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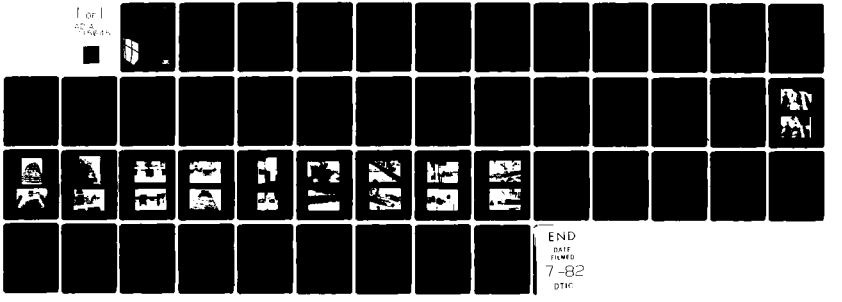

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TECHNICAL REPORT M-312
March 1982

INVESTIGATION OF MATERIALS FOR WATERPROOFING LEAKY CORRUGATED GALVANIZED STEEL-ARCH MAGAZINES FROM THE INSIDE

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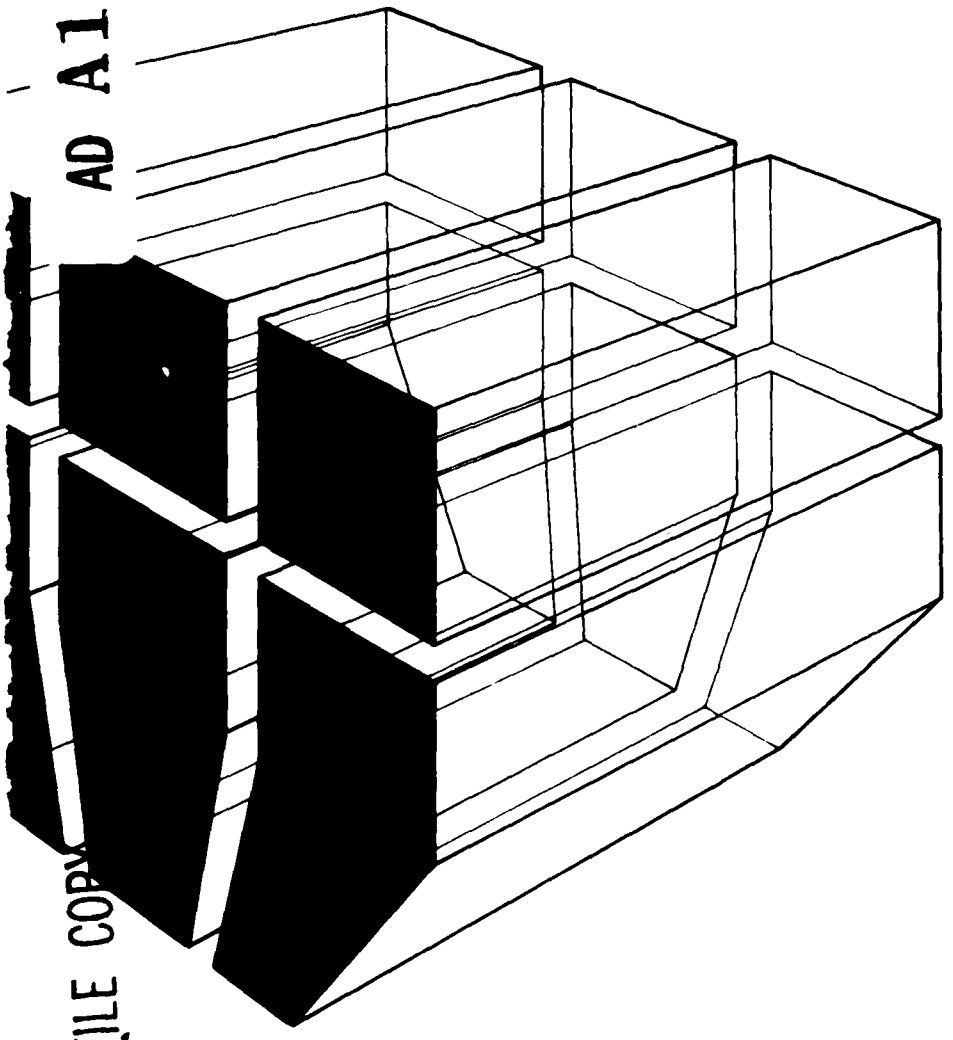

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Leaky ammunition storage magazines are a serious problem both because of the deterioration of stored materiel and the high cost of repair. The usual repair procedure for galvanized steel and concrete magazines is to remove the earth cover, clean and waterproof the exterior surface, then replace the earth cover.

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This study evaluates materials that can be used to waterproof leaky corrugated galvanized steel magazines from the inside—the most economical approach. While this method has been tried before, it generally has been unsuccessful because of the types of materials used and application procedures.

For this investigation, literature on the subject was reviewed, military installations with steel-arch leakage problems were contacted and remedial methods identified, military installations were visited as required, and 50 manufacturers were contacted for recommendations on sealing and waterproofing materials for galvanized steel magazines. Twenty-eight manufacturers furnished 50 samples of sealants, including new materials, for tests.

A laboratory procedure was developed and equipment designed and made to test the sealants. Three tests were conducted: adhesion-peel on a corrugated galvanized steel sheet, both normal and after water immersion; adhesion compatibility to a butyl rubber gasket; and resistance to hydrostatic pressure.

As a result of these tests 12 satisfactory sealants were identified.

FOREWORD

This research was conducted for the Naval Facilities Engineering Command (NAVFAC) under MIPR No. N00025-81-MP-NFA07 and the Directorate of Military Programs, Office of the Chief of Engineers (OCE), under Funding Authorization Document No. MP-81-1, dated 1 October 1980. The work was performed by the Engineering and Materials Division (EM), U.S. Army Construction Engineering Research Laboratory (CERL). Dr. R. Quattrone is Chief of EM. The NAVFAC Technical Monitor was Mr. Howard Nickerson; the OCE Technical Monitor was Mr. Dick Wight, DAEN-MPE-T.

The assistance of Mr. Steven C. Sweeney and Mr. Guy Morrow is acknowledged. Cooperation of the Navy, Army, Marine Corps, and Air Force installation personnel is also heartily acknowledged.

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

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CONTENTS

TABLES

FIGURES

FIGURES (cont'd)

INVESTIGATION OF MATERIALS FOR WATERPROOFING LEAKY CORRUGATED GALVANIZED STEEL-ARCH MAGAZINES FROM THE INSIDE

1 INTRODUCTION

Background

The U. S. Army and Navy have had problems with water seepage in newly constructed and existing earth-covered, steel-arch, ammunition-storage magazines. Repair methods (removal of earth cover and recoating and sealing) are expensive, time consuming, and not always effective.

The Office of the Chief of Engineers (OCE) and the Naval Facilities Engineering Command (NAVFAC) asked the U.S. Army Construction Engineering Research Laboratory (CERL) to investigate the various materials that could be used to waterproof these steel-arch storage magazines from the inside. While standard designs for these structures incorporate elaborate waterproofing schemes, if a leak still occurs, there have been no remedies short of removing the earth cover and starting over.

Objective

The objective of this study was to investigate and evaluate recommended sealant materials (including new materials) for waterproofing leaks on the inside of steel-arch magazines.

Approach

To achieve this objective, CERL:

1. Reviewed the literature on this subject.

2. Contacted military installations with steel-arch leakage problems and identified remedial methods used.

3. Visited military installations as required.

4. Contacted manufacturers for recommendations on inside waterproofing materials for galvanized steel and obtained samples.

5. Developed laboratory tests and equipment, prepared corrugated steel plate sealant adhesion specimens, applied various sealant materials selected to evaluate their resistance to prolonged hydrostatic load, and obtained information about the cost of materials found acceptable.

Mode of Technology Transfer

Information contained in this report will have a potential impact on Corps of Engineers Basic Drawing 33-15-73 (Oval Steel-Arch), Standard Drawing AW 33-15-64 (Semi-Circular Steel-Arch Magazine as opposed to oval), and Design Guide (DG) 1110-3-70, *Ammunition and Explosive Storage Structures.*

This information will also have a potential impact on NAVFAC Drawing Nos. 1059128 to 1059130, 1059132, 1069906, 1355460, 1355461, "Earth Covered Steel Circular Arch Magazine," and Drawing Nos. 1404026 to 1404034, "Oval Arch Earth Covered Steel Magazine."

2 FIELD INVESTIGATION

Review of Literature

A review of literature on waterproofing problems in galvanized steel magazines and remedial measures used revealed no significant information. The review included searches of the Defense Technical Information Center, the National Technical Information Service, and the Engineering Index.

Installation Survey

Seventeen Army, 17 Navy and Marine Corps. and 7 Air Force and other installations were contacted for information on water seepage in corrugated galvanized steel-arch magazines. Four Army and four Navy installations did not have steel magazines. Of the 13 Army installations with steel magazines, five (38 percent) had leaks mainly at the anchor base or at bolts. Of 13 Navy and Marine Corps installations, eight (61 percent) had leaks through bolts, seams, and at the anchor base.* Three of the eight installations already had repaired their leaks. In the "Air Force and others" group, three installations (43 percent) had leaks; two of the three had completed repair work.

*Some other sources of moisture are excessive condensation and leaks in the end walls. Corrosion posed a problem in some of the dry desert areas (Yuma Proving Ground, for example), as well as in other locations.

The Army installations contacted had about 255 steel magazines of which 52 (20.4 percent) leaked. The Navy and Marine Corps installations had approximately 215 magazines, of which 169 (78.6 percent) leaked, including 32 percent that had already been repaired. The "Air Force and others" group had about 83 magazines, of which 16 (19.2 percent) leaked; 10.8 percent already had been repaired. Table 1 summarizes these findings.

Various simple and complex procedures were used to repair leaks in steel magazines. Attempts were made to seal the inside of the structures, but the materials used proved to be unsatisfactory. Information on types of sealants tried and application techniques used was not generally available. However, some of the sealants were roofing tar, polysulfide, Bitumastic, Thoroseal, asphalt, and plastic cement; one installation thought silicone was satisfactory. Various materials have been used over the earth cover—asphalt hotmix, concrete, gunite, polyethylene sheet nailed down, and caps of bituminous soil cement. Combinations of as many as nine materials have been applied fairly recently over corrugated galvanized steel magazines. About $37,500 to $130,000 per magazine has been spent to control leaking. For more details, see Appendix A, Tables A1 through A3. Tables A2 and A3, particularly, indicate the complex systems chosen for exterior treatment of leaky magazines.

Installation Visits

During this study, magazines at two Army installations were examined. Camp Shelby, MS, had 15 corrugated galvanized steel-arch magazines built between 1971 and 1977, all had leaks. Water seepage was primarily at bolts in different areas of the arch. Magazine #6K was empty; during the visit, eight different sealants were applied over the leaky bolt areas, around each of the marked nuts, and over the top of the nuts. The sealants were Chevron CIM TG, Fulaprene 303, Geocel 2000, 3M-1792, Neobon Trowel Cement, Tremco 50V, Tremco 60V, and Mameco Int'l. Vulkem 116. The effectiveness of these applications will be known when the rainy season begins.

The Iowa Army Ammunition Plant (AAP) in Middletown, IA, had both galvanized steel and concrete magazines. Six steel magazines built in 1969 and 1973 were investigated. Leaks were mainly at the anchor bolts that join the corrugated steel sheets to the anchor plate at the concrete base. (The contractor was called back several times before completion of construction to seal leaks, especially around bolts.) Water seepage was also noted in some of the longitudinal seams. Corrosion and rust were present in a few areas. Drainage troughs were not provided in the floor next to each wall since drainage tile had been installed on the exterior of the concrete bases. One experimental method used at Iowa AAP to solve the seepage problem in steel magazines was to strip off the sod cover of the earth embankment and replace it with a 1/2-in. (12.7-mm)-thick, asphalt-impregnated mat liner to seal the surface. This method has been successful but requires yearly maintenance similar to roofing. A major difficulty is the settling and movement of the earth, which causes the liner to crack.

This investigation, like CERL's work on sealing leaky concrete ammunition storage bunkers, confirmed that outside repairing, though sometimes effective, is expensive and time consuming.[1] Significant maintenance and repair savings are possible if an efficient, reliable inside repair technique can be developed to seal leaking magazines.

3 LABORATORY INVESTIGATIONS

In general, the laboratory investigations consisted of: (1) planning and developing test procedures and techniques; (2) designing testing equipment and purchasing materials and parts for tests; (3) building a multiple-sample hydrostatic test assembly for evaluation of screened sealant materials; (4) obtaining manufacturer-recommended waterproofing materials; (5) application of sealant materials to corrugated galvanized steel panels for adhesion-peel tests, and to the butyl seam gasketing to determine adhesion compatibility; and (6) application of selected sealant materials to the hydrostatic pressure test unit and subjecting the sealants to a pressure test at a hydrostatic pressure that could be expected in the field.

Sealant Materials

About 50 manufacturers were contacted for their recommendations about material that could be used to waterproof leaks in corrugated galvanized steel-arch

[1] Stanley M. Kanarowski, *Investigation of Materials for Waterproofing Leaky Concrete Ammunition Storage Bunkers From The Inside*, Special Report M-256/ADA064731 (U.S. Army Construction Engineering Research Laboratory [CERL], January 1979).

magazines. Twenty-eight manufacturers recommended sealants and furnished 50 samples, which fell into two general categories: (1) caulks, sealants, and mastics, and (2) epoxies.

Only flexible materials were selected for final evaluation because of the possibility of movement (settling and thermal) in the magazine structure. Detailed information about the manufacturers and other organizations contacted is given in Appendix B. Table 2 is a generic classification of the sealant materials received and the manufacturers.

Laboratory Evaluation Tests

Laboratory evaluations of sealant materials were conducted in the following order: (1) adhesion-peel –normal and after 1 and 2 weeks of immersion in water, (2) sealant adhesion compatibility with butyl seam gasket–normal and after 1 week of water immersion, and (3) hydrostatic pressure resistance of selected sealants.

Adhesion Peel

Preparation of Corrugated Galvanized Steel Panels for Sealants. The purpose of this test was to screen sealants that adhered poorly to galvanized steel. Sealants with good adhesion would then be tested hydrostatically.

Armco corrugated galvanized steel-arch panels were used as the substrate for sealant application. The three panels were similar to those used for magazine construction. All were No. 1 U.S. Standard Gage, 0.259 in. (6.58 mm) in thickness; two were 33-9/16-in. wide x 10-ft long (0.85 x 3.05 m). One was 52-3/4-in. x 10 ft (1.34 x 3.05 m). Before sealant application, the three steel panels were power wire brushed to remove dirt and any rust or other corrosion products, and were then wiped and cleaned with toluene to remove any grease. The surface seemed fairly smooth.

Application of Sealant Materials to the Steel Panels and Testing. Two sets of duplicate sealant specimens, 3-in wide x 8-in. long (76 x 203 mm) were applied on a spaced template over the crest of the corrugations of the galvanized steel from valley to valley, one set on each panel (Figures 1 through 4). Aluminum insect screening wire was imbedded in the sealant, which was about 1/4-in. thick (6.35 mm). After curing, the specimens were cut into 1-in.-wide strips (25.4 mm) for pull tests on normal samples and on samples to be immersed in water for 1 and 2 weeks. The whole panel with all the applied samples was immersed.

After curing (on normal specimens), or at the conclusion of immersion in water, the 1-in. (25.4-mm)-wide specimens were clamped in a modified vise-grip locking plier attached to a spring scale and pulled by hand at a steady slow rate until the specimen either pulled off the steel or broke (Figure 5). The highest scale reading in pounds (kilograms) was noted, recorded, and averaged for two specimens of each sealant. Adhesion strength of the sealant to the galvanized steel was rated as follows:

Scale Reading in Lbs, Average	*Adhesion Classification*
30+	Excellent*–adhesion and sealant strength
20–29	Good*–adhesion and sealant strength
15–19	Fair or spotty (nonuniform adhesion)
1–14	Weak–usually soft sealant
0	Pulls off easily by hand

Table 3 lists the adhesion ratings for all the sealants evaluated.

Adhesion Test Results and Discussion. In the pull test, the soft sealants (low cohesive strength) gave low pull values and were classified as "weak," but adhered to the steel. It took little pull strength to pull them apart. This type of sealant would not be able to resist hydrostatic pressure. Some sealants were strong or tough but did not adhere well. Other sealants held well but pulled loose from the steel at higher pull-pound values. The best sealants in this test had high pull values and good adhesion. A sealant with good adhesion would break or tear at a high pull value and still adhere to the steel. Cohesion would be strong–but weaker than adhesive strength. Figures 6 through 9 illustrate good and poor adhesion to galvanized steel.

The screening wire reinforcement kept the specimens from breaking while being pulled so that a higher stress could be exerted on the sealant/steel adhesion interface.

Sealant/Butyl-Gasket Adhesion Compatibility. In the regular procedure for bolting corrugated steel panels in magazine construction, a gasket sheet is used between the lap splice metal joints. It is normally about 1/8-in. thick x 4-1/4-in. wide (3.2 x 108 mm). Armco 101 Multi-Plate Seam Gasket, for example, is a butyl, cloth-reinforced sheet made by 3M.** After the

*Specimen breaks with no loss of adhesion to the steel.

**3M 1202-T Sealant Tape.

gasket is installed, holes are pierced in the area of the bolt holes, the bolt inserted, and a torque wrench is used to tighten together the panels (150 to 300 ft-lb torque [667 to 1334 N]). Tightening will force the uncured gasket to flow and form a water seal. This process is not always effective, and sometimes voids are left at seams or bolt holes through which the water can leak.

In some cases the material used for sealing the leak may touch the butyl gasket; thus, the sealant's adhesion compatibility with the gasket should be known. Figure 10 shows the specimens used in the visual and hand pull tests for determining the adhesion compatibility between the sealant and the butyl gasket.

This test was conducted by applying the sealant being evaluated to 6-in (152-mm) lengths of 4-1/4-in. (108-mm)-wide gasket. After cure, the sample was cut in half lengthwise, and one specimen was immersed in water for 1 week at room temperature. Specimens were flexed and bent 180 degrees; adhesion, cracking, and color change were noted. Test results are listed in Table 4. Out of 46 sealant specimens in this test, there were 20 with good adhesion and no cracks, eight with bad adhesion, and 18 that were loose at the edge, had cracks, or were soft and tacky. The immersed specimens (1 week) were generally unaffected by the water, but were discolored slightly or looked a bit dirtier. Figures 11 and 12 show good and poor sealant/butyl-gasket adhesion compatibility.

Sealant Materials Selected for Further Testing. On the basis of the adhesion-peel test results, the following sealants were selected for hydrostatic pressure resistance tests:

No.	
4	Weatherban Sealant 202, 3M
5	Weatherban Sealant 404, 3M
7	Water Seal 100, Geocel
8	Construction 2000 Sealant, Geocel
10	Fulaprene 303, H. B. Fuller
12	Non-Sag Sealing Compound 12-4, Goodyear
13	Scotch Seal Metal Sealant 1792, 3M
17	Rubber Calk 7000, PRC
18	Vulkem 116, Mameco International
19	Sonolastic NPI, Sonneborn-Contech
25	Tremproof 60V, Tremco
29	Vertiseal, A. C. Horn
36	(a) Neobon Trowel Cement with Chloroprime Primer, Atlas Minerals and Chemicals
36	(b) Neobon Trowel Cement with Chloroprime and NTC Adhesive, Atlas Minerals and Chemicals
37	Chevron CIM-TG, Chevron
38	Tremproof 50V, Tremco
45	Carboline 163-2 Caulk, Carboline
50	Dymeric, Tremco

Resistance of Sealants to Hydrostatic Pressure

Preparation of Test Unit. The equipment designed for measuring the hydrostatic pressure resistance of sealants consisted of a galvanized steel pipe, 4-1/2-in. outside diameter by 10-ft long (114 mm x 3.05 m); see Figure 13. For testing each sealant, the pipe had a combination of a slit and two sets of holes in parallel around the pipe: first was a 1/16-in. x 2-in. slit (1.6 x 51 mm); then two 1/16-in. holes (1.6 mm) with a 3/16-in. hole (4.8 mm) in between, and finally three 1/8-in. holes (3.2 mm); see Figure 14. This combination was repeated on the pipe for 19 sealants although 18 were tested. The nineteenth complete set was sealed off.

After the holes were drilled and the slits cut, the inside of the pipe was cleaned thoroughly by swabbing several times with a rag soaked in toluene. The exterior surface of the pipe was power wire brushed lightly and then wiped and cleaned with toluene to remove any surface grease or oil.

Application of Sealant Materials. Sealants were applied according to the manufacturers' instructions; primers were used when required. Sealant materials in cans or pails were applied with a wooden tongue depressor or spatula. A caulking gun was used for sealants in cartridges. The sealant materials were applied to a nominal 1/4-in. thickness (6.4 mm) and 1-in. width (25.4 mm) centered over the holes, and to 1 in. (25.4 mm) beyond the ends of the slits or the end holes (Figure 15). Specimens were allowed to cure as stated in the manufacturers' specifications, and the water pressure was turned on to 5 to 6 psig (34.5 to 41.4 kN/m^2). Pressure was cycled by turning the water off at the end of the workday and on again in the morning. The overnight pressure, however, did not drop to zero but was between zero and the test pressure. This procedure was continued throughout the test. Figure 16 shows a resistance wire attachment for warming the pipe to accelerate curing of the sealants. Figures 17 and 18 show the control ends of the hydrostatic test pipe.

Results of Hydrostatic Pressure Test. Six sealant materials failed within 3/4 to 21 hours of hydrostatic pressure:

	Hours to Failure, Average
Construction 2000 Sealant, Geocel	Less than 1
Water Seal 100, Geocel	Less than 1
Non-Sag Sealing Compound 12-4, Goodyear	1
Weatherban Sealant 202, 3M	4
Scotch Seal Metal Sealant, 1792, 3M	16
Weatherban Sealant 404, 3M	21

The remaining 12 sealants resisted hydrostatic pressure for 300 hours at 5 to 6 psig (34.5 to 41.4 kN/m^2), followed by 1000+ hours at 7 to 8 psig (48.3 to 55.2 kN/m^2). Figures 19 and 20 show sealants that failed the hydrostatic pressure test. Note the stream of water coming out of the leak.

Cost Comparison

Of the 12 sealants which performed satisfactorily in the tests, there were five one-component and seven two-component types. Tremco Tremproof 60V, a one-component, requires a primer. Five of the two-component sealants require a primer. Four of the one-component sealants are furnished in cartridge containers for application with common caulking guns. Table 5 provides detailed cost information on the successful sealants; for easy reference, Table 6 summarizes costs per gallon.

4 CONCLUSIONS

Laboratory tests indicated that 12 materials can satisfactorily seal leaky corrugated galvanized steel magazines: Fulaprene 303, PRC Rubber Calk 7000, Vulkem 116, Sonolastic NPI, Tremproof 60V, Vertiseal, Neobon Trowel Cement with Chloroprime Primer, Neobon Trowel Cement with Chloroprime and NTC Adhesive, Chevron CIM-TG, Tremproof 50V, Carboline 163-2 Caulk, Dymeric (Table 2). Field tests, using inside sealing techniques, should be done for 2 years to verify the effectiveness of these materials.

Table 1
Water Seepage Reported in Corrugated Galvanized Steel-Arch Magazines

	Army	Navy and Marine Corps	Air Force and Others
Active installations contacted	17	17	7
Installations with galvanized steel magazines	13	13	7
Seepage reported, no. of installations	5 (38%)	5 3* 8 (61%)	1 2* 3 (43%)
Approximate total of steel magazines involved	255	215	83
Leaky magazines	52 (20.4%)	100 (46.5%) 69† (32.1%) 169 (78.6%)	7 (8.4%) 9† (10.8%) 16 (19.2%)

*Installations that already had repaired leaky magazines.
†Leaky magazines that already had been repaired.

Table 2
Material Types Recommended by Manufacturers for Waterproofing Leaks in Corrugated Galvanized Steel-Arch Ammunition-Storage Magazines From the Inside

Sample No. and Type		Trade Name	Manufacturer
	Caulk or Sealant, One-Component Elastomeric		
1	Acrylic	60+ Unicrylic	Pecora
2(a,b,c)*	Butyl	Butyl Caulk[1]	Atlas Minerals & Chemicals
3		Flexiseal CW-100	DAP
4		Weatherban Sealant 202	3M
5		Weatherban Sealant 404	3M
6		BC-158	Pecora
7	Modified Ethylene	Water & Weather Sealant 100	Geocel
8	Copolymer	Construction Caulking Sealant 2000	Geocel
9		Bathroom Caulking Sealant	Geocel
10	Neoprene	Fulaprene 303	H. B. Fuller
11	Nitrile	Self-Leveling Sealant 12-3	Goodyear Tire & Rubber
12		Non-Sag Sealing Compound 12-4	Goodyear Tire & Rubber
13		Scotch-Seal Metal Sealant 1792	3M
14	Styrene Butadiene Rubber	Pinchweld Glass Primer 4584[2]	Tremco
15	Polypropenate	Chem-Calk 800	Woodmont Products
16	Polysulfide	Weatherban Sealant 101	3M
17		PRC Rubber Calk 7000	Products Research & Chemical
18	Polyurethane	Vulkem 116[3]	Mameco International
19		Sonolastic NPI	Sonneborn Div., Contech
20	Silicone	Silicone Rubber Sealant 732[4]	Dow Corning
21		Silpruf Weatherproofing Sealant[5]	General Electric
22		Chem-Calk 1000, Low Modulus[6]	Woodmont Products
23	Styrene Ethylene-Butylene Block-Copolymer	Plio-Seam Sealant	Goodyear Tire & Rubber
24	Acrylic, Asphalt Extended	No. 26	Al-Chroma
25	Polyurethane, Bitumen Modified	Tremproof 60 Vertical[7]	Tremco

*Parenthetical letters designate different systems.

[1] a, no primer; b, with Thioment primer; c, Ampvar primer.

[2] With 200 cleaner.

[3] With Cleaner Conditioner.

[4] With Primer #1200.

[5] With SCP 3153 Silicone Metal Primer.

[6] With N-40 Primer.

[7] With 200 Cleaner and Primer No. 6.

Table 2 (Cont'd)

Sample No. and Type		Trade Name	Manufacturer
	Miscellaneous Sealants, One-Component		
26	Proprietary Wax Type Sprayable	Nox Rust 3000	Daubert Chemical
27	Butyl Rubber Adhesive and Sealant Laminated to Soft Aluminum Foil	Alumaflash	Republic Powdered Metals
	Caulk or Sealant, Two-Component Elastomeric		
28	Polysulfide	GC-401 Class B Sealing Compound	Goal Chemical Sealants
29		Vertiseal (with primer)	A. C. Horn
30		PRC Rubber Calk 350	Products Research & Chemical
31		H-705 Gray Sealant	Steelcote Manufacturing
32		#126-188 Gray Sealant	Steelcote Manufacturing
33(a,b,c,d)	Polyurethane	Polytok-Deck Coating 131/522[8]	Carboline
34		Coating 132-82	Steelcote Manufacturing
35		Sealant 132-84	Steelcote Manufacturing
	Mastic-Type Sealants, Two-Component Elastomeric		
36 (a,b,c)	Neoprene Base	Neobon Trowel Cement[9]	Atlas Mineral & Chemicals
37	Polyurethane, Asphalt Extended	Chevron Industrial Membrane Trowel Grade (CIM-TG)[10]	Chevron U.S.A.
38	Polyurethane, Bitumen Modified	Tremproof 50V[11]	Tremco
	Epoxy-Sealants, Two-Component*		
39	Epoxy-Modified Aliphatic Amine	Concresive AEX-1438	Adhesive Engineering
40		Concresive AEX-1459	Adhesive Engineering
41		46-X-3/46-T-6 Epoxy Liner	Mobil Chemical
42		Sikastix 360, Sikadur Lo-Mod Gel	Sika Chemical
43	Epoxy-Modified Polyamido Amine	Epi-Rez 510/Epi-Cure 892	Celanese Plastics & Specialties

[8] Used as furnished, then added #2400 Silica to increase viscosity. Also used with Primer CE, or with Wash Primer 1037 followed by CE.

[9] With Chloroprime, or Chloroprime and Neobon Trowel Cement Adhesive, or Ampvar Primer and Neobon Trowel Cement Adhesive.

[10] With Bonding Agent Primer.

[11] With 200 Cleaner and Primer No. 6.

*Except No. 50, which is three-component.

Table 2 (Cont'd)

Sample No. and Type		Trade Name	Manufacturer
44		Epi-Rez 510/Epi-Cure 892/24-219	Celanese Plastics & Specialties
45	Epoxy-Polyamide	Carboline 163-2	Carboline
46		A-788 Splash Zone Compound	Koppers
47		46-X-16 Epoxy Patching Compound	Mobil Chemical
48	Epoxy-Polyamine	Aquatopoxy	American Chemical
49	Epoxy-Polysulfide	Caulking Compound 225	Carboline
50	Epoxidized Polyurethane Terpolymer	Dymeric[12], 3-Component	Tremco

[12] Use with 200 Cleaner and Primer No. 6.

Table 3
Results of Adhesion-Peel Test

Sample No.	Caulk or Sealant	Normal	After Water Immersion		Comment
			1 Week	2 Weeks	
	One-Component Elastomeric				
1	60+ Unicrylic (Pecora)	Weak	Weak, pulled off	Weak, pulled off	Soft sealant
2(a,b,c)	Butyl Caulk[1] (Atlas)	Weak Sealant is soft and has low cohesive strength	Weak	Weak	3 without or with primers
3	Flexiseal CW-100 (DAP)	Pulled off metal completely			
4	Weatherban 202 (3M)	Weak	Pulled off at 28 lb*	Pulled off at 40 lb	
5	Weatherban 404 (3M)	Spotty	Spotty to good	Pulled off at 35 lb	
6	BC-158 (Pecora)	Weak Sealant is soft and has low cohesive strength	Weak	Weak	
7	Sealant 100 (Geocel)	Good	Good	Excellent	
8	Sealant 2000 (Geocel)	Good	Excellent	Excellent	
9	Bathroom Caulking (Geocel) Sealant	Good	Good	Excellent	
10	Fulaprene 303 (H. B. Fuller)	Excellent	(Good to Excellent)		

[1] a, no primer; b, with Thioment primer; c, Ampvar primer.

*1 lb = 0.454 kg.

Table 3 (Cont'd)
Results of Adhesion-Peel Test

Sample No.	Caulk or Sealant	Normal	After Water Immersion		Comment
			1 Week	2 Weeks	
11	Sealant 12-3 (Goodyear)	Pulled off metal		(No specimens)	Self-leveling
12	Sealant 12-4 (Goodyear)	Spotty	Good	Good	
13	Metal Sealant 1792 (3M)	Excellent	Good	Good to excellent	
14	Pinchweld Glass Primer[2] (Tremco) #4584	Pulled off metal		(No specimens)	
15	Chem-Calk 800 (Woodmont)	Weak Sealant is soft and has low cohesive strength	Weak	Weak	Soft and sticky
16	Weatherban 101 (3M)	Spotty	Good	Good	Soft and sticky
17	Rubber-Calk 7000 (PRC)	Good	Good to excellent, spotty adhesion	Excellent, spotty adhesion	
18	Vulkem 116[3] (Mameco Int'l.)	Excellent	Excellent	Excellent	
19	Sonolastic NPI (Sonneborn-Div.)	Weak	Good to excellent, spotty adhesion	Good to excellent, spotty adhesion	
20	Silicone 732[4] (Dow Corning)	Good	Weak, spotty adhesion	Weak	Affected by water
21	Silpruf[5] (General Electric)	Excellent	Excellent, spotty adhesion	Pulled off at 20 lb	Affected by water
22	Chem-Calk 1000[6] (Woodmont)	Pulled off at 3 lb	Pulled off	Pulled off at 5 lb	
23	Plio-Seam (Goodyear)	Pulled off	Pulled off	No specimen	
24	No. 26 (Al-Chroma)	Pulled off at 15 and 30 lb	Pulled off at 10 lb	Pulled off at 20 and 28 lb	
25	Tremproof 60V[7] (Tremco)	Excellent	Excellent	Excellent	

[2]With 200 cleaner.

[3]With Cleaner Conditoner.

[4]With Primer #1200.

[5]With SCP 3153 Silicone Metal Primer.

[6]With N-40 Primer.

[7]With 200 Cleaner and Primer No. 6.

Table 3 (Cont'd)

Sample No.	Caulk or Sealant	Normal	After Water Immersion		Comment
			1 Week	2 Weeks	
26	Too thin a material (self-leveling); must be nonsag-type.				
27	Alumaflash (Republic Powdered Metals)	Weak, material broke	---	---	Adhesion was good
Two-Component Elastomeric					
28	GC-401 Class B (Goal Chemical)	Excellent	Pulled off at 25 lb	Pulled off at 25 and 35 lb	Affected by water
29	Vertiseal (with primer) (A. C. Horn)	Good to excellent	Good to excellent	Good to excellent	All had some areas of weak adhesion
30	Rubber Calk 350 (PRC)	Weak, pulled off	Pulled off at 13 and 20 lb	Pulled off at 30 lb	
31	H-705 (Steelcote)	Viscosity too low	Not for vertical applications		
32	126-188 (Steelcote)	Weak, pulled off	Weak, pulled off	Pulled off at 25 lb	
33(a)	131/522[8] (Carboline)	Viscosity too low	Not for vertical applications		No added filler
33(b)	131/522[8] (Carboline)	Viscosity too low	Not for vertical applications		Added 20% of total wt-Silica Flour
33(c)	131/522[8] (Carboline)	Good	Spotty adhesion	Pulled off at 20 lb	Added 45% of total wt-Silica Flour, used primer CE
33(d)	131/522 (Carboline)	Good	Good	Good	With 45% of total wt-Silica Flour, Primers 1037 and CE
34	132-82 Ctg (Steelcote)	Viscosity too low	Not for vertical applications		
35	132-84 (Steelcote)	Pulled off	Good but spotty adhesion	Pulled off at 30 lb	
36(a)	Neobon T. C.[9] (Atlas)	Excellent	Good to excellent	Excellent, pulled off at 55 lb	With Chloroprime Primer
36(b)	Neobon T. C.[9] (Atlas)	Excellent, spotty adhesion	Weak to excellent	Good to excellent	With Chloroprime and NTC adhesive
36(c)	Neobon T. C.[9] (Atlas)	Pulled off at 15 and 20 lb	Pulled off at 25 lb	Pulled off at 22 lb	With Ampvar Primer and NTC adhesive

[8] Used as furnished, then added #2400 Silica to increase viscosity. Also used with Primer CE, or with Wash Primer 1037 followed by CE. See "Comment."

[9] With Chloroprime, or Chloroprime and Neobon Trowel Cement Adhesive, or Ampvar Primer and Neobon Trowel Cement Adhesive. See "Comment."

Table 3 (Cont'd)

Sample No.	Caulk or Sealant	Normal	After Water Immersion		Comment
			1 Week	2 Weeks	
37	CIM TG[10] (Chevron)	Excellent	Good to excellent	Excellent	With bonding agent primer
38	Tremproof 50V[11] (Tremco)	Excellent	Good to excellent	Excellent	With cleaner and primer
	Two-Component Epoxy				
48	Aquatapoxy (American Chemical)	Pulled off easily	Pulled off easily	----	
49	Caulking Compound 225 (Carboline)	Weak– pulled off at 6 lb	Pulled off at 15 lb	Pulled off at 15 lb	
50	Dymeric[12] (Tremco)	Excellent	Good to excellent	Good to excellent	With cleaner and primer

[10]With Bonding Agent Primer.

[11]With 200 Cleaner and Primer No. 6.

[12]Use with 200 Cleaner and Primer No. 6.

Table 4
Sealant/Butyl Gasket Adhesion Compatibility

Sample No.	Caulk or Sealant	Normal	Immersed 1 Week	Comment
1	60+ Unicrylic (Pecora)	Flexible, no cracks. Good adhesion.	Same as normal except slight (sl.) color change.	Good
2(a)	Butyl Caulk (Atlas)	Flexible, no cracks. Good adhesion.	Same as normal except dirtier color.	Sticky and soft
3	Flexiseal CW-100 (DAP)	Flexible, no cracks. Good adhesion.	Same as normal except some color change.	Good
4	Weatherban 202 (3M)	Flexible, no cracks. Good adhesion.	Same as normal except some color change.	Tacky and soft
5	Weatherban 404 (3M)	Flexible, no cracks. Good adhesion.	Same as normal.	Tacky and sl. soft
6	BC-158 (Pecora)	Flexible, no cracks. Good adhesion.	Same as normal except some color change.	Soft
7	Sealant 100 (Geocel)	Flexible, no cracks. Good adhesion.	Same as normal except sl. yellowing.	Good
8	Sealant 2000 (Geocel)	Flexible, no cracks. Good adhesion.	Same as normal except sl. yellowing.	Good
9	Bathr. Caukg. Sealant (Geocel)	Flexible, no cracks. Good adhesion.	Same as normal except sl. yellowing.	Good

Table 4 (Cont'd)

Sample No.	Caulk or Sealant	Normal	Immersed 1 Week	Comment
10	Fulaprene 303 (H. B. Fuller)	Flexible, no cracks. Good adhesion.	Same as normal except duller finish.	Good
11	Sealant 12-3 (Goodyear)	Flexible, no cracks. Good adhesion.	Same as normal except sl. darker and tendency to pull loose at edge.	Tendency to pull loose at edge
12	Sealant 12-4 (Goodyear)	Flexible, no cracks. Adhesion not good.	Same as normal except sl. darker.	Adhesion not good
13	Metal Sealant 1792 (3M)	Flexible, no cracks. Adhesion good.	Same as normal except sl. darker.	Good
14	Pinchweld Glass Primer (Tremco) #4584	Flexible, no cracks. Adhesion good.	Same as normal.	Tacky
15	Chem-Calk 800 (Woodmont)	Flexible, no cracks. Adhesion not good.	Same as normal except sl. color change.	Adhesion not good
16	Weatherban 101 (3M)	Flexible, no cracks. Adhesion not good.	Same as normal except some color change.	Adhesion not good
17	Rubber-Calk 7000 (PRC)	Flexible, no cracks. Adhesion good.	Same as normal except sl. color change.	Good
18	Vulkem 116 (Mameco Int'l.)	Flexible, no cracks. Good adhesion.	Same as normal except sl. color change.	Good
19	Sonolastic NPI (Sonneborn-Div.)	Flexible, no cracks. Good adhesion.	Same as normal except sl. color change.	Good
20	Silicone 732 (Dow Corning)	Flexible, no cracks. Adhesion not good.	Same as normal except sl. color change.	Adhesion not good
21	Silpruf (General Electric)	Flexible, no cracks. Adhesion not good.	Same as normal except sl. darker.	Adhesion not good
22	Chem-Calk 1000 (Woodmont)	Flexible, no cracks. Adhesion not good.	Same as normal except sl. darker.	Adhesion not good
23	Plio-Seam (Goodyear)	Flexible, no cracks. Adhesion not good.	Same as normal except sl. darker.	Adhesion not good
24	No. 26 (Al-Chroma)	Flexible, no cracks. Good adhesion.	Same as normal.	Good
25	Tremproof 60V (Tremco)	Flexible, no cracks. Good adhesion.	Same as normal.	Good, sl. tacky
26	Too thin a material (self-leveling); must be non-sag type.			
27	Alumaflash (Republic Powdered Metals)	Flexible, foil cracks. Adhesion good.	Same as normal except no foil cracks.	Foil Cracks
28	GC-401 Class B (Goal Chemical)	Flexible, no cracks. Good adhesion.	Same as normal except sl. darker.	Good

Table 4 (Cont'd)

Sample No.	Caulk or Sealant	Normal	Immersed 1 Week	Comment
29	Vertiseal (A. C. Horn)	Flexible, no cracks. Good adhesion.	Same as normal except sl. color change.	Good
30	Rubber Calk 350 (PRC)	Flexible, no cracks. Good adhesion.	Same as normal except dirtier color.	Good
31	H-705 (Steelcote)	Flexible, no cracks. Adhesion not good.	Same as normal except sl. color change.	Adhesion not good
32	No sample			
33(b)	131/522 (Carboline)	Flexible, no cracks but tendency. Good adhesion.	Same as normal.	Cracking tendency
34	132-82 Ctg. (Steelcote)	Flexible, no cracks. Sl. tendency to pull loose at edge.	Same as normal.	Tendency to pull loose at edge
35	132-84 (Steelcote)	Flexible, get sl. cracks at edge where folded. Adhesion not good at cracks.	Same as normal.	Get fold cracks.
36(a)	Neobon T. C. (Atlas)	Flexible, no cracks. Good adhesion.	Same as normal.	Good
37	CIM-TG (Chevron)	Flexible, no cracks. Good adhesion.	Same as normal.	Good
38	Tremproof 50V (Tremco)	Flexible, no cracks. Good adhesion.	Same as normal.	Good
39	Concr.-AEX-1438 (Adh. Engrg.)	Cracks, brittle. Good adhesion.	Same as normal. Tendency to pull off. Sl. color change.	Cracks
40	Concr-AEX-1459 (Adh. Engrg.)	Flexible but get edge tears. Good adhesion.	Same as normal except sl. darker.	Edge tears
41	Too thin in viscosity			
42	Sika 360, S.Lo-Mod Gel (Sika)	Some flexibility but cracks. Good adhesion.	Brittle, cracked, otherwise like normal.	Cracks
43	510/892 (Celanese)	Cracks on bending. Brittle. Good adhesion.	Same as normal.	Cracks
44	Too thin in viscosity			
45	Carboline 163-2 (Carboline)	Brittle, cracks on bending. Good adhesion.	Same as normal except sl. duller color.	Cracks

Table 4 (Cont'd)

Sample No.	Caulk or Sealant	Normal	Immersed 1 Week	Comment
46	A-788 (Koppers)	Brittle, cracks easily. Good adhesion.	Same as normal except loss in gloss.	Cracks
47	46-X-16 (Mobil)	Brittle, cracks on folding. Good adhesion.	Same as normal but color not as shiny.	Cracks
48	Aquatapoxy (American Chemical)	Flexible, no cracks. Good adhesion.	Same as normal. Sl. dirtier color.	Good
49	Caulking Compound 225 (Carboline)	Flexible but cracks. Good adhesion.	Same as normal except sl. darker.	Cracks
50	Dymeric (Tremco)	Flexible, no cracks. Good adhesion.	Same as normal except dirtier color.	Good

Table 5
Cost of Successful Sealant Materials for Galvanized Steel*

Caulk or Sealant	Order Size***	Bulk Cost Per Gallon** 1-Gal Pail	2-Gal Pail	5-Gal Pail	55-Gal Drum
One-Component					
10. H. B. Fuller Fulaprene 303 (FOB Grand Rapids, MI)	1-5 cases: $3.01/cartridge+	--	--	(1-5) $19.04/gal	(1-5) $17.48/gal
	6-10 cases: $2.78/cartridge+	--	--	(6-10) $17.57/gal	(6-10) $16.14/gal
	11-39 cases: $2.54/cartridge+	--	--	(11-39) $16.11/gal	(11-39) $14.79/gal
18. Mameco International Vulkem 116 (FOB Cleveland, OH)	Under 500 gal: $2.07/cartridge	(1-500) $16.95	(1-250) $16.75/gal	(1-100) $16.30/gal	(1-9) $15.50/gal
	Over 500 gal: $1.97/cartridge	(500+) $16.05	(250+) $15.90/gal	(100+) $15.40/gal	(10+) $14.65/gal
Cleaner-Conditioner		$1.85/qt; $7.35/gal			
17. PRC Rubber Calk 7000 (FOB Glendale, CA)	1-49 gal: $2.12/cartridge	--	(1-49) $19.53/gal	(1-49) $19.53/gal	--
19. Sonneborn-Contech Sonolastic NPI (FOB Chicago, IL)	$2.25/cartridge++	--	$20.00/gal	--	--

*Does not include shipping or cleanup solvents.

**Manufacturers' variations in these sizes are noted for specific materials.

***Cartridges usually have 11 fl oz.

+24 cartridges/case.

++30 cartridges/case.

Table 5 (Cont'd)

Caulk or Sealant	Order Size	Bulk Cost Per Gallon** 1-Gal Pail	2-Gal Pail	5-Gal Pail	55-Gal Drum
25. Tremco Tremproof 60V (FOB Warehouse)	Under $500 order No. of gallons	--	--	$11.90–$12.25/gal 1–42; 1–40	--
	$500–$1499 order No. of gallons	--	--	$10.65–$11.00/gal 47–140; 46–136	--
	$1500+ order No. of gallons	--	--	$9.50–$9.85/gal 158+; 153+	--
Plus 200 Cleaner	Any size order	$16.05–$16.55	--	--	--
Plus Primer No. 6	Under $500 order	$34.85–$35.35 (1–14 gal)	--	--	--
	Over $500 order	$31.50–$32.00 (16+ gal)	--	--	--
38. Tremco				Available only in 4-gal units	
Tremproof 50V (FOB Warehouse)	Under $500 order	--	--	$12.10–$12.45/gal (1–45 gal)	--
	$500–$1499 order	--	--	$11.00–$11.35/gal (48–140 gal)	--
	$1500+ order	--	--	$10.65–$11.00/gal (141+ gal)	--
Plus 200 Cleaner	Any size order	$16.05–$16.55	--	--	--
Plus Primer No. 6	Under $500 order	$34.85–$35.35 (1–14 gal)			
	Over $500 order	$31.50–$32.00 (16+ gal)	--	--	--
Three-Components					
50. Tremco Dymeric (FOB Warehouse)	Under $500 order No. of units, 1–1/2 gal		$28.37–$28.93/gal 1–14	--	--
	$500–$1499 order No. of units, 1–1/2 gal		$22.57–$23.13/gal 15–52	--	--
	$1500+ order No. of units, 1–1/2 gal		$19.10–$19.67/gal 53+	--	--
Plus Color Pak Carton contains 5 Paks; $8.50, $7.50, or $6.50, depending on order size. One Pak used per 1–1/2-gal unit = $1.70, $1.50, $1.30.			Max. = $1.70/unit		

**Manufacturers' variations in these sizes are noted for specific materials.

Table 5 (Cont'd)

Caulk or Sealant	Order Size	Bulk Cost Per Gallon** 1-Gal Pail	2-Gal Pail	5-Gal Pail	55-Gal Drum
Plus 200 Cleaner	Any size order	$16.05-$16.55			
Plus Primer No. 6	Under $500 order	$34.85-$35.35 (1-14 gal)			
	Over $500 order	$31.50-$32.00 (16+ gal)			
Two Components					
36(a). Atlas Minerals and Chemicals Neobon Trowel Cement (NTC) (FOB Mertztown, PA)	Any size order	$56.00	--	$52.00/gal	--
Plus Chloroprime	Any size order (About 63+ gal of NTC for every gallon of Chloroprime)	$26.50	--	$26.00/gal	--
36(b). Atlas Minerals and Chemicals Neobon Trowel Cement (NTC) (FOB Mertztown, PA)	Any size order	$56.00	--	$52.00/gal	--
Plus Chloroprime	Any size order (About 63+ gal of NTC for every gallon of Chloroprime)	$26.50	--	$26.00/gal	--
Plus NTC Adhesive	Any size order (About 31+ gal of NTC for every gallon of NTC Adhesive)	$29.00	--	--	--
45. Carboline 163-2 (FOB Xenia, OH)	Volume discount possible	--	--	$33.25/gal (15-gal kit)	--
37. Chevron CIM-TG (FOB Oakland, CA)	--	--	--	$12.15/gal (4-1/2-gal unit)	--
Plus Bonding Agent (Each 4-1/2-gal unit of CIM-TG contains 4 gal of Premix and 1/2 gal of Activator.)		--	--	$7.80/gal	--

**Manufacturers' variations in these sizes are noted for specific materials.

Table 5 (Cont'd)

Caulk or Sealant	Order Size	Bulk Cost Per Gallon** 1-Gal Pail	2-Gal Pail	5-Gal Pail	55-Gal Drum
29. A. C. Horn Vertiseal Plus Primer (FOB Addison, IL)	--	$36.00/gal (3/4 gal unit; includes Vertiseal Primer)	--	--	--

**Manufacturers' variations in these sizes are noted for specific materials.

Table 6
Sealant Cost Comparison*

Caulk or Sealant	Cost, $/Gal	Components	Primer Needed
37. Chevron CIM-TG	12.15 + bonding agent	2	Yes
25. Tremco Tremproof 60V	11.90–12.25 + primer	1	Yes
38. Tremco Tremproof 50V	12.10–12.45 + primer	2	Yes
18. Mameco Int'l., Vulkem 116	16.30 + cleaner/conditioner	1	Cleaner/Conditioner
10. H. B. Fuller, Fulaprene 303	17.57	1	None
17. PRC Rubber Calk 7000	19.53	1	None
19. Sonneborn-Sonolastic NPI	20.00	1	None
50. Tremco Dymeric	28.37–28.93 + 1.70 max. + primer	3	Yes
45. Carboline 163-2	33.25	2	None
29. H. C. Horn, Vertiseal	36.00 (primer included)	2	Yes
36(a) & 36(b). Atlas Min. Chem., Neobon T.C.	52.00 + primer + NTC adh	2	Yes (2 systems)

*In order of increasing cost, limited to intermediate gallon quantities, FOB plant or warehouse. Cost of cleaners not included since they are needed for all sealants.

Figure 1. Application of sealant over template on steel panel.

Figure 2. Screen wire placed on sealant and imbedded with additional sealant.

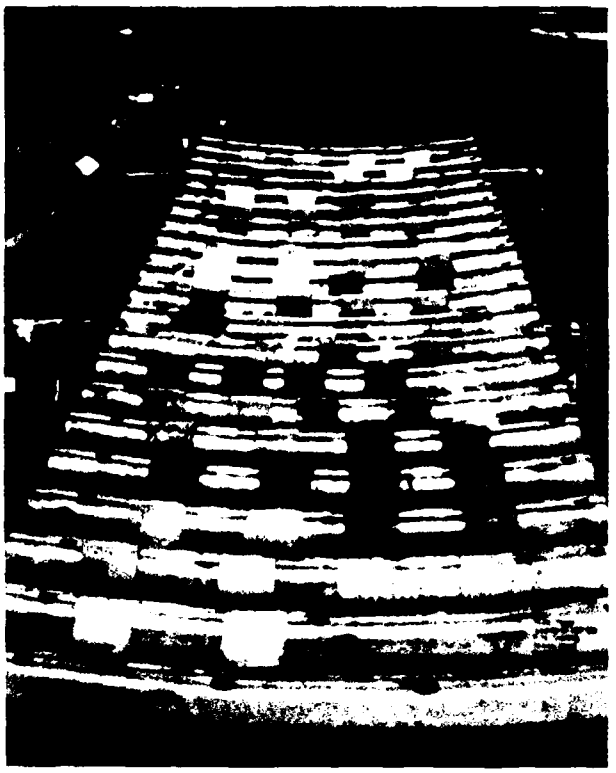

Figure 3. Corrugated galvanized steel panel with sealant specimens for normal adhesion-peel test.

Figure 4. Corrugated galvanized steel panel with sealant specimens immersed in water.

Figure 5. Sealant specimen clamped and pulled with an attached spring scale to determine adhesion-peel strength.

Figure 6. Sealant specimen No. 18: good adhesion-peel strength.

Figure 7. Sealant specimen No. 38: good adhesion-peel strength.

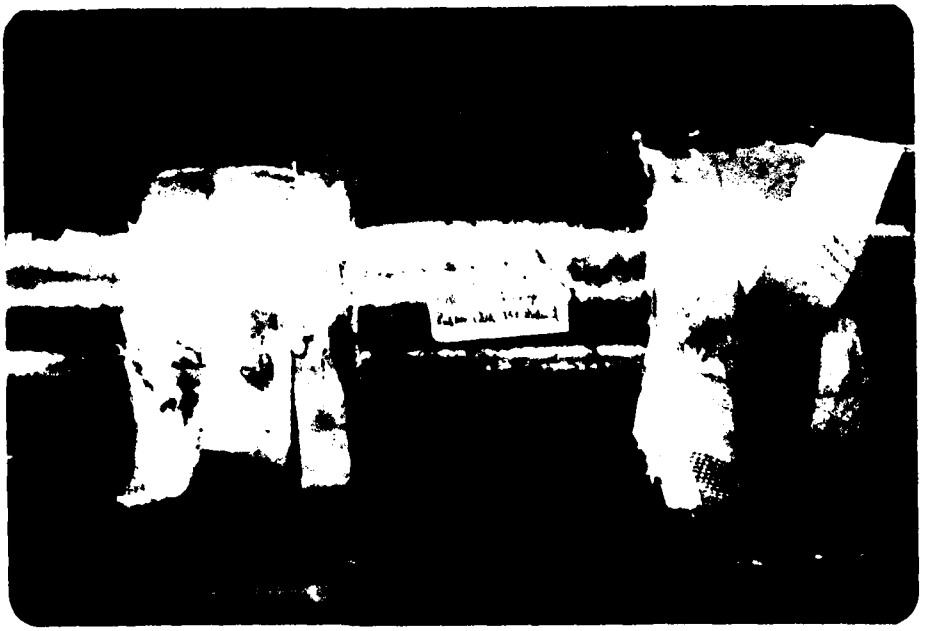

Figure 8. Sealant specimen No. 30: poor adhesion to galvanized steel.

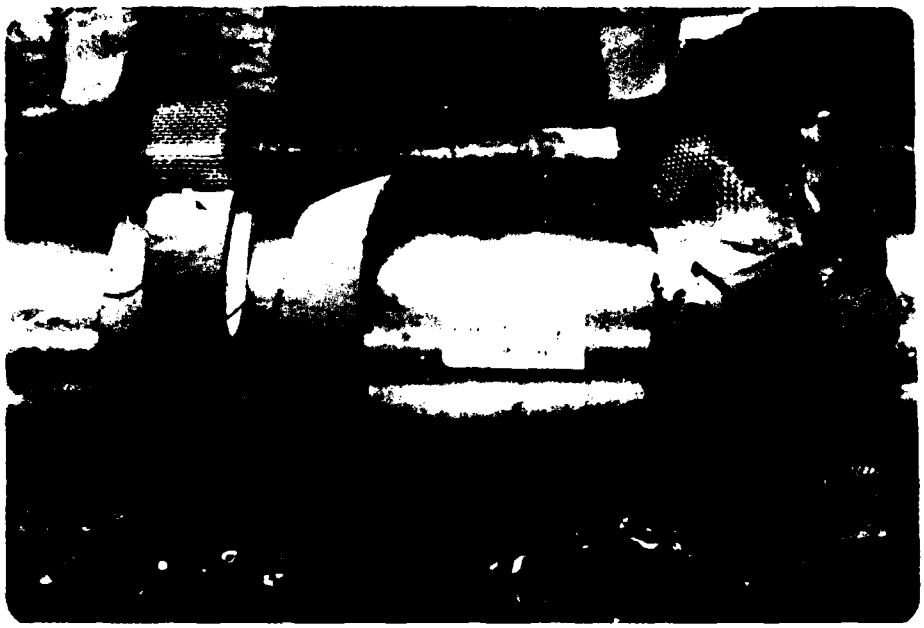

Figure 9. Sealant specimen No. 22: poor adhesion to galvanized steel.

Figure 10. Sealant-butyl gasket adhesion compatibility specimens.

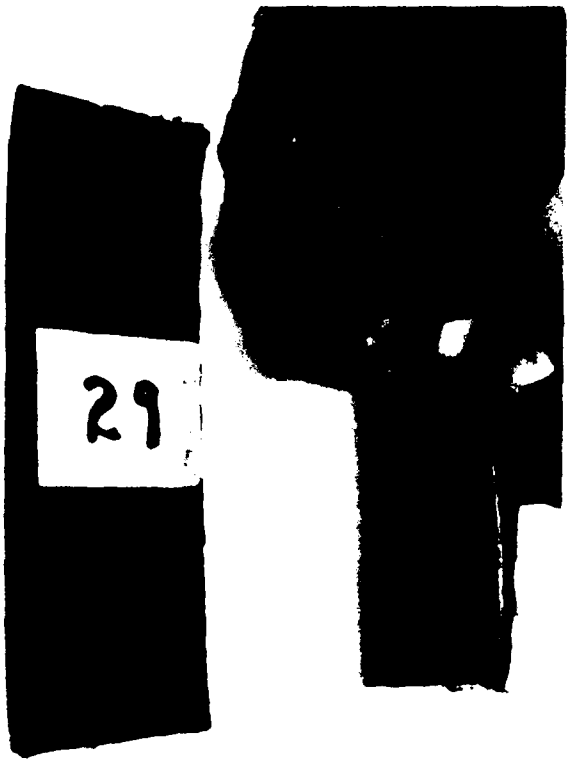

Figure 11. Sealants with good butyl gasket adhesion compatibility.

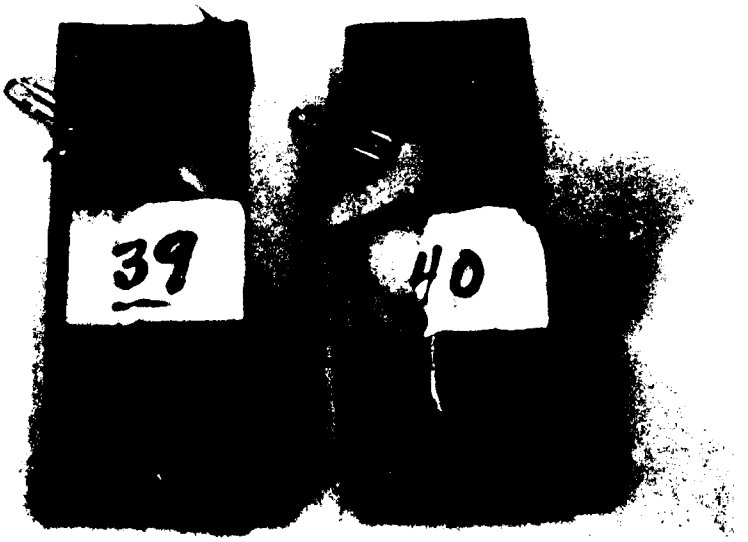

Figure 12. Sealants with poor butyl gasket adhesion compatibility.

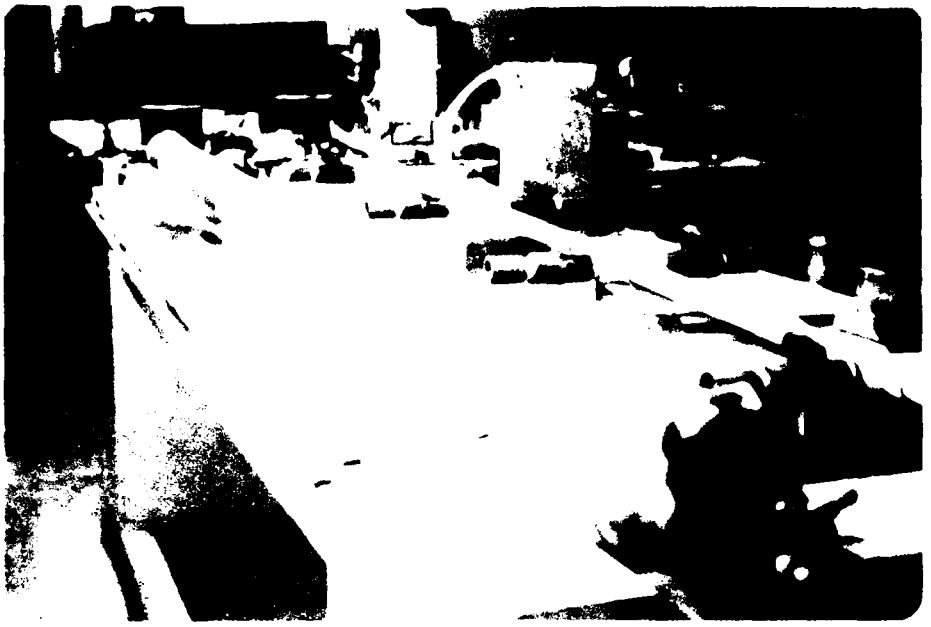

Figure 13. Galvanized steel pipe used for measuring resistance of sealants to hydrostatic pressure leaks.

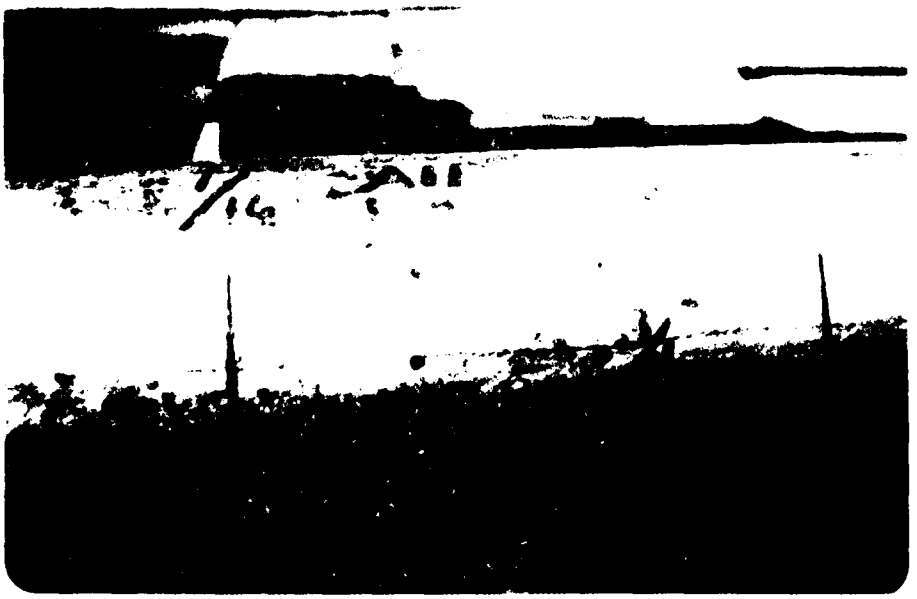

Figure 14. Three sets of holes made in pipe for each sealant, 19 sets in whole pipe.

Figure 15. Application of sealant over holes in hydrostatic pressure test pipe.

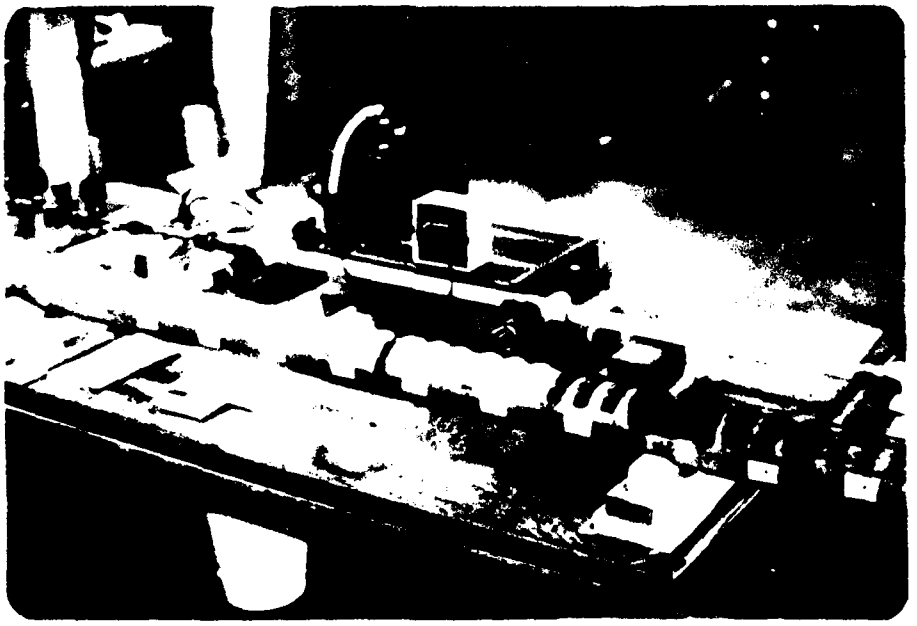

Figure 16. Hydrostatic pressure test unit with resistance wire heating attachment.

Figure 17. Hydrostatic pressure test unit inlet assembly.

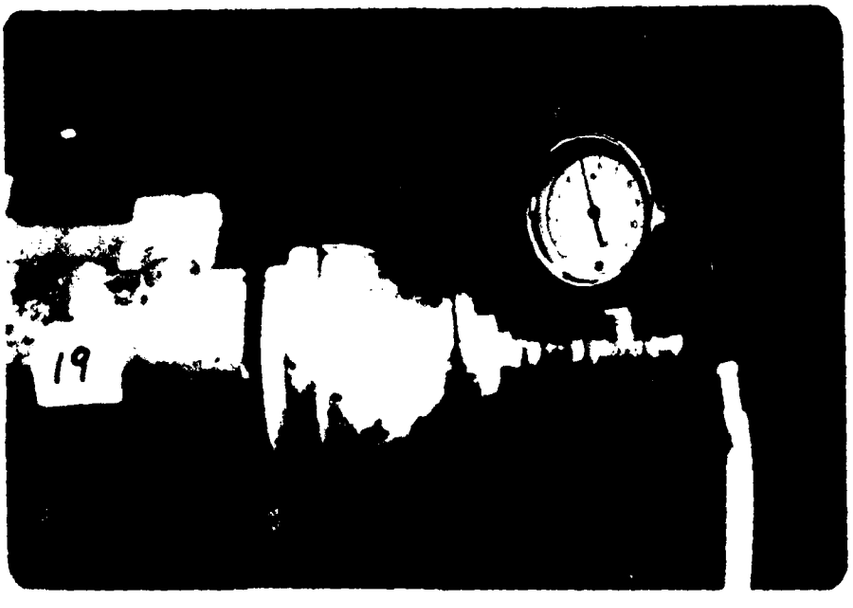

Figure 18. Hydrostatic pressure test unit outlet assembly.

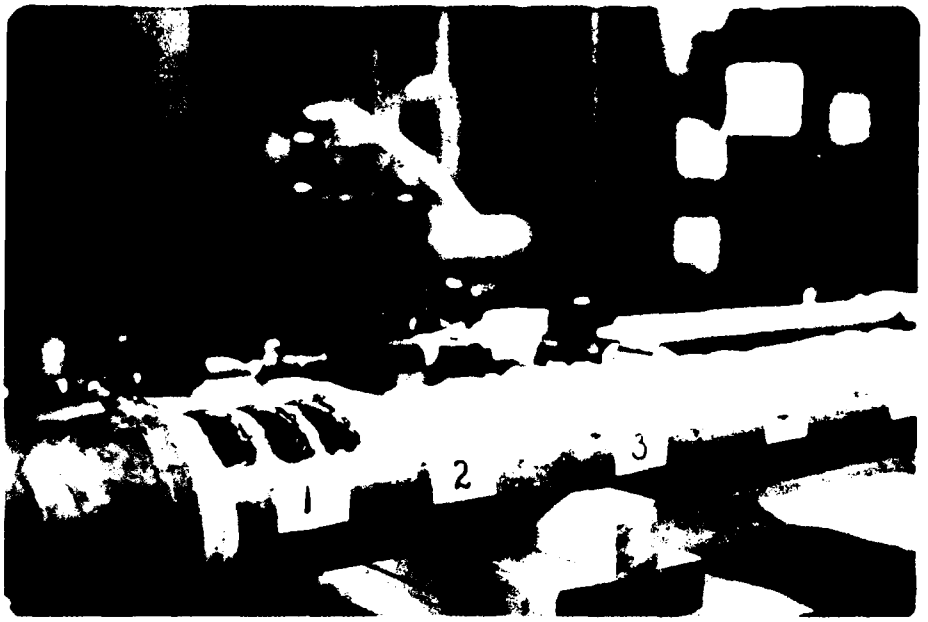

Figure 19. Example of two sealants failing in hydrostatic pressure test. Note water streams.

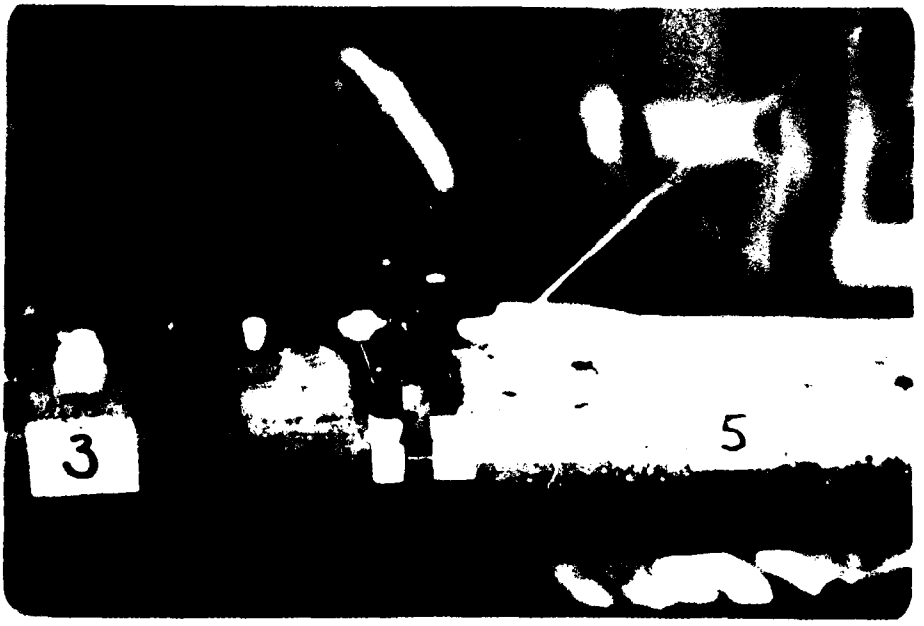

Figure 20. Example of sealant failing in hydrostatic pressure test.

APPENDIX A

DATA FROM FIELD INVESTIGATIONS

Table A1
U.S. Army Installations Contacted

Installation	Location	Water Seepage Problems	Contact
1. Air National Guard	Peoria, IL	None. Changed building plan. No galvanized steel magazines scheduled.	COL Ballow, 309-697-6400.
2. Anniston Army Depot	Anniston, AL	Have four small earth-covered steel magazines built in late 1960s. Three have leaks at anchor base. Water runs on floor.	Bill Camp or Carl Pace, 205-238-7501, x7515 or 6151, respectively.
3. Badger Army Ammunition Plant	Baraboo, WI	Have 14, built on grade about 1975, not earth-covered. No leaks. Previously used Galvanoleum (Rustoleum Corp.) and Al-Chroma #40 asbestos-aluminum asphalt roof coating. Magazines were rectangular.	Bill Clement and Chuck Mensik, 608-356-5525.
4. Camp Shelby	Hattiesburg, MS	Have 15 built in 1971-77. All have water seepage primarily at bolts. Eight sealants are now under test in one magazine, under CERL recommendation.	MAJ R. Johnson, 601-545-2871, x2683; MAJ Holly Piner, 601-545-2871, x2690.
5. Fort Bragg	NC	Have 33 earth covered, 1956 construction. If have heavy rains for a day or two there is no problem. No major water leakage.	Fred Reeves, Chief of Buildings and Structures. 919-396-7908
6. Fort Carson	CO	Have two built in 1978. No leakage. Dry climate. Have problem with doors. They are hard to operate. Has a better design idea for doors.	Dave Nicholson, 303-579-3513.
7. Fort Leonard Wood	MO	Have eight earth covered built about 1978. Had no leaks when contacted. Rainfall was low. Used silicone sealant at one time on inside, and it was satisfactory. Majority of leaks were at the base where metal was embedded. Has a better idea on the ventilation system. Condensation is excessive.	Gene A. Pahlmann, FTS 270-2510.
8. Fort Polk	LA	Have 20 or 21, WW II type (1940). 95 percent of them leak. Can't tell if leaking through seam or bolt. Tried roofing tar on inside but it didn't work. Expect large expansion in FY83.	Robert Morgan, FTS 495-2911, x4806.
9. Iowa Army Ammunition Plant	Middletown, IA	Have six structures eight and twelve years old, and a few others. Inactive at present. All earth covered. Used polysulfide sealant at leaky bolts and seams at concrete base.	Mr. D. L. Pranger, 319-753-7502.
10. Letterkenny Army Depot	Chambersburg, PA	No regular steel magazines. Use Butler-type buildings. These are on grade and not earth covered; made of corrugated galvanized steel or aluminum. There are no reports of leakage.	Duane Peacock, Michael Myers, 717-263-6111. FTS 591-3810.

Table A1 (Cont'd)

	Installation	Location	Water Seepage Problems	Contact
11.	Longhorn Army Ammunition Plant	Marshall, TX	Have eight built before 1976. Three are earth covered and five are on grade. No water seepage problem. Rainfall is heavy at times.	Dale Hall, 214-679-2544.
12.	Louisiana Army Ammunition Plant	Shreveport, LA	Have 25, two built in 1969, 23 in 1973. No water seepage. In 1976 had water in seam area due to mastic coating improperly applied.	William Sheppard 318-459-5199.
13.	Red River Army Depot	Texarkana, TX	No steel magazines. Have only concrete and these were leaky. Outside work on re-waterproofing 20 igloos completed 3 months ago at cost of $9126 each. May do same work on 44 more.	Wiley Rood, 214-838-2673; Stewart McDonald, 214-838-3245.
14.	Redstone Arsenal	Huntsville, AL	No steel magazines. Have eight "Lane Catecombs" test cells made from drainage culvert material built 1966-67. They are 5 1/2 ft tall.	Harbel Lawson, FTS 876-5055.
15.	Sunflower Army Ammunition Plant	De Soto, KS	Have eight, built in 1980, and all leak. Contractor instructed not to use them. Also have a condensation problem. May try a 1- to 2-in. urethane foam application on inside if approved. Area is munition sensitive.	Jim Daly, 913-843-3800, x343.
16.	Tooele Army Depot	Tooele, UT	Have 72, contract started in 1978. Have problems with head walls and proper grounding. Not much rainfall. All covered on outside with Keeperkote M1 or Perma-gard.	B. L. McIntyre and Dennis Bingham, 801-833-2515 and 2115 respectively.
17.	Yuma Proving Ground	Yuma, AZ	Have 44 built from 1950 to 1975. Leaks present no problem. They are of short duration. Soil is high in salt content and corrosion is bad. The 10-to-15-year old magazines are being abandoned since they aren't structurally safe. Five-year-old magazines had inadequate cathodic protection. Corrosion is mostly at ridge, middle, and ceiling at top.	Willard Robinson, 602-328-2151.

Table A2
U.S. Navy and Marine Corps Installations Contacted

	Installation	Location	Water Seepage Problems	Contact
1.	Marine Corps Base	Camp Pendelton, CA	In one area, four out of 13 steel magazines leaked. Two years ago had heavy rains; there were leaks in seams and around bolts. Bolts could not be tightened. Tried Bitumastic on inside but this didn't work. Decided to work on outside; no contract yet. Have leaks only when it rains hard. The climate is generally dry.	M. Rekdahl, FTS 892-4626.
2.	Marine Corps Air Station	Yuma, AZ	Have 12, completed in July 1976. No water problems or corrosion. Corrosion is possible from the salt. Soil cover is stabilized with hot-mix, soil is sandy. Thinks that gunite with joints would work better over the earth cover than asphalt hot-mix. Thinks cathodic protection used in steel plate for protection from salt.	Leroy Lindamood, 602-726-2808.
3.	Naval Air Station	Alameda, CA	Have steel magazines. Would not say how many. Have no water seepage. Do have condensation.	Ensign Jerry Richardson, 415-869-4731.
4.	Naval Air Station	Brunswick, ME	Have four built in 1943. Moved three to another location about 3 mi away. They were partially dismantled. Exterior surface was painted with asphalt-aluminum paint after scraping and wire brushing. There are no leaks; none of the four has ever leaked. One is near a swampy area and gets some groundwater but no leaks through seams or at bolts.	Dick Gould, 207-921-2445.
5.	Naval Air Station	Cecil Field, FL	Have 40 steel magazines completed in 1978. Still working on waterproofing. Not all serviceable yet. Original roof construction consisted of 4 ft of soil over bare metal then 6 in. of concrete; one slab over 20 magazines. Water banked up between magazines and went through bolt holes and seams. New system (modification) consisted of removing the concrete on the top and placing a polyethylene film (10 mils thick) over the metal then soil and sodding. Drainage pipes put between magazines. No leakage since June 1980.	Bill Wilson, 904-778-5620.
6.	Naval Air Station	Norfolk, VA	Have 16 steel magazines. Constructed two groups of eight each with a common head wall with magazines side by side under the same berm. Dirt fill is between magazines. Completed in 1978; Moved in during 1981. Developed 4-ft head of water between magazines. This caused leakage at bottom of steel arch. Tried two-component sealant, but this did not help. Roof construction had a 6-mil polyethylene film over the steel. This was covered with earth a minimum of 2 ft. Presently have leakage at anchor base and too much condensation.	LT J. M. Cain 804-444-1364; Ray Margeson, Gunner's Mate Technician Chief, 804-444-4533, or FTS 954-4533, FTS 954-1364.

Table A2 (Cont'd)

Installation	Location	Water Seepage Problems	Contact
7. Naval Air Station	North Island, CA	Have 40 steel magazines completed 1980, built in three stages. Had many leaks. First set had no coating on outside, second set had brittle coating, and third had PVC liner on top and no coating--ground rods pushed through liner. Remedy: (1) Uncovered all 40 to metal, (2) cleaned and primed with asphaltic material, (3) applied Systemized SP11, 90 mils on outside and a gravel layer, (4) filter blanket protective put over top and sides, (5) coarse gravel then put over, 6 to 8 in., (6) another filter blanket, and (7) back filled to 1 ft then 6 in. of gravel and 6 in. clay. Did water test before back filling and after. No leaks. Completed in April and good so far. Note: before priming, all bolts and seams caulked with butyl rubber sealant. Cost $1.5 million. Includes 4-in. perforated drains on each side of magazines on the outside.	Larry Lind, 415-877-7410.
8. Naval Air Station	Willow Grove, PA	Have two steel magazines 20 ft x 40 ft, have leaks in both (built about 1943). Have water seepage along foundation and due to condensation. Rusting metal is deteriorating. Cleaned the magazines, caulked them, and painted. Problem is still there.	Mr. Rocco Stella, 215-443-1000.
9. Naval Ordnance Station	Indian Head, MD	No steel-arch magazines. Have only reinforced concrete. Vary in age from WW II to recent.	Tim Rath, FTS 364-4844.
10. Naval Submarine Base, New London	Groton, CT	Have 25 steel magazines built in 1971-72. Water was seeping in through bolts. Tried to tighten but couldn't tighten all. Eroded soil replaced and 6 in. of sand, then a Dacron supported chlorinated polyethylene liner was put on. Liner is held in valleys with round boulders 6 in. and less in size. The liner was installed on 20 magazines in 1975. A 5-in. cap of bituminous soil cement is placed over the liner to stabilize soil. Cap is 10 ft x 12 ft and is centered over the crown of each magazine. Fourteen of the magazines are arranged in a row containing seven magazines placed back to back. One liner goes over all 14 magazines. One liner is also placed over the six magazines. There are no leaks.	Mike Murphy, FTS 644-3941.
11. Naval Under Sea War Engineering Station	Keyport, WA	Do not have steel magazines. Have $0.5 million project for repairing cracks in concrete magazines by epoxy resin injection.	Bob Aske, Les Baker, 206-396-2411.
12. Naval Weapons Center	China Lake, CA	Have 17 steel magazines or 34 if include small ones. Built in early 1940s and 1950s. Have problem with soil erosion. Asphalt coating becomes exposed and deteriorates from sun. Too costly to eliminate. They push more dirt on top. This is a dry desert area.	Jerry Brooks, 714-939-3411.

Table A2 (Cont'd)

Installation	Location	Water Seepage Problems	Contact
13. Naval Weapons Station	Charleston, SC	Have five large and 10 small steel magazines. All leaked. Cover was stripped on four of the five and 2-in. shotcrete applied on outside, then a heavy polyethylene liner, 2-ft minimum earth fill, then 2 in. of hot mix asphalt paving over the earth. This was tried in 1976 on one, then on three more in 1978. Performance is excellent. No evidence of leakage. Inside repairs were tried, but didn't work. Thoroseal, asphalt and plastic cement were used. On the small magazines, a bituminous roof coating was used, 4-in. of stone base then paved with 2-in. of hot asphalt. Cost for this work including drains was $100,000 in 1976 and $130,000 in 1978 per magazine. Work was done in a maximum security area.	Dave Lovett, 803-743-7626. FTS 679-7626.
14. Naval Weapons Station	Concord, CA	Have 37 steel magazines just built. Had many leaks at bolts and seams. Now in process of re-doing whole exterior similar to job done at North Island. Cost may run to $2.3 million for all 37 magazines. See item 7 for North Island data.	Dave Brown, 415-877-7402.
15. Naval Weapons Station, Earle	Colts Neck, NJ	Have only concrete magazines. 99 percent are 40 years old. No major problems.	Bill Oborne, 201-462-9500.
16. Naval Weapons Station	Seal Beach, CA	No steel magazines.	Jim Orrico, 213-594-7011.
17. Mayport Naval Base	Mayport, FL	Have four steel magazines built in 1970-71. No water seepage although rainfall is heavy, about 50 in. per yr. All built in a swamp. Four concrete igloos are being built currently.	Gunther Houck 904-246-5235 Clyde Bradley, 904-246-5184.

Table A3
U.S. Air Force and Other Installations Contacted

Installation	Location	Water Seepage Problem	Contact
1. Blytheville, AFB,	AK	Have three steel magazines. Leaked when rained. Water came in through seams. Remedy: stripped vegetation, applied 6 mil Visqueen over soil, then 1-½-in. gunite, chicken wire 2-in. mesh, and finally 1-½ in. of gunite; no earth cover. Gunite used on front walls after joints sealed. Now third summer since work done and results are good. Last year had a few shrinkage cracks in gunite and these were sealed with SC70 cutback asphalt. Thinks they got payback now because of less maintenance.	Ray Clouse, 501-762-7000; Tom Talley, 501-762-7000.
2. Robins AFB,	GA	Have seven standard size and 4 of class A, B, and C. The seven were built in February 1980. These are not earth covered. All seven have leaks at channel iron anchor joint. Civil engineering department will decide what to do.	Rex Kent, FTS 286-4444, direct; 912-926-4444. Claude Adams, FTS 286-5168, direct; 912-926-5168.

Table A3 (Cont'd)

Installation	Location	Water Seepage Problem	Contact
3. Warren AFB	Cheyenne, WY	Have three steel magazines probably built in mid 1972. No leakage that he is aware of. They are in good condition. Climate is dry, about 17 in. of rain per year.	Reuben Altergott, 307-775-3909. Dick Riddell, 307-775-2438 or 2759.
4. Air Defense Command	Walla Walla, WA	Have six steel magazines, not earth-covered, built in early 1960's. No leakage complaints. In good condition. Rainfall is a bit heavy, about 40 in. per year.	Ray Tyrrell, FTS 442-5485; Doug Winn, FTS 442-5500, 509-529-0843.
5. Allegheny Ballistics Laboratory	Cumberland, MD	Have six steel Government magazines and contractor (Hercules) has 18 cubicles, 12- to 15-ft wide x 12-ft high at several different lengths. These were all built in the last 10 years. The Government magazines leaked initially and were cleaned off and redone. Now there is condensation but no leakage. The cubicles had minor leaks originally but none now. They are maintained at 158° to 180°F inside. Tried urethane foam inside and outside; liked outside better.	Bill Lang, 304-726-4500, x8107 Michael Cunningham, 304-726-4500, x8003.
6. Pantex Plant	Amarillo, TX	Have 50 to 60 steel magazines; there is no leakage. These were built 3 to 18 years ago. Asphalt roofing cement and 45-lb asphalted roofing felt put over bolts and seams. More of the roofing cement placed on edges then ground cover. On some, Gulf Seal sheets used on earth cover for erosion control (nailed down). End of Gulf Seal is buried. No drain tile used inside or outside. Have a lot of wind, but rainfall is only 20 in. annually.	Jerry Pennington, 806-335-1581, x2281. FTS 572-2281, direct. Bill Colvin, FTS 738-7011.
7. McDonnel Douglas	Huntington, CA	Have three steel magazines; all shipped to Idaho in last year. They were built 5 years ago. Condition today is good. These were made of 10-gage not 1-gage steel. They were sealed with a bitumen coating on the outside. The base was caulked with asphalt. Rainfall is only about 22 to 25-in. annually.	Bob Goethe, FTS 798-2000, 714-896-1481.

APPENDIX B:

SEALANT MANUFACTURERS CONTACTED

Manufacturers Who Recommended Materials and Furnished Samples

Elastomeric Sealants

1. Al-Chroma, Incorporated
   P.O. Box 226
   Stevens Point, WI 54481
   (715) 344-4691 and 344-4696
   Mr. Virgil Peters

2. Atlas Minerals & Chemicals, Inc.
   Farmington Road
   Mertztown, PA 19539
   (215) 682-7171
   Mr. Donald G. Reinert

3. Carboline
   350 Hanley Industrial Court
   St. Louis, MO 63144
   (314) 644-1000
   Mr. Paul Litzinger

4. Chevron U.S.A, Inc.
   Asphalt Division
   575 Market St.
   San Francisco, CA 94105
   (415) 894-4400
   Mr. J. E. Henry

5. Dap Inc.
   Subsidiary of Plough, Inc.
   Dayton, OH 45401
   (513) 253-7152
   Mr. Ward Treat

6. Daubert Chemical Co.
   1200 Jorie Blvd.
   Oak Brook, IL 60521
   (312) 986-4600
   Mr. Scott Lucas

7. Dow Corning Corp.
   P.O. Box 1767
   Midland, MI 48640
   (517) 496-4000 and 800-248-2345
   Mr. Bud Smith

8. H. B. Fuller Company
   5220 Main Street N.E.
   Minneapolis, MN 55421
   (612) 560-4350
   (800) 328-7307
   Mr. James Collins

9. General Electric Co.
   Silicone Product Division
   Waterford, NY 12188
   (518) 237-3330
   Mr. Jim Brower

10. Geocel Limited, Inc.
    P.O. Box 398
    Elkhart, IN 46515
    (219) 264-0645
    Mr. Robert Sherellis

11. Goal Chemical Sealants Corp.
    3137 East 26th Street
    Los Angeles, CA 90023
    (213) 269-0461
    Mr. Marvin Smith

12. Goodyear Chemicals
    Ashland, OH
    (419) 289-9588
    Mr. Ron Lenhard
    Dist: W. J. Ruscoe Company
    483 Kenmore Blvd.
    Akron, OH 44301
    (216) 253-8148
    Mr. Ed Mobley

13. A. C. Horn, Inc.
    1555 Wrightwood Court
    Addison, IL 60101
    (312) 629-4243
    Mr. Victor Weber

14. Mameco International
    Vulkem Sealants Division
    4475 East 175th Street
    Cleveland, OH 44128
    (216) 752-4400
    Dr. R. B. Greene

15. 3M Company
    Adhesives, Coatings and Sealers Division
    223-6NE, 3M Center
    St. Paul, MN 55101
    (612) 733-6999
    Mr. Dale Smestad

16. Pecora Corporation
    165 Wambold Road
    Harleysville, PA 19438
    (215) 723-6051
    Mr. Al Kilchesty or Glen Holmes

17. Products Research and Chemical Corp.
    PRC Coating and Sealants Division
    5454 San Fernando Road
    Glendale, CA 91203
    (213) 240-2060
    Mr. Roger Cournoyer

18. Republic Powdered Metals
    2628 Pearl Road
    Medina, OH 44256
    (216) 225-3192
    Mr. Dan Struger

19. Sonneborn Building Products
    Division of Contech Inc.
    7711 Computer Avenue
    Minneapolis, MN 55435
    (612) 835-3434
    Mr. Al Galin

20. Steelcote Manufacturing Co.
    3418 Gratiot St.
    St. Louis, MO 63103
    (314) 771-8053
    Mr. Herbert Rosenblatt

21. Tremco
    10701 Shaker Blvd.
    Cleveland, OH 44104
    (216) 229-3000
    Mr. Sanford Wohl

22. Woodmont Products, Inc.
    County Line and New Roads
    P.O. Box 8
    Huntington Valley, PA 19006
    (215) 357-0755
    Mr. Kirt Zintner

Epoxy Sealants

23. Adhesive Engineering Co.
    1411 Industrial Road
    San Carlos, CA 94070
    (415) 592-7900
    Ms. Claudia Clark

24. American Chemical Corp.
    81 Encina Ave.
    Palo Alto, CA 94301
    (415) 327-5210
    Mr. Bill Warner

25. Carboline
    350 Hanley Court
    St. Louis, MO 63144
    (314) 644-1000
    Mr. Paul Litzinger

26. Celanese Plastics & Specialties Co.
    One Riverfront Plaza
    Louisville, KY 40202
    (502) 585-8078
    Mr. Jack Avery

27. Koppers Company, Inc.
    Organic Materials Group
    1900 Koppers Building
    Pittsburgh, PA 15219
    (412) 227-2000
    Mr. Mike Carvlin

28. Mobil Chemical Company
    Maintenance and Marine Coatings Dept.
    901 North Greenwood Avenue
    Kankakee, IL 60901
    (815) 933-5561
    Mr. Bob Waldrop

29. Sika Chemical Corporation
    Box 297
    Lyndhurst, NJ 07071
    (201) 933-8801
    Mr. Steve Sidler

Other Manufacturers Contacted

30. Colorado Chemical Specialties, Inc.
    4295 McIntyre St. Dept. 25
    Golden, CO 80401
    (303) 278-1963

31. Copolymer Rubber and Chemical Corp.
    P.O. Box 2591
    Baton Rouge, LA 70821
    (504) 355-5655

32. Dayton Coatings and Chemical Division
Whittaker Corp.
P.O. Box 27
West Alexandria, OH 45381
(513) 839-4612
(513) 835-5656

33. DuPont Co.
Chemical, Dyes and Pigments Dept.
1007 Market St.
Wilmington, DE 19898
(302) 774-2421

34. Effective Building Products, Inc.
2950 Metro Drive, Suite 305
Minneapolis, MN 55420
(612) 854-3588
Bryan M. McGroarty

35. General Tire and Rubber Co.
Industrial Products Division
One General St.
Wabash, IN 46992
(219) 563-1121

36. Gibson-Homans Co.
1755-T Enterprise Pky.
Twinsburg, OH 44087
(216) 425-3255

37. Hughson Chemicals
2010 W. Grandview Blvd.
P.O. Box 1099
Erie, PA 16512
(814) 868-3611

38. Inmont Corp.
1133 Ave. of Americas
New York, NY 10036
(212) 930-1300
St. Louis, MO (314) 577-1100

39. Master Builders
Div. of Marietta Corp.
23700-T Chagrin Blvd.
Cleveland, OH 44122
(216) 831-5500

40. Mobay Chemical Corp.
Plastics and Coatings Div.
Penn-Lincoln Pky, W.
Pittsburgh, PA 15205
(412) 777-2000

41. Olin Corp.
Winchester-Western Div.
275 Winchester Ave.
New Haven, CT 06504
(203) 777-7911
Olin Research Center
(203) 789-5773

42. Petrarch Systems, Inc.
Box 141-A
Levittown, PA 19059
(215) 638-0490

43. Rust-Oleum Corp.
11 Hawthorn Pkwy.
Vernon Hills, IL 60061
(312) 367-7700

44. Shell Chemical Co.
One Shell Plaza
Houston, TX 77001
(713) 241-6161
Shell Development Co.
(713) 493-7171

45. K. T. Snyder Co.
9601 West Tidwell
Houston, TX 77041
(800) 231-4549
(713) 462-8536

46. Thiokol Corp., Specialty Chemicals Div.
930 Lower Ferry Rd.
Box 8296
Trenton, NJ 08650
(609) 396-4001

47. Union Carbide Corp.
Old Ridgebury Rd.
Danbury, CT 06817
(203) 794-2000
(203) 794-2665

48. United Gilsonite Laboratories
1396 Jefferson Ave.
Scranton, PA 18501
(717) 344-1202

49. U.S. Gypsum Co.
101 S. Wacker Dr.
Chicago, IL 60606
(312) 321-4000
(312) 694-2070
Research Center
(312) 299-3381

50. Weatherguard Marbleoid Products, Inc.
2515 Newbold Ave.
Bronx, NY 10462
(212) 828-8300

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Little Rock 72203
Los Angeles 90053
Louisville 40201
Memphis 38103
Mobile 36628
Nashville 37202
New Orleans 70160
New York 10007
Norfolk 23510
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Army Matls. and Mechanics Res. Ctr.
Corpus Christi Army Depot 78419
Harry Diamond Laboratories 20783
Dugway Proving Ground 84022
Jefferson Proving Ground 47250
Fort Monmouth 07703
Letterkenny Army Depot 17201
Natick R&D Ctr. 01760
New Cumberland Army Depot 17070
Pueblo Army Depot 81001
Red River Army Depot 75501
Redstone Arsenal 35809
Rock Island Arsenal 61299
Savanna Army Depot 61074
Sharpe Army Depot 95331
Seneca Army Depot 14541
Tobyhanna Army Depot 18466
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Yuma Proving Ground 85364
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Fort Wainwright 99703
Vancouver Bks. 98660

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Walter Reed Army Medical Center 20012

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Vint Hill Farms Station 22186

MDW
ATTN: Facilities Engineer
Cameron Station 22314
Fort Lesley J. McNair 20319
Fort Myer 22211

MTMC
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ATTN: Facilities Engineer
Oakland Army Base 94626
Bayonne MOT 07002
Sunny Point MOT 28461

NARADCOM, ATTN: DRDNA-F 01760

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