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Fire-Retardant Paint Systems for Nuclear Submarine Interiors

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ABSTRACT

The Navy needs a fire-retardant paint for submarine interiors that will release little or no toxic materials into the atmosphere during and after application. The paint should possess good leveling properties so that an attractive surface free of brush marks is obtained, should have a short drying time, and should show good freeze-thaw stability. The dry film should be flexible, should possess good hiding power, and should have a 60° gloss between 35 and 50%. A water-based coating system has been developed that should meet these requirements.

Such a coating system consists of a fire-retardant undercoat and a decorative topcoat. The topcoat alone is combustible, but when used in combination with the fire-retardant undercoat, the complete system is self-extinguishing. Although the system will burn when exposed to an extraneous flame or fire, the burning film will immediately self-extinguish when the ignition source is removed or when that part of the film exposed to the fire is consumed.

The Navy currently uses three proprietary water-based paints in cases where the normally specified solvent-based, fire-retardant paint (a chlorinated alkyd) leads to contamination of the submarine atmosphere. The NRL coating system appears to be superior in all respects to these three proprietary paints but inferior in some properties to the standard solvent-based paint.

PROBLEM STATUS

This is a final report on this phase of the problem, work is continuing on other phases of submarine habitability.

AUTHORIZATION

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FIRE-RETARDANT PAINT SYSTEMS FOR NUCLEAR SUBMARINE INTERIORS

INTRODUCTION

Much of the interior of nuclear-powered submarines is painted with a solvent-based, fire-retardant, chlorinated alkyd paint (MIL-E-17970C, the white-tint formulation, MIL-E-17971C, the pastel-green formulation, and MIL-E-17972C, the gray formulation). Since the composition of the atmosphere in nuclear-powered submarines must be rigorously controlled (1) to protect personnel, special painting instructions were developed to avoid the introduction of significant amounts of organic solvents into the atmosphere of closed submarines. Essentially all painting with organic-solvent-thinned paints must be completed 5 days prior to departure on patrol (2). Since it is desirable, and often necessary, to delay most interior painting until other construction and maintenance work is completed, a large amount of painting may remain to be done during this 5-day period. To meet this need, three proprietary fire-retardant, water-based paints have been approved for use in the interior of nuclear submarines (3) during this 5-day interval. These three paints are also applied to surfaces of elastomeric foamed plastic insulation (MIL-P-15280), which is used extensively throughout the submarine (4). Although these paints represent the best currently available, they have a number of deficiencies which make them objectionable for this special application. They possess a gloss that is too low, poor leveling characteristics, hiding power that is too low, poor freeze-thaw stability, and poor scrub resistance when compared to chlorinated alkyd formulation (MIL-E-17970C, MIL-E-17971C, or MIL-E-17972C).

Furthermore, because of scheduling problems in painting during maintenance periods, it is desirable to be able to do most of the touchup painting while the submarine is on patrol, when more time and manpower are available. Although the three proprietary paints are water based, they often contain appreciable quantities of volatile organics, which have been added as coalescing aids, drying regulators, and antifreezing agents. Since the amounts and type of additives are proprietary information, these three paints have not been approved for use while the submarine is on patrol under sealed ship conditions.

Thus, a need exists for a paint with improved performance over presently available water-based paints, and it should have a composition that would permit its use under sealed ship conditions.

DEFINITION OF PROBLEM

Because of its organic-solvent content, it is desirable to replace the Navy's standard, fire-retardant, chlorinated alkyd paint (MIL-E-17970C, Formula 124/58) with an organic-solvent-free paint of equal performance. This replacement is not only for use aboard nuclear submarines but also in many other situations aboard any ship where fire and health hazards may arise during normal paint application. Although the normally specified paint has some deficiencies, it is doubtful within present-day technology that a water-based, fire-retardant paint can be developed with a complement of properties which could replace the standard paint in all nonhazardous situations. Thus, the primary

Table 1
Desirable Properties of an Interior Submarine Paint

Property	Requirement
Hiding power	Complete hiding in one coat
60° gloss (Gardner)	Medium gloss, 35-50%
Leveling (NYPC leveling test blade)	At least 7, so a surface free of brush marks can be obtained
Freeze-thaw stability (0°F to 72°F)	Pass at least 5 cycles
Flexibility	Sufficient resilient so that the dry coating will not crack on the elastomeric foamed plastic insulation
Water scrub resistance (cycles for film failure)*	3700
Toxicity	Little or no volatile organics
Fire retardancy	Immediately self-extinguishing or non-flaming

*Determined with Gardner Model 105 straight-line washability and abrasion machine. The dry film thickness was approximately 2.5 mils. The abrasion medium contained 15 g of 400 cps methocel, 10 g of castile soap, and 30 g of pumice powder in a kilogram of water. The film surface was scrubbed with a hog-bristle brush.

objective was to develop a paint with acceptable performance and to include insofar as possible all the properties of a high-quality decorative enamel. Table 1 summarizes some of the properties sought.

The two overriding requirements of such a paint are (1) that it release little or no toxic volatile organic compounds into the submarine's atmosphere during and after application and (2) that it be nonflaming or self-extinguishing when the source of ignition is removed. Since these paints will be applied only to steel structures or nonburning, flexible insulation, the ability of the paint to protect a combustible substrate is of little or no interest. The fire-retardant quality is to prevent the possibility of a localized fire spreading to other areas by way of a burning paint film. This hazard becomes more serious as the number of paint layers accumulates over the years. Other normal properties and performance of the paint must be achieved without adversely affecting these two properties.

One-coat hiding is desirable because of the economy of one coat over several. Further, fire retardancy decreases as film thickness increases; thus, if two or three coats are required for complete hiding, film thickness builds up much more rapidly. A paint with a 60° gloss between 35 to 50% has greater resistance to soilage, is easier cleaned, and is more decorative than a flat paint. A higher gloss increases the possibility of annoying glare. Good leveling is required to obtain smooth surfaces free of brush marks. Poor leveling particularly is a problem with semigloss and gloss paint where residual brush marks are quite noticeable. Although most latex paints should be protected from freezing, it is desirable that the paint survive freezing cycles that might

occur accidentally during storage. The dried film should be flexible so that it will not crack when applied over the elastomeric foamed plastic insulation. The solvent-based chlorinated alkyd (Formula 124/58) cannot be used on this resilient material, because it dries to a brittle and nonflexible film, which cracks severely. Good scrub resistance is needed so that a dirty paint film can be cleaned without removing most of the paint along with the dirt. Finally, it must still perform its primary function of protecting the structure materials from corrosion and deterioration.

APPROACH

In spite of intensive efforts over an extended period it has thus far been impossible to combine in a single paint all the properties which have been enumerated. In many instances shortcomings have been attributed to the adverse effect of the fire-retardant additives (mainly antimony oxide and heavily halogenated organic compounds) as these affect application properties, appearance, and durability.

As an alternative to a single material, a two-coat system was devised in which the first coat imparts fire retardancy, while the second coat provides decorative qualities. In this manner the fire-retardant additives, which are responsible for poor appearance, can be confined to the undercoat, which, in turn, is concealed by the decorative topcoat. Although the topcoat alone might be combustible, in combination with the fire-retardant undercoat the total system is self-extinguishing.

Although this approach requires the application of two coats of paint, it is considered practical and, in fact, conforms with general painting practice. In many common paint systems even three different coats are used to obtain a degree of protection and performance that can not be designed into one or two coatings.

RESULTS

Laboratory studies indicate that the complete system (that is, the topcoat over the undercoat) is an improvement in all respects over the three proprietary, fire-retardant, water-based paints currently used in the submarines. Although the topcoat is completely combustible by itself, when used in combination with the fire-retardant undercoat, the complete system is self-extinguishing.

Both the fire-retardant undercoat and the decorative topcoat were formulated to contain a minimum of organic additives. These formulations are shown in Appendixes A and B. Propylene glycol, 5.0% in the undercoat and 5.4% in the topcoat, is the major volatile organic additive in both formulations, while approximately 0.04% isopropyl alcohol is introduced into each with the surfactants. Propylene glycol is reported to be completely nontoxic (5,6), even when taken internally. Isopropyl alcohol is present in such small quantities, approximately 2 g/gal, that the 24-hour exposure limit of 200 ppm would never be reached even if 2 gal of paint were accidentally spilled in a small, isolated compartment. At present, however, it is not recommended that this paint be used under sealed ship conditions, because all ingredients are commercial materials that could be contaminated with undesirable by-products not removed in manufacturing. Until this coating system is shown to be an acceptable replacement for the three proprietary paints through actual field testing on submarines, it would not be practical to carry out a detailed analysis on the numerous ingredients. If field testing supports the use of this coating system and a detailed analysis shows it to be unsuitable because of volatile toxic contaminants, it is quite possible that appropriate substitutions or simple purification of the offending ingredient(s) could be made. But even if this coating system could not be used under sealed ship conditions (that is, on patrol), its superior performance would recommend its use over the present three proprietary paints.

To support this view, a comparison of the properties and performance of the three proprietary paints and the NRL system is made in Table 2. Data on the solvent-based, fire-retardant paint also are included for reference.

The three proprietary materials require at least two to three coats for complete hiding. The NRL coating normally gives complete hiding with one coat each of undercoat and topcoat. Both Ocean 634 and Amercoat 1768 produce a very low gloss. Although the gloss of the Devflex MD2707 is better, it is still inferior to the 42% gloss of the NRL system. All three proprietary paints show brush marks when applied by brushing, and although the Devflex is preferable to the Ocean 634 and Amercoat 1768, it is poorer than the NRL system. All four paints dry in 1 to 4 hours; however, the Devflex MD2707 and Ocean 634 have a slight after-tack that is present for several weeks after application. The NRL coating is superior in freeze-thaw stability and scrub resistance. The adhesion of the NRL system, the Ocean 634, and the Amercoat 1768 was evaluated as applied to cold-rolled steel panels treated with wash primer (Formula 117; MIL-P-15328). By scratching the dried coatings with the fingernail, the NRL coating system (one coat undercoat, two coats topcoat) displayed much better adhesion than either proprietary paint. This qualitative evaluation was confirmed using the Arco Microknife Test (7) in which the NRL coating had an adhesion value of 2.29, Ocean had a value of 5.67, and Amercoat had a value of 6.12. Finally, as will be shown later, the fire-retardant qualities of the NRL system are better than those of the three proprietary paints but inferior to the chlorinated alkyd.

FIRE-RETARDANT STUDIES

Since the paints in this program are to be used on noncombustible substrates, the burning characteristics of the films themselves were of prime interest, while their ability to protect a combustible substrate was of little concern. Since most fire-retardancy tests, including ASTM, required paints to be applied to combustible substrates, a test uncomplicated by the presence of a combustible substrate was developed. The paints are evaluated on asbestos paper (Fisher Catalog 1-470) approximately 1/64 in. thick or on aluminum foil 0.8 mil thick. In preparing the test sample, the substrate is held flat by a Bird Vacuum plate, and the paint is applied with a brush or film caster to the desired thickness.

The film is allowed to dry for at least 5 days, and then the coated area is cut into 1-by-11-in. test strips after being ruled off at 2, 3-1/2, and 9-1/2 in. from the bottom. The sample preparation is illustrated in Fig. 1. Since the ruled lines may become covered with soot or smoke or otherwise obscured during the test, it is convenient to punch a small hole in the test strips at the two locations shown to facilitate the identification of these positions. The test is made in a cabinet whose interior dimensions are 19 by 13 by 33 in. The cabinet has a glass front door through which the burning sample can be observed. Along the bottom of each side, several 1/2-in.-diameter holes have been placed for ventilation. The top of the box has two holes (1-in. diameter) diagonally opposite each other and one in the center over which a small exhaust fan is positioned to help remove the smoke formed during the test. The cabinet is placed in an exhaust hood, which is kept running during the test to remove combustion gases. With the cabinet door closed and the hood and small exhaust fan running, there is little or no flame disturbance caused by air currents. The 1-by-11-in. test strip is suspended vertically in the cabinet by any suitable means. One convenient method is to use two nails held in position by clamps on a 1/2-in.-diameter rod fastened to the top and bottom of the cabinet. The clamps are approximately 10-in. apart, and the asbestos strip is simply pushed onto the nails. The test apparatus is shown in Figs. 2 and 3. To prevent the asbestos from tearing when tightening and aligning the test strip, a small piece of masking tape on the backside of the sample at the point of puncture is helpful.

Table 2
Performance of Interior Paints for Nuclear Submarines

Properties	MIL-E-17971C Formula 125/58 (chlorinated alkyd)	Devflex MD2707	Amercoat 1768	Ocean 634	NRL Undercoat Formulation N4001-69	NRL Topcoat Formulation N4001-67	NRL System*
Hiding (qualitative)	Good-Excellent	Fair†	Fair†	Fair†	Poor	Good	Good
60° gloss (Gardner)	35-50%	32%	23-32%	9%	5%	42%	42%
Leveling (NYPC test blade)	7 (Very Good)	6 (Good)	5 (Fair)	0 (Poor)	6 (Good)	6 (Good)	—
Flexibility on elastomeric plastic insulation	Cracks	Does not crack	Does not crack	Does not crack	Does not crack	Does not crack	Does not crack
No. of freeze-thaw cycles passed	Stable	0	>2	0	Will pass a few cycles	Stable	—
Scrub resistance	3500	1450	850	1300	—	2550	—
Drying time (hr)	2-7	1	1-2	1	1-2	1-4	—
Adhesion (see Ref. 8)	—	—	6.12 (worst)	5.67	—	—	2.29 (best)

*The system consists of one coat of the NRL undercoat and two coats of the NRL topcoat.
†At least two coats were needed for complete hiding.

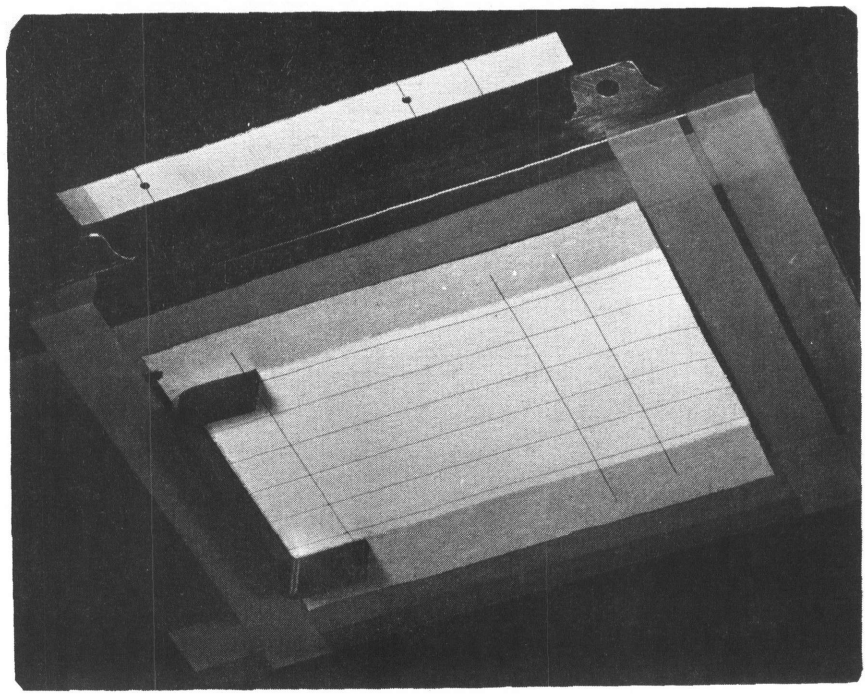

Fig. 1 - Preparation of test specimens for the NRL fire-retardancy test

After the test strip has been positioned, a microburner is aligned with it so that a line passing through the barrel of the burner is perpendicular to the strip at the center of the 2-in. mark, and the tip of the barrel is 2 in. from the strip. The torch is lit with the air intake port closed so that a yellow flame is formed that burns straight up and does not reach the sample. The cabinet door is closed, and the air intake of the burner is fully opened by an external linkage. This produces a hot blue flame, which burns straight out and ignites the sample. The time for the paint film to ignite and burn from the 2-in. mark to the 3-1/2-in. mark, at which point the burner is extinguished, and from the 3-1/2-in. mark to the 9-1/2-in. mark is measured with two stopwatches. The time to burn the 1-1/2 in. is called the ignition time and is related to the ease of ignition of the paint. The time to burn the 6 in. after the torch has been extinguished is referred to as the burning time and is directly related to the fire retardancy of the coating.

Ideally, the coating would self-extinguish as soon as the microburner is turned off and, therefore, would have a nonfinite burning time for the 6-in. length. However, depending on the degree of fire retardancy, it may continue to burn for a time before it self-extinguishes, or it may burn the entire length at a rate proportional to its degree of fire retardancy. The sum of the ignition and the 6-in. burning times is called the total burning time. For those films which are completely burned, the total burning time appears to be the more useful and reproducible value in correlating the burning behavior with paint composition.

Although this test might seem more elaborate than needed, it was desirable, particularly in our earlier work (8-10), to have a method that quantitatively described the effect of fire-retardant additives and formulation changes on the burning characteristics of the paint to provide guidelines for further modification. The method also provided fairly rapid screening for the numerous formulations that were studied. A number of

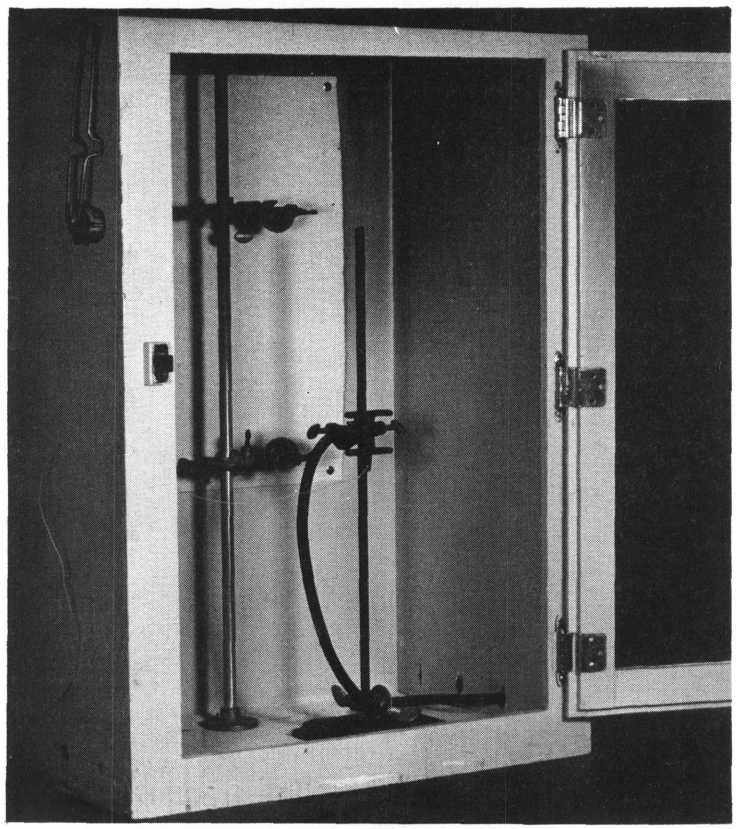

Fig. 2 - NRL's fire-retardancy test apparatus with test specimen

variables which could affect the burning rate of the film were not controlled, such as variation in moisture content of the asbestos and dried paint films. Small differences in coating thicknesses and variations in the microburner flame temperature also may have varied. Once minor problems were worked out and a standard procedure adopted, data were quite reproducible, and the method seemed well suited to the need.

Measurable differences in film thickness were taken into consideration. Figure 4 shows data for an acrylic formulation at various film thicknesses. Dry film thickness, which was measured with a micrometer, and the wet film thickness as represented by film caster clearance are shown. The substrate was asbestos paper. Since the burning time increases with film thickness, the inference might be drawn that the fire retardancy of the paint improves. Actually, the flammability of the paint has not improved, but since more of it was present, it required more time to burn. Thus, the question arises whether the change in burning time results from a change in the fire retardancy of the paint or from a change in film thickness. The two effects can be distinguished by observing the nature of the flame. Thus, with a true increase in fire retardancy, the film will burn with a small, less intense flame, while increased film thickness results in a larger, brighter, and hotter flame.

Actually, the fire-retardant qualities of these coatings diminish as film thickness increases. A coating of 1-mil thickness might self-extinguish immediately, but at 4 mils it may burn for several seconds before self-extinguishing, and at 7 mils it may even burn

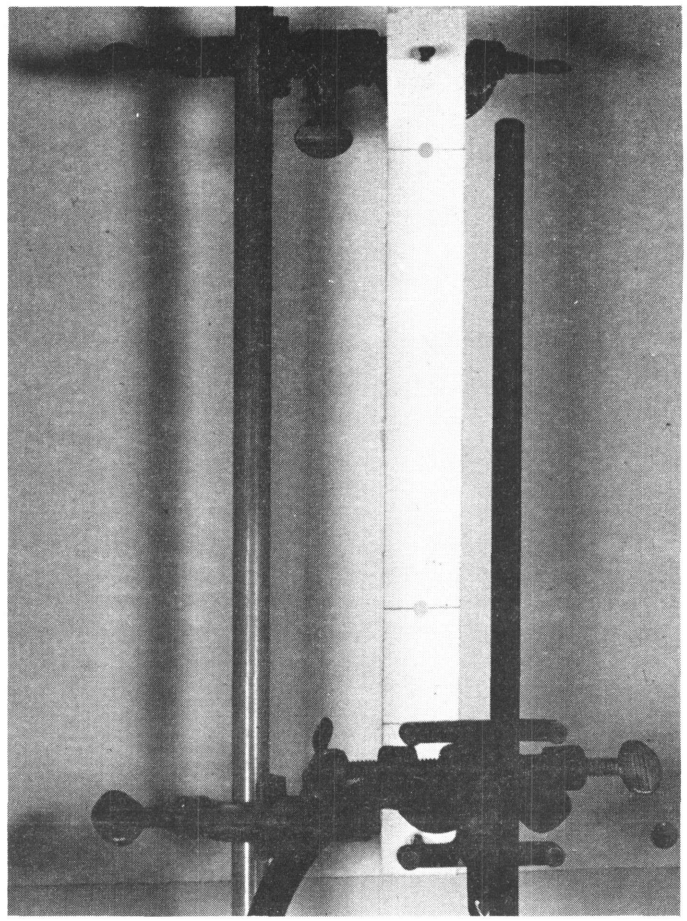

Fig. 3 - Closeup view of test specimen in fire retardancy test apparatus

completely. Thus, comparison between coatings should be made at approximately the same dry film thickness. Film thicknesses varying no more than 20% should produce comparable results.

With an aluminum-foil substrate, the dry film thickness could be measured very accurately with a micrometer, and it was easily determined if comparisons were being made between films of approximately the same thickness. However, with asbestos paper, it was difficult to obtain reliable measurements because of nonuniformity in this substrate. For this reason, the wet film thickness as indicated by the film caster clearance was used as a measurement for thickness of paints applied to an asbestos substrate. It is realized that a number of factors affect dry film thickness, including viscosity, solids content, and shrinkage during drying or curing; therefore, paints applied by a brush or laid down at the same film caster clearance will not necessarily give dry films of equal thickness. However, except for the solvent-based chlorinated alkyd, the paints discussed in this report give dry films of comparable thicknesses, within 20% of each other, when applied under similar conditions.

As pointed out earlier, all water-based paints contain some volatile organic materials used as coalescing agents, drying regulators, antifreeze agents, etc. The NRL system

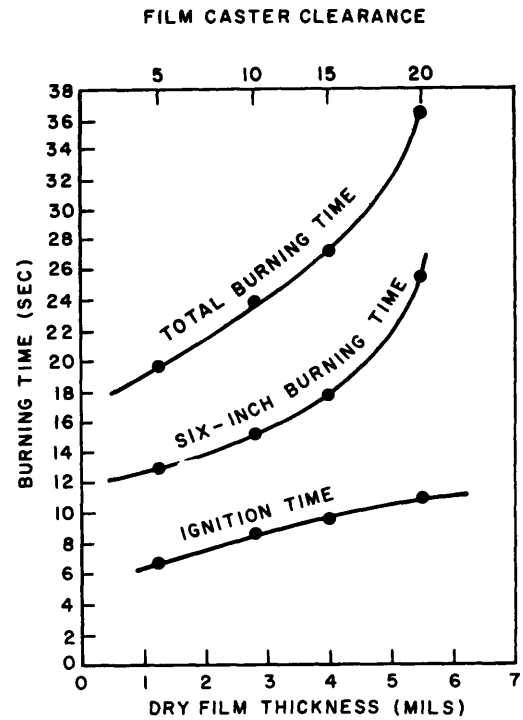

Fig. 4 - Relationship between film thickness and burning time for NRL acrylic paint on an asbestos substrate

contains approximately 5% propylene glycol, while the compositions of the proprietary paints are unknown. Until these organic compounds are completely evaporated from the film, they can reduce fire-retardant properties. The fire-retardant quality of the paint should be such as to negate the effects of any residual solvents remaining in the paint film after 5 days of drying at ambient conditions; therefore, measurements were made only after samples had dried for this period. However, additional measurements were made on samples dried for longer periods of time and/or under more drastic conditions to detect any effect of residual solvents.

Tables 3 through 7 summarize some of the NRL fire-retardancy tests on the NRL system and the three proprietary paints. In Table 3, the proprietary paints were applied to asbestos with a film caster having a 10-mil clearance. The dry films are estimated to be approximately 2.5 mils thick, equivalent to approximately three brush coats. The NRL coatings are slightly thicker.

The results indicate that Ocean 634 paint may have some sensitivity to drying conditions, since one sample burned completely after drying for only 5 days, while the samples dried for 25 days self-extinguished. However, the data from the other tables do not strongly support this drying sensitivity, and the data could be interpreted as indicating the fire-retardant performance of the Ocean 634 paint to be marginal at this film thickness. Although some excess solvent may have been trapped in this sample, while not in others, some slight variable in the test could have caused the anomalous behavior. The Amercoat 1768 paint and Devflex MD2707 paint appear to have acceptable performance at this film thickness even though a majority of the samples required from 1 to 2 seconds before self-extinguishing. All trials using the NRL coating system immediately self-extinguished when the source of ignition was removed. It should be pointed out that the

Table 3
NRL Evaluation of Thin Films of Fire-Retardant Paints on Asbestos-Paper Substrate

Coating*	Drying Time, Ambient Conditions (days)	No. of Samples	Results
Ocean 634	5	1	Burned 19.6 sec
	5	1	SE† after 2.2 sec
	25	3	SE after 2.0 sec
Amercoat 1768	5	1	SE after 1.7 sec
	5	1	Immed. SE
	25	3	SE after 1.6 sec
Devflex MD2707	5	1	SE after 1.2 sec
	5	1	Immed. SE
	25	2	SE after 0.8 sec
	25	1	Immed. SE
NRL Coating System			
12-mil DCT‡/12-mil FRU§	5	2	Immed. SE
	25	2	Immed. SE
12-mil DCT/6-mil FRU	5	2	Immed. SE
	25	2	Immed. SE
6-mil DCT/6-mil FRU	5	2	Immed. SE
	25	2	Immed. SE

*Film caster clearance was 10 mils unless otherwise shown.
†SE = Self-extinguishing.
‡NRL decorative, combustible topcoat.
§NRL fire-retardant undercoat.

total film thicknesses of the NRL systems were greater than those of the proprietary paints; if anything, this should make the test conditions more severe on the NRL coating, and poorer performance might have been expected.

In Table 4, thicker films of the proprietary paints were used to match more closely the thickness of the NRL system. The 12-mil caster would be expected to produce a dry film approximately 2.8 mils thick. The NRL coatings are the same as reported in Table 3. The performance of the proprietary paints is, in general, poorer than the thinner samples reported in Table 3. The fact that a Devflex sample burned completely after only 5 days of drying time may be due to residual organic solvents trapped in the thicker film. The results in Table 5 appear to support this conclusion, since the two Devflex samples burned completely after drying for only 5 to 6 days, while the two which dried for 25 days were self-extinguishing.

The samples reported in Table 5 were prepared with a 20-mil film caster and, as expected, performed even poorer. Both the Ocean 634 and Amercoat 1768 were unacceptable with respect to fire retardancy as indicated in this test. At the greater film

Table 4
NRL Evaluation of Medium Thick Films of Fire-Retardant Paints on Asbestos-Paper Substrate

Coating*	Drying Time, Ambient Conditions (days)	No. of Samples	Results
Ocean 634	5	2	SE† after 4.5 sec
	25	2	SE after 3.8 sec
Amercoat 1768	5	2	SE after 5.8 sec
	25	2	SE after 5.1 sec
Devflex MD2707	5	1	Burned 25.1 sec
	5	1	SE after 1.8 sec
	25	2	SE after 1.3 sec
NRL Coating System			
12-mil DCT‡/12-mil FRU§	5	2	Immed. SE
	25	2	Immed. SE
12-mil DCT/6-mil FRU	5	2	Immed. SE
	25	2	Immed. SE
6-mil DCT/6-mil FRU	5	2	Immed. SE
	25	2	Immed. SE

*Film caster clearance was 12 mils unless otherwise shown.
†SE = Self-extinguishing
‡NRL decorative, combustible topcoat.
§NRL fire-retardant, undercoat.

thicknesses, the retardancy of the NRL system decreases perceptibly. However, the performance is still quite good as shown by three out of four samples self-extinguishing immediately and the fourth self-extinguishing after 1.8 seconds. The use of thicker films not only offers a means for differentiating between the fire-retardant qualities of these coatings but also indicates the type of protection to be expected from them as film thickness builds up over the years of maintenance painting. In the case of the Ocean 634 and Amercoat 1768, it appears that after three or four coats have been applied it will be necessary to remove the old paint before further painting can be tolerated.

Because these paints are used on steel bulkheads and overheads, performance on a metal substrate was of interest. Since thick metal provides a heat sink making the ignition of the paint film difficult, thin aluminum foil was chosen. Further, it was possible that some of the fire-retardant additives in the proprietary paints could have been lost by absorption or migration into the porous asbestos paper. This was not expected with the NRL system, since the chlorinated paraffin is a solid with fairly large particle size. However, a liquid fire-retardant additive, such as chlorinated phosphate ester, could be lost in this manner and cause a corresponding decrease in fire retardancy. Testing on aluminum foil would eliminate this complication.

Table 5
NRL Evaluation of Thick Films of Fire-Retardant Paints on Asbestos-Paper Substrate

Coating*	Drying Time (days)†	No. of Samples	Results
Ocean 634	5	1	Burned 35.7 sec
	5 at RT, 1 at 50°C	1	Burned 37.0 sec
	25	1	SE‡ after 1.0 sec
	25	1	Burned 34.8 sec
Amercoat 1768	5	1	Burned 34.3 sec
	5 at RT, 1 at 50°C	1	Burned 31.1 sec
	25	2	Burned 36.2 sec
Devflex MD2707	5	1	Burned 15.2 sec
	5 at RT, 1 at 50°C	1	Burned 16.2 sec
	25	1	SE after 1.6 sec
	25	1	Immed. SE
NRL Coating System			
20-mil DCT§/10-mil FRU¶	5	1	Immed. SE
	5	1	SE after 1.8 sec
	25	2	Immed. SE

*Film caster clearance was 20 mils unless otherwise shown.
†Film was dried at ambient conditions unless otherwise shown.
‡SE = self-extinguishing.
§NRL decorative, combustible topcoat.
¶NRL fire-retardant undercoat.

In Table 6, it can be seen that the three proprietary paints burned completely on the aluminum foil. With the NRL system, two of the samples burned completely, and two self-extinguished after approximately 5 seconds. The two samples that burned were dried for only 2 and 6 days before testing, and the poorer performance may be caused by the trapped solvent propylene glycol.

The total dry film thickness of the NRL system was 10 mils, 6.5 mils for the topcoat and 3.5 mils for the undercoat, as compared to a range of 6.6 to 7.7 for the proprietary paints. The chlorinated alkyd paint (Formula 124/58) exhibited good performance at a dry film thickness of only 5.7 mils; but, if it were evaluated at film thicknesses comparable to the NRL system, its performance would not have been as good.

In Table 7, the fire retardancy of thinner films on aluminum foil is summarized. At dry film thicknesses of 2.8 to 3.1 mils, the proprietary paints still burned the full 6-in. length. The Ocean 634 even burned when the dry film thickness was only 0.9 mil. Although three of the Devflex MD2707 samples self-extinguished at a film thickness of 0.7 mil, two samples did burn completely. Further, it is quite likely that the three samples that did self-extinguish did so because there was insufficient heat generated from the very thin films to support combustion. Devflex MD2707 films at 1.6 and 2.4 mils burned completely.

Table 6
NRL Evaluation of Thick Films of Fire-Retardant Paints on 0.8-Mil Aluminum-Foil Substrate

Coating*	Drying Time† (days)	Dry Film Thickness (mils)	No. of Samples	Results
Ocean 634	5	6.6	2	Burned 24.1 sec
	15	6.6	1	Burned 22.8 sec
	10 at RT, 4 at 50°C	6.6	1	Burned 22.6 sec
Amercoat 1768	5	7.2	2	Burned 20.6 sec
	15	7.2	1	Burned 20.6 sec
	10 at RT, 4 at 50°C	7.2	1	Burned 17.3 sec
Devflex MD2707	5	7.7	2	Burned 27.0 sec
	15	7.7	1	Burned 26.8 sec
	10 at RT, 4 at 50°C	7.7	1	Burned 32.2 sec
Cl-alkyd (124/58)	3	5.7	1	SE‡ after 1.3 sec
	6	5.7	1	Immed. SE
NRL Coating System				
20-mil DCT§/10-mil FRU¶	2	6.5/3.5	1	Burned 39.4 sec
	6	6.5/3.5	1	Burned 15.0 sec
	6	6.5/3.5	1	SE after 4.7 sec
	6 at RT, 4 at 50°C	6.5/3.5	1	SE after 5.7 sec

*Film caster clearance was 20 mils unless otherwise shown.
†Films were dried at ambient conditions unless otherwise shown.
‡SE = Self-extinguishing.
§NRL decorative, combustible topcoat.
¶NRL fire-retardant undercoat.

The performance of the NRL system was found to be unsatisfactory on aluminum when the ratio of the topcoat to undercoat thickness was above 2 to 1. At ratios approximately 1 to 1, or smaller, the fire retardancy is very good. Earlier studies on the asbestos substrate had indicated that two and even three coats of the topcoat could be applied over a single coat of the undercoat with no appreciable decrease in fire retardancy. However, the aluminum substrate provides a more severe test, and the effect of an excessively thick topcoat over the undercoat is readily apparent as shown by the first and last series in the group of samples of the NRL system. However, the fire retardancy is still quite good after three applications of the coating system, where each application consisted of one coat of the undercoat and one coat of the topcoat. Since these coatings were applied by brush, the film thicknesses are what might be expected in touchup painting of the submarine. As discussed earlier, one coat of the undercoat and one coat of the topcoat should be sufficient to give complete hiding and coverage. However, since frequent painting is required, it is quite important that the coating retain its fire-retardancy performance after several coats have been applied. It appears that the NRL coating will meet this requirement, if the undercoat is applied each time before the topcoat and at approximately the same thickness as the topcoat.

Table 7
NRL Evaluation of Thin Films of Fire-Retardant Paints on 0.8 Mil Aluminum-Foil Substrate

Coating	Film Caster Clearance or Number of Brush Coatings	Drying Time, Ambient Conditions (days)	Dry Film Thickness (mils)	No. of Samples	Results
Ocean 634	10 mils	21	2.8	5	Burned; 10.3 sec
Amercoat 1768	10 mils	21	3.1	5	Burned; 9.5 sec
Devflex MD2707	10 mils	21	2.9	5	Burned; 11.5 sec
Ocean 634	1 brush coating	21	0.9	5	Burned; 4.4 sec
	2 brush coatings	20	1.7	5	Burned; 7.5 sec
	3 brush coatings	18	2.5	5	Burned; 10.1 sec
Devflex MD2707	1 brush coating	21	0.7	2	Burned; 3.9 sec
	1 brush coating	21	0.7	1	SE* after 1-2 sec
	1 brush coating	21	0.7	2	Immed. SE
	2 brush coatings	20	1.6	5	Burned; 6.7 sec
	3 brush coatings	18	2.4	4	Burned; 8.9 sec
NRL Coating System (DCT†/FRU‡)					
(2.4/1.4)§	10 mils/brush	20	3.8	4	Burned; 12.6 sec
		20	3.8	1	SE after 1.5 sec
(0.8/1.4)	All brush	21	2.2	4	Immed. SE
		21	2.2	4	SE after 1.2 sec
(0.9/1.2) (0.9/1.2)	All brush	20	4.2	3	SE after 1.5 sec
		20	4.2	2	Immed. SE
(1.2/1.2) (1.0/0.9) (0.6/1.1)	All brush	18	6.0	4	SE after 1.4 sec
DCT/DCT/FRU					
(0.8/1.5/1.0)	All brush	20	3.3	3	Burned; 10.5 sec
		20	3.3	1	SE after 2.0 sec

*SE = Self-extinguishing.
†NRL decorative, combustible topcoat.
‡NRL fire-retardant undercoat.
§Individual dry film thicknesses.

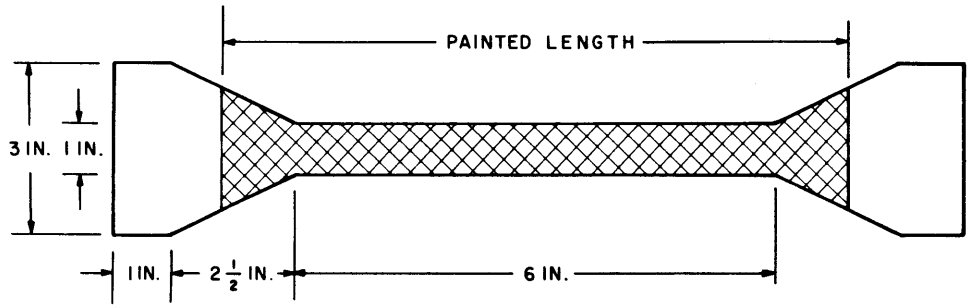

Fig. 5 - Test panel for the thermoelectric tester
(the panel was 15 ± 0.5 mils thick)

The fire retardancy of the NRL system was also evaluated by the Mare Island Paint Laboratory.* At Mare Island, the flammability of paints is evaluated thermoelectrically. This test determines if a paint will ignite into flame when the sole ignition source is the metallic substrate to which the paint adheres. The test is essentially the same as described by Birnbaum and Markowitz in 1948 (11). A large current is passed through a steel specimen coated on both sides with the paint. The dimensions of the panel are shown in Fig. 5. The steel specimen is attached to the test apparatus at the uncoated ends, and the current is delivered by a motor generator which rapidly heats the steel specimen to approximately 1800°F in 60 seconds. The specimen is observed for ignition, flashes, or burns.

Results from Mare Island are reported in Table 8 but do not include Amercoat 1768 of which no sample was available there. Three samples of Ocean 634 ignited at 1800°F and burned for an average of 27 seconds. No Devflex MD2707 sample ignited.

The effect of increasing the number of topcoats in the NRL system is also shown in Table 8. With a single topcoat, none of the three specimens ignited; with two topcoats, the three specimens ignited after 84 seconds and burned for 12 seconds. Although this is superior to Ocean 634 at a thickness of 5.3 mils, it probably would not be at comparable thicknesses. With three topcoats, the samples had an average ignition time of 72 seconds and an average burning time of 49 seconds. These data support earlier conclusions that only one topcoat should be applied over the fire-retardant undercoat. If it is necessary to apply a second coat to get complete hiding of a very dark surface with a light color, the fire-retardant undercoat should be applied between. The effectiveness of this approach is shown by the last series in which three applications of the NRL system were made in this manner. One of the specimens did not ignite, while the other two ignited after 89 seconds and burned for 24 seconds. This performance is better than Ocean 634 but inferior to the Devflex MD2707. However, the thickness of the Devflex specimens was only 5.5 mils compared to 8.0 mils for the specimens containing three applications of the NRL system. If the Devflex films were 8 mils thick, it is quite likely that its performance would be no better than the three coats of the NRL system.

SUMMARY

The studies at NRL and at the Mare Island Paint Laboratory have indicated that the NRL coating is at least as good as the three proprietary paints and probably better.

*San Francisco Bay Naval Shipyard, Vallejo, California.

Table 8
Summary of Mare Island Paint Laboratory's Evaluation of Fire-Retardant Paints on Thermoelectric Tester (Metal Substrate)

Coating*	Average Dry Film Thickness (mils)	Samples	Results
Ocean 634	5.3	3	Burned 27 sec (ignited at 1800°F)
Amercoat 1768	—	-	Not tested
Devflex MD2707	5.5	3	No ignition
NRL Coating System			
1 coat DCT†/1 coat FRU‡	2.7	3	No ignition
2 coats DCT/1 coat FRU	4.3	3	Burned 12 sec (ignited after 84 sec)
3 coats DCT/1 coat FRU	5.0	3	Burned 49 sec (ignited after 72 sec)
3 coats (1 coat DCT/1 coat FRU)	8.0	1	No ignition
3 coats (1 coat DCT/1 coat FRU)	8.0	2	Burned 24 sec (ignited after 89 sec)

*Films were dried for 30 days at room temperature.
†NRL decorative, combustible topcoat.
‡NRL fire-retardant undercoat.

The fire-retardant undercoat and the decorative topcoat should be applied at approximately the same dry film thickness, and if more than one coat is needed, the undercoat should be used between each additional topcoat. In this manner, the coating will exhibit its maximum fire-retardant and decorative qualities, which appear to be superior to the three proprietary paints in all respects. Since propylene glycol was used as the cosolvent in the NRL system, it is expected to be even less toxic than the proprietary paints.

RECOMMENDATIONS

It is recommended that the NRL coating be evaluated on a nuclear-powered submarine to determine the acceptability of this coating in the fleet. Eight gal of the fire-retardant undercoat and decorative combustible topcoat have been prepared and are available for this initial evaluation. If results of this evaluation are favorable, 100 to 200 gal should be procured from a paint manufacturer for more widespread evaluation. If the results continue to be favorable, specifications should be written and the coating system incorporated into the Federal Supply System.

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Appendix A

FIRE RETARDANT UNDERCOAT, NRL
(Formulation N4001-69)

Ingredients	Supplier	WT-Percent
Water		13.748
Propylene glycol, U.S.P.	Fisher	4.979
Tamol 731 (25% solids)*	Rohm and Haas	1.178
Triton CF-10	Rohm and Haas	0.119
Nopco NDW	Nopco	0.119
G-11 (Hexachlorophene, U.S.P.)	Sindar	0.040
Antimony oxide, KR grade	Harshaw	16.511
Eldefoam	Foremost	0.295
Polyglycol P1200	Dow	0.297
Triton GR-5 (60% solids)†	Rohm and Haas	0.189
Rhoplex AC-22X (44.5% solids)‡	Rohm and Haas	33.501
Rhoplex C-73 (46.5% solids)‡	Rohm and Haas	3.183
Delvet 65 (65% solids)§	Diamond Alkali	25.627
Bubble breaker 746	Balab	0.214
Total		100.000

*Aqueous solution.
†Aqueous solution containing 20% isopropanol.
‡Aqueous dispersion, contains no mercury preservative.
§Aqueous dispersion.

Density	10.91 lb/gal
PVC	10.76%
Wt-% Solids	50.75
Wt-% Volatile Organics	5.017

Appendix B

DECORATIVE, COMBUSTIBLE TOPCOAT, NRL
(Formulation N4001-67)

Ingredients	Supplier	WT-Percent
Water		10.076
Tamol 731 (25% solids)*	Rohm and Haas	2.105
Propylene glycol, U.S.P.	Fisher	5.420
Triton CF-10	Rohm and Haas	0.188
Nopco NDW	Nopco	0.188
G-11 (Hexachlorophene, U.S.P.)	Sindar	0.091
Titanium dioxide, R-900	Dupont	29.633
Eldefoam 2892	Foremost	0.462
Polyglycol P1200	Dow	0.463
Triton GR-5 (60% solids)†	Rohm and Haas	0.195
Rhoplex AC-22X (44.5% solids)‡	Rohm and Haas	45.939
Rhoplex C-73 (46.5% solids)‡	Rohm and Haas	4.909
Bubble breaker 746	Balab	0.331
Total		100.000

*Aqueous solution.
†Aqueous solution containing 20% isopropanol.
‡Aqueous dispersion, contains no mercury preservative.

Density	11.42 lbs/gal
PVC	26.33%
Wt-% Solids	54.26
Wt-% Volatile Organics	5.459

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5. AUTHOR(S) *(First name, middle initial, last name)*

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13. ABSTRACT

The Navy needs a fire-retardant paint for submarine interiors that will release little or no toxic materials into the atmosphere during and after application. The paint should possess good leveling properties so that an attractive surface free of brush marks is obtained, should have a short drying time, and should show good freeze-thaw stability. The dry film should be flexible, should possess good hiding power, and should have a 60° gloss between 35 and 50%. A water-based coating system has been developed that should meet these requirements.

Such a coating system consists of a fire-retardant undercoat and a decorative topcoat. The topcoat alone is combustible, but when used in combination with the fire-retardant undercoat, the complete system is self-extinguishing. Although the system will burn when exposed to an extraneous flame or fire, the burning film will immediately self-extinguish when the ignition source is removed or when that part of the film exposed to the fire is consumed.

The Navy currently uses three proprietary water-based paints in cases where the normally specified solvent-based, fire-retardant paint (a chlorinated alkyd) leads to contamination of the submarine atmosphere. The NRL coating system appears to be superior in all respects to these three proprietary paints but inferior in some properties to the standard solvent-based paint.

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