposed	No. Failed (cumulative)	% of Total (cumulative)
3	6	50
4	9	75
6	10	83
7	11	92
10	12	100

Generally the coatings in this group declined in their ability to waterproof the concrete roof deck with exposure. The prime factors contributing to the decline were blistering, cracking, embrittlement, loss of adhesion to substrate and a general deterioration. Typical examples of failures in the mastic coatings are shown in Figures 2 and 3.

3.4.2 Class II - Paints. (12 Materials)

Years Exposed	No. Failed (cumulative)	% of Total (cumulative)
1	3	25
2	4	33
3	7	58
4	10	83
10	12	100

In some cases the materials included in this class initially failed to waterproof the concrete slab due to poor coverage at the high spreading rates recommended for these materials. The remaining materials failed to perform due to peeling, blistering, flaking, and in their ability to bridge even small structural or shrinkage cracks which developed in the concrete deck. Typical examples of failures which were common to coatings of this class are shown in Figures 4 and 5.

3.4.3 Class III - Emulsions. (6 Materials)

Years Exposed	No. Failed (cumulative)	% of Total (cumulative)
1	1	17
4	4	67
6	6	100

As expected, the bituminous emulsions indicated good weather resistance which is characteristic of this class of coatings. However, they declined rather rapidly in their ability to waterproof the slab due to other factors as: erosion, cracking, and in one case, blistering. Figures 6 and 7 show examples of defects observed.

FIGURE 1. ROOF TEST AREA. DEPENDENT HOUSING, N. C. S., FINEGAYEN, GUAM

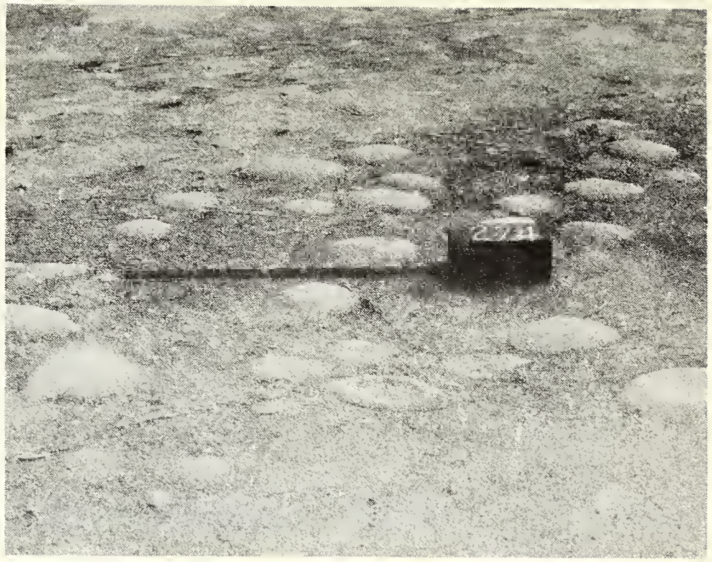

FIGURE 2. SEVERE BLISTERING OF A MASTIC TYPE MATERIAL. AGE 45 MONTHS.

FIGURE 3. GENERAL DETERIORATION OF AN ALUMINUM COATING. AGE 38 MONTHS.

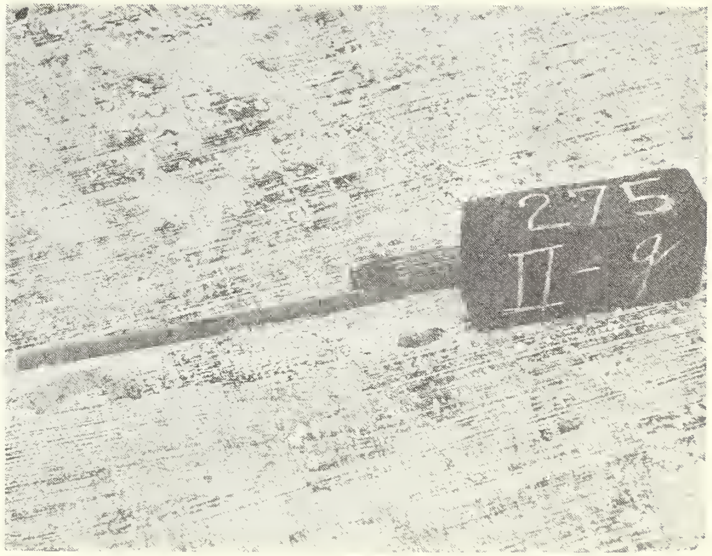

FIGURE 4. EROSION OF A PAINT TYPE COATING. AGE 45 MONTHS.

3.4.4 Class IV - Reinforced Membranes. (8 Materials)

Years Exposed	No. Failed (cumulative)	% of Total (cumulative)
3	1	12
4	3	37
10	5	63

The membranes employing metallic foils in combination with organic compounds gave the poorer performance of this class. Wrinkling, buckling, and poor adhesion between components were the primary causes of failure.

The emulsion-glass felt and the epoxy-glass fabric combinations performed quite satisfactorily, but were rated as failed after 10 years exposure. The former exhibited breaks and small blisters, while the latter indicated erosion of the top coating and an accumulation of mildew as shown in Figure 8.

The cold-process, smooth-surfaced roof and the conventional aggretate-surfaced built-up roofs, whether coal-tar pitch or asphalt, were performing well after 10 years exposure.

It was obvious that the reinforced membrane class gave the better service among the five classes tested.

3.4.5 Class V - Miscellaneous. (8 Materials)

Years Exposed	No. Failed (cumulative)	% of Total (cumulative)
1	4	50
2	7	87
4	8	100

The materials included in this class gave the poorest performance of all candidates included in the entire program. The poor performance is apparent from the data which show 100% failure within a 4-year exposure period. Generally the materials failed to waterproof the slab either initially or after short periods of exposure. Further the materials had little value from an aesthetic or solar reflectance standpoint.

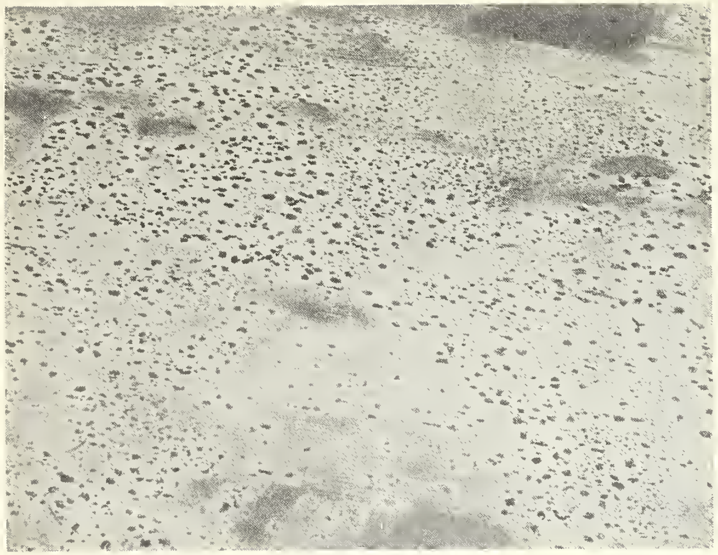

FIGURE 5. FAILED PAINT TYPE COATING. AGE 45 MONTHS.

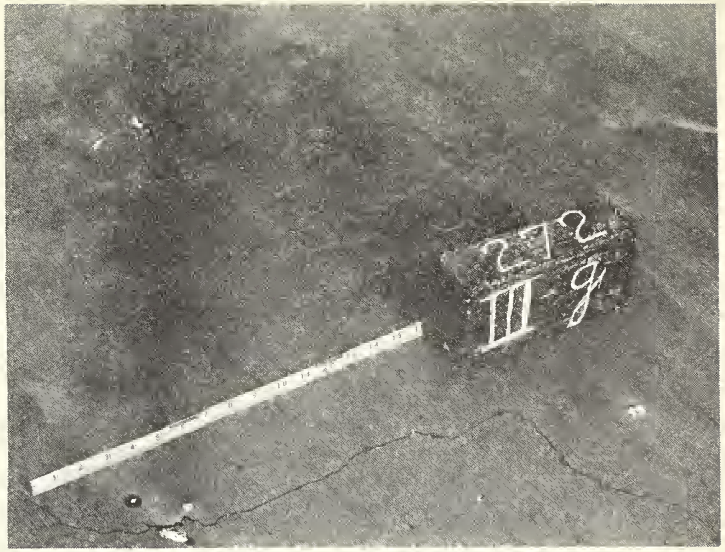

FIGURE 6. CRACKING AND FLAKING OF AN EMULSION TYPE COATING. AGE 45 MONTHS.

FIGURE 7. BLISTERING AND SALT DEPOSITS ON EMULSION COATING. AGE 45 MONTHS.

FIGURE 8. CONDITION OF REINFORCED MEMBRANE SYSTEM SHOWING MILDEW GROWTH. AGE 75 MONTHS.

3.5 Summary and Conclusions

The data which were obtained during the 10-year evaluation program clearly demonstrated that the reinforced membrane class of roofing systems outperformed the many candidates of the four remaining classes, both individually and collectively. However, only three candidates within this class are still performing adequately after 10 years exposure, namely:

a. Cold-process asphalt built-up roof
b. Aggregate-surfaced coal-tar-pitch built-up roof
c. Aggregate-surfaced asphalt built-up roof.

It is our opinion that the aggregate-surfaced bituminous built-up roofs gave excellent performance after 10 years exposure and, based on our examination of these roofings during April 1964, we believe that a life expectancy of 15 or more years is probable. This prediction is strengthened by the performance of aggregate-surfaced asphalt built-up roofs in actual service on Guam Island as reported in NBS Report No. 8352, 20 May 1964.

It is ironic that the results of the evaluation program showed that the very roofing systems whose replacement was indicated at the onset of the program were the systems which gave the best performance.

As a group, the mastics performed better than the materials in the remaining classes. They were followed closely by the bituminous emulsions. The performance of the materials included in the paint and miscellaneous classes must be considered unsatisfactory in regard to weatherproofing the concrete roof decks during exposure on Guam Island.

Based on the results of the 1954 Guam Roof Evaluation program and on considerable field experience with the performance of roofing materials in tropical areas, we are of the opinion that when a roofing system is required to weatherproof a roof deck of a permanent structure, a surfaced, multiple-ply, bituminous built-up roof is indicated. The application of other reinforced membrane systems consisting of mastics or emulsions in combination with various reinforcing mediums may be useful for maintenance and repair work and for the short term protection of semi-permanent structures. The use of mastics and emulsions may also be employed for maintenance purposes and for temporary roof protection, but the materials in the paint class should be employed only in conjunction with another material for solar reflectance or aesthetic purposes. Materials in the miscellaneous class must be considered unsatisfactory for use as a roofing system.

4. NEW ROOFING MATERIAL EVALUATION PROGRAM

4.1 Background

Conventional roofing systems used to protect roof decks on permanent structures located in tropical areas have caused continuing problems. Premature failures in these systems frequently occurred despite the apparently adequate design criteria and construction methods recommended by the construction agencies of the Defense Department.

A roofing material evaluation program, conducted by the Bureau of Yards and Docks, U. S. Navy, and described in Section 3 of this report, has shown the better performing system to be the multiple-ply, bituminous built-up roof. However, it was apparent that these systems have certain inherent limitations which restrict or prohibit their use in many locations. Therefore, there was a need for a roofing system which was easily applied, had good weathering properties, and possessed one or more of the following characteristics: a) lightweight, b) high elasticity, and c) high reflectance.

The National Bureau of Standards has had many new roofing materials under observation for several years, as reported in NBS Report No. 7737, Progress Report on New Roof Systems, 1 November 1962. The results of these observations revealed that a number of the systems possessed many desirable properties regarding exposure to tropical conditions, and therefore, seven materials were selected for inclusion in the evaluation program on Guam, M.I.

The test roofs were installed by the Honolulu Roofing Company, Ltd., under the supervision of personnel of Materials Testing and Evaluation Laboratory, OICC, Bureau of Yards and Docks, Guam.

4.2 Location and Description of Test Installations

The buildings selected for the roofing tests were permanent quarters in the Tipalao Housing Area located on the Orote Peninsula, Guam. Figure 9 shows a typical house. The semi-detached, single-storey residences were scheduled for reroofing in 1964 and, therefore, were selected to receive the new roof systems.

Originally, the roof decks were protected with smooth-surfaced, insulated built-up roofs applied in 1950. Figure 10 shows a typical roof section prior to removal. The old roofing and insulation were removed and the deck was made as clean as possible. Although the prepared decks were suitable for application of the single-ply or multiple-ply membranes, it was questionable whether the decks were sufficiently clean for application of the fluid-applied systems.

The test decks were constructed of waffle-type, precast concrete slabs of a thickness of about 1-5/8" between the ribs. The roof decks sloped slightly from ridge to eave giving an incline of about 1% ($<$ 1/4 in./ft.) and were about 20 squares in area.

4.3 Description and Application of Test Systems

4.3.1 1964 Series.

The following roofing systems were applied during March-April 1964:

4.3.1.1 Asphalt-glass felt built-up membrane, surfaced with mineral surfaced cap sheet. Manufacturer: Owens-Corning Fiberglas Corporation.

Test Roof No. 1A - Address: No. 26 Pacifico Street.

The roof system consisted of a 15 lb. base sheet mopped to the deck with hot asphalt, a 1-inch thickness of Fiberglas roof insulation, and two plies of 11 lb. asphalt-impregnated glass felt cemented to the insulation and to each other with hot asphalt. A granule-surfaced glass base cap sheet was applied as the weather surface as shown in Figure 11. Prior to the application of the built-up membrane, the joints between units of insulation were taped with a 6-inch wide roof tape.

Test Roof No. 1B - Address: No. 22 Pacifico Street.

The roof system was as described above except the one-inch thickness of Fiberglas roof insulation was omitted.

4.3.1.2 Polyisobutylene film laminated to an asbestos felt. Manufacturer: Johns-Manville Corporation.

The roofing material is a laminate of a 0.030-in. polyisobutylene film and a 0.025-in. elastomer bonded asbestos felt.

Test Roof No. 2A - Address No. 28 Pacifico Street.

The roof system consisted of a sheet of "ventsulation" felt, spot mopped to the concrete deck with hot asphalt to which was mopped a one-inch thick perlite type insulation board. The one-ply membrane described above was cemented to the insulation using a ribbon pouring of a solvent-type polyisobutylene adhesive. The surface was roller coated with an elastomer-base white coating as shown in Figure 12.

FIGURE 9. TYPICAL HOUSE USED IN 1964 ROOF EVALUATION PROGRAM, TIPALAO HOUSING AREA, GUAM

FIGURE 10. CONDITION OF WEATHERED BITUMINOUS ROOFING BEFORE REMOVAL.

FIGURE 11. APPLICATION OF MINERAL SURFACED CAP SHEET.

FIGURE 12. APPLICATION OF WHITE SURFACE COATING TO POLYISOBUTYLENE-ASBESTOS FELT SYSTEM.

Test Roof No. 2B - Address: No. 24 Pacifico Street.

The roof system was essentially the same as that described above except that the insulation was omitted from the system.

4.3.1.3 Polyvinyl fluoride film laminated to an asbestos felt.
Manufacturer: The Ruberoid Company.

The roofing material ia a laminate of a 0.002-in. white, pigmented, polyvinyl fluoride film and a neoprene bonded asbestos felt.

Test Roof No. 3A - Address: No. 11 Portola Street.

The roof system consisted of one ply of "vensulation" felt, spot mopped to the concrete deck with hot asphalt to which a one-inch thick perlite insulation board was mopped. A 43 lb., asphalt-saturated and coated base sheet was cemented to the insulation with a solvent-type, asphalt adhesive. The base sheet was surfaced with the one-ply polyvinyl fluoride-asbestos felt laminate which was also cemented with the cold asphalt adhesive as shown in Figure 13. No surface coating was applied to this system.

Test Roof No. 3B - Address: No. 21 Portola Street.

The roof system was identical to that described for No. 11 Portola Street except that the insulation board was omitted.

4.3.1.4 Butyl Rubber (Sheet) Roofing.
Manufacturer: Carlisle Tire and Rubber Division, Carlisle Corp.

The roofing material consisted of a co-polymer of isobutylene and isoprene which is available in sheet form of various sizes and thicknesses.

Test Roof No. 4A - Address: No. 13 Portola Street.

The roofing system consisted of one ply of "vensulation" felt, mopped to the deck with hot asphalt and a one-inch thickness of a perlite insulation board to which a 0.0625 (1/16 in.) thick sheet of butyl rubber roofing was applied using a solvent-type rubber base adhesive. An unvulcanized butyl rubber tape was used in conjunction with a butyl rubber adhesive to secure tight laps, as shown in Figure 14. The black butyl roofing was surfaced with a white chlorosulfonated polyethylene roofing solution applied by roller.

Test Roof No. 4B - Address: No. 19 Portola Street.

The roofing system was the same as that described for No. 13 Portola Street except that the insulation and "vensulation" felt were omitted from the system.

4.3.1.5 Butyl Latex - Sprayable Roof.
Manufacturer: Enjay Chemical Company.

The Butyl latex is a chemically-stable emulsion of butyl rubber in water containing about 55% solids.

Test Roof No. 5 - Address: No. 16 North Columbus Avenue.

The roof system consisted of an anchor coat of the latex applied by roller about 0.015 to 0.020 in. in thickness into which a fibrous glass scrim was embedded. An additional 0.030 to 0.040 in. coating of latex was applied after the first coat was set. The surface was coated with a roller coating of a white chlorosulfonated polyethylene roofing solution.

Due to the nature of this material, insulation was not employed in the system.

4.3.2 1961, 1962 Series.

As part of the continuing evaluation of roofing materials, exposure tests were initiated on new roofing systems by Public Works personnel during 1961 and 1962. Two systems of interest in the current evaluation program are included in this report.

4.3.2.1 Neoprene-chlorosulfonated polyethylene system.
Manufacturer: Protex-a-cote. Inc., Verona, New Jersey.

Guam Test No. 3 - Address: Building No. 34-36, Tipalao Housing Area.

The roofing system was installed in September 1961 over a concrete deck previously protected with a multiple-ply built-up roof. It consisted of a neoprene primer and two coats of a neoprene roofing solution applied by roller. This in turn was coated with two applications of a white chlorosulfonated roofing solution also applied by roller.

4.3.2.2 Asphalt emulsion -chopped glass fiber roofing system.
Manufacturer: The Flintkote Company.

Guam Test No. 2A - Address: Building Nos. 1, 2, 3 and 35, Nimitz Hill Housing.

The system was applied in September 1961 and consisted of a base sheet to which a clay-type, asphalt emulsion and chopped glass fibers were applied by a special gun which sprays the emulsion and glass fibers simultaneously. The ratio of emulsion to glass fiber was reported to be 12 gallons of emulsion to 4 pounds of chopped glass per square. The surface was sprayed with a white, emulsion coating for reflectance purposes.

4.4 Discussion

The results of simulated service tests conducted in our laboratory on new roofing materials included in the Guam program indicated good durability characteristics. These results have been confirmed by their performance in the field after 2 to 7 years exposure in many areas of the United States. In addition to the establishment of good weathering characteristics, the data which were obtained in these tests, also indicated some advantages of the newer materials over the more conventional systems. Generally, they are light in weight, are relatively easy to apply, and provide, either in themselves or with a surface coating, a highly reflective surface. These properties are considered as definite assets for materials intended for use in overseas locations in tropical areas. Further, the inspection and maintenance procedures, which should be conducted during installation and after periods of exposure, are simplified in these systems.

The new roofing materials possess certain inherent limitations which must also be considered. In the case of a one-ply system, any weakness at an end or side lap cannot be tolerated. Further, the new systems frequently depend on a very thin plastic material to provide resistance to water and solar radiation. Generally, the weakness of the fluid applied systems has been their inability to provide permanent bridging at joints or imperfections in the deck.

The duration of the Guam Program has not been sufficiently long to indicate a trend regarding the performance or durability of the new roofing systems in tropical areas. However, the data obtained regarding application and utilization have already proven most helpful.

It was apparent from our observation and from the reports of the roofing constructor and Naval Personnel that no particular difficulties were experienced during the installation of the systems. The application instructions provided by the respective manufacturers were clear, concise and easily followed by the roof applicators.

The importance of using compatible materials in any single system was clearly demonstrated during the Guam Tests. A chlorosulfonated polyethylene roofing solution, which was intended for use on one system was inadvertently used as the surface coating on the Butyl rubber sheet roofing. A complete discoloration of the surface occurred within a day, due to an interaction between the roofing solution and the butyl rubber, as shown in Figure 15.

Our observations of the neoprene-chlorosulfonated polyethylene roofing systems and the asphalt emulsion-chopped glass sytems which had been exposed in excess of 2 years indicated that both possessed good weathering properties under certain conditions. The former performed well when applied to a clean substrate,but exhibited wrinkling and poor adhesion when applied to a contaminated surface, as shown in Figure 16. The latter performed satisfactorily once it was cured in place. However, "wash offs" were experienced with emulsion type coatings from the action of frequent unexpected showers on these materials whose drying was delayed by exposure to the high humidities experienced on Guam.

In light of the experience, we are of the opinion that the fluid-applied systems should be used only on roof decks which have not been previously covered. It is not considered economical to attempt to clean a used deck to such a condition that will provide an acceptable surface. Further, we believe that emulsion-type systems (not including easily-dried surface coatings) should be applied only during dry seasons when relative humidities are low and the chance of unexpected showers is minimal.

On the other hand, the one-ply or multiple-ply systems will provide a satisfactory covering for most roof decks, whether sloping or flat, insulated or not insulated, or whether new or previously used.

We have obtained cost data on each of the roof systems described in Section 4.3.1 of this report. The costs include materials, removal of the old system and installation of the new system. We are reluctant to publish the estimated costs here since they are far out of line with costs of similar systems in continental United States. However, we can report that the new systems are not competitive at this time with the conventional roofing systems currently used on Guam.

4.5 Summary

A roof system can be considered adequate only when it has a history of good performance exceeding 10 years in an extreme climate and 15 to 20 or more years in a less extreme climate. Obviously, in the case of the systems included in the Guam tests, this history is lacking. Therefore, we are unable to predict now their long-term performance under tropical conditions. Nevertheless, the data, which were obtained in previous laboratory and field tests, indicated that the new one-ply and multiple-ply roof systems can be used for special applications at this time in tropical areas where the conventional systems are not practicable for one reason or another. However, sufficient exposure data, regarding performance in tropical areas, has not yet been developed to recommend the extended use of the newer systems. The question now arises as to what is a reasonable exposure time before the extended use of a roofing material can be

FIGURE 13. APPLICATION OF POLYVINYL FLUORIDE - ASBESTOS FELT SYSTEM.

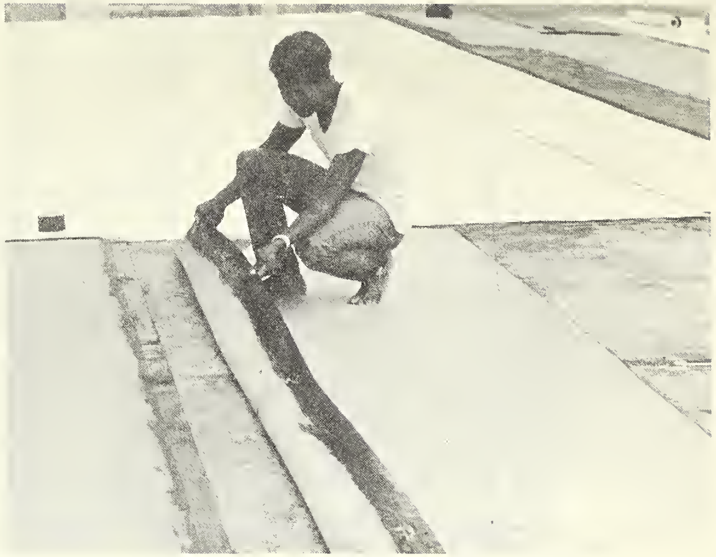

FIGURE 14. MAKING A LAP DURING INSTALLATION OF BUTYL SHEET RUBBER ROOFING.

FIGURE 15. DISCOLORATION OF BUTYL SHEET ROOFING ATTRIBUTED TO USE OF INCOMPATIBLE MATERIALS.

FIGURE 16. DEFECTS IN FLUID-APPLIED SYSTEM ATTRIBUTED TO POOR PREPARATION OF CONCRETE DECK

considered. We cannot answer with certainty because of many factors involved. However, we believe that two years exposure in the Guam Tests will provide a guide as to whether or not the extended use of a given system in tropical areas is warranted.

In summary, we believe the advantages of the new roofing systems included in the Guam Tests outweigh their limitations and we are optimistic regarding their performance. This optimism is based not only on our impressions on the observation of the Guam Test, but also on considerable laboratory and field experience. Regardless of the outcome of the test, we emphasize that the use of these systems are no panacea for all roofing problems associated with tropical exposures. There are no substitutions for adequate design criteria, proper application techniques, selection of materials commensurate with the end use of the system, and timely maintenance.

4.6 Recommendations

Inspections of the test roofing systems should be conducted on a semi-annual basis for 3 years and on an annual basis thereafter, by the Engineering Personnel of the Materials Testing and Evaluation Laboratory, OICC, Bureau of Yards and Docks, Guam.

It is recommended that additional tests on new roofing systems be initiated on Guam under the supervision of Material Testing and Evaluation Laboratory Personnel with the technical assistance provided by the Building Research Division, National Bureau of Standards.

In future tests, fluid-applied roofing systems should be applied only to new concrete roof decks.

5. ACKNOWLEDGMENT

The author expresses his sincere appreciation to many persons representing the Bureau of Yards and Docks, U. S. Navy, for their excellent cooperation in planning and making the inspections and for providing photographs and many data used in this report. In addition, the assistance and cooperation of the following companies are acknowledged:

Carlisle Tire and Rubber Division
Enjay Chemical Company
Johns-Manville Corporation
Owens-Corning Fiberglas Corporation
The Ruberoid Company

DEPARTMENT OF COMMERCE

NATIONAL BUREAU OF STANDARDS