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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.

N 2799

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.

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

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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 1 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_1—one coat, two-mil thickness
System F_2—two coats, each one-mil thickness

Systems H_4, H_5, and H_6—five-, ten-, and fifteen-mil thickness, respectively

Systems O, O_4, and Q—two coats, each ½-mill 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 1

Paint Composition and Coating Data

Designation	Type of Coating	Type of Cure	Coating System	Paint Formula — Pigment: Per Cent	Pigment: Composition	Pigment: Per Cent	Vehicle: Per Cent	Vehicle: Composition	Vehicle: Per Cent	Remarks
A	Red lead/phenolic modified alkyd	Air dry	1 coat, 1 mil thick	80	Red lead (97 per cent)	100 100	20	Beckosol 1316 (50 per cent N.V.M.) 6 per cent Co naphthenate sol. 6 per cent Mn naphthenate sol. ASA	96.97 0.134 0.134 2.76 100	Beckosol 1316 is a medium-long alkyd modified with a phenolic type resin P.V.R., 32.4
B	Iron oxide/raw linseed oil/modified tung, linseed, phenolic	Air dry	1 coat, 1 mil thick	60.2	#500 Iron oxide Asbestine 3x Celite 110 Pearless No. 1 china clay	40.6 8.2 24.7 26.5 100	39.8	An-TT-V-118 varnish sol. Raw linseed oil Mineral spirits Benzene 6 per cent Co naphthenate sol. 6 per cent Mn naphthenate sol. 24 per cent Pb naphthenate sol.	28.20 53.2 9.2 10.3 0.2 0.3 0.6 100	An-TT-V-118 varnish from Bakelite Corp.: VF-661; 33-gallon varnish based on Bakelite pure phenolic BR-254 resin, 60 per cent N.V.M.
C	Red lead/mixed linseed oil	Air dry	1 coat, 1 mil thick	80.7	Red lead (97 per cent)	100 100	19.3	OKO linseed oil Raw linseed oil 6 per cent Co naphthenate sol. 6 per cent Mn naphthenate sol. 24 per cent Pb naphthenate sol.	18.90 80.86 0.02 0.02 0.20 100	2½ M viscosity OKO oil. P.V.R., 30.8

TABLE 1 (CONTINUED)

Designation	Type of Coating	Type of Cure	Coating System	Paint Formula: Pigment Per Cent	Pigment Composition	Per Cent	Vehicle Per Cent	Vehicle Composition	Per Cent	Remarks
D	Zn dust, Zn oxide/linseed oil, alkyd	Air dry	1 coat, 1 mil thick	76.7	Zn dust	79.6	23.3	Rezyl 869	99.76	P.V.R., 34.0.
					Zn oxide	24.4		6 per cent Co naphthenate sol.	0.02	
								6 per cent Mn naphthenate sol.	0.02	
								24 per cent Pb naphthenate sol.	0.20	
						100			100	
E	Zn dust, Zn oxide, Fe oxide/alkyd resin	Air dry	1 coat, 1 mil thick	74.7	#500 Spanish iron oxide	50	24.3	Rezyl 869	99.76	P.V.R., 35.6.
					Zn oxide (AZO-ZZZ-55)	20		6 per cent Co naphthenate sol.	0.02	
					Zn dust (325 mesh)	50		6 per cent Mn naphthenate sol.	0.02	
								24 per cent Pb naphthenate sol.	0.20	
						100			100	
F1	Iron oxide, Zn chromate/phenolic varnish	Air dry	1 coat, 1 mil thick	52	Zn Chromate	25	48	Varnish 52-V-17	100	52-V-17 is a 25-gallon varnish of a 50/50 mixture of linseed and tung oils based on a pure phenolic resin. It is supplied at 60 per cent N.V.M. in a solvent consisting of 80 per cent mineral spirits and 20 per cent xylene. P.V.R., 34.5.
					#500 Spanish iron oxide	50				
					Asbestine 3x	15				
					Celite 110	10				
						100			100	
F2	Iron oxide, Zn chromate/phenolic varnish	Air dry	1 coat, 2 mils thick	52	Zn Chromate	25	48	Varnish 52-V-17	100	
					#500 Spanish iron oxide	50				
					Asbestine 3x	15				
					Celite 110	10				
						100			100	

TABLE 1 (CONTINUED)

Designation	Type of Coating	Type of Cure	Coating System	Paint Formula: Pigment Per Cent	Pigment Composition	Per Cent	Vehicle Per Cent	Vehicle Composition	Per Cent	Remarks
F	Iron oxide, Zn chromate/phenolic varnish	Air dry	2 coats, each 1 mil thick	52	Zn Chromate #509 Spanish iron oxide Asbestine 3x Celite 110	25 50 15 10 100	48	Varnish 52-V-17	100 100	
G	Lead chromate, red oxide/alkyd resin	Air dry	1 coat, 1 mil thick	50	Ferric oxide Basic Pb chromate Inerts (Asbestine, Silica, etc.)	43.5 27.0 29.5 100	50	Alkyd resin sol. (50 per cent sol. in mineral spirits) Mineral spirits Epoxy No. 2 Naphthenate (5207 Type I) Naphthenate (5207 Type II) Naphthenate (5207 Type III)	75.2 20.5 2.92 0.98 0.24 0.36 100	Resin solids: 15-18 per cent polyhydric alcohol 34-40 per cent phthalic Anhydride 42-51 per cent linseed oil acids
H1	Asphalt type	Air dry	1 coat, 1 mil thick				100	Asphalt Gilsonite Mineral spirits	40 10 50 100	—
H2	Asphalt type	Air dry	5 mils sprayed				100	Asphalt Gilsonite Mineral spirits	40 10 50 100	—
H3	Asphalt type	Air dry	10 mils sprayed				100	Asphalt Gilsonite Mineral spirits	40 10 50 100	

TABLE 1 (CONTINUED)

Designation	Type of Coating	Type of Cure	Coating System	Paint Formula: Pigment, Per Cent	Pigment Composition	Pigment Composition, Per Cent	Vehicle, Per Cent	Vehicle Composition	Vehicle Composition, Per Cent	Remarks
H.	Asphalt type	Air dry	15 mils sprayed				100	Asphalt Gilsonite Mineral spirits	40 10 50 100	
I	Zn chromate, iron oxide/alkyd vehicle	Air dry	1 coat, 1 mil thick	38	Spanish iron oxide 84 per cent Fe_2O_3 Zn chromate	67 33 100	62	Alkyd resin (43 per cent glyc. phth.) Volatile solvent	45 55 100	Essentially Formula 77, Bureau of Standards Report, BMS 102
B.	Iron oxide/raw linseed oil	Air dry	1 coat, 1 mil thick	60.2	#500 Spanish iron oxide Asbestine 3x Celite 110 Peerless No. 1 china clay	40.9 8.2 24.6 26.3 100	39.8	Raw linseed oil Naphtha 6 per cent Co naphthenate sol. 6 per cent Mn naphthenate sol. 24 per cent Pb naphthenate sol. ASA	78.6 20.0 0.2 0.3 0.7 0.3 100	
C.	Red lead/raw linseed oil	Air dry	1 coat, 1 mil thick	80.6	Red lead (97 per cent)	100 100	19.4	Raw linseed oil 6 per cent Co naphthenate sol. 6 per cent Mn naphthenate sol. 24 per cent Pb naphthenate sol. ASA	98.2 0.3 0.3 0.7 0.5 100	

TABLE I (CONTINUED)

Designation	Type of Coating	Type of Cure	Coating System	Paint Formula: Pigment, Per Cent	Pigment Composition	Per Cent	Paint Formula: Vehicle, Per Cent	Vehicle Composition	Per Cent	Remarks
L	Zn dust, iron oxide Zn oxide/alkyd	Baked 1 hr. at 250F.-275F.	1 coat, 1 mil thick	61.0	Zn dust-22 Iron oxide Zn oxide XX50	50 30 20 100	39.0	Glyptal 2458 sol. Mineral spirits	86 14 100	Add all the Zn dust 22 to the oxide mixture prior to use. Vehicle by volume: 55 per cent N V M. by wt.; 77.7 per cent Vac. (No. 4 Ford cup): 1 min. 57 sec.
M	Iron oxide, Zn chromate, Zn oxide/alkyd	Baked 1 hr. at 250F.-275F.	1 coat, 1 mil thick	44	Iron oxide Zn chromate Zn oxide XX50	60 30 10 100	56	Glyptal 2458 sol. Mineral spirits	88 12 100	Vehicle by volume: 53.7 per cent. Vac. (No. 4 Ford cup): 1 min. 25 sec.
N	Iron oxide, Zn oxide/alkyd	Baked 1 hr. at 250F.-275F.	1 coat, 1 mil thick	47	Iron oxide Zn oxide XX50	80 20 100	53	Glyptal 2458 sol. Mineral spirits	86 14 100	N V M. by wt.: 70.9 per cent. Vac. (No. 4 Ford cup): 1 min. 11 sec. Volatile 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 ½ mil thick	Wash Primer (WP-1) 8	Y-565-D DuPont pigment (Zn chromate) Asbestine	86.3 13.7 100	92	Vinylite polyvinyl butyral XYHL 99 per cent Isopropanol Methyl isobutyl ketone Diluent to be added before using: 85 per cent phosphoric acid Water 99 per cent Isopropanol	7.8 54.8 15.7 3.7 3.7 14.4 100	Add the acid diluent to the wash primer base at 1:4. The mixed primer WP-1 is usable 10-12 hrs. Apply WP-1 at a thickness of 0.3-0.4 mil, air dry and apply 1 coat AP-1—if sprayed, thin AP-1 with methyl isobutyl ketone. Pot life until 48 hrs. WP-1: N V M. by wt.: 17.9 per cent. Vac. (No. 4 Ford cup): 27 sec.
				Anticorrosive Primer (AP-1) 22.5	Red lead (97 per cent)	100 100	77.5	Vinylite resin VAGH Methyl isobutyl ketone Toluene Methyl isobutyl ketone	19.4 5.8 38.1 36.7 100	AP-1: N V M. by wt.: 43.05 per cent. Vac. (No. 4 Ford cup): 135 sec.

TABLE 1 (CONTINUED)

Designation	Type of Coating	Type of Cure	Coating System	Paint Formula: Pigment — Per Cent	Pigment — Composition	Pigment — Per Cent	Vehicle — Per Cent	Vehicle — Composition	Vehicle — Per Cent	Remarks
P	Zn chromate/vinyl wash primer/red lead/vinyl	Air dry then bake 10 min. at 325F.		Anticorrosive Primer (AP-1) 22.5	Red lead (97 per cent)	100 100	77.5	Vinylite resin VAGH Methyl isobutyl ketone Toluene Methyl isobutyl ketone	19.4 3.8 38.1 38.7 100	AP-1: N.V.M. by wt.: 43.85 per cent. Visc. (No. 4 Ford cup): 135 sec.
Q	Red lead/vinyl-Zn chromate/vinyl Butyral	Air dry	2 coats, each ½ mil thick	Wash Primer (WP-2) 10.0	Basic zinc chromate Y-563-D Asbestine	86 14 100	90	Modified vinyl butyral sol. XL 5567 Butanol	81.2 18.8 100	One thin coat (WP-2) (alcohol as solvent) followed by one coat (AP-1). WP-2: N.V.M. by wt.: 20.9 per cent. Visc. (No. 4 Ford cup): 26 sec.
				Anticorrosive Primer (AP-1) 22.5	Red lead (97 per cent)	100 100	77.5	Vinylite resin VAGH Methyl isobutyl ketone Toluene Methyl isobutyl ketone	19.4 3.8 38.1 37.2 100	AP-1: N.V.M. by wt.: 43.85 per cent. Visc. (No. 4 Ford cup): 119 sec.
R	Zn chromate, iron oxide/CWO, phenolic	Air dry	1 coat, 1 mil thick	44.7	Zn chromate Iron oxide Mg silicate	23 48 29 100	55.3	16 gallon CWO/ Phenolic 45 per cent solids	100 100	Acid No. 20-60. No glyceryl phthalate. N.V.M. by wt. 72 per cent. Visc. (No. 4 Ford cup): 97 sec.
S	Red lead, Zn oxide lead chromate/ alkyd	Air dry	1 coat, 1 mil thick	61.7	Red lead Zn oxide Mg silicate Pb chromate	25 15 10 50 100	38.3	Alkyd 45.7 per cent solids (Linseed oil)	100 100	Acid No: 4.5 glyceryl phthalate 44 per cent. N.V.M. by wt.: 80.1 per cent Visc. (No. 4 Ford cup): 66 sec.
T	Zn chromate, iron oxide, Zn oxide/ alkyd	Air dry	1 coat, 1 mil thick	56.7	Zn chromate Iron oxide Zn oxide Mg silicate Tinting colors	7 62 12 16 3 100	43.3	Alkyd 44 per cent solids (Linseed oil)	100 100	Acid No. 6.5 glyceryl phthalate 46 per cent. N.V.M. by wt.: 70.3 per cent. Visc. (No. 4 Ford cup): 35 sec.

TABLE 1 (CONTINUED)

Designation	Type of Coating	Type of Cure	Coating System	Paint Formula: Pigment Per Cent	Pigment Composition	Per Cent	Vehicle Per Cent	Vehicle Composition	Per Cent	Remarks
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 5 20 100	50.8	Alkyd, 38.7 per cent solids (Linseed oil)	100 100	Acid No. 4.5 glyceryl phthalate 44 per cent. N.V.M. by wt.: 72.3 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, 43.6 per cent solids	100 100	Acid No. 4.5 glyceryl phthalate 44 per cent
W	Zn chromate, iron oxide/alkyd	Air dry	1 coat, 1 mil thick	47.3	Zn chromate Iron oxide Mg silicate	60 20 20 100	52.7	Alkyd, 42.9 per cent solids (Linseed oil)	100 100	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	38.2	Alkyd, 34.2 per cent solids (Linseed oil)	100 100	Acid No. 4.0 glyceryl phthalate 19 per cent Acid No. 4.0 glyceryl phthalate 38 per cent
Z	Zn dust, Zn oxide linseed, phenolic	Air dry	1 coat, 1 mil thick	73.5	Zn dust Zn oxide	80 20 100	26.5	25 gal. linseed oil Phenolic varnish 44.5 per cent solids	100 100	Conforms to U.S. Army Corps of Engineers spec. T-1713a, type 1, April 27, 1943. Acid No. 20-40 glyceryl phthalate 0 per cent. N.V.M. by wt.: 86.5 per cent. Visc. (No. 4 Ford cup): 91 sec.

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TABLE 1 (CONTINUED)

Designation	Type of Coating	Type of Cure	Coating System	Paint Formula: Pigment Per Cent	Pigment Composition	Per Cent	Vehicle Per Cent	Vehicle Composition	Per Cent	Remarks
BB	Red lead, iron oxide/phenolic	Air dry	1 coat, 1 mil thick	59.2	Red lead (97 per cent) Iron oxide Aluminum stearate	 75 24.7 0.3 100	40.8	Thinner and drier Phenolic varnish, 25 gal., proprietary amyl phenol formaldehyde resin chinawood oil varnish 60 per cent solids	39.6 60.4 100	Wt./gal. 15.5 lbs. PV 36.8 Add petroleum XYLOL to paint on basis of 1.8 parts to 100 parts of paint.
BC	Red lead, iron oxide/phenolic varnish	Air dry	1 coat, 1 mil thick	62.0	Red lead (97 per cent) Iron oxide Aluminum stearate	 75.6 24.1 0.3 100	38.0	Thinner and drier Phenolic varnish, 25 gal., para-alkyl 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 alkyd	Air dry	1 coat, 1 mil thick	51.6	Red lead (97 per cent) Zn oxide Zn yellow Iron oxide Graphite mica	 55 10 10 7 18 100	48.4	Thinner and drier Castor oil alkyd, 45 per cent glyceryl phthalate 65 per cent solids	31.0 69.0 100	Wt./gal. 13.2 lbs. PV 33.0
BE	Red lead, silicate/phenolic varnish	Air dry	1 coat, 1 mil thick	65.9	Red lead (97 per cent) Diatomaceous silica Magnesium silicate Aluminum stearate	 85.0 8.0 6.6 0.4 100	34.1	Thinner and drier Phenolic varnish, 25 gal., proprietary amyl phenol formaldehyde resin chinawood oil varnish 60 per cent solids	25.8 74.2 100	Wt./gal. 17.0 lbs. PV 41.7 Proposed federal spec. TT-P-86a 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_1. 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_2, H_3, and H_4. 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 at 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 100F for 3000 Hours

Designation	Panel No.	Number Of Coats	Film Thickness Range—Mils	Avg. Film Thickness—Mils	Film Wt.—Grams	Time To First Blister—Hours	Blister Rating—Water Phase**									
							100 Hrs.		500 Hrs.		1000 Hrs.		2000 Hrs.		3000 Hrs.	
							Blister Size	Per Cent Area Blistered	Blister Size	Per Cent Area Blistered	Blister Size	Per Cent Area Blistered	Blister Size	Per Cent Area Blistered	Blister Size	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
	65-43	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	2.32	40-91	8-9	75	2-7	75	2-6	75	2-3	75	0	100
	70-8	1	1.15-1.40	1.29	2.32	40-91	8-9	75	2-7	75	2-6	75	2-3	75	0	100
	70-10	1	1.15-1.33	1.30	2.30	40-91	8-9	75	2-7	75	2-6	75	2-3	75	0	100
C	87-36*	1	1.20-1.35	1.25	4.22	1200	10	0	10	0	10	0	8-9	1	8-9	1
	87-30	1	1.20-1.30	1.25	4.17	1200	10	0	10	0	10	0	8-9	1	8-9	1
	87-33	1	1.13-1.35	1.25	4.17	1200	10	0	10	0	10	0	8-9	1	8-9	1
D	64-29*	1	1.17-1.39	1.22	3.37	451	10	0	9	5	7-9	10	6-9	75	4-8	100
	64-31	1	1.19-1.39	1.27	3.34	451	10	0	9	5	7-9	10	6-9	75	4-8	100
	64-20	1	1.21-1.39	1.29	3.51	40-91	8	1	6-8	5	6-8	25	6-8	75	4-8	100
E	81-15*	1	1.21-1.36	1.27	3.18	239	10	0	9	10	8-9	25	6-8	50	6-8	75
	81-22	1	1.28-1.42	1.33	3.25	239	10	0	8	25	7-9	25	6-8	50	6-8	75
	81-21	1	1.28-1.42	1.36	3.28	239	10	0	8	25	8-9	25	6-8	50	6-8	75
F_1	78-21*	1	1.15-1.31	1.23	2.10	91	8	50	3-4	50	2-3	50	1	75	1	100
	78-31	1	1.19-1.31	1.26	2.15	91	8-9	50	3-4	50	2-3	50	1	75	1	100
	78-25	1	1.19-1.28	1.23	2.14	91	8	50	3-4	50	2-3	50	1	75	1	100
F_2	76-39*	2	2.75-2.95	2.85	4.90	100	8-9	20	3-4	50	3-4	50	2-3	75	1	100
	76-41	2	2.70-2.95	2.80	4.90	91	9-10	20	3-4	50	3-4	50	2-3	75	1	100
	76-35	2	2.70-2.80	2.75	4.39	115	10	0	3-4	50	3-4	50	2	75	1	100
F_3	80-50*	1	2.65-3.50	2.82	2.40	91	8-9	20	3-4	50	2-3	50	2-3	75	1	100
	80-64	1	2.85-3.00	2.80	2.39	91	8	20	3	50	2	50	2	75	1	100
	80-60	1	2.75-2.85	2.80	2.43	100	8-9	20	3-4	50	2-3	50	2-3	75	1	100
G	84-26*	1	1.28-1.40	1.33	2.80	91	8	20	4-8	20	4-7	50	4-6	100	2-4	100
	84-31	1	1.28-1.39	1.33	2.86	91	8	20	4-8	20	4-7	50	4-6	100	2-4	100
	84-28	1	1.31-1.39	1.33	2.79	91	8	20	4-8	20	4-7	50	4-6	100	2-4	100

TABLE 2 (CONTINUED)

Designation	Panel No.	Number Of Coats	Film Thickness Range—Mils	Avg. Film Thickness—Mils	Film Wt.—Grams	Time To First Blister—Hours	Blister Rating—Water Phase**									
							100 Hrs.		500 Hrs.		1000 Hrs.		2000 Hrs.		3000 Hrs.	
							Blister Size	Per Cent Area Blistered	Blister Size	Per Cent Area Blistered	Blister Size	Per Cent Area Blistered	Blister Size	Per Cent Area Blistered	Blister Size	Per Cent Area Blistered
K1	90-3*	1	1.09-1.19	1.15	1.07	1000	10	0	10	0	9-10	1	9	1	9	1
	90-10	1	1.09-1.15	1.13	1.05	—	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
K2	91-21*	1	6.00-6.90	6.40	5.54	—	10	0	10	0	10	0	10	0	10	0
	91-15	1	5.00-6.20	5.30	4.71	—	10	0	10	0	10	0	10	0	10	0
	91-13	1	5.10-6.20	5.50	4.74	—	10	0	10	0	10	0	10	0	10	0
K3	92-12*	1	9.50-11.50	10.20	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
	92-4	1	9.20-11.50	10.50	8.91	—	10	0	10	0	10	0	10	0	10	0
K4	93-13*	1	14.50-17.00	15.50	15.59	—	10	0	10	0	10	0	10	0	10	0
	93-15	1	15.00-17.00	16.10	13.57	—	10	0	10	0	10	0	10	0	10	0
	93-16	1	14.00-17.00	15.10	13.20	—	10	0	10	0	10	0	10	0	10	0
I	88-11*	1	1.19-1.28	1.24	2.15	91	8	5	6-8	5	6-8	10	4-6	50	2	75
	88-14	1	1.19-1.28	1.23	2.15	91	8	5	6-8	5	6-8	10	4-6	50	2	75
	88-10	1	1.19-1.80	1.24	2.11	91	8	5	6-8	5	6-8	10	4-6	50	2	75
L	2182*	1	1.15-1.25	1.20	2.94	100	9	1	8	5	7	10	6	50	4	75
	2256	1	1.20-1.50	1.25	3.05	100	9	1	8	5	7	10	6	50	4	75
	2178	1	1.20-1.35	1.30	2.98	100	9	1	8	5	7	10	6	50	4	75
M	2240*	1	0.95-1.15	1.05	2.05	44	8	5	7	10	5	25	3	50	5	75
	2150	1	1.20-1.30	1.25	2.15	322	10	0	7	10	5	25	3	50	5	75
	2265	1	1.25-1.40	1.35	2.41	44	8	5	7	10	5	25	3	50	5	75
N	2170*	1	1.20-1.30	1.25	2.50	44	7	25	7	25	5	50	3	75	2	90
	2114	1	1.20-1.30	1.25	2.64	44	7	25	7	25	5	50	3	75	2	90
	2092	1	1.20-1.30	1.25	2.65	44	7	25	7	25	5	50	3	50	2	90
O	5540*	2	1.00-1.10	1.05	1.95	100	9	1	7	5	7	5	6	5	6	5
	5541	2	1.00-1.05	1.02	1.91	100	9	1	7	5	7	5	6	5	6	5
	5542	2	1.00-1.05	1.05	1.95	100	9	1	7	5	7	5	6	5	6	5
Q	2019*	2	1.20-1.40	1.35	1.49	100	8	5	7	10	5	25	4	25	4	25
	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	1.55	100	8	5	7	10	5	25	4	25	4	25

TABLE 2 (CONTINUED)

Designation	Panel No.	Number Of Coats	Film Thickness Range—Mils	Avg. Film Thickness—Mils	Film Wt.—Grams	Time To Form Blisters—Hours	Blister Rating—Water Phase**									
							100 Hrs.		500 Hrs.		1000 Hrs.		2000 Hrs.		3000 Hrs.	
							Blister Size	Per Cent Area Blistered	Blister Size	Per Cent Area Blistered	Blister Size	Per Cent Area Blistered	Blister Size	Per Cent Area Blistered	Blister Size	Per Cent Area Blistered
R	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
S	2207*	1	1.15-1.45	1.30	3.14	16	7	25	5	50	5	75	5	75	1	90
	2210	1	1.20-1.40	1.30	3.23	16	7	25	6	50	4	75	5	75	1	90
	2084	1	1.20-1.40	1.30	3.15	16	7	25	5	50	5	75	5	75	1	90
T	2064*	1	1.00-1.20	1.15	2.05	16	7	25	5	50	5	75	5	75	1	90
	2065	1	1.00-1.10	1.05	2.00	16	7	25	5	50	5	75	5	75	1	90
	2067	1	0.95-1.20	1.05	2.04	16	7	25	5	50	5	75	5	75	1	90
U	5328*	1	1.10-1.25	1.15	2.64	16	5	50	5	75	2	75	1	90	1	90
	5345	1	1.10-1.20	1.15	2.65	16	5	50	5	75	5	75	1	90	0	100
	5329	1	1.15-1.35	1.25	2.60	16	5	50	5	75	2	75	1	90	0	100
V	5276*	1	1.10-1.20	1.14	1.91	46	7	25	6	50	4[a]	50	4	50	4	50
	5277	1	1.05-1.10	1.08	1.76	46	7	25	6	50	4	50	4	50	4	50
	5297	1	1.09-1.12	1.10	1.77	46	7	25	6	50	4	50	4	50	4	50
W	5218*	1	1.08-1.15	1.10	1.80	46	7	5	4	10	5	25	5	25	5	25
	5219	1	1.08-1.18	1.10	1.90	46	7	5	4	10	5[a]	25	5	25	5	25
	5205	1	1.10-1.15	1.12	1.85	46	7	5	4	10	5	25	5	25	5	25
X	5230*	1	1.05-1.20	1.10	2.80	982	10	0	10	6[a]	9	5[a]	8	25[a]	6	50[a]
	5232	1	1.00-1.20	1.12	2.87	982	10	0	10	6[a]	9	5[a]	8	25[a]	6	50[a]
	5231	1	1.05-1.25	1.14	2.89	982	10	0	10	6[a]	9	5[a]	8	25[a]	6	50[a]
Z	2203*	1	1.50-1.65	1.60	4.32	166	10	0	7	25	6	50	6	50	6	50
	2552	1	1.15-1.30	1.20	3.46	166	10	0	7	25	6	50	6	50	6	50
	2550	1	1.20-1.40	1.37	3.65	166	10	0	7	25	6	50	6	50	6	50
BB	5012*	1	1.10-1.20	1.14	2.60	144	10	0	6	5	4[a]	25	4	25	4	25
	5464	1	1.10-1.20	1.14	2.72	144	10	0	6	5	4	25	4	25	4	25
	5789	1	1.10-1.20	1.16	2.72	144	10	0	6	5	4	25	4	25	4	25
BC	5212*	1	1.00-1.02	1.00	2.57	—	10	0	10	0	10	0	10	0		
	5211	1	1.00-1.02	1.00	2.50	—	10	0	10	0	10	0	10	0		
	5228	1	1.00-1.02	1.00	2.50	—	10	0	10	0	10	0	10	0		

TABLE 2 (CONTINUED)

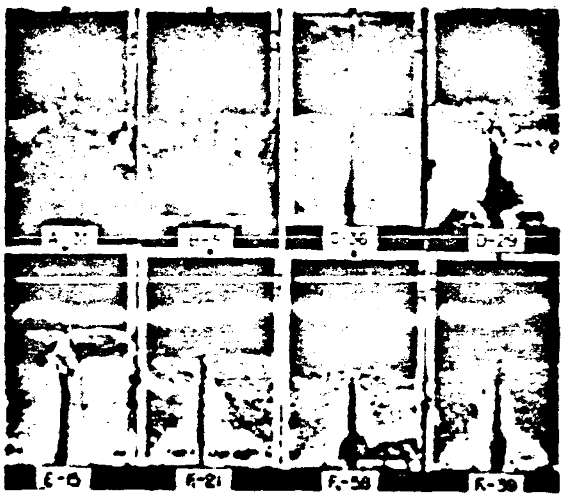
Designation	Panel No.	Number Of Coats	Film Thickness Range—Mils	Avg. Film Thickness—Mils	Film Wt.—Grams	Time To First Blisters—Hours	Blister Rating—Water Phase** 100 Hrs. Blister Size	100 Hrs. Per Cent Area Blistered	500 Hrs. Blister Size	500 Hrs. Per Cent Area Blistered	1000 Hrs. Blister Size	1000 Hrs. Per Cent Area Blistered	3000 Hrs. Blister Size	3000 Hrs. Per Cent Area Blistered	5000 Hrs. Blister Size	5000 Hrs. Per Cent Area Blistered
BD	5359*	1	1.05-1.10	1.08	2.16	46	6	25	5	50	5	50	5	50		
	5374	1	1.00-1.10	1.08	2.19	46	6	25	5	50	5	50	5	50		
	5356	1	1.05-1.10	1.08	2.19	46	6	25	5	50	5	50	5	50		
BE	5378*	1	1.10-1.25	1.16	2.81	144	10	0	7	5	6	25	6	25		
	5376	1	1.10-1.25	1.16	2.80	144	10	0	7	5	6	25	6	25		
	5377	1	1.10-1.20	1.16	2.80	144	10	0	7	5	6	25	6	25		
B	15*	1	0.95-1.20	1.08	1.27	16	6	75	2	80	1	100	1	100	0	100
	16	1	0.90-1.20	1.08	1.28	16	6	75	2	80	1	100	1	100	0	100
	23	1	1.00-1.30	1.08	1.28	16	6	75	2	80	1	100	1	100	0	100
C	59-20*	1	1.00-1.30	1.08	2.94	600	10	0	10	0	7	5	7	5	7	5
	59-21	1	1.02-1.30	1.10	2.91	600	10	0	10	0	7	5	7	5	7	5
	59-22	1	1.01-1.30	1.10	2.96	600	10	0	10	0	7	5	7	5	7	5
E	82-31*	1	1.27-1.40	1.37	3.43	260	10	0	9	5	7	25	6	30	4	75
	81-4	1	1.28-1.45	1.40	3.44	260	10	0	9	5	7	25	6	30	4	75
	81-24	1	1.21-1.52	1.40	3.32	260	10	0	9	5	7	25	6	30	4	75
G	85-10*	1	1.27-1.36	1.31	2.88	16	6	30	2	75	2	75	0	100	0	100
	85-7	1	1.28-1.36	1.33	2.97	16	6	30	2	75	2	75	0	100	0	100
	85-14	1	1.34-1.44	1.39	3.02	16	6	30	2	75	2	75	0	100	0	100
D	67-43*	1	1.21-1.34	1.26	3.39	500	10	0	9	1	8	5	8	5	8	5
	67-40	1	1.10-1.30	1.23	3.26	500	10	0	9	1	8	5	8	5	8	5
	68-36	1	1.30-1.61	1.40	4.02	100	9	1	9	1	8	5	8	5	8	5
I	88-27*	1	1.15-1.30	1.22	2.16	44	7	5	6	10	5	30	5	75	2	75
	88-26	1	1.15-1.25	1.24	2.15	44	7	5	6	10	5	30	5	75	2	75
	89-30	1	1.19-1.30	1.25	2.10	44	7	5	6	10	5	30	5	75	2	75
Q	5259*	2	1.00-1.40	1.08	1.84	—	10	0	10	0	10	0	10	0		
	5271	2	1.05-1.15	1.08	1.98	—	10	0	10	0	10	0	10	0		
	5280	2	1.00-1.30	1.08	2.05	—	10	0	10	0	10	0	10	0		

* [illegible]
[illegible]
[illegible]
[illegible]
[illegible]
** See ASTM [illegible] D 714-45 Pt. II, 1946 Standards, page 1171. Blister sizes are represented by numbers within the scale 0 to 10, in which 0 represents the presence of very large blisters and 10 represents no blistering 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.

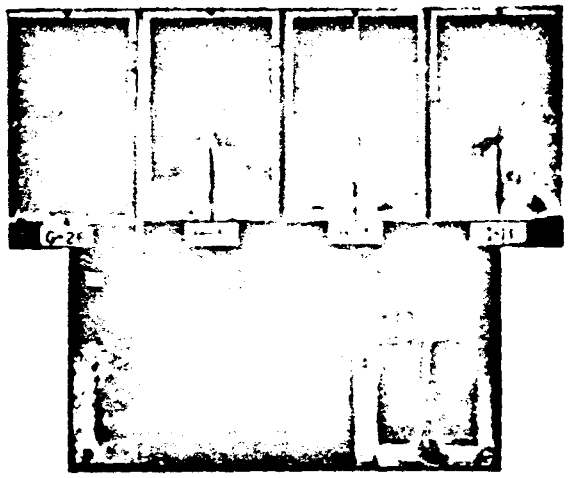
Photographs of the painted panels (damaged), after 3000 hours exposure for essentially all of the paint systems, are shown in Figs. 1, 2, 3, and 4. Systems H_5 (5 mils) and H_{10} (10 mils) are not shown, since they had the same appearance as H_{15} (15 mils) and O[illegible] was not tested in the damaged 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 100F for 3000 hours



60436, 60438

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

60440, 60436

Fig. 3—Condition of coated panels after exposure to continuous partial immersion in distilled water at 100F 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, indicate that only Systems C and C_6 (red lead); H_1, H_4, H_5, and H_6 (asphalt type); O (Zn chromate-red lead); and possibly BC (red lead-iron oxide-phenolic) and O_b (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

60439, 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 at 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, H_1, H_2, H_3, I, and possibly D afforded the greatest amount of protection, while Systems B, B_1, E, F_1, F_2, 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—Grams: Individual	Metal Loss—Grams: Average	Appearance of Base Metal** Undamaged Panel: Water Phase	Appearance of Base Metal** Undamaged Panel: Air Phase	Condition at Damaged Zone, Water Phase: Degree of Undercutting***	Condition at Damaged Zone, Water Phase: Degree of Penetration****	Blister Rating—1000 Hrs.: Blister Size	Blister Rating—1000 Hrs.: Per Cent Area Blistered
A	63-35*					D	D	0	100
	63-43	0.30		C	A			0	100
	63-39	0.28	0.29	B	A			0	100
B	70-5*					A	D	0	100
	70-8	0.91		D	A			0	100
	70-10	0.83	0.87	D	A			0	100
C	87-36*					A	B	8-9	1
	87-30	0.89		A	A			8-9	1
	87-33	0.86	0.87	A	A			8-9	1
D	66-29*					A	D	4-8	100
	66-31	0.20		C	A			4-8	100
	66-28	0.19	0.19	C	A			4-8	100
E	81-13*					A	D	6-8	75
	81-22	0.31		C	A			6-8	75
	81-21	0.33	0.32	C	A			6-8	75
F_1	78-21*					D	D	1	100
	78-31	0.32		C	A			1	100
	78-25	0.33	0.32	D	A			1	100
F_2	76-39*					B	D	1	100
	76-41	0.33		C	A			1	100
	76-35	0.31	0.32	D	A			1	100
F_3	80-30*					D	D	1	100
	80-64	0.29		C	A			1	100
	80-60	0.27	0.28	D	A			1	100

TABLE 3 (CONTINUED)

Designation	Panel No.	Metal Loss—Grams: Individual	Metal Loss—Grams: Average	Appearance of Base Metal** Undamaged Panel: Water Phase	Appearance of Base Metal** Undamaged Panel: Air Phase	Condition at Damaged Area, Water Phase: Degree of Undercutting***	Condition at Damaged Area, Water Phase: Degree of Penetration****	Blister Rating—1000 Hrs.: Blister Size	Blister Rating—1000 Hrs.: Per Cent Area Blistered
G	84-26*					D	D	2-4	100
	84-31	0.57		D	A			2-4	100
	84-28	0.58	0.57	D	A			2-4	100
H.	90-5*					A	D	9	1
	90-10	0.19		A	B			9	1
	90-9	0.25	0.22	A	B			9	1
H.	91-21*					A	D	10	0
	91-15	0.07		B	B			10	0
	91-13	0.07	0.07	B	B			10	0
H.	92-12*					A	D	10	0
	92-11	0.05		B	B			10	0
	92-4	0.03	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	0.03	B	B			10	0
I	88-11*					B	D	2	75
	88-14	0.11		A	A			2	75
	88-10	0.11	0.11	A	A			2	75
L	2182*					C	C	4	75
	2256			B	B			4	75
	2178			B	B			4	75
M	2240*					C	C	3	75
	2150			A	A			3	75
	2265			B	A			3	75
N	2170*					C	D	2	90
	2114			B	A			2	90
	2092			B	A			2	90
O	5340*					A	D	6	5
	5341			B	A			6	5
	5342			B	A			6	5
Q	2019*					A	D	4	25
	2034			C	A			4	25
	2022			C	A			4	25

TABLE 3 (CONTINUED)

Designation	Panel No.	Metal Loss—Grams		Appearance of Bare Metal** Undamaged Panel		Condition at Damaged Area Water Phase		Blister Rating—1000 Hour	
		Individual	Average	Water Phase	Air Phase	Degree of Undercutting***	Degree of Penetration****	Blister Size	Per Cent Area Blistered
R	2236*					B	D	5	25
	2151			A	A			5	25
	2228			A	A			5	25
S	2207*					C	C	1	90
	2218			A	A			1	90
	2084			C	A			1	90
T	2064*					D	C	1	90
	2065			A-	A			1	90
	2067			C	A			1	90
U	3320*					D	C	1	90
	3345			A	A			0	100
	3329			C	A			0	100
V	3276*					A	A-D'	4	30
	3277			A	A			4	30
	3297			B	A			4	30
W	3218*					A	A-D'	3	25
	3219			A	A			3	25
	3205			A	A			3	25
X	3230*					A	D	6	30
	3232			B	A			6	30
	3231			B'	A			6	30
Z	2283*					A	D	6	30
	2352			A	A			6	30
	2350			B	A			6	30
BB	3612*					B	D	4	25
	3404			B	A			4	25
	3778B			C	A			4	25
BC	3212*					A	C	10'	0'
	3211			A	A			10	0
	3228			A	A			10	0
BD	3359*					C	C	5	30'
	3374			A	A			5	30
	3356			A	A			5	30

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TABLE 3 (CONTINUED)

Designation	Panel No.	Metal Loss—Grams: Individual	Average	Appearance of Bare Metal** Undamaged Panel: Water Phase	Air Phase	Condition at Damaged Zone Water Phase: Degree of Undercutting***	Degree of Penetration****	Blister Rating—3000 Hrs.: Blister Size	Per Cent Area Blistered
BE	5578*					A	C	6	25ᵃ
	5576			A	A			6	25
	5577			A	A			6	25
B_4	58-15*					D[b]	D[b]	0	100
	58-16	3.02		D[b]	A			0	100
	58-23	2.35	2.68	D	A			0	100
C_4	59-20*					A	C	7	5
	59-21			A	A			7	5
	59-22			A	A			7	5
E	82-51*					B	C	4	75
	81-4	0.20		C	A			4	75
	81-34	0.28	0.24	B	A			4	75
G	83-10*					D	D	0	100
	83-7	0.25		C	A			0	100
	83-14	0.31	0.28	C	A			0	100
D	67-45*					C	D	8	5
	67-40	0.00		A	A			8	5
	68-56	0.01	0.01	B	A			8	5
I	86-27					D	D	2	75
	86-36	0.00		A	A			2	75
	89-30	0.04	0.02	A	A			2	75
O_4	5259*					Not Damaged		10	0[a]
	5271			A[c]	A[c]			10	0
	5289			A	A			10	0

* Intentionally damaged before test

** A Negligible attack
B Slight attack
C Moderate attack
D Severe attack

*** A No undercutting
B Slight
C Moderate
D Severe

**** A Negligible penetration into bare metal
B Slight
C Moderate
D Severe

[a] 3000 Hrs. exposure
[b] Localized attack
[c] Pitted
[d] Unusually severe attack
[e] Marked by severe general attack

TABLE 4

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

	Rating*															
	A				B				C				D			
Appearance of Base Metal in the water phase:	A E BB	C W C_1	H_1 BC O_1	I BD I	H_1 M T Z	H_1 N U D	H_1 O V	L S X	D G	E E	Q	BB	B G	F_1 B_1	F_1	F_1
Appearance of Base Metal in the air phase:	A E E G O T X BD E Q_1	B F_1 I Q U Z BE G	C F_1 M E V BB BA D	D F_1 N S W BC C_1 I	H_1 L	H_1	H_1	H_1								
Degree of undercutting at damaged zone in the water phase:	B H_1 W BE	C H_1 O X C_1	D H_1 Q Z	E H_1 V BC	F_1 I	E	BD	E	L BD	M D	N	S	A T I	F_1 U	F_1 B_1	G G
Degree of penetration at damaged zone in the water phase:					C				L U C_1	M BC E	S BD B**	T BE	A F_1 H_1 I E Z I	B F_1 H_1 N V BB	D F_1 H_1 O W	E G H_1 Q X

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

** General rusting was sufficiently severe on this panel to partially mask 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, B_x, E, F_1, F_2, F_3, 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 C_x (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 O_x, a two-coat system (same as O except baked), shows promise and might be equally as good or even better than C or C_x, 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 H_1, H_2, H_3, H_4, 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 H_1, H_2, H_3, H_4, F_1, F_2, and F_3).

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 5 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, C_2, H_1, H_2, H_3, H_4, 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, B_2, E, F_1, F_2, F_3, 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, H_4, and I afford excellent protection under these test conditions and are followed very closely by A, D, H_2, and H_3. Systems B, B_4, E, F_1, F_2, 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, C_4, 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, C_4, 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

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TABLE 5

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

							Blister Rating**									
							100 Hrs.		500 Hrs.		1000 Hrs.		2000 Hrs.		3000 Hrs.	
Designation	Panel No.	Number Of Coats	Film Thickness Range—Mils	Avg. Film Thickness—Mils	Film Wt.—Grams	Time To Form Blister—Hours	Blister Size	Per Cent Area Blistered	Blister Size	Per Cent Area Blistered	Blister Size	Per Cent Area Blistered	Blister Size	Per Cent Area Blistered	Blister Size	Per Cent Area Blistered
A	62-32*	1	1.11-1.21	1.16	3.49	645	10	0	10	0	10	0	8	50	8	50
	62-34	1	1.11-1.21	1.16	3.63	1175	10	0	10	0	10	0	8	50	8	50
	62-35	1	1.11-1.21	1.16	3.57	1175	10	0	10	0	10	0	8	50	8	50
B	70-9*	1	1.21-1.40	1.27	2.27	95	8	50	6-8	50	6-8	75	6	75	6	100
	70-12	1	1.16-1.39	1.28	2.28	95	8	50	6-8	50	6-8	75	6	75	6	100
	70-15	1	1.19-1.35	1.28	2.30	95	8	50	6-8	50	6-8	75	6	75	6	100
C	87-31*	1	1.13-1.56	1.34	4.15	1175	10	0	10	0	10	0	9	1	9	1
	87-28	1	1.22-1.35	1.25	4.82	1175	10	0	10	0	10	0	9-10	1	9	1
	87-29	1	1.19-1.39	1.25	4.88	1175	10	0	10	0	10	0	9-10	1	9	1
D	66-30*	1	1.20-1.40	1.25	3.56	955	10	0	10	0	9	5	9	5	9	5
	66-26	1	1.15-1.33	1.21	3.45	645	10	0	10	0	9	5	9	5	9	5
	67-41	1	1.17-1.30	1.22	3.35	955	10	0	10	0	9	5	9	5	9	5
E	81-19*	1	1.22-1.33	1.28	3.29	1175	10	0	10	0	10	0	7	75	7	75
	81-17	1	1.24-1.39	1.32	3.25	1175	10	0	10	0	10	0	7	75	7	75
	81-16	1	1.21-1.44	1.30	3.21	1175	10	0	10	0	10	0	7	75	7	75
F_1	78-18*	1	1.11-1.20	1.21	2.08	60	9	50	5	50	5	50	2-5	50	2-5	50
	78-22	1	1.19-1.28	1.24	2.10	60	8-9	50	5	50	5	50	2-5	50	2-5	50
	78-20	1	1.12-1.28	1.23	2.14	60	9	50	5	50	5	50	2-5	50	2-5	50
F_2	76-29*	2	2.65-2.75	2.68	4.29	95	10	0	8	25	4-6	50	4-5	50	4-5	50
	75-24	2	2.65-2.80	2.69	4.18	95	8	50	6	50	4-6	50	4-5	50	4-5	50
	75-14	2	2.65-2.80	2.69	4.26	95	10	0	8	25	4-6	50	4-5	50	4-5	50

TABLE 5 (CONTINUED)

Designation	Panel No.	Number Of Coats	Film Thickness Range—Mils	Avg. Film Thickness—Mils	Film Wt.—Grams	Time To First Blister—Hours	Blister Rating** 100 Hrs. Blister Size	100 Hrs. Per Cent Area Blistered	500 Hrs. Blister Size	500 Hrs. Per Cent Area Blistered	1000 Hrs. Blister Size	1000 Hrs. Per Cent Area Blistered	2000 Hrs. Blister Size	2000 Hrs. Per Cent Area Blistered	3000 Hrs. Blister Size	3000 Hrs. Per Cent Area Blistered
F	80-61*	1	2.80-3.00	2.89	2.43	95	8	20	6-8	25	3-6	50	2-4	50	2-4	50
	79-46	1	2.82-3.00	2.94	2.71	95	9	10	6-8	25	3-6	50	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	50	2-4	50	2-4	50
G	83-8*	1	1.28-1.39	1.33	2.86	95	8-9	50	6-8	75	4-6	75	4-6	75	4-6	75
	83-6	1	1.31-1.39	1.34	2.87	95	8	50	6-8	75	4-6	75	4-6	75	4-6	75
	83-25	1	1.33-1.39	1.36	2.87	95	8	50	6-8	75	4-6	75	4-6	75	4-6	75
H_1	90-5*	1	1.11-1.15	1.20	1.80	1000	10	0	10	0	9	1	9	1	9	1
	90-1	1	1.07-1.19	1.13	1.09	—	10	0	10	0	10	0	10	0	10	0
	90-7	1	1.07-1.25	1.12	1.05	—	10	0	10	0	10	0	10	0	10	0
H_2	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	4.32	—	10	0	10	0	10	0	10	0	10	0
	91-12	1	4.9-6.4	5.5	4.70	—	10	0	10	0	10	0	10	0	10	0
H_3	92-2*	1	9.7-10.7	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
H_4	95-5*	1	14.0-17.0	15.6	12.89	—	10	0	10	0	10	0	10	0	10	0
	95-6	1	13.0-16.2	15.4	13.44	—	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	88-5*	1	1.15-1.28	1.20	2.00	1000	10	0	10	0	9	3	9	5	9	5
	88-9	1	1.15-1.28	1.22	2.16	1512	10	0	10	0	10	0	9	5	9	5
	88-6	1	1.18-1.28	1.21	2.15	1512	10	0	10	0	10	0	9	5	9	5
L	3168*	1	1.20-1.40	1.35	3.05	599	10	0	10	0	9	1	7	5	7	5
	2120	1	1.25-1.30	1.28	3.05	599	10	0	10	0	9	1	7	5	7	5
	2179	1	1.20-1.35	1.30	3.10	599	10	0	10	0	9	1	7	5	7	5

TABLE 5 (CONTINUED)

Designation	Panel No.	Number Of Coats	Film Thickness Range—Mils	Avg. Film Thickness —Mils	Film Wt. —Grams	Time To First Blister —Hours	Blister Rating** 100 Hrs. Blister Size	100 Hrs. Per Cent Area Blistered	500 Hrs. Blister Size	500 Hrs. Per Cent Area Blistered	1000 Hrs. Blister Size	1000 Hrs. Per Cent Area Blistered	2000 Hrs. Blister Size	2000 Hrs. Per Cent Area Blistered	3000 Hrs. Blister Size	3000 Hrs. Per Cent Area Blistered
M	2239*	1	1.20-1.35	1.30	2.14	44	8	1	8	1	8	1	6	5	6	5
	2234	1	1.20-1.40	1.25	2.16	44	8	1	8	1	8	1	6	5	6	5
	2240	1	0.95-1.10	1.05	2.05	44	9	1	9	1	9	1	7	5	6	5
N	2125*	1	1.10-1.22	1.20	2.52	44	8	25	8	25	7	50	5	75	4	75
	2115	1	1.20-1.40	1.38	2.64	44	8	25	8	25	7	50	5	75	4	75
	2096	1	1.25-1.40	1.30	2.73	44	8	25	8	25	7	50	5	75	4	75
O	5344*	2	1.00-1.30	1.06	1.91	77	9	1	9	1	9	1	8	5	8	5
	5270	2	1.00-1.15	1.02	1.88	77	9	1	9	1	9	1	8	5	8	5
	5263	2	1.00-1.10	1.05	2.06	77	9	1	9	1	9	1	8	5	8	5
Q	2025*	2	1.05-1.20	1.10	No Data	77	9	1	9	1	7	5	7	5	7	5
	2134	2	1.05-1.30	1.18	"	77	9	1	9	1	8	5	6	5	6	5
	2245	2	1.05-1.30	1.20	"	77	9	1	9	1	8	5	7	5	7	5
R	2221*	1	1.35-1.45	1.39	2.05	—	10	0	10	0	10	0	10	0	10	0
	2210	1	1.40-1.50	1.48	2.23	—	10	0	10	0	10	0	10	0	10	0
	2057	1	1.35-1.45	1.40	2.17	—	10	0	10	0	10	0	10	0	10	0
S	2040*	1	1.40-1.50	1.42	3.50	16	9	25	6	50	6	50	4	50	2	75
	2039	1	1.40-1.60	1.42	3.40	16	9	25	7	50	7	50	4	50	2	75
	2038	1	1.35-1.60	1.45	3.63	16	9	25	7	50	6	50	4	50	2	75
T	2149*	1	1.05-1.20	1.10	2.13	16	5	50	7	50	5	50	3	75	1	90
	2001	1	0.95-1.10	1.05	1.97	16	6	50	5	50	5	50	4	75	1	90
	2000	1	1.00-1.20	1.10	2.12	16	5	50	5	50	5	50	5	75	1	90
U	5335*	1	1.20-1.35	1.25	2.80	16	8	5	7	10	6-7	25	5-7	50	2-6	75
	5260	1	1.20-1.40	1.25	2.86	16	8	5	7	10	6-7	25	5-7	50	2-6	75
	5334	1	1.10-1.30	1.25	2.80	16	7	5	7	10	5-7	25	5-7	50	2-6	75

TABLE 5 (CONTINUED)

Designation	Panel No.	Number Of Coats	Film Thickness Range—Mils	Avg. Film Thickness—Mils	Film Wt—Grams	Time To Form Blister—Hours	Blister Rating** 100 Hrs. Blister Size	Per Cent Area Blistered	500 Hrs. Blister Size	Per Cent Area Blistered	1000 Hrs. Blister Size	Per Cent Area Blistered	2000 Hrs. Blister Size	Per Cent Area Blistered	3000 Hrs. Blister Size	Per Cent Area Blistered
Z	2317*	1	1.50-1.65	1.60	4.59	—	10	0	10	0	10	0	10	0	10	0
	2366	1	1.30-1.60	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	1.28	16	5[a]	30	5	30	5[a]	30	5	30	5	30
	24	1	1.02-1.30	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	1.00-1.30	1.08	2.96	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	1.01-1.35	1.05	2.67	500	10	0	9	1	9	1	9	1	9	1
D	67-43*	1	1.13-1.40	1.25	3.37	—	10	0	10	0	10	0	10	0	10	0
	60-54	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	1.45	3.83	1100	10	0	10	0	10	0	9	1	9	1
E	82-30*	1	1.28-1.49	1.37	3.24	1272	10	0	10	0	10	0	9	1	9	3
	81-25	1	1.31-1.55	1.43	3.55	1272	10	0	10	0	10	0	9	1	9	3
	82-33	1	1.36-1.47	1.40	3.45	1272	10	0	10	0	10	0	9	1	9	3
G	83-11*	1	1.33-1.46	1.40	2.96	44	9	1	8[a]	3	7	3	6	3	6	3
	83-16	1	1.37-1.47	1.30	3.04	44	9	1	7	3	7	3	6	3	6	3
	83-17	1	1.34-1.47	1.30	2.97	44	9	1	7	3	7	3	6	3	6	3
I	88-28*	1	1.16-1.27	1.24	2.79	776	10	0	10	0	9	1	9	1	9	1
	89-29	1	1.17-1.26	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

* [illegible]

[a] [illegible]

[b] [illegible]

** See ASTM Specification D 714-45, Pt. II, 1946 Standards, page 1171. Blister sizes are expressed by numbers within the scale of 0 to 10, in which 0 represents the presence of very large blisters and 10 represents no blistering under the test conditions.

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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.	Metal Loss—Grams		Appearance of Base Metal**	Condition at Damaged Zone		Blister Rating—3000 Hrs.	
		Ind.	Avg.	[illegible] Panel	Degree of Undercutting***	Degree of Penetration****	Blister Size	Per Cent Area Blistered
A	62-32*				C	B	8	30
	62-34	0.06		A			8	30
	62-33	0.08	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	87-31*				A	A	9	1
	87-28	0.08		A			9	1
	87-29	0.05	0.06	A			9	1
D	66-30*				B	B	9	3
	66-26	0.08		A			9	3
	67-41	0.08	0.08	B			9	3
E	81-19*				C	B	7	75
	81-17	0.12		B			7	75
	81-16	0.10	0.11	B			7	75
F_1	78-18*				B	A	2-3	50
	78-22	0.13		C			2-3	50
	78-20	0.14	0.13	C			2-3	50
F_2	76-29*				B	A	4-5	50
	75-24	0.06		B			4-5	50
	75-14	0.14	0.10	C			4-5	50
F_3	80-61*				B	A	2-4	50
	79-46	0.22		D			2-4	50
	80-55	0.12	0.17	C			2-4	50
G	85-8*				B	B	5-6	75
	85-6	0.12		B			5-6	75
	85-25	0.10	0.11	B			5-6	75
H_1	90-5*				A	C	9	1
	90-1	0.12		B			10	0
	90-7	0.12	0.12	B			10	0
H_2	91-14*				A	C	10	0
	91-11	0.04		B			10	0
	91-12	0.04	0.04	B			10	0
H_3	92-2*				A	C	10	0
	92-3	0.05		B			10	0
	92-1	0.04	0.04	B			10	0
H_4	95-5*				B	B	10	0
	95-6	0.00		B			10	0
	95-3	0.02	0.01	B			10	0
I	88-5*				A	A	9	3
	88-9	0.00		A			9	3
	88-6	0.05	0.02	A			9	3
L	2160*				A	B	7	3
	2120			B			7	3
	2179			B			7	3

TABLE 6 (CONTINUED)

Designation	Panel No.	Metal Loss—Grams Ind	Metal Loss—Grams Avg	Appearance of Bare Metal** Undamaged Panel	Condition at Damaged Zone: Degree of Undercutting***	Condition at Damaged Zone: Degree of Penetration****	Blister Rating—1000 Hrs: Blister Size	Blister Rating—1000 Hrs: Per Cent Area Blistered
M	2239*				A	B	6	5
	2238			A			6	5
	2243			A			6	5
N	2125*				B	B	4	75
	2115			C			4	75
	2096			C			4	75
O	5344*				A	B	8	5
	5270			B			8	5
	5265			B			8	5
Q	2025*				A	B	7	5
	2134			C			6	5
	2209			C			7	5
R	2221*				B	B	10	0
	2210*			A			10	0
	2047			A			10	0
S	2040*				A	A	2	75
	2039			A			2	75
	2038			A			2	75
T	2149*				A	B	1	90
	2001			C			1	90
	2000			C			1	90
U	5355*				B	B	3-6	75
	5260			C			3-6	75
	5154			C			3-6	75
Z	2317*				A	B	10	0
	2280			B			10	0
	2187			B			10	0
B	56-17*				A	B	5	50
	56-24	0.89		C			5	50
	56-25	0.75	0.82	C			5	50
C	59-21*				A	A	9	1
	59-14			A			9	1
	59-8			A			9	1
D	67-43*				B	B	10	0
	66-54	0.05		B			10	0
	66-55	0.10	0.07	B			9	1
E	82-30*				B	B	9	5
	81-25	0.08		B			9	5
	82-33	0.07	0.07	B			9	5
G	81-9*				A	A	6	5
	81-16	0.00		A			6	5
	81-17	0.03	0.02	B			6	5
I	86-28*				A	A	9	1
	89-31	0.00		A			9	1
	86-29	0.00	0.00	A			9	1

* Intentionally damaged before test

** A Negligible attack
B Slight attack
C Moderate attack
D Severe attack

*** A No undercutting
B Slight
C Moderate
D Severe

**** A Negligible penetration into bare metal
B Slight
C Moderate
D Severe

* Top part of panel

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 R M	C S	I C	M I	D M O G	E M Z	G D	M L E	B N R	F Q	R T	R U	
Degree of undercutting at the damaged zone	C I Q R I	M L S C	M M T E	M O Z G	D G U	R M D	R N E	F R	A	B	E		
Degree of penetration at damaged zone	C I I	F S	F C	F G	A G N T D	B M O U E	D L Q Z	E M R R	M	M	M		—

* Value of Ratings A, B, C, and D are shown in Table 8.

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 F_1, and all three panels for Coating H_2. 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 attacks 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, F_1, F_2, F_3, G, H_1, 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 H_2, H_3, and H_4 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

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TABLE 8

Coating and Blister Data for Painted Panels Exposed to Alternate Wet and Dry Conditions for 7300 Hours

Paint Code Designation	Panel No.	Number of Coats	Film Thickness Range, Mils	Avg. Film Thickness, Mils	Film Wt., Grams	Min. Time to First Blister	Blister Rating**	
							Blister Size	Area Blistered Per Cent
A	65-49*	1	1.17-1.24	1.22	3.61	6100	8	1
	65-45	1	1.15-1.24	1.20	3.54	—	10	0
	62-37	1	1.17-1.26	1.23	3.60	—	10	0
B	71-20*	1	1.27-1.42	1.37	2.42	5545	8	1
	71-19	1	1.24-1.40	1.36	2.40	—	—	—
	71-18	1	1.26-1.45	1.36	2.38	—	—	—
C	86-22*	1	1.22-1.45	1.55	4.36	—	10	0
	86-21	1	1.24-1.44	1.55	4.55	—	10	0
	86-20	1	1.29-1.45	1.52	4.26	—	10	0
D	66-35*	1	1.22-1.41	1.24	3.52	—	10	0
	66-34	1	1.21-1.42	1.25	3.47	—	10	0
	66-33	1	1.07-1.42	1.22	3.42	—	10	0
E	82-34*	1	1.32-1.54	1.45	3.47	—	10	0
	81-11	1	1.36-1.54	1.50	3.45	—	10	0
	81-7	1	1.33-1.54	1.44	3.46	—	10	0
F_1	79-34*	1	1.25-1.38	1.32	2.25	5545	8	1
	79-33	1	1.22-1.37	1.32	2.17	—	10	0
	79-32	1	1.26-1.38	1.34	2.23	—	10	0
F_2	75-21*	2	2.55-2.67	2.64	4.15	—	10	0
	75-20	2	2.50-2.70	2.62	4.19	—	10	0
	75-18	2	2.55-2.70	2.61	4.21	—	10	0
F_3	80-71*	1	2.86-3.05	3.02	4.66	—	10	0
	80-72	1	3.00-3.05	3.02	4.75	—	10	0
	80-70	1	3.00-3.05	3.01	4.86	—	10	0
G	84-32*	1	1.25-1.34	1.31	2.80	—	10	0
	83-24	1	1.25-1.37	1.28	2.79	—	10	0
	83-25	1	1.22-1.34	1.30	2.80	—	10	0
H_1	90-20*	1	1.07-1.11	1.08	0.99	6100	8	3
	90-18		1.05-1.09	1.75	0.99	6100	8	3
	90-16		1.07-1.11	1.09	1.20	6100	8	5
H_2	91-10*	Sprayed	5.5-7.5	6.6	5.25	—	10	0
	91-9		4.9-7.6	6.2	4.95	—	10	0
	91-8		4.8-7.5	6.7	5.18	—	10	0
H_3	92-20*	Sprayed	9.5-11.0	10.8	8.45	—	10	0
	92-16		9.5-11.0	10.5	8.85	—	10	0
	92-6		8.7-11.0	10.1	8.40	—	10	0
H_4	93-9*	Sprayed	14.0-17.0	15.2	13.51	—	10	0
	93-8		14.0-17.0	15.3	13.64	—	10	0
	93-7		14.0-17.0	16.1	13.58	—	10	0
J	88-21*	1	1.18-1.28	1.25	2.04	—	10	0
	88-20	1	1.19-1.30	1.22	2.15	—	10	0
	88-16	1	1.19-1.30	1.25	2.12	—	10	0

* Intentionally Damaged Before Test

** See Table I.

TABLE 9

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

Designation	Panel No.	Metal Loss, Grams		Appearance of Base Metal**	Condition at Damaged Zone		Blister Rating	
		Ind	Avg	Undamaged Panel	Degree of Undercutting***	Degree of Penetration****	Blister Size	Area Rusted Per Cent
A	63-49*	—	—	—	D	A	6	1
	63-45	0.05	—	B	—	—	10	0
	62-57	0.02	0.02	B	—	—	10	0
B	71-20*	—	—	—	D	A	6	1
	71-19	0.52	—	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	66-35*	—	—	—	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
F1	79-34*	—	—	—	D	A	8	1
	79-33	0.10	—	C	—	—	10	0
	79-32	0.12	0.13	C	—	—	10	0
F2	73-27*	—	—	—	D	A	10	0
	73-20	0.10	—	B	—	—	10	0
	73-18	0.06	0.08	B	—	—	10	0
F3	80-73*	—	—	—	D	A	10	0
	80-72	0.00	—	A	—	—	10	0
	80-70	0.00	0.00	A	—	—	10	0
G	84-32*	—	—	—	D	A	10	0
	83-24	0.01	—	B	—	—	10	0
	83-23	0.02	0.01	B	—	—	10	0
H1	90-20*	—	—	—	C	B	8	3
	90-18	0.43	—	C	—	—	8	3
	90-16	0.40	0.42	C	—	—	8	3
H2	91-10*	—	—	—	A	B	10	0
	91-9	0.00	—	A	—	—	10	0
	91-8	0.00	0.00	A	—	—	10	0
H3	92-30*	—	—	—	A	B	10	0
	92-16	0.00	—	A	—	—	10	0
	92-6	0.00	0.00	A	—	—	10	0
H4	93-9*	—	—	—	A	B	10	0
	93-8	0.00	—	A	—	—	10	0
	93-7	0.00	0.00	A	—	—	10	0
I	88-21*	—	—	—	D	A	10	0
	88-20	0.05	—	B	—	—	10	0
	88-16	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 Banroc).

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 (H_1 and H_2) or those whose pigment is essentially red lead or zinc chromate, alone or in combination (C, C_4, O, O_6, 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, C_4), or predominately so (BC, BD, BE), or contained zinc chromate (I, R, W, and O_6). The asphaltum-type paints (H_1, H_2, H_3, H_4) 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

	Range* A				Range* B				Range* C				Range* D			
Appearance of base metal	C F H	D G	E H	H	A I		F	G	H	F			B			
Degree of undercutting at the damaged zone	C	H	H	H	D				H				A F	B B	E G	F I
Degree of penetration at damaged zone	A E G	B F I	C B	D B	H	H	H	H								

* Values of Ranges A, B, C, and D are shown in Table 5.

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

Paint Designation	Panel No.	Time to First Blister, Hours	Blister Rating**—Contact With Neutral-Type Insulation: Below Water Line, Blister Size	Below Water Line, Per Cent Area	Above Water Line, Blister Size	Above Water Line, Per Cent Area	Panel No.	Time to First Blister, Hours	Blister Rating**—Contact With Alkaline-Type Insulation: Below Water Line, Blister Size	Below Water Line, Per Cent Area	Above Water Line, Blister Size	Above Water Line, Per Cent Area
B	38-4*	100	2	90	2	90	38-18*	100	2	75	2	75
	38-6	100	2	90	2	90	38-22	100	2	75	2	75
	38-8	100	2	90	2	90	38-12	100	2	75	2	75
C	86-10*	—	10	0	10	0	86-6*	210	10	0	9	1
	86-11	—	10	0	10	0	86-7	—	10	0	10	0
	86-12	—	10	0	10	0	86-8	—	10	0	10	0
C	39-9*	—	10	0	10	0	39-1*	210	10	0	7	5
	39-10	—	10	0	10	0	39-2	210	10	0	9	1
	39-11	—	10	0	10	0	39-4	—	10	0	10	0
D	63-4*	360	6	50	10	0	63-1*	100	4	30	7	30
	63-5	360	6	75	10	0	63-2	100	4-8	75	8	30
	63-6	360	6	75	10	0	63-3	100	3	30	6	30
G	84-37*	100	1	100	1	100	83-15*	100	2	75	2	75
	83-11	100	1	109	1	100	84-35	130	0	100	2	75
	84-27	100	1	100	1	100	83-12	100	2	75	2	75
H	90-19*	—	10	0	10	0	90-25*	—	10	0	10	0
	90-21	—	10	0	10	0	90-15*	—	10	0	10	0
	90-4	—	10	0	10	0	90-14	—	10	0	10	0
H	91-17*	—	10	0	10	0	91-19	—	10	0	10	0
	91-25	—	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)

Paint Designation	Panel No.	Time to First Blister, Hours	Blister Rating**—Coatings With [illegible] Type Insulation: Below Water Line, Blister Size	Below Water Line, Per Cent Area	Above Water Line, Blister Size	Above Water Line, Per Cent Area	Panel No.	Time to First Blister, Hours	Blister Rating**—Coatings With [illegible] Type Insulation: Below Water Line, Size Blister	Below Water Line, Per Cent Area	Above Water Line, Blister Size	Above Water Line, Per Cent Area
F	5042*	100	7	30	8	30	5695	100	6	75	5	75
	5034	130	8	30	8	30	5339	100	8	75	8	75
	5335	100	8	30	8	30	5403	100	8	75	8	75
O	5269*	240	8	1	10	0	5273	100	9	1	9	1
	5286	240	8	1	10	0	5276	100	9	1	9	1
	5274	240	8	1	10	0	5258	100	9	1	9	1
Q	5287*	430	7	1	10	0	5288	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
R	2122*	—	10	0	10	0	2150	—	10	0	10	0
	2214	—	10	0	10	0	2255	—	10	0	10	0
	2215	—	10	0	10	0	2225	—	10	0	10	0
X	5223*	100	6	30	10	0	5237	100	4	75	6	50
	5224	100	8	10	10	0	5243	210	7	30	9	30
	5222	100	8	10	10	0	5244	210	7	75	9	30
X_1	5413*	430	6	30	10	0	5417	400	5	30	8	25
	5418	430	6	30	10	0	5722	400	7	30	9	25
	5775	—	6	30	10	0	5690	400	4	30	9	25
BC	5386*	430	9	3	10	0	5380	—	10	0	10	0
	5384	430	9	3	10	0	5387	—	10	0	10	0
	5385	430	9	3	10	0	5346	—	10	0	10	0

* Intentionally damaged before storage.
** See Table 2
[illegible] in Table 1. [illegible]
[illegible]
[illegible]

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-raw linseed oil vehicle (C[illegible]) 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 (O[illegible]) 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 C[illegible]) when considering protection at the damaged zone. Coatings in which the pigment was predominantly iron oxide (B, B[illegible], F_1, F_2, F[illegible]) 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 (C[illegible]), which was formulated with a linseed oil vehicle, offers more protection, in most cases, than the one formulated with a phenolic modified alkyd (A).

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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, 3 (1947), page 501.

[3] Kittelberger, 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 Continuity of Synthetic Coatings—Test Methods, Ind. Eng. Chem., 29, 1277 (1937).

[5] Doty, 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] Woolley, 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, 158, 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 Stds., 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

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

[15] Changes in Protective Properties of Organic Coatings on Steel Surfaces When Subjected to Immersion, ASTM Standards, 1944 Supplement, BS II (ES-55), 1189.