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Demonstration Of Biodegradable, Environmentally Safe, Non-Toxic Fire Suppression Liquids

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David W. Stroup, Editors

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National Institute of Standards and Technology
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APPENDIX C

AGENT CHARACTERISTICS

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Note: In this section, non-SI units have been used, in certain cases, since those are the customary terms that are widely used and recognized.

1 Background

In 1986 when the USDA Forest Service began using foam as a tool in its wildfire management program, products were evaluated and procured using a set of Interim Requirements [1]. The requirements were fundamental to all wildland fire chemicals being used at the time. Although these requirements did not include all of the performance characteristics known to be desired in a wildland fire foam product, they included characteristics deemed to be necessary for chemicals used in existing wildland fire operations. The characteristics were defined in requirements for health and safety, stability, and corrosion.

In 1992 an International Foam Specification Workshop was held in Missoula, Montana. The participants compiled a list of the characteristics of foam concentrate, foam solution, and foam thought to impact effectiveness, be of importance to users, or cause concern to any of the user agencies. These characteristics were incorporated into a draft "International Wildland Fire Foam Specification." This document was reviewed by representatives of the firefighting branches of natural resource agencies and chemical suppliers from the United States, Canada, France, and Australia. Comments were incorporated into a revised specification [2].

Test methods and performance requirements were specified if they were readily available and known to be applicable. In other cases test methods were specified without performance requirements (for information and classification purposes). In a few cases even the test method had to be modified or developed. A Wildland Fire Foam Characterization Study was undertaken to provide the information necessary to transform the resulting characteristics and requirements list into a formal specification.

The characteristics to be studied can be grouped into several broad categories:

Health, Safety, and Environment
Corrosion and Materials Effects
Physical/Chemical Properties
Effectiveness
Stability

For each characteristic a suitable test method was defined, the performance of foams currently in use evaluated in accordance with the selected method, and a range of acceptable performance levels determined for those tests that were still considered to be necessary. Some characteristics that did not provide useful information were eliminated from the study. The performance results were then packaged in a form that was accessible to the end users to assist in product selection. This chapter is a summary of that performance information and of experimental work still in progress.

2 Health Safety, and Environment

2.1 Review of Product Composition and Risk Assessment

Forest Service policy requires that all chemicals used for fire fighting be evaluated prior to use [3]. As a part of the evaluation, an initial submission package including a confidential disclosure of all ingredients is required. This information is reviewed for compliance with Forest Service Policy which precludes the use of products containing ingredients on certain regulatory lists unless a Risk Assessment determines the use will not result in increased risks to the firefighters, the general public, or the environment. The regulatory lists to be used are:

1. 40 CFR 355 Appendix A, CERCLA Extremely Hazardous Substances (EHS)
2. National Toxicology Program's (NTP) Annual Report on Carcinogens (U.S. Department of Health and Human Services)
3. International Agency for Research on Cancer (IARC) monographs (potential carcinogens)

Additional lists are also reviewed by the Forest Service and other natural resources agencies to determine the status of ingredients and any regulatory requirements. The regulatory lists are shown below:

1. 40 CFR 302.4, CERCLA Hazardous Substances
2. 40 CFR 261.33, RCRA Acutely Hazardous and Toxic Products
3. 40 CFR 372, SARA Title III, sec. 313

Ingredients present in small amount in various concentrates were found on these lists. In most cases the quantities present were far below any threshold for reporting. One ingredient was found on the list of extremely hazardous ingredients. This ingredient was included in the Risk Assessment performed by Labat-Anderson. Its effect on total risk was found to be insignificant.

2.2 Risk Assessment

In keeping with the National Environmental Policy Act (NEPA), the Forest Service conducted a risk assessment to determine the risk from the use of wildland fire fighting chemicals and whether an environmental assessment was required. Labat-Anderson under contact to the Forest Service performed a risk assessment on the use of all Forest Service qualified/approved wildland fire fighting chemicals. Risks to humans, both firefighters and the general public, aquatic species, terrestrial and avian species, and vegetation were determined using existing information available to the public and confidential information supplied by the product manufacturers.

Little information is available on the formulated products, although there is currently work being done by several Department of the Interior agencies to determine the impacts of these products on aquatic and terrestrial species. More information is available on the individual ingredients and this was included in the risk assessment. All of the information was consolidated, summarized, and incorporated into human health and ecological models to determine the potential impacts. These impacts were studied in relation to the predicted impact from unsuppressed fire.

Under typical use conditions there is little risk from using any of these products in the intended manner. The complete report "Chemicals Used in Wildland Fire Suppression; A Risk Assessment" [4] is available through the Forest Service's National Wildfire Suppression Technology Program.

2.3 Mammalian Toxicity

Health and safety testing on laboratory mammals has been a part of the required testing from the time the first foam was evaluated. These tests are based on standard toxicology procedures. Standard protocols [5-9] were followed by Stillmeadow, Inc. to determine the performance of foam concentrates and 1.0-percent foam solutions. All products were tested for acute oral and dermal toxicity, and skin and eye irritation. Table 1 shows the results of the tests; Table 1A shows the grading scheme for the skin and eye irritation results.

In the event that acute oral or acute dermal toxicity exceeds the main performance level, there is provision to perform an inhalation toxicity test. If the results are satisfactory, the product may be used. To date, this provision has not been used by the Forest Service for approval of Class A foams.

All of the foam concentrates cause moderate to severe irritation to eyes. To prevent eye injury splash goggles should be worn when handling the concentrates. In addition, exposure can cause slight to moderate skin irritation and chapping. Wearing suitable impervious gloves will prevent exposure.

The results of the health and safety testing, requirements, and protective equipment and safe handling procedures were reviewed by the Forest Service Safety and Health Branch.
All manufacturers have listed appropriate protective equipment on their Material Safety Data Sheets (MSDS). These guidelines should be followed when handling these products.

2.4 Inhalation/Smoke Toxicity

The inhalation toxicity of fire fighting chemicals, including foams, alone and when applied to Ponderosa pine needles and then burned is being investigated in a pilot study.

In phase 1, each concentrate or powder was injected into the breathing zone of the test rats. Powders were suspended as fine particulate. Liquids were misted as fine aerosols. The concentration of each chemical that could be put into the breathing zone is a limiting factor in the preliminary study. The maximum amount of each product in the air is less than the LC_{50} for that product. This results in the maximum amount of material that can be put into the aerosol being shown as the LC_{50}.

In phase 2, finely chopped Ponderosa pine needles were gently heated, the smoke and vapors trapped in the breathing zone of the test animals, and an LC_{50} determined for the needles. Each product was then added to Ponderosa pine needles and the tests repeated to determine the effects of breathing smoke from chemically treated fuels. This work is in progress.

Following completion of the pilot study and review of the results, additional testing may be added to the study.

2.5 Biodegradability

The Class A foam concentrates were tested for biodegradability using two similar test methods. The first method, the aerobic aquatic biodegradability test (as required by the National Fire Protection Association standard 298, 1994[10]) [11], is most applicable for use in sewer treatment and industrial effluent plants where the bacterial cultures are exposed to the same chemicals continually or frequently. The aerobic aquatic biodegradability test may also be applicable when dealing with the concerns of fixed-wing tanker bases. This test specifies a period of time for the bacterial medium to acclimate to the test product. The progress of the biodegradation is determined by measurement of the carbon dioxide formed. Progress of the reaction is followed for 28 days by classical wet chemistry techniques.

The second method, the ready biodegradability or closed bottle test [12] appears to more closely fit a typical wildland fire use scenario. There is a single or short-term exposure to a chemical during fire fighting operations. In most cases additional exposures will occur at widely spaced time intervals, possibly years or decades. This test calls for the inoculation of the bacterial medium with the product to be tested, with no acclimation period, and the decrease in oxygen content monitored for 28 days by instrumental methods to determine the extent of biodegradation.

Table 2 shows the results of the biodegradability tests. Using the ready biodegradability method, four of the foam concentrates were determined to be readily biodegradable while two were not biodegradable. Using the aerobic aquatic biodegradability test method, one product was determined to be readily biodegradable, one product was partially biodegradable, and four products were determined to be not biodegradable.

There were unexpected differences in results from some of the tests, when compared to results of supplier-sponsored biodegradability tests performed using the same general test method. Further work needs to be performed to address this inconsistency prior to imposing a specific biodegradability test limit of foam concentrates. If the test is sensitive to interlaboratory variability or the foams are at the boundary between biodegradable and not biodegradable, this type of contradictory results can occur. Further work on this problem is being discussed.

Based on the similarity between test exposures and actual field exposures, the ready biodegradability test is the preferred method to determine the biodegradability of wildland fire fighting foams.

2.6 Fish Toxicity

In 1993, the Midwest Sciences Center, U.S. Fish and Wildlife Service (now the Biological Resources Division of the U.S. Geological Survey) laboratory in Yankton, South Dakota performed a series of toxicity tests to determine the effect of several representative wildland fire control chemicals on aquatic organisms throughout the food chain from green algae, through daphnids and hyallelas to rainbow trout, fathead minnows, and chinook salmon. Several different lifestages were tested for each species. The testing was performed in accordance with ASTM method E-729-88a, "Standard Guide for Conducting Acute Toxicity Tests with Fishes, Macroinvertebrates, and Amphibians" [13] using both ASTM hard and soft water.

The results of these tests suggest that young (60 days post hatch) rainbow trout (Oncorhynchus mykiss) are as sensitive as any and more sensitive than most of the tested organisms [14]. Based on this finding, further testing can be done on a plentiful species with reasonable assurance that acceptable levels of toxicity to trout will provide an adequate level of safety for species of potentially greater concern. Generally, toxicity in hard water is similar to toxicity in soft water. Further testing will use soft water since that is the more common laboratory test condition and additional information would be more readily available.

Following the work performed in 1993, an additional study was undertaken in 1996, to determine the effect of all of the approved wildland fire fighting chemicals to a single lifestage of rainbow trout. As part of the study, exposures of 60 days (±15) days post hatch (dph) rainbow trout to each of the foam concentrates in ATSM soft water were conducted and evaluated [15].

The results of the toxicity tests on rainbow trout using all of the approved foams are summarized in Table 3. Although there is a wide range of results, all meet proposed requirements of $LC_{50} > 10$ mg/liter of ASTM soft water when measured after 96 hours [16].

NFPA 298 [10] uses a slightly different set of protocols. Depending on the conditions specified, the protocols may be equivalent. In any case, it is important that all conditions and procedures be defined as completely as possible, to minimize variation.

2.7 Flash/Fire Point

Several methods of determining flash point have applicability to the varied ways in which foam concentrate is used, handled and stored in practice. The open-cup method (and fire point) is a measure of the hazard in the workplace, such as when the concentrate is being transferred into reservoir tanks, especially at high temperatures or near hot equipment. Closed-cup methods are more applicable in determining the hazards involved in storing and transporting the concentrate.

All of the approved products were submitted to an outside testing laboratory for determination of both the open-cup and closed-cup flash point and fire point. The Pensky-Martens method (D-93) was chosen for the closed cup flash point tests [17] and the

Cleveland method (D-92) was used for the open cup flash and fire point tests [18]. The results are shown in Table 4. Only one of the concentrates had a flash point by either open or closed cup method. The closed-cup flash point was substantially lower than the open-cup flash point for this product [19,20].

2.8 Vapor Pressure

The Reid vapor pressure [21] was determined on all of the concentrates. There is concern that the alertness and general abilities of the flight crews of aircraft with open storage systems could be impaired by the vapors of some of the products. Vapor pressure values can assist in determining this.

The vapor pressure of each of the concentrates on the qualified/approved products list has been determined by an outside laboratory. As shown in Table 5, all of the values are between 4.1 kPa (0.6 psi) and 6.9 kPa (1.0 psi) [19,20]. For comparison, the vapor pressure of methanol is 12.9 kPa (1.9 psi) and of gasoline is 53.3 kPa (7.7 psi).

It is possible that looking up the vapor pressure of the solvents and the health categories of these solvents will provide similar information.

3 Corrosion and Materials Effects

3.1 Uniform Corrosion

All of the approved products were tested to determine the corrosivity of the foam concentrates and solutions (0.1-percent and 1.0-percent) to four alloys (2024-T3 aluminum, 4130 steel, yellow brass, and Az31B magnesium) at two temperatures (20 °C and 50 °C) and two immersion conditions: totally immersed and partially immersed (half in vapor and half in the solution) following the procedures in Forest Service Interim Requirements [1].

Table 6A shows the specific requirements for each category of product and alloy. Table 6 lists the results of the corrosion tests on fresh material and from solutions prepared from stored concentrate. With one exception, all of the results are within the required limits of 2 to 5 mils (thousandths of an inch), dependent on the specific alloy, temperature, and immersion conditions for use from fixed-wing airtankers, helicopter buckets, and ground engines. Only one of the products meets the requirements for corrosion to magnesium alloys, which is part of the criteria for application from fixed-tank helicopters. If the corrosion rate exceeds that limit, it may not be used from fixed-tank helicopters but it may still be used in other applications.

Individual agencies may further restrict use based on other policies and considerations. Currently, the Forest Service does not approve the use of foams from fixed-wing airtankers.

3.2 Intergranular Corrosion

Intergranular corrosion is the removal of small quantities of material from the grain boundaries. Weakening of the structural parts is out of proportion to the amount of material corroded. Representative aluminum coupons exposed to the foam solutions under all conditions were sliced, mounted, etched, and examined for intergranular corrosion following accepted methods [1]. No intergranular corrosion is allowed, and none was found.

In addition, if the foam is to be approved for use from fixed-tank helicopters, there must be no intergranular corrosion found on representative magnesium coupons exposed under all test conditions. No intergranular corrosion was found on magnesium coupons exposed to the product that met the uniform corrosion requirements for magnesium.

3.3 Corrosion to 6061-T6 Aluminum

There are currently no requirements, pertaining to the corrosion of 6061-T6 aluminum, for any of the wildland fire chemicals. However, as a result of severe pitting corrosion to the tank doors (made of 6061-T6 aluminum) of several aircraft following a single fire season of use, work has been on-going to determine the specific type and/or sequence of exposure that caused the corrosion. Three foam concentrates were included in the tests, which also included exposure to several of the commonly used long-term retardants. The study has been conducted in several parts; the results of each affecting the specific conditions used in the next. When completed this study may provide information that will result in additional requirements for all wildland fire chemicals.

The test method described in the Interim Requirements [1] but substituting 6061-T6 aluminum for 2024-T3 was used to determine the uniform corrosion rate. Corrosion results were less than 1.0 mils-per-year (mpy). The limit set for 2024-T3 aluminum is 2.0 mpy.

During phase 2 the test pieces of 6061-T6 aluminum were totally immersed in long-term retardant for 2 weeks. After air drying, the coupons were totally immersed in water for 24 hours and again allowed to air dry. The coupons were then totally immersed in foam concentrate or solution at room temperature for 24 hours and again allowed to air dry. Finally the coupons were totally immersed in room temperature water and for an extended period of time. Half of the coupons were removed from the water, cleaned, weighed, and the uniform corrosion rate determined. A second coupon was exposed in the same manner but removed from water at 90, 120, 150, and 180 days, visually inspected and reimmersed in water. After 180 days these coupons were cleaned, weighed, and the uniform corrosion rate determined. All coupons exhibited pitting, ranging from slight to severe, and the typical flower growth on the surface.

In the third phase of the study, the coupons were alternately immersed in retardant for 23 hours and foam solution for 1 hour, for three days and then totally immersed in room temperature water for 90 or 180 days as described for phase 2. Pitting and flower growths were found on all test specimens.

For the fourth phase, coupons were alternately exposed to foam solution for 8 hours and air for 16 hours for three days, followed by 90-day and 180-day immersion in water.

Again, pitting was found on all test specimens.

Based on the results of the laboratory tests and the field surveys conducted immediately following discovery of the pitting, exposure to foam and water rather than exposure to long-term retardants seems to be the factor that allows the pitting to occur.

3.4 Effects on Non-metallic Components

For some time, Canadair has had their own specification for foam products used in their water-scooping aircraft. The specification contains requirements that the foam concentrates and solutions not significantly degrade (determined by changes in volume or hardness) several non-metallic materials of construction. These materials are primarily found in their foam kits but may also be found elsewhere. These same materials are commonly used throughout the industry for storage and handling of foam concentrates and therefore the test results are of interest beyond that originally expressed by Canadair.

The materials originally considered were nitrile rubber, cross-linked polyethylene/nylon, PVC, fiberglass with epoxy resin and S-8802 sealant. Additional materials were added as they were incorporated into new foam kits. These include S-81733 sealant, neoprene rubber, high-density polyethylene, teflon and flexible polyolefin.

A pilot study using two foam concentrates was performed. Canadair supplied NWST with several of the test materials listed in their specification [22]. The tests followed the Canadair requirements for materials and exposures. Their in-house procedures (alternately immersing the materials in the test liquid and then allowing them to drain and air dry) were followed as closely as possible.

Some materials showed changes in hardness or volume following exposure. The changes in hardness were within limits set by Canadair; however, several of the volume changes exceeded the limit. Due to size and shape of the test samples and the method of measuring the volume, change in fluid level before and after sample immersion, the volume changes are probably not significant.

3.5 Effects on Protective Coatings

Canadair makes extensive use of protective coatings to minimize the corrosion damage to its aircraft. This has been so successful that its warranties may be voided if unacceptable products are used in its aircraft. The Canadair specification for Class A foams has a fairly long list of alloys (2024-T3 aluminum, 5052-T6 aluminum, 4130 steel, 6Al-4V titanium, and corrosion resistant steel 302) and protective coatings through all steps in the finishing process that are tested [22]. The test itself is straightforward, involving repetitions of alternately exposing the materials to the foam (concentrate or solution) and to the air. At the end of 20 repetitions, the integrity of the coating is determined.

NWST performed a pilot study using test materials (alloys and coatings) provided by Canadair. These were exposed to two foam concentrates and 1.0-percent solutions following

Canadair procedures. Some blistering and changes in the surface finish were noted.

Additional consultation with Canadair will be required to determine whether this testing responsibility will be transferred to NWST or whether it will continue to be conducted by Canadair as needed. Transfer of testing to NWST would likely make the results more generally available; however, these results may not be as widely applicable as those on the non-metallic components.

4 Physical/Chemical Properties

4.1 Viscosity, Density and pH

The general physical and chemical properties may be measured easily and used to track some changes in the product over time or with changing temperatures. Baseline measurements on the viscosity, density, and pH [23] of the foam concentrates at room temperature (approximately 21 °C) have been made.

These results, shown in Table 7. Viscosities range from 30 to 145 centipoise; densities from 1.010 to 1.042 grams per milliliter; and pH from 6.6 to 8.9.

Many of the physical/chemical characteristics do not have a numeric requirement but instead the determination of a baseline value is made and, in some cases, comparison to values determined after storage or other treatment [2].

The changes from the baseline values, especially for viscosity, vary significantly. Some products perform more consistently across a wide range of temperatures while others are significantly affected by fairly small temperature variations.

4.2 Surface Tension

Surface tension is related to the wetting ability of the foam solution, either unaerated or drained from an aerated foam. While this is an indirect measurement, it lends itself to reproducible, quantifiable results in the laboratory.

Surface tension tests were performed on all of the foam products, using dilutions from 0.01 percent to 6.0 percent. All tests were performed following the procedures found in ASTM D-1331 [24]. Dilutions were made using laboratory tap water. All products were tested at concentrations from 0.01 percent to 6.0 percent. This exceeds the Forest Service approved use levels, 0.1 percent and 1.0 percent, at both ends of the range, but does show the relative stability of the surface tension measurement. As shown in Table 8, the measured surface tension values are contained in a fairly narrow range. Within the approved use range, values varied from 21.9 to 27.0 dynes/cm. For comparison, water has a surface tension of approximately 73 dynes/cm and a Forest Service approved wetting agent had surface tension values of 28.5 to 48.3 dynes/cm over the same range of dilutions.

4.3 Conductivity

Measuring the conductivity of a foam solution using an inexpensive, hand-held conductivity-pen is a simple means of determining the concentration of the solution. However, both water quality and temperature have a significant affect on the measured values, in some cases the changes are at least as large as the changes due to concentration differences. Using the same water, both quality and temperature, to prepare calibration standards for the specific foam concentrate will minimize these impacts.

Table 9A shows the results of concentration changes for the selected foam solutions when the same source of water is used for all dilutions and the solution temperature is held constant. Table 9B shows the effect of changing the solution temperature for a solution of fixed concentration.

Measurements of conductivity are used by several equipment manufacturers to determine the concentration of a foam solution. With care this is a fairly reliable, accurate, and simple method; however, a better approach may be to calibrate the equipment before field use rather than in the field.

Care should also be taken when using some of the commercially available concentration measuring devices. These often use conductivity to determine the concentration, and work well for the several foam concentrates with similar conductivity characteristics. However, some of the products have significantly different conductivity ranges and the meters must be calibrated specifically for that product.

4.4 Refractive Index

Simple hand-held refractometers incorporating an arbitrary scale are recommended to determine the concentration of Class B foam in some widely used standards. Class B foam is typically used at 3 or 6 percent, with no intermediate points, which makes it fairly easy to determine whether or not the concentrate level is acceptable. In theory this can also be done for Class A foam; but the changes in refractive index with small changes in concentration are very slight.

Less than one full unit on either of two typical refractometers covering the range of concentration from 0.1 percent to 1.0 percent. Typical readability of these refractometers is 0.25 and the precision is about ± 0.5. This makes it very difficult to get meaningful measurements.

A benchtop refractometer was used to determine the refractive indices of several dilutions, covering the approved range, of one of the foam products. The change in readings over that range was so slight that it is unlikely that currently available hand-held instruments will be able to distinguish between them.

5 Effectiveness

5.1 Pour Point

The pour point is the lowest temperature at which a liquid will flow. It is a very simple test that can be performed easily in the field or the laboratory. It provides a value similar to the freezing point of a simple liquid but without the more complex equipment needed to determine freezing points, which are often not meaningful when dealing with mixtures, especially if several components are of near equal volume but very different freezing points.

The method used for the Class A foams followed the general procedure found in ASTM D-97 [25] but used a stepped test to determine the ability of the concentrate to flow at three specific temperatures, rather than to determine the actual temperature at which the concentrate would no longer flow. The three temperatures used for this test are 4 °C, 0.6 °C, and –15 °C.

All of the approved products were tested to determine pour point. The results are shown in Table 10. All of the products were fluid at 4 °C but became less so at 0.6 °C and were solid at –15 °C.

This test does not measure how easily the concentrates flow or how fast, but just that they will flow. Additional testing by another method would be needed to determine flow rates under specific conditions.

5.2 Viscosity as a Function of Temperature

The viscosity of the concentrate is related to the ability of the concentrate to flow and the ease, accuracy and reproducibility of proportioning. The viscosity of each concentrate was measured using a viscometer as the concentrate warmed, beginning at 2 °C (35 °F), and at ten-degree intervals from 4 °C to 49°C (40 °F to 120 °F) [26].

Table 11 shows the changes in viscosity as temperature is decreased. Maximum viscosities for the various concentrates range from 65 to 1120 centipoise at the lowest temperatures and from 18 to 40 centipoise at the highest temperatures.

With this amount of variation it is likely that products will have different flow characteristics at different temperatures, and that different products will have different flow characteristics at some temperatures, especially at the extremes of the test range.

5.3 Flow-Through Time as a Function of Temperature

Other tests which may be more direct measures of the ability of the concentrate to flow consistently regardless of temperature can also be made. A Marsh funnel, about 2 liters capacity [27], and a Zahn cup [28], about 50 milliliters capacity, have been used. In each case the reservoir is filled with the concentrate and the time for a fixed volume to flow out of an orifice in the bottom is measured.

Measurements using the Marsh Funnel with a small tip insert [29] were made. Initially, two products were tested at 5 °C, 21 °C, and 38 °C (40 °F, 70 °F, and 100 °F). Times for 1 quart of concentrate to flow from the funnel ranged from 40 second to 168 seconds.

This method shows some promise for a simple laboratory test of flow that may better relate proportionability. All of the currently approved foam concentrates have been tested using the Marsh Funnel. Results, shown in Table 16, indicate differences at 21 °C (70 °F) and 38 °C (100 °F), with some overlap of values. The flow-through times at 21°C (70 °F) range from 49 seconds to 77 seconds. The values at 38 °C (100 °F) range from 41 seconds to 58 seconds. There are much larger differences in flow-through times at 5 °C (40 °F), with different concentrates taking from 76 seconds to 234 seconds for 1 quart of concentrate.

The Zahn cup has a fixed orifice. A different cup is selected when a different size orifice is needed. Three different orifice sizes were purchased that represented the typical viscosities encountered with foam concentrates. There is some overlap such that some viscosities could be measured with more than one orifice size.

To take a measurement, the Zahn cup is immersed in the test fluid then quickly pulled straight up out of the fluid when it is full (50 ml). The time is measured from when the cup rises above the surface of the fluid until concentrate stream flowing out of the cup separates rather than being a straight stream. The results of testing all of the approved products are shown in Table 17. The results are similar to those found using the Marsh funnel and related well to the Brookfield viscosity values.

The Zahn cup has an advantage over the Marsh funnel of using a small volume of concentrate and being small enough to fit directly through the drum or bucket opening of the foam concentrate containers. Because the concentrate can flow from the cup directly back into the container mess and cleanup are minimized. This is convenient in the laboratory, but would be a real plus for field use.

5.3 Effect of Temperature Changes on Proportioning

Several of the tests that have been performed over a range of temperatures are attempts to determine how a product might behave during proportioning typical field situations. Recently several very low flow proportioners have become available that would make direct measurement of proportioning possible in the laboratory. It may be possible to develop a test method for laboratory trials.

5.4 Miscibility

Many of the aerial foam generating systems in use, helicopter buckets and fixed-tanks, do not contain mixers to assure that foam concentrate and water are well mixed prior to application. Therefore the ease with which concentrate goes into water solution, miscibility, application. Therefore the ease with which concentrate goes into water solution, miscibility, is of interest.

The foam concentrate and water at several temperatures were combined with controllable agitation to determine miscibility. The general method is similar to that for determining the foaming properties of wetting agents [29].

A pre-measured volume of foam concentrate is added to water, while stirring slowly at 60 $\pm$ 10 rpm. After each 10 revolutions, the stirrer is stopped and the contents of the beaker examined. If the contents were not visually homogeneous, the process is repeated, with 10 revolution increments of stirring between observations. If the solution was not uniform after 100 revolutions of mixing, the concentrate was considered to be not miscible.

In the first series of tests all solutions were prepared using tap water. The four combinations of 4.4 °C and 21 °C water and 4.4 °C and 21 °C foam concentrate were used. Most of the solutions prepared with 21 °C water and concentrate were homogeneous after 10 revolutions of the stirrer, and all were homogeneous after 90 revolutions. As temperatures decrease it generally takes more revolutions before the solutions became homogeneous. When both water and concentrate were cold, four products were homogeneous, three products required 90 to 100 revolutions, and one never dispersed.

The next series of tests were performed with distilled, tap, and synthetic seawater. Table 12 summarizes the results of these tests. Warm concentrates were readily miscible in warm distilled and tap water. Other solutions produced a variety of results. Mixing foam concentrate with seawater often results in a cloudy liquid, a gelatinous mixture, or a layer of precipitate on the bottom of the test vessel. Clearly some products are not salt water compatible under these conditions. It should be noted that some of the products that produced a cloudy solution when added to seawater did produce reasonable foam expansions and drain times under the same conditions.

This test may have some significance when selecting a foam provided that the results are considered, in context, along with the results of the other tests to determine suitability to a particular situation. In general, products that will not disperse easily probably should not be used in dipping and scooping operations without good on-board mixing systems.

5.5 Wetting Ability (Drave's Skein Test)

The Drave's skein test is commonly used in the detergent industry to assess the effectiveness of the wetting agents in their products. The time is takes for a standard skein of cotton thread, attached to a weight, to sink when dropped into a graduated cylinder containing the test solution is measured. Other than the test skeins, the only equipment needed to perform this simple test is a graduated cylinder, a stop watch or watch with a second hand, and a standard weight.

Test measurements were made in accordance with ASTM D-2281, "Standard Method for

Evaluation of Wetting Agents by the Skein Test" [30]. Using the standard weight (3.0 grams), very fast sink times were obtained with the products tested. The very fast sink times made accurate time measurements difficult and did not allow for differentiation between products.

A modification, recommended in the ASTM standard, was made to the procedure and a lighter, 0.8 gram, S-hook was used. This resulted in slower sink times and showed differences in performance for different products and for different concentrations of the same product. This looked promising until measurements at low concentrations were being run. With some products and especially the lower, 0.1 percent, concentrations of most products inconsistent results were sometimes noted. In some cases the skein did not sink even after long periods of time. This suggested that the weight was too light.

A second modification was made, using an intermediate weight, about 1.5 gram, hook. This resulted in moderate sink times, changes between products and between dilutions of the same product and gave sink times in all cases.

Table 13 shows the results from testing all of the approved foam concentrates at four concentrations over the approved use range. The effects of changes in concentration on the wetting effectiveness of each of the foams are readily apparent. Unlike surface tension, which tends to be constant throughout the use range, there are significant differences in the wetting behavior of different products and different concentrations of the same product. Either the test is much more sensitive than surface tension or some factor other than surface tension is influencing the wetting effectiveness.

While a skein of spun cotton thread is certainly not the same as natural forest fuels, the skein test may be a reasonable method of determining the wetting characteristics of foam solutions.

5.6 Foaming Ability

A simple shake test was used to provide a simple assessment of the foaming ability of a foam solution. Ten milliliters of a solution of a known concentration and temperature were poured into a 100-milliliter graduated cylinder and the stopper inserted. The cylinder was agitated vigorously for ten seconds, then the volume of foam in the cylinder determined. Immediately after shaking, and at one-minute intervals for 5 minutes, then at 10 and 15 minutes, the volume of solution drained from the foam was measured.

A preliminary test was performed on two products with distinct visual differences in foam producing capabilities. Differences were also seen using this test. The product that was a better foamer when tested in the foam generator also produced more, longer lasting foam in the graduated cylinder.

Tests were performed on all of the approved products at several different concentrations and water types. The visible foam structure remains intact through most of the test period, so that the more meaningful values are the total height of foam in the cylinder and the amount of solution drained out at 1 or 2 minutes. Additional tests were run to determine the repeatability of the method. This test shows sufficient repeatability that it may be suitable as a field quality control test. It may also be suitable as a simple test to assure that a product is a foam rather than a non-foaming wetting agent.

Table 14 shows the effect of varying the solution concentration on the total volume of foam produced and on the drain time of the foam. Table 15 shows the effects of altering the water temperature and/or quality for the same test.

This test is not designed to be quantitative or to relate directly to the foam produced from an operational system. What is shows is whether or not the product will produce foam. There is not a specific relationship between the expansion and drain time produced in this test and what would be produced using a specific set of field equipment. It is simply a means of monitoring performance of a specific foam over time or from batch to batch.

The test has several features that are preferred for field quality control testing; it is simple, quick, and relatively reproducible. It also shows different performance for different foams and concentrations. This test may be useful to field units when determining relative behavior of stored concentrate. It may also be used to determine whether a new brand of foam concentrate can be expected to give the same performance as the familiar product, at the same concentration.

5.7 Blender Foam Tests

Tests have been done on foam prepared in a standard household type, multi-speed blender. The findings from a matrix of mixing speeds and times show the following:

> Distilled water yields a greater foam volume than tap water but the drain rates are similar for the same blending speed and time.
>
> Blending at slow speeds for a longer time yields the most stable foam. High speeds break the foam down.
>
> Foam volume did not vary much with mix time or speed until the greatest times and speeds were reached, when the foam volume tended to decrease.

While a blender can be used for generating and evaluating foam, it is not as desirable as a foam generator. The foams tend to have very small bubbles and very long drain times, which are not typical of many foams produced in the field. A blender may be able to be used in somewhat the same manner as the foaming ability test to do comparative testing for field information.

6 Expansion and Drain Time

Expansion and drain time are a function of the foam concentrate, concentration, generating system, water quality, and temperatures. The combination of all of these factors, and probably others, determines the quality of the foam produced.

6.1 Foam Generator

NWST has been using a laboratory generator built on-site to determine the behavior of foam produced from the test concentrates. This generator is not likely to be reproduced but another of the same general type should give similar results. This generator functions on building-supplied compressed air. The foam solution is batch mixed into a cone-bottomed stainless steel container with the exit at the lowest point. Compressed air is used to push the foam solution through the system where it is aerated by the addition of compressed air into the fluid stream. The aerated solution then goes through a short mixing chamber containing glass beads. The final foam is delivered through a slotted tube that allows application to a fuel bed or standard collection vessel.

The pressure of the compressed air flowing into the generator can be controlled at each point to produce a variety of foam types from the same solution. Following some preliminary testing and evaluation, four settings have been adopted as test standards. The foam produced by this system is consistent from test to test and day to day for the same settings.

Because of the concerns expressed at the earlier workshop about having a test system that could not be repeated at other locations, a second foam generator has been built from readily available components. It shares the same general features as the first generator but is somewhat smaller and includes flow meters so that the same production parameters can be developed in several laboratories. Quick disconnect components were added at some points to make it easier to modify the system and also to clean it at the end of a test.

The foams produced from this system are similar but not identical to those from the original generator. Additional work is proceeding that should allow description of a set of generation parameters to give a standard foam for interlaboratory comparisons. It has been used to study the changes in foam characteristics when flows are changed and when nozzle length or diameter is varied.

6.2 Test Matrix

There are many factors that will potentially affect the characteristics of the foam that is generated. The factors that can be controlled and measured were identified. Several points were selected for testing. It is likely that trends in performance will carry over to points between test points. It is also likely that other factors will influence performance.

The basic matrix, shown below, looks simple, but results in many hundreds of tests.

Foam concentrate: All approved and candidate products
Water: Distilled, tap, artificial seawater
Temperature: 4 °C, 21 °C, and 38 °C (40 °F, 70 °F, and 100 °F)
Concentration: 0.1%, 0.3%, 0.6%, and 1.0%
Concentrate condition: Fresh, frozen (2-3 days), aged (1 year)
Generator: 4 settings to simulate dry foam, fluid foam, and wet foam, and very wet (near or barely) foam

Generator: 4 settings to simulate dry foam, fluid foam, and wet foam, and very wet (near or barely) foam

A simplified sea water formula was included in the last draft of the specification. The simplified formula is preferable to many of the more complex recipes for several reasons. The complex formulas may be very representative of seawater in one location but much less representative for another. The generic formula representatives (to a degree) seawater as opposed to tap or municipal water. The complex formulas contain a large number of minerals including several heavy metal salts, increasing complexity, increasing the likelihood of error in making the sea water, and also increasing the expense. The heavy metal salts must be disposed of in accordance with the applicable hazardous waste regulations.

The original test matrix, including all of the approved products, has been completed using the original laboratory generator. Additional tests are being performed as needed to check and verify results and as new products are submitted.

6.3 Drain Time

The time that it takes for 25 percent of the fluid to drain from a foam, the 25-percent drain time, is a fairly standard measure of foam quality used for Class B foams. Class A foams used in natural resource fire suppression tend to be fast draining foams. The drain time is dependent not only on the foam but also on the method used to measure the drain time.

The standard vessel used to measure drain time of a Class B foam (National Fire Protection Association 1994) is a 1-liter graduated cylinder having a diameter of approximately two inches. The volume of solution in the bottom of the cylinder is measured at specific times. The data can then be used to prepare a graph of time versus the drain volume, and a 25-percent drain time determined.

A dry foam does not readily flow into the cylinder; as a result large holes often form in the foam. The very fluid foams drain so quickly that it is difficult to determine the proper volume of foam to add. One solution to the first problem is to use a foam collection container with a flat, broad profile similar to a show box. This is easier to fill evenly. This style of container is also easier to fill quickly. Provided that the foam generator being used is capable of higher production, it is possible to get a more accurate fill of a fast draining foam with the type of container. The volume of foam solution drained out is more difficult to measure accurately in a flat container. One method of determining the volume drained from the foam is by weight differences.

Each container, of known volume, has a series of thirteen, 0.043-inch holes, arranged in a roughly circular pattern having about a 0.5-inch diameter. The holes can be covered with a small piece of masking tape and the container weighed. After filling with foam the container is again weighed to determine the weight of foam solution. The container is placed on a balance so that as the corner with the holes is over a receiving flask, not on the balance. When the tape is removed from the holes, the solution drains from the holes, and the weight of solution decreases. The weight loss is monitored by computer, which calculates the 25-

percent, 50-percent, and 75-percent drain times. The percent drained in 5, 10, and 15 minutes is also calculated. Figure 1 shows drain curves for a fast and a slow draining foam.

In general except for the dry foams at the highest concentrations, all of the foams drained in one to three minutes. Decreasing the number and/or size of the drain holes could increase the differentiation between different drain times.

Looking at the results from the opposite perspective some foams have only drained five or ten percent in 10 minutes while others have drained more than ninety percent in 5 minutes. This information would be useful in selecting foams or foam types for a specific job such an exposure protection or building wet line for backfiring.

6.4 Expansion

The data have been summarized in a series of bar charts. Figures 2 through 9 illustrate the variations of expansion that can be obtained. The results of these tests show that some products are more sensitive to the presence of chemical salts in the water than others, some perform nearly as well in hot or cold water (assuming that the initial mixing of the concentrate and water is adequate), and some seem to have a much greater range of readily attainable expansions and drain times than others.

Expansions from 1.5:1 to nearly 25:1 have been produced. Combinations of some foam brands and generator settings yield distinctly different foams, especially with the high and low water temperatures. Using the bar graphs rather than precise values when analyzing the results is helpful in seeing trends and more accurately reflects the level of repeatability of the expansion tests.

Comparing the results of distilled water foam and tap water foam suggests that some products are much more sensitive to water quality especially the presence of some mineral salts. Similarly, some products perform equally well in cold or warm water, while others show significant differences in performance.

6.5 Stability

Stability of foam concentrates is assessed by comparing the performance of the fresh concentrate to an aged concentrate. The comparison may also be between solutions made from fresh and aged concentrate. Aged concentrate may or may not have undergone specific changes in temperature, daylight, or other factors.

Fresh solutions made from concentrates that have been stored for one to three years generally have the same performance as fresh solutions made from fresh concentrate. Solutions that are stored as solution, however, degrade quickly. In a day or less the foam expansion and drain time characteristics change. Expansions decrease from what is typical with fresh solution and drain times are faster.

Changes in corrosivity are typically minor and within the usual range of repeatability. Most characteristics have only minor changes or do not change at all. The viscosity temperature relationships appear to be the one exception. Once they undergo heating and cooling, some products do not behave in the same manner as when fresh. Other characteristics have not been systematically studied, but this should be included in future work.

7 Foam Fire Testing

7.1 Moisture Retention

One aspect of the fire performance of any suppressant is the moisture retention or rate of evaporation. Because suppressants depend on the water they contain for their effectiveness, a product that slows evaporation will be considered more effective than another with a faster rate of evaporation.

A series of drying tests were performed comparing water and all of the foams, both as solutions and fairly wet and dry foams. Using the general procedures and experimental parameters of "Influence of Moisture on Effectiveness of Fire Retardants" [31] each product or water was applied to fuel beds of shredded aspen excelsior or Ponderosa pine needles in a consistent manner using the NWST foam generator. Standard applications of 3.8 liters (1 gal) and 7.6 liters (2 gal) of solution per 9.3 m^2 (100 ft^2) of fuel surface (1 GPC and 2 GPC) were used.

A series of nine test beds on individual balances, monitored by a computer, were set up in the wind tunnel and conditioned for four hours at 32 °C (90 °F), 20% relative humidity, and 2.2 m/s (5 mph) of wind. The weight loss of each bed was continuously recorded by computer until all added moisture was driven off.

Figure 10 shows representative data sets from the drying study. In all cases, the variations in time to reach dryness were within the experimental variation of the test so that no differences were seen.

7.2 Long-term Combustion Retarding Effectiveness

A pilot study was conducted to determine whether or not the foam fire suppressants may have long-term retardant effects. Two of the approved foams and 10.6-percent diammonium phosphate (DAP) solution were applied to the fuel beds and burned in accordance with the procedures described in the Forest Service specification for long-term retardants.

In each case at least three fuel beds containing aspen excelsior and three fuel beds containing pine needles were treated with 1 gallon-per-hundred-square-feet (GPC) of test product. Three additional beds of each fuel type were treated with 2 GPC of product. All beds were dried under standard test conditions, 32 °C (90 °F) and 20-percent relative humidity, until 95 to 100 percent of the added moisture was driven off. All beds were burned in the wind tunnel with 5 mph of wind. Rate of weight loss and rate of flame spread were determined and compared with the same parameters from untreated beds.

product. The foams had superiority factors of -1 and -3.

7.3 Fire Suppression Effectiveness Testing

Lack of a fire effectiveness test has been recognized as a deficiency in the current requirements and proposed specification. There are a large number of types of tests that have been proposed, and some have been tried with varying degrees of success.

No one test is likely to be suitable as a single evaluation tool for fire foams. Following the 1994 meeting at Thunder Bay, a series of interrelated tests was proposed. It included tests to determine moisture retention, stability, and insulation on vertical surfaces, direct attack of low to moderate intensity fires, and penetration into surface fuels.

Working for several different groups, Underwriters Laboratory (UL) and National Institutes of Standards and Technology (NIST) have performed series of fire tests with inconclusive results. Hopefully, a method can be defined that will differentiate between different foams in a manner consistent with field reports. A great deal of time and effort remain before the development of a standardized fire suppression effectiveness test is completed.

8 Foam Compatibility

The compatibility of foam concentrates and the possible effects on performance of non-compatibility have always been a concern. That concern has become greater as more engines and aircraft go to on-board holding tanks for concentrate. It is seldom possible to completely empty the tank before refilling and some intermixing is likely. Because of the numbers of possible combinations of products and effects little work has been done.

Anecdotal evidence suggests that some combinations of foams may decrease the foaming and wetting ability of the resulting solution. Limiting the effects to look for would make this type of testing much more attainable. It is likely to remain a low priority until other work has been completed.

In the interim it is important to minimize intermixing. Empty the concentrate reservoir as completely as possible. Do not refill a partially full reservoir but add several buckets and use. Repeating this process several times will result in a small amount of intermixing and use of the mixtures quickly.

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Table 1

Toxicity of Fire Suppressant Foams[1]

Product	Concentration	Acute Oral LD_{50}	Acute Dermal LD_{50}	Skin Irritation[2]	Eye Irritation Unwashed Eyes	Eye Irritation Washed Eyes
Requirement	Concentrate	>500 mg/Kg[3]	>2000 mg/Kg[4]	P.I. score: <5.0[5]	≤Mildly irritating[5]	≤Mildly irritating[5]
	1.0% (V/V)	>5000 mg/Kg	>2000 mg/Kg	P.I. score: <5.0	≤Mildly irritating	≤Mildly irritating
Phos-Chek WD 861	Concentrate	**>5000 mg/Kg**	**>2000 mg/Kg**	**P.I. score: 3.2** Moderately irritating Toxicity category III	**Severely irritating** Irritation score: 56.0 Toxicity category I	**Severely irritating** Irritation score: 61.0 Toxicity category I
	1.0% (V/V)	**>5000 mg/Kg**	**>2000 mg/Kg**	**P.I. score: 0.3** Slightly irritating Toxicity category IV	**Minimally irritating** Irritation score: 7.3 Toxicity category IV	**Minimally irritating** Irritation score: 10.0 Toxicity category IV
Ansul Silv-Ex	Concentrate	**>5050 mg/Kg**	**>2020 mg/Kg**	**P.I. score: 2.7** Moderately irritating Toxicity category III	**Severely irritating** Irritation score: 42.2 Toxicity category I	**Severely irritating** Irritation score: 40.3 Toxicity category I
	1.0% (V/V)	**>5050 mg/Kg**	**>2020 mg/Kg**	**P.I. score: 0.4** Slightly irritating Toxicity category IV	**Minimally irritating** Irritation score: 4.0 Toxicity category III	**Minimally irritating** Irritation score: 6.0 Toxicity category III

1 Scores and ratings for acceptance under Forest Service specification and requirements are shown in bold face. All others are for informational purposes.

2 P.I. score is the primary irritation score based on the first 72 hours of observation.

3 If $LD_{50} \geq 50$ but ≤ 500, then recommend protective gear and safe handling procedures. No $LD_{50} < 50$ is acceptable.

4 If $LD_{50} \geq 200$ but ≤ 2000, then recommend protective gear and safe handling procedures. No $LD_{50} < 200$ is acceptable.

5 If more irritating, recommend protective gear and safe handling procedures.

Table 1 (continued)

Toxicity of Fire Suppressant Foams[1]

Product	**Concentration**	**Acute Oral LD_{50}**	**Acute Dermal LD_{50}**	**Skin Irritation**[2]	**Eye Irritation Unwashed Eyes**	**Eye Irritation Washed Eyes**
Requirement	Concentrate	>500 mg/Kg[3]	>2000 mg/Kg[4]	P.I. score: <5.0[5]	$\leq$ Mildly irritating[5]	$\leq$ Mildly irritating[5]
	1.0% (V/V)	>5000 mg/Kg	>2000 mg/Kg	P.I. score: <5.0	$\leq$ Mildly irritating	$\leq$ Mildly irritating
Fire-Trol FireFoam 103B	Concentrate	**>5050 mg/Kg**	**>2010 mg/Kg**	**P.I. score: 1.8** Slightly irritating Toxicity category IV	**Moderately irritating** Irritation score: 22.5 Toxicity category I	**Moderately irritating** Irritation score: 23.0 Toxicity category I
	1.0% (V/V)	**>5050 mg/Kg**	**>2010 mg/Kg**	**P.I. score: 0.3** Slightly irritating Toxicity category IV	**Minimally irritating** Irritation score: 4.0 Toxicity category III	**Minimally irritating** Irritation score: 4.7 Toxicity category III
Phos-Chek WD 881	Concentrate	**>5000 mg/Kg**	**>2000 mg/Kg**	**P.I. score: 4.0** Moderately irritating Toxicity category III	**Severely irritating** Irritation score: 63.5 Toxicity category I	**Severely irritating** Irritation score: 57.7 Toxicity category II
	1.0% (V/V)	**>5000 mg/Kg**	**>2000 mg/Kg**	**P.I. score: 0.3** Slightly irritating Toxicity category IV	**Minimally irritating** Irritation score: 2.0 Toxicity category III	**Practically non-irritating** Irritation score: 2.0 Toxicity category IV

1 Scores and ratings for acceptance under Forest Service specification and requirements are shown in bold face. All others are for informational purposes.

2 P.I. score is the primary irritation score based on the first 72 hours of observation.

3 If $LD_{50} \geq 50$ but ≤ 500, then recommend protective gear and safe handling procedures. No $LD_{50} < 50$ is acceptable.

4 If $LD_{50} \geq 200$ but ≤ 2000, then recommend protective gear and safe handling procedures. No $LD_{50} < 200$ is acceptable.

5 If more irritating, recommend protective gear and safe handling procedures.

Table 1 (continued)

Toxicity of Fire Suppressant Foams[1]

Product	Concentration	Acute Oral LD_{50}	Acute Dermal LD_{50}	Skin Irritation[2]	Eye Irritation Unwashed Eyes	Eye Irritation Washed Eyes
Requirement	Concentrate	>500 mg/Kg[3]	>2000 mg/Kg[4]	P.I. score: <5.0[5]	$\leq$Mildly irritating[5]	$\leq$Mildly irritating[5]
	1.0% (V/V)	>5000 mg/Kg	>2000 mg/Kg	P.I. score: <5.0	$\leq$Mildly irritating	$\leq$Mildly irritating
Fire-Trol FireFoam 104A	Concentrate	**>5050 mg/Kg**	**>2020 mg/Kg**	**P.I. score: 3.9** Moderately irritating Toxicity category III	**Moderately irritating** Irritation score: 29.3 Toxicity category I	**Moderately irritating** Irritation score: 20.016.0 Toxicity category II
	1.0% (V/V)	**>5050 mg/Kg**	**>2020 mg/Kg**	**P.I. score: 0.5** Slightly irritating Toxicity category IV	**Minimally irritating** Irritation score: 5.3 Toxicity category III	**Minimally irritating** Irritation score: 5.3 Toxicity category III
Angus ForExpan S	Concentrate	**>505 mg/Kg**	**>2020 mg/Kg**	**P.I. score: 2.0** Moderately ir9itating Toxicity category III	**Moderately irritating** Irritation score: 19.5 Toxicity category I	**Moderately irritating** Irritation score: 19.3 Toxicity category II
	1.0% (V/V)	**>5050 mg/Kg**	**>2020 mg/Kg**	**P.I. score: 0.7** Slightly irritating Toxicity category IV	**Minimally irritating** Irritation score: 3.7 Toxicity category IV	**Minimally irritating** Irritation score: 6.3 Toxicity category IV

1 Scores and ratings for acceptance under Forest Service specification and requirements are shown in bold face. All others are for informational purposes.

2 P.I. score is the primary irritation score based on the first 72 hours of observation.

3 If $LD_{50} \geq 50$ but ≤ 500, then recommend protective gear and safe handling procedures. No $LD_{50} < 50$ is acceptable.

4 If $LD_{50} \geq 200$ but ≤ 2000, then recommend protective gear and safe handling procedures. No $LD_{50} < 200$ is acceptable.

5 If more irritating, recommend protective gear and safe handling procedures.

Table 1 (continued)

Toxicity of Fire Suppressant Foams[1]

Product	Concentration	Acute Oral LD_{50}	Acute Dermal LD_{50}	Skin Irritation[2]	Eye Irritation Unwashed Eyes	Eye Irritation Washed Eyes
Requirement	Concentrate	>500 mg/Kg[3]	>2000 mg/Kg[4]	P.I. score: <5.0[5]	≤Mildly irritating[5]	≤Mildly irritating[5]
	1.0% (V/V)	>5000 mg/Kg	>2000 mg/Kg	P.I. score: <5.0	≤Mildly irritating	≤Mildly irritating
Pyrocap B-136	Concentrate	**>5050 mg/Kg**	**>2020 mg/Kg**	**P.I. score: 2.3** Moderately irritating Toxicity category IV	**Moderately irritating** Irritation score: 18.7 Toxicity category I	**Moderately irritating** Irritation score: 16.0 Toxicity category II
	1.0% (V/V)	**>5050 mg/Kg**	**>2020 mg/Kg**	**P.I. score: 0.3** Slightly irritating Toxicity category IV	**Minimally irritating** Irritation score: 3.0 Toxicity category IV	**Minimally irritating** Irritation score: 4.0 Toxicity category IV
Fire Quench	Concentrate	**>5050 mg/Kg**	**>2020 mg/Kg**	**P.I. score: 2.0** Moderately irritating Toxicity category IV	**Moderately irritating** Irritation score: 20.5 Toxicity category I	**Moderately irritating** Irritation score: 16.7 Toxicity category I
	1.0% (V/V)	**>5050 mg/Kg**	**>2020 mg/Kg**	**P.I. score: 0.1** Slightly irritating Toxicity category IV	**Minimally irritating** Irritation score: 8.3 Toxicity category III	**Minimally irritating** Irritation score: 8.0 Toxicity category III

[1] Scores and ratings for acceptance under Forest Service specification and requirements are shown in bold face. All others are for informational purposes.

[2] P.I. score is the primary irritation score based on the first 72 hours of observation.

[3] If $LD_{50} \geq 50$ but ≤ 500, then recommend protective gear and safe handling procedures. No $LD_{50} < 50$ is acceptable.

[4] If $LD_{50} \geq 200$ but ≤ 2000, then recommend protective gear and safe handling procedures. No $LD_{50} < 200$ is acceptable.

[5] If more irritating, recommend protective gear and safe handling procedures.

Table 1A

Key to Toxicity Ratings for Skin Irritation Tests

Primary Irritation Index - Calculation

An irritation score for each rabbit is determined. Two factors, inflammation and swelling, are scored at each observation with a maximum score of 4 for each factor at each observation.

The irritation scores for each rabbit, determined at 0.5, 24, 48, and 72 hours, are averaged

The average for each rabbit is added to determine "total irritation"

The total is divided by the number of rabbits tested to determine the primary irritation index

Primary Irritation Descriptive Rating

A descriptive rating is assigned, based on the primary irritation index, as shown below:

Descriptive Rating	Primary Irritation Index
Non irritating	0.0
Slightly irritating	0.1-1.9
Moderately irritating	2.0-5.0
Severely irritating	5.1-8.0

Dermal Irritation Toxicity Categories (40 CFR 162.10)

Toxicity Category	Irritation Level at 72 Hours
I	Corrosive
II	Severe irritation
III	Moderate irritation
IV	Mild or slight irritation

Table 1B

Key to Toxicity Ratings for Eye Irritation Tests

Eye Irritation Grading Scale

The cornea, iris, and conjunctivae are examined and scores assigned based on a standard scale for several factors of appearance, swelling, discharge, and area of irritation. The total score is the simple sum of all of the category scores. The maximum score is 110.

A rating category is assigned, based on the maximum eye irritation score. If the eye irritation continues at a specific level beyond the allotted time, the category may be increased by one level.

The rating categories are described below:

Rating Category	Average Score	Category Description
Non-irritating	0.0-0.5	All scores must be zero at 24 hours; otherwise, increase category one level
Practically Non-irritating	0.5-2.5	All scores must be zero at 24 hours; otherwise, increase category one level
Minimally Irritating	2.5-15.0	All scores must be zero at 72 hours; otherwise, increase category one level
Mildly Irritating	15.0-25.0	All scores must be zero at 7 days; otherwise, increase category one level
Moderately Irritating	25.0-50.0	Scores must be ≤10 for 60% or more of the rabbits. The mean score at 7 days must be ≤20. If the 7-day mean score is ≤20, but <60% of rabbits have scores <10, then no rabbit can have a score >30; otherwise, increase category one level
Severely Irritating	50.0-80.0	Scores must be ≤30 for 60% or more of the rabbits. The mean score at 7 days must be ≤40. If the 7-day mean score is ≤40, but <60% of rabbits have scores <30, then no rabbit can have a score >60; otherwise, increase category one level
Extremely Irritating	80.0-110.0	

Eye Irritation Toxicity Categories

Category	Descriptive Criteria for Eye Irritation Ratings
I	Corrosive (irreversible destruction of ocular tissue) or corneal involvement or conjunctival irritation persisting through Day 21.
II	Corneal involvement or conjunctival irritation clearing in 8-21 days.
III	Corneal involvement or conjunctival irritation clearing in 7 days or less.
IV	Minimal effects clearing in less than 24 hours.

Table 2

Biodegradability
Summary of Results by Two Methods

Product	Aerobic Aquatic Biodegradability[1]	Ready Biodegradability Closed Bottle Test[2]
Ansul Silv-Ex	Readily Biodegradable 100% DOC at 28 days	Readily Biodegradable ≥60% at 28 days
Fire-Trol FireFoam 103B	Not Biodegradable	Not Biodegradable < 45% at 28 days
Phos-Chek WD 881	Not Biodegradable	Readily Biodegradable ≥60% at 28 days
Angus ForExpan S	Not Biodegradable	Readily Biodegradable ≥60% at 28 days
Pyrocap B-136	Partially Biodegradable 27% DOC at 28 days	Not Biodegradable <55% at 28 days
Fire Quench	Not Biodegradable	Readily Biodegradable ≥60% at 28 days

1 Results of the aerobic aquatic biodegradability tests are based on the initial dissolved oxygen content.

2 Results of the ready biodegradability tests have been corrected for the amount of water in the concentrate.

Table 3

Toxicity of Foam Concentrates
To Selected Life-Stages of Rainbow Trout[1]

Product	Egg	Embryo larvae	Swim-up fry	60 DPH[3]	90 DPH[3]
	96-Hr LC_{50}[2] at Each Life State				
	milligrams/liter				
Ansul Silv-Ex	>78	15	20	22	22
Fire-Trol FireFoam 103B				12[4]	
Phos-Chek WD 881	44	13	13	15	20
Fire-Trol FireFoam 104				13[4]	
Angus ForExpan S				22[4]	
Pyrocap B-136				156[4]	
Fire Quench				39[4]	

1 Testing was performed by National Biological Service at Yankton, SD.

2 ASTM soft water was used for all of the tests.

3 DPH = days post hatch; a deviation from nominal of ± 15 days is acceptable.

4 These tests were performed in 1996. The remaining tests were performed in 1993.

Table 4

Flash Point and Fire Point

Product	Pensky-Martens[1] Closed Cup Flash Point °C (°F)	Cleveland Open Cup[2] Flash Point °C (°F)	Cleveland Open Cup[2] Fire Point °C (°F)
Phos-Chek WD 861	None	None	None
Ansul Silv-Ex	46 (115)	85 (185)	85 (185)
Fire-Trol FireFoam 103B	None	None	None
Phos-Chek WD 881	None	None	None
Fire-Trol FireFoam 104	None	None	None
Angus ForExpan S	None	None	None
Pyrocap B-136	None	None	None
Fire Quench	None	None	None

1 Tested in accordance with ASTM D-93.

2 Tested in accordance with ASTM D-92.

Table 5

Vapor Pressure[1]
of Foam Concentrates

Product	Vapor Pressure
Phos-Chek WD 861	4137 Pa
Ansul Silv-Ex	4137 Pa
Fire-Trol FireFoam 103B	3447 Pa
Phos-Chek WD 881	6895 Pa
Fire-Trol FireFoam 104	6895 Pa
Angus ForExpan S	4137 Pa
Pyrocap B-136	6205 Pa
Fire Quench	6895 Pa

1 All tests were conducted in accordance with ASTM D-323; Standard Methods of Test for Vapor Pressure of Petroleum Products (Reid Method).

Table 6A

Maximum Allowable Corrosion Rates (mil-per-year) for Wildland Fire Chemicals.[1]

Alloy:	2024-T3 Aluminum				4130 Steel				Yellow Brass				Az-31-B Magnesium			
Immersion:	Total		Partial		Total		Partial		Total		Partial		Total		Partial	
Temperature: °F	70	120	70	120	70	120	70	120	70	120	70	120	70	120	70	120
	mils-per-year															
Premix Components																
Liquid components & 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	---	---	---	---
Liquid components & 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	10.0	10.0	10.0	10.0
Mixed Retardants																
Fixed-wing airtankers[3]	2.0	2.0	2.0	2.0	2.0	2.0	5.0	5.0	2.0	2.0	5.0	5.0	---	---	---	---
Helicopter with internal or fixed tank[4]	2.0	2.0	2.0	2.0	2.0	2.0	5.0	5.0	2.0	2.0	5.0	5.0	2.0	4.0	2.0	4.0
Ground application or helicopter with bucket[2]	2.0	2.0	2.0	2.0	2.0	2.0	5.0	5.0	2.0	2.0	5.0	5.0	---	---	---	---

1 All corrosion rates will be determined by 90-day weight loss tests. All uniform corrosion rates are the maximum allowable average of at least 3 replicates.

2 Magnesium corrosion tests will be performed for performance information.

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

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

Table 6

Uniform corrosion rates determined by 90-day weight loss tests for coupons exposed to fire fighting foams

Alloy:	2024-T3 Aluminum				4130 Steel				Yellow Brass				Az-31-B Magnesium			
Immersion:	Total		Partial		Total		Partial		Total		Partial		Total		Partial	
Temperature: °F	70	120	70	120	70	120	70	120	70	120	70	120	70	120	70	120
	mils-per-year															
Phos-Chek WD 861																
Concentrate Fresh	1.0	3.1	.58	3.7	.66	1.7	.78	2.1	.29	.13	.24	.38	4.8	1.9	2.0	1.2
	No intergranular attack on magnesium; pitting attack up to 0.056" on magnesium.															
1.0-percent solution Fresh	.03	.14	.04	.11	.32	1.6	.61	2.2	.38	.79	.21	.65	2.4	2.3	1.9	1.9
	No intergranular attack on aluminum or magnesium; pitting attack up to 0.001" on aluminum, up to 0.0072" on magnesium.															
1 year Missoula	.01	.09	.04	.05	.37	1.5	.73	2.4	.12	.12	.12	.09	---	---	---	---
	No intergranular attack on aluminum; no pitting attack on aluminum.															
1 year San Dimas	.01	.08	.02	.06	.50	1.3	.61	2.5	.06	.08	.05	.06	---	---	---	---
	No intergranular attack on aluminum; no pitting attack on aluminum.															
0.1-percent solution Fresh	.01	.07	.01	.06	.75	2.0	.67	2.4	.08	.12	.08	.10	2.1	1.4	2.0	1.1
	No intergranular attack on aluminum or magnesium; pitting attack up to 0.001" on aluminum, up to 0.066" on magnesium.															
1 year Missoula	.03	.05	.04	.01	.73	1.7	.78	2.1	.03	.03	.03	.03	---	---	---	---
	No intergranular attack on aluminum; pitting attack up to 0.0056"on aluminum.															
1 year San Dimas	.02	.03	.02	.03	.93	1.5	.86	2.0	.04	.01	.02	.02	---	---	---	---s
	No intergranular attack on aluminum, no pitting attack on aluminum.															

Table 6 (continued)

Uniform corrosion rates determined by 90-day weight loss tests for coupons exposed to fire fighting foams

Alloy:	2024-T3 Aluminum				4130 Steel				Yellow Brass				Az-31-B Magnesium			
Immersion:	Total		Partial		Total		Partial		Total		Partial		Total		Partial	
Temperature: °F	70	120	70	120	70	120	70	120	70	120	70	120	70	120	70	120
	mils-per-year															
Ansul Silv-Ex																
Concentrate Fresh	.05	.08	.02	.06	.98	2.9	1.3	4.9	1.7	1.8	1.7	3.5	25.	31.	15.	23.
1.0-percent solution Fresh	.15	.03	.10	.02	.31	1.8	.87	2.8	.01	.01	.06	.06	2.7	1.5	3.0	1.0
	No intergranular attack on aluminum or magnesium; pitting attack up to 0.001" on aluminum, up to 0.0028" on magnesium.															
1 year Missoula	.01	.04	.09	.02	.55	2.0	.91	4.4	.23	.09	.11	.08	---	---	---	---
	No intergranular attack on aluminum; pitting attack up to 0.0014" on aluminum.															
1 year San Dimas	.01	.02	.04	.01	.70	2.0	.74	3.9	.28	.07	.06	.07	---	---	---	---
	No intergranular attack on aluminum; pitting attack up to 0.0062" on aluminum.															
0.1-percent solution Fresh	.01	.06	.01	.04	.58	1.7	.64	1.9	.01	.02	.02	.03	1.9	1.4	1.0	.91
	No intergranular attack on aluminum or magnesium; pitting attack up to 0.001" on aluminum, up to 0.0038" on magnesium.															
1 year Missoula	.12	.45	.09	.24	.69	1.9	.74	2.4	.04	.02	.06	.05	---	---	---	---
	No intergranular attack on aluminum; pitting attack up to 0.0058" on aluminum.															
1 year San Dimas	.10	.32	.13	.26	.52	1.5	.70	2.2	.07	.03	.06	.08	---	---	---	---
	No intergranular attack on aluminum; pitting attack up to 0.0056" on aluminum.															

Table 6 (continued)

Uniform corrosion rates determined by 90-day weight loss tests for coupons exposed to fire fighting foams

Alloy:	2024-T3 Aluminum				4130 Steel				Yellow Brass				Az-31-B Magnesium			
Immersion:	Total		Partial		Total		Partial		Total		Partial		Total		Partial	
Temperature: °F	70	120	70	120	70	120	70	120	70	120	70	120	70	120	70	120
	mils-per-year															
Fire-Trol FireFoam 103																
Concentrate Fresh	.01	.03	.02	.02	1.2	1.5	1.3	3.8	.01	.15	.01	.18	.86	.67	.67	.77
	No intergranular attack on magnesium; pitting attack up to 0.0038" on magnesium.															
1.0-percent solution Fresh	.03	.19	.02	.09	.98	1.9	.99	2.7	.01	.06	.02	.06	1.4	2.3	1.1	1.7
	No intergranular attack on aluminum or magnesium; no pitting attack on aluminum, up to 0.0040" on magnesium.															
1 year Missoula	.01	.09	.01	.04	.77	1.5	.76	2.0	.02	.06	.03	.04	2.0	2.6	1.5	1.8
	No intergranular attack on aluminum; no pitting attack on aluminum.															
1 year San Dimas	.01	.08	.01	.01	.86	2.1	1.1	3.4	.03	.03	.02	.02	1.7	2.1	.86	1.2
	No intergranular attack on aluminum; no pitting attack on aluminum.															
0.1-percent solution Fresh	.01	.03	.01	.01	1.0	1.6	1.0	2.1	.07	.08	.04	.12	2.6	2.2	2.0	1.2
	No intergranular attack on aluminum or magnesium; no pitting attack on aluminum, up to 0.0026" on magnesium.															
1 year Missoula	.01	.01	.01	.01	.87	1.7	.56	2.1	.02	.06	.01	.05	1.9	2.0	1.2	1.2
	No intergranular attack on aluminum; pitting attack up to 0.0058" on aluminum.															
1 year San Dimas	.01	.03	.01	.01	1.2	2.3	.89	2.5	.05	.10	.02	.08	1.7	2.7	1.5	1.7
	No intergranular attack on aluminum, no pitting attack on aluminum.															

Table 6 (continued)

Uniform corrosion rates determined by 90-day weight loss tests for coupons exposed to fire fighting foams

Alloy:	2024-T3 Aluminum				4130 Steel				Yellow Brass				Az-31-B Magnesium			
Immersion:	Total		Partial		Total		Partial		Total		Partial		Total		Partial	
Temperature: °F	70	120	70	120	70	120	70	120	70	120	70	120	70	120	70	120
	mils-per-year															
Phos-Chek WD 881																
Concentrate																
Fresh	.04	.12	.19	.78	1.3	1.9	1.2	2.2	.01	.03	.08	.59	.90	.74	.54	.89
	No intergranular attack on magnesium; pitting attack up to 0.0060" on magnesium.															
1.0-percent solution																
Fresh	.02	.06	.01	.01	.75	1.6	.74	2.6	.03	.05	.03	.03	1.8	2.5	1.5	1.1
	No intergranular attack on aluminum or magnesium; no pitting attack on aluminum, up to 0.0034" on magnesium.															
1 year Missoula	.02	.14	.03	.14	.24	2.3	.53	3.4	.13	.22	1.1	.10	2.8	3.1	2.1	1.6
	No intergranular attack on aluminum or magnesium; no pitting attack on aluminum, up to 0.0058" on magnesium.															
1 year San Dimas	.06	.12	.05	.13	.59	1.4	1.6	3.2	.14	.08	.06	.11	2.4	3.2	1.6	2.3
	No intergranular attack on aluminum or magnesium; no pitting attack on aluminum, up to 0.0060" on magnesium.															
0.1-percent solution																
Fresh	.01	.01	.01	.01	1.2	1.8	.87	2.3	.04	.03	.01	.01	1.7	2.2	1.5	1.4
	No intergranular attack on aluminum or magnesium; no pitting attack on aluminum, up to 0.0082" on magnesium.															
1 year Missoula	.03	.01	.01	.06	.91	1.7	.75	2.0	.05	.04	.02	.04	2.1	2.2	1.7	1.5
	No intergranular attack on aluminum or magnesium; no pitting attack on aluminum, up to 0.0064" on magnesium.															
1 year San Dimas	.02	.03	.02	.04	.75	2.0	.71	2.2	.06	.04	.07	.03	2.9	2.1	2.0	1.5
	No intergranular attack on aluminum or magnesium, no pitting attack on aluminum, up to 0.0056" on magnesium.															

Table 6 (continued)

Uniform corrosion rates determined by 90-day weight loss tests for coupons exposed to fire fighting foams

Alloy:	2024-T3 Aluminum				4130 Steel				Yellow Brass				Az-31-B Magnesium			
Immersion:	Total		Partial		Total		Partial		Total		Partial		Total		Partial	
Temperature: °F	70	120	70	120	70	120	70	120	70	120	70	120	70	120	70	120
	--- mils-per-year ---															
Fire-Trol FireFoam 104																
Concentrate																
Fresh	.05	.21	.11	.16	1.1	2.8	.92	2.5	.41	.88	.94	.84	.44	.93	.82	.81
1.0-percent solution																
Fresh	.01	.07	.01	.04	.24	1.8	.58	2.7	.22	.12	.15	.13	2.6	2.4	1.7	1.6
	No intergranular attack on aluminum; no pitting attack on aluminum.															
1 year Missoula	.01	.05	.01	.03	.26	1.9	.64	3.4	.12	.16	.15	.07	2.4	3.5	1.6	2.1
	No intergranular attack on aluminum; no pitting attack on aluminum.															
1 year San Dimas	.01	.08	.01	.02	.39	1.8	.50	3.2	.20	.16	.12	.11	2.4	3.8	1.7	2.3
	No intergranular attack on aluminum; no pitting attack on aluminum.															
0.1-percent solution																
Fresh	.02	.02	.01	.02	1.4	1.8	1.0	1.9	.07	.07	.06	.07	1.9	2.2	1.2	1.3
	No intergranular attack on aluminum; no pitting attack on aluminum.															
1 year Missoula	.01	.01	.01	.01	.62	1.6	.57	1.7	.03	.08	.01	.02	1.9	1.9	1.2	1.1
	No intergranular attack on aluminum; no pitting attack on aluminum.															
1 year San Dimas	.01	.01	.01	.01	.77	1.8	.67	2.2	.03	.06	.02	.02	2.5	2.3	1.4	1.4
	No intergranular attack on aluminum, no pitting attack on aluminum.															

Table 6 (continued)

Uniform corrosion rates determined by 90-day weight loss tests for coupons exposed to fire fighting foams

Alloy:	2024-T3 Aluminum				4130 Steel				Yellow Brass				Az-31-B Magnesium			
Immersion:	Total		Partial		Total		Partial		Total		Partial		Total		Partial	
Temperature: °F	70	120	70	120	70	120	70	120	70	120	70	120	70	120	70	120
	mils-per-year															
Angus ForExpan																
Concentrate																
Fresh	.06	.07	.02	.03	.04	.14	.15	.64	.02	.06	.03	.17	1.1	1.9	1.1	2.2
1.0-percent solution																
Fresh	.01	.02	.01	.01	.14	1.6	.54	3.2	.03	.02	.04	.05	5.4	1.9	4.1	1.5
	No intergranular attack on aluminum; pitting attack up to 0.0014" on aluminum.															
1 year Missoula	.01	.01	.01	.01	.24	1.8	.33	3.5	.01	.01	.01	.01	---	---	---	---
	No intergranular attack on aluminum; no pitting attack on aluminum.															
1 year San Dimas	.02	.03	.01	.01	.16	1.8	.40	2.7	.01	.01	.01	.02	---	---	---	---
	No intergranular attack on aluminum; no pitting attack on aluminum.															
0.1-percent solution																
Fresh	.01	.08	.01	.04	.62	1.5	1.1	2.1	.03	.03	.03	.06	2.5	1.4	1.6	1.2
	No intergranular attack on aluminum; pitting attack up to 0.0012" on aluminum.															
1 year Missoula	.01	.01	.01	.01	.37	1.6	.47	1.6	.01	.01	.01	.01	---	---	---	---
	No intergranular attack on aluminum; no pitting attack on aluminum.															
1 year San Dimas	.01	.02	.01	.02	.44	1.8	.62	2.3	.01	.01	.01	.04	---	---	---	---
	No intergranular attack on aluminum; no pitting attack on aluminum.															

Table 6 (continued)

Uniform corrosion rates determined by 90-day weight loss tests for coupons exposed to fire fighting foams

Alloy:	2024-T3 Aluminum				4130 Steel				Yellow Brass				Az-31-B Magnesium			
Immersion:	Total		Partial		Total		Partial		Total		Partial		Total		Partial	
Temperature: °F	70	120	70	120	70	120	70	120	70	120	70	120	70	120	70	120
	mils-per-year															
Pyrocap B-136																
Concentrate																
Fresh	.03	.01	.06	.08	.76	.42	.27	1.6	.07	.11	.24	.15	7.1	9.7	4.8	19.
1.0-percent solution																
Fresh	.01	.28	.02	.06	.51	1.9	.65	2.7	.04	.01	.03	.04	3.0	1.8	1.6	1.6
	No intergranular attack on aluminum; pitting attack up to 0.0015" on aluminum.															
1 year Missoula	.01	.10	.01	.09	.52	1.8	.46	2.7	.07	.03	.04	.03	---	---	---	---
	No intergranular or pitting attack on aluminum.															
1 year San Dimas	.01	.15	.01	.15	.47	1.9	.54	2.3	.07	.03	.04	.03	---	---	---	---
	No intergranular or pitting attack on aluminum.															
0.1-percent solution																
Fresh	.01	.07	.01	.02	.55	1.3	.64	1.9	.01	.02	.01	.03	1.4	1.0	1.1	1.0
	No intergranular or pitting attack on aluminum.															
1 year Missoula	.01	.10	.01	.09	.52	2.1	.46	2.7	.07	.03	.04	.03	---	---	---	---
	No intergranular or pitting attack on aluminum.															
1 year San Dimas	.01	.06	.03	.03	.86	1.8	.87	1.7	.02	.03	.01	.03	---	---	---	---
	No intergranular or pitting attack on aluminum.															

Table 6 (continued)

Uniform corrosion rates determined by 90-day weight loss tests for coupons exposed to fire fighting foams

Alloy:	2024-T3 Aluminum				4130 Steel				Yellow Brass				Az-31-B Magnesium			
Immersion:	Total		Partial		Total		Partial		Total		Partial		Total		Partial	
Temperature: °F	70	120	70	120	70	120	70	120	70	120	70	120	70	120	70	120
	mils-per-year															
Fire Quench																
Concentrate Fresh	.01	.06	.03	.03	.27	1.0	.64	1.9	.21	.25	.13	.26	2.5	2.9	1.5	1.6
1.0-percent solution Fresh	.01	.11	.01	.03	.94	1.5	.93	2.2	.01	.02	.02	.04	1.5	2.5	1.2	1.7
	No intergranular attack on aluminum or magnesium; pitting attack up to 0.0018" on aluminum, up to 0.0284" on magnesium.															
1 year Missoula	.01	.05	.02	.01	.78	1.5	.88	1.6	.02	.02	.02	.02	1.6	2.8	1.4	2.0
	No intergranular attack on aluminum or magnesium; pitting attack up to 0.0018" on aluminum, up to 0.0028" on magnesium.															
1 year San Dimas	.01	.13	.02	.03	.76	1.3	.85	2.0	.03	.04	.02	.04	2.0	2.8	1.4	1.9
	No intergranular attack on aluminum or magnesium; pitting attack up to 0.0066" on aluminum, up to 0.0050" on magnesium.															
0.1-percent solution Fresh	.01	.02	.01	.01	1.3	1.9	1.1	1.9	.01	.01	.01	.04	1.2	1.7	.85	1.2
	No intergranular attack on aluminum or magnesium; no pitting attack on aluminum, up to 0.0054" on magnesium.															
1 year Missoula	.01	.03	.03	.01	1.4	2.0	1.3	2.0	.01	.01	.01	.02	1.6	1.8	1.2	1.3
	No intergranular attack on aluminum or magnesium; pitting attack up to 0.0072" on aluminum, up to 0.0052" on magnesium.															
1 year San Dimas	.01	.04	.04	.01	1.2	1.8	1.2	2.0	.01	.01	.01	.04	1.8	1.5	1.4	1.3
	No intergranular attack on aluminum or magnesium; pitting attack up to 0.0068" on aluminum, up to 0.0044" on magnesium.															

Table 7

Physical Properties[1]
of Foam Concentrates

Product	Viscosity[2] centipoise	Density[3] g/cm^3	pH
Phos-Chek WD 861	49	1.026	7.8
Ansul Silv-Ex	25	1.010	7.9
Fire-Trol FireFoam 103B	48	1.028	8.9
Phos-Chek WD 881	52	1.029	7.2
Fire-Trol FireFoam 104	32	1.010	6.6
Angus ForExpan S	30	1.042	7.3
Pyrocap B-136	145	1.037	8.1
Fire Quench	385	1.024	7.8

1 All values were determined at room temperature.

2 Viscosity measurements were made with a Brookfield model LVF viscometer and number 2 spindle.

3 Density measurements were made with a Mettler/Paar model DMA 35 density meter.

Table 8

Surface Tension
of Dilutions of Foam Concentrates[1]

Product	Surface Tension at Indicated Concentration[2]								
	0.01%	0.05%	0.1%	0.3%	0.6%	1.0%	2.0%	3.0%	6.0%
	dynes/centimeter								
Phos-Chek WD 861	36.9	29.0	26.6	23.4	23.8	23.8	27.9	27.9	27.0
Ansul Silv-Ex	37.8	29.0	24.6	21.9	22.4	21.9	22.4	22.7	22.4
Fire-Trol FireFoam 103B	33.5	24.2	24.4	24.6	24.6	26.6	28.2	27.3	25.7
Phos-Chek WD 881 B	38.4	26.6	24.6	23.8	24.2	22.1	23.2	23.8	23.8
Fire-Trol FireFoam 104	36.9	27.3	26.0	25.5	24.4	25.5	27.9	27.9	27.9
Angus ForExpan S	37.4	28.8	25.5	22.9	24.6	23.2	25.5	26.6	28.2
Pyrocap B-136	40.7	28.2	24.5	24.5	24.5	24.5	25.5	25.5	26.0
Fire Quench	39.8	27.9	26.6	26.6	24.6	27.0	26.6	26.6	27.9

1 Surface tension values have been corrected for the diameter of the wire and the diameter of the ring used in the determinations.

2 Concentrations between 0.1 and 1.0 percent are approved for use by the Forest Service. Additional values are given to show trends in surface tension behavior.

Table 9

Conductivity as a Function of Concentration

Product	Conductivity[1]				
	0.0%	0.2%	0.3%	0.6%	1.0%
	micro Siemens				
Foam A	370	440	500	630	830
Foam B	360	410	490	630	820
Foam C	370	430	460	560	730
Foam D	370	380	410	440	510

1 All test solutions were prepared with tap water.

Table 9A - Conductivity of Foam Solutions[1] as a Function of Concentration

Product	Concentration 0.0%	0.1%	0.3%	0.6%	1.0%
	Conductivity, micro Siemens				
Phos-Chek WD 861	360	410	490	630	830
Ansul Silv-Ex	370	440	500	630	830
Fire-Trol FireFoam 103B	360	420	490	630	860
Phos-Chek WD 881	360	410	490	630	830
Fire-Trol FireFoam 104	360	420	470	730	880
Angus ForExpan S	370	400	500	690	870
Pyrocap B-136	370	440	460	570	740
Fire Quench	370	380	410	440	510

[1] All solutions were prepared with tap water and measured at 70 °F.

Table 9B - Conductivity[1] of Foam Solutions, at 0.6%, as a Function of Temperature

Temperature:	40 °F	50 °F	60 °F	70 °F	80 °F	90 °F	100 °F	110 °F	120 °F
				Conductivity of Foam Solution, micro Siemens					
Phos-Chek WD 861	344	415	470	465	809	893	1005	1100	1221
Ansul Silv-Ex	240	287	362	554	642	705	787	823	892
Fire-Trol FireFoam 103B	372	431	512	565	640	710	683	888	985
Phos-Chek WD 881	482	555	632	510	595	651	731	840	918
Fire-Trol FireFoam 104	331	392	445	511	580	620	709	798	880
Angus ForExpan S	370	415	500	519	639	725	804	820	982
Pyrocap B-136	374	433	500	513	629	700	769	841	920
Fire Quench	226	288	338	368	432	489	531	578	648

[1] All test solutions were prepared with tap water.

Table 9C - Conductivity[1] of Foam Solutions, at 70 °F, as a Function of Concentration

Concentrations:	0.1%	0.2%	0.3%	0.4%	0.5%	0.6%	0.7%	0.8%	0.9%	1.0%
	Conductivity of Foam Solution, micro Siemens									
Phos-Chek WD 861	372	430	485	520	532	465	534	862	925	979
Ansul Silv-Ex	351	397	448	487	511	554	600	362	680	730
Fire-Trol FireFoam 103B	376	408	440	483	514	565	586	645	697	718
Phos-Chek WD 881	362	379	405	440	485	510	548	578	610	642
Fire-Trol FireFoam 104	342	381	404	436	475	511	532	595	611	648
Angus ForExpan S	358	391	422	455	495	519	562	617	645	700
Pyrocap B-136	370	389	421	458	492	513	558	600	630	655
Fire Quench	332	331	340	355	368	368	360	384	402	405

[1] All test solutions were prepared with tap water.

Table 10

Pour Point of Foam Concentrates[1]

Product	Measured Pour Point	---- Fluidity of Concentrate ---- 40 °F	33 °F	5 °F
Phos-Chek WD 861	32 °F	Fluid	Semi Solid	Solid
Ansul Silv-Ex	18 °F	Fluid	Fluid	Solid
Fire-Trol FireFoam 103B	12 °F	Fluid	Fluid	Semi Fluid-Solid
Phos-Chek WD 881	27 °F	Fluid	Fluid	Solid
Fire-Trol FireFoam 104	16 °F	Fluid	Fluid	Semi Fluid-Solid
Angus ForExpan S	14 °F	Fluid	Fluid	Semi Fluid-Solid
Pyrocap B-136	10 °F	Fluid	Fluid	Solid
Fire Quench	33 °F	Fluid	Semi Solid	Solid

1 Pour point determination is based on ASTM D-97.

Table 11

Viscosity of Foam Concentrates as a Function of Temperature

Product	35 °F	40 °F	50 °F	60 °F	70 °F	80 °F	90 °F	100 °F	110 °F	120 °F
	Viscosity of Foam Concentrate[1] (centipoise)									
Phos-Chek WD 861	650	165	85	65	48	40	30	29	23	22
Ansul Silv-Ex	55	43	39	31	25	23	21	17	15	13
Fire-Trol FireFoam 103B	119	92	74	56	41	34	28	24	22	19
Phos-Chek WD 881	233	113	75	59	45	38	29	27	22	20
Fire-Trol FireFoam 104	84	65	53	42	33	28	23	20	18	16
Angus ForExpan S	63	53	44	35	29	25	20	19	18	15
Pyrocap B-136	1200	1025	700	404	312	282	311	326	370	
Fire Quench	1750	1338	925	800	580	298	143	52	54	33

[1] All viscosities were measured using a Brookfield model LVF viscometer.

Table 12

Miscibility of Foam Concentrates[1]

Product (0.6% Dilutions)	Water Quality	--- Number of Revolutions to Achieve Homogeneity --- Warm Water: Warm Conc	Warm Water: Cold Conc	Cold Water: Warm Conc	Cold Water: Cold Conc
Phos-Chek WD 861	Distilled Water	20 rev	90 rev	100 rev	NM
	Tap Water	10 rev	30 rev	25 rev	85 rev
	Sea Water	50 rev	90 rev	90 rev	NM
Ansul Silv-Ex	Distilled Water	10 rev	30 rev	40 rev	60 rev
	Tap Water	10 rev	10 rev	10 rev	15 rev
	Sea Water	20 rev	20 rev	NM	90 rev
Fire-Trol FireFoam 103B	Distilled Water	20 rev	70 rev	40 rev	NM
	Tap Water	15 rev	10 rev	15 rev	50 rev
	Sea Water	70 rev	60 rev	NM	NM
Phos-Chek WD 881	Distilled Water	20 rev	80 rev	30 rev	30 rev
	Tap Water	15 rev	10 rev	15 rev	20 rev
	Sea Water	NM	NM	NM	NM
Fire-Trol FireFoam 104	Distilled Water	20 rev	30 rev	50 rev	80 rev
	Tap Water	10 rev	10 rev	10 rev	40 rev
	Sea Water	10 rev	NM	NM	NM
Angus ForExpan S	Distilled Water	10 rev	10 rev	40 rev	30 rev
	Tap Water	15 rev	10 rev	15 rev	20 rev
	Sea Water	10 rev	10 rev	30 rev	25 rev
Pyrocap B-136	Distilled Water	NM	NM	NM	NM
	Tap Water	65 rev	NM	NM	NM
	Sea Water	NM	NM	NM	NM
Fire Quench	Distilled Water	50 rev	60 rev	NM	50 rev
	Tap Water	20 rev	40 rev	40 rev	90 rev
	Sea Water	NM	NM	NM	NM

[1] Concentrate was rated as not miscible (NM) if the solution was not homogeneous after 100 revolutions, if the solution was too cloudy to evaluate, or if there was a precipitate in the bottom of the container. Foam quality may or may not be affected depending on the amount of concentrate that di go into solution.

Table 13

Wetting Ability of Foam Solutions[1]
As a Function of Concentration

Product	Time for Skein to Sink (seconds)[2]					
	0.1%	0.3%	0.6%	1.0%	3.0%	6.0%
Phos-Chek WD 861						
0.8-gram hook	>300	47	27	24		
1.5-gram hook	**>180**	**36**	**18**	**13**	**10**	**7**
3.0-gram hook	>225	22	13	10		
Ansul Silv-Ex						
0.8-gram hook	>300	60	26	62		
1.5-gram hook	**>180**	**32**	**22**	**11**	**4**	**2**
3.0-gram hook	>300	28	14	6		
Fire-Trol FireFoam 103B						
0.8-gram hook	>300	35	27	21		
1.5-gram hook	**>180**	**27**	**12**	**8**	**5**	**--**
3.0-gram hook	176	16	12	6		
Phos-Chek WD 881						
0.8-gram hook	>300	74	37	21		
1.5-gram hook	**>180**	**54**	**28**	**12**	**5**	**5**
3.0-gram hook	>300	41	16	10		

[1] Wetting ability was determined by Drave's Skein Test, ASTM 2281.

[2] Tests with the 0.8-gram and 3.0-gram hooks used skeins that were not corrected to 5.0 grams.

Table 13 (continued)

Wetting Ability of Foam Solutions[1]
As a Function of Concentration

Product	Time for Skein to Sink (seconds)[2] 0.1%	0.3%	0.6%	1.0%	3.0%	6.0%
Fire-Trol FireFoam 104						
0.8-gram hook	>300	37	23	20		
1.5-gram hook	**>180**	**35**	**17**	**9**	**4**	--
3.0-gram hook	197	21	9	--		
Angus ForExpan S						
0.8-gram hook	>300	48	32	21		
1.5-gram hook	**>180**	**40**	**20**	**14**	–	**2**
3.0-gram hook	211	24	13	8		
Pyrocap B-136						
0.8-gram hook	>300	50	24	13		
1.5-gram hook	**>180**	**50**	**16**	**9**	**3**	–
3.0-gram hook	>300	30	11	6		
Fire Quench						
0.8-gram hook	>300	35	22	14		
1.5-gram hook	**>180**	**29**	**12**	**7**	**3**	**3**
3.0-gram hook	>300	20	8	5		

1 Wetting ability was determined by Drave's Skein Test, ASTM 2281.

2 Tests with the 0.8-gram and 3.0-gram hooks used skeins that were not corrected to 5.0 grams.

Table 14

Foaming Ability of Foam Solutions
As a Function of Concentration

Product	Total Foam Volume (milliliters)	Volume of Drained Solution (milliliters) 1 min	5 min	10 min
Phos-Chek WD 861				
1.0%	80	5.5	9.0	9.0
0.6%	70	4.0	7.0	8.0
0.3%	60	5.5	8.0	9.0
0.1%	50	4.5	8.0	9.0
Ansul Silv-Ex				
1.0%	70	4.0	7.5	9.0
0.6%	60	4.0	7.5	9.0
0.3%	53	3.0	7.0	8.5
0.1%	35	5.5	9.0	9.5
Fire-Trol FireFoam 103B				
1.0%	90	8.0	10.5	10.5
0.6%	70	7.5	9.5	10.0
0.3%	70	7.5	10.0	10.5
0.1%	55	6.0	9.5	10.0
Phos-Chek WD 881				
1.0%	75	4.5	7.5	9.0
0.6%	65	4.0	7.5	9.0
0.3%	55	2.5	7.0	8.5
0.1%	45	5.5	9.0	9.5
Fire-Trol FireFoam 104				
1.0%	87	8.0	10.0	10.5
0.6%	78	8.0	10.0	10.0
0.3%	61	8.0	10.0	10.5
0.1%	70	8.0	10.0	10.0

Table 14 (continued)

Foaming Ability of Foam Solutions
As a Function of Concentration

Product	Total Foam Volume milliliters	Volume of Drained Solution 1 min	5 min	10 min
		- - - - - - - - - milliliters - - - - - - - - -		
Angus ForExpan S				
1.0%	70	5.0	7.5	9.0
0.6%	65	5.5	8.5	9.0
0.3%	55	4.0	7.5	9.0
0.1%	40	8.0	9.5	10.0
Pyrocap B-136				
1.0%	55	4.0	9.0	10.0
0.6%	47	6.5	10.0	10.0
0.3%	37	7.0	9.5	10.0
0.1%	30	9.0	10.0	10.0
Fire Quench				
1.0%	65	7.0	9.5	10.0
0.6%	55	7.0	10.0	10.0
0.3%	34	7.5	9.5	9.5
0.1%	23	9.0	10.0	10.0

Table 15

Foaming Ability of Foam Solutions[1]
As a Function of Water Quality
and Temperature

Product Water Quality & Temperature	Total Foam Volume milliliters	Volume of Drained Solution 1 min	 5 min milliliters	 10 min
Phos-Chek WD 861				
Tap - 40 °F	65	3.0	7.0	8.0
Tap - 70 °F	72	7.0	8.5	9.0
Distilled - 40 °F	62	4.0	7.0	7.5
Distilled - 70 °F	88	8.0	9.5	10.0
Sea - 40 °F	53	3.0	6.0	8.0
Sea - 70 °F	60	4.0	8.0	9.0
Ansul Silv-Ex				
Tap - 40 °F	54	3.0	6.5	8.0
Tap - 70 °F	60	7.0	8.5	9.0
Distilled - 40 °F	54	4.0	7.0	8.0
Distilled - 70 °F	68	5.0	8.0	9.0
Sea - 40 °F	45	3.0	6.5	8.0
Sea - 70 °F	45	2.5	6.0	8.0
Fire-Trol FireFoam 103B				
Tap - 40 °F	68	6.0	10.0	10.0
Tap - 70 °F	83	8.5	9.5	10.0
Distilled - 40 °F	83	8.0	9.0	9.0
Distilled - 70 °F	80	9.0	10.0	10.0
Sea - 40 °F	52	4.0	8.5	9.0
Sea - 70 °F	58	5.0	9.5	10.0
Phos-Chek WD 881				
Tap - 40 °F	57	5.0	8.0	9.0
Tap - 70 °F	52	7.0	8.5	8.5
Distilled - 40 °F	58	5.0	8.0	9.0
Distilled - 70 °F	70	7.0	9.0	9.5
Sea - 40 °F	55	5.0	9.0	9.5
Sea - 70 °F	45	4.5	9.0	9.5

[1] All tests were performed on 0.6-percent solutions of the concentrate in water.

Table 15 (continued)

Foaming Ability of Foam Solutions[1]
As a Function of Water Quality
and Temperature

Product Water Quality & Temperature	Total Foam Volume milliliters	Volume of Drained Solution 1 min	 5 min milliliters	 10 min
Fire-Trol FireFoam 104				
Tap - 40 °F	64	7.0	10.0	10.0
Tap - 70 °F	65	8.0	9.0	9.5
Distilled - 40 °F	75	8.0	9.5	9.5
Distilled - 70 °F	87	7.0	10.0	10.0
Sea - 40 °F	50	4.0	8.0	9.0
Sea - 70 °F	63	5.0	9.0	10.0
Angus ForExpan S				
Tap - 40 °F	65	4.0	7.0	8.0
Tap - 70 °F	88	6.5	8.0	9.0
Distilled - 40 °F	64	5.5	8.0	9.0
Distilled - 70 °F	79	7.0	9.0	9.5
Sea - 40 °F	40	3.5	7.0	8.5
Sea - 70 °F	48	5.0	9.0	9.0
Pyrocap B-136				
Tap - 40 °F	35	5.0	9.0	9.5
Tap - 70 °F	50	7.0	9.0	9.0
Distilled - 40 °F	45	6.5	9.0	9.0
Distilled - 70 °F	65	9.0	10.0	10.0
Sea - 40 °F	15	9.5	10.0	10.0
Sea - 70 °F	15	9.5	10.0	10.0
Fire Quench				
Tap - 40 °F	25	8.0	9.5	9.5
Tap - 70 °F	29	8.0	9.0	9.0
Distilled - 40 °F	64	6.0	9.0	9.0
Distilled - 70 °F	83	9.0	10.0	10.0
Sea - 40 °F	15	10.0	10.0	10.0
Sea - 70 °F	15	10.0	10.0	10.0

[1] All tests were performed on 0.6-percent solutions of the concentrate in water.

Table 16

Viscosity Measured by Marsh Funnel[1]
as a
Function of Temperature

Product	---- Flow-Through Time (min:sec)[2] ----		
	40 °F	70 °F	100 °F
Phos-Chek WD 861	2:27 (210 cP)	1:10 (48 cP)	0:50 (28 cP)
Ansul Silv-Ex	1:11 (48 cP)	0:47 (50 cP)	0:41 (20 cP)
Fire-Trol FireFoam 103B	4:10 (555 cP)	1:04 (41 cP)	0:48 (25 cP)
Phos-Chek WD 881	2:20 (101 cP)	1:08 (53 cP)	0:48 (25 cP)
Fire-Trol FireFoam 104	1:28 (56 cP)	0:51 (28 cP)	0:42 (18 cP)
Angus ForExpan S	1:18 (55 cP)	0:46 (28 cP)	0:40 (15 cP)
Pyrocap B-136	1:46 (850 cP)	1:01 (208 cP)	0:59 (47 cP)
Fire Quench	27:59 (1270 cP)	9:39 (575 cP)	1:55 (72 cP)

[1] Corresponding Brookfield viscosities are shown in parentheses.

[2] Time for 1 quart of concentrate to flow through the small orifice of a Marsh Funnel.

Table 17

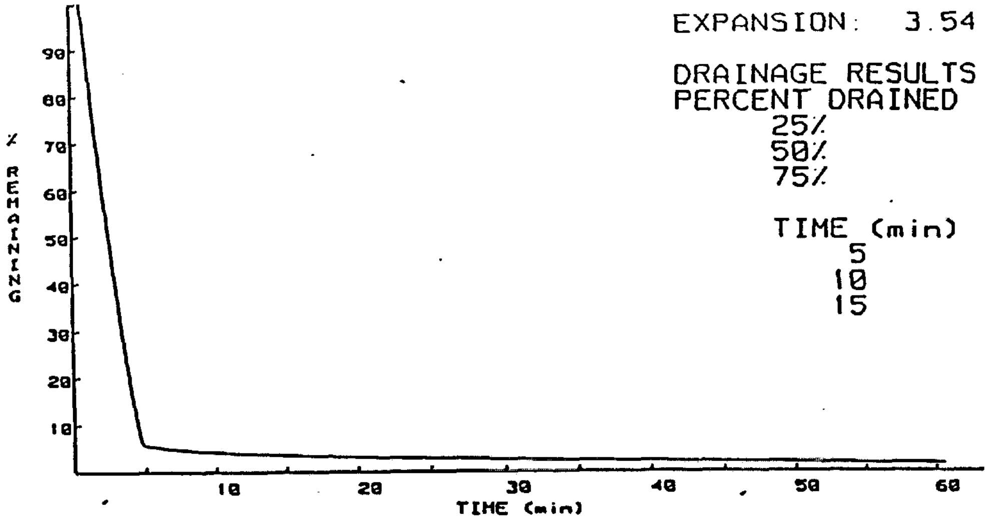
Viscosity Measured by Zahn Cup Flow-Through Time[1]

Product	Brookfield Viscosity	Flow-Through Time[2] ------ Zahn Cup Number ------ #1	#2	#3
	centipoise	----------- seconds -----------		
Phos-Chek WD 861	41	64 (41)	**24 (36)**	9 (20)
Ansul Silv-Ex	23	**46 (19)**	19 (14)	8 (13)
Fire-Trol FireFoam 103B	36	61 (37)	**23 (30)**	9 (20)
Phos-Chek WD 881	40	62 (38)	**23 (30)**	8 (13)
Fire-Trol FireFoam 104	31	**51 (26)**	**21 (19)**	8 (13)
Angus ForExpan S	25	**46 (19)**	19 (14)	8 (13)
Pyrocap B-136	123	61 (37)	**52 (131)**	**22 (195)**
Fire-Quench	244	277 (239)	111 (303)	**29 (267)**

1 Highlighted values are within the manufacturer's recommended drain times for the specific cup used for the measurement.

2 Numbers in parentheses are the viscosity values related to the measured flow-through times.

Figure 1 - Typical Drain Curves for a Fast Draining Foam and a Slow Draining Foam

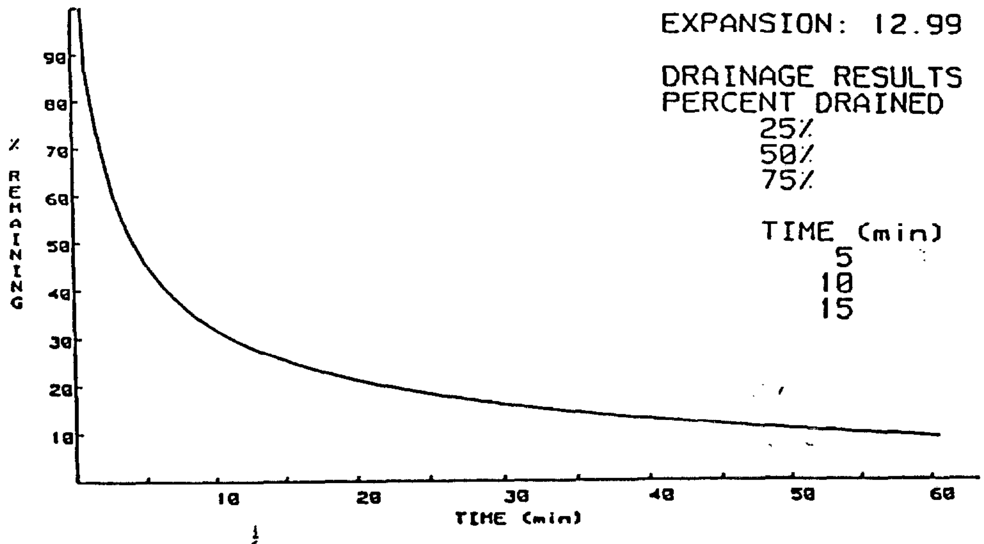


EXPANSION: 3.54

DRAINAGE RESULTS

PERCENT DRAINED	TIME (min)
25%	2
50%	3
75%	4

TIME (min)	% DRAINED
5	94.49
10	95.89
15	96.53

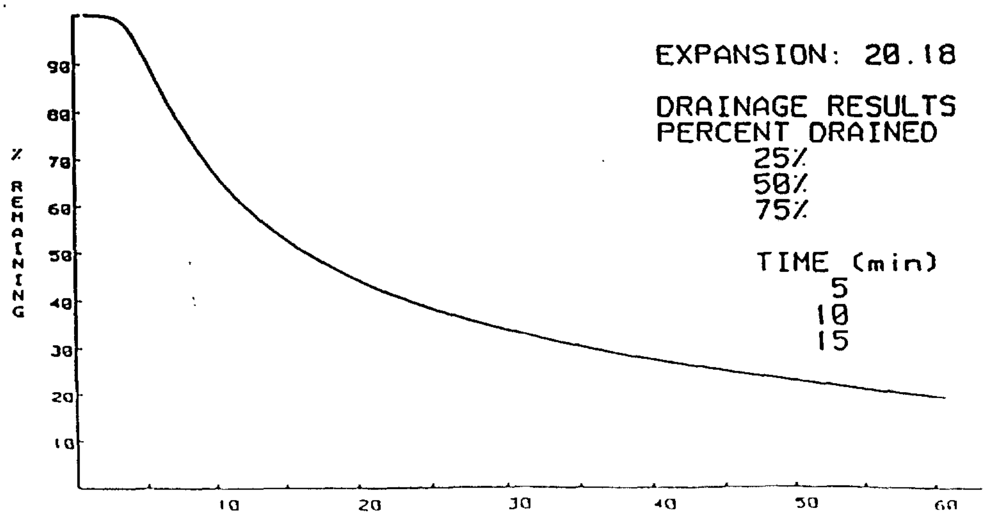


EXPANSION: 12.99

DRAINAGE RESULTS

PERCENT DRAINED	TIME (min)
25%	2
50%	4
75%	15

TIME (min)	% DRAINED
5	54.09
10	68.01
15	74.65



EXPANSION: 20.18

DRAINAGE RESULTS

PERCENT DRAINED	TIME (min)
25%	8
50%	17
75%	45

TIME (min)	% DRAINED
5	8.86
10	32.76
15	46.67

Figure 2 - Expansion of Phos-Chek WD 861 as a Function of Production Variables.

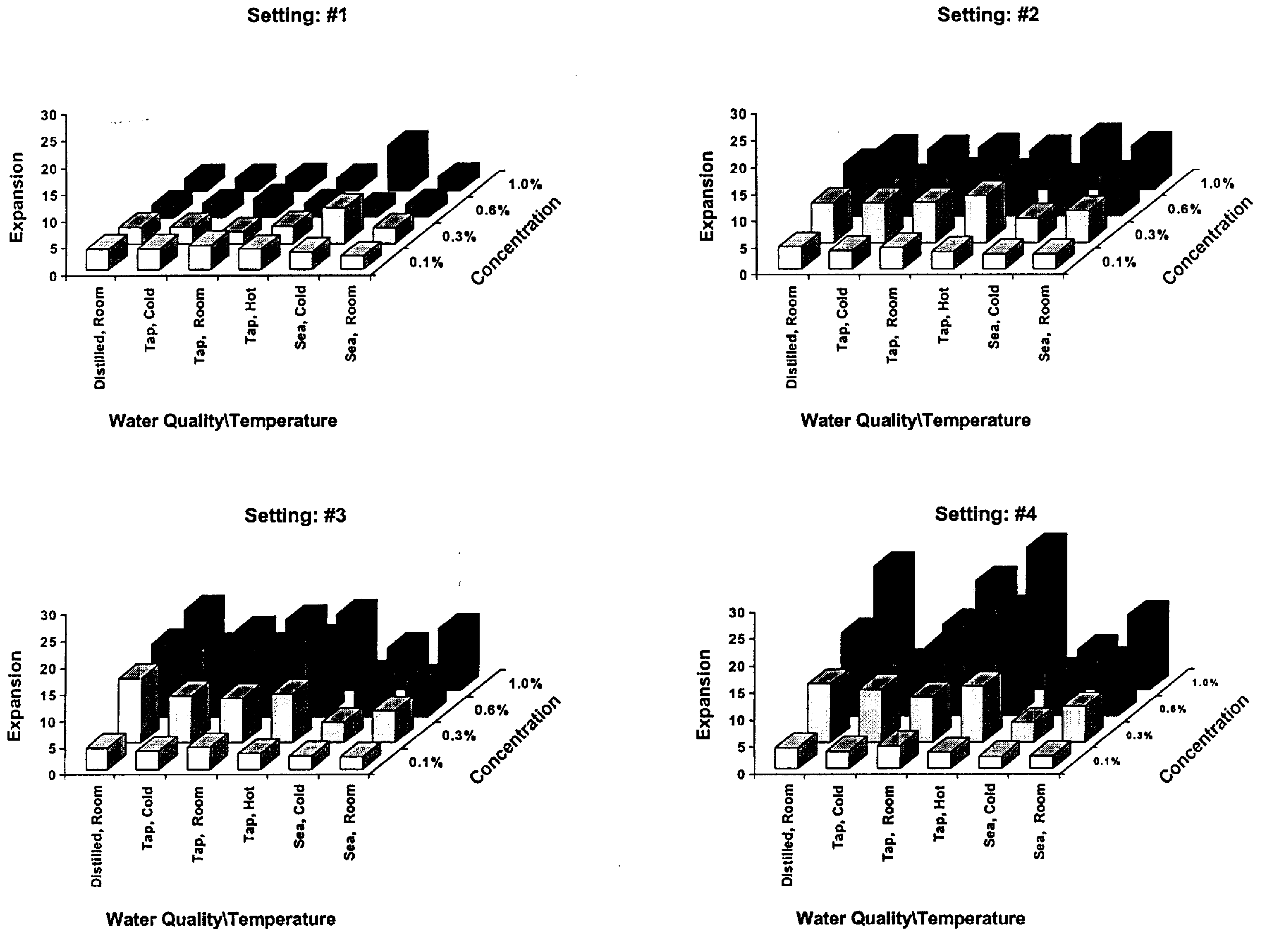


Figure 3 - Expansion of Ansul Silv-Ex as a Function of Production Variables.

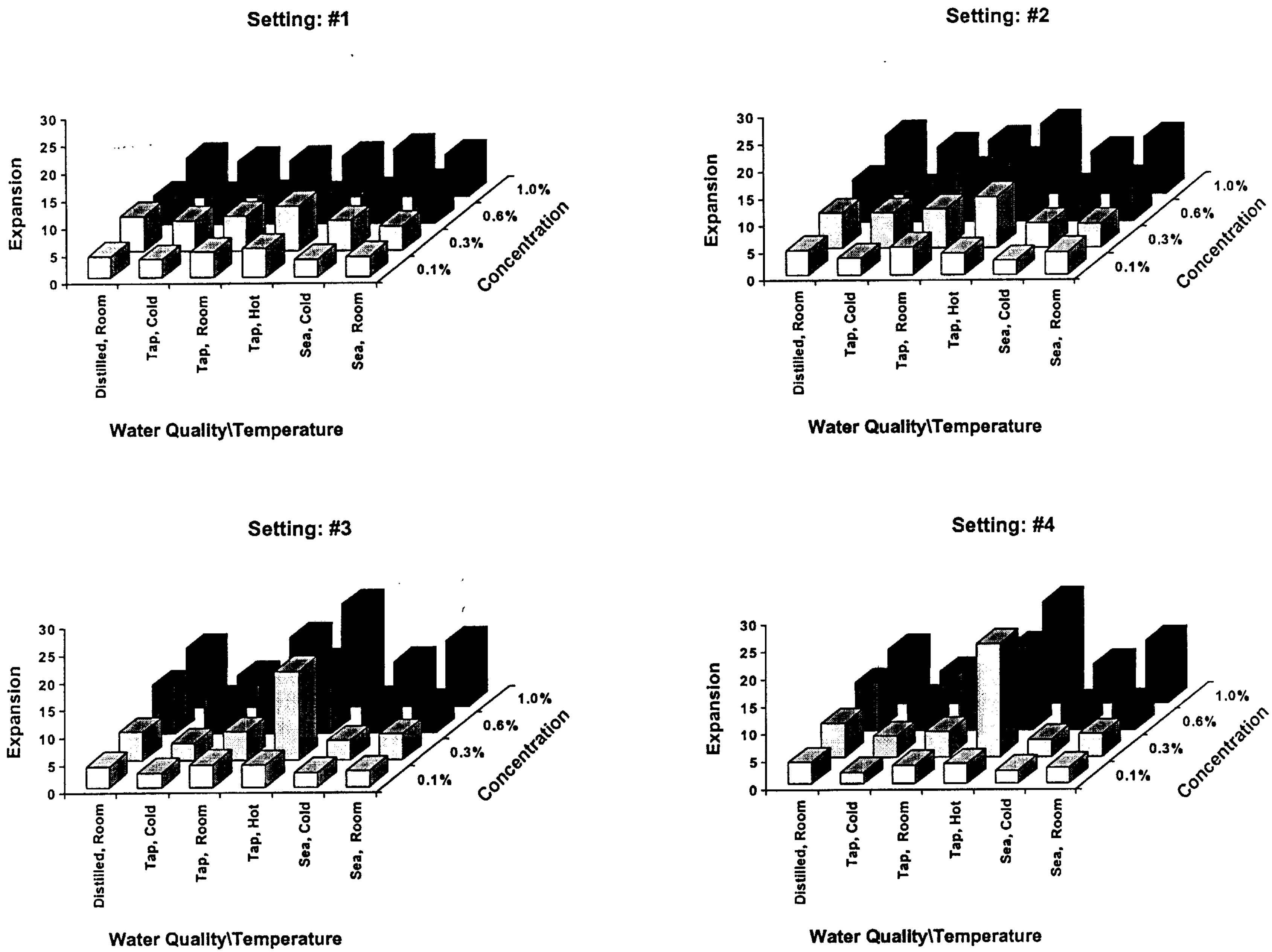


Figure 4 - Expansion of Fire-Trol FireFoam 103B as a Function of Production Variables

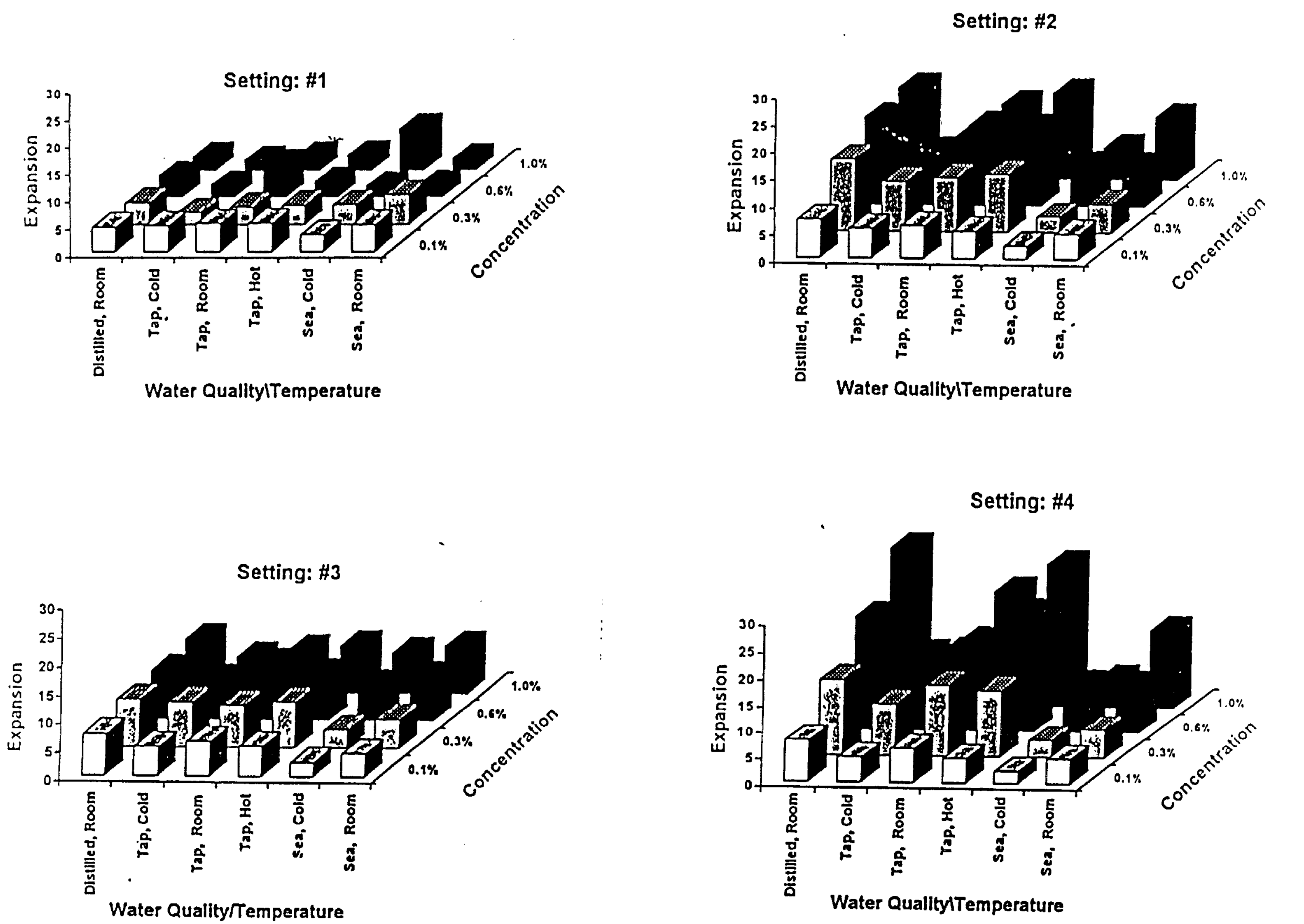


Figure 5 - Expansion of Phos-Chek WD 881 as a Function of Production Variables.

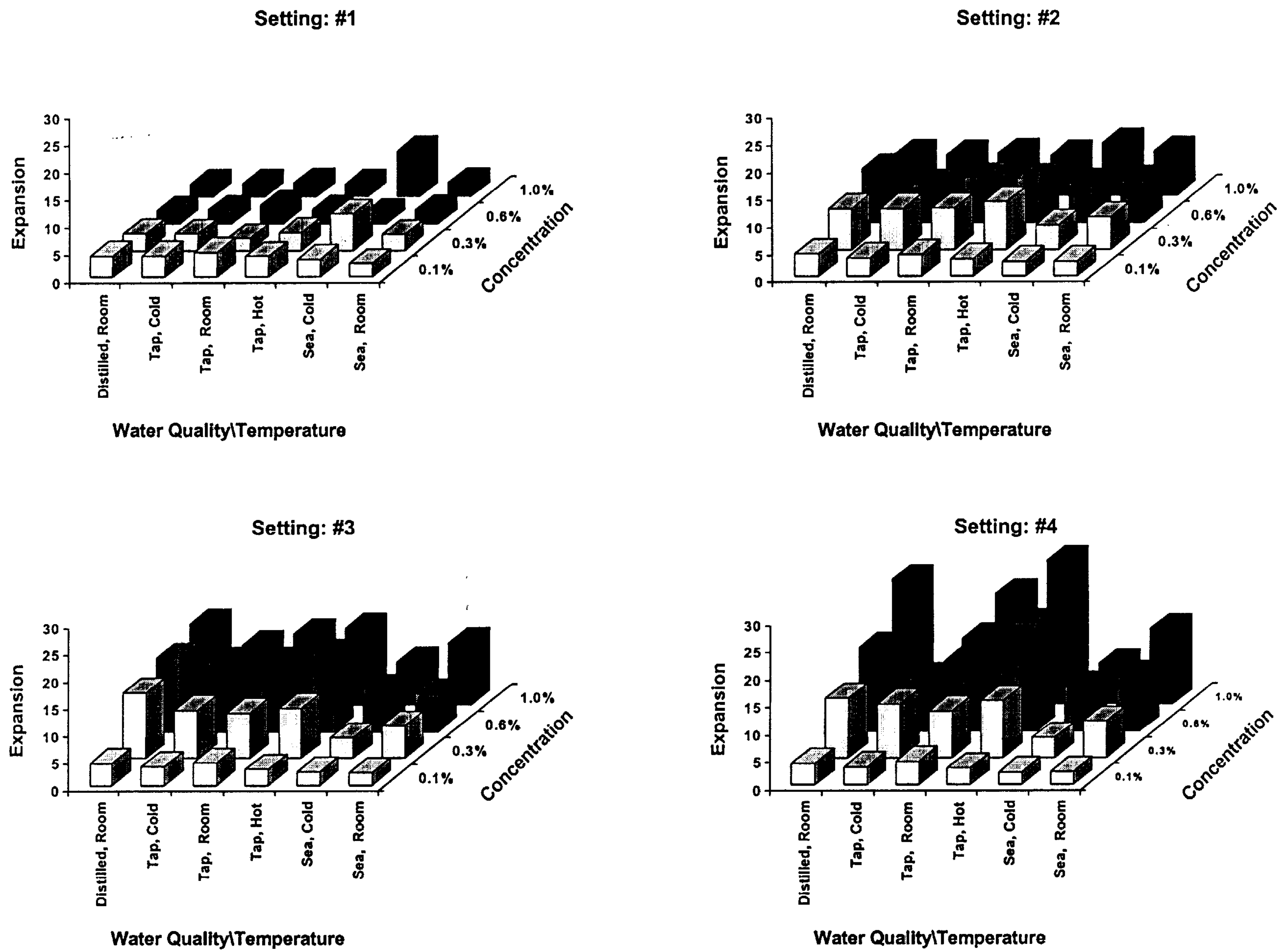


Figure 6 - Expansion of Fire-Trol FireFoam 104 as a Function of Production Variables

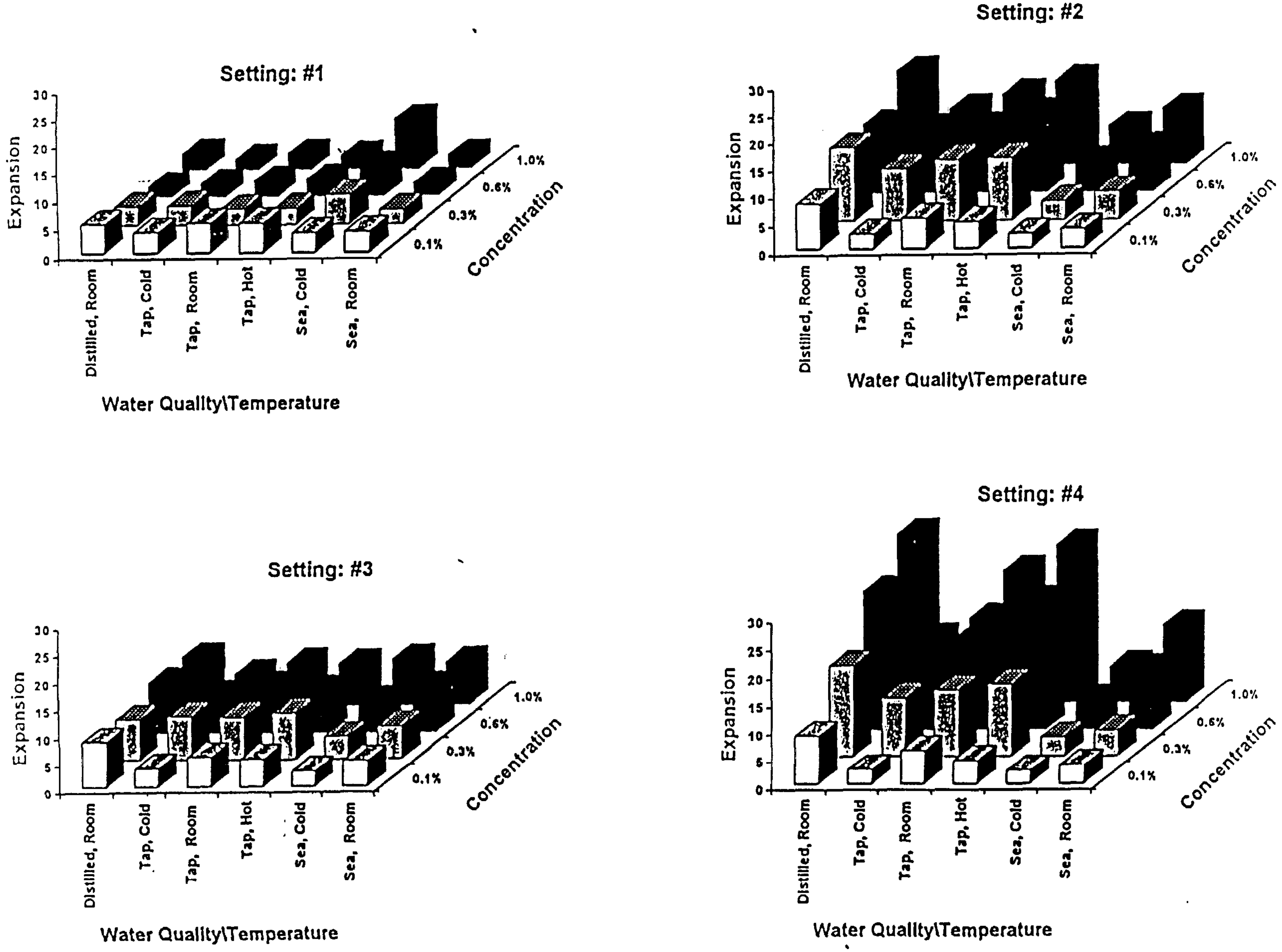


Figure 7 - Expansion of Angus ForExpan S as a Function of Production Variables

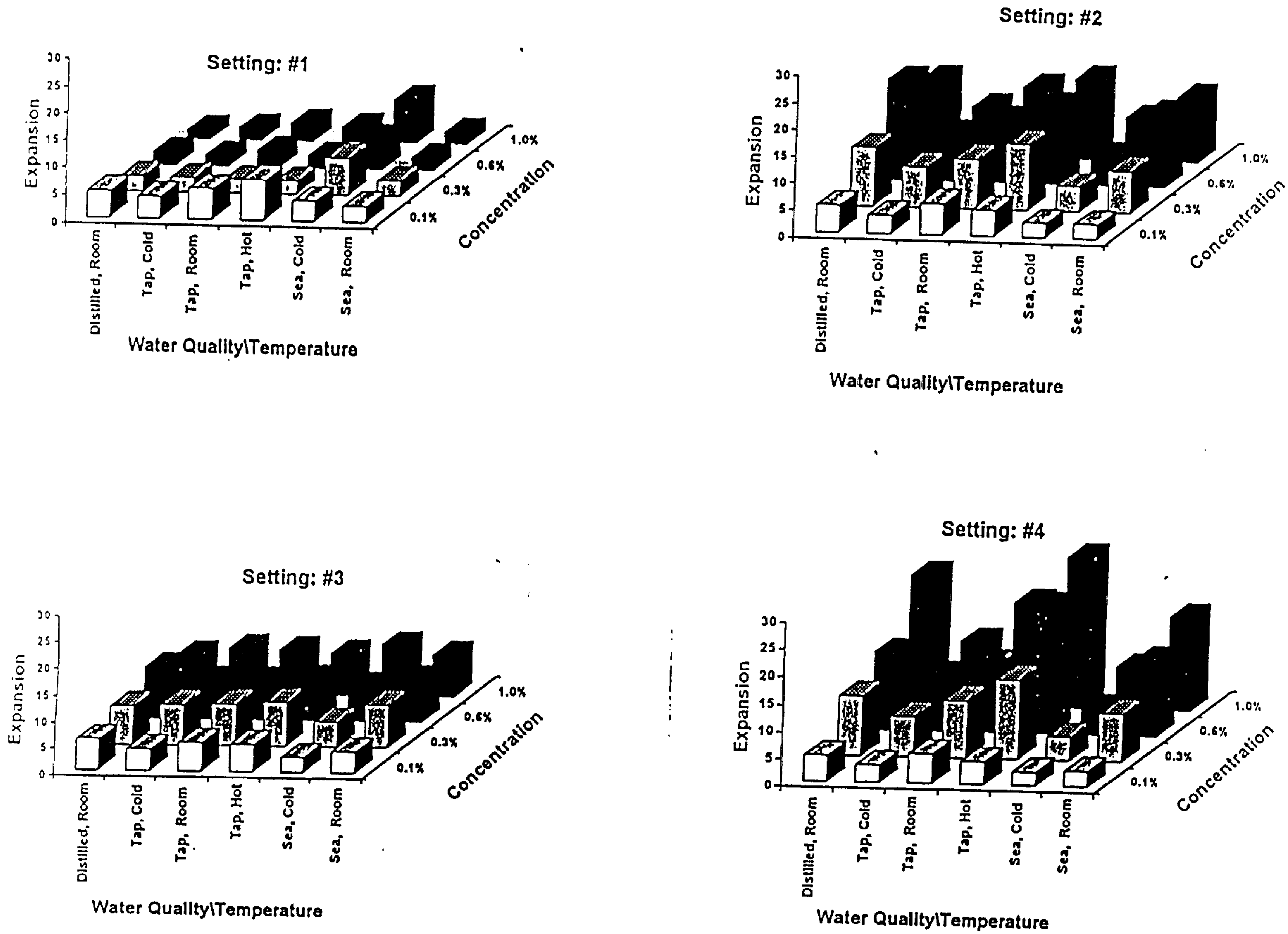


Figure 8 - Expansion of Pyrocap B-136 as a Function of Production Variables.

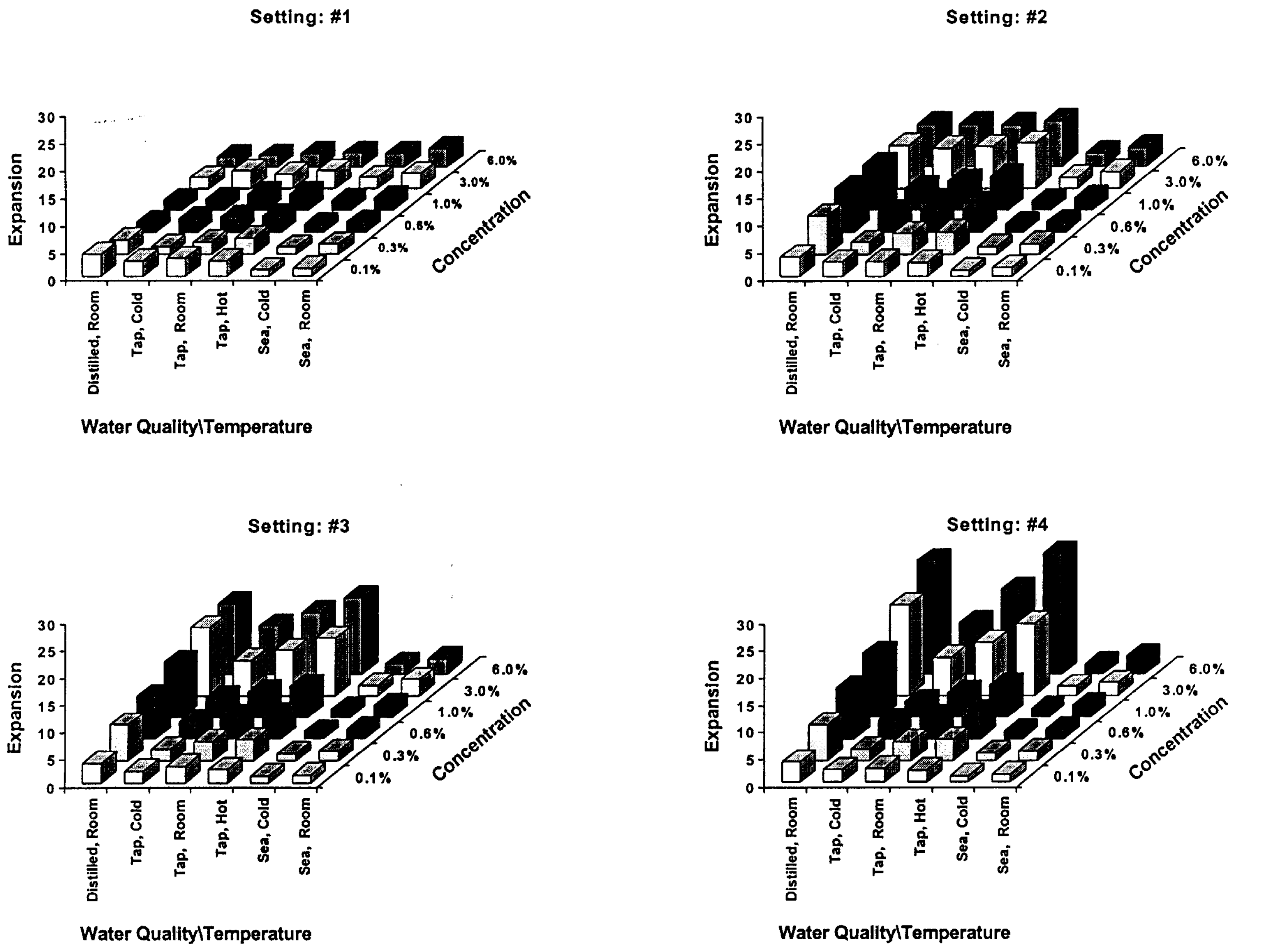


Figure 9 - Expansion of Fire Quench as a Function of Production Variables.

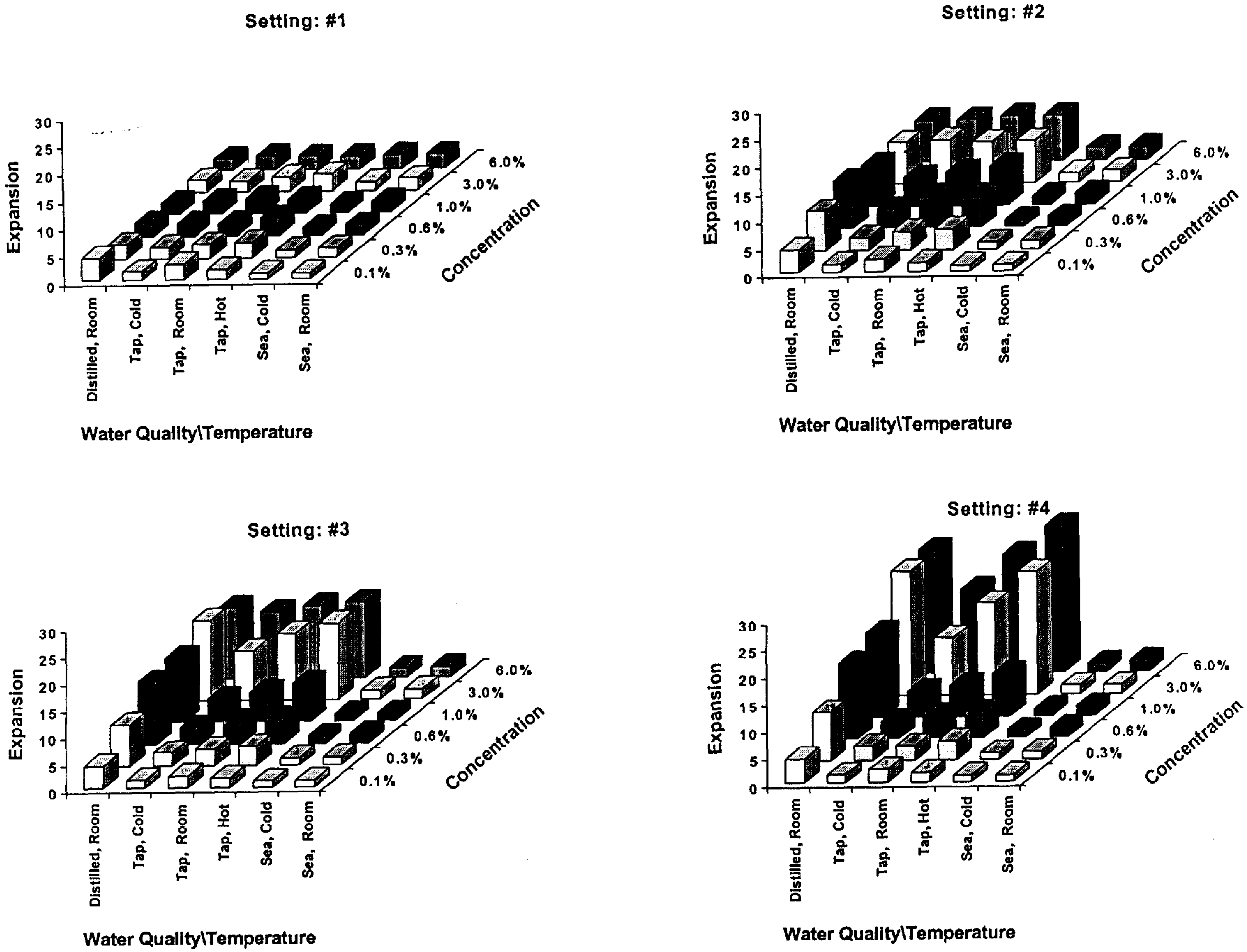
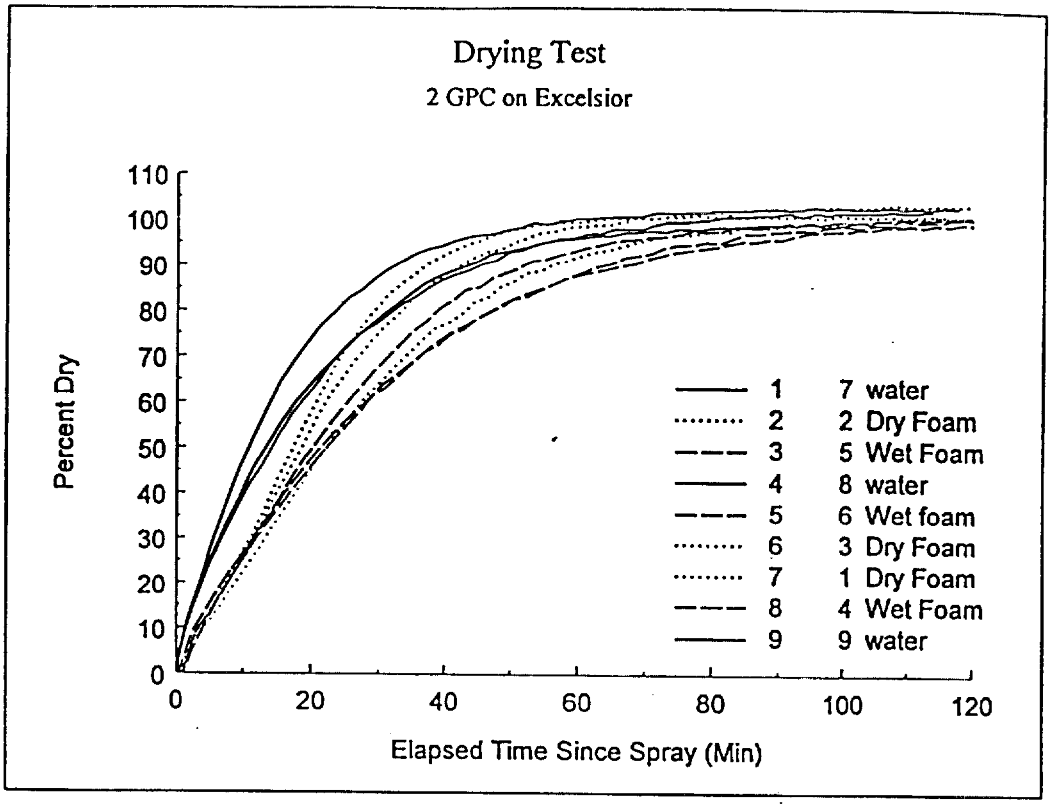


Figure 10 - Typical Drying Curves for Water and Foam on Aspen Excelsior and P. Pine Needles



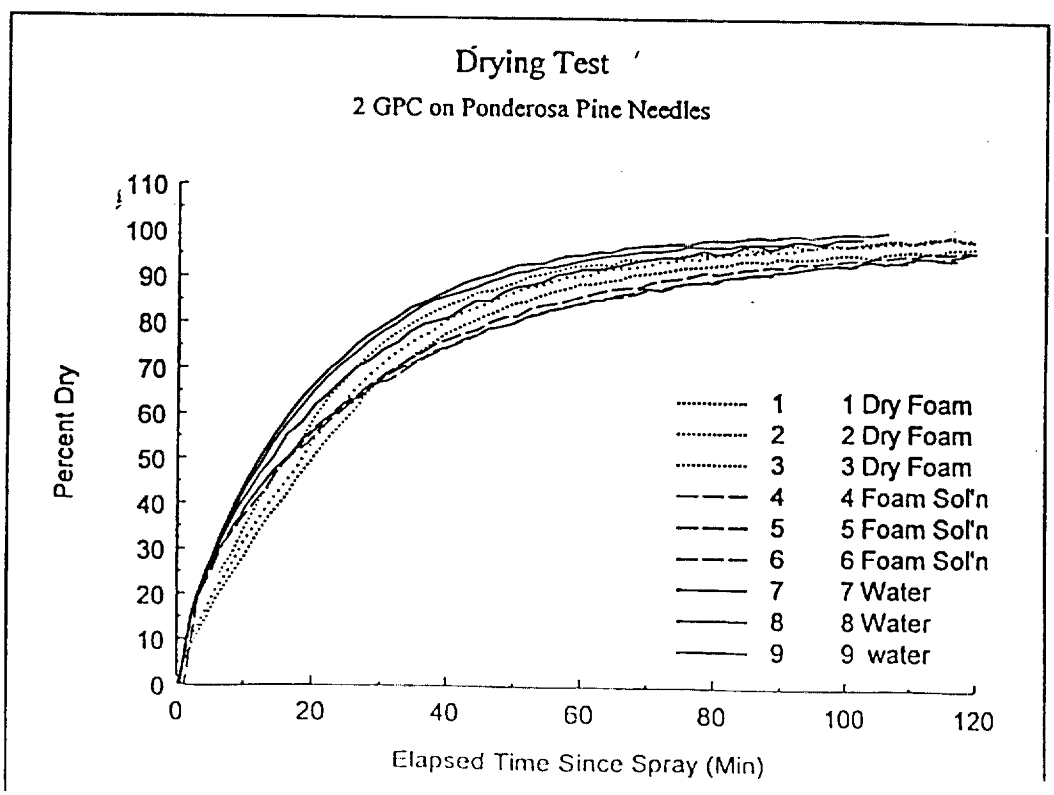


Figure 11 - Burning Curves for Rate of Weight Loss and Rate of Spread for Two Foams Tested as Long-Term Retardants