

Attached is a technical report on a comprehensive investigation carried out at Battelle Memorial Institute under the sponsorship of the American Iron and Steel Institute on protective paints for enclosed structural members in steel housing construction. It contains comparative moisture resistance data on many types of paint compositions.

Whether you are concerned with this specific problem or with the general problem of protecting steel surfaces against rust, we believe this report will prove valuable.

Additional copies of this report may be obtained without charge from the Lead Industries Association, 420 Lexington Ave., New York 17, New York.

LIA07870

This paper is the first formal report resulting from a research project at the Battelle Memorial Institute under the sponsorship of the American Iron and Steel Institute and directed by the Committee on General Research, the Committee on Protective Coatings and the Committee on Building Codes.

Other reports will follow as the work progresses.

Abstract of paper which was read before General Meeting of American Iron and Steel Institute, at New York, May 23-24, 1949

A STUDY OF PAINTS FOR ENCLOSED STRUCTURAL MEMBERS IN STEEL HOUSING CONSTRUCTION

By

H. A. PRAY
Supervisor

and

R. S. PROPLIS
Assistant Supervisor
Battelle Memorial Institute

Introduction

IN recent years, isolated instances of corrosion difficulties resulting from condensation of moisture between the interior and exterior walls of dwelling houses constructed from steel have attracted considerable attention and interest. When condensation occurs to a sufficient degree, damage to the strength properties of the structure may result. No definite statistics are available to indicate how widespread the problem is, but there is no doubt that structural members must be coated for corrosion protection, and that coating systems vary in their effectiveness for this purpose.

The present investigation of paint systems for the protection of steel was undertaken as a part of the research program initiated by the Technical Committee on Protective Coatings of American Iron and Steel Institute. Its primary objective was to evaluate paint coatings by laboratory testing under environmental conditions, simulating those which may be encountered during the life of steel housing units.

The conditions which bring about the deterioration of paint films and the corrosion of coated steel in the service under discussion are somewhat different from those ordinarily encountered. It is conceivable, in fact, it has been observed that, under certain conditions of climate and design, structural members may be subjected to continuous immersion in water. They may

be subjected to contact with insulation in the presence of water, to moisture condensation that is continuous over extended periods of time, to periodic wet-dry conditions, and to an environment of high humidity at relatively high temperatures. The usually important effect of ultraviolet light on the deterioration of organic coatings is entirely absent in this case, involving only enclosed members.

Further, the criteria used for evaluating deterioration in connection with this type of service are, in some respects, unique. The appearance of the coating is of no importance whatever. Its exclusive function is to protect the steel from corrosion and consequent loss in strength. Discontinuities in the protective film are inevitable because of the damage resulting from handling subsequent to painting. The behavior of both film and steel in areas where the film is damaged must be considered in the evaluation of paint systems.

Some 34 kinds of paint systems have been studied. Most of them are fairly well known and established systems, although a few are of more recent development. Most were of the single-coat, air-dry type. Coated panels were subjected to at least one or more of the following tests: (1) continuous immersion in water, (2) contact with air at high humidity, (3) continuous condensation, (4) alternate wet-dry conditions, and (5) continuous contact with insulation in the presence of water. These tests were intended to simulate both severe and moderate conditions of service and should form a basis for valid comparisons between the effectiveness of the coating systems studied.

Of the extensive literature relating to the protectiveness of paint films, those considered to be most directly related to the present problem are listed at the end of this paper.

Paint Systems Studied

Table I contains the details, with respect to paint composition and coating data, for the paint systems which have been applied to steel panels for study. All systems were cured by air drying, with the exception of L, M, N, and O, which were baked, and all comprised one coat of essentially one-mil minimum thickness except for the following:

System F—one coat, two-mil thickness

System P—two coats, each one-mil thickness

Systems H₁, H₂, and H₃—five-, ten-, and fifteen-mil thickness, respectively

Systems O, O₁, and Q—two coats, each 1/2-mil thickness

EXPERIMENTAL

Test Panels

The test panels for coating purposes were prepared from 20-gage (0.0375 in.) cold rolled sheet steel with a Carnegie No. 5 finish. Chemical analysis of this material indicated C—0.06 per cent, Mn—0.29 per cent, P—0.06 per cent, S—0.028 per cent, Si—0.001 per cent, and Cu—0.05 per cent. The panels were approximately four by six inches in size and all edges and corners were smooth and uniformly rounded.

Preparation of Panels for Coating

Panels were prepared for coating by Procedure "A", Cleaning, outlined in the 1945 ASTM Book of Standards, Part I, page 192. It consisted essentially of vapor degreasing (trichloroethylene) until the panels showed no water break when immersed in distilled water. The panels were then immersed in hot isopropyl alcohol, removed, and allowed to dry at approximately 150 F. They were then either painted immediately or stored in a desiccator pending coating.

Procedure for Coating Test Panels

Preliminary investigation indicated that the most standard and reproducible method for applying a uniform paint coating (of the thickness desired) to a test panel was by a controlled dipping procedure. Considerable exploratory work was done to determine the necessary adjustments in paint viscosities and withdrawal rates which would result in uniform coating thickness, not only upon individual panels but from panel to panel for each paint system. It was necessary in some cases to decrease the viscosity of the paint by the addition of a suitable solvent, while in others the viscosity was increased to the desired value by evaporation of the volatile material. The procedure used for coating the test panels consisted essentially of the following operations.

TABLE I
Paint Composition and Coating Data

Designation	Type of Coating	Type of Cure	Coating thickness	Paint Formulation						Remarks
				Pigments			Vehicle			
				Per Cent	Composition	Per Cent	Per Cent	Composition	Per Cent	
A	Red lead/phenolic modified alkyd	Air dry	1 coat, 1 mil thick	89	Red lead (97 per cent)	100	20	Berkelund 1516 (50 per cent N.V.M.)	96.97	Berkelund 1516 is a medium-long alkyd modified with a phenolic type resin P.V.B., 32.6
								6 per cent Co naphthenate oil.	0.134	
								6 per cent Mn naphthenate oil.	0.134	
						100		ASA	2.76	
									100	
B	Iron oxide / zinc laurad oil / modified tung, laurad, phenolic	Air dry	1 coat, 1 mil thick	60.2	#700 iron oxide Advanox 3a Celene 118 Purilon No. 1 china clay	40.6 8.2 24.7 26.5	99.8	An-TT-V-118 varnish oil. Raw laurad oil Mental spirit Bismar 6 per cent Co naphthenate oil. 6 per cent Mn naphthenate oil. 24 per cent Pb naphthenate oil.	28.20 33.2 9.2 10.5 0.2 0.3 0.6	An-TT-V-118 varnish from Bakelite Corp.: VF-461; 55-gallon varnish based on Bakelite pure phenolic BR-254 resin, 60 per cent N.V.M.
						100			100	
C	Red lead / zinc laurad oil	Air dry	1 coat, 1 mil thick	80.7	Red lead (97 per cent)	100	19.3	CHCO laurad oil Raw laurad oil 6 per cent Co naphthenate oil. 6 per cent Mn naphthenate oil. 24 per cent Pb naphthenate oil.	18.90 80.86 0.82 0.82 0.30	2 1/2 M viscosity CHCO oil. P.V.B., 30.8
						100			100	

TABLE 1 (CONTINUED)

Designation	Type of Coating	Type of Coat	Coating System	Paint Formulas						Remarks
				Pigments		Vehicles				
				Per Cent	Components	Per Cent	Per Cent	Components	Per Cent	
D	Zn dust, Zn oxide/ limestone oil, alkyl	Air dry	1 coat, 1 mil thick	6.7	Zn dust Zn oxide	79.6 24.4	23.3	Ronyl 809 6 per cent Co naphthene oil. 6 per cent Mn naphthene oil. 24 per cent Pb naphthene oil.	99.76 0.82 0.82 0.30 100	P.V.B., 34.9.
E	Zn dust, Zn oxide, Fe oxide/alkyl resin	Air dry	1 coat, 1 mil thick	4.7	#700 Ispenath iron oxide Zn oxide (AZO-ZZZ-55) Zn dust (325 mesh)	30 20 30	24.3	Ronyl 809 6 per cent Co naphthene oil. 6 per cent Mn naphthene oil. 24 per cent Pb naphthene oil.	99.76 0.82 0.82 0.30 100	P.V.B., 33.6.
F	Iron oxide, Zn chromate/phenolic varnish	Air dry	1 coat, 1 mil thick	32	Zn Chromate #700 Ispenath iron oxide Admanex 30 Color 110	25 30 15 10	40	Varnish 32-V-17	100 100	32-V-17 is a 25-gallon varnish of a 50/50 mixture of Isocel and tung oil based on a pure phenolic resin. It is supplied as 60 per cent N.V.M. in a solvent consist- ing of 80 per cent mineral spirit and 20 per cent xylene. P.V.B., 34.3.
F ₁	Iron oxide, Zn chromate/phenolic varnish	Air dry	1 coat, 2 mils thick	32	Zn Chromate #700 Ispenath iron oxide Admanex 30 Color 110	25 30 15 10 100	40	Varnish 32-V-17	100 100	

TABLE 1 (CONTINUED)

Designation	Type of Coating	Type of Coat	Coating System	Paint Formula						Remarks
				Pigments			Vehicles			
				Per Cent	Composition	Per Cent	Per Cent	Composition	Per Cent	
F	Iron oxide, Zn chromate/phthalic varnish	Air dry	2 coats, each 1 mil thick	52	Zn Chromate 8500 Sparat iron oxide Autobond 32 Celac 110	25 50 15 10 100	40	Versabond 52-V-47	100	
G	Lead chromate, red oxide/alkyd resin	Air dry	1 coat, 1 mil thick	50	Ferric oxide Basic Pb chromate Inerts (Autobond, Solan, etc.)	43.5 27.0 29.5	50	Alkyd resin sol. (50 per cent sol. in mineral spirits) Mineral spirits Easoy No. 2 Naphthorone (5207 Type I) Naphthorone (5207 Type II) Naphthorone (5207 Type III)	75.2 20.3 2.92 0.90 0.34 0.16 100	Resin solids: 15-18 per cent polyphthalic anhydride 34-40 per cent phthalic anhydride 42-51 per cent linseed oil solids
H	Asphalt type	Air dry	1 coat, 1 mil thick				100	Asphalt Celacene Mineral spirits	40 10 50 100	
M	Asphalt type	Air dry	5 mils sprayed				100	Asphalt Celacene Mineral spirits	40 10 50 100	
N	Asphalt type	Air dry	10 mils sprayed				100	Asphalt Celacene Mineral spirits	40 10 50 100	

TABLE 1 (CONTINUED)

Disp. Index	Type of Coating	Type of Case	Coating Thickness	Paint Formulas					Remarks
				Pigments		Vehicles			
				Per Cent	Components	Per Cent	Components	Per Cent	
L	Zn dust, iron oxide Zn oxide/ethyl	Baked 1 hr. at 250°F. 2750.	1 coat, 1 mil thick	51.8	Zn dust 22 Iron oxide Zn oxide XX50	39.8	Glycid 2456 sol. Mineral spirits	86 14 100	Add all the Zn dust 22 to the vehicle mixture prior to use. Vehicle by volume: 55 per cent N.V.M. by wt.: 17.5 per cent V.M. (Min. 4 Ford cup): 1 min. 57 sec.
M	Iron oxide, Zn chromate, Zn oxide/ethyl	Baked 1 hr. at 250°F. 2750.	1 coat, 1 mil thick	44	Iron oxide Zn chromate Zn oxide XX50	56	Glycid 2456 sol. Mineral spirits	88 12 100	Vehicle by volume: 55.7 per cent V.M. (Min. 4 Ford cup): 1 min. 25 sec.
N	Iron oxide, Zn oxide/ethyl	Baked 1 hr. at 250°F. 2750.	1 coat, 1 mil thick	47	Iron oxide Zn oxide XX50	53	Glycid 2456 sol. Mineral spirits	86 14 100	N.V.M. by wt.: 70.9 per cent V.M. (Min. 4 Ford cup): 1 min. 11 sec. Vehicle by vol.: 56.6 per cent
O	Zn chromate/vinyl wash primer/red lead/vinyl	Air dry	2 coats, one coat wash primer and one coat of anticorrosive primer each 1/2 mil thick	Wash Primer (WP-1) 8 Y-36 I-D DuPont pigment (Zn chromate) Adhesives	86.3 13.7 100	92 Vinylac polyvinyl butyral KYNE 99 per cent Isopropyl Methyl isobutyl ketone Diluent to be added before using 83 per cent phosphoric acid Wash 99 per cent Isopropyl	7.8 54.8 15.7 1.7 1.7 14.4 100	Add the acid diluent to the wash primer base at 1:4. The mixed primer WP-1 is stable 10-12 hrs. Apply WP-1 at a thickness of 0.3-0.6 mil, air dry and apply 1 coat AP-1-10 sprayed, this AP-1 with methyl isobutyl ketone. Polishes shell 40 hrs. WP-1 N.V.M. by wt.: 17.9 per cent V.M. (Min. 4 Ford cup): 27 sec.	
				Anticorrosive Primer (AP-1) 22.5 Red lead (97 per cent)	100 100 100	77.5 Vinylac resin VAGH Methyl isobutyl ketone Toluene Methyl isobutyl ketone	19.4 5.8 58.1 100	AP-1 N.V.M. by wt.: 43.85 per cent V.M. (Min. 4 Ford cup): 155 sec.	

TABLE 1 (CONTINUED)

Designation	Type of Coating	Type of Coar	Coating System	Parts Per Hundred						Remarks
				Pigments			Vehicles			
				Per Cent	Composition	Per Cent	Per Cent	Composition	Per Cent	
U	Red lead, Zn chromate, Zn oxide/alkyd	Air dry	1 coat, 1 mil thick	49.2	Red lead Zn chromate Zn oxide Mg silicate	55 20 3 20 100	56.8	Alkyd, 56.7 per cent solids (Lanoxol oil)	100	Acid No. 4.5 glyceryl phthalate 44 per cent. N.V.M. by wt.: 72.5 per cent. Visc. (No. 4 Ford cup): 75 sec.
V	Zn chromate, iron oxide/alkyd	Air dry	1 coat, 1 mil thick	44.5	Zn chromate iron oxide Mg silicate	40 40 20 100	55.5	Alkyd, 45.6 per cent solids	100	Acid No. 4.5 glyceryl phthalate 44 per cent
W	Zn chromate, iron oxide/alkyd	Air dry	1 coat, 1 mil thick	47.5	Zn chromate iron oxide Mg silicate	60 20 20 100	52.7	Alkyd, 42.9 per cent solids (Lanoxol oil)	100	Acid No. 4.5 glyceryl phthalate 44 per cent
X	Zn dust, Zn oxide/alkyd	Air dry	1 coat, 1 mil thick	61.8	Zn dust Zn oxide	80 20 100	56.2	Alkyd, 54.2 per cent solids (Lanoxol oil)	100	Acid No. 4.8 glyceryl phthalate 19 per cent Acid No. 4.8 glyceryl phthalate 58 per cent
Z	Zn dust, Zn oxide, lanoxol, phthalate	Air dry	1 coat, 1 mil thick	71.5	Zn dust Zn oxide	80 20 100	26.5	75 gal. lanoxol oil Phthalic anhydride 44.5 per cent solids	100	Conforms to U.S. Army Corps of Engineers spec. T-1115a, type I, April 27, 1943. Acid No. 20-60 glyceryl phthalate 6 per cent. N.V.M. by wt.: 66.5 per cent. Visc. (No. 4 Ford cup): 91 sec.

TABLE 1 (CONTINUED)

Designation	Type of Coating	Type of Cure	Coating Thickness	Parts Formula						Remarks
				Pigments			Vehicles			
				Per Cent	Composition	Per Cent	Per Cent	Composition	Per Cent	
BB	Red lead, iron oxide/phenolic	Air dry	1 coat, 1 mil thick	99.2	Red lead (97 per cent) iron oxide Aluminum stearate	75 24.7 0.3	60.8	Thinner and drier Phenolic varnish, 75 gal., proprietary amyl phenol formaldehyde resin chlorinated oil varnish 60 per cent solids	39.6 66.4 100	Wt./gal. 15.5 lbs. PV 36.3 Add petroleum XYLOL to paint on basis of 1.5 parts to 100 parts of paint.
BC	Red lead, iron oxide/phenolic varnish	Air dry	1 coat, 1 mil thick	92.0	Red lead (97 per cent) iron oxide Aluminum stearate	75.6 24.1 0.3	56.0	Thinner and drier Phenolic varnish, 75 gal., para-allyl phenol formaldehyde resin, dehydrated castor oil Varnish 59 per cent solids	27.0 73.0 100	Wt./gal. 16.2 lbs. PV 34.7
BD	Red lead, Zn oxide Zn yellow, iron oxide/castor oil allyd	Air dry	1 coat, 1 mil thick	91.6	Red lead (97 per cent) Zn oxide Zn yellow iron oxide Graphite mix	55 10 10 7 18	66.4	Thinner and drier Castor oil allyd, 45 per cent glycerol phthalate 65 per cent solids	31.0 60.0 100	Wt./gal. 13.2 lbs. PV 33.0
BE	Red lead, silicate/phenolic varnish	Air dry	1 coat, 1 mil thick	63.9	Red lead (97 per cent) Dioctyltin oxide Magnesium silicate Aluminum stearate	65.0 8.0 6.6 0.4	54.1	Thinner and drier Phenolic varnish, 75 gal., proprietary amyl phenol formaldehyde resin chlorinated oil varnish 60 per cent solids	25.0 74.2 100	Wt./gal. 17.0 lbs. PV 41.7 Prepared-to-apply type, TT-P-84a Type IV

After adjustment of the viscosity of the coating material in question, the panels were lowered into the paint and removed by means of a Fisher-Payne dip coater at a withdrawal rate of one inch per minute. The painted panels were then either dried in a constant-temperature and constant-humidity room (78 F and 50 per cent relative humidity) for at least three weeks before being subject to test or baked, as in the case of L, M, N, and O. During actual dipping, the viscosity of each paint was rechecked, after coating five test panels, and readjusted if necessary. Each panel was weighed prior to coating and reweighed after drying, in order to determine the weight of film applied to the test panel.

The above-described dipping procedure was utilized in preparing panels of all paint systems, with the exception of H_a, H_b, and H_c. In these cases, it was necessary to apply the paint by spraying in order to obtain film thicknesses of 5, 10, and 15 mils.

Panels Prepared and Film Thicknesses

To insure an adequate supply for test purposes and to provide a sufficient number from which the most uniform, with respect to film thickness, could be selected, 30 to 60 panels were prepared for each system listed in Table 1.

The actual thickness of the dried paint film (either air dried for 3 weeks or baked) on each panel was measured by means of a General Electric Type "A" thickness gage. Measurements of film thickness were made at six different locations on each side of each coated panel. Film-thickness range and average film-thickness data, together with the weight of the dried film for individual panels, are included with the corrosion test data described later.

Test Procedures and Results

The tests were conducted on triplicate panels for each coating system, two panels in the as-painted condition and one intentionally damaged before exposure. Damaging of the paint film was accomplished as follows: The panel was placed on a machine shop surface grinder and a scratch ground lengthwise through the paint film to the base metal. The width of the

scratch for each panel was maintained at 1/16 inch, and the depth was controlled so as to expose the base metal with the least possible loss of metal. Prior to exposure, the edges of each test panel were afforded additional protection by masking.

Several criteria were used to rate the coating systems for each test condition; (1) the time to the appearance of the first blister, (2) blister size and per cent of area covered, (3) appearance of base metal after removal of paint film, (4) weight loss of metal, and (5) degree of undercutting (under film attack) of paint film and penetration into base metal or damaged zone. It was convenient to record the most typical blister size by reference to the ASTM photographic standards (ASTM Designation D714-45, B.S. II, page 1171, 1946). For blister size designations used, a No. 10 indicates no blistering, a No. 8 small blisters (pin point), a No. 6 somewhat larger, and so on to No. 0, which indicates the presence of very large blisters. In many cases a coating system may contain an assortment of blister sizes, which fact is indicated in the tabulated data.

For most of the paint systems, the panel, after testing, was stripped of paint in a ten per cent KOH solution at 100 F and the underlying rust (if any) was removed by cathodic treatment in a ten per cent sodium cyanide solution at room temperature.

Continuous Partial Immersion Tests in Distilled Water

In the continuous immersion tests, panels were held vertically in a Lucite block containing suitable grooves. The assembly of panels and Lucite block was placed at the bottom of a 9-liter Pyrex glass battery jar and distilled water was added until the panels were 50 per cent immersed. Constant-temperature water baths were used to maintain the battery jars at 100 F. Under the conditions of the test, the upper portion of the panel was exposed to moist air at essentially 100 per cent relative humidity, whereas the lower half is in continuous contact with distilled water at 100 F. Evaporation losses were regularly made up with distilled water. Each formulation was tested in a separate vessel and, as previously stated, in triplicate. The coating on one panel was damaged and on the other two undamaged.

TABLE 2
Coating and Blister Data for Painted Panels Exposed
to Partial Immersion in Distilled Water at 100°F
for 3000 Hours

Designation	Panel No.	Number of Coats	Film Thickness Range—Mils	Avg Film Thickness—Mils	Film Weight—Gms	Time to Form Blister—Hours	Blister Rating—Water Phase*									
							100 Hrs.		500 Hrs.		1000 Hrs.		2000 Hrs.		3000 Hrs.	
							Blister Rating	Per-Cent Area Blistered	Blister Rating	Per-Cent Area Blistered	Blister Rating	Per-Cent Area Blistered	Blister Rating	Per-Cent Area Blistered	Blister Rating	Per-Cent Area Blistered
A	62-35*	1	1.11-1.19	1.16	3.65	619	10	0	10	0	4.6	20	2-3	75	0	100
	65-45	1	1.17-1.21	1.20	3.52	691	10	0	10	0	4.6	20	2-3	75	0	100
	62-39	1	1.15-1.19	1.18	3.62	691	10	0	10	0	4.6	20	2-3	75	0	100
B	70-5*	1	1.19-1.30	1.26	2.52	46-91	0-9	75	2-7	75	2.6	75	2-3	75	0	100
	70-6	1	1.15-1.00	1.29	2.52	46-91	0-9	75	2-7	75	2.6	75	2-3	75	0	100
	70-10	1	1.15-1.53	1.30	2.50	46-91	0-9	75	2-7	75	2.6	75	2-3	75	0	100
C	87-36*	1	1.20-1.35	1.25	4.22	1700	10	0	10	0	10	0	0-9	1	0-9	1
	87-38	1	1.20-1.30	1.25	4.17	1700	10	0	10	0	10	0	0-9	1	0-9	1
	87-33	1	1.15-1.35	1.25	4.17	1700	10	0	10	0	10	0	0-9	1	0-9	1
D	66-39*	1	1.17-1.39	1.22	3.57	451	10	0	9	5	7.9	10	0-9	75	4.6	100
	66-31	1	1.19-1.39	1.27	3.54	451	10	0	9	5	7.9	10	0-9	75	4.6	100
	66-38	1	1.21-1.39	1.29	3.51	46-91	0	1	6-8	5	6.8	25	0-6	75	4.6	100
E	81-15*	1	1.21-1.36	1.27	3.10	759	10	0	9	10	0-9	25	0-6	50	0-6	75
	81-22	1	1.26-1.42	1.33	3.25	759	10	0	0	25	7.9	25	0-6	50	0-6	75
	81-21	1	1.20-1.42	1.36	3.20	759	10	0	0	25	0-9	25	0-6	50	0-6	75
F	70-21*	1	0.15-1.31	1.23	2.10	91	0	20	3-4	50	2-3	50	1	75	1	100
	70-31	1	1.10-1.51	1.26	2.15	91	0-9	50	3-4	50	2-3	50	1	75	1	100
	70-23	1	1.10-1.20	1.23	2.14	91	0	50	3-4	50	2-3	50	1	75	1	100
F	70-39*	2	2.75-2.95	2.85	4.99	100	0-9	20	3-4	50	3-4	50	2-3	75	1	100
	70-41	2	2.70-2.95	2.80	4.90	91	0-10	20	3-4	50	3-4	50	2-3	75	1	100
	70-35	2	2.70-2.80	2.75	4.99	115	10	0	3-4	50	3-4	50	2	75	1	100
F	80-30*	1	2.65-3.50	2.82	2.60	91	0-9	20	3-4	50	2-3	50	2-3	75	1	100
	80-44	1	2.85-3.00	2.88	2.59	91	0	20	3	50	1	50	2	75	1	100
	80-40	1	2.75-2.85	2.80	2.45	100	0-9	20	3-4	50	2-3	50	2-3	75	1	100
G	84-26*	1	1.20-1.40	1.35	2.80	91	0	20	4.6	20	4.7	50	4.6	100	2.4	100
	84-31	1	1.20-1.30	1.35	2.86	91	0	20	4.6	20	4.7	50	4.6	100	2.4	100
	84-28	1	1.51-1.39	1.35	2.79	91	0	20	4.6	20	4.7	50	4.6	100	2.4	100

TABLE 2 (CONTINUED)

Drug	Prod No	Number Of Cases	Pain Threshold Range—Mds	Avg Pain Threshold—Mds	Pain Wt — Grams	Time To First Sleep—Hours	Shunt Range—Wet Pump*									
							100 Mm.		500 Mm.		1000 Mm.		2000 Mm.		5000 Mm.	
							Shunt Per Case	Shunt Per Case	Shunt Per Case	Shunt Per Case	Shunt Per Case	Shunt Per Case	Shunt Per Case	Shunt Per Case	Shunt Per Case	Shunt Per Case
N	90-1*	1	1.09-1.19	1.13	1.07	1000	10	0	10	0	9-10	1	9	1	9	1
	90-10	1	1.09-1.15	1.13	1.09	—	10	0	10	0	9-10	1	9	1	9	1
	90-9	1	1.07-1.15	1.10	1.02	—	10	0	10	0	9-10	1	9	1	9	1
	91-21*	1	6.00-6.90	6.40	5.54	—	10	0	10	0	10	0	10	0	10	0
N	91-15	1	5.00-6.20	5.50	4.71	—	10	0	10	0	10	0	10	0	10	0
	91-15	1	5.10-6.20	5.50	4.74	—	10	0	10	0	10	0	10	0	10	0
	92-12*	1	9.50-11.50	10.50	8.77	—	10	0	10	0	10	0	10	0	10	0
	92-11	1	9.00-11.50	9.80	8.17	—	10	0	10	0	10	0	10	0	10	0
N	92-4	1	9.80-11.50	10.50	8.91	—	10	0	10	0	10	0	10	0	10	0
	93-13*	1	14.50-17.00	15.50	13.59	—	10	0	10	0	10	0	10	0	10	0
	93-13	1	15.00-17.00	16.10	13.57	—	10	0	10	0	10	0	10	0	10	0
	93-14	1	14.00-17.00	15.10	13.20	—	10	0	10	0	10	0	10	0	10	0
I	88-11*	1	1.19-1.29	1.24	2.15	91	8	5	6-8	5	6-8	10	4-6	50	2	73
	88-14	1	1.19-1.29	1.23	2.15	91	8	5	6-8	5	6-8	10	4-6	50	2	73
	88-10	1	1.19-1.20	1.24	2.11	91	8	5	6-8	5	6-8	10	4-6	50	2	73
	2182*	1	1.15-1.25	1.20	2.94	100	9	1	8	5	7	10	6	50	4	73
L	2256	1	1.20-1.30	1.25	1.05	100	9	1	8	5	7	10	6	50	4	73
	2178	1	1.20-1.35	1.30	2.90	100	9	1	8	5	7	10	6	50	4	73
	2240*	1	0.95-1.15	1.05	2.05	44	8	5	7	10	5	25	3	50	3	73
	2150	1	1.20-1.30	1.25	2.15	527	10	0	7	10	5	25	3	50	3	73
M	2265	1	1.25-1.40	1.35	2.41	44	8	5	7	10	5	25	3	50	3	73
	2170*	1	1.20-1.30	1.25	2.50	44	7	25	7	25	5	50	3	73	2	73
	2174	1	1.20-1.30	1.25	2.64	44	7	25	7	25	5	50	3	73	2	73
	2092	1	1.20-1.30	1.25	2.65	44	7	25	7	25	5	50	3	73	2	73
O	5540*	2	1.00-1.10	1.05	1.95	100	9	1	7	5	7	5	6	6	6	6
	5541	2	1.00-1.05	1.02	1.91	100	9	1	7	5	7	5	6	6	6	6
	5542	2	1.00-1.05	1.05	1.95	100	9	1	7	5	7	5	6	6	6	6
	2019*	2	1.20-1.40	1.35	1.49	100	8	5	7	10	5	25	4	25	4	25
Q	2034	2	1.20-1.40	1.30	1.40	100	8	5	7	10	5	25	4	25	4	25
	2022	2	1.20-1.40	1.35	1.51	100	8	5	7	10	5	25	4	25	4	25

TABLE 2 (CONTINUED)

Design Area	Panel No.	Member Of Group	Pin Thickness Range—Inch	Avg. Pin Thickness— Inch	Pin Sp.— Inch	Time To Fus. Bolt— Hours	Bolt Range—Wear Factor*									
							100 Min.		500 Min.		1000 Min.		2000 Min.		5000 Min.	
							Shear Inch	Per-Cent Area Stress	Shear Inch	Per-Cent Area Stress	Shear Inch	Per-Cent Area Stress	Shear Inch	Per-Cent Area Stress	Shear Inch	Per-Cent Area Stress
A	2236*	1	1.05-1.25	1.20	1.81	430	10	0	8	1	8	5	7	10	5	25
	2151	1	1.10-1.20	1.15	1.74	430	10	0	8	1	8	5	7	10	5	25
	2220	1	1.20-1.40	1.30	1.90	430	10	0	8	1	8	5	7	10	5	25
B	2207*	1	1.15-1.45	1.30	1.14	16	7	25	5	50	75	75	75	75	75	75
	2210	1	1.20-1.40	1.30	1.23	16	7	25	5	50	75	75	75	75	75	75
	2084	1	1.20-1.40	1.30	1.15	16	7	25	5	50	75	75	75	75	75	75
T	2064*	1	1.00-1.20	1.15	2.05	16	7	25	5	50	75	75	75	75	75	75
	2065	1	1.00-1.10	1.05	2.00	16	7	25	5	50	75	75	75	75	75	75
	2067	1	0.95-1.20	1.05	2.04	16	7	25	5	50	75	75	75	75	75	75
U	5528*	1	1.10-1.25	1.15	2.44	16	5	50	5	75	75	75	75	75	75	75
	5545	1	1.10-1.20	1.15	2.65	16	5	50	5	75	75	75	75	75	75	75
	5529	1	1.15-1.35	1.25	2.60	16	5	50	5	75	75	75	75	75	75	75
V	5276*	1	1.10-1.20	1.14	1.91	46	7	25	6	50	75	75	75	75	75	75
	5277	1	1.05-1.10	1.08	1.76	46	7	25	6	50	75	75	75	75	75	75
	5297	1	1.09-1.12	1.10	1.77	46	7	25	6	50	75	75	75	75	75	75
W	5218*	1	1.08-1.15	1.10	1.80	46	7	5	4	10	25	25	25	25	25	25
	5219	1	1.08-1.10	1.10	1.90	46	7	5	4	10	25	25	25	25	25	25
	5205	1	1.10-1.15	1.12	1.85	46	7	5	4	10	25	25	25	25	25	25
X	5230*	1	1.05-1.20	1.10	2.00	982	10	0	10	0	0	0	0	0	0	0
	5252	1	1.00-1.20	1.12	2.87	982	10	0	10	0	0	0	0	0	0	0
	5251	1	1.05-1.25	1.14	2.89	982	10	0	10	0	0	0	0	0	0	0
Z	2285*	1	1.50-1.65	1.60	4.32	166	10	0	7	25	66	66	66	66	66	66
	2552	1	1.15-1.30	1.20	5.46	166	10	0	7	25	66	66	66	66	66	66
	2550	1	1.20-1.40	1.37	3.65	166	10	0	7	25	66	66	66	66	66	66
BB	5012*	1	1.10-1.20	1.14	2.60	144	10	0	6	5	44	44	44	44	44	44
	5464	1	1.10-1.20	1.14	2.72	144	10	0	6	5	44	44	44	44	44	44
	5799	1	1.10-1.20	1.16	2.72	144	10	0	6	5	44	44	44	44	44	44
CC	5212*	1	1.00-1.02	1.00	2.57	11	10	0	10	0	10	0	10	0	10	0
	5211	1	1.00-1.02	1.00	2.50	11	10	0	10	0	10	0	10	0	10	0
	5220	1	1.00-1.02	1.00	2.50	11	10	0	10	0	10	0	10	0	10	0

TABLE 2 (CONTINUED)

Storage Ratings—Wet Phase**																										
ID	Part No.	Number of Cells	Pin Threshold Range-MHz	Avg Pin Threshold-MHz	Pin Wt - Grams	Time To Full Discharge-Min	100 Min.				500 Min.				1000 Min.				3000 Min.				10000 Min.			
							Storage	Perf	Comp	Assn	Storage	Perf	Comp	Assn	Storage	Perf	Comp	Assn	Storage	Perf	Comp	Assn	Storage	Perf	Comp	Assn
B	5559*	1	1.05-1.10	1.08	2.16	46	6	25	3	50	3	50	3	50	3	50	3	50	3	50	3	50				
	5574	1	1.00-1.10	1.08	2.19	46	6	25	3	50	3	50	3	50	3	50	3	50	3	50	3	50				
	5556	1	1.05-1.10	1.08	2.19	46	6	25	3	50	3	50	3	50	3	50	3	50	3	50	3	50				
	5578*	1	1.10-1.25	1.16	2.81	144	10	0	7	3	6	23	3	6	23	3	6	23	3	6	23	3				
F	5576	1	1.10-1.25	1.16	2.80	144	10	0	7	3	6	23	3	6	23	3	6	23	3	6	23	3				
	5577	1	1.10-1.20	1.16	2.80	144	10	0	7	3	6	23	3	6	23	3	6	23	3	6	23	3				
	15*	1	0.95-1.20	1.08	1.27	16	6	75	2	80	1	100	0	1	100	0	1	100	0	1	100	0				
	16	1	0.90-1.20	1.08	1.20	16	6	75	2	80	1	100	0	1	100	0	1	100	0	1	100	0				
C	23	1	1.00-1.50	1.20	1.30	16	6	75	2	80	1	100	0	1	100	0	1	100	0	1	100	0				
	75-20*	1	1.00-1.50	1.20	2.94	600	10	0	10	0	7	7	7	7	7	7	7	7	7	7	7	7				
	76-21	1	1.02-1.50	1.10	2.91	600	10	0	10	0	7	7	7	7	7	7	7	7	7	7	7	7				
	76-22	1	1.01-1.50	1.10	2.96	600	10	0	10	0	7	7	7	7	7	7	7	7	7	7	7	7				
E	82-31*	1	1.27-1.40	1.37	3.45	260	10	0	9	3	7	23	6	30	4	75	4	75	4	75	4	75				
	81-4	1	1.28-1.45	1.40	3.44	260	10	0	9	3	7	23	6	30	4	75	4	75	4	75	4	75				
	81-34	1	1.21-1.52	1.40	3.32	260	10	0	9	3	7	23	6	30	4	75	4	75	4	75	4	75				
	85-10*	1	1.27-1.36	1.31	2.80	16	6	30	2	75	2	75	2	75	2	75	2	75	2	75	2	75				
O	85-7	1	1.28-1.36	1.33	2.97	16	6	30	2	75	2	75	2	75	2	75	2	75	2	75	2	75				
	85-14	1	1.34-1.44	1.39	3.02	16	6	30	2	75	2	75	2	75	2	75	2	75	2	75	2	75				
	6*-45*	1	1.21-1.34	1.26	3.39	300	10	0	9	1	0	0	0	0	0	0	0	0	0	0	0	0				
	6*-40	1	1.10-1.30	1.23	3.26	300	10	0	9	1	0	0	0	0	0	0	0	0	0	0	0	0				
I	66-56	1	1.30-1.61	1.40	4.02	100	9	1	9	1	0	0	0	0	0	0	0	0	0	0	0	0				
	86-77*	1	1.15-1.30	1.22	2.16	44	7	3	6	10	3	6	10	3	6	10	3	6	10	3	6	10				
	86-26	1	1.15-1.25	1.24	2.13	44	7	3	6	10	3	6	10	3	6	10	3	6	10	3	6	10				
	86-30	1	1.19-1.50	1.25	2.16	44	7	3	6	10	3	6	10	3	6	10	3	6	10	3	6	10				
Q	5250*	2	1.00-1.40	1.00	1.04	—	10	0	10	0	10	0	10	0	10	0	10	0	10	0	10	0				
	5271	2	1.05-1.15	1.00	1.00	—	10	0	10	0	10	0	10	0	10	0	10	0	10	0	10	0				
	5280	2	1.00-1.20	1.00	2.05	—	10	0	10	0	10	0	10	0	10	0	10	0	10	0	10	0				

- * Storage tests during cell.
 * Only one pass was attempted.
 * Storage could be used as pass even in the presence of pass margin.
 * No storage tests were attempted after 1000 min. Storage could be used as pass even in the presence of pass margin.
 * Intermittently damaged battery testing.
 * See AL7736, Item 10, page 11, 1964 Handbook, page 1171. Storage tests are represented by numbers within the code 0 to 99, in which 0 represents the presence of very large storage and 99 represents no storage under the test conditions.

Table 2 contains coating and blister data for 34 paint systems tested under these conditions. Systems A through I were tested over a different calendar period than the others and Systems D, G, E, and I were tested during both exposure periods for control and comparison purposes. Time to first blister is recorded together with degree, size, and extent of blistering for the indicated exposure times up to 3000 hours.

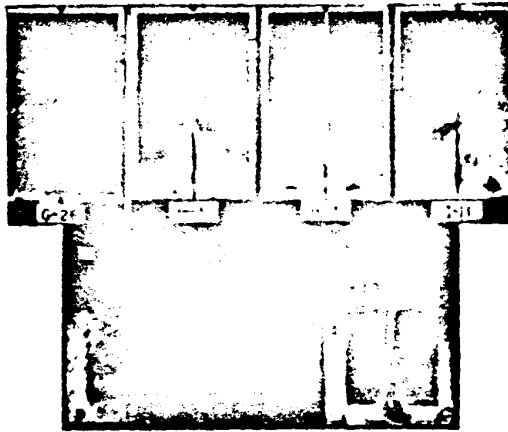
Photographs of the painted panels (damaged), after 3000 hours exposure for essentially all of the paint systems, are shown in Figs. 1, 2, 3, and 4. Systems H₁ (5 mils) and H₂ (10 mils) are not shown, since they had the same appearance as H₃ (15 mils) and O₁ was not tested in the damaged condition.

It can be seen from the photographs that the severest damage to the film has taken place at and below the water line



52144, 52142

Fig. 1—Condition of coated panels after exposure to continuous partial immersion in distilled water at 100°F for 3000 hours



60436, 60438

Fig. 2—Condition of metal parts after exposure to continuous partial immersion in distilled water at 100°F for 3000 hours



60440, 60436

Fig. 3—Condition of metal parts after exposure to continuous partial immersion in distilled water at 100°F for 3000 hours

and, at least in some cases, adjacent to the scratch line. The upper half of each specimen was in contact with air at practically 100 per cent relative humidity. Essentially no blistering was observed on these upper surfaces. At and below the water line, blisters developed in many of the coating systems which were quite large in size and formed at a rather early stage. Consideration of the data contained in Table 2 and the appearance of the panels (water phase), as shown in the figures, indicates that only Systems C and C₂ (red lead); H₁, H₂, H₃, and H₄ (asphalt type); O (Zn chromate-red lead); and possibly BC (red lead-iron oxide-phenolic) and O₂ (same as O except baked) either did not blister or showed blisters that were relatively few and small in size. The 3000-hour blister rating for Systems D, E, I, and G over both calendar periods were in fair agreement, with the exception of D. Since the panels (coated with D, E, I, and G) tested over both periods were coated at the same time, the only known difference was in the length of air drying. Those tested with Systems A through I had a 3-week



60435, 60436

Fig. 4—Condition of coated panels after exposure to continuous partial immersion in distilled water at 100°F for 3000 hours

drying period, while those tested with the other systems had been prepared about six months before testing. This might significantly affect the protection afforded the base metal by these particular systems, but comparison can still be made of those systems tested over the same calendar period.

The penetration of water through the immersed portion of the paint film by endosmosis gives rise to the blisters and to possible attack on the steel base metal. In the case of a damaged panel, the driving force of the water is increased by the fact that electric currents tend to flow between the exposed metal (anodic) and the steel areas protected by the moistened paint coating. It is not surprising, therefore, that panels with scratch lines, exposed edges, or other damage usually suffer more severe attack than similar panels completely covered by the paint film.

To determine the amount of protection afforded the steel by the various coatings, the above group of panels were stripped of their paint film by a suitable solvent, any rust removed by the sodium cyanide cathodic treatment, and examined.

Table 3 contains the weight loss of the base metal and a description of its condition after stripping the paint from the panels. Arbitrary rating values were assigned to describe the appearance of the base metal on the undamaged panels in both the water and air phase, and for the condition of the damaged zone (damaged panels) in the water phase, with respect to both degree of undercutting and penetration. The values of these ratings are described in a footnote to the table. Blister ratings after 3000 hours exposure are included for comparison purposes.

Considering the weight loss of base metal, the data for the systems tested indicate that Systems C, H₁, H₂, H₃, I, and possibly D afforded the greatest amount of protection, while Systems B, B₁, E, F₁, F₂, and G afforded the least. The others were of intermediate classification. In general, for these systems the panels (undamaged) having the greatest weight loss showed the severest blistering, and for those with little metal loss the least blistering. As can be noted from the data contained in the table, the duplicate tests on Systems D, E, G, and I were not, in every case, in good agreement. However, certain trends can be noted by comparison of those systems tested over the same calendar period.

TABLE 3
Weight Loss and Condition of Base Metal After Stripping
Painted Panels Exposed to Partial Immersion in Distilled
Water at 100F for 3000 Hrs. Blister Rating
Also Included

Designation	Panel No.	Metal Loss—Gross		Appearance of Base Metal**		Condition at Damaged Edge		Blister Rating—1000 Hrs.	
		Individual	Average	Undamaged Panel		Water Phase		Blister Test	Per Cent Area Retained
				Water Phase	Air Phase	Degree of Underpinning***	Degree of Pitting****		
A	63-15*	0.30		C	A	D	D	0	100
	65-43	0.30	0.30	B	A			0	100
	63-59	0.30		B	A	A	D	0	100
B	70-9*	0.51		D	A			0	100
	70-6	0.51	0.57	D	A	A	B	0	100
	70-10	0.51		D	A			0	100
C	67-16*	0.65		A	A			0-5	1
	67-10	0.65	0.67	A	A			0-5	1
	67-13	0.68		A	A	A	D	0-5	100
D	66-29*	0.30		C	A			0-5	100
	66-31	0.30	0.19	C	A	A	D	0-5	100
	66-28	0.19		C	A	A	D	0-5	100
E	61-13*	0.31		C	A			0-5	75
	61-22	0.31	0.32	C	A			0-5	75
	61-21	0.33		C	A	D	D	0-5	100
F	75-31*	0.32		C	A			0-5	100
	75-31	0.32	0.32	C	A	B	D	0-5	100
	75-25	0.33		C	A			0-5	100
G	76-19*	0.33		C	A			0-5	100
	76-41	0.33	0.32	C	A			0-5	100
	76-15	0.34		C	A	D	D	0-5	100
H	80-50*	0.29		C	A			0-5	100
	80-44	0.27	0.30	C	A			0-5	100

TABLE 3 (CONTINUED)

Designation	Pond No.	Mud Loss—Grains		Appearance of Mud Mud**		Condition of Damaged Area		Shore Rating—1000 Mm.	
		Individual	Average	Undamaged Pond		Water Pond		Shore Line	Per Cent Area Damaged
				Water Pond	Air Pond	Degree of Under-lying***	Degree of Prominence****		
G	84-26*			D	A	D	D	2-4	100
	84-31	0.57	0.57	D	A			2-4	100
	84-28	0.50						2-4	100
H	90-5*	0.19		A	B	A	D	9	1
	90-10	0.25	0.22	A	B			9	1
	90-9							9	1
H	91-21*					A	D	10	0
	91-13	0.07		B	B			10	0
	91-15	0.07	0.07	B	B			10	0
	92-12*					A	D	10	0
	92-11	0.05		B	B			10	0
	92-4	0.05	0.04	B	B			10	0
H	93-13*					A	D	10	0
	93-15	0.02		B	B			10	0
	93-14	0.04	0.05	B	B			10	0
I	88-11*					B	D	10	0
	88-14	0.11		A	A			10	0
	88-10	0.11	0.11	A	A			10	0
L	2182*					C	C	4	73
	2236			B	B			4	73
	2178			B	B			4	73
M	2240*					C	C	4	73
	2130			A	A			4	73
	2263			B	A			4	73
M	2170*					C	D	4	73
	2114			B	A			4	73
	2092			B	A			4	73
O	3540*					A	D	4	73
	3541			B	A			4	73
	3542			B	A			4	73
Q	3019*					A	D	4	73
	3034							4	73
	3022			C	A			4	73

TABLE 3 (CONTINUED)

Designation	Panel No.	Mand Loss—Gross		Appearance of Bone Mand**		Condensate or Damaged Bone		Stem Rating—1000 Bar	
		Individual	Average	Undamaged Point		Wear Phase		Stem Bar	Per Cent Area Damaged
				Wear Phase	Air Phase	Depth of Lesion Rating***	Depth of Pitting Rating***		
R	2236*					B	D	3	23
	2151			A	A			3	23
S	2228			A	A			3	23
	2287*					C	C	3	23
T	2218			A	A			3	23
	2064*			C	A	D	C	3	23
U	2065			A	A			3	23
	2067			C	A			3	23
V	3126*					D	C	3	23
	3143			A	A			3	23
W	3129			C	A			3	23
	3176*					A	A-D	3	23
X	3177			A	A			3	23
	3197			B	A			3	23
Y	3118*					A	A-D	3	23
	3219			A	A			3	23
Z	3205			A	A			3	23
	3236*					A	D	3	23
AA	3252			B	A			3	23
	3251			B	A			3	23
BB	2281*					A	D	3	23
	2552			A	A			3	23
CC	3190			B	A			3	23
	3012*					B	D	3	23
DD	3084			B	A			3	23
	3778*			C	A			3	23
EE	3212*					A	C	3	23
	3211			A	A			3	23
FF	3228			A	A			3	23
	3159*					C	C	3	23
GG	3174			A	A			3	23
	3156			A	A			3	23

TABLE 3 (CONTINUED)

Disposition	Panel No.	Mud Loss—Gross		Appearance of Box Head**		Condition of Damaged Box		Box Rating—1000 lbs	
		Undamaged Panel		Wear Phase		Wear Phase		Wear Phase	
		Individual	Average	Wear Phase	Air Phase	Degree of Undercutting***	Degree of Penetration****	Shore Bar	Per Cent Area Blasted
B	5578*			A	A	A	C	6	25
	5576			A	A			6	25
	5577					D	F	6	100
	56-15*			D	A			6	100
	56-16	1.82	1.66	D	A			6	100
	56-23	2.35						6	100
	56-26*			A	A	A	C	7	5
	56-27			A	A			7	5
	56-22			A	A	B	C	4	75
	62-31*			C	A			4	75
G	81-4	0.36	0.34	B	A			4	75
	81-24	0.36		C	A	D	D	6	100
	81-18*			C	A			6	100
	81-7	0.25	0.26	C	A	C	D	6	100
D	81-14	0.31						6	100
	67-45*			A	A			6	5
	67-40	0.66	0.61	B	A			6	5
I	66-56	0.61				D	D	6	5
	66-27			A	A			6	75
	66-26	0.66	0.62	A	A			6	75
Q	69-10	0.66		A	A			6	75
	5259*			A	A	Not Damaged		10	0
	5271							10	0
	5289			A	A			10	0

* Immediately damaged before use

** A: Slightly cracked

B: Cracked

C: Cracked

D: Cracked

E: Cracked

F: Cracked

G: Cracked

H: Cracked

I: Cracked

J: Cracked

K: Cracked

L: Cracked

M: Cracked

N: Cracked

O: Cracked

P: Cracked

Q: Cracked

R: Cracked

S: Cracked

T: Cracked

U: Cracked

V: Cracked

W: Cracked

X: Cracked

Y: Cracked

Z: Cracked

**** A: Slightly cracked

B: Cracked

C: Cracked

D: Cracked

E: Cracked

F: Cracked

G: Cracked

H: Cracked

I: Cracked

J: Cracked

K: Cracked

L: Cracked

M: Cracked

N: Cracked

O: Cracked

P: Cracked

Q: Cracked

R: Cracked

S: Cracked

T: Cracked

U: Cracked

V: Cracked

W: Cracked

X: Cracked

Y: Cracked

Z: Cracked

* 1000 lbs. capacity

* Limited data

* Panel

* Usually over rated

* Marked by stress ground mark

TABLE 4
Rating of the Various Paint Systems Taken From Table 3 (Partial Immersion Tests) and Arranged For Convenient Comparison

	A				B				C				D			
Appearance of Bare Metal in the water phase:	A E H	C W C	H BC O	I NO I	M MT E	N NU D	N OV V	L IX X	D O	E E	Q	BB	B G	F R	P	N
Appearance of Bare Metal in the air phase:	A G O T X NO b Q	B F I O U Z M G	C M E V BB BA D	D F N S W BC C I	M L	M	N	N								
Degree of undercutting at damaged zone in the water phase:	B H W BE	C N O X C	D H O Z	E H V BC	P I	R	BB	S	L NO	M D	N	S	A T I	R U	P R	G O
Degree of penetration at damaged zone in the water phase:					C				L UC	M BC I	S NO 9*	T M	A R N I E E I	B R N V BB	D M OW	B H ON MO

* Value of average A, B, C, and D are shown in Table 1.

** General results are sufficiently shown on the panel to partially reach penetration at damaged zone.

Base Metal Appearance

Table 4 contains the ratings of the paint systems with respect to appearance of base metal (undamaged panels) in both the water and air phase, and the degree of undercutting and penetration at the damaged zone taken from Table 3 and arranged for convenient comparison. Consideration of these data, together with those contained in Tables 2 and 3, suggests certain conclusions:

1. All systems appear to afford excellent protection to that portion of the panel exposed to the air phase (essentially saturated with moisture at 100 F.).
2. A considerable number of coatings afford excellent protection in the water phase if the coatings are continuous and free from damage. Those which seem to have little merit are Systems B, D, Ba, E, F, Fa, Fb, G, and Q.
3. In the case of damaged films exposed to the water phase, a decidedly different story is presented. Only System C (red lead) offered protection to the bare steel in the damaged zone. In fact, for the majority of the other systems, continued exposure would have resulted in actual perforation of the base metal in this area in a relatively short period of time. This seems to be an extremely important point, even though it is realized that the type of damage to which these panels were subjected, may not exactly duplicate that which occurs in service. Several compositions resisted undercutting of the paint film at the scratch line, but did not protect the bare steel.

Red Lead Is Outstanding

4. Considering all factors in rating the various coatings, System C (red lead) appears to be outstanding. It has a good blister rating, it affords excellent protection to the base metal, as evidenced by low weight loss and slight visual evidence of attack on the steel and, as previously mentioned, penetration and undercutting at the damaged zone are either negligible or slight. The same is true of C₀ (same pigment as C but formulated with raw linseed oil), but it appears to have a slightly lower rating in the damaged area, which may not be significant. System O₀, a two-coat system (same as O except baked), shows promise and might be equally as good or even better than C or C₀, although a definite statement cannot be made in the

absence of information on damaged panels. Systems BC, BD, BE, and W offer good protection in all cases except at the damaged zone. This is also true of Systems H₁, H₂, H₃, H₄, and I but to a lesser degree.

5. Applying thicker coatings or increasing the number of coatings of the iron-oxide and asphaltum types has little effect on protectiveness under continuous immersion conditions for either the damaged or undamaged coatings (note the data for Systems H₁, H₂, H₃, H₄, F₁, F₂, and F₃).

6. The baked films, L, M, and N, do not exhibit unusual protectiveness in comparison to the air-dry films and, in many cases, they are not so good.

7. Coating continuity appears to be a very important factor when considering coating performance.

Continuous Condensation Tests

In this type of humidity test, continuous condensation is achieved by securing the painted panels to coolers made from copper plate, through which water is circulated to control the sample temperature at 100 F. The coolers are contained in a humidity cabinet which is maintained at 110 F and 100 per cent relative humidity. The coolers are triangular in cross section and each panel is exposed at a 75-degree angle with the horizontal. Under these conditions, moisture condenses on the painted panels with continuous run off.

Most of the same coating systems which were evaluated under continuous, partial immersion conditions were subjected to continuous condensation tests. Table 3 contains the coating and blister data for the 26 paint coatings tested. As in the case of the partial immersion tests, since Systems A through I were tested over one calendar period and the others over a different one, Systems D, G, E, and I were tested during both periods. Consequently, two sets of data are included for these coatings. Time to first blister is recorded, together with the blister rating for the indicated exposure times. Systems C, G, H₁, H₂, H₃, H₄, R, and Z developed essentially no blistering during the 3000-hour exposure period. Systems D, E, I, L, M, O, and Q showed some blistering but not to any great extent. Blisters of considerable size, which covered almost the entire area of the test panel, formed on Systems A, B, B₁, E, F₁, F₂, F₃, G, N, S, T, and U. The blisters formed on these coatings

after a short exposure period. It can also be noted that the blister ratings of Systems D, E, G, and I for the duplicate tests were not in good agreement. As previously mentioned for the partial immersion tests, the only known difference is the length of air drying.

Data Tabulated

The panels were stripped, cleaned, and examined at the conclusion of the test. Table 6 contains the weight loss of the steel, a description of the condition of the base metal after stripping, and the blister ratings (at 3000 hours) of the test panels. Rating methods and values are the same as those used in the continuous, partial immersion tests. For those panels for which weight loss is available, the data indicate that coating systems C, H₁, and I afford excellent protection under these test conditions and are followed very closely by A, D, H₂, and H₃. Systems B, B₁, E, F₁, F₂, G, and H are the least protective. With the exception of System G, the duplicate tests on D, E, I, and G seem to yield the same test results.

Table 7 contains the ratings of the various paint systems with respect to appearance of base metal (undamaged panels) after stripping and degree of undercutting and penetration at the damaged zone.

The results indicate that many of the coating systems protect the steel satisfactorily under conditions of continuous condensation. This is true for both the panels containing a continuous film (undamaged) and those intentionally damaged. Systems C, C₁, and I seem to be the most outstanding, while B seems to be the least. The others show an intermediate behavior. It should be borne in mind, in evaluating the protectiveness of the coatings to these test conditions, that no severe attack was noted in any case. However, considering all factors, C, C₁, and I appear to afford the greatest degree of protection.

Alternate Wet-Dry Tests

Selected paint coatings were tested by cyclic immersion in distilled water. A cycle of ten minutes complete immersion, followed by ten minutes emersion in air, was used in the tests. Losses due to evaporation from the water were made up daily.

The coating systems were tested for 7300 hours (approximately 304 days or 10 months). It became apparent after

TABLE 9

Coating and Blister Data for Painted Panels Exposed to Continuous
Condensation Conditions at 100°F for 3000 Hrs.

Designation	Panel No.	Number of Coats	Film Thickness Range—Mils	Avg. Film Thickness—Mils	Film Wt.—Gms./sq. ft.	Time to First Blister—Hours	Blister Rating**							
							100 Hrs.		500 Hrs.		1000 Hrs.		2000 Hrs.	
							Blister Size	Per Coat Area Blistered	Blister Size	Per Coat Area Blistered	Blister Size	Per Coat Area Blistered	Blister Size	Per Coat Area Blistered
A	62-12*	1	1.11-1.21	1.16	3.49	645	10	0	10	0	10	0	0	50
	62-14	1	1.11-1.21	1.16	3.61	1175	10	0	10	0	10	0	0	50
	62-31	1	1.11-1.21	1.16	3.57	1175	10	0	10	0	10	0	0	50
B	76-9*	1	1.21-1.40	1.27	2.27	95	0	30	6-6	50	6-6	75	6	75
	76-12	1	1.16-1.99	1.28	2.28	95	0	30	6-6	50	6-6	75	6	75
	76-15	1	1.19-1.35	1.26	2.30	95	0	30	6-6	50	6-6	75	6	75
C	87-11*	1	1.15-1.56	1.34	4.15	1175	10	0	10	0	10	0	9	1
	87-28	1	1.22-1.15	1.25	4.82	1175	10	0	10	0	10	0	9-10	1
	87-29	1	1.19-1.99	1.25	4.88	1175	10	0	10	0	10	0	9-10	1
D	66-10*	1	1.20-1.80	1.25	1.56	915	10	0	10	0	9	5	9	5
	66-26	1	1.15-1.55	1.25	1.45	645	10	0	10	0	9	5	9	5
	67-41	1	1.17-1.50	1.22	5.35	915	10	0	10	0	9	5	9	5
E	81-19*	1	1.22-1.55	1.28	5.29	1175	10	0	10	0	10	0	7	75
	81-17	1	1.24-1.99	1.41	5.25	1175	10	0	10	0	10	0	7	75
	81-16	1	1.21-1.44	1.30	5.21	1175	10	0	10	0	10	0	7	75
F	78-18*	1	1.11-1.20	1.21	2.88	60	9	50	5	50	5	50	3-5	50
	78-22	1	1.19-1.28	1.24	2.10	60	8-9	50	5	50	5	50	2-5	50
	78-20	1	1.12-1.28	1.25	2.14	60	9	50	5	50	5	50	3-5	50
G	76-29*	2	2.65-2.75	2.68	6.29	95	10	0	0	25	4-6	50	4-5	50
	75-24	2	2.65-2.80	2.69	4.18	95	0	30	6	50	4-6	50	4-5	50
	75-14	2	2.65-2.80	2.69	4.26	95	10	0	0	25	4-6	50	4-5	50

TABLE 5 (CONTINUED)

Disc mm	Point No.	Number Of Cams	Pin Thickness Range—mm	Avg. Pin Thickness —mm	Pin Wt. —grams	Time To Fire Bombs —hours	Bombs Remaining									
							100 Mm		300 Mm		1000 Mm		2000 Mm		3000 Mm	
							Bombs Left	Per Cent Amm Remaining	Bombs Left	Per Cent Amm Remaining	Bombs Left	Per Cent Amm Remaining	Bombs Left	Per Cent Amm Remaining	Bombs Left	Per Cent Amm Remaining
F	80-61*	1	2.80-3.00	2.89	2.43	95	0	20	6-8	25	3-6	30	2-4	50	2-4	50
	79-66	1	2.82-3.00	2.94	2.71	95	9	10	6-8	25	3-6	30	2-4	50	2-4	50
	80-55	1	2.70-2.85	2.85	2.43	95	9	10	6-8	25	3-6	30	2-4	50	2-4	50
G	81-6*	1	1.28-1.30	1.31	2.86	95	0-9	50	6-8	75	4-6	75	4-6	75	4-6	75
	81-6	1	1.31-1.39	1.34	2.87	95	0	50	6-8	75	4-6	75	4-6	75	4-6	75
	81-25	1	1.31-1.39	1.36	2.87	95	0	50	6-8	75	4-6	75	4-6	75	4-6	75
H	90-5*	1	1.11-1.15	1.20	1.09	1000	10	0	10	0	9	1	9	1	9	1
	90-1	1	1.07-1.10	1.13	1.09	—	10	0	10	0	10	0	10	0	10	0
	90-7	1	1.07-1.15	1.12	1.05	—	10	0	10	0	10	0	10	0	10	0
M	91-14*	1	5.0-5.7	5.4	4.70	—	10	0	10	0	10	0	10	0	10	0
	91-11	1	4.6-5.9	5.7	4.52	—	10	0	10	0	10	0	10	0	10	0
	91-12	1	4.9-6.4	7.3	4.70	—	10	0	10	0	10	0	10	0	10	0
M	92-2*	1	9"-10.7	10.2	8.74	—	10	0	10	0	10	0	10	0	10	0
	92-5	1	10.0-11.0	10.4	8.81	—	10	0	10	0	10	0	10	0	10	0
	92-1	1	9.4-11.0	10.2	8.62	—	10	0	10	0	10	0	10	0	10	0
M	95-5*	1	14.0-17.0	15.6	12.80	—	10	0	10	0	10	0	10	0	10	0
	95-6	1	15.0-16.2	15.4	11.44	—	10	0	10	0	10	0	10	0	10	0
	95-3	1	14.0-17.0	16.2	13.95	—	10	0	10	0	10	0	10	0	10	0
I	10-5*	1	1.15-1.20	1.20	2.00	1000	10	0	10	0	9	3	9	3	9	3
	10-9	1	1.15-1.20	1.22	2.16	1512	10	0	10	0	10	0	9	3	9	3
	10-6	1	1.10-1.20	1.21	2.13	1512	10	0	10	0	10	0	9	3	9	3
L	3160*	1	1.20-1.40	1.35	5.05	500	10	0	10	0	9	1	7	5	7	5
	2120	1	1.25-1.40	1.30	5.05	500	10	0	10	0	9	1	7	5	7	5
	2170	1	1.20-1.35	1.30	5.10	500	10	0	10	0	9	1	7	5	7	5

TABLE 5 (CONTINUED)

ID	Part No.	Number Of Cells	Pin Thickness Range—Mils	Avg. Pin Thickness—Mils	Pin Wt.—Grams	Type Of Pin Mounting	Mount Range*									
							100 Min.		500 Min.		1000 Min.		2000 Min.		5000 Min.	
							Mount Loc.	Per Cent Area Mounted	Mount Loc.	Per Cent Area Mounted	Mount Loc.	Per Cent Area Mounted	Mount Loc.	Per Cent Area Mounted	Mount Loc.	Per Cent Area Mounted
N	2230*	1	1.30-1.35	1.30	2.14	44	0	1	0	1	0	1	0	3	0	3
	2236	1	1.30-1.40	1.35	2.16	44	0	1	0	1	0	1	1	3	0	3
	2240	2	0.95-1.10	1.05	2.05	44	0	1	0	1	0	1	7	3	0	3
N	2125*	0	1.10-1.22	1.20	2.52	44	0	25	0	25	7	50	3	75	4	75
	2115	1	1.20-1.40	1.30	2.64	44	0	25	0	25	7	50	3	75	4	75
	2096	1	1.25-1.40	1.30	2.73	44	0	25	0	25	7	50	3	75	4	75
O	5544*	2	1.00-1.30	1.04	1.91	77	0	1	0	1	0	1	0	3	0	3
	5270	2	1.00-1.25	1.02	1.88	77	0	1	0	1	0	1	0	3	0	3
	5265	2	1.00-1.10	1.05	2.04	77	0	1	0	1	0	1	0	3	0	3
Q	2025*	2	1.05-1.30	1.10	No Data	77	0	1	0	1	7	5	5	5	7	5
	2134	2	1.05-1.30	1.10	-	77	0	1	0	1	0	5	5	5	7	5
	2245	2	1.05-1.30	1.20	-	77	0	1	0	1	0	5	5	5	7	5
R	2221*	1	1.15-1.45	1.30	2.05	11	10	0	10	0	10	0	10	0	10	0
	2210	1	1.00-1.50	1.00	2.23	11	10	0	10	0	10	0	10	0	10	0
	2037	1	1.15-1.45	1.00	2.17	11	10	0	10	0	10	0	10	0	10	0
S	2040*	1	1.40-1.50	1.42	1.90	16	0	25	0	25	6	50	4	50	2	75
	2030	1	1.40-1.60	1.42	1.60	16	0	25	7	50	7	50	4	50	2	75
	2036	1	1.15-1.60	1.45	1.65	16	0	25	7	50	6	50	4	50	2	75
T	2140*	1	1.05-1.30	1.10	2.13	16	5	50	5	50	5	50	3	75	1	90
	2001	1	0.95-1.10	1.05	1.97	16	0	50	5	50	5	50	4	75	1	90
	2080	1	1.00-1.30	1.10	2.12	16	5	50	5	50	5	50	3	75	1	90
U	5555*	1	1.20-1.35	1.25	2.00	16	0	5	7	10	6.7	25	3	50	24	75
	5260	1	1.20-1.40	1.25	2.06	16	0	5	7	10	6.7	25	3	50	24	75
	5554	1	1.10-1.30	1.25	2.00	16	7	5	7	10	6.7	25	3	50	24	75

TABLE 5 (CONTINUED)

Designation	Pond No.	Number Of Cows	Piles Thickness Range—Mils	Avg. Pile Thickness—Mils	Pile Wt—Grams	Time To Pile Blows—Minutes	Blow Range**									
							100 Min.		500 Min.		1000 Min.		2000 Min.		3000 Min.	
							Blows Per	Per Cent Area Blasted	Blows Per	Per Cent Area Blasted	Blows Per	Per Cent Area Blasted	Blows Per	Per Cent Area Blasted	Blows Per	Per Cent Area Blasted
Z	2317*	1	1.50-1.65	1.60	4.59	—	10	0	10	0	10	0	10	0	10	0
	2366	1	1.50-1.60	1.45	3.87	—	10	0	10	0	10	0	10	0	10	0
	2187	1	1.20-1.40	1.34	3.97	—	10	0	10	0	10	0	10	0	10	0
B	17*	1	1.02-1.15	1.08	1.20	16	5	30	5	30	5	30	5	30	5	30
	24	1	1.02-1.50	1.28	1.46	16	5	30	5	30	5	30	5	30	5	30
	25	1	1.00-1.30	1.08	1.23	16	5	30	5	30	5	30	5	30	5	30
C	23*	1	1.00-1.50	1.08	2.06	500	10	0	9	1	9	1	9	1	9	1
	14	1	0.90-1.12	1.00	2.75	500	10	0	9	1	9	1	9	1	9	1
	8	1	1.01-1.55	1.05	2.67	500	10	0	9	1	9	1	9	1	9	1
D	67-45*	1	1.15-1.40	1.25	3.37	—	10	0	10	0	10	0	10	0	10	0
	60-34	1	1.35-1.51	1.44	3.92	—	10	0	10	0	10	0	10	0	10	0
	60-55	1	1.39-1.54	1.43	3.83	1100	10	0	10	0	10	0	9	1	9	1
E	82-30*	1	1.28-1.49	1.37	3.34	1272	10	0	10	0	10	0	9	1	9	1
	81-25	1	1.31-1.55	1.43	3.55	1272	10	0	10	0	10	0	9	1	9	1
	82-35	1	1.36-1.47	1.40	3.45	1272	10	0	10	0	10	0	9	1	9	1
G	83-11*	1	1.33-1.44	1.40	2.96	44	9	1	7	3	7	3	6	5	6	5
	83-16	1	1.37-1.47	1.50	3.04	44	9	1	7	3	7	3	6	5	6	5
	83-17	1	1.34-1.47	1.50	2.97	44	9	1	7	3	7	3	6	5	6	5
I	80-20*	1	1.16-1.27	1.24	2.79	776	10	0	10	0	9	1	9	1	9	1
	89-29	1	1.17-1.36	1.24	2.80	322	10	0	9	1	9	1	9	1	9	1
	89-31	1	1.24-1.36	1.27	2.86	776	10	0	10	0	9	1	9	1	9	1

* Blows from during test.

* Only top joint was blasted.

* Intermittently damaged before testing.

** See ASTM Specification D 114-61, Pt. II, 1946 Standard, page 1171. Blow rate are expressed by numbers within the circle of 0 to 10, in which 0 represents the percent of very large blows and 10 represents no blowing under the test conditions.

TABLE 6

Weight Loss and Condition of Base Metal After Stripping
Painted Panel Exposed to Continuous Condensation
at 100F for 3000 Hrs. Blister Rating after
3000 Hrs. Included Also

Designation	Panel No.	Weight Loss - Grams		Appearance of Base Metal**	Condition of Damaged Zone		Blister Rating after 3000 Hrs.	
		Ind.	Avg.	Unstripped Panel	Depth of Undercoating***	Depth of Porosity***	Blister Size	Per Cent Area Blistered
A	62-52*				C	B	8	30
	62-54	0.06		A			8	30
	62-55	0.06	0.07	A			8	30
B	70-9*				C	B	6	100
	70-12	0.21		C			6	100
	70-13	0.24	0.22	C			6	100
C	87-51*				A	A	9	100
	87-28	0.08		A			9	100
	87-29	0.03	0.06	A			9	100
D	66-30*				B	B	9	100
	66-26	0.08		A			9	100
	67-41	0.08	0.08	B			9	100
E	81-19*				C	B	7	73
	81-17	0.12		B			7	73
	81-16	0.10	0.11	B			7	73
F	78-18*				B	A	2-3	20
	78-22	0.13		C			2-3	20
	78-20	0.14	0.13	C			2-3	20
F	76-29*				B	A	4-5	20
	75-34	0.06		B			4-5	20
	75-14	0.14	0.10	C			4-5	20
R	80-61*				B	A	2-4	10
	79-46	0.22		D			2-4	10
	80-55	0.12	0.17	C			2-4	10
G	83-6*				B	B	2-6	73
	83-6	0.12		B			2-6	73
	83-25	0.10	0.11	B			2-6	73
H	90-5*				A	C	9	100
	90-1	0.12		B			10	100
	90-7	0.12	0.12	B			10	100
H	91-14*				A	C	10	100
	91-11	0.04		B			10	100
	91-12	0.04	0.04	B			10	100
H	92-2*				A	C	10	100
	92-3	0.05		B			10	100
	92-1	0.04	0.04	B			10	100
H	93-5*				B	B	10	100
	93-6	0.08		B			10	100
	93-3	0.02	0.01	B			10	100
I	80-5*				A	A	9	100
	80-9	0.08		A			9	100
	80-6	0.05	0.02	A			9	100
L	216*				A	B	7	7
	217			B			7	7
	217			B			7	7

TABLE 6 (CONTINUED)

Designation	Point No.	Metal Loss —Corrosion		Assessment of Steel Member**	Condition of Damaged Zone		Stress Ratio —100% Min	
		Ind	Avg	Undamaged Point	Degree of Undermining***	Degree of Penetration****	Stress Ratio	Per Cent Area Remained
M	2239*			A	A	B	6	3
	2240			A			6	3
	2241			A			6	3
M	2125*			B	B	B	4	73
	2115			C			4	73
	2096			C			4	73
O	5344*			B	A	B	8	3
	5270			B			8	3
	5265			B			7	3
Q	2025*			C	A	B	6	3
	2154			C			7	3
	2205						7	3
R	2221*			A	B	B	10	0
	2216*			A			10	0
	2047			A			10	0
S	2040*			A	A	A	2	73
	2039			A			2	73
	2038			A			2	73
T	2109*			C	A	B	1	88
	2081			C			1	88
	2080			C			1	88
U	5155*			C	B	B	24	73
	5260			C			24	73
	5154			C			24	73
Z	2117*			B	A	B	10	0
	2280			B			10	0
	2187			B			10	0
B	56-17*			C	A	B	3	30
	56-24	0.89		C			3	30
	56-25	0.75	0.82	C			3	30
C	56-25*			A	A	A	9	1
	56-14			A			9	1
	56-8			A			9	1
D	67-45*			B	B	B	10	0
	66-54	0.95		B			10	0
	66-55	0.90	0.87	B			9	0
E	82-50*			B	B	B	9	0
	81-25	0.88		B			9	0
	82-55	0.87	0.87	B			9	0
G	81-9*			A	A	A	6	3
	81-16	0.88		A			6	3
	81-17	0.95	0.82	B			6	3
I	86-28*			A	A	A	6	3
	86-31	0.88		A			6	3
	86-29	0.88	0.88	A			6	3

* Immediately damaged before test

** A: Marginally good
B: Fair
C: Poor
D: Very poor
E: Not applicable

*** Degree of undermining
**** Degree of penetration
***** Per cent area remained

TABLE 7

Ratings of the Various Paint Systems Taken from
Table 6 (Continuous Condensation Tests) and
Arranged for Convenient Comparison

	Rating*															
	A				B				C				D			
Appearance of bare metal	A B C D E F G H I J K L M N O P Q R S T U V W X Y Z	C D E F G H I J K L M N O P Q R S T U V W X Y Z	I J K L M N O P Q R S T U V W X Y Z	M N O P Q R S T U V W X Y Z	D E F G H I J K L M N O P Q R S T U V W X Y Z	E F G H I J K L M N O P Q R S T U V W X Y Z	G H I J K L M N O P Q R S T U V W X Y Z	N O P Q R S T U V W X Y Z	B C D E F G H I J K L M N O P Q R S T U V W X Y Z	F G H I J K L M N O P Q R S T U V W X Y Z	H I J K L M N O P Q R S T U V W X Y Z	R S T U V W X Y Z				
Degree of underpinning at the damaged zone	C D E F G H I J K L M N O P Q R S T U V W X Y Z	M N O P Q R S T U V W X Y Z	N O P Q R S T U V W X Y Z	N O P Q R S T U V W X Y Z	D E F G H I J K L M N O P Q R S T U V W X Y Z	F G H I J K L M N O P Q R S T U V W X Y Z	H I J K L M N O P Q R S T U V W X Y Z	R S T U V W X Y Z	A B C D E F G H I J K L M N O P Q R S T U V W X Y Z	B C D E F G H I J K L M N O P Q R S T U V W X Y Z	E F G H I J K L M N O P Q R S T U V W X Y Z					
Degree of penetration at damaged zone	C D E F G H I J K L M N O P Q R S T U V W X Y Z	F G H I J K L M N O P Q R S T U V W X Y Z	H I J K L M N O P Q R S T U V W X Y Z	H I J K L M N O P Q R S T U V W X Y Z	A B C D E F G H I J K L M N O P Q R S T U V W X Y Z	B C D E F G H I J K L M N O P Q R S T U V W X Y Z	D E F G H I J K L M N O P Q R S T U V W X Y Z	E F G H I J K L M N O P Q R S T U V W X Y Z	M N O P Q R S T U V W X Y Z	N O P Q R S T U V W X Y Z	N O P Q R S T U V W X Y Z					

* Value of Ratings A, B, C, and D are shown in Table 6.

3000 hours exposure that these test conditions were not so severe as continuous condensation or continuous partial immersion and that a long exposure period would be necessary to show differences if they existed. As indicated by the results described below, even after 7300 hours exposure, very few differences could be noted among the majority of the coating systems.

Table 8 contains the coating and blister data after 7300 hours exposure. With a few exceptions, there was no evidence of blistering on the panels. The exceptions were the intentionally damaged panels of Coatings A, B, and F₁, and all three panels for Coating H₁. Blistering, however, was not exceptionally severe in any case. It was noted that Coating B contained a considerable number of cracks.

The weight loss and condition of base metal after stripping the paint from the tested panels are shown in Table 9, while the rating values for the condition of the base metal are arranged in Table 10 for convenient comparison. It is evident from the weight-loss data that little attack occurred on the base metal of the undamaged panels for all systems with the exception of B, F, and H, even after 7300 hours exposure (10 months). However, considering the degree of film undercutting on the intentionally damaged panels in the damaged zone, Systems A, B, E, F₁, F₂, F₃, G, H₁, and I would have to be given a lower rating. Considering all factors, Systems C and D seem to afford the greatest protection to the base metal under these test conditions. Coatings H₂, H₃, and H₄ are nearly as effective.

Insulation Tests

As previously described for the partial immersion tests, three coated panels (one damaged, two completely coated) representing the same paint system were held vertically in a Lucite block containing grooves which space the panels approximately 1½ inches apart, the center panel being the damaged one. This same arrangement was used in the insulation tests. Prior to placing the above assembly in the battery jar, insulation was inserted into the 1½-inch spaces between the damaged panel and the two which were undamaged so that approximately two-thirds of the depth of the panels were covered. The assembly of panels, Lucite block, and insulation was then

TABLE 8

Coating and Blister Data for Painted Panels Exposed to Alternate Wet and Dry Conditions for 7500 Hours

Panel	Paint	Number of Coats	Pin Thickness, mils	Pin Type	Pin Size	Pin Count	No. of Blister	Blister Rating*	
								Blister Size	Avg. Blister Count
A	65-40*	1	1.17-1.24	1.22	1.61	6100	1	0	1
	65-45	1	1.15-1.24	1.20	1.54	1	10	0	0
	62-57	1	1.17-1.26	1.21	1.60	1	10	0	0
B	71-30*	1	1.27-1.42	1.37	2.42	5545	0	1	1
	71-19	1	1.24-1.40	1.36	2.40	1	10	0	0
	71-18	1	1.26-1.45	1.36	2.30	1	10	0	0
C	86-22*	1	1.22-1.45	1.35	4.16	1	10	0	0
	86-21	1	1.24-1.44	1.35	4.15	1	10	0	0
	86-20	1	1.29-1.45	1.37	4.16	1	10	0	0
D	66-55*	1	1.22-1.41	1.24	3.32	1	10	0	0
	66-54	1	1.21-1.42	1.25	3.47	1	10	0	0
	66-53	1	1.07-1.42	1.22	3.42	1	10	0	0
E	82-34*	1	1.12-1.54	1.45	3.47	1	10	0	0
	81-11	1	1.16-1.54	1.30	3.45	1	10	0	0
	81-7	1	1.19-1.54	1.40	3.46	1	10	0	0
F	75-34*	1	1.25-1.38	1.32	2.25	5545	0	1	1
	75-33	1	1.22-1.37	1.32	2.17	1	10	0	0
	75-32	1	1.26-1.38	1.34	2.25	1	10	0	0
G	75-31*	1	2.55-2.67	2.64	4.15	1	10	0	0
	75-30	1	2.50-2.70	2.62	4.19	1	10	0	0
	75-18	1	2.55-2.70	2.61	4.21	1	10	0	0
H	88-71*	1	2.00-3.05	3.02	4.66	1	10	0	0
	88-72	1	3.00-3.05	3.02	4.75	1	10	0	0
	88-70	1	3.00-3.05	3.01	4.86	1	10	0	0
I	94-12*	1	1.25-1.54	1.31	2.30	1	10	0	0
	94-24	1	1.25-1.57	1.38	2.79	1	10	0	0
	95-25	1	1.22-1.54	1.30	2.30	1	10	0	0
J	98-30*	1	1.07-1.11	1.08	0.99	6100	0	0	0
	98-18	1	1.05-1.09	1.05	0.99	6100	0	0	0
	98-16	1	1.07-1.11	1.09	1.20	6100	0	0	0
K	91-10*	Sprayed	5.57-5.5	6.4	5.25	1	10	0	0
	91-9	Sprayed	4.97-5	6.2	4.95	1	10	0	0
	91-8	Sprayed	4.87-5	6.7	5.10	1	10	0	0
L	92-30*	Sprayed	9.5-11.0	10.1	8.45	1	10	0	0
	92-16	Sprayed	9.5-11.0	10.5	8.05	1	10	0	0
	92-4	Sprayed	8.7-11.0	10.1	8.40	1	10	0	0
M	95-9*	Sprayed	14.0-17.0	15.2	13.51	1	10	0	0
	95-8	Sprayed	14.0-17.0	15.3	13.64	1	10	0	0
	95-7	Sprayed	14.0-17.0	16.1	13.50	1	10	0	0
N	10-21*	1	1.10-1.20	1.25	2.04	1	10	0	0
	10-20	1	1.19-1.30	1.22	2.15	1	10	0	0
	10-16	1	1.19-1.30	1.25	2.12	1	10	0	0

* Immersively Degassed Before Test

** See Table 1.

LIA07909

TABLE 9

Weight Loss and Condition of Base Metal After Stripping
Painted Panels Exposed to Alternate Wet and Dry
Conditions for 7300 Hours

Drop Letter	Panel No.	Metal Loss, Grams		Appearance of Base Metal**	Condition of Painted Zone		Moisture Rating	
		Initial	Final		Uncoated Panel	Degree of Under- mining***	Degree of Pitting****	Moisture Rating
A	65-09*	—	—	—	D	A	6	1
	65-45	0.05	—	—	B	—	10	0
	62-37	0.02	0.02	B	—	A	10	0
B	71-36*	—	—	—	D	—	6	1
	71-19	0.32	—	D	—	—	—	—
	71-18	0.41	0.45	D	—	—	—	—
C	86-22*	—	—	—	A	A	10	0
	86-21	0.02	—	A	—	—	10	0
	86-20	0.03	0.02	A	—	—	10	0
D	66-15*	—	—	—	B	A	10	0
	66-34	0.00	—	A	—	—	10	0
	66-33	0.00	0.00	A	—	—	10	0
E	82-34*	—	—	—	B	A	10	0
	81-11	0.00	—	A	—	—	10	0
	81-7	0.00	0.00	A	—	—	10	0
F	79-34*	—	—	—	D	A	6	1
	79-33	0.10	—	C	—	—	10	0
	79-32	0.12	0.13	C	—	—	10	0
H	75-27*	—	—	—	D	A	10	0
	75-30	0.10	—	B	—	—	10	0
	75-18	0.06	0.06	B	—	—	10	0
J	86-75*	—	—	—	D	A	10	0
	86-72	0.00	—	A	—	—	10	0
	86-70	0.00	0.00	A	—	—	10	0
G	84-32*	—	—	—	D	A	10	0
	81-24	0.01	—	B	—	—	10	0
	81-23	0.02	0.01	B	—	—	10	0
M	90-30*	—	—	—	C	B	6	3
	90-18	0.25	—	C	—	—	6	3
	90-16	0.40	0.42	C	—	—	6	3
N	91-10*	—	—	—	A	B	10	0
	91-9	0.00	—	A	—	—	10	0
	91-8	0.00	0.00	A	—	—	10	0
N	92-30*	—	—	—	A	B	10	0
	92-16	0.00	—	A	—	—	10	0
	92-6	0.00	0.00	A	—	—	10	0
N	93-9*	—	—	—	A	B	10	0
	93-8	0.00	—	A	—	—	10	0
	93-7	0.00	0.00	A	—	—	10	0
I	86-21*	—	—	—	D	A	10	0
	86-30	0.05	—	B	—	—	10	0
	86-16	0.02	0.02	B	—	—	10	0

... See Table 8.
...
...

placed at the bottom of the Pyrex glass battery jar and distilled water added until the panels were 50 per cent immersed. The battery jars were maintained at a temperature of 100 F. Under these test conditions, the lower half of the panel (below water line) was in continuous contact with insulation and water, while part of the upper half (above water line) was in contact with moist insulation and part simply exposed to moist air at essentially 100 per cent relative humidity.

Two types of insulating material were studied, one representing a neutral type (Owens-Corning Fiberglas) and one representing an alkaline type (Johns-Manville Baeroc).

Table 11 contains blister data after 500 hours exposure for those coating systems selected to be tested under the above-described conditions. Time to first blister is recorded, together with the size and extent of blistering after 500 hours (21 days) contact with both types of insulation in the presence of water. The pH of the water during the test period ranged from six to seven for the neutral-type insulation tests and 8 to 9 for the alkaline insulation tests.

Examination of the data contained in the table indicates that the asphaltum-type coatings (H₁ and H₂) or those whose pigment is essentially red lead or zinc chromate, alone or in combination (C, C₁, O, O₁, and BC), exhibit excellent resistance to blistering when in contact with either type insulation. This would tend to indicate that they would afford the best protection to the steel. The other coating systems blistered to some extent during the exposure period. Only the air-dry zinc dust-zinc oxide-alkyd system (X) showed rust spots.

Discussion of Paint Tests

Consideration of the results of the above-described tests indicates that continuous immersion in water is the most severely corrosive condition studied. Many of the coating systems deteriorated rather rapidly when subjected to this exposure which resulted in attack on the base steel. The systems which seemed to afford maximum protection (little evidence of base metal attack) when the steel is completely coated were those in which the pigment was either essentially 100 per cent red lead (A, C, C₁), or predominately so (BC, BD, BE), or contained zinc chromate (I, R, W, and O₁). The asphaltum-type paints (H₁, H₂, H₃, H₄) and those whose pigment contained

TABLE 10

Rating of the Various Paint Systems Taken from
Table 9 (Alternate Wet-Dry Conditions) and
Arranged for Convenient Comparison

	Rating*											
	A				B				C			
Appearance of bare metal	C F H	D G H	E H H	H	A I		F G	H H	F H			B
Degree of undercoating at the damaged zone	C	H	H	H	D				H			A F
Degree of penetration at damaged zone	A E G	B F I	C H H	D H	H H	H H	H H					B G I

* Values of Ratings A, B, C, and D are shown in Table 9.

TABLE 11

Blister Data After 500 Hours for Painted Exposure Steel Panels
In Continuous Contact with Either Neutral- or Alkaline-Type
Insulation in the Presence of Water

Type of Insulation	Panel No.	Time to First Blister, Hours	Blister Rating**—Constant With Neutral Type Insulation				Panel No.	Time to First Blister, Hours	Blister Rating**—Constant With Alkaline Type Insulation			
			Below Water Line		Above Water Line				Below Water Line		Above Water Line	
			Blister Size	Per Cent Area	Blister Size	Per Cent Area			Blister Size	Per Cent Area	Blister Size	Per Cent Area
N	56-4°	100	2	90	2	90	56-18°	100	2	73	2	73
	56-6°	100	2	90	2	90	56-22°	100	2	73	2	73
	56-8°	100	2	90	2	90	56-12°	100	2	73	2	73
	56-10°	—	10	0	10	0	56-4°	210	10	0	9	1
	56-11°	—	10	0	10	0	56-7°	—	10	0	10	0
	56-12°	—	10	0	10	0	56-8°	10	0	10	0	
	56-9°	—	10	0	10	0	56-1°	210	10	0	7	1
	56-10°	—	10	0	10	0	56-2°	210	10	0	9	1
	56-11°	—	10	0	10	0	56-4°	—	10	0	10	0
	56-12°	—	10	0	10	0	56-1°	100	4	50	7	50
C	61-3°	360	6	20	10	0	61-2°	100	4-8	73	0	50
	61-5°	360	6	75	10	0	61-3°	100	3	50	6	50
	61-6°	360	6	75	10	0	61-1°	100	2	73	2	73
	61-7°	100	1	100	1	100	61-15°	100	2	73	2	73
G	81-11°	100	1	105	1	100	84-35°	120	0	100	0	100
	84-27°	100	1	100	1	100	81-12°	100	2	73	2	73
	90-19°	—	10	0	10	0	90-25°	—	10	0	10	0
	90-21°	—	10	0	10	0	90-15°	—	10	0	10	0
M	90-4°	—	10	0	10	0	90-14°	—	10	0	10	0
	91-17°	—	10	0	10	0	91-19°	—	10	0	10	0
	91-23°	—	10	0	10	0	91-20°	—	10	0	10	0
	91-18°	—	10	0	10	0	91-22°	—	10	0	10	0

TABLE 11 (CONTINUED)

TYPE	Panel No.	Time or Feet, Minutes	Shower Range "A"—Common With Removal Type Installation				Panel No.	Time or Feet, Minutes	Shower Range "B"—Common With Absorption Type Installation			
			Before Water Leak		After Water Leak				Before Water Leak		After Water Leak	
			Shower Seat	Per Cent Am.	Shower Seat	Per Cent Am.			Shower Seat	Per Cent Am.	Shower Seat	Per Cent Am.
O	5642*	100	7	30	0	30	5695	100	6	75	0	75
	5634	130	0	50	0	50	5559	100	0	75	0	75
	5555	100	0	50	0	50	5603	100	0	75	0	75
	5269*	240	0	1	10	0	5275	100	9	1	9	1
	5286	240	0	1	10	0	5256	100	9	1	9	1
Q	5274	430	0	1	10	0	5250	100	9	1	9	1
	5287*	430	7	1	10	0	5280	210	9	1	9	1
	5280	430	9	1	10	0	5267	210	9	1	9	1
	5282	430	9	1	10	0	5279	210	9	1	9	1
	5122*	—	10	0	10	0	5150	—	10	0	10	0
R	5214	—	10	0	10	0	5255	—	10	0	10	0
	5215	—	10	0	10	0	5225	—	10	0	10	0
	5225	100	6	30	10	0	5257	—	47	75	6	75
	5224	100	0	10	10	0	5243	210	7	50	9	50
	5222	100	0	10	10	0	5244	210	7	75	9	50
Z	5415*	450	6	30	10	0	5417	400	5	50	9	25
	5418	450	6	30	10	0	5222	400	7	50	9	25
	5275	—	6	30	10	0	5490	400	4	50	9	25
	5346*	450	9	5	10	0	5380	—	10	0	10	0
	5384	450	9	5	10	0	5387	—	10	0	10	0
H	5385	450	9	5	10	0	5346	—	10	0	10	0

- Incompletely damaged before survey.
- See Table 2
- Four listed in Table 1 have compensation as 2 but 1 listed
- 100 have exposure only
- Small run going appearing on outside of starting

zinc dust, zinc oxide, or zinc chromate in some combination were next in the order of merit.

However, with few exceptions, the protectiveness of the above systems would have to be given a lower rating when the steel was not completely coated. The red lead-rare linseed oil vehicle (C₁) and the red lead, part raw and part bodied (polymerized), linseed oil vehicle (C) systems were the outstanding exceptions since they afforded definite protection of the base at the damaged area. The baked (O₁) zinc chromate-red lead-vinyl system shows definite promise, but additional information is needed before it can be fully evaluated. The air-dry systems, red lead-iron oxide-phenolic (BC), red lead-zinc oxide-zinc yellow-alkyd (BD), red lead-silicate-phenolic (BE), and zinc chromate-iron oxide-alkyd (I and W) rated high but had a lower over-all rating than the red lead-linseed oil systems (C and C₁) when considering protection at the damaged zone. Coatings in which the pigment was predominantly iron oxide (B, B₁, F₁, F₂, F₃) were the poorest in regard to corrosion protection.

In continuous contact with either a neutral or alkaline-type insulation and in the presence of water, the paint systems in which the pigments were predominantly red lead and or zinc chromate showed superior resistance to blistering.

Continuous condensation represents a moderately corrosive condition and, accordingly, many of the paint systems satisfactorily protect the steel either when completely coated or when the coating is damaged. As in the case of the continuous immersion tests, the systems containing red lead or zinc chromate appear to be the most outstanding, while those containing predominantly iron oxide are the least outstanding.

An environment of high humidity at relatively high temperature or periodic wet-dry exposure are the least severe conditions studied with respect to deterioration of the paint films. With the possible exception of the predominantly iron-oxide systems, practically no blistering was observed on any of the coatings, nor was severe attack on the base metal noted even after extended exposure. This was particularly true when the coating was continuous.

The effect of type and vehicle composition on corrosion protection under the various exposure conditions is not too evident. However, the red lead system (C₁), which was formulated

with a linseed oil vehicle, offers more protection, in most cases, than the one formulated with a phenolic modified alkyl (A).

Acknowledgements

We wish to acknowledge the help and suggestions of the Technical Committee on Protective Coatings and of R. E. McSweeney, E. R. Mueller, K. E. Jackson, F. W. Fink, B. E. Friedl, and others of the staff of Battelle Memorial Institute.

References

- ¹ Elm, A. C., Paints as Moisture Barriers, Official Digest, April, 1947.
- ² Elm, A. C., Principles of Immersion and Humidity Testing of Metal Protective Paints, Corrosion, 5 (1947), page 501.
- ³ Kattelberger, W. W., Water Immersion Testing of Metal Protective Paints—Influence of Bare Metal Areas, Ind. Eng. Chem., 34, 1943 (1942).
- ⁴ Young, G. H., and Gerhardt, G. N., Film Coarseness of Synthetic Coatings—Ten Methods, Ind. Eng. Chem., 29, 1277 (1937).
- ⁵ Dory, P. M., Aiken, W. H., and Mark, H., Water-Vapor Permeability of Organic Films, Ind. Eng. Chem., Anal. Ed., 16, 686 (1944).
- ⁶ Carrick, L. L., Marine Primers, Official Digest, April, 1947.
- ⁷ Post-War Building Studies No. 1, House Construction (1944), His Majesty's Stationery Office, London, England.
- ⁸ Methods of Protection Against Corrosion for Light-Gage Steel and Wrought Iron Used in Permanent Building Construction, British Standards Institute, P.D. 420, November, 1945.
- ⁹ Porter, W. C., Painting Steel, Building Materials and Structures, Report BMS 102, National Bureau of Standards.
- ¹⁰ Wurdley, H. W., Moisture Condensation in Building Walls, Building Materials and Structures Report BMS 63, National Bureau of Standards.
- ¹¹ First Report of the Methods of Testing (Corrosion) Subcommittee, Journal of the Iron and Steel Institute, 758, Pt. 4, p. 463, April, 1948. Standards of Protection for Iron and Steel Used in Building Construction.
- ¹² Light and Water Exposure Apparatus for Testing Paint, Varnish, Lacquer, and Related Products, Recommended Practice for Operating, ASTM Sect., 1945 suppl. Part II (D822-45T), 194.
- ¹³ Zahn, Harold, Laboratory, Evaluation of Corrosion-Resistant Pigments and Vehicles, Paint, Oil, and Chemical Review 109, September 5, 1946.
- ¹⁴ Pollard, R. E., Porter, W. C., Surface Treatment of Steel Prior to

LIA07916

Painting, Building Materials and Structures, Report BMS 44, National Bureau of Standards.

¹¹ Changes in Protective Properties of Organic Coatings on Steel Surfaces When Subjected to Immersion, ASTM Standards, 1944 Supplement, D8 II (E3-55), 1189.