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Relative Corrosivity of Currently Approved Wildland Fire Chemicals

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ORIGINAL
COMPLETED

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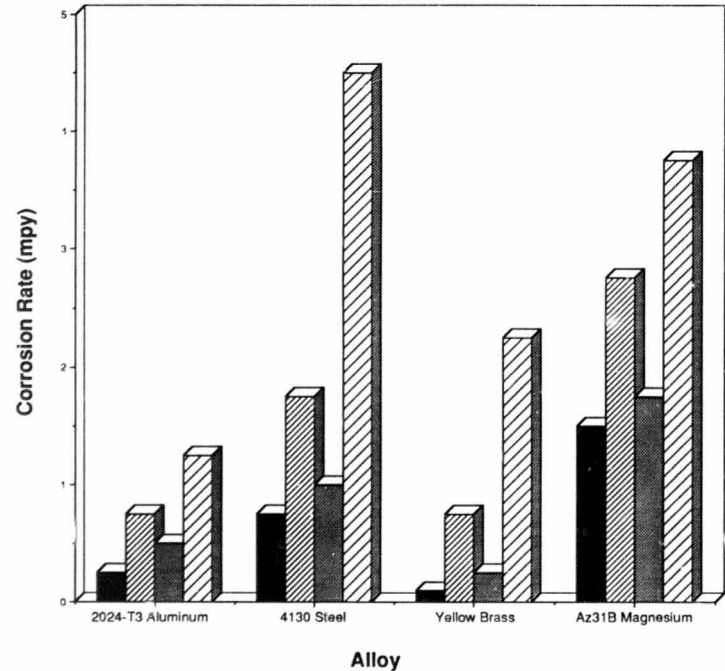
RESEARCH SUMMARY

Extensive research resulted in recommendations for improved test procedures and inclusion of alloys and exposures that would give more accurate indications of corrosion found in the field. Following these recommendations, tests have been completed on a number of long- and short-term retardants and fire suppressant foams, including all those presently approved.

Uniform corrosion tests were performed on currently approved wildland fire chemicals (long-term retardant, short-term retardant, and fire suppressant foam) using four alloys representative of those identified during field inspections as being used in air or ground tankers and at retardant mix facilities. Two temperatures (70 and 120 °F) and two immersion conditions (totally immersed and partially immersed) were originally selected so that the combinations of temperature and immersion conditions gave results that reflected the types and extent of corrosion damage typically found at retardant bases.

Aluminum and magnesium are known to be susceptible to intergranular corrosion. Coupons of these alloys were examined microscopically, after exposure to fire retardant chemicals during uniform corrosion tests. No intergranular corrosion was found in most cases, although the base salts found in current fire retardants can cause intergranular corrosion. It is likely that the inhibitors that are being included in the present formulations for uniform corrosion can also eliminate intergranular corrosion.

All of the currently used retardants meet Forest Service specifications and interim requirements. But there is significant variation in performance within the required limits. This information should assist field personnel in selecting a retardant best suited for their specific needs or application.



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INTRODUCTION

From the early stages of the development of chemicals for wildland fire control, damage from fire retardant corrosion was recognized as a serious problem. Extensive damage was done to equipment used in the handling, mixing, storing, and delivery of retardants (Davis and Phillips 1965; USDA FS 1964a). Corrosion-related damage, especially to aircraft, creates unsafe conditions. Preventing this damage reduces the potential risk of injury and death; moreover, everyone benefits from reduced expenditures for equipment repair and replacement.

A program to evaluate and control corrosion damage was initiated in the mid-1960's. Formal studies were undertaken at that time. A number of different test methods and materials were used by laboratories to determine the extent and likelihood of corrosion damage (USDA FS 1964b, 1968). Progress was complicated by the number of different types of corrosion attack that were found in the field, the variety of materials found at retardant facilities, and the number of chemicals being investigated for use as fire retardants.

By the early 1970's fire retardant specifications, Forest Service interim specifications 5100-00301 (1969) and 5100-00302 (1970), were in place. These documents specified acceptable corrosion performance and set the allowable limits of corrosive attack if a retardant was to be used by the Forest Service. Early specifications set limits for corrosion to 2024-T3 aluminum (commonly found on fixed-wing airtankers). New products were required to meet these limits when evaluated using a short-duration (40 hours) electrochemical test procedure (USDA FS 1969, 1970). Later the specifications were amended to include other alloys specific to the intended use and application method for the retardant (USDA FS 1975a, 1975b).

Enforcement of the corrosion requirements led to improved corrosion performance in the field. Nevertheless, it was not uncommon to have extensive

corrosion damage in the field caused by a retardant that showed very little corrosion when tested in the laboratory. Clearly more work was needed. A research program was undertaken to improve the correlation between laboratory evaluation results and the corrosion damage seen in the field. Results of this work would allow more realistic limits of corrosion to be set.

As a first step in the study, Ocean City Research Corporation (OCRC), under a contract awarded in 1973, performed a field survey of mixing plants, airtanker bases, and airtankers to assess the severity and types of corrosion damage occurring and the alloys being attacked (Gehring 1974).

At the same time a study was undertaken to evaluate the corrosivity of forest fire retardants and improve the methods of determining the potential damage. A number of corrosion measurements and test conditions were investigated to try to obtain the best correlations with field experience. The contract with OCRC was expanded to assist the Forest Service in this effort to develop more realistic test methods and performance limits (Gehring 1978, 1980).

As a result of extensive work by OCRC and the Forest Service, new corrosion requirements and methods of evaluation were proposed and evaluated. Inclusion of new test conditions and methods into a new long-term fire retardant specification, Forest Service interim specification 5100-00304 (USDA FS 1982, revised 1986a), used to qualify fire retardant chemicals should limit the extent of damage being done by these chemicals.

A phase-in period was established so that retardant manufacturers would have time to respond to the new requirements. Response could consist of modifying existing products, developing new retardants when the existing products could not meet the new standards, or dropping out of the market. The new Forest Service specification went into effect in September 1984. The corrosion requirements associated with the new specification are shown in table 1.

Table 1—Corrosion requirements (in mils per year) for wildland fire chemicals¹

Alloy: Immersion: Temperature, °F:	2024-T3 aluminum				4130 steel				Yellow brass				Az-31-B magnesium					
	Total		Partial		Total		Partial		Total		Partial		Total		Partial			
	70	120	70	120	70	120	70	120	70	120	70	120	70	120	70	120		
-----Mils per year-----																		
Premix components																		
Liquid components and concentrates (except fixed-tank helicopters) ²	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	—	—	—	—
Liquid components and concentrates for fixed-tank helicopters	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	10.0	10.0	10.0	10.0
Mixed retardants																		
Fixed-wing ³	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	—	—	—	—
Helicopter with internal or fixed tank ⁴	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	4.0	2.0	4.0
Ground application or helicopter with bucket ⁵	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	—	—	—	—

¹All corrosion rates will be determined by 90-day weight loss. All uniform corrosion rates are the maximum allowable average of at least three replicates.

²Magnesium corrosion tests will be performed for performance information.

³Intergranular corrosion tests will be performed on aluminum coupons; no intergranular corrosion is allowed. Magnesium corrosion tests will be performed for performance information.

⁴Intergranular corrosion tests will be performed on aluminum and magnesium coupons; no intergranular corrosion is allowed.

During the mid-1970's and early 1980's the price of long-term retardants increased significantly as the costs of many of the raw materials rose. Although the prices of all ingredients increased, the rising costs of the fertilizers, especially phosphates, that are the major component in fire retardants contributed most to the overall increase. In response, some field units showed a renewed interest in short-term retardants. These materials contain thickening agents to improve drop performance and increase the ability of the water to cling to the fuels rather than run off, and coloring agents so the retardants can be seen against the forest fuels when viewed from the air. Because they contain no retardant salts, short-term retardants are not effective after the water has evaporated. For the same reason they are considerably less expensive than long-term retardants.

Short-term retardants were evaluated under a short-term retardant evaluation plan. This plan included laboratory performance evaluation of several characteristics including corrosion (George and Johnson 1984). The numerical limits for corrosion caused by short-term retardants are the same as for long-term retardants. The test method was modified to take into account the differences in the way

that long- and short-term retardants are formulated and used. In 1987, the corrosion requirements and modified test method were formalized in a specification, Forest Service interim specification 5100-00306, for short-term fire retardants (USDA FS 1987). All currently approved short-term retardants have been tested and approved using the procedures and requirements found in this specification.

In 1986 the Forest Service added still another tool to its firefighting arsenal when it began the conceptual evaluation of firefighting foam. Like short-term retardants, foams depend on the water they contain for their effectiveness, but unlike short-term retardants they do not contain polymeric thickeners. Instead they consist of foaming agents and wetting agents. These chemicals are formulated to allow slower release of the entrapped moisture and improve its ability to penetrate the fuels. In certain situations the foam may also provide insulation and/or vapor barrier action.

The Forest Service developed a plan for the field evaluation of wildland fire foam products in 1986. A list of laboratory test requirements that were to be met prior to a product being included in the field evaluation was prepared. The evaluation criteria and performance requirements are described in

"Interim Requirements and Manufacturer Submission Procedures for Wildland Fire Foam" (USDA FS 1986b). One of the required tests was a complete corrosion series. The same corrosion test method and requirements previously discussed for long-term retardants were adopted because the chemicals were to be used in the same way.

This report describes in detail the method used by the Forest Service to evaluate the corrosiveness of forest fire retardants. Products that meet all of the requirements detailed in the specifications and interim requirements are included on the Forest Service list of qualified and approved products (see appendix). This list is updated each year to include new products and reflect changes in the status of any of the fire chemicals listed. The corrosion performance of products included on that list is included.

THE STUDY

Tests were conducted to determine the extent of uniform corrosion and intergranular corrosion associated with long- and short-term fire retardants and wildland fire foams.

Uniform corrosion is the loss of mass from large areas of the metal surface in a relatively even manner. The corrosion rate is expressed as the thickness of metal lost over time, in this case thousandths of an inch (mils) per year (or mpy). Uniform corrosion to four alloys, 2024-T3 aluminum, AISI 4130 steel, yellow brass (65 Cu-35 Zn), and Az-31-B magnesium, representative of those exposed in airtankers and helicopters and in use at retardant mixing and storage facilities, was determined by standard weight loss tests over a 90-day test period. These alloys and their common applications are discussed in detail in several reports by Ocean City Research Corporation (Gehring 1974; Gehring and George 1986). This information is summarized in table 2.

For the test conditions, two temperatures and two immersion conditions were selected: 70 °F is a moderate temperature likely to be encountered often during normal field operations; 120 °F is an elevated but not unreasonable temperature that could be encountered in the field especially in small storage or mix tanks or in airtankers that are required to sit loaded, as is often the case in California. (Temperatures from freezing to 100 °F have been observed in the field in storage tanks; data on file at Intermountain Fire Sciences Laboratory.) Elevated temperatures accelerate the rate of chemical reactions, including corrosion of the exposed metal.

The two immersion conditions chosen were: total immersion where the coupon is completely submerged in the retardant solution and partial immersion where the coupon is suspended so that one-half

Table 2—Common applications of alloys used in wildland fire chemical specifications

Metal alloy	Application
2024-T3 aluminum	Aircraft tanks and gates Loading valves
AISI 4130 steel	Aircraft torque tubes and wheel treadles Mixing and storage tanks
Yellow brass	Valves, pipe and tank fittings, turn- buckles, and cable clamps Pumps and hose couplings
Az-31-B magnesium	Aircraft wheel rims, hydraulic cylin- der heads, numerous helicopter components

of the coupon is submerged in the retardant and the other half is in the vapor above the retardant. This is shown in figure 1. The combination of elevated exposure temperatures and partial immersion causes corrosion similar to the more severe corrosion sometimes seen in the field but not in the moderate-temperature, total immersion test (the only type of test required in previous specifications). Figure 2 shows an example of corrosion damage as seen in the lab and the field.

One test method was used for most of the fire chemicals. Chemicals tested were long-term retardants, both liquid concentrates and mixed retardant; wildland fire foams, both liquid concentrates and the mixed solutions; and short-term retardant liquid concentrates. For these types of products, a test coupon was immersed in a sample of the chemical being evaluated. The container with the retardant and coupon then was left undisturbed for the entire 90-day duration of the test.

Short-term retardant mixed solutions required a slightly different procedure. Because short-term retardants are designed to be used immediately after mixing, they may not normally contain bactericides, nor are they likely to be stable for extended periods. The test procedure was therefore modified to more accurately reflect normal field use of the mixed retardant. For uniform corrosion testing of the mixed short-term retardants, the coupon was immersed in a sample of the product being evaluated. Every 7 days, the short-term retardant was removed from the test container. The container was rinsed with tap water and then refilled to the same level with freshly mixed short-term retardant. This process was repeated every 7 days throughout the 90-day test period.

Standards developed by OCRC and the Intermountain Fire Sciences Laboratory, based on

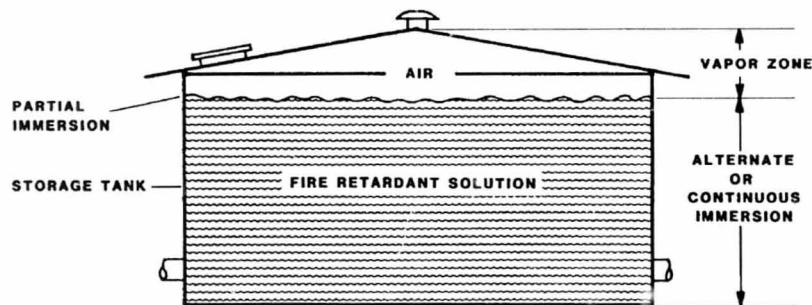


Figure 1—Common examples of metal/retardant exposure that can result in corrosion.

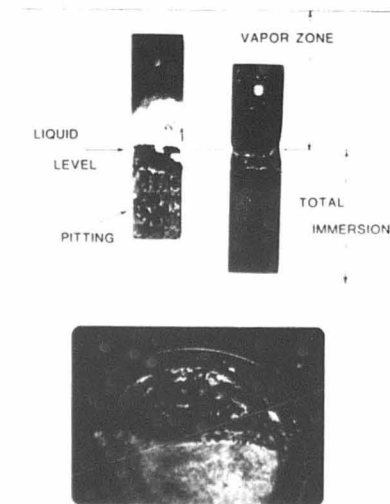


Figure 2—An example of corrosion in the field reflected in the corrosion found during laboratory testing.

practical test methods refined during earlier studies, were used for this work. These methods are now included in the Forest Service specifications and requirements for all types of wildland fire chemicals.

Intergranular corrosion is selective attack at the boundary between grains of the metal. This results in a decrease in the strength of the metal beyond expectation based on the small amounts of metal destroyed. Intergranular corrosion tests were conducted only when all uniform corrosion results were within the required limits. Aluminum coupons that had been exposed to retardant during the weight-loss tests were examined for intergranular corrosion if the retardant was designed for aerial application from either fixed-wing airtankers or helicopters with fixed tanks. In addition, if the retardant was designed for use from fixed-tank helicopters, then the magnesium coupons were also examined for intergranular corrosion.

The corrosion rates were determined on all freshly mixed fire chemical solutions. In addition, a series of tests were performed after these same solutions had been stored outside for 1 year at San Dimas, CA, and Missoula, MT. Each 5-gallon sample was stored in a polyethylene carboy containing a mild steel coupon 1/8 by 2 by 12 inches to approximate the ratio of metal surface in contact with the retardant in a typical storage tank. Designed to reflect the conditions normally encountered in storage, these tests were used to determine whether the corrosion inhibitors that manufacturers added to their formulations would be sufficient to protect the alloys against altered corrosion characteristics that may result from changes in retardant chemistry over time, as well as changes in the inhibitor effectiveness caused by storage time and conditions.

Table 3—Cleaning procedures for corrosion test alloys

Alloy	Chemical ¹	Time	Temperature	Remarks
		<i>Min</i>		
Aluminum	70% HNO ₃ (concentrated)	2-3	Room	Follow with light scrub using a nonmetallic brush.
Aluminum	2% CrO ₃ in 5% H ₃ PO ₄	10	175-185 °F	Use when film resists nitric acid treatment. Alternate the two treatments with light scrubbing as needed.
Brass	15-20% HCl (half strength)	2-3	Room	Follow with light scrub using a nonmetallic brush.
Steel	50 g SnCl ₂ + 20 g SbCl ₅ /L conc HCl	3-5	Cold (ice bath)	Follow with light scrub using a nonmetallic brush.
Magnesium	15% CrO ₃ + 1% AgCrO ₄ in distilled H ₂ O	15	Boiling	Follow with light scrub using a nonmetallic brush.

¹Cleaning solutions should be discarded as they become used or discolored. If in doubt, replace it. When cleaning exposed coupons, special care is needed to prevent erroneous results and, in the case of the magnesium solution, fresh chemical should be used for each coupon.

TEST METHOD

Uniform Corrosion

Corrosion test coupons, 1 by 4 by 1/8 inches, were purchased from a commercial supplier. Each coupon had a small hole drilled near one end for suspending the coupon in the retardant solution. The coupons were marked with a unique identification number using a vibrating engraver and measured in each dimension to the nearest 0.001 cm. Prior to use, the coupons were degreased by rinsing with "409" brand all-purpose liquid cleaner and chemically cleaned using the methods described in table 3. This process removed existing scale and naturally occurring protective films. After cleaning, the coupons were rinsed in distilled water, wiped with a clean lint-free cloth to remove most of the water clinging to them, and dried at 50 to 60 °C. After drying, the coupons were allowed to cool to room temperature, weighed to the nearest 0.1 mg, and stored in a desiccator until used. To prevent contamination the cleaned coupons were handled with gloves or forceps (National Association of Corrosion Engineers 1969).

One coupon was suspended by a length of braided dacron fishing line in each 1-quart glass jar that had been filled with the prescribed amount of retardant solution. The coupon was hung in such a manner that the coupon did not touch the sides or bottom of the jar. For a total immersion test, the jar contained 800 mL of retardant and the coupon was completely submerged in the retardant. For a partial immersion test, the jar contained 400 mL of

solution and the coupon was suspended so that the lower half (2 inches) of the coupon was submerged in the retardant. Figure 3 shows coupons totally and partially immersed in a retardant sample. The jars were closed with tightly fitting nonmetallic screw caps and labeled with the coupon number and date the test was started.

All test samples were placed in an incubator to maintain a temperature of either 70 or 120 °F during the 90-day test period. The test samples of long-term retardants (liquid concentrates and mixed for use), foams (concentrates and solutions mixed for use), and short-term retardant concentrates were

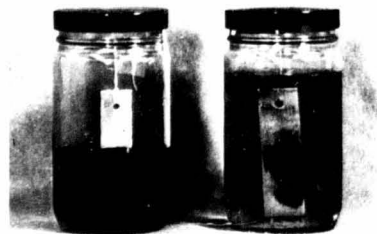


Figure 3—Corrosion test coupons partially and totally immersed in retardant during the uniform corrosion test.

not disturbed during the entire 90-day test period. As described earlier, the samples of short-term retardants mixed for use were changed every week. The old solution was removed from the container and replaced with freshly prepared solution after the jar and coupon were rinsed with tap water to remove retardant residue. All samples were then returned to the proper incubator and left until the next weekly change.

At the end of the 90-day test period, the coupons were removed from the test solution and scrubbed with a toothbrush (or other nonmetallic brush) under tap water to remove loose scale and deposits. They were then chemically cleaned in the same manner as was done prior to exposure in the retardant solution. The cleaning removed corrosion products, inhibitors, or other films that might have formed. At the same time, an unused, previously cleaned coupon was cleaned using the same solutions to determine the amount of metal lost during the cleaning process. After cleaning, the coupons were rinsed in distilled water, dried, cooled, and weighed as before.

The corrosion rate in mils-per-year (mpy) for each coupon was calculated by the formula:

$$Cr = \frac{534(W_t - W_t - W_t - W_t)}{(A)(t)(p)}$$

where

W_t	= initial coupon weight, mg
W_t	= final coupon weight, mg
W_t	= weight loss of the control, mg
A	= exposed area of the coupon, in ²
t	= exposure time, h
p	= density of the alloy, g/cm ³ :
	2024-T3 aluminum = 2.77 g/cm ³
	4130 steel = 7.86 g/cm ³
	yellow brass = 8.47 g/cm ³
	Az-31-B magnesium = 1.77 g/cm ³

Intergranular Corrosion

If the uniform corrosion rates met the prescribed performance limits specified in table 1, and if the retardant was designed for application from a fixed-wing aircraft or a fixed-tank helicopter, one aluminum coupon that had been exposed to the mixed retardant at each temperature and immersion condition during the weight loss test was examined for intergranular corrosion. If the retardant was designed to be used from a fixed-tank helicopter, a magnesium coupon from each exposure condition was also examined.

Due to the specialized nature of the intergranular corrosion test, and the expertise necessary for the microscopic examination to yield valid results, all

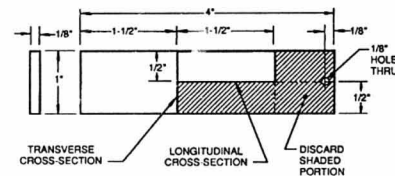


Figure 4—A coupon showing the location of the slice and surfaces to be inspected for intergranular corrosion.

intergranular corrosion tests were performed by an outside laboratory specializing in these procedures. Ocean City Research Corporation of Ocean City, NJ, and MQS Inspection, Inc. (formerly Magnaflux Quality Services) of Los Angeles, CA, have been performing these tests for the Forest Service.

Each coupon was sliced according to the diagram in figure 4, and the sections mounted, polished to 0.3 micron alumina finish, and etched with appropriate reagents using standard metallurgical techniques and then examined microscopically at a magnification of 500x for intergranular corrosion. Figure 5 shows coupons mounted and polished ready for microscopic examination.

If intergranular corrosion was found, photomicrographs were taken and the location of the intergranular attack noted along with the extent of the damage and whether it was an isolated occurrence or widespread.

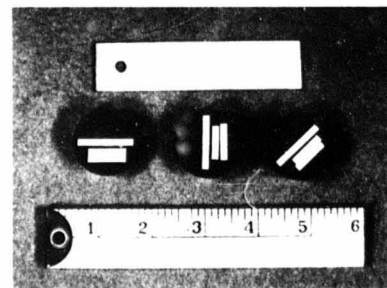


Figure 5—Coupons that have been cut, mounted, polished, and etched for microscopic examination for intergranular corrosion are shown beside an unexposed coupon.

Table 4—Uniform corrosion rates (in mils per year) determined by 90-day weight loss tests for coupons exposed to freshly prepared samples of currently approved long-term retardants

Alloy: Immersion: Temperature, °F:	2024-T3 aluminum				4130 steel				Yellow brass				Az-31-B magnesium			
	Total		Partial		Total		Partial		Total		Partial		Total		Partial	
	70	120	70	120	70	120	70	120	70	120	70	120	70	120	70	120
<i>Mils per year</i>																
Ammonium Sulfate Based Retardants																
Fire-Trol GTS-R	0.03	0.06	0.03	0.04	0.06	0.05	0.93	3.2	0.06	0.04	0.10	1.5	172	199	93	100
Fire-Trol GTS-F	.01	.02	<.01	.01	.09	.08	4.8	3.8	.08	.08	.16	2.0	170			
Sulfate-Phosphate Combination Retardants																
Phos-Chek D75-R	.09	.15	.06	.11	.15	.37	4.8	1.0	.05	.05	.04	.08	195	207	107	105
Phos-Chek D75-F	.06	.11	.05	.08	.13	.29	8.8	2.9	.01	.02	.02	.02	195	183	103	105
Phos-Chek G75-F	.10	.14	.06	.10	.39	.59	5.0	6.1	.04	.05	.03	.03	19			
Phos-Chek G75-W	.10	.14	.06	.09	.34	.56	4.4	1.0	.02	.03	.01	.03	19			
Fire-Trol PS-F	.04	.10	.02	.05	.10	.23	2.1	3.3	.03	.03	.21	.18	24	190	10	84
Diammonium Phosphate Based Retardants																
Phos-Chek 259-F	.74	1.9	.47	.93	.27	.44	.19	.47	.04	.05	1.0	1.2	1.1	3.1	69	2.0
Ammonium Polyphosphate Based Retardants																
Fire-Trol LC-A Concentrate	.08	.08	.07	.10	.01	.04	.01	.03	.03	.04	.02	.05	12	7.4	5.0	3.6
5:1	.79	1.4	.54	.49	.08	.30	.07	.46	.08	.13	.09	.19	47	2.9	28	15

RESULTS

The results of the uniform corrosion tests on freshly prepared long-term retardant samples are shown in table 4. All results on aluminum, mild steel, and yellow brass are averages of three tests. Unless the retardant is designed for use from fixed-tank helicopters, only one sample was tested on magnesium. If the retardant was designed for fixed-tank helicopters, three replicates of each test were run.

After the retardants had been stored outside for 1 year, corrosion tests were run on the stored material using the same methods. If magnesium test results from the initial tests were unacceptable, then no magnesium coupons were exposed to the stored material. Retardants that were designed for ground application and/or helicopter use only were not stored for 1 year. Because results were not significantly different for the freshly prepared retardant and the stored retardant, the results of the tests of the stored retardant are not included in the tabulation but will be discussed.

Table 5 summarizes the results of the uniform corrosion tests on short-term retardant concentrates and mixed solutions. Two samples of each retardant were tested in each combination of alloy, temperature, and immersion.

The uniform corrosion results for foam concentrates and freshly mixed foam solutions of 1 percent and 0.1 percent concentrations are given in table 6.

The results shown are the average of three tests. The amount of liquid concentrate in a foam solution varies from about 0.1 percent to 1 percent depending on the intended use and method of mixing and application. These levels are bracketed by the test concentrations. If the corrosion performance of solutions at the upper and lower ends of the use range is acceptable it is likely that the corrosion performance of intermediate solutions will also be acceptable.

DISCUSSION

All of the wildland fire chemicals included in this report had uniform and intergranular corrosion performance within the limits required by the appropriate specifications or requirements. Many other products failed to meet these requirements and were rejected (data on file at Intermountain Fire Sciences Laboratory).

The products discussed in this paper are those approved by the Forest Service and other agencies using Forest Service specifications for purchase and use in the field. Besides the corrosion performance requirements discussed here, they have also met the other requirements described in the appropriate specifications. These products are listed on the Qualified Products List, which is updated each year and distributed by Fire and Aviation Management, Washington Office of the Forest Service (see appendix for a copy of the February 16, 1990, list).

Table 5—Uniform corrosion rates (in mils per year) determined by 90-day weight loss tests for coupons exposed to freshly prepared samples of currently approved short-term retardants

Alloy: Immersion: Temperature, °F:	2024-T3 aluminum				4130 steel				Yellow brass				Az-31-B magnesium			
	Total		Partial		Total		Partial		Total		Partial		Total		Partial	
	70	120	70	120	70	120	70	120	70	120	70	120	70	120	70	120
<i>Mils per year</i>																
Fire-Trol ST-poly																
Concentrate	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	0.05	0.07	0.03	0.38	0.61	4.8	0.30	2.3
0.25 percent	.02	.12	.02	.03	.32	.42	.78	.85	.02	.07	.05	.07	3.9	3.6	2.7	2.2
0.5 percent	.01	.10	.01	<.01	.21	.41	.65	.84	<.01	.06	.02	.11	5.8	4.0	3.1	2.3
0.75 percent	.02	.10	.01	<.01	.18	.32	.69	.52	<.01	.05	.02	.06	6.0	4.5	3.9	2.7
Phos-Chek FS IIP F																
Concentrate	<.01	.01	<.01	<.01	<.01	<.01	<.01	<.01	.03	.03	.02	.04	<.01	<.01	<.01	<.01
0.25 percent	.08	.14	.05	.04	.18	.48	.86	1.08	.02	.06	.03	.05	3.8	4.4	2.2	2.1
0.5 percent	.03	.11	.03	.02	.15	.89	.36	.96	<.01	<.01	<.01	<.01	4.8	2.8	3.0	1.5
Phos-Chek FS HV																
Concentrate	.02	.02	.02	.02	<.01	<.01	<.01	<.01	.03	.09	.02	.12	.03	.05	.18	.02
0.25 percent	.06	.23	.09	.19	.23	.36	.35	.82	.01	.02	.02	.05	2.5	1.9	1.8	1.2
0.5 percent	.02	.15	.02	.03	.07	.13	.24	.45	.01	.02	.02	.07	5.1	3.9	2.9	2.1
Fire-Trol STH-F																
Concentrate	.01	.01	.01	.01	<.01	.01	.01	.01	.01	.04	.03	.05	<.01	<.01	<.01	<.01
0.71 percent	.02	.02	.02	.01	.06	.01	.27	.30	<.01	.04	.01	.03	.25	.20	.19	.19
Fire-Trol ST2 J																
Concentrate	<.01	<.01	<.01	<.01	.02	<.01	<.01	<.01	.13	.13	.08	.11	.10	.31	.09	.15
0.2 percent	.07	.20	.06	.08	.31	.51	.66	1.1	.02	.05	.04	.06	6.2	2.4	3.9	1.3
0.75 percent	.05	.18	.03	.03	.18	.41	.50	.89	.04	.06	.04	.07	4.8	2.6	3.0	1.6

Table 6—Uniform corrosion rates (in mils per year) determined by 90-day weight loss tests for coupons exposed to currently approved fire fighting foams

Alloy: Immersion: Temperature, °F:	2024-T3 aluminum				4130 steel				Yellow brass				Az-31-B magnesium			
	Total		Partial		Total		Partial		Total		Partial		Total		Partial	
	70	120	70	120	70	120	70	120	70	120	70	120	70	120	70	120
<i>Mils per year</i>																
Phos-Chek WD 861																
Concentrate	1.0	3.1	0.58	3.7	0.66	1.7	0.78	2.1	0.29	0.13	0.24	0.38	4.8	1.9	2.0	1.2
1 percent	.03	.14	.04	.11	.32	1.6	6.1	2.2	.38	.79	.21	.55	2.4	2.3	1.9	1.9
0.1 percent	.01	.07	.01	.06	.75	2.0	6.7	2.4	.08	1.2	.08	1.0	2.1	1.4	2.0	1.1
Wormald Silv-ex																
Concentrate	.05	.08	.02	.06	.98	2.9	1.3	4.9	1.7	1.8	1.7	3.5	25	3.1	15	23
1 percent	.15	.03	1.0	.02	.31	1.8	.87	2.8	.01	.01	.06	.06	2.7	1.5	3.0	1.0
0.1 percent	.01	.06	.01	.04	.58	1.7	.64	1.9	.01	.02	.02	.03	1.9	1.4	1.0	.91
Fire-Trol FireFoam 103																
Concentrate	.01	.03	.02	.02	1.2	1.5	1.3	3.8	.01	.15	.01	.18	.86	.67	.67	.77
1 percent	.03	.19	.02	.09	.98	1.9	.99	2.7	.01	.06	.02	.06	1.4	2.3	1.1	1.7
0.1 percent	.01	.03	.01	.01	1.0	1.6	1.0	2.1	.07	.08	.04	.12	2.6	2.2	2.0	1.2
Angus Fire Armour ForExpan																
Concentrate	.10	.09	.04	.06	.07	.16	.26	1.2	.07	.11	.03	.30	1.1	3.2	.74	4.9
1 percent	.01	.07	.01	.02	.41	2.0	5.2	2.5	.02	.02	.03	.06	3.4	1.1	3.0	.99
0.1 percent	.01	.05	.01	.02	.59	1.9	6.7	1.8	.04	.02	.02	.05	1.8	2.0	1.2	1.1
Phos-Chek WD 881																
Concentrate	.04	.12	.19	.78	1.3	1.9	1.2	2.2	.01	.03	.08	.59	.90	.74	.54	.89
1 percent	.02	.06	.01	.01	.75	1.6	.74	2.6	.03	.05	.03	.03	1.8	2.5	1.5	1.1
0.1 percent	.01	.01	.01	.01	1.2	1.8	.87	2.3	.04	.03	.01	.01	1.7	2.2	1.5	1.4

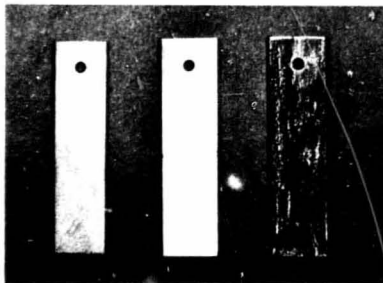


Figure 6—Examples of exposed corrosion coupons (left coupon is aluminum, totally immersed, 2.4 mpy; center coupon is aluminum, partially immersed, 4.3 mpy; right coupon is magnesium, totally immersed, 10.4 mpy).

Figure 6 shows typical uniform corrosion to test coupons after a 90-day test. Illustrations of intergranular corrosion are shown in figure 7. This type of attack was not found on coupons exposed to the retardants discussed here. Such damage is unacceptable under all of the specifications and interim requirements cited.

There is considerable variation in the performance of the individual retardants. To a great extent, these variations can be traced to the basic retardant salt used in each formulation or the absence of any

salt in the case of the short-term retardants and foam. Although these characteristic types of behavior can be modified to some extent by the addition of corrosion inhibitors, the behavior can still be seen.

The sulfate-based retardants are particularly corrosive to mild steel, especially when the steel is only partially immersed, and to a somewhat lesser extent to brass. The corrosive performance of these products has been moderated by careful choices of corrosion inhibitors, but the concentrations necessary to accomplish this must be balanced against additional cost incurred by adding larger amounts of additives.

The phosphate-based retardants are generally less corrosive to steel and brass than are the sulfates. They are, however, usually higher in cost than sulfate-based products, due primarily to the higher cost of the basic retardant salts.

As a result of tradeoffs in cost and performance (corrosion, effectiveness, logistics), many of the products currently in use contain combinations of sulfate and phosphate, which give a lower cost retardant than phosphates alone, but do not have either the low corrosion performance of phosphate or the somewhat greater corrosiveness of sulfate alone.

Both short-term retardants and foam solutions have generally lower corrosion rates than the long-term retardants. This can be attributed at least in part to the lack of fire-retarding salt in the formulations.

During the last few fire seasons, there have been numerous cases where the same airtanker has been exposed to nearly all of the approved fire chemicals in the course of a single season. These airtankers have also been operated under the operational

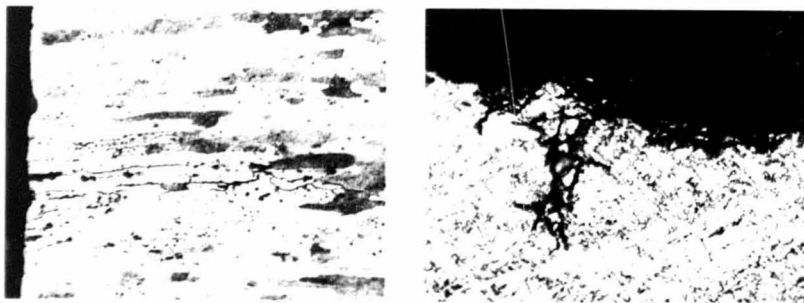


Figure 7—Photomicrographs of coupons exhibiting intergranular corrosion; left, aluminum 2024-T3 (200x); right, magnesium Az-31-B. The fire chemicals responsible for the intergranular corrosion damage seen here were disqualified for use in any type of aircraft.

procedures of more than one agency. Significant corrosion was found on the tank system of tanker 01 (Aero Union SP-2H). While results of the investigation were not conclusive, it appears likely that having the aircraft sit loaded with water prior to injection of foam concentrate in addition to previous and/or subsequent use of long-term retardants provided conditions conducive to corrosion, causing this type of damage. Other combinations of chemicals may also be a cause of severe corrosion. Therefore caution and special attention to cleaning and maintenance are necessary whenever there is a possibility of exposure to more than one fire chemical (Gehring 1989).

Corrosion to magnesium is a continuing problem. Retardant suppliers have found that the use of diammonium phosphate as the retardant base salt has made it possible to reduce the magnesium corrosion caused by long-term fire retardants to a level acceptable for use in fixed-tank helicopters. The cost of retardant approved for fixed-tank helicopters is increased as diammonium phosphate is substantially higher in cost than the other base salts that are in use.

Most foams and short-term retardants (with the exception of Fire-Trol STH-F, especially formulated for fixed-tank helicopters) exceed the limits for corrosion to magnesium. The problem with these types of chemicals appears solvable, however, as the corrosion rates are only slightly above the level required.

The necessity for the requirement limiting corrosion of magnesium is being questioned as fewer surplus military helicopters and more civilian type helicopters are being used for firefighting. Although military helicopters made extensive use of magnesium, much less is being used in the newer civilian types.

The current fire retardant formulations do not generally cause intergranular corrosion. But based on the data collected to date, there is no way to predict which salt/inhibitor combinations will cause intergranular corrosion. As a result this type of testing will continue to be an important part of the overall testing sequence.

MANAGEMENT APPLICATIONS

The Value Analysis process in use by the Forest Service determines the most cost-effective fire chemicals to be used at fixed-wing airtanker bases. This procedure permits consideration of all factors related to support equipment and local services that affect the final performance-cost ratio in the analysis. All products that are qualified or approved for use under the requirements of Forest Service specification 5100-304a (long-term retardants) must be considered in this process.

If special considerations are applicable, such as specialized equipment available at a base, or specific application needs, this information can be included in the value analysis when deciding which retardant should be selected for use at a specific base.

At the present time, if fixed-tank helicopters are being used the only options are between types of chemical, namely, water, foam, long- or short-term retardant. This is because only one long-term retardant (Phos-Chek 259-F) and one short-term retardant (Fire-Trol STH-F) are approved for use with the fixed-tank helicopters. None of the currently approved fire suppressant foams are fully qualified for use with fixed-tank helicopters. Fire-Trol FireFoam 103 and Phos-Chek WD 881 fire suppressant foams have been granted a conditional approval for use from fixed-tank helicopters. This approval will apply only until such time as a new or modified product can fully meet the requirements.

A substantial amount of the retardant used at a particular location is from fixed-tank helicopters, either a product approved for that use may be chosen for use exclusively, or additional equipment required to maintain two separate product lines could be purchased and installed.

The corrosion limits in the specifications have been set as low as is feasible and still be cost effective. Further benefits can be obtained by careful selection of retardant tank and ground support materials, especially when replacement is necessary. For example, loading valves may be specified in aluminum or stainless steel rather than brass. If mixing and storage tanks can be lined or suitably coated, their life will be extended. Gehring and George (1986) have made recommendations concerning selection of both materials and coatings that can minimize the impact of corrosion damage.

Management can use the measured corrosion rates during a Value Analysis where appropriate. For example, if a retardant base has a large investment in brass loading valves, couplers, and pumps, then a sulfate-phosphate combination may be awarded points because of its low corrosion to brass at the elevated temperatures and partial immersion conditions typical in loading valves lying on the ground. If the equipment in use at a particular location is of aluminum or stainless steel, then the ratings for corrosion would be the same for all retardants.

Similarly, in areas such as the Southwest where elevated temperatures are common, the corrosion of mild steel storage tanks may be of concern if they cannot be adequately protected by suitable coatings (Gehring and George 1986) or fiberglass or plastic liners. In this case awarding points for low corrosion to mild steel at elevated temperatures would be appropriate.

Managers must be kept informed of the continually changing state of knowledge in this field in order to protect and maintain the equipment in their care. Recently the Forest Service made a decision to discontinue the evaluation of firefighting foams from fixed-wing airtankers until further work has been conducted to determine the cause of the extensive corrosion damage to one airtanker. Suggestions were provided that could be used by other agencies who choose to continue this use of foam. These include not letting airtankers sit loaded with water (especially those that have been exposed to wildland fire foams) and maintaining a strict maintenance and inspection program to detect corrosion before damage is severe.

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APPENDIX: QUALIFIED PRODUCTS LIST, DECEMBER 1, 1990¹

FIRE CHEMICALS

(Qualified or Approved and commercially available)

Chemical	Mix Ratio	Status	Qualified/Approved Applications ¹			
			Fixed-Wing Airtanker	Fixed-Tank Helicopter	Helicopter Bucket	Ground Engine
LONG-TERM RETARDANTS (Qualified under specification 5100-304a)						
Fire-Trol GTS-R	1.66 lb/gal	Qualified	•		•	
Phos-Chek D75-R, D75-F	1.20 lb/gal	Qualified	•		•	
Phos-Chek 259-F	1.14 lb/gal	Qualified	•	•	•	•
Phos-Chek G75-W, G75-F	1.12 lb/gal	Qualified			•	•
Fire-Trol LC-A	5:1	Qualified	•		•	
Fire-Trol PS-F	1.27 lb/gal	Qualified	•		•	
Fire-Trol PS-R	1.25 lb/gal	Conditional ²	◦		◦	

- ¹ • Fully qualified
◦ Conditional Approval

² Conditional approval: qualification pending successful completion of operational field testing.

³The Qualified Products List changes frequently as new products are qualified and current products are modified or dropped. Contact Fire & Aviation Management, WO, if the latest list is needed.

FIRE CHEMICALS
(Qualified or Approved and commercially available)

Chemical	Mix Ratio	Status	Qualified/Approved		Applications ¹	
			Fixed-Wing Airtanker	Fixed-Tank Helicopter	Helicopter Bucket	Ground Engine
SHORT-TERM RETARDANT (Qualified under specification 5100-00306)						
Fire-Trol ST-poly F	.50-.75%	Qualified	•			
	.25-.50%	Qualified			•	•
Phos-Chek FS IIP F	.50-.75%	Qualified	•			
	.25-.35%	Qualified			•	•
Phos-Chek FS HV	.50%	Qualified	•			
	.25%	Qualified			•	•
Fire-Trol STH-F	.71%	Qualified	•	•	•	•
Fire-Trol ST2-U	.2-.75%	Qualified	•		•	•

WETTING AGENTS (Qualified under specification 5100-305a)

Fire Chem	2 qt/1,000 gal	Qualified			•	•
KCR	2 qt/1,000 gal	Qualified			•	•

- ¹ • Fully qualified
○ Conditional Approval

Chemical	Mix Ratio	Status	Qualified/Approved		Applications ¹	
			Fixed-Wing Airtanker	Fixed-Tank Helicopter	Helicopter Bucket	Ground Engine
WILDLAND FIRE FOAM (Administrative approval using Interim Requirements for Wildland Fire Foam)						
Phos-Chek WD 861	.1-1%	Adm. Approval			•	•
Ansul Silv-Ex	.1-1%	Adm. Approval			•	•
Fire-Trol FireFoam 103	.1-1%	Adm. Approval ²		○	•	•
Phos-Chek WD 881	.1-1%	Adm. Approval ²		○	•	•

- ¹ Administrative approval given when interim requirements are met.
• Administratively Approved
○ Temporary administrative approval

- ² Temporary administrative for use from fixed-tank helicopters until a new or modified formulation meets magnesium corrosion requirements.

Johnson, Cecilia W.; George, Charles W. 1990. Relative corrosivity of currently approved wildland fire chemicals. Res. Pap. INT-437. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 13 p.

Laboratory studies of fire retardant corrosion have been conducted on four alloys commonly used in air and ground tankers and mixing plants. All currently used retardants met Forest Service specifications and requirements, but with considerable variations in performance. Comparative results are presented for long-term and short-term retardants, and fire suppressant foams.

KEYWORDS: fire retardant, long-term retardant, short-term retardant, fire suppressant foam, uniform corrosion, intergranular corrosion

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