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Gibbons, E. V.

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BEHAVIOUR OF ORGANIC COATINGS ON HYDROCARBON FUEL STORAGE DRUMS -- A PROGRESS REPORT

by

E. V. Gibbons

Internal Report No. 292

of the

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PREFACE

The Division became involved in the studies of the Group on Drum Storage of Fuels through the participation of its Paint Laboratory when it was decided to study the possible improvements that might be achieved through the coating of steel fuel storage drums. The work carried out on the selection and preparation of coatings, the supervision of the manufacture of test drums, and subsequent examination of a portion of these after five years of exposure are now reported. The filling and fuel testing were carried out by others participating in the work of the Group. Examinations will be made of the interior coatings of the remaining drums, still under exposure, at the end of 7 years (1964) and 10 years (1967).

All of the work done to the end of the five-year exposure period was carried out under the immediate direction of Mr. John Harris, senior officer in the Paint Laboratory. Much credit is due to him for the way in which this portion of the work was carried out. The work was taken over by Mr. E. V. Gibbons, Head of the Organic Materials Section when Mr. Harris left the Division to accept another position. Mr. Gibbons, the author of this report, was responsible for the final inspections and the evaluation of the results to date.

Ottawa
April 1964

N. B. Hutcheon
Assistant Director

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BEHAVIOUR OF ORGANIC COATINGS ON HYDROCARBON FUEL STORAGE DRUMS -- A PROGRESS REPORT

by E. V. Gibbons

Aviation has for more than 30 years been closely associated with all activities requiring transport in the Canadian North. This has always required the establishment of caches of fuel at strategic locations throughout the North. Only a few of the larger settlements could be expected to meet fuel needs through established commercial outlets and for many years fuel was handled and stored almost exclusively in steel drums, often for prolonged periods. With the further development of aviation and other activities in the North there was the need for increased quantity, quality, and variety of fuels, and this, together with economic considerations, indicated the need for improvement in drum storage. Since the over-all problem was one of concern to several agencies, a joint study was indicated. Representatives from the NRC Division of Mechanical Engineering, the Royal Canadian Air Force and oil companies formed the Group on Drum Storage of Fuels. When the Group reached the stage of considering improvements in drum storage by means of special coatings, the participation of the Paint Laboratory of the NRC Division of Building Research was solicited. The studies now reported were undertaken by this Division as a contribution to the program sponsored by the Group.

The work encompassed studies which would enable the most suitable selection to be made of different interior and exterior organic coatings for the steel drums. The drums were to be used for the long-term storage caches of aviation and motor equipment fuels in northern parts of Canada. The coatings were required to provide protection against corrosion and damage from impact in handling, particularly at low temperatures. In addition, the interior coatings were required to not affect the fuels nor to deteriorate during storage. Protection for periods as long as ten years was envisioned. The project was shared jointly with the Fuels and Lubricants Laboratory of the NRC Division of Mechanical Engineering. It was the responsibility of DBR to select the coatings for the long-term exposure trials, arrange for the fabrication of the drums, their inspection and application of the various coatings. The Fuels and Lubricants Laboratory selected the fuels to be used, and arranged for the filling of the drums and periodic inspection of the fuels after prescribed periods of exposure.

The field testing program of the coated and fuel-filled drums was preceded by a comprehensive laboratory evaluation of several different exterior and interior coatings. Those coatings showing the most promise were eventually selected for application to the test drums.

EXTERIOR COATINGS

In the preliminary program it was believed that the following characteristics of a coating were required for acceptance:

(a) good exterior durability
(b) good resistance to gasoline and water
(c) good flexibility and hardness
(d) good retention of gloss and colour without excessive chalking.

A series of enamels was prepared in three colours, red, black and white. The non-volatile vehicles in this initial series included oil-modified alkyd resins of both the baking and air-drying types, phenolated alkyd resins, styrenated alkyd resins, epoxy ester resins and catalytically cured epoxy resins. The enamels made with these resins for testing purposes were applied to 4- by 6-in. panels of 24-gauge, SAE 1020, cold-rolled steel. All coatings were applied by spraying to give a dried film thickness of 1.4 ± 0.2 mil. Each enamel was tested for gasoline resistance, water resistance, flexibility, hardness, accelerated weathering and exterior durability.

The results of the laboratory tests performed on these enamels did not reveal any vehicle which had markedly superior properties over the others. The results indicated that all of them had good flexibility, hardness, water resistance and gasoline resistance. The results obtained after outdoor exposure were more informative in establishing a trend.

The exterior exposure of those enamels based on air-drying, medium length, oil-modified alkyds, showed them to have good initial gloss values, fair gloss retention and chalk resistance properties. Severe whitening occurred with the solid colours over a 15-month exposure period. With the remaining 4 vehicles, although initial gloss was acceptable, gloss retention and chalk resistance properties were poor. In general the white enamels formulated from any of the vehicles selected for these initial tests had superior over-all properties when compared with the corresponding black and red enamels.

From these preliminary results white alkyd enamels of the baking and air-drying types along with a styrenated alkyd and a phenolated alkyd were chosen for the long-term field tests. A baking-type vinyl (which had shown good performance in other test programs) was added to this selection.

The exterior paints systems chosen for application to drums are shown in Table I and their formulations are included in Appendix A.

INTERIOR COATINGS

Preliminary studies were also undertaken to evaluate the performance of several different interior coatings that from previous experience had shown possibilities of giving satisfactory performance. The interior coatings were also expected to give protection for periods as long as 10 years and in addition have good resistance to solution by the fuel being stored, corrosion, and fracture by impact at low temperature.

Two series of clear coatings were evaluated in these initial studies. The first series was of an exploratory nature (1) and was applied to 20-gauge SAE 1010, cold-rolled steel. The test panels were dip-coated to provide a dried film thickness of 0.2 mil. After the required baking schedule or, in the case of the air-drying coatings after drying for one week at 73 ± 3.5°F and 50 ± 5 per cent relative humidity, the panels were subjected to tests to measure gasoline resistance, reverse impact at low temperature, corrosion resistance, and resistance to steam and alkali.

Based on the performance of the first series, a second series of a more comprehensive group of formulations was prepared. This group included phenolic-epoxy, phenolic-polyvinyl butyral and several plasticized vinyl chloride-vinyl acetate copolymer formulations. These coatings were applied to 24-gauge, SAE 1020 cold-rolled steel in dried film thicknesses of 0.5 ±0.1 mil. They were tested in a similar manner to the first series except that the reverse impact tests were performed at 32°F, -4°F, and -13°F. The use of the wash-primed steel surface and of a phosphatized surface to improve adhesion and corrosion resistance was also investigated.

It was found that several coatings withstood the reverse impact test at -13°F when the surface was wash-primed. The phosphatized surface did not improve the results in the reverse impact test, but it did improve the corrosion resistance properties of the system. All of the coatings tested showed excellent resistance to gasoline. On the basis of these results, surface pretreatment of the drums was recommended for the field trials in conjunction with the interior coating shown in Table II. The composition of these different coatings is given in Appendix B.

SURFACE PREPARATION OF THE STEEL

Four types of surface preparation were believed to be essential for the field testing program:

1. Plain, clean, degreased steel and designated as "S". To obtain this condition, rust-free surfaces of metal were vapour degreased to remove all dirt and grease. An acceptable surface was one that did not produce a water break when wetted with distilled water.

2. Grit-blasted surfaces designated "G". The clean vapour degreased steel was grit blasted with No. 30 alumina grit to produce a shallow texture. No areas of the original surface were allowed to remain.

3. Phosphated surfaces designated "P". The clean vapour degreased steel was treated to produce a zinc phosphate coating of 150 milligrams per square foot. The correct quantity of this coating was ensured by the preparation of test panels for laboratory examination to comply with CGSB Specification 31-GP-105 at the time of processing.

4. Wash-primed surfaces designated "W". A vinyl wash primer similar to 1-GP-121 was applied to clean, vapour degreased steel to a film thickness of 0.2 to 0.3 mil. It was allowed to dry a minimum of 1 hr, but not more than 2 hr prior to the application of the designated coating.

DRUMS, MANUFACTURE AND MARKING

The manufacture of the substantial number of drums required for the exposure test program posed a special problem in view of the small length of run on any one combination of coatings, and of the substantial number of different coatings being considered. After considerable negotiation arrangements were made with a manufacturer possessing the necessary equipment and experience to carry out the work required under contract. Continuous close supervision and inspection were provided by the research officer in charge of the project.

The cylindrical, 45-gallon drums were fabricated from 16-gauge, cold-rolled, rust-free steel. The side seams were arc-welded, the end seams were pressure formed after application of a hydrocarbon-resistant sealant compound. One end of the drum was provided with one-$2\frac{1}{2}$ in. and one 1-in. bung hole. The other end had stamped and raised identification in the form of letters and numbers. For example, with the stamped marking "WS11", the first letter refers to the internal surface treatment of the steel, the second letter to the external surface treatment, and the last two figures represent the number of the internal and external coating system that was used. Reference is made to this code in Table III. The body and ends of the drums were preformed and coated separately in accordance with the coating requirements. Assembly was carried out as soon as possible to preserve the cleanliness of the coated surface. The drums were also numbered consecutively on one end and the body. A total of 288 drums was fabricated. This enabled 12 groups to be provided in which a different interior and exterior coating was applied on the appropriate surface finish. From the 24 drums of each group prepared, 18 were selected that complied in detail with the requirements laid down. The extra drums were to be available for any tests subsequently believed necessary.

APPLICATION OF INTERIOR COATINGS

Six clear interior coatings were applied to three steel surfaces which were either a wash-primed plain steel, a grit-blasted or a phosphated surface. The coatings were applied to give a dry film thickness of 1.0 to 1.2 mil. Application was by spray to give uniform films free from bubbles, blisters, or other imperfections. An air-drying period was provided prior to baking for the elimination of solvent as detailed in Table II. The wash primer was used with the coatings 11026B, 11042B and 10965.

APPLICATION OF EXTERIOR COATINGS

Five drum enamels and two priming paints were used in the exterior paint systems. The priming paints were applied at a dry film thickness between 1.0 to 1.2 mil. All of the alkyd enamel topcoats were applied at a dry film thickness of 1.5 ± 0.1 mil. The vinyl topcoat was applied at a dry film thickness between 1.0 and 1.2 mil. To facilitate application of the exterior paint system the drums were classified into 12 groups. Details of the coatings and their curing are given in Tables I and III.

OUTDOOR EXPOSURE OF FUEL DRUMS

For the field tests 168 drums of the 288 coated were filled with different fuels and set out at the Ottawa exposure site of the DBR. This site provided a wide range of temperature conditions as well as a convenient location for periodic examination of the coatings and sampling of the fuels. To receive these drums the area required to accommodate them was covered with a coarse crushed rock. An earthen dike was pushed up around this area to serve as a fire-break and to retain any large quantities of fuel released by accident. Wooden racks were placed in 4 rows that held the drums off the ground in a horizontal position. The $2\frac{1}{2}$-in. bung was placed at 3 o'clock (Figure 1).

Three different types of hydrocarbon fuel were selected by the Fuels Laboratory: Aviation Gasoline Turbine Fuel Type II (Jet Fuel), Aviation Gasoline, Grade 100/130 and Automotive Combat Gasoline. The drums were filled during the late summer and early fall of 1957. A few drums developed leaks shortly after being filled. These were replaced with others as shown in Table III. Analyses of the fuels, after prescribed periods of exposure, have been made and are included in reports issued by the NRC Division of Mechanical Engineering (2, 3).

RESULTS

Exterior Coatings

The exterior coatings of the drums were first examined in detail during July 1959, about two years after application and the start of their outdoor exposure. They were examined again in August 1960, September 1961, and August 1963. Each drum was examined for the appearance of cracking, peeling, rusting, and chalking of the coating. The location of any failure was noted and the extent to which it was occurring was estimated and recorded. Blistering tendencies were also assessed with respect to density, size of blister, and type.

The field examinations were made by one observer. In addition, each drum had been placed at random on the exposure site racks with respect to the fuel it contained and its exterior coating. This enabled independent observations to be made of the drums with the same coating system and also of the performance of the different paints under test. Following the 1963 examination, the observations recorded for each year were grouped together for each 14 drums with the same paint system. This enabled the behaviour of the 12 groups of drums, each having a different coating system, to be carefully assessed and rated.

To assist with the rating of the various coatings a number system was used. A value of 10 was given to those coatings that showed no change. A value of 0 indicated complete failure. Intermediate numerical values were assigned for poor, fair, good, and very good. Using this system the appropriate number was placed on the field notes that had been recorded each year. The highest value was given top rating. This was done independently by two operators and thus the ratings given in Table IV are based on a composite judgement.

After six years of exposure the over-all performance of the different coating systems was considered to have been good. Although some were much better than others, none was believed to have deteriorated to such an extent that it were no longer useful. The air-drying alkyd enamel and primer on the phosphated steel drums (Group 2), was found to be best. This system was followed closely in performance by the baked styrenated alkyd with the quick-drying iron oxide-alkyd primer (Group 5). The coatings on the drums of Groups 2 and 5 were judged to be considerably better than any of the other groups. In instances where breaks had occurred in these coatings they were of a minor nature and believed to have been caused in handling. There was very little change recorded in their appearance up to and including the 1963 observations. Their paint systems were applied to phosphated surfaces which to date appears to be the preferable pretreatment.

The bung end of the drums in each group was in most instances usually in the worst condition. It was quite noticeable that areas of weakness occurred in locations where the surface changed direction. Frequently small cracks started here and extended over larger areas with time. Cracking at the circumference of the head where it changed in direction to the vertical was quite common with several of the coating systems. A severe case of cracking followed by peeling is shown in Figure 2. In general the coatings performed best on the body of the drums. Exceptions to this were observed on the chimes and rolling hoop surfaces where breaks in the surface were quite noticeable. It was also observed that the failures were progressive. For example, the coatings on the drums of Group 6 showed excessive rust blistering at the time of their first examinations which progressively developed into rust areas by the time of subsequent examinations.

The resistance to chalking of the air-drying and baking-type alkyd enamels was found to be best and both were rated as excellent. The styrenated alkyd enamels and the phenolated alkyd gave good chalking resistance with the former just slightly better. Only the baking-type vinyl enamel was considered as showing excessive chalking. The tendencies of the different paint systems to resist chalking are shown in Table V.

<u>Interior Coatings</u>

The interior coating exposures were made in triplicate. One drum of each three was opened for a detailed examination in 1962 after five years of outdoor exposure. Five drums were removed from each of the 12 groups so that every combination of surface treatment, interior coating, fuel and fuel-water mixture was represented in the 60 drums selected. Their numbers are underlined in Table III.

A sample of the fuel was removed from each of these drums by the Fuels Laboratory for analysis. The remainder of the fuel was removed by pumping after which the drums were up-ended to drain. The heads were cut out of the bung ends to facilitate examination of the interior coating. This was done with an electric shear which avoided damage to the coating except in the immediate area of cutting (Figure 3).

The coatings of the drums opened were examined for rusted metal, rust stains and blisters, peeling, and whitening. The location and extent of failures was recorded. Colour photographs were taken of the interior of each of these drums for future reference in comparing their performance with the remaining two drums of the three set out originally. It is planned to open the second and third drums of these different lots during 1964 and 1967, respectively.

A numerical system similar to that used for rating the exterior coatings was used in assessing the behaviour of the interior coatings. The following performance rating has been given to them after being exposed for 5 years to various fuels and fuel-water mixtures. (Details of the latter are provided in Table III.)

The interior coating system W6, on Group 11 drums, was given the highest performance rating. It consisted of a vinyl wash primer applied to clean, vapour degreased steel and top-coated with a baked epoxy. This system was in excellent condition after five years of exposure to the different fuels. It still retained its high gloss finish and the only two small breaks recorded in this coating were on bulges that had been formed by sharp blows on the exterior.

The two coating systems, P4 and P6, on Groups 7 and 12, respectively, were just slightly below the performance of coating W6. They were placed in second position because of a slight whitening of the coating P4 in drum No. 152 and also with P6 in drum No. 278. Both of these drums contained fuels to which water had been added. The coatings were applied to phosphated surfaces with the Group 7 drums receiving a phenolic-polyvinyl butyral baked topcoat and Group 12 finished with the baked epoxy that performed so well in getting first rating.

The interior drum coatings of Groups 8 and 10 were judged to be about the same. The most noticeable difference between these two groups and those given No. 2 rating was the more pronounced whitening and the first evidence of rusting. This applies only to the two drums of each group to which water had been added to the fuel since their remaining three drums were still in good condition.

The coatings rated 4 and below were starting to show signs of failure even with drums to which water had not been added to the fuels. Although more pronounced in instances where water was present, rust stains, whitening, or small blisters were starting to show on the other drums of the group. The lower the rating given to a particular coating the greater the degree of failure. An extreme case of failure is shown in Figure 5.

It was observed that all drums containing M. E. gasoline had had a heavy brown deposit accumulate on their low side during storage. The deposit was readily removed from the coating by wiping and the coating did not appear to have been affected by its presence. Samples of this deposit were taken for analyses by the Fuels and Lubricants Laboratory. Analysis, also made by this laboratory on the different fuels after four years of exposure to the coatings, has indicated few significant changes. Details of these changes and the methods of test used are included in the Mechanical Engineering Report MP-24 (3).

CONCLUSIONS

After six years of outdoor exposure the best exterior coating system has been found to be the air-drying alkyd enamel (1-GP-81) and primer (1-GP-88) on phosphated steel. From these preliminary examinations it is also believed that the baked styrenated alkyd with an iron oxide alkyd and primer used on the phosphated steel of Group 5 would be equally satisfactory. The baked styrenated alkyd was next in order and in view of its quite good performance it will be of interest to see how it weathers during the next few years. The phosphated surface at this stage of the field testing appears to give superior performance.

Tentative conclusions only can be drawn at this time with regard to the performance of the interior coatings. This is because only one of the drums exposed in triplicate of the different coatings to the various fuel mixtures has been examined. The best interior coating after five years of exposure was found to be the baked epoxy over a vinyl wash primer applied to vapour degreased steel of drums in Group 11. This same clear coating was found to be particularly good over the phosphated steel surface treatment of Group 12. Its performance along with the phenolic-polyvinyl butyral coating will be followed with interest when the next lot of drums are opened for examination.

ACKNOWLEDGEMENT

The assistance given by R. C. Seeley in assessing the performance of the different coatings is gratefully acknowledged.

REFERENCES

1. Dennis, D., B.S. Stafford and J. Harris. Organic Coatings for the Interior of Gasoline Drums, National Research Council, Division of Building Research Internal Report No. 51, November 1954.

2. Strigner, P. L. and R. B. White. Long Term Storage of Hydrocarbon Fuels in Coated Drums Part I: Setting up of Project. National Research Council, Division of Mechanical Engineering, Report MP-14, May 1959.

3. Strigner, P. L. Long Term Storage of Hydrocarbon Fuels in Coated Drums Part II: Examination of Fuel After Four Years of Storage. National Research Council, Division of Mechanical Engineering, Report MP-24, March 1962.

Table I - EXTERIOR PAINT SYSTEMS

Paint System No.	Primer Type	Coats	Topcoat Type	Coats	Curing
1	Air dry alkyd 1-GP-81 Type 1	1	Air dry alkyd 1-GP-88 Type 1	1	Air dry primer 6 hr. Air dry topcoat - 8 hr.
2	Baking alkyd 1-GP-81 Type 2	2	Baking alkyd 1-GP-88 Type 2	1	Bake primer 15 min. and topcoat 30 min. both at 250°F.
3	Air dry alkyd 1-GP-105	1	Styrenated alkyd	1	Air dry primer 1 hr. Force dry topcoat 15 min. at 250°F.
4	None	-	Styrenated alkyd	2	Air dry first coat 1 hr. and force dry the 2 coats 15 min. at 250°F.
5	Air dry alkyd 1-GP-105	1	Phenolated alkyd	1	Air dry primer 1 hr. Force dry topcoat 15 min. at 250°F.
6	None	-	Phenolated alkyd	2	Air dry first coat 1 hr. Force dry 2 coats 15 min. at 250°F.
7	Vinyl wash primer 1-GP-121	-	Vinyl	2	Air dry primer 1 hr. Air dry first coat of vinyl 30 min. and force dry combined 2 coats 15 min. at 250°F.

Table II - INTERIOR CLEAR COATINGS

Coating Number	Lab Number	Type	Coats	Curing
1	11026B	Phenolic-epoxy polyvinyl butyral	1	Air dry - 20 min. Bake - 30 min. at 350°F.
2	11022B	Catalytically cured epoxy coating	1	Air dry - 6 hr.
3	11031B	Phenolic-epoxy polyvinyl butyral	1	Air dry - 20 min. Bake - 30 min. at 350°F.
4	11040B	Phenolic-polyvinyl butyral	1	Air dry - 20 min. Bake - 30 min. at 350°F.
5	11042B	Vinyl chloride-vinyl acetate copolymer	1	Air dry - 20 min. Bake - 30 min. at 350°F.
6	10965	Commercial epoxy coating	1	Air dry - 20 min. Bake - 30 min. at 350°F.

Table III - ASSIGNMENT OF COATING SYSTEMS AND FUELS

Drum Group No.	Surface Preparation: Interior	Surface Preparation: Exterior	Interior Coatings	Exterior Coatings	Drums Coded	Drum Numbers and Fuels: Avn. Fuel	Avn. Fuel & Water	Jet Fuel	Jet Fuel & Water	M.E. Gas
1	Wash primer	Plain	Int. Paint	Ext. Paint		1	5	8	16	23
	air dry 1-2 hr	steel de-	System #1	System #1						
	W	greased	Lab # 11026	1-GP-81						
		S	Air dry 6 hr	Air dry 6 hr	WS11	2	6	9	17	
				1-GP-88 T.* 1						18
				Air dry 8 hr		3	7	15	20	~~24~~
2	Phosphate	Phos-	Int. Paint	Ext. Paint		29	33	36	39	44
	P	phate	System #1	System #1						
		P	Lab # 11026	1-GP-81						
			Air dry 6 hr	Air dry 6 hr	PP11	30	34	37	40	
				1-GP-88 T. 1				46		
				Air dry 8 hr		32	35	~~38~~	41	45
3	Phosphate	Phos-	Int. Paint	Ext. Paint		49	52	55	58	61
	P	phate	System #2	System #2						
		P	Lab # 11022	1-GP-81 T. 2						
			Air dry	Air dry	PP22	69		66		
			20 min	20 min		~~50~~	53	~~56~~	59	62
			Bake 30 min	Bake 15 min						
			at 350°F	at 250°F						
				1-GP-88 T. 2						
				Air dry						
				20 min		51	54	57	60	
				Bake 30 min						
				at 250°F						
4	Degrease	Plain	Int. Paint	Ext. Paint		75	78	81	84	87
	grit blast.	steel de-	System #2	System #3						
	G	greased	Lab # 11022	1-GP-105						
		S	Air dry	Air dry 1 hr	GS23	76	79	82	85	88
			20 min	Styrenated						
			Bake 30 min	alkyd						
			at 350°F	Air dry						
				20 min		77	80	83	86	
				Bake 15 min						
				at 250°F						
5	Phosphate	Phos-	Int. Paint	Ext. Paint		97	100	103	106	109
	P	phate	System #3	System #3						
		P	Lab # 11031	1-GP-105						
			Air dry	Air dry 1 hr	PP33	98	101	104	107	
			20 min	Styrenated						
			Bake 30 min	alkyd						
			at 350°F	Air dry						
				20 min		99	102	105	108	110
				Bake 15 min						
				at 250°F						
6	Degrease	Plain	Int. Paint	Ext. Paint		123	121	130	133	136
	grit blast.	steel de-	System #3	System #4		~~124~~	~~129~~			
	G	greased	Lab # 11031	Styrenated						
		S	Air dry	alkyd						
			20 min	Air dry 1 hr	GS34	125	128	131	134	142
			Bake 30 min	Styrenated						~~137~~
			at 350°F	alkyd						
				Air dry						
				20 min		126	129	132	135	
				Bake 15 min						
				at 250°F						

* T. = Type

Table III - ASSIGNMENT OF COATING SYSTEMS AND FUELS (cont'd)

7	Phosphate P	Phosphate P	Int. Paint System #4 Lab # 11040 Air dry 20 min Bake 30 min at 350°F	Ext. Paint System #4 Styrenated alkyd Air dry 1 hr Styrenated alkyd Air dry 20 min Bake 15 min at 250°F	PP44	149 150 151	152 153 154	155 156 157	158 159 160	161 162
8	Degrease grit blast. G	Plain steel degreased S	Int. Paint System #4 Lab # 11040 Air dry 20 min Bake 30 min at 350°F	Ext. Paint System #5 1-GP-105 Air dry 1 hr Phenolated alkyd Air dry 20 min Bake 15 min at 250°F	GS45	169 170 171	172 173 174	187 ~~175~~ 176 177	184 ~~178~~ 179 180	181 182
9	Washprimer air dry 1-2 hr W	Wash primer air dry 1-2 hr W	Int. Paint System #5 Lab # 11042 Air dry 20 min Bake 15 min at 250°F	Ext. Paint System #7 Vinyl Air dry 30 min Vinyl Air dry 20 min Bake 15 min at 250°F	WW57	193 194 195	196 197 198	199 200 201	202 203 204	205 206
10	Phosphate P	Phosphate P	Int. Paint System #5 Lab # 11042 Air dry 20 min Bake 15 min at 250°F	Ext. Paint System #5 1-GP-105 Air dry 1 hr Phenolated alkyd Air dry 20 min Bake 15 min at 250°F	PP55	221 222 223	240 ~~224~~ 225 226	233 234 235	236 237 238	229 231
11	Washprimer air dry 1-2 hr W	Plain steel degreased S	Int. Paint System #6 Lab # 10965 Air dry 20 min Bake 30 min at 350°F	Ext. Paint System #2 1-GP-81 T. 2 Air dry 20 min Bake 15 min at 250°F 1-GP-88 T. 2 Air dry 20 min Bake 30 min at 250°F	WS62	243 244 245	246 247 248	249 250 251	252 253 254	255 256
12	Phosphate P	Phosphate P	Int. Paint System #6 Lab # 10965 Air dry 20 min Bake 30 min at 350°F	Ext. Paint System #6 Phenolated alkyd Air dry 1 hr Phenolated alkyd Air dry 20 min Bake 15 min at 250°F	PP66	269 270 271	272 273 274	275 276 277	278 279 280	281 282

NOTES - Drum numbers with oblique strokes removed because of leaks and replaced.
- Drum numbers underlined removed in 1962 for examination of interior coating.

Table IV - RATING OF EXTERIOR SYSTEMS

Rating	Drum Group Number and Appearance	Exterior System
1	2 - Excellent - Good	P1
2	5 - Good - Excellent	P3
3	7 - Good	P4
4	9 - Good - Fair	W7
5	10 - Good - Fair	P5
6	11 - 1 - Fair	S2, S1
7	8 - Fair	S5
8	3 - Fair	P2
9	4 - Fair - Poor	S3
10	12 - Fair - Poor	P6
11	6 - Poor - Fair	S4

Table V - RESISTANCE TO CHALKING

Group No.	Top-coat of Paint System	Numerical Rating* 1959 of a possible 98	1960 of a possible 98	1961 of a possible 98	1963 ** of a possible 63	4 yr. total of a possible 357
1	Air dry alkyd	80	72	64	41	257
2	Air dry alkyd	94	75	69	42	280
3	Alkyd-baked	81	77	61	41	260
4	Styrenated alkyd-baked	66	59	51	34	210
5	Styrenated alkyd-baked	60	59	48	29	196
6	Styrenated alkyd-baked	62	58	52	32	204
7	Styrenated alkyd-baked	59	62	41	28	190
8	Phenolated alkyd-baked	54	63	42	30	189
9	Vinyl-baked	33	44	24	13	114
10	Phenolated alkyd-baked	58	53	48	28	187
11	Alkyd-baked	79	69	68	41	257
12	Phenolated alkyd-baked	53	61	47	35	196

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Notes: * The rating is based on giving those coatings with no chalking a numerical value of 7. This value was decreased to 1 for coatings with marked chalking.

** Lower values are recorded since a number of the drums had been removed in 1962 for the examination of the interior coatings.

Table VI - RATING OF INTERIOR SYSTEMS

Rating	Drum Group Number	Interior System
1	11	W6
2	7 and 12	P4 and P6
3	8 and 10	G4 and P5
4	9	W5
5	5	P3
6	1 and 3	W1 and P2
7	2, 4 and 6	P1, G2 and G3

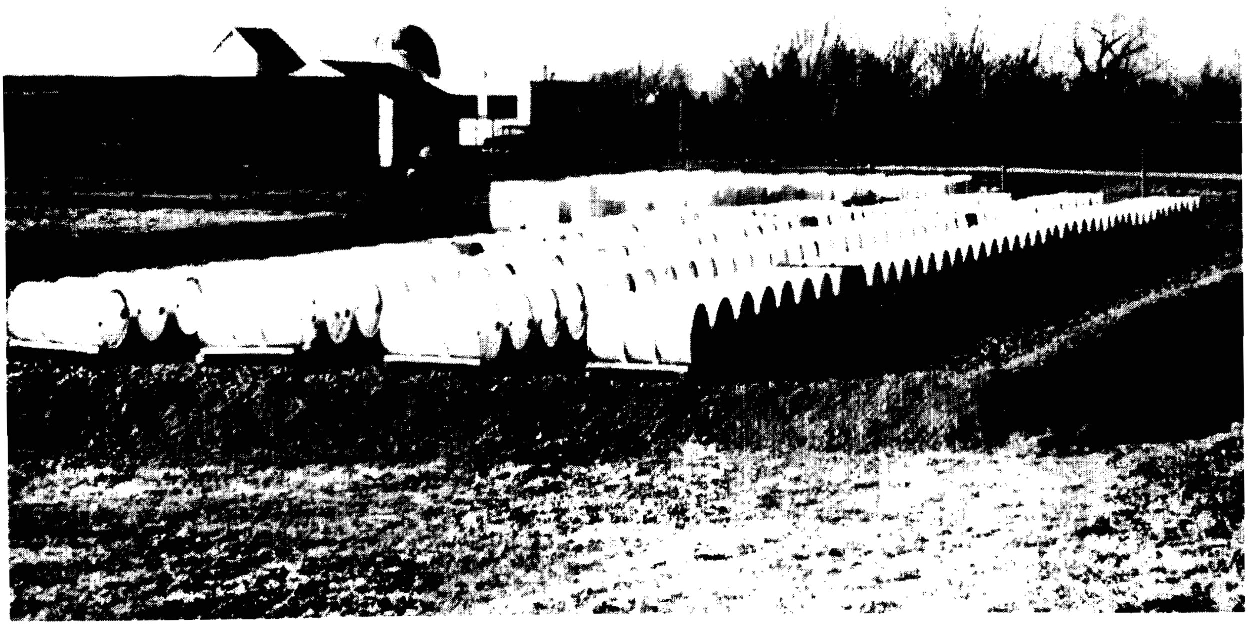

Figure 1 Drum Exposure Site

Figure 2 Peeling Around Bung

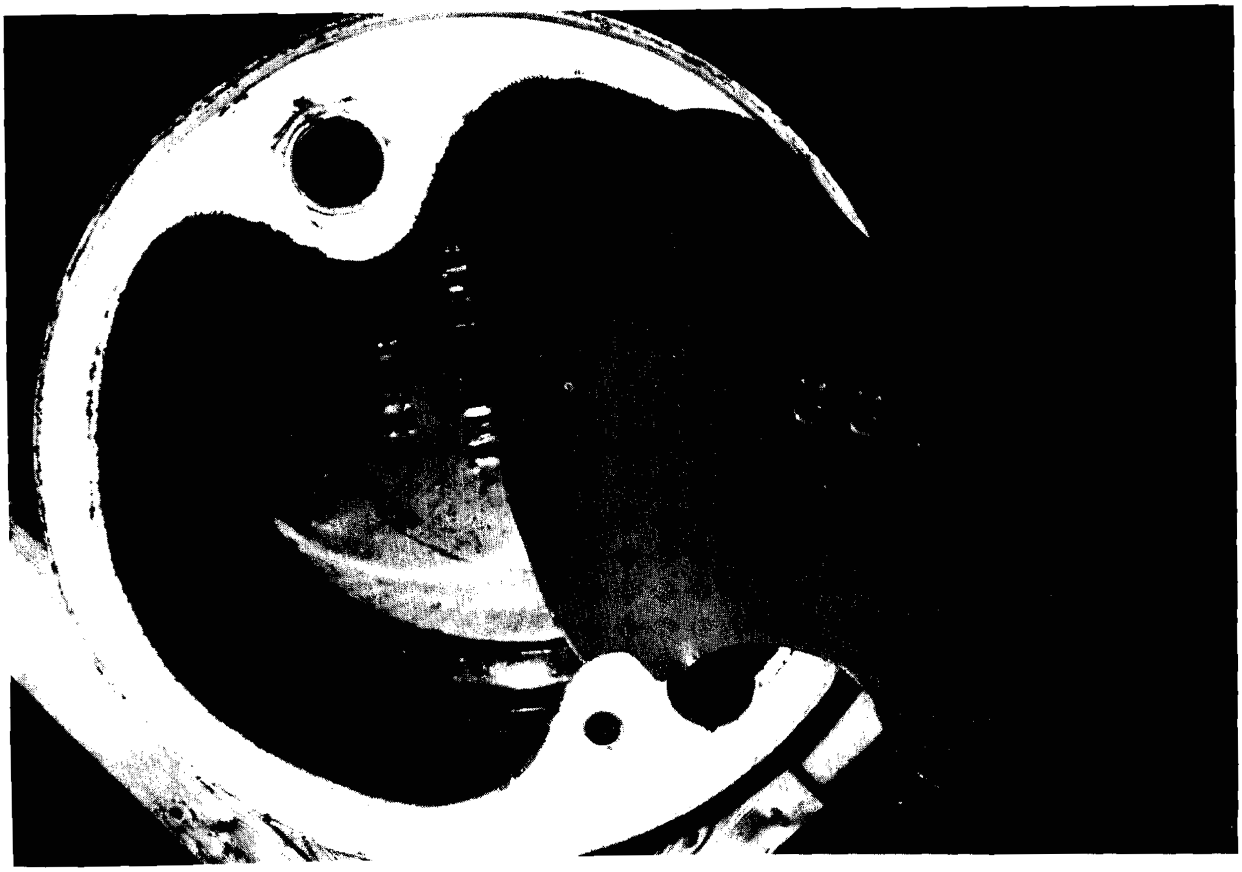

Figure 3 Drum With Head Open

Figure 4 Hairline Cracking Near Chime

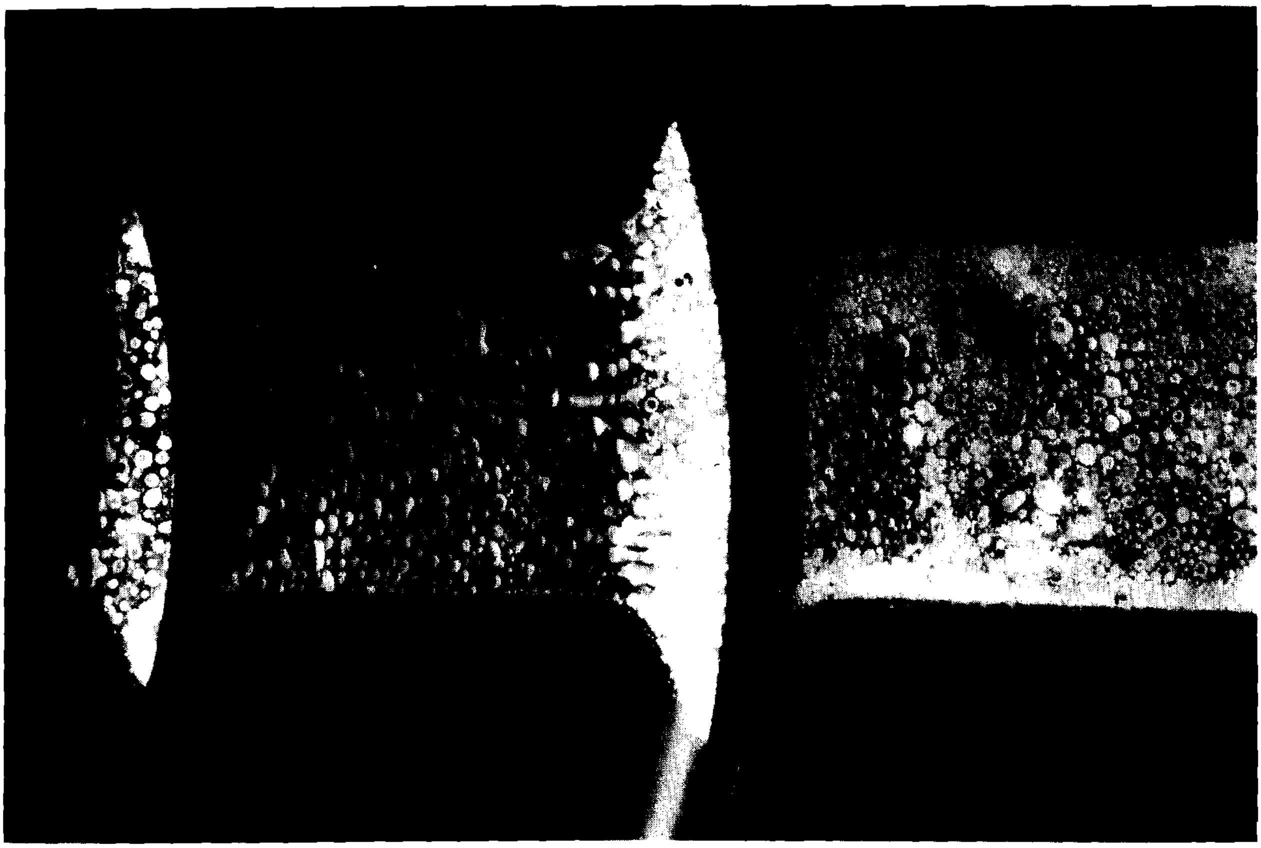

Figure 5 Failure of Interior Coating on Lower Side by Whitening, Dense Blistering, Peeling and Rusting

APPENDIX A

COMPOSITION OF EXTERIOR COATINGS

White Alkyd Enamel, 1-GP-88 Type 1

Alkyd Resin Solution *	80 pounds
Alkyd Resin Solution **	720
Rutile TiO_2	200
Bentone 34	10
Mineral Spirits	40
Lead Naphthenate Solution (24% Pb)	10
Cobalt Naphthenate Solution (6% Co)	4
Calcium Naphthenate Solution (6% Ca)	5
Zinc Naphthenate Solution (5% Zn)	5
ASA	2

Grind = 7

* CPI Alkyd 48% Solids in mineral spirits, 37% PA, Visc. W-X

** CPI Alkyd 50% Solids in mineral spirits, 29½ PA, Visc. W-X

White Alkyd Enamel, Baking Type, 1-GP-88 Type 2

Alkyd Resin Solution *	695
Melmac 245-8	34.6
Rutile TiO_2	210
Xylol	71
TS-28	90

Grind = 6

* CPI Alkyd 50% Solids, 40% PA, Cottonseed, Visc. F, Cut in TS-28

Styrenated Alkyd Enamel

Styrenated Alkyd Resin Solution *	585 pounds
Rutile TiO_2	273
Zinc Oxide	18
Bentone 34	2
Mineral Spirits	162
Enjay 150	62
Lead Naphthenate (24% Pb)	5
Cobalt Naphthenate (6% Co)	2
ASA	1

Grind = 6

* Cycpol S101-1

Phenolated Alkyd Enamel

Alkyd Resin Solution *	585
Rutile TiO_2	273
Zinc Oxide	15
Bentone 34	2
Thinner - TS-28	50
Mineral Spirits	172
Lead Naphthenate (24% Pb)	5
Cobalt Naphthenate (6% Co)	2
ASA	1

Grind = 6

* CPI Alkyd 50% solids in mineral spirits.
21% PA and 21% phenolic modifier
Visc. - Y

Vinyl Enamel, Baking Type

Vinyl Resin VAGH	160 pounds
Rutile TiO_2	190
Isophorone	176
MIBK	296
Paraplex G-60	23
Snow White Parmel #1	2
Xylol	167
Toluol	10
1% Silicone Solution	2
Tricresyl Phosphate	42

Grind = 7

Alkyd Primer 1-GP-81 Types 1 and 2

Alkyd Resin Solution *	570
Raw Linseed Oil	9
Potassium Zinc Chromate	54
Zinc Oxide	28
Synthetic Iron Oxide	153
China Clay	294
Mineral Spirits	45
Lead Naphthenate (24% Pb)	4
Cobalt Naphthenate (6% Co)	2
ASA	2

Grind = 5

* CPI Alkyd 50% solids in mineral spirits, Visc. U
$29\frac{1}{2}$% P. A.

Alkyd Primer, Cuick Drying - 1-GP-105

Alkyd Resin Solution *	297 pounds
Potassium Zinc Chromate	46
Zinc Oxide	47
Iron Oxide **	233
Barium Sulphate	51
Talc	51
Dispersion Resin ***	62
Toluol	28
Xylol	421
Castor Oil	6
Lead Naphthenate (24% Pb)	4
Cobalt Naphthenate (6% Co)	6
ASA	1

Grind = 6

* CPI Alkyd - 60% solids in xylol, 38½% PA, Linseed, Visc. Z_4

** Synthetic Iron Oxide - 80% Fe_2O_3 - 20% Silicious Matter

*** Bakelite BK 3962

NOTE: These paints were manufactured by Canadian Pittsburg Industries Limited, Toronto, on special order. Where necessary, in order to identify fully certain of the materials used, the abbreviation CPI has been used to identify these as products of Canadian Pittsburg Industries Ltd.

APPENDIX B

COMPOSITION OF INTERIOR COATINGS (MODIFIED)

Coating No. 11022B

Part A

		Percent by Weight
Epoxy Resin	: Epon 1001	35.33
Amino Resin	: Beetle 216-8	1.09
Silicone Resin	: S R 82	0.74
Methyl Isobutyl Ketone		16.76
Butyl Cellosolve		4.18
Toluene		41.88

Part B

		Percent by Weight
Ethylene Diamine	: Technical 76%	60.0
N-Butanol		26.6
Toluene		13.4

Mix 20 parts of A with 1 part of B.

Coating No. 11026B

		Percent by Weight
Epoxy Resin	: Epon 1007	12.30
Vinyl Butyral Resin	: Butvar B-76	2.02
Phenolic Resin	: G-E R108	13.17
Methyl Isobutyl Ketone		11.51
N-Butanol		11.51
Toluene		23.01
Methyl Isobutyl Ketone		6.58
N-Butanol		6.58
Toluene		13.17
Phosphoric Acid (85%)		0.13

Coating No. 11031B

		Percent by Weight
Phenolic Resin	: Bakelite 10673	22.71
Epoxy Resin	: Epon 1004	4.19
Vinyl Butyral Resin	: Vinylite XYHL	3.25
N-Butanol		22.45
N-Butyl Acetate		4.80
Methyl Isobutyl Ketone		16.68
Diacetone		9.21
Toluene		16.72

Coating No. 11040B

		Percent by Weight
Vinyl Butyral Resin	: Butvar B-76	4.96
Phenolic Resin	: Monsanto P-97	14.88
N-Butanol		15.21
Methyl Isobutyl Ketone		21.63
Toluene		43.32

Coating No. 11042B

		Percent by Weight
Vinyl Resin	: Vinylite VAGH	13.85
Di-Butyl Tin Maleate		0.28
Methyl Isobutyl Ketone		42.48
Toluene		43.40

Coating No. 10965

Commercial Epoxy Material

Note on Modifications to Formulae

The original formulae selected from the NRC report[1] on the laboratory evaluations of interior coatings for fuel drums were numbers 11022, 11026, 11031, 11040 and 11042. A commercial material No. 10965 was also included. In the preliminary trial part of the actual drum coating program it was found that the application properties of the first five coatings were not satisfactory. It was also found undesirable to do the thinning at the plant at the time of application. Accordingly, after this trial run, additional laboratory development was carried out on the solvent portion of these formulae to improve their application properties. In the case of formula number 11042 a heat stabilizer was also added to prevent decomposition during the force drying of the coating and in formula 11022 additional flow agent in the form of silicone resin was added to overcome some tendency to fisheye. The five formulae 11022B, 11026B, 11031B, 11040B and 11042B given are the modified formulae. The modifications included the adjustment of viscosity to make it suitable for spraying without further thinning at the plant. New batches of materials were prepared conforming to these modified formulae and supplied to the contractor for the project.

Coating 10965 did not require any modification.