AEROSPACE INFORMATION REPORT

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Superseding AIR4275A

(R) Jet Reference Fluid Study for Fuel Tank Sealants

RATIONALE

Modify this AIR to include the efforts of the JRF Subcommittee of SAE G-9 to develop the new Jet Reference Fuel (JRF-3) identified in AMS2629E. JRF-3 more closely represents current JP-5 and JP-8 fuels and was designed to provide a reference fuel for a wider variety of fuel system materials than currently use AMS2629.

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TABLE OF CONTENTS

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1. SCOPE

This information report covers two distinct projects to formulate Jet Refrence Fluids (JRF) for testing of material compatibility. The first effort began in 1978 and focused on producing a formulation (JRF-2) that simulated JP-4 and included composition with metallic ions that reproduced chalking of fuel tank sealants. This effort resulted in the preparation of AMS2629 that defined the formulation of JRF-2 (Type 1) and the same formulation with metallic ions (Type 2). The second effort began in 2002 and focused on preparing a JRF that simulated Jet A, JP-5 and JP-8. This effort went through multiple iterations, but eventually resulted in a JRF-3 formulation composed of Jet A plus military additives spiked to 25% aromatic content and high levels of sulfur experienced in the global fuel supply. Since the metallic ions added to JRF-2 demonstrated their ability to simulate a chalking reaction, chalking was not tested with the ions added to JRF-3. AMS2629 was changed multiple times to reflect the onging changes of this project and included both Type 1 and Type 2 formulations.

1.1 Background

Standard reference fluids, or test fluids, have long been used to evaluate the effects of hydrocarbon fuels on various materials, such as integral fuel tank sealants. Standard fluids are required because hydrocarbon fuels, such as JP-4, vary widely in composition depending on crude source, refining techniques, and other factors. To ensure reliable and reproducible results when determining the fuel resistance of materials, reference fluids of known composition, using worst-case fuel compositions, are used. The original Jet Reference Fluid (JRF) called out in military sealant specifications was developed in the mid-1950s specifically as a JP-4-type test fluid formulation to be used for the accelerated laboratory testing of integral fuel tank sealants.

In August, 1978, chalking of the polysulfide sealant in integral fuel tanks of some new aircraft at Edwards Air Force Base in California was discovered after only 1 year of service. Chalking is a phenomenon that occurs in polymeric materials used in the fuel tanks of military and civil aircraft. It manifests as a white, chalky deposit on the surface of the material (sealant, seal, slosh coating, etc.) and is a consequence of chemical attack by certain constituents of aviation fuel (metallic ions, sulfur-containing compounds, naphthenic compounds, etc.). Reversion of the organic matrix renders it soluble in the aviation fuel, depositing the inorganic fraction (fillers, extenders, rheology agents) on the surface as it dissolves. The degree of chalking can be classified as “Slight,” “Moderate,” or “Heavy” depending upon the amount of inorganic material deposited. Although chalking of polysulfide sealants had been observed occasionally in the past, the rate of chalking was unprecedented. The results of an investigation showed that the rapid chalking of the polysulfide sealant was caused by a chemical reaction involving metal ions (copper, cadmium, lead, and iron) and mercaptan sulfur in the fuel. It was also noted that qualification testing of the sealant used had not predicted the chalking that occurred in service. Further investigation disclosed that the sealant had passed the chalking test in the military specification because the JRF used in the specifications chalking test did not contain trace metal ions as did the fuel removed from the tanks of the affected aircraft. The special Air Force investigating team included in its final report a recommendation that the JRF specification be reviewed and revised.

The above chalking incident coupled with concerns resulting from deficiencies observed with the original JRF, and from changing sources of JP-4, indicated that an update of the JRF formulation in the sealant specifications was needed. A proposal was made to the SAE Aerospace Sealing Committee (G-9) which then formed a subcommittee for the development of the original Jet Reference Fluid (JRF) for the evaluation of integral fuel tank sealants.

In the 1990s the Air Force converted from JP-4, a kerosene/gasoline blend, to JP-8 which is a kerosene based fuel. The Navy had been using JP-5, a higher flash point kerosene-based fuel, for aircraft on carriers since the 1950s. The change for the Air Force stimulated the need to develop JRF-3 as a simulant to JP-5 and JP-8. A subcommittee was formed in AMS G-9 in the Fall of 2002 with active members from government and industry.

The first JRF-3 formulation (AMS2629 Revision C) was a synthetic mixture incorporating discrete fuel and additive components but resulted in a surrogate that was costly to produce. Recognizing that Jet A-1 (and subsequently Jet A) was the basis for JP-8, the final approach (AMS2629 Revision E) was to spike Jet A to the maximum allowed aromatic and sulfur concentrations. Other changes included adjustments to accommodate high global fuel supply sulfur and mercaptan levels and reductions in icing inhibitor concentrations to follow reductions in fuel specification limits. AMS2629 was revised four times during this effort and ultimately delivered a reference fuel composition of reasonable cost, ease of production, maximized consistency with in-serice fuels, and an option open to many fuel system materials.

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1.2 Program Organization

1.2.1 JRF-2

The organization of the first committee and its functions were discussed at a meeting in Long Beach, CA, on 23 May 1979. The prime purpose of this meeting was to define objectives, establish the scope of effort, and to develop a program plan so that it could get started on the technical effort. Simply stated, the objective of this committee was to develop a new JRF for sealant evaluation which would reasonably reflect the worst to be expected from fuels derived from existing and expected sources, provide reliable sealant differentiation, and have none of the known deficiencies of the original JRF.

1.2.2 JRF-3

The SAE G-9 JRF subcommittee was activated at the 46th SAE G-9 meeting in Oklahoma City, OK. The goal of the subcommittee was to develop a new JRF composition to more closely simulate JP-5 and JP-8 fuels used in service and still maintain the objectives of the JRF-2 effort. The committee worked with AFRL/RQ fuels branch to determine the best approach.

1.3 Approach

1.3.1 JRF-2

The original JRF called out in MIL-S-8802 and MIL-S-83430 sealant specifications was selected as a suitable starting point for discussion and planning. Knowledge of the rationale used for the development of the original JRF and the selection of its components coupled with the problems encountered with its use was considered essential to the development of a new replacement fluid. Establishing the scope of effort proved to be difficult. However, there was general agreement that a broad, two-level program to define the requirements for, develop the composition of, and fully evaluate a new JRF was needed. It consisted of a short-term effort addressing current, urgent problems and a long-term effort to address the full spectrum of fuels, seal and sealant materials, and potential environments. As a minimum, the new JRF should address the following:

a. Both military and commercial requirements, with an emphasis on the military

b. Composition of JRF to simulate existing fuels (i.e., JP-4, JP-5, JP-8, and Jet A) and future alternate fuels as developed

c. The effects of JRF on the following classes of materials: polysulfides, fluorosilicones, fluorocarbons, and nitriles

d. Problems experienced with the original JRF

e. Analytical techniques and handling/storage requirements to ensure adequate quality control of the JRF

f. The potential requirement for more than one JRF (i.e., high and low aromatics content) for different applications

g. An appropriate method for governing the new JRF with provisions for future review and revisions

h. Appropriate and adequate testing

Although a detailed program plan was not accomplished at that time, the following considerations for the Short-Term Program and the Long-Term Program were initially identified:

a. Short-Term Program

  1. Consider polysulfide sealants only

  2. Concentrate on reliable sealant differentiation

  3. Establish a common source

  4. Establish analytical techniques for quality control

  5. Establish problem contaminant content (i.e., metal ions and mercaptan sulfur)

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6. Revise original chalking test

7. Formulate to better represent the worst to be expected from fuels derived from existing and expected sources

b. Long-Term Program

1. Evaluate mercaptan content

(a) Kind

(b) Level

2. Formulate to represent future fuel compositions

3. Evaluate potential problem fuel components

(a) Sulfur compounds

(b) Additives

(c) Aromatics composition and content

(d) Nitrogen compounds

4. Consider other sealant materials (i.e., fluorosilicones, fluorocarbons, and nitriles)

It was later decided that the mercaptan study, as well as aromatics, nitrogen compounds, and other sulfur compounds and additives, needed to be addressed in the short-term program in order to properly formulate a new JRF.

1.3.2 JRF-3

The second Jet Reference Fluid (JRF-2), in use since 1989, was formulated to closely represent JP-4, a kerosene/gasoline blend fuel widely used by the Air Force. Since that time, JP-8, a kerosene-based fuel, formulated with Jet A-1 (ultimately Jet A), replaced JP-4; JP-5, used by the Navy since the 1950s, was also a kerosene-based fuel. To update the reference fluid to more closely represent fuel compositions in use by both the Air Force and Navy, an SAE G-9 subcommittee was formed to investigate and develop a new formulation. The goal for this new reference fluid, similar to JRF-2 goals, was to exhibit “worst case” conditions within the limits of the current fuel specifications. The resultant test fluid, designated JRF-3, was created using commercially available paraffin and aromatic blends and maximized sulfur, mercaptan, and additive packages to be consistent with fuel specifications. Screening tests for JRF-3 were performed on eleven sealants and testing was ultimately expanded to include compatibility with nine groups of non-metallic materials currently used in military aircraft fuel systems. This was done not only to validate JRF-3 as a fuel surrogate but to expand the potential for use of JRF-3, via AMS2629, in additional material specifications. Based on compatibility testing, this JRF-3 composition was incorporated into AMS2629 Revision C. Before there was any significant transfer to JRF-3, it became clear that the synthetic formula was too costly for labs to produce and/or procure. The G-9 JRF subcommittee changed the approach and investigated basing JRF on Jet A that is spiked to the highest allowed specification limits for aromatics and sulfur content. With help of AFRL/RQ, a large batch of JRF-3 was produced and tested. This formulation change was incorporated into AMS2629 Revision E in 2017.

In recent years, a number of lighter-weight fuel tank sealants have been developed for qualification to AMS3281 and used in military aircraft applications. However, there is some concern that these newer sealants will not hold up after long-term fuel aging. The purpose of this effort was to compare the tensile strength and elongation, Shore A hardness, and peel properties of these sealants to the older, existing sealants that have been in use in the military for years, after continuous aging in JRF-3-1 at 200 °F.

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2. REFERENCES

2.1 Applicable Documents

The following publications form a part of this document to the extent specified herein. The latest issue of SAE publications shall apply. The applicable issue of other publications shall be the issue in effect on the date of the purchase order. In the event of conflict between the text of this document and references cited herein, the text of this document takes precedence. Nothing in this document, however, supersedes applicable laws and regulations unless a specific examption has been obtained.

2.1.1 SAE Publications

Available from SAE International, 400 Commonwealth Drive, Warrendale, PA 15096-0001, Tel: 877-606-7323 (inside USA and Canada) or +1 724-776-4970 (outside USA), www.sae.org.

AMS2629 Jet Reference Fluid

2.1.2 Other Publications

University of Dayton Research Institute Report No. UDR-TR-2005-00181, Small Particulate Emission Control Fuel Additives Material Compatibiity Study.

University of Dayton Research Institute Report No. UDR-TR-2007-00135, Material Compatibility Testing Using JRF-3-1.

University of Dayton Research Institute Report No. UDR-TR-2009-00185, Long Term Fuel Compatibility Evaluation.

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3. DEVELOPMENT CONSIDERATIONS

3.1 Historical development of JRF

The history/background of the development of JRF was traced to determine the basic factors considered by the formulating committee (ARTC Panel W-83, 1955 to 1956) in determining its composition. A fairly complete picture was pieced together from information obtained from the files of former members of the W-83 Panel and from the microfilm files of the Aircraft Industries Association (AIA) in Washington, D.C.

As early as 1953, concern was expressed by the Aircraft Industry that the reference fluid Type III called out in MIL-H-3136 for testing rubber and sealants for acceptability with 115/145 octane aviation gasoline might not be appropriate as a screening fluid for rubbers and sealants to be used with JP-4. It was suspected that the composition of JP-4 would vary widely due to different sources of crude oil and due to differences in refining techniques. The unknown variety of as-yet unidentified contaminants might well introduce new deleterious effect.

This was brought to the attention of the Coordinating Research Council (CRC) Inc., an organization to which the aircraft industry and the oil industry belonged. They failed to act, prompting the formation of a W-83 subcommittee of the Aerospace Research and Testing Committee of AIAA (ARTC) in July 1955. Subsequently, CRC recommended several consultants from the oil companies to assist in the study to establish an appropriate JRF composition to screen rubber and sealants to be exposed to JP-4.

The ARTC Plan was as follows:

a. Learn from the oil companies the variability in composition of JP-4 to be expected from different sources of crude oil and different refining methods.

b. Establish a base fluid, then add various aromatics, mercaptans, olefins, and other types of compounds (such as sulfides, sulfones, nitrogen bearing compounds, oxygenated materials (peroxides), and organometallic compounds). These compositions would be evaluated on the basis of their effects on EC-801 (a lead catalyzed polysulfide sealant) then qualified to the MIL-S-7502 specification.

A detailed set of experiments was then conducted to establish the composition of a representative JRF. The composition selected was:

Toluene (TT-T-548)	30 Volumes
Cyclohexane (95 MOL% minimum)	60 Volumes
Iso Octane (MIL-S-3136 Type I)	10 Volumes
Tert-Dibutyl Disulfide (Phillips)	1 Volume
Tert-Butyl Mercaptan (Phillips)	0.015 ± percent by weight of the other components

The total sulfur content of this JRF composition is 0.4% and the mercaptan sulfur is 0.0045%.

Recommendations were also made to limit the test temperature to 160 °F due to volatility and to set a maximum shelf life of 90 days on the mixed JRF. The data found in the documents did not give a complete basis for the composition selected for the JRF. Whether additional data were available and not presented, or whether some of the selection of elements of composition were arbitrarily selected, is not known. The following “gaps” of information were noted:

a. No data were available to support the selection of 0.4% sulfide sulfur as an upper limit.

b. No mention was made of any implementation of plans to evaluate the effects of organometallic compounds.

c. No data were available to show the variability in composition of production JP-4; thus, no direct data could be reviewed on the concentrations of organic materials.

The original JRF was called out in the MIL-S-8802 and MIL-S-83430 sealant specifications, and, in general, served well since its development. However, problems, deficiences, and concerns were identified. Some of the major problems are listed below:

a. The JRF was inadequate for use in the MIL-S-8802 chalk tests because it lacked controlled metal ion content.

b. It was difficult to establish a reliable common source.

c. The composition relative to the composition of current fuels (i.e., JP-4, JP-5, and JP-8) was questionable (see Table 1).

d. Analysis for quality control purposes was difficult.

e. The aromatics components and content may not be appropriate.

f. It did not contain common fuel additives or suitable simulants.

g. The sulfur compounds may not be appropriate or adequate.

It was clear that the time had some to upgrade the original JRF or develop a new one.

3.1.1 Composition of Fuels from Existing and Expected Sources

Researchers at the Air Force Wright Aeronautical Laboratories Aeropropulsion Laboratory searched the literature for information on the hydrocarbon composition and nitrogen content of jet fuels produced from various sources. He compiled data showing typical compositions for JP-4, JP-5, JP-8, and Jet A fuels from three different sources: petroleum, shale, and coal (see Table 1). The data included percentage ranges for paraffins, cycloparaffins, alkyl benzenes, naphthalenes, and sulfur. He also tabulated concentration ranges for the following impurities: mercaptan sulfur, total sulfur, total nitrogen, and trace metals (see Table 2).

It was observed that jet fuel derived from shale presented a less severe environment than that derived from petroleum because the aromatic content was considerably lower (6 to 13% versus 9 to 19% for JP-4). Nitrogen was higher (0.01% versus 0.0027%); present jet fuel specifications, however, limit nitrogen to 0.01% maximum to maintain fuel stability.

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JP-4 from coal could contain higher concentration of aromatics (19 to 30%); however, all present jet fuel specifications limit the aromatic content to 25% maximum, since higher concentrations greatly reduce engine life. JP-4 from coal will contain twice the concentrations of cycloparaffins (62 to 73%) compared with JP-4 from petroleum (27 to 40%). This is not expected to be more detrimental, since tests with 100% cycloparaffins produced sealant changes (volume swell) which were less significant than a model jet fuel mix containing 20% aromatics. (Original JRF composition contains 30% aromatics.)

A comparison of anticipated compositions of jet fuel made from petroleum, shale oil, and coal is given in Appendix A. Additional information concerning the composition of JP-4, JP-5, and JP-8 are given in Appendices B, C, and D.

Table 1 - Composition of fuels

Fuel Type	Source	Paraffins (%)	Cycloparaffins (%)	Alkyl Benzenes (%)	Naphthalenes (%)	Sulfur (%)
JP-4	Petroleum	39-64	27-40	9-19	0-1	0-0.15
	Shale	49-67	20-45	6-13	0	0.006
	Coal	5-11	62-73	19-30	0	0.002
JP-5	Petroleum	31-51	21-50	11-27	1-4	0-0.23
JP-8	Shale	44-51	30-40	8-22	0-2	0.002
Jet A	Petroleum	5-13	53-66	20-41	0	0.003 0.0005

NOTE 1: Oil shale fuels are quite similar to petroleum. Aromatics content is dependent upon degree of hydrotreatment required to remove nitrogen.

NOTE 2: Coal fuels are quite different with low paraffins content. Cycloparaffin and aromatics content will depend upon degree of hydrotreatment used.

Table 2 - Fuel impurities

Fuel Type	Source	Mercaptan Sulfur (Weight %)	Total Sulfur (Weight %)	Total Nitrogen (Weight %)
JP-4	Petroleum	0-0.001	Unknown	Unknown
	Oil Shale	Unknown	Unknown	0-0.01
	Coal	Unknown	0-0.001	0-0.002
JP-5, JP-8	Petroleum	0-0.002	0-0.16	Unknown
Jet A	Petroleum	0-0.005	0-0.23	Unknown
Kerosene	Oil Shale	Unknown	0-0.001	0-0.24
	Coal	Unknown	0-0.003	0-0.005

NOTE: Expect N_2 must be held to <100 ppm for fuel stability. Sulfur tends to be removed along with N_2.

3.1.2 Possible Relaxation of Restrictions on Jet Fuel Compositions for Greater Availability

Boiling Point: Relaxation of freezing and boiling point limitations would permit the use of high boiling fractions.

Cycloparaffin Content: Fuels from coal would contain a significantly higher content of cycloparaffins. Fuel speficiation limits might be raised.

Nitrogen Level: The higher nitrogren of shale oil fuels could be reduced by hydrotreating. Nitrogen levels are kept low for acceptable jet fuel storage stability.

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Fuel Additives: Fuel icing inhibitors and fuel biocides at the original 0.2 to 0.5% levels in jet fuels have no detrimental effects on sealants (Navy study per NADC). These limits are not expected to change.

NOTE: Icing inhibitor concentrations were found to affect fuel tank coatings (MIL-PRF-27725) and concentrations were reduced in both JP-5 and JP-8 specifications around the 2015-2016 timeframe.

3.1.3 Tests Performed During the Committee's Investigation

Special tests were run by Air Force Materials Laboratory (AFML), Naval Air Defense Command (NADC), and General Dynamics, Fort Worth Division. These laboratories, along with McDonnell Douglas Long Beach and two sealant suppliers, Essex Chemical Corporation and Products Research and Chemical Corporation, also participated in a round robin test program.

3.1.3.1 Effects of Metal Ions

Exploratory tests with metal ions at 10, 5, and 1 ppm indicated that copper ions and cadmium ions caused rapid chalking of sealant in the JRF solution. Calcium, iron, lead, magnesium, manganese, and nickel ions also caused chalking, but at a much slower rate. Metallic naphthanates were found by NADC to be the most stable organometallic vehicle for the introduction of metal ions into a JRF formulation.

Initial round robin tests utilized the original JRF composition but modified it to include 0.10 ppm by weight of copper ions and 0.10 ppm by weight of cadmium ions. This "first fix" recognized the effects of cadmium fasteners on sealant in F-16 fuel tanks where chalking had been observed.

Specimens of sealant (1/8 inch x 1/8 inch x 5 inch) cut from cured sheets were suspended totally immersed in a closed glass container containing 900 cc of the test fluid at 140 °F. The fluid was changed twice per week (Mondays and Thursdays) and was examined for chalking daily and qualitatively rated as no chalk, slight chalk, moderate chalk, or heavy chalk. This was continued until all samples exhibited heavy chalk. The sealants used were:

PR-1422 A polysulfide, dichromate cured system qualified to MIL-S-8802 (Type 1)

Pro Seal 890 A manganese dioxide cured polysulfide qualified to MIL-S-8802 (Type2)

Pro Seal 899 A manganese dioxide cured polysulfide qualified to MIL-S-83430

Results: the samples showed a slight chalk in 1 to 2 weeks, and a heavy chalk in 3 to 4 weeks.

A modified procedure was evaluated in which the concentration of copper and cadmium ions was increased to 0.5 ppm each, and the immersion conducted at 77 °F. Under these conditions, no significant chalking was observed until after 6 or 7 days. It was decided that this was a satisfactory procedure and should be incorporated into MIL-S-8802. The detailed test procedure is shown in 3.5.5 of this report.

3.1.3.2 Effects of Aromatic Compounds

The results showed that test fluids composed of 40% cyclohexane, 35% iso-octane, and 25% aromatic, the bicylic aromatic compounds (and alkyl derivatives) caused much greater swell (22 to 35%) than the alkyl benzenes (7 to 14%); however, bicyclic compounds occur in jet fuels only in low concentrations (less than 1%). Only indene and tetralin chemically degraded the sealants, but this occurred at a concentration of 5% or greater. No degradation was apparent at concentrations less than 1% (swell and weight loss data shown in Appendix E).

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3.1.3.3 Effects of Paraffins and Cycloparaffins

Regarding the effects of paraffins and cycloparaffins, sealant properties were observed before and after immersion in various fluids for 266 hours at 140 °F. The study included alkanes, alkenes, and cycloalkanes in the C_6 to C_{16} range. The results were compared with control samples of JP-4, JP-5, and JP-8 (from petroleum), and a sample of JP-4 derived from shale oil. The results showed that the effects of alkanes, alkenes, cycloalkanes, and mixtures on sealant properties were roughly equivalent to that of the control samples. When blends were prepared containing 20% toluene in addition, the volume swell was 2 to 3 times greater than the same blends without toluene added. Alkanes as pure compounds affected the sealant less than cycloalkanes. Within any given class of compound (alkanes, alkenes, cycloalkanes), there was little variation in results over the range of carbon numbers studies. It was, therefore, concluded that a single alkane and a single cycloalkane should be adequate for representing these classes in the JRF formulation and should be present in proportions representative of original jet fuel compositions. Iso-octane and cyclohexane were selected considering purity and availability, as well as low cost. (Data shown in Appendix F.)

3.1.3.4 Effects of Sulfur Compounds

Mercaptan sulfur appears to react with certain elemental metals. In the cases of copper and cadmium, the ions thus produced can cause chalking of sealants. It is important to note that if metal is repesented only in ionic form, the chalking rate is independent of mercaptan concentration. Mercaptans appear to have no effect on sealant volume or weight. Chalking tests were run with JRF containing metal ions both with and without mercaptans present. When mercaptans were absent, no chalking occurred. The conclusion was drawn that both metal ion and mercaptan must be present in order to produce chalking.

Regarding disulfides, similar tests were run with and without disulfides being present. Although there was some indication that the presence of disulfides intensifies volume swell, it has little effect on chalking.

The concentration limits of total sulfur in jet fuels is not expected to change. As refineries switch to the use of higher sulfur crude oils, they will be forced to use hydrodesulfurization. This could result in a reduction in the average sulfur content of jet fuels in the future. A decision was made to maintain the total sulfur concentration in the new JRF at 0.4% by weight and to adjust to that level through the use of tertiary butyl disulfide, as was done in the past with the original JRF.

3.1.3.5 Miscellaneous

Conclusions concerning other potential deleterious contaminates are as follows:

a. Peroxides - Original fuel specifications are adequate to prevent the formation of peroxides in jet fuels; thus, no test of the effects of peroxides on sealant is necessary.

b. Acidity - Fuel specifications control the acidity of fuels to acceptable levels.

c. Thiophenes (Aromatic Sulfur Compounds) - No information is available regarding the current levels of thiophenes in jet fuels. They are easily removed by hydrotreating. There is no evidence that these materials currently present a problem.

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3.2 Historical Development of JRF-2

3.2.1 Composition

Based on the preceding surveys and laboratory tests, a formulation was established that represented the worst to be expected from fuels derived from existing and expected sources. Furthermore, the formulation provided reliable sealant differentiation and had none of the known deficiences of the original JRF. The fluid was designated JRF-2. The composition is shown below, along with the original JRF and typical JP-4 fuel. The toluene level was reduced from 30% by volume to 25% by volume to better simulate the highest level to be expected in typical fuels. JP-4, JP-5, JP-8, and Jet A fuel specifications limited the aromatic content to 25%; consequently, testing at higher levels was considered to be unrealistic. The cyclohexane level was reduced from 60% to 35% by volume, and the iso-octane was increased from 10% to 40% by volume to better represent the ranges of paraffins and cycloparaffins actually found in typical fuels. Tertiary dibutyl disulfide and tertiary butyl mercaptan were retained at their previous levels and trace amounts of copper and cadmium ions (0.5 ppm each) were added to the base composition for chalking tests. Since the presence of trace amounts of metal ions had no apparent effect on sealant properties other than chalking, they were omitted for all other tests.

Table 3 - JRF-2 formulation

Constituents Note: % volume unless otherwise stated	**JRF-2**	**Original JRF**	**JP-4**
Toluene (TT-T-548)	25% by volume	30% by volume	10-20% by volume
Cyclohexane (Tech Grade)	35% by volume	60% by volume	27-40% by volume
Iso-Octane (TT-S-735 TY I)	40% by volume	10% by volume	39-64% by volume
Tertiary Dibutyl Disulfide[1]	1% by volume	1% by volume	(Total Sulfur 0.03% weight)
Tertiary Butyl Mercaptan[2]	0.015 weight % + 0.0015 weight %	(Mercaptan Sulfur 0.0004% weight)	
Copper Ions[3,4]	0.50 ppm by weight	0	0-0.025 ppm
Cadmium Ions[4]	0.50 ppm by weight	0	0-0.014 ppm

[1]Total sulfur content: 0.400 weight % ± 0.005 weight %.
[2]Mercaptan sulfur content: 0.0050 weight % ± 0.005 weight %.
[3]To be added as soluble naphthalenate with final concentration of 0.50 ppm ± 0.50 ppm by weight.
[4]Metal ions added to JRF-2 composition for chalking tests only.

3.2.2 Formulation Changes

As shown in Table 4, the formulation for JRF-2 changed several times from its original composition. This table outlines JRF-2 formulation changes documented in AMS2629 from initial publishing through Revision B.

Table 4 - JRF-2 formulations per AMS2629

Constituents Note: % volume unless otherwise stated	**AMS2629 (1989)**	**AMS2629A (1991)**	**AMS2629B (1994)**
Toluene, TT-T-548	28 ± 1	28 ± 1	28 ± 1
Cyclohexane, Technical grade	34 ± 1	34 ± 1	34 ± 1
Isooctane, TT-S-735, Type I	38 ± 1	38 ± 1	38 ± 1
Tertiary dibutyl disulfide, doctor sweet	1 ± 0.005[1]	See footnote 3	See footnote 3
Tertiary butyl mercaptan	0.015 ± 0.0015[2] % mass	See footnote 4	See footnote 2

[1]Sufficient amount to provide a total sulfur concentration of 0.4 ± 0.005 % by weight.
[2]Sufficient amount to provide a mercaptan sulfur concentration of 0.005 ± 0.0005 % by weight.
[3]Sufficient amount to provide a total sulfur concentration of 0.42 ± 0.02 % by weight.
[4]Sufficient amount to provide a mercaptan sulfur concentration of 0.005 ± 0.0005 % by volume.

3.2.3 Preparation of the JRF-2 Formulation

Omitting the metal ions, mix the ingredients in the JRF-2 proportions given in the JRF-2 composition shown in Table 3 (or Table 4). If the solution is to be used either immediately or at a later date for chalking tests with metal ions added, store the mixture from the start in amber class containers.

Analyze for total sulfur and mercaptan sulfur.

The procedure for adding metal ions for chalking tests is described in 3.2.5.

3.2.4 Comparison of JRF-2 and Original JRF

Tests were conducted by subcommittee members to compare the old and new formulations. Tensile strength, elongation, hardness, and volume change of three sealant samples were measured following 7- and 14-day immersion in the two fluids. Data are shown in Appendix G.

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3.2.5 Chalking Test Using Metal Ion Additives

3.2.5.1 Fluid Makeup

Combine the five individual components of JRF-2 shown in Table 3 (or Table 4).

NOTE: Do not use commercial JRF-2 unless analysis shows the mixture to contain less than 0.05 ppm copper or cadmium ions.

Add copper and cadmium ions from a standard reference concentrate of copper and cadmium naphthanates certified to contain 500 ppm copper and 500 ppm cadmium. Add 1.0 mL of this concentrate to 999 mL of the other five components. This will result in a final copper and cadmium concentration of 0.5 ppm ± 0.05 ppm each. Store fluid in amber glass (avoid contact with any metals).

There is currently no suitable quantitative analysis available for metal ion concentration. The desired method of preparing the JRF-2 with metal ions, therefore, must be done carefully.

3.2.5.2 Procedure

Cut four 1/8 inch x 1/8 inch x 5 inch specimens from a sheet of the sealing compound that has been cured for 14 days at 77 °F ± 2 °F and 50% RH ± 2% RH. The specimens shall be suspended on nylon cord in a closed glass container with 900 mL of test fluid so that the specimens are totally immersed in the fluid. Aluminum foil shall be used to seal the lids of the containers. No metal items shall be allowed to be in contact with the fluid or specimens during the immersion period. The specimens shall not touch each other, so that all sides are exposed to the fluid. The immersion temperature shall be 77 °F ± 2 °F. The tests will be started on a Wednesday and the fluid changed on the following Friday. The specimens shall be examined for chalking on the following Monday. Remove specimens from the fluid and allow the fluid to evaporate. The specimens are not to be blotted or wiped.

Examine strips in well-lighted area. To detect chalking, use an unexposed specimen for comparison with specimens under test.

3.2.5.3 Rating Criteria

a. Slight chalk - Initial observation of white or light gray formation, usually starting at edges of the sealant.

b. Moderate chalk - The white or light gray formation has spread to about one-quarter to one-half of the surface area.

c. Heavy chalk - The white or light gray formation has spread to about three-quarters or more of the surface.

Observations of chalking greater than moderate after 5 days of immersion shall be cause for rejection of the test sealant.

3.2.6 Commercial Sources of Supply for JRF-2 and Metal Ions

Phillips Petroleum, Borger, Texas, manufactured and sold the JRF-2 composition (without metal ions) in drums and in smaller containers. The amount of metal ion that might be imposed upon the solution from the container itself was not considered to be significant in affecting sealant properties for any immersion tests, except the chalking test. It was strongly recommended that JRF-2 solutions to be used for chalking tests be made up directly in the laboratory of the using facility, and that the resultant solution be stored in amber glass containers.

Metal ions (copper and cadmium) as the naphthanates could be purchased as primary standards in Drakeol #9 oil from National Spectrographic Labs, Inc., 7650 Hub Parkway, Cleveland, OH 44125; telephone number (216) 447-1550.

3.2.7 JRF-2 Conclusions

The efforts of the JRF subcommittee were summarized as follows:

a. Conducted surveys to determine compositions of jet fuels derived from current and expected sources.

b. Conducted laboratory tests to determine the effects of fuel constituents on polysulfide sealants.

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c. Conducted laboratory tests to determine the effects of fuel contaminants, including sulfur compounds and metal ions, on polysulfide sealants.

d. Based on the preceding studies, a new JRF formulation (JRF-2) was devised and recommended for committee approval; the new fluid reasonably reflected the worst to be expected from fuels from existing and expected sources, provided reliable sealant differentiation, and had none of the known deficiencies of the original JRF.

e. A test fluid formulation was devised for testing for chalking of polysulfide sealants (JRF-2, plus metal ions).

f. A test procedure for chalking was established.

g. Sources were identified for JRF-2 fluid, and for metal ion concentrates.

h. Consideration of future fuels and sealants other than polysulfides, such as fluorosilicones, fluorocarbons, and nitriles was postponed to a later date.

3.3 Development of JRF-3

3.3.1 Composition

As noted at the conclusion of the JRF-2 effort, newer fuels/fuel changes were anticipated and testing with a wider variety of sealants and other fuel system materials would expand the benefit of developing a consistent jet fuel surrogate. While the JRF-2 composition was validated as a surrogate for JP-4, JP-5, JP-8, and Jet A on several polysulfide sealants, the use of individual components (toluene, iso-octane, cyclohexane) with narrow molecular weight distributions resulted in a fluid which caused excessive reactions with some newer fuel system materials. To address these issues, a new kerosene-based Jet Reference Fluid, JRF-3, was developed as a more representative surrogate for modern fuels with respect to compatibility testing of a wider range of materials. During the development of JRF-3, several other in-service issues with jet fuels such as icing inhibitor attack on fuel tank coatings and increasing sulfur levels in international fuel reserves drove changes that were incorporated into the reference fluid effort. Table 5 lists the history of JRF-3's formulation changes in AMS2629 Revision C through Revision F.

Table 5 - JRF-3 formulation

Constituents Note: % by volume unless otherwise stated	**Revision C (2013)**	**Revision D (2014)**	**Revision E (2017)**	**Revision F (2020)**
Parrafins	74.2 ± 1[1]	74.2 ± 1[1]	N/A	N/A
Jet A Fuel	N/A	N/A	73.8 ± 1	73.8 ± 1
Aromatics	25 ± 1[2]	25 ± 1[3]	25 ± 1[4]	25 ± 1[4]
Sulfur	0.3 ± 0.02% mass	0.3 ± 0.02% mass	0.42 ± 0.02% mass	0.42 ± 0.02% mass
Mercaptan	0.002 ± 0.0005% mass	0.002 ± 0.0005% mass	0.005 ± 0.0005% mass	0.005 ± 0.0005% mass
Fuel System Icing Inhibitor	0.15 ± 0.02	0.15 ± 0.02	0.11 ± 0.02	0.11 ± 0.02
Lubricity Improver/ Corrosion Inhibitor	0.0017 ± 0.0002	0.0017 ± 0.0002	0.0017 ± 0.0002	0.0017 ± 0.0002

[1]Exxsol D-40, 37.1%; and Exxsol D-80 37.1%.
[2]Aromatic 100, 6.25 ± 0.5%; Aromatic 150 13.25 ± 0.5%; and Aromatic 200 5.5 ± .5%.
[3]Aromatic 100, 7.5 ± 0.5%; Aromatic 150 15 ± 0.5%; and Aromatic 200 2.5 ± 0.5%.
[4]Aromatic blend ratio: Aromatic 100, 30 ± 0.5%; Aromatic 150, 60 ± 0.5%; and Aromatic 200, 10 ± 0.5%.

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3.3.2 Testing

3.3.2.1 Short-Term Testing

All testing was conducted in accordance with established ASTM and SAE test procedures outlined below. The materials tested included five adhesives (FM 47 (vinyl/phenolic), Epon 828/DTA (epoxy), Scotchweld AF-10 (nitrile/phenolic), Loctite 609 (methacrylate), and Loctite 495 (cyanoacrylate)), two fuel bladder materials (EF 51956 (nitrile) and EF 5904C (polyurethane)), five coatings (MIL-S-4383 nitrile (EC 776), MIL-C-27725 urethane, BMS 10-20 epoxy, BMS 10-39 epoxy and MIL-P-24441 epoxy/polyamide), six sealants (MIL-S-8802 polysulfide (PR 1422 and PR 1440), Q4-2817 fluorosilicone, PR-2911 polyurethane, AMS3277 polythioether (PR-1828), and AMS3281 polysulfide (PR-1776)), two composite materials (AS4/3501-6 graphite/epoxy and IM7/5250-4 graphite/bismaleimide), one explosion-suppression foam material (MIL-F-87260 (Foamex, Type VI polyurethane)), four specific types of O-rings (MIL-P-5315 nitrile (Parker N-602), MIL-R-25988 fluorosilicone (Parker L1120-70), MIL-R-83485 acrylic/nitrile (Parker VO-835), and MIL-R-83248 fluorocarbon (Parker V-1226-75)), two fuel hose materials (MIL-H-4495 acrylic/nitrile (AC-603-01) and MIL-H-26521 nitrile (EC-614-01)), and four wire insulation films (TFE Teflon, polyethylene, Dupont Zytel 101 (Nylon 101), and UPILEX (Kapton)). Required testing included the following:

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Adhesives:

- Lap Shear (ASTM D1002)
- Static Shear (MIL-R-46082, Method A)

Fuel Bladders:

- Tensile Strength and Elongation (ASTM D412)
- Volume Swell (ASTM D471)

Coatings:

- Pencil Hardness (MIL-C-83286A)
- Tape Adhesion (Fed. Std. 141, Method 6301)
- Taber Test (ASTM D4066)

Sealants:

- Peel Strength (AS5127/1)
- Hardness, Shore A (ASTM D2240, AS5127/1)
- Tensile Strength and Elongation (ASTM D412, AS5127/1)
- Volume Swell (ASTM D471, AS5127/1)

Composite Materials:

- Interlaminar Shear (ASTM D790)

Foam Material:

- Tensile Strength and Elongation (ASTM D412)
- Resistivity (ASTM D257)

O-rings:

- Hardness, Shore M (ASTM D2240)
- Tensile Strength and Elongation (ASTM D1414)
- Compression Set (ASTM D365)
- Volume Swell (ASTM D471)

Hose Material:

- Hardness, Shore A (ASTM D2240)
- Tensile Strength and Elongation (ASTM D412)
- Volume Swell (ASTM D471)

Wire Insulation:

- Tensile Strength and Elongation (ASTM D412)

3.3.2.1.1 Test Results

Results of material compatibility testing with the newly formulated Jet Reference Fluid, designated JRF-3-1, are contained in Appendix J, Tables 1 through 9. Results after fluid aging were compared against unaged specimens and changes were calculated and notated in the tables. Results after aging in JP-8 (POSF 4751) were shown for comparison purposes. Pass/fail criteria were determined by personnel at the Air Force Research Lab (AFRL). Retested data is indicated in the tables with a pound sign (#). The following summarizes the effects of JRF-3-1 on the tested materials:

1. Adhesives: There were no concerns raised after testing the adhesives, except for the static shear strength for the Loctite 495, which exhibited some drop-off after aging in the JRF-3-1 (Appendix J, Table 1).
2. Bladder Materials: There were no concerns raised after testing the bladder materials, except volume swell of the EF 5904C polyurethane material exceeded the allowable volume swell as noted by the pass/fail criteria (Appendix J, Table 2). This was consistent with results for the JP-8 fuel.
3. Coatings: Pencil hardness for EC-776 and MIL-P-24441 and the wear index results for MIL-P-24441 after taber testing exceeded the allowable values as noted by the pass/fail criteria (Appendix J, Table 3).
4. Sealants: The only out-of-spec conditions after testing all six sealants were tensile results for PR-1776 B-1/2, and volume swell and Shore A hardness for PR-1828 B-2 and PR-1776 B-1/2 (Appendix J, Table 4).
5. Composites: There were no concerns raised after testing the two composite materials (Appendix J, Table 5).
6. Foam: There were no concerns raised after testing the explosion-suppression foam material (Appendix J, Table 6).
7. O-rings: Change in volume swell and Shore M hardness for the N602-70 nitrile O-rings exceeded the limits after aging in the JRF-3-1 fuel. Tensile strength and elongation and compression set for the L1120-70 fluorosilicone O-ring material was out-of-spec after aging in the JRF-3-1 (Appendix J, Table 7).
8. Hoses: Tensile strength and elongation, volume swell, and change in Shore A hardness properties for both hose materials after aging in JRF-3-1 were out-of-spec (Appendix J, Table 8).
9. Wire Insulation: There were no concerns raised after testing the four insulation materials (Appendix J, Table 9).

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3.3.3 Long-Term Testing

All testing was in accordance with established ASTM and SAE test procedures outlined below. All peel strength test panels consisted of AMS4045 (7075 T-6 bare) aluminum, sulfuric acid anodized per AMS2471, and coated with AMS-C-27725 polyurethane coating. The fuel used in each of the individual specimen quart jars was not replaced periodically but topped off as necessary to maintain full specimen coverage during aging. Required testing included the following:

Sealants:

- Hardness, Shore A (ASTM D2240)
- Tensile Strength and Elongation (ASTM D412)
- Peel Strength (AS5127/1)

3.3.3.1 Test Results

Individual test results for each material are described below. In general, all of the fuel used in aging exhibited a trend over time of increasing discoloration and formation of particulate during the aging cycle (See Appendix K, Figures 7 through 9). All of the specimens were suspended in the fuel during the aging process but most of the longer-aged specimens eventually became so soft that they fell to the bottom of the aging container. Some of these specimens could still be tested, but some could not. The ones that could not be tested appeared to be reverting. Samples of this sealant was analyzed, and it was determined that at elevated temperature the sealant exhibited reduced fuel resistance. Additionally, even though the extent of cure (degree of crosslinking) was sufficient to prevent the bulk polymer from disentangling and dissolving, it was not sufficient to prevent excessive fuel absorption and the loss of structural integrity. The extent of crosslinking was also insufficient to prevent the loss of a second polymer (polyethylene) into the fuel. This corresponded with the results of analyzing the particulate found in the fuel, which was determined to be polyethylene. Finally, each data table notes at what point the material could no longer be tested. All the graphs indicate the AMS3281 minimum specification requirement for tensile strength (125 psi), elongation (25%), and Shore A hardness (30 pts) for reference. For the materials that were still testable after twelve months of aging, the acid number of the fuel was analyzed and recorded. Acid number gives an indication of the usage life of the fluid. Manufacturers recommend changing the fluid if it exceeds 2.0 mg KOH/g.

PR-1776: A graphic summary of the data trend results for PR-1776 B-2 polysulfide sealant after aging in JRF-3 at 200 °F is shown in Appendix K, Figure 1. Data results are listed in Appendix K, Table 1. After two months aging, the fuel was still clear with only a light particulate discernable. Tensile strength and elongation results exhibited a downward trend over twelve months. After eighteen months of aging, the specimens could not be tested. Shore A hardness results exhibited a downward trend through two months of aging. After six months of aging, hardness values went back up. Peel strength results decreased over eighteen months while maintaining 100% cohesive failure for all specimens. Fuel samples tested for acid number showed a peak level of 0.34 mg KOH/g for the twelve month aging sample.

PR-2007: A graphic summary of the data trend results for PR-2007 B-2 polysulfide sealant after aging in JRF-3 at 200 °F is shown in Appendix K, Figure 2. Data results are listed in Appendix K, Table 1. After two months aging, the fuel was still clear with only a light particulate discernable. Tensile strength and elongation results exhibited a downward trend over twelve months. After eighteen months, the tensile strength increased slightly while the elongation continued to decrease. Shore A hardness values decreased through two months but from six months and later, the hardness results steadily increased. Peel strength results decreased over eighteen months while maintaining 100% cohesive failure for all specimens, except for the six month test result of 78% cohesive failure. Fuel samples tested for acid number showed a peak level of 1.18 mg KOH/g for the twelve month aging sample.

AC 330: A graphic summary of the data trend results for AC 330 B-2 polysulfide sealant after aging in JRF-3 at 200 °F is shown in Appendix K, Figure 3. Data results are listed in Appendix K, Table 1. After two months aging, the fuel was discolored with heavy particulate throughout. Tensile strength and elongation and Shore A hardness results exhibited a downward trend over two months. After six months the tensile specimens could no longer be tested. However, peel strength was able to be tested for the full eighteen months. Results were somewhat ambiguous with the 28 day and two-month results showing less than 100% cohesive failure. Overall, the peel strengths trended downward over the eighteen month period. Only one fuel sample was tested for acid number and it showed a level of 0.1 mg KOH/g for the eighteen month aging sample.

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AC 370: A graphic summary of the data trend results for AC 370 B-2 polysulfide sealant after aging in JRF-3 at 200 °F is shown in Appendix K, Figure 4. Data results are listed in Appendix K, Table 1. After only two months aging, the fuel was discolored with heavy particulate throughout and both the tensile and peel strength specimens showing some signs of reversion (see Appendix K, Figures 7 through 9). Test results after only 28 days aging showed a significant decrease in all material properties and after two months all specimens were unable to be tested. No fuel samples were tested for acid number.

WS 8030: A graphic summary of the data trend results for WS 8030 B-2 polysulfide sealant after aging in JRF-3 at 200 °F is shown in Appendix K, Figure 5. Data results are listed in Appendix K, Table 1. After two months aging, the fuel was discolored and particulate was discernable in the fuel but the specimens were still able to be tested. Tensile strength and elongation and Shore A hardness results exhibited a downward trend through six months of aging. After twelve months the tensile specimens could no longer be tested. However, peel strength was able to be tested for the full eighteen months. Fuel samples tested for acid number showed a peak level of 1.01 mg KOH/g for the twelve month aging sample.

WS 8031: A graphic summary of the data trend results for WS 8031 B-2 polysulfide sealant after aging in JRF-3 at 200 °F is shown in Appendix K, Figure 6. Data results are listed in Appendix K, Table 1. After two months aging, the fuel was discolored, and particulate was discernable in the fuel but the specimens were still able to be tested. Tensile strength and elongation and Shore A hardness results exhibited a downward trend through six months of aging. After twelve months the tensile specimens could no longer be tested. However, peel strength was able to be tested for the full eighteen months. Fuel samples tested for acid number showed a peak level of 1.01 mg KOH/g for the twelve month aging sample.

4. NOTES

4.1 Revision Indicator

A change bar (l) located in the left margin is for the convenience of the user in locating areas where technical revisions, not editorial changes, have been made to the previous issue of this document. An (R) symbol to the left of the document title indicates a complete revision of the document, including technical revisions. Change bars and (R) are not used in original publications, nor in documents that contain editorial changes only.

PREPARED BY SAE AMS COMMITTEE "G-9"

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APPENDIX A - COMPOSITION, YESTERDAY - TODAY - TOMORROW

Table A1 - JP-4 composition, JP-5, -8, and jet A yesterday-today-tomorrow

				Aromatics		Sulfur		
Fuel Type	Source	Paraffins (%)	Cyclo Paraffins	Alkyl Benzenes	Naphthalenes	Mercaptan	Total	Total Nitrogen[1]
JP-4	Petroleum	39-64	27-40	9-19	0-1	0-0.001	0-0.2	0-0.002
	Shale	49-67	20-45	6-13	0	?	0.006	0-0.01
	Coal	5-11	62-73	19-30	0		0-0.002	0-0.002
JP-5	Petroleum	31-51	21-50	11-27	1-4		0-0.23	
JP-8	Shale	44-51	30-40	8-22	0-2		0.002	
Jet A	Coal	5-13	53-66	20-41	0		0.003	

[1]Nitrogen will be held to 0.01% max for fuel stability.

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APPENDIX B - CORRELATION OF AVIATION TURBINE FUEL PROPERTIES[1]

Some of the important properties of aviation turbine fuels produced from petroleum were correlated with density and aromatic content in order to provide a framework for estimating the properties of aviation turbine fuels produced from synthetic fuels.

B.1 COMPOSITION

The composition of various jet fuels was evaluated by Kearns (36). JP-4 and JP-5 differ in the molecular weight of their aromatic components. JP-5 also has a lower concentration of paraffins. Table B1 lists the composition of these fuels, as determined by Kearns. Those compositions are compared with a straight run kerosene.

Table B2 illustrates the effects of molecular structure on the physical properties of jet fuel hydrocarbon components. Paraffins have the lowest density, melting point, boiling point, and highest heating value per carbon atom. Aromatics have the highest density, melting point, boiling point, and lowest heating values. Naphthenes fall between aromatics and paraffins in properties but resemble aromatics more closely.

A correlation based on Siemssen's (35) work is presented in Figure B1. The calculations are based on a naphthene density of 0.8233 g/cm^3, an aromatic density of 0.9195 g/cm^3, and a paraffin density of 0.7487 g/cm^3. Note that these densities were obtained from a regression of the composition presented by Armstrong et al., (33). Eisen's results (15) do not fall on the triangular graph, probably because the COED-based jet fuel contains higher molecular weight naphthenes than are present in petroleum-based fuel. The naphthene density seems to be on the order of 0.85 g/cm^3, as compared with the correlation number of 0.8233 g/cm^3. Also, the product from Western Kentucky coal appears to have higher molecular weight cyclic compounds than the Utah coal jet fuel product.

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[1]Prepared by Exxon Research and Engineering Company, Government Research Laboratory, Linden, New Jersey 07036. March 1975. Section VI.

Table B1 - Composition of jet fuels in volume percent (36)

	JP-4	JP-5	Kerosene
Benzenes			
C9	13.1	1.7	0.3
C10	4.1	4.6	1.4
C11	1.1	2.5	1.6
C12	0.5	1.0	1.0
C13	0.3	0.7	0.8
C14		0.2	0.5
C15		0.1	0.3
C16			0.2
Indanes			
C10	0.1	0.3	0.2
C11	0.1	1.0	1.0
C12	0.1	1.0	1.5
C13		0.4	1.2
C14		0.1	0.7
C15			0.3
C16			0.1
Indenes			
C11		0.1	
C12		0.1	0.1
C13		0.1	0.2
C14			0.2
C15			0.1
Naphthalenes			
C10	0.1	0.4	0.1
C11	0.2	1.5	0.6
C12	0.2	1.7	1.5
C13		0.4	1.0
C14		0.1	0.3
C15			0.1
Totals			
Alkanes	38.7	30.8	41.7
Non-Condensed Cycloalkanes	32.1	34.4	27.2
Condensed Cycloalkanes	7.4	16.8	12.9
Olefins	1.9	0.0	2.8
Aromatics	19.9	18.0	15.4

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Table B2 - Properties of hydrocarbons in the jet fuel range

Name	Formula	Hydrogen % (Weight)	MW	Density g/cm^3	MP °C	BP °C	LHV kJ/g
Aromatics							
Benzene	C_6H_6	7.74	78.11	0.879	5.5	80.1	40.1
Naphthalene	$C_{10}H_8$	6.29	128.16	1.025	80.2	217.9	40.2
Toluene	$C_6H_5CH_3$	8.75	92.13	0.866	-95	110.8	40.5
Xylene, o	$C_6H_4(CH_3)_2$	9.50	106.16	0.881	-25	144	40.8
Xylene, m	$C_6H_4(CH_3)_2$	9.50	106.16	0.867	-47.4	139.3	40.8
Xylene, p	$C_6H_4(CH_3)_2$	9.50	106.16	0.861	13.2	138.5	40.8
Naphthenes							
Cyclohexane	C_6H_{12}	14.37	84.16	0.779	6.5	80	43.4
Decalin, cis	$C_{10}H_{18}$	13.13	138.24	0.895	-51	193	42.8
Decalin, trans	$C_{10}H_{18}$	13.13	138.24	0.872	-32	185	42.8
Methyl Cyclohexane	C_7H_{14}	14.37	98.18	0.769	-126.3	101	43.4
Dimethyl Cyclohexane							
cis 1,2	C_8H_{16}	14.38	112.13	0.796	-50.1	129.7	43.4
trans 1,2	C_8H_{16}	14.38	112.13	0.776	-89.2	123.4	43.4
cis 1,3	C_8H_{16}	14.38	112.13	0.776	-75.6	120.1	43.4
trans 1,3	C_8H_{16}	14.38	112.13	0.784	-90.1	124.5	43.4
cis 1,4	C_8H_{16}	14.38	112.13	0.783	-87.4	124.3	43.4
trans 1,4	C_8H_{16}	14.38	112.13	0.763	-37.0	119.4	43.4
Paraffins							
h-hexane	$CH_3(CH_2)_4CH_3$	16.38	86.17	0.659	-94	69	44.7
i-hexane		16.38	86.17	0.654	-153.7	60.2	44.6
neo-hexane	$(CH_3)_3C\ C_2H_5$	16.38	86.17	0.649	-98.2	49.7	44.6
	$(CH_3)_2CHCH(CH_3)_2$	16.38	86.17	0.662	-129.8	58.0	44.6
n-heptane	C_7H_{16}	16.09	100.21	0.684	-90.61	98.4	44.6
n-octane	C_8H_{18}	15.88	114.23	0.703	-56.8	125.7	44.4
n-decane	$C_{10}H_{22}$	15.59	142.28	0.730	-29.7	174.0	44.2

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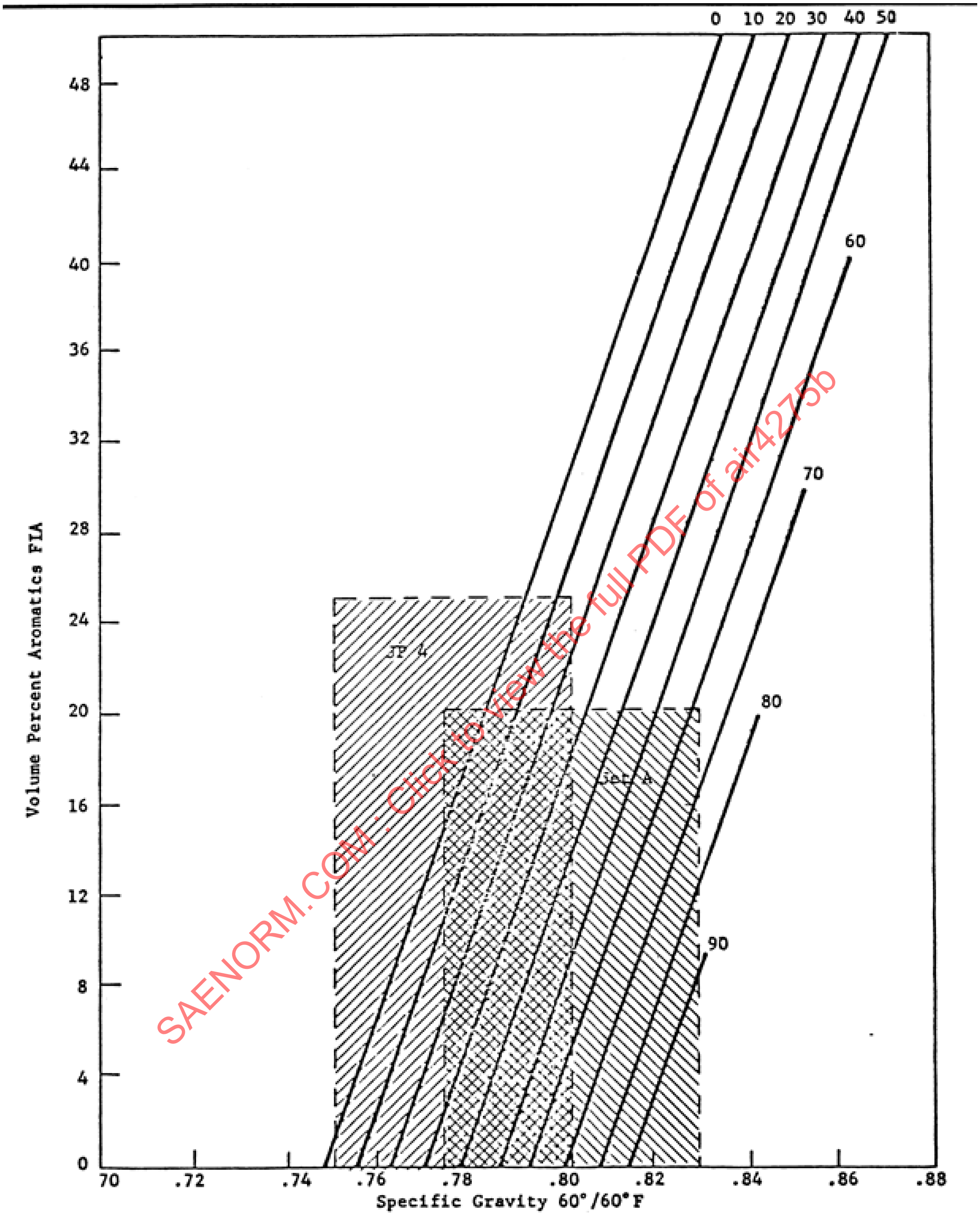

Figure B1 - Volume percent naphthenes

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APPENDIX C[2] - AIR FORCE AERO PROPULSION LABORATORY TECHNICAL REPORT, "ANALYSIS OF AIRCRAFT FUELS AND RELATED MATERIAL, TABLES 64, 77, 78, 79"

Table C1 - Hydrocarbon-type analysis

	JP-8		Xylene Composite		2040 Solvent	
	Weight %	Average Carbon No.	Weight %	Average Carbon No.	Weight %	Average Carbon No.
Paraffins	41.8	12.1	-	-	-	-
Cycloparaffins	37.5	12.0	-	-	-	-
Dicycloparaffins	6.1		-	-	-	-
Tricycloparaffins	1.1		-	-	-	-
Alkylbenzenes	7.5	10.9	100.0	8.9	35.5	10.5
Indanes/Tetralins	3.8		-	-	6.8	11.0
Indenes	0.7		-	-	0.09	11.0
Naphthalene[1]	0.2		-	-	18.6	10.0
Naphthalenes	1.5	11.6	-	-	39.0	11.2
Acenaphthenes	-		-	-	-	-
Acenaphthylenes	-		-	-	-	-
Tricyclic aromatics	-		-	-	-	-
Analytical Method	ASTM D2549 and ASTM D2425		ASTM D2789		ASTM D2425	

[1]Refers to the unsubstituted compound.
[2]Dash indicates none was detected.

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[2]From Hodgson, F.N. and Tobias, J.D., Analysis of Aircraft Fuels and Related Materials, Monsanto Research Corp., Dayton, OH 45407. March 1979.

Table C2 - Boiling point distribution (ASTM D2887)

	JP-4, Tank B-11 (Temperature)		JP-4 (Temperature)	
Percent Recovered	°C	°F	°C	°F
0.5 (initial boiling point)	26	78.8		
5.0	69	156	61	
10.0	89	192	75	
20.0	103	217	98	
30.0	119	246	117	
40.0	134	273	127	
50.0	153	307	151	
60.0	178	352	170	
70.0	199	390	189	
80.0	218	424	211	
90.0	237.5	459	235	
95.0	252	485	252	
99.5 (end point)	279	534	275	

Table C3 - Heat of combustion

	Gross, BTU/lb.	Net, BTU/lb.
JP-4, Tank B-11	20046	
	20031	
	Average 20039	18717
JP-4, 8-24-77	20092	
	20089	
	Average 20091	18767

Table C4 - Hydrocarbon-type distribution

Compound Type	Volume Percent JP-4, 8-24-77	Volume Percent JP-4, Tank
Paraffins	60.5	62.1
Monocycloparaffins	24.6	21.4
Dicycloparaffins	4.3	5.3
Alkylbenzenes	8.5	8.7
Indanes & Tetralins	1.6	1.5
Naphthalenes	0.5	1.0
Average Carbon Number	8.7	9.5

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APPENDIX D - MERCAPTANS IN JET FUELS

Mercaptan sulfur compounds found in aviation turbine fuels (jet fuels) tend to have the same chemical types as found in the fuel. Thus, fuels composed predominately of paraffinic molecules would tend to have primarily paraffin-derived mercaptans, while fuels having a high concentration of aromatics would tend to have mercaptans of the mercapto-benzene (thiophenol) type.

The specification limit for military aviation turbine fuels is 0.001% mercaptan sulfur by weight. However, if the fuel is determined to be "Doctor Sweet" by ASTM D484, the fuel is normally acceptable. For the Doctor test to be negative (i.e., sweet), the mercaptan present must not exceed the following concentration:

Methanethiol (methyl mercaptan)	0.002%
Ethanethiol (ethyl mercaptan)	0.0006%
Propanethiol (propyl mercaptan)	0.0009%
2-methyl-2 propanethiol (tert-butyl mercaptan)	0.0004%
3-methyl-1 butanethiol (i-amyl mercaptan)	0.0003%
Heptanethiol (n-heptyl mercaptan)	0.0001%
Mercapto benzene (thiophenol)	0.002%[3]

Thus, an acceptable jet fuel by the Doctor test may have less than 0.0001% by weight mercaptan sulfur (if the only mercaptan present is heptanethiol) or as much as 0.002% mercaptan sulfur (if the mercaptan present is either methanethiol or mercapto benzene).

An analysis of the mercaptan sulfur compounds found in jet fuel kerosene distillates could not be found. However, for straight run gasolines from mid-continent crude oils, the mercaptans usually consisted of methanethiol, ethanethiol, propanethiol, butanethiols, and pentanethiols with hexyl mercaptans and heavier mercaptans occasionally present. Mercapto benzene was present in some cases.[4]

In Table D1, the boiling range of typical jet fuels, the boilingi points for the jet referee fuel constituents, and the boiling points for various mercaptan sulfur compounds typically found in gasoline and heavier distillate fuels are listed. As the mercaptans present in a distillate fuel will have the same boiling range as the fuel, a JP-4 fuel would be expected to contain ethanethiol, propanethiols, butanethiols, and higher molecular weight mercaptans. JP-5 and JP-8 fuels, which have a significantly higher initial boiling point than JP-4, would have hexanethiol and heavier mercaptans. Mercapto benzene, which has a boiling point within the boiling ranges of JP-4, JP-5, and JP-8, would be expected to be found in all three fuels.

Shell Research Limited[5] noted that mercapto benzene was more severe than tert-octyl mercaptan in its attach on Thiokol-type rubbers. As it is known that mercapto benzene may be present in JP-4, JP-5, and JP-8 in concentrations as high as 0.002% by weight, the jet reference fuels should possibly contain mercapto benzene as the primary mercaptan sulfur compound to generate a worst-case fuel for elastomer testing.

A series of tests is recommended to compare the rate of attach of various mercaptan compounds on polysulfide sealants of the MIL-S-8802 variety. The mercaptans to be tested should include tert-octyl mercaptan, mercapto benzene, and butanethiol. These tests should help to determine the choice of mercaptan compound(s) to be used in future jet reference fuels. Concentrations of the mercaptans should range between 0.001 and 0.005% by weight.

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[3] "Jet Fuel Treatment," by K. M. Brown, UOP Process Division, Universal Oil Products Company, presented at the South East Fuel Quality Assn., Jet Fuel Quality Protection Group, Memphis, TN, 23 Sept. 71.
[4] "Petroleum Refinery Engineering," W. L. Nelson, 4th Edition, McGraw-Hill Book Company, New York, NY.
[5] "The Corrosion of Certain Aero-Gas Turbine Fuel System Components by Mercaptans and the Effect of the Latter on Synthetic Rubbers," Shell Research Limited, Thornton Research Centre Report K. 127, March 1955.

Table D1 - Boiling points of mercaptan compounds and fuels

Product	Boiling Point, °C
JP-4 (Distillation range)	0-320
JP-5 (Distillation range)	115-320
JP-8 (Distillation range)	100-320
Jet Reference Fuel Constituents	
Toluene	111
Cyclohexane	81
Iso-Octane	100
Mercaptans	
Ethanethiol	37
N-Propanethiol	67-68
2-Propanethiol	57-60
2-Methyl-2-Propanethiol (Tert-Butyl Mercaptan)	64.2
1-Butanethiol (N-Butyl Mercaptan)	97-98
2-Butanethiol	85-95
1-Hexanethiol	151
2-Hexanethiol	140
Cyclohexanethiol	158-160
1-Heptanethiol	177
1-Octanethiol	199
2-Octanethiol	186
1-Nonanethiol	220
Mercapto Benzene (Thiophenol)	170
Mercapto Toluene (Toluenethiol)	194-195

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APPENDIX E - EFFECT OF AROMATIC FUEL COMPONENTS ON POLYSULFIDE FUEL TANK SEALANTS

Table E1 - Effects of aromatics on polysulfide sealants

Fluid Immersion	
Fluid	500 mL
Temp	140 °F & 150 °F ± 1.8 °F
Time	266 hours (266 hours ± 0.25 hour)
Specimens	
1 in x 2 in x 0.075 in ± 0.005 in	
4 per jar	
Sealants	
MIL-S-8802 (Type 1)	Chromate cure – RTV for 14 days
MIL-S-8802 (Type 2)	MnO_2 cure – RTV for 14 days
MIL-S-83430	MnO_2 cure – RTV for 14 days
Data	
Volume change	Swollen & dried
Weight change	Swollen & dried
Hardness change (Dry)	
Tensile strength change (Dry)	
Elongation at brake change (Dry)	

Table E2 - Composition of jet fuels in volume percent

	JP-4	JP-5	Kerosene
Alkanes	38.7	30.8	41.7
Cycloalkanes	39.5	51.2	40.1
Olefins	1.9	0	2.8
Aromatics	19.9	18.0	15.4

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Table E3 - Composition of jet fuels in volume percent

	JP-4	JP-5	Kerosene
Benzenes			
C9	13.1	1.7	0.3
C10	4.1	4.6	1.4
C11	1.1	2.5	1.6
C12	0.5	1.0	1.0
C13	0.3	0.7	0.8
C14		0.2	0.5
C15		0.1	0.3
C16			0.2
Indanes			
C10	0.1	0.3	0.2
C11	0.1	1.0	1.0
C12	0.1	1.0	1.5
C13		0.4	1.2
C14		0.1	0.7
C15			0.3
C16			0.1
Naphthalenes			
C10	0.1	0.4	0.1
C11	0.2	1.5	0.6
C12	0.2	1.7	1.5
C13		0.4	1.0
C14		0.1	0.3
C15			0.1
Totals			
Alkanes	38.7	30.8	41.7
Non-condensed Cycloalkanes	32.1	34.4	27.2
Condensed Cycloalkanes	7.4	16.8	12.9
Olefins	1.9	0.0	2.8
Aromatics	19.9	18.0	15.4

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Table E4 - Hydrocarbon-type analysis

	JP-8		Xylene Composite		2040 Solvent	
	Weight %	Average Carbon No.	Weight %	Average Carbon No.	Weight %	Average Carbon No.
Paraffin	37.5	12.1	-	-	-	-
Cycloparaffins	41.8	12.0	-	-	-	-
Dicycloparaffins	6.1		-	-	-	-
Tricycloparaffins	1.1		-	8.9	15.5	18.8
Alkylbenzenes	7.5	10.9	100.0	8.9	35.5	10.5
Indanes/Tetralins	3.8		-	-	6.8	11.0
Indenes	0.7		-	-	10.09	11.0
Naphthalene[1]	0.2		-	-	18.6	10.0
Naphthalenes	1.5	11.6	-	-	39.0	11.2
Acenaphthenes	-		-	-	-	
Acenaphthylenes	-		-	-	-	-
Tricyclic Aromatics	-		-	-	-	-
Analytical Method	ASTM D2549 and ASTM D2425		ASTM D2789		ASTM D2425	

[1]Refers to the unsubstituted compound.
[2]Dash indicates none was detected.

Table E5 - Identification of "xylene bottoms" by kouats indices on a 117 m ou17 column

Compound	K. I. Sample	K. I. Library	K. I.	Area %
Ethyl Benzene	944.17	944.10	+0.07	0.45
P-Xylene	948.53	948.44	+0.09	0.87
M-Xylene	949.96	950.03	-0.07	2.68
O-Xylene	981.50	981.56	-0.06	3.63
Cumene	1006.04	1006.06	-0.02	10.29
N-Propyl Benzene	1035.57	1035.65	-0.08	8.65
1-Ethyl-3-Methyl Benzene	1046.45	1046.12	+0.33	33.03
1,3,5 Trimethyl Benzene	1051.49	1051.36	+0.13	7.89
1-Ethyl-2-Methyl Benzene	1070.54	1070.46	+0.12	6.93
1, 2, 4 Trimethyl Benzene	1081.29	1080.84	+0.45	19.63
Iso-Butyl Benzene	1083.01	1082.90	+0.11	0.18
Sec-Butyl Benzene	1090.44	1090.33	+0.11	0.36
1-Methyl-3-Isopropyl Benzene	1104.02	1103.84	+0.18	0.45
1,2,3 Trimethyl Benzene	1120.47	1120.33	+0.14	1.89
1-Methyl-3-Propyl Benzene	1134.72	1134.57	+0.15	0.50
Indane	1147.67	1147.39	+0.28	0.53
Total				97.96

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Table E6 - Aromatic solvents

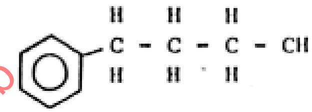
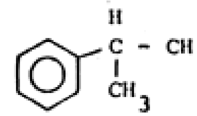
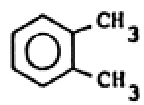
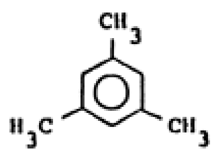
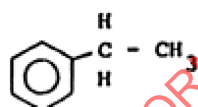
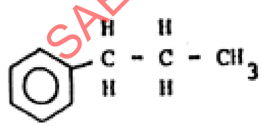
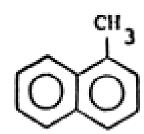
Solvent	Structure	Solvent	Structure
Benzene		Butylbenzene	
Toluene		Cumene	
Xylene	 ortho, meta and para	Indene	
Mesitylene		Indane	
Ethylbenzene		Tetralin	
Propylbenzene		1-Methylnaphthalene	

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Table E7- Aromatic compounds

Aromatic Compound	Fluid Compositions to be Run A	B	C	D
Indene	X	X		X
Phenanthrene (solid)	X			
Benzene	X	X		
Toluene	X	X	X	
Xylene, ortho	X	X		X
Xylene, meta	X	X		
Xylene, para	X	X		
Ethyl Benzene	X	X		
Cumene (Isopropyl Benzene)	X	X		X
1,3,5 Trimethylbenzene (Mesitylene)	X	X		X
Acenaphthene (solid)	X			
Tetralin	X	X		X
Indane				X
Propylbenzene	X			X
Butylbenzene	X			
Xylene bottoms	X	X	X	
2040 Solvent	X	X	X	
1-Methylnaphthalene	X			X

Table E8 - Aromatic test fluids

JP-4 Spec Simulation with Max Aromatic and Max Cycloparaffin	
Cyclohexane	40%
Iso-Octane	35%
Aromatic	25%
Aromatic compound	100%
Cyclohexane	40%
Iso-Octane	45%
Aromatic	15%
Cyclohexane	40%
Iso-Octane	35%
Toluene	20%
Aromatic	5%

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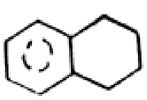
Table E9 - MIL-S-83430

	25% Aromatic				20% Toluene, 5% Aromatic			
Cycloaromatics	Vol. Ch. (Wet)	Wt. Ch.	T.S. Ch.	% E. Ch.	Vol. Ch. (Wet)	Wt. Ch.	T.S. Ch.	% E. Ch.
 Toluene	+12.4	-6.6	+33	-28	+12.4	-6.6	+33	-28
 Indane	+22.2	-6.1	+11	-11	+15.0	-6.3	+19	-21
 Indene	Reverted				Reverted			
 Tetralin	Reverted				+13.3	-6.3	+16	-19

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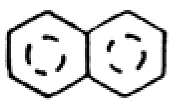
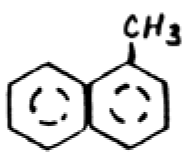
	25% Aromatic			
Naphthalenes	Vol. Ch. (Wet)	Wt. Ch.	T.S. Ch.	% E. Ch.
 Toluene	+12.4	-6.6	+33	-28
 Naphthalene				
 1-Methylnaphthalene	+22.9	-6.3	+15	-26
 Acenaphthene	+35.0	-1.3	+25	+33
2040 Fluid	+16	+7	+17	-26

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Table E10 - MIL-S-83430 (pro seal 899)

Aromatic Compound		Original			After Fluid Immersion						
					Swollen					Dry	
		Hardness	Tensile Strength	% Elongation	Hardness	Tensile Strength	% Elongation	Volume Change	Weight Change	Volume Change	Weight Change
Toluene	100%	49	391	360	72	613	230	+142	+74	-25	-17
	25	49	391	360	66	519	260	+12.4	+5.6	-11.4	-6.6
	5	49	391	360	67	448	300	+8.1	+3.2	-11.6	-6.7
	0	49	391	360	64	458	335	+2.2	+0.1	-10.8	-6.0
Xylene Bottoms	100%	49	391	360	69	530	280	+38	+20	-17.5	-11.0
	25	49	391	360	65	470	300	+10.1	+4.3	-11.3	-6.6
	5	49	391	360	67	490	280	+6.6	+2.5	-11.7	-6.7
	0	49	391	360	64	458	335	+2.2	+0.1	-10.8	-6.0
2040 Fluid	100%	49	391	360	68	470	315	+330	+200	-14.7	-10.9
	25	49	391	360	68	458	265	+15.9	+8.4	-12.2	-7.1
	5	49	391	360	67	489	310	+11.0	+5.4	-11.9	-6.8
	0	49	391	360	64	458	335	+2.2	+0.1	-10.8	-6.0

Table E11 - Effect of aromatics on polysulfide sealants - 100% aromatics

Aromatic Compound	Original			After Fluid Immersion (266 hours at 140 °F)						
				Swollen					Dry	
	Hardness	Tensile Strength	% Elongation	Hardness	Tensile Strength	% Elongation	Volume Change	Weight Change	Volume Change	Weight Change
Pro Seal 899										
None	49	390	360							
Benzene				77	560	140	+600	+200	-26.0	-18.1
Toluene				72	615	230	+140	+74	-25	-17
Xylene, ortho				74	585	205	+95	+50	-21.3	-14.7
Xylene, meta				71	585	220	+44	+22	-17.9	-11.5
Xylene, para				70	580	250	+39	+20	-17.5	-11.0
Ethyl Benzene				73	590	235	+48	+24	-18.1	-11.7
Cumene				70	475	255	+19	+9.35	-16.8	-10.3
1,3,5 Trimethyl Benzene				71	540	255	+20	+10	-14.7	-8.9
1-Methylnaphthalene				63	525	290	+960	+515	-25.4	-18.3
Indane										
n, Propylbenzene										
Xylene Bottoms				69	530	280	+39	+20	-17.5	-11.0
2040 Fluid				-	365	355	+330	+200	-14.7	-10.9
None				64	460	355	+2.2	+0.1	-10.8	-6.0

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Aromatic Compound	Original			After Fluid Immersion (266 hours at 140 °F)						
				Swollen					Dry	
	Hardness	Tensile Strength	% Elongation	Hardness	Tensile Strength	% Elongation	Volume Change	Weight Change	Volume Change	Weight Change
PR 1422										
Benzene	74	465	155	83	735	145	+232	+137	-15.8	-10.0
Toluene				80	650	140	+186	+106	-23	-17
Xylene, ortho				80	595	130	+92	+53	-17.0	-11.3
Xylene, meta				80	640	165	+59	+35	-12.8	-7.5
Xylene, para				80	625	160	+54	+32	-11.6	-6.7
Ethyl Benzene				83	570	120	+52	+29	-20.0	-13.5
Cumene				77	355	75	+19	+10	-21.6	-14.0
1,3,5 Trimethyl Benzene				79	575	185	+28	+17	-10.6	-5.7
1-Methylnaphthalene										
Indane										
n, Propylbenzene										
Xylene Bottoms				76	595	200	+53	+30	-12.6	-7.7
2040 Fluid				76	505	250	+197	+127	-14.9	-10.2
None				77	535	185	+1.7	+0.7	-2.1	-1.2
Pro Seal 890										
Benzene	46	370	415	77	570	120	+655	+245	-30.3	-22.4
Toluene				75	620	220	+130	+66	-28	-20
Xylene, ortho				76	600	190	+84	+42	-23.0	-16.2
Xylene, meta				74	590	215	+39	+19	-18.6	-12.6
Xylene, para				73	560	115	+35	+17	-18.1	-12.3
Ethyl Benzene				73	565	225	+43	+21	-18.8	-12.8
Cumene				70	500	245	+16	+6.5	-17.4	-11.5
1,3,5 Trimethyl Benzene				70	535	245	+17	+7.6	-14.9	-9.7
1-Methylnaphthalene										
Indane										
n, Propylbenzene										
Xylene Bottoms				72	540	255	+34	+16	-18.0	-12.2
2040 Fluid				74	470	260	+337	+200	-26.5	-19.6
None				66	480	300	+3.5	+0.2	-10.0	-5.9

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Table E12 - Effect of aromatics on polysulfides - fluid blend (25% aromatics)

	Original			After Fluid Immersion (266 hours at 140 °F)						
				Swollen					Dry	
Aromatic Compound	Hardness	Tensile Strength	% Elongation	Hardness	Tensile Strength	% Elongation	Volume Change	Weight Change	Volume Change	Weight Change
Pro Seal 899										
Benzene	49	391	360	66	515	250	+14.7	+7.0	-11.8	-6.8
Toluene	49	391	360	66	519	260	+12.4	+5.6	-11.4	-6.6
Xylene, ortho	49	391	360	67	534	270	+11.1	+5.1	-11.6	-6.6
Xylene, meta	49	391	360	66	505	270	+9.5	+4.1	-11.5	-6.7
Xylene, para	49	391	360	66	530	255	+9.3	+4.1	-11.5	-6.6
Ethyl Benzene	49	391	360	65	497	255	+10.1	+4.4	-11.2	-6.5
Cumene	49	391	360	65	497	255	+10.1	+4.4	-11.2	-6.5
1,3,5 Trimethyl Benzene (Mesitylene)	49	391	360	67	518	265	+7.4	+3.0	-11.1	-6.4
Indene	49	391	360	Too soft and sticky to determine						est. +3
Tetralin	49	391	360	Very soft and sticky						est. -5.1
Acenaphthene	49	391	360	56	490	480	+35.0	+22.6	-5.6	-1.3
Phenanthrene	49	391	360							
1-Methylnaphthalene	49	391	360	65	450	265	+22.9	+13.0	-11.2	-6.3
Indane	49	391	360	61	435	320	+22.2	+11.7	-11.3	-6.1
n, Propylbenzene	49	391	360	66	491	270	+8.6	+3.5	-11.9	-6.8
PR-1422										
Benzene	74	464	155	79	575	155	+14.4	+8.2	-6.6	-4.1
Toluene	74	464	155	79	575	145	+10.8	+6.1	-6.2	-3.9
Xylene, ortho	74	464	155	79	593	155	+10.2	+5.7	-6.0	-3.8
Xylene, meta	74	464	155	79	587	155	+8.0	+4.3	-6.1	-4.0
Xylene, para	74	464	155	79	566	145	+8.1	+4.3	-5.9	-3.9
Ethyl Benzene	74	464	155	78	550	160	+8.1	+4.7	-6.1	-3.8
Cumene	74	464	155	76	503	140	+5.0	+2.6	-7.3	-4.5
1,3,5 Trimethyl Benzene	74	464	155	79	575	150	+6.1	+3.4	-5.9	-3.7
Indene	74	464	155	Too soft and sticky to determine						est. +4
Tetralin	74	464	155	Very soft and sticky						est. -3.4
Acenaphthene	74	464	155							
Phenanthrene	74	464	155							
1-Methylnaphthalene	74	464	155	77	560	170	+26.5	+17.3	-5.7	-3.0
Indane	74	464	155	67	216	85	+10.6	+8.3	-8.7	-3.5
Propylbenzene	74	464	155	77	531	140	+7.0	+3.8	-5.6	-3.4

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Table E13 - Effect of aromatics on polysulfide sealants - fluid d: 20% toluene, 5% aromatic

	Original			After Fluid Immersion (266 hours at 140 °F)						
				Swollen					Dry	
Aromatic Compound	Hardness	Tensile Strength	% Elongation	Hardness	Tensile Strength	% Elongation	Volume Change	Weight Change	Volume Change	Weight Change
Pro Seal 899										
Benzene	49	390	360							
Toluene	49	390	360	66	520	260	+12.4	+5.6	-11.4	-6.6
Xylene, ortho	49	390	360	65	480	300	+13.2	+5.8	-10.8	-6.5
Xylene, meta	49	390	360							
Xylene, para	49	390	360							
Ethyl Benzene	49	390	360							
Cumene	49	390	360	66	465	300	+13.1	+5.9	-11.1	-6.6
1,3,5 Trimethyl Benzene	49	390	360	66	460	285	+12.1	+5.3	-11.1	-6.5
1-Methylnaphthalene	49	390	360	66	465	300	+17.4	+8.6	-9.8	-5.6
Indane	49	390	360	67	465	285	+15.0	+7.1	-11.0	-6.3
n, Propylbenzene	49	390	360	66	785	270	+12.6	+5.6	-11.0	-6.5
Xylene Bottoms	49	390	360							
2040 Fluid	49	390	360							
Indene	49	390	360	Reverted						
Tetralin	49	390	360	66	455	290	+13.3	+6.0	-10.8	-6.3

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Table E14 - Effect of aromatics on polysulfides - fluid blend (25% aromatics)

	Original			After Fluid Immersion (266 hours at 140 °F)						
				Swollen					Dry	
Aromatic Compound	Hardness	Tensile Strength	% Elongation	Hardness	Tensile Strength	% Elongation	Volume Change	Weight Change	Volume Change	Weight Change
Pro Seal 899										
Benzene	46	370	415	66	459	260	+17.0	+7.1	-12.5	-8.9
Toluene	46	370	415	66	493	275	+14.8	+5.9	-12.2	-7.7
Xylene, ortho	46	370	415	66	519	265	+13.8	+5.4	-12.4	-7.8
Xylene, meta	46	370	415	65	492	270	+11.8	+4.3	-12.4	-7.8
Xylene, para	46	370	415	65	513	270	+12.2	+4.5	-12.3	-7.7
Ethyl Benzene	46	370	415	66	485	260	+12.6	+4.7	-12.2	-7.7
Cumene	46	370	415	67	484	290	+11.8	+4.3	-12.1	-7.5
1,3,5 Trimethyl Benzene	46	370	415	67	496	250	+10.1	+3.5	-12.1	-7.6
Indene	46	370	415	Reverted – glob on bottom of jar						
Tetralin	46	370	415	Very soft and sticky						est. -1.1
Acenaphthene	46	370	415							
Phenanthrene	46	370	415							
1-Methylnaphthalene	46	370	415	65	470	245	+25.3	+13.4	-11.7	-7.2
Indane	46	370	415							
Propylbenzene	46	370	415							
PR-1422										
Benzene	74	465	155							
Toluene	74	465	155	79	575	145	+10.8	+6.1	-6.2	-3.9
Xylene, ortho	74	465	155	76	520	210	+10.4	+6.0	-6.2	-3.9
Xylene, meta	74	465	155							
Xylene, para	74	465	155							
Ethyl Benzene	74	465	155							
Cumene	74	465	155	75	505	225	+9.6	+5.2	-6.3	-4.2
1,3,5 Trimethyl Benzene	74	465	155	76	560	210	+10.2	+5.9	-5.6	-3.5
1-Methylnaphthalene	74	465	155	76	530	165	+15.6	+9.4	-5.0	-2.9
Indane	74	465	155	73	735	200	+12.0	+7.2	-6.4	-3.5
n, Propylbenzene	74	465	155	76	555	200	+13.1	+7.7	-5.7	-3.3
Xylene Bottoms	74	465	155							
2040 Fluid	74	465	155							
Indene	74	465	155	40	57	260	+37.8	+27.7	+19.0	+10.5
Tetralin	74	465	155	76	520	200	+11.5	+6.5	-5.7	-3.7
Pro Seal 890										
Benzene	46	370	415							
Toluene	46	370	415	66	495	275	+14.8	+5.9	-12.2	-7.7
Xylene, ortho	46	370	415	67	480	290	+12.8	+5.3	-11.6	-7.3
Xylene, meta	46	370	415							

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Aromatic Compound	Original			After Fluid Immersion (266 hours at 140 °F)						
				Swollen					Dry	
	Hardness	Tensile Strength	% Elongation	Hardness	Tensile Strength	% Elongation	Volume Change	Weight Change	Volume Change	Weight Change
Xylene, para	46	370	415							
Ethyl Benzene	46	370	415							
Cumene	46	370	415	67	460	290	+13.9	+5.7	-11.4	-7.2
1,3,5 Trimethyl Benzene	46	370	415	68	500	270	+12.2	+4.8	-11.3	-7.0
1-Methylnaphthalene	46	370	415	68	495	280	+17.5	+7.9	-11.1	-6.9
Indane	46	370	415	67	490	280	+15.5	+6.7	-11.3	-7.0
n, Propylbenzene	46	370	415	67	510	260	+12.5	+4.9	-11.4	-7.2
Xylene Bottoms	46	370	415							
2040 Fluid	46	370	415							
Indene	46	370	415	Reverted						
Tetralin	46	370	415	67	485	300	+13.0	+5.4	-11.4	-7.0

Table E15 - Toluene

Aromatic Content	Original			After Fluid Immersion						
				Swollen					Dry	
	Hardness	Tensile Strength	% Elongation	Hardness	Tensile Strength	% Elongation	Volume Change	Weight Change	Volume Change	Weight Change
Pro Seal 899										
100%	49	391	360	72	613	230	+142	+74	-25	-17
25%	49	391	360	66	519	260	+12.4	+5.6	-11.4	-6.6
15%	49	391	360	67	448	300	+8.1	+3.2	-11.6	-6.7
0%	49	391	360	64	458	335	+2.2	+0.1	-10.8	-6.0
PR-1422										
100%	74	464	155	80	651	140	+186	+106	-23	-17
25%	74	464	155	79	575	145	+10.8	+6.1	-6.2	-3.9
15%	74	464	155	78	577	170	+7.5	+4.1	-5.2	-3.1
0%	74	464	155	77	533	185	+1.7*	+0.7*	-2.1*	-1.2*
Pro Seal 890										
100%	46	370	415	75	618	220	+130	+66	-28	-20
25%	46	370	415	66	493	275	+14.8	+5.9	-12.2	-7.7
15%	46	370	415	67	460	330	+9.7	+3.3	-11.5	-7.0
0%	46	370	415	66	480	300	+3.5*	+0.2*	-10.0*	-5.9*
*Some fluid lost										

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Table E16 - Xylene bottoms

Aromatic Content	Original: Hardness	Original: Tensile Strength	Original: % Elongation	After Fluid Immersion, Swollen: Hardness	Swollen: Tensile Strength	Swollen: % Elongation	Swollen: Volume Change	Swollen: Weight Change	Dry: Volume Change	Dry: Weight Change
Pro Seal 899										
100%	49	391	360	69	530	280	+38.8	+20.0	-17.5	-11.0
25%	49	391	360	65	470	300	+10.1	+4.3	-11.3	-6.6
15%	49	391	360	67	490	280	+6.6	+2.5	-11.7	-6.7
0%	49	391	360	64	458	335	+2.2	+0.1	-10.8	-6.0
PR-1422										
100%	74	464	155	76	597	200	+52.9	+30.3	-12.6	-7.7
25%	74	464	155	78	544	200	+8.6	+5.1	-6.0	-3.3
15%	74	464	155	78	548	190	+6.1	+3.4	-5.7	-3.3
0%	74	464	155	77	533	185	+1.7*	+0.7*	-2.1*	-1.2*
Pro Seal 890										
100%	46	370	415	72	542	255	+34.1	+16.1	-18.0	-12.2
25%	46	370	415	66	449	295	+11.8	+4.2	-11.8	-7.4
15%	46	370	415	67	475	280	+8.4	+2.6	-11.6	-7.2
0%	46	370	415	66	418	300	+3.5	+0.2	-10.0	-5.9
*Some fluid lost										

Table E17 - 2040 fluid

Aromatic Content	Original: Hardness	Original: Tensile Strength	Original: % Elongation	After Fluid Immersion, Swollen: Hardness	Swollen: Tensile Strength	Swollen: % Elongation	Swollen: Volume Change	Swollen: Weight Change	Dry: Volume Change	Dry: Weight Change
Pro Seal 899										
100%	49	391	360	68	470	315	+330.5	+199.7	-14.7	-10.9
25%	49	391	360	68	458	265	+15.9	+8.4	-12.2	-7.1
15%	49	391	360	67	489	310	+11.0	+5.4	-11.9	-6.8
0%	49	391	360	64	458	335	+2.2	+0.1	-10.8	-6.0
PR-1422										
100%	74	464	155	76	507	250	+197.1	+127.4	-14.9	-10.2
25%	74	464	155	79	527	185	+17.5	+11.3	-6.6	-3.4
15%	74	464	155	77	499	165	+11.4	+7.0	-5.3	-3.1
0%	74	464	155	77	533	185	+2.2	+0.1	-10.8	-6.0
Pro Seal 890										
100%	46	370	415	74	471	260	+336.6	+199.9	-26.5	-19.6
25%	46	370	415	68	455	285	+16.5	+8.0	-12.4	-7.8
15%	46	370	415	66	480	300	+12.2	+5.2	-11.7	-7.2
0%	46	370	415	66	418	300	+3.5	+0.2	-10.0	-5.9

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Table E18 - Effect of aromatics on polysulfide sealants

Fluid Immersion	
Fluid	500 cc
Temp	140 °F & 158 °F ± 1.8 °F
Time	266 hours (266 hours ± 0.25 hour)
Specimens	
1 in x 2 in x 0.075 in ± 0.005 in	
4 per jar	
Sealants	
MIL-S-8802 (Type 1)	Chromate cure – RTV for 14 days
MIL-S-8802 (Type 2)	$Mn0_2$ cure – RTV for 14 days
MIL-S-83430	$Mn0_2$ cure – RTV for 14 days
Data	
Volume change	Swollen & dried
Weight change	Swollen & dried
Hardness change (Dry)	
Tensile strength change (Dry)	
Elongation at break change (Dry)	

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Table E19 - Effect of naphthalenes on MIL-S-83430

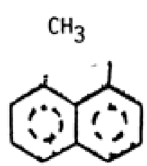
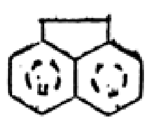
	25% Naphthalene				20% Toluene, 5% Naphthalene			
	Vol. Ch. (Wet)	Wt. Ch.	T.S. Ch.	% E. Ch.	Vol. Ch.	Wt. Ch.	T.S. Ch.	% E. Ch.
 Toluene	+12.4	-6.6	+33	-28	+12.4	-6.6	+33	-28
 Naphthalene	+24.1	-6.6	+22	-22	+21.2	-6.4	+17	-34
 1,Methylnaphthalene	+22.9	-6.3	+15	-26	+17.4	-5.6	+19	-17
 Acenaphthalene	+35.0	-1.3	+25	+33				

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Table E20 - Effect of cycloaromatics on MIL-S-83430

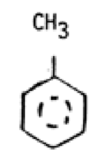
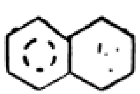
	25% Cycloaromatic				20% Toluene 5% Cycloaromatic				24% Toluene 1% Cycloaromatic			
	Vol. Ch.	Wt. Ch.	T.S. Ch.	% E. Ch.	Vol. Ch.	Wt. Ch.	T.S. Ch.	% E. Ch.	Vol. Ch.	Wt. Ch.	T.S. Ch.	% E. Ch.
 Toluene	+12.4	-6.6	+33	-28	+12.4	-6.6	+33	-28				
 Indane	+22.2	-6.1	+11	-11	+15	-6.3	+19	-21				
 Indene	REVERTED				REVERTED				+17.5	-6.1	+13	-28
 Tetralin	REVERTED				+13.3	-6.3	+16	-19	+26.4	-5.9	+18	-38

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Table E21 - Sealant properties after exposure to aromatic compounds

	Original			After Fluid Immersion						
				Swollen					Dry	
Aromatic Compound	Hardness	Tensile Strength	% Elongation	Hardness	Tensile Strength	% Elongation	Volume Change	Weight Change	Volume Change	Weight Change
Pro Seal 899										
Naphthalene at 25%	57	410	400	72	500	310	+24.1	-13.5	-10.4	-6.6
Naphthalene at 5% with 20% Toluene	57	410	400	72	480	265	+21.2	+10.0	-10.1	-6.4
Indene at 1% with 24% Toluene	57	410	400	72	485	250	+26.4	+12.1	-9.4	-5.9
PR-1422										
Naphthalene at 25% Naphthalene at 5% with 20% Toluene Indene at 1% with 24% Toluene Tetralin at 1% with 24% Toluene	78	515	170	75	485	200	+15.9	+9.6	-3.9	-2.0

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APPENDIX F- EFFECT OF ALKANE AND CYCLOHEXAND FUEL COMPONENTS ON POLYSULFIDE FUEL TANK SEALANTS

Table F1 - Analysis of control fuels

Composition	JP-4 Petroleum (%)	JP-4 Shale (%)	JP-5 Petroleum (%)	JP-8 Petroleum (%)
Paraffins	61.4	45.6	45.4	43.2
Monocycloparaffins	23.6	43.4	38.9	39.9
Dicycloparaffins	5.0	-	2.8	3.7
Alkylbenzenes	8.5	7.4	7.5	7.4
Indanes & Tetralins	1.0	3.6	3.0	3.9
Indenes & Dihydronaphthalenes	-	-	-	-
Naphthalenes	0.5	TRACE	2.4	1.9
Total Paraffins	90.0	89.0	87.1	86.8
Total Aromatics	10.0	11.0	12.9	13.2
Olefins	1.5	1.0	1.7	2.1
Hydrogen (weight %)	14.5	14.3	13.8	13.9
Sulfur:				
Mercaptan (weight %)	0.0004	0.0005	-	0.0004
Total (weight %)	0.03	0.03	-	0.11
Additives (anti-icing)	0.07	0.10	-	0.14

Table F2 - Effect of alkanes/cycloalkanes on polysulfide sealants

<u>Fluid Immersion</u>	
Fluid	500 mL
Temp	140 °F
Time	266 hours
<u>Specimens</u>	
1 in x 2 in x 0.075 in ± 0.005 in	
4 per jar	
<u>Sealants</u>	
MIL-S-8802 (Type 1)	Chromate cure – RTV for 14 days
MIL-S-8802 (Type 2)	MnO_2 cure – RTV for 14 days
MIL-S-83430	MnO_2 cure – RTV for 14 days
<u>Data</u>	
Volume change	Swollen & dried
Weight change	Swollen & dried
Hardness change (Dry)	
Tensile strength change (Dry)	
Elongation at break change (Dry)	

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Table F3 - Test matrix

Test Fluid		A	B	C	D	E
Hexane	C_6	X	X	X		X
Heptane	C_7	X	X			
N – Octane	C_8	X	X			
N – Nonane	C_9	X	X			
N – Decane	C_{10}	X	X	X		X
N – Undecane	C_{11}	X	X			
N – Dodecane	C_{12}	X	X			
N – Hexadecane	C_{16}	X	X	X		X
I – Hexene	C_6	X	X	X		X
I – Octene	C_8	X	X			
Iso-Octane	C_8	X	X	X		X
Cyclohexane	C_6	X	X		X	X
Decalin	C_{10}	X	X		X	X
Methylcyclohexane	C_7	X	X			
JP-4, Petroleum						X
JP-4, Shale						X
JP-5, Petroleum						X
JP-8, Petroleum						X

Table F4 - Fluid blends

Blend A	Iso-Octane	45
	Cyclohexane	45
	Paraffin/Cycloparaffin	10
Blend B	Iso-Octane	35
	Cyclohexane	35
	Toluene	20
	Paraffin/Cycloparaffin	10
Blend C	Cyclohexane	50
	Paraffin	50
Blend D	Iso-Octane	50
	Cycloparaffin	50
Blend E	Paraffin/Cycloparaffin	100

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Table F5 - Property changes

MIL-S-8802 - Chromate Core	Alkane 10%		45 Iso-Octane 45 Cyclohexane	
Alkane	Vol. Ch.	Wt. Ch.	T.S. Ch.	% E. Ch.
c-c-c-c-c-c Hexane	+3.0	-2.0	+9.7	+8.8
c-c-c-c-c-c-c Heptane	+2.7	-1.9	+10.7	+2.9
c-c-c-c-c-c-c-c n-Octane	+2.9	-2.0	+14.6	0
c-c-c-c-c-c-c-c-c n-Nonane	+2.7	-2.1	+15.5	+2.9
c-c-c-c-c-c-c-c-c-c n-Decane	+2.7	-2.0	+12.6	-2.9

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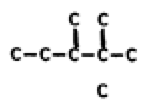
MIL-S-8802 - Chromate Core Alkane	Alkane 10%		45 Iso-Octane 45 Cyclohexane	
	Vol. Ch.	Wt. Ch.	T.S. Ch.	% E. Ch.
 Iso-Octane	+2.6	-2.0	+18.4	+5.9
C=C-C-C-C-C Hexene	+3.0	-2.1	+17.5	-2.9
JP-4, Petroleum	+4.2	-1.9	+5.8	+5.9
JP-4, Shale	+3.0	-2.0	+9.7	+8.8

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MIL-S-8802 – Chromate Core Alkane	Alkane 10%		45 Iso-Octane 45 Cyclohexane	
	Vol. Ch.	Wt. Ch.	T.S. Ch.	% E. Ch.
JP-5, Pet.	+2.9	-1.9	+6.8	+8.8
JP-8, Pet.	+3.0	-2.0	+8.7	+11.8

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Table F6 - Effects of alkane and toluene

MIL-S-83430 Alkane	Alkane 10%				Toluene 20%, Alkane 10%			
	Vol. (Wet)	Wt.	T.S.	% E.	Vol. (Wet)	Wt.	T.S.	% E.
c-c-c-c-c-c Hexane	+5.7	-5.3	+15	-30	+15.3	-6.0	+21	-34
c-c-c-c-c-c-c Heptane	+5.7	-5.3	+20	-33	+14.7	-6.0	+17	-35
c-c-c-c-c-c-c-c n-Octane	+5.4	-5.4	+17	-26	+14.4	-6.0	+20	-33
c-c-c-c-c-c-c-c-c n-Nonane	+5.0	-5.4	+17	-33	+14.5	-6.0	+18	-31
c-c-c-c-c-c-c-c-c-c n-Decane	+4.7	-5.2	+17	-30	+14.2	-5.9	+21	-33

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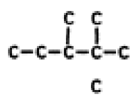
MIL-S-83430 Alkane	Alkane 10% Vol. (Wet)	Alkane 10% Wt.	Alkane 10% T.S.	Alkane 10% % E.	Toluene 20%, Alkane 10% Vol. (Wet)	Toluene 20%, Alkane 10% Wt.	Toluene 20%, Alkane 10% T.S.	Toluene 20%, Alkane 10% % E.
 Iso-Octane	+5.0	-5.3	+17	-30	+14.1	-5.9	+20	-33
C=C-C-C-C-C Hexene	+6.2	-5.4	+20	-31	+15.4	-6.0	+23	-34
JP-4, Pet.	+5.6	-5.1	+18	-28	+5.6	-5.1	+18	-28
JP-4, Shale	+3.3	-5.2	+18	-33	+3.3	-5.2	+18	-33
JP-5, Pet.	+1.6	-5.2	+17	-28	+1.6	-5.2	+17	-28

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MIL-S-83430 Alkane	Alkane 10%				Toluene 20%, Alkane 10%			
	Vol. (Wet)	Wt.	T.S.	% E.	Vol. (Wet)	Wt.	T.S.	% E.
JP-8, Pet.	+1.8	-5.2	+20	-28	+1.8	-5.2	+20	-28

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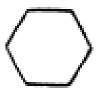
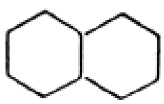
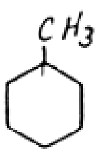
Table F7 - Effects of iso-octane and cyclohexane

	Iso-Octane 45%, Cyclohexane 45%				Iso-Octane 35%, Cyclohexane 35%			
	10% Cycloalkane				20% Toluene, 10% Cycloalkane			
MIL-S-83430 Cycloalkanes	Vol. Ch. (Wet)	Wt. Ch.	T.S. Ch.	% E. Ch.	Vol. Ch. (Wet)	Wt. Ch.	T.S. Ch.	% E. Ch.
 Cyclohexane	+6.3	-5.4	+23	-30	+15.8	-5.9	+26	-30
 Decalin	+7.1	-5.5	+16	-36	+15.8	-6.2	+18	-35
 Methylcyclohexane	+6.5	-5.2	+18	-31	+15.6	-5.8	+21	-33
JP-4, Petroleum	+5.6	-5.1	+18	-28	+5.6	-5.1	+18	-28
JP-4, Shale	+3.3	-5.2	+18	-33	+3.3	-5.2	+18	-33

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MIL-S-83430 Cycloalkanes	Iso-Octane 45%, Cyclohexane 45% 10% Cycloalkane				Iso-Octane 35%, Cyclohexane 35% 20% Toluene, 10% Cycloalkane			
	Vol. Ch. (Wet)	Wt. Ch.	T.S. Ch.	% E. Ch.	Vol. Ch. (Wet)	Wt. Ch.	T.S. Ch.	% E. Ch.
JP-5, Petroleum	+1.6	-5.2	+17	-28	+1.6	-5.2	+17	-28
JP-8, Petroleum	+1.8	-5.2	+20	-28	+1.8	-5.2	+20	-28

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Table F8 - Effects of alkane/cycloalkane

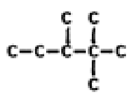
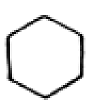
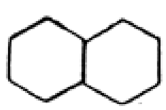
MIL-S-83430 Alkane/Cycloalkane	100% Alkane/Cycloalkane				50% Alkane, 50% Cyclohexane 50% Iso-Octane, 50% Cycloalkane			
	Vol. Ch. (Wet)	Wt. Ch.	T.S. Ch.	% E. Ch.	Vol. Ch. (Wet)	Wt. Ch.	T.S. Ch.	% E. Ch.
c-c-c-c-c-c Hexane	+0.6	-5.1	+21	-29	+12.3	-5.3	+15	-35
 Iso-Octane	-0.5	-4.9	+18	-33	+5.6	-5.3	+17	-34
 Cyclohexane	+14.6	-5.6	+20	-33	+5.6	-5.3	+20	-33
 Decalin					+6.7	-5.7	+12	-36
JP-4, Petroleum	+5.6	-5.1	+18	-28	+5.6	-5.1	+18	-28

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Table F9 - Analysis of control fuels

Composition	JP-4 Petroleum	JP-4 Shale	JP-4 Petroleum	JP-8 Petroleum	JRF
Paraffins	61	46	45	43	10
Cycloparaffins	29	43	42	44	60
Aromatics	10	11	13	13	30
Mercaptan Sulfur	0.0004	0.0005	-	0.0004	0.005
Total Sulfur	0.03	0.03	-	0.11	0.40
Hydrogen	14.5	14.3	13.8	13.9	-

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Table F10 - Effect on polysulfide sealants - mix a
(iso-octane 45, cyclohexane 45, paraffin/cycloparaffin 10)

	Original			After Fluid Immersion						
				Swollen					Dry	
Paraffin/Cycloparaffin	Hardness	Tensile Strength	% Elongation	Hardness	Tensile Strength	% Elongation	Volume Change	Weight Change	Volume Change	Weight Change
PR-1422										
Hexane	78	515	170	78	565	185	+3.0	+1.4	-2.9	-2.0
Heptane	78	515	170	78	570	175	+2.7	+1.3	-3.0	-1.9
n-Octane	78	515	170	78	590	170	+2.9	+1.4	-3.0	-2.0
n-Nonane	78	515	170	78	595	175	+2.7	+1.3	-3.0	-2.0
n-Decane	78	515	170	78	580	165	+2.7	+1.3	-3.0	-2.0
Iso-Octane	78	515	170	78	610	180	+2.6	+1.3	-2.9	-2.0
Hexene	78	515	170	78	605	165	+3.0	+1.5	-3.0	-2.1
Cyclohexane	78	515	170	78	600	155	+3.0	+1.7	-3.1	-2.1
Decalin	78	515	170	79	585	165	+2.9	+1.6	-3.3	-2.3
Methylcyclohexane	78	515	170	78	560	160	+3.0	+1.5	-3.4	-2.1
JP-4, Petroleum	78	515	170	77	545	180	+4.2	+2.5	-3.0	-1.9
JP-4, Shale	78	515	170	79	565	185	+3.0	+1.7	-3.2	-2.0
JP-8	78	515	170	78	560	190	+3.0	+1.8	-2.9	-2.0
JP-5	78	515	170	78	550	185	+2.9	+1.7	-2.7	-1.9
Pro Seal 899										
Hexane	57	410	400	71	470	280	+5.7	+1.2	-8.4	-5.3
Heptane	57	410	400	72	290	270	+5.7	+1.2	-8.3	-5.3
n-Octane	57	410	400	72	480	295	+5.4	+1.0	-8.6	-5.4
n-Nonane	57	410	400	71	480	270	+5.0	+1.0	-8.6	-5.4
n-Decane	57	410	400	72	480	280	+4.7	+0.9	-8.2	-5.2
Iso-Octane	57	410	400	71	480	280	+5.0	+1.0	-8.3	-5.3
Hexene	57	410	400	72	490	275	+6.2	+1.5	-8.5	-5.4
Cyclohexane	57	410	400	72	505	280	+6.3	+1.6	-8.6	-5.4
Decalin	57	410	400	72	475	255	+7.1	+2.0	-8.6	-5.5
Methylcyclohexane	57	410	400	71	485	275	+6.5	+1.7	-8.4	-5.2
JP-4, Petroleum	57	410	400	71	485	290	+5.6	+1.8	-8.2	-5.1
JP-4, Shale	57	410	400	72	485	270	+3.3	+0.7	-8.4	-5.2
JP-8	57	410	400	71	490	290	+1.8	+0.2	-8.3	-5.2
JP-5	57	410	400	70	480	290	+1.6	0	-8.2	-5.2

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Table F11 - Effect on polysulfide sealants (mix b)
(iso-octane 35, cyclohexane 35, toluene 20, paraffin/cycloparaffin 10)

Paraffin/Cycloparaffin	Original			After Fluid Immersion						
				Swollen					Dry	
	Hardness	Tensile Strength	% Elongation	Hardness	Tensile Strength	% Elongation	Volume Change	Weight Change	Volume Change	Weight Change
Pro Seal 899										
Hexane	57	410	400	73	495	265	+15.3	+6.1	-9.5	-6.0
Heptane	57	410	400	73	480	260	+14.7	+5.9	-9.4	-6.0
n-Octane	57	410	400	72	490	270	+14.4	-5.8	-9.6	-6.0
n-Nonane	57	410	400	72	485	275	+14.5	+5.9	-9.5	-6.0
n-Decane	57	410	400	72	495	270	+14.2	+5.7	-9.3	-5.9
Iso-Octane	57	410	400	72	490	270	+14.1	+5.8	-9.3	-5.9
Hexane	57	410	400	72	505	265	+15.4	+6.3	-9.5	-6.0
Cyclohexane	57	410	400	73	518	280	+15.8	+6.6	-9.3	-5.9
Decalin	57	410	400	73	485	260	+15.8	+6.6	-9.7	-6.2
Methylcyclohexane	57	410	400	73	495	270	+15.6	+6.4	-9.3	-5.8
JP-4, Petroleum	57	410	400	71	485	290	+5.6	+1.8	-8.2	-5.1
JP-4, Shale	57	410	400	72	485	270	+3.3	+0.7	-8.4	-5.2
JP-8	57	410	400	71	490	290	+1.8	+0.2	-8.3	-5.2
JP-5	57	410	400	70	480	290	+1.6	0	-8.2	-5.2

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Table F12 - Effect on polysulfide sealants (mix c and d)
(c - cyclohexane 50, paraffin 50; d - iso-octane 50, cycloparaffin 50)

Paraffin/Cycloparaffin	Original Hardness	Original Tensile Strength	Original % Elongation	After Fluid Immersion, Swollen Hardness	Swollen Tensile Strength	Swollen % Elongation	Swollen Volume Change	Swollen Weight Change	Dry Volume Change	Dry Weight Change
Pro Seal 899										
Hexane	57	410	400	72	470	260	+12.3	+4.2	-8.5	-5.3
Heptane										
n-Octane										
n-Nonane										
n-Decane										
Iso-Octane	57	410	400	72	480	265	+5.6	+1.3	-8.4	-5.3
Hexene										
Cyclohexane	57	410	400	72	490	270	+5.6	+1.2	-8.3	-5.3
Decalin	57	410	400	72	460	255	+6.7	+2.2	-9.0	-5.7
JP-4, Petroleum	57	410	400	71	485	290	+5.6	+1.8	-8.2	-5.1
JP-4, Shale	57	410	400	72	485	270	+3.3	+0.7	-8.4	-5.2
JP-8	57	410	400	71	490	290	+1.8	+0.2	-8.3	-5.2
JP-5	57	410	400	70	480	290	+1.6	0	-8.2	-5.2

Table F13 - Effect of polysulfide sealant blend e
pure paraffin/cycloparaffin (100%)

Paraffin/Cycloparaffin	Original Hardness	Original Tensile Strength	Original % Elongation	After Fluid Immersion, Swollen Hardness	Swollen Tensile Strength	Swollen % Elongation	Swollen Volume Change	Swollen Weight Change	Dry Volume Change	Dry Weight Change
Pro Seal 899										
Hexane	57	410	400	72	495	285	+0.6	-1.4	-8.3	-5.1
Heptane										
n-Octane										
n-Nonane										
n-Decane										
Iso-Octane	57	410	400	71	485	270	-0.5	-1.6	-7.8	-4.9
Hexene										
Cyclohexane	57	410	400	72	490	270	+14.6	+5.8	-8.8	-5.6
Decalin										
JP-4, Petroleum	57	410	400	71	485	290	+5.6	+1.8	-8.2	-5.1
JP-4, Shale	57	410	400	72	485	270	+3.3	+0.7	-8.4	-5.2
JP-8	57	410	400	71	490	290	+1.8	+0.2	-8.3	-5.2
JP-5	57	410	400	70	480	490	+1.6	0	-8.2	-5.2

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APPENDIX G - COMPARISON OF JRF-2 AND ORIGINAL JRF
IN 7- AND 14-DAY IMMERSION TEST

Table G1 - New JRF cross test (JRF-2) 7-day immersion test

		Tensile Strength (psi)	% Change	Elongation (%)	% Change	Hardness	% Change	Weight Change Swollen (%)	Weight Change Dried (%)	Volume Change Swollen (%)	Volume Change Dried (%)
PS 890	Control	346	-	258	-	59	-	-	-	-	-
	Aged in JRF	447	29.0	190	-26.4	67	13.6	3.5	-9.1	12.2	-12.3
	Aged in JRF-2	429	24.0	169	-34.5	67	13.6	7.7	-4.1	16.7	-6.9
PS 899	Control	416	-	233	-	59	-	-	-	-	-
	Aged in JRF	426	2.40	220	-5.58	64	8.47	7.8	-5.6	15.7	-10.0
	Aged in JRF-2	440	5.77	221	-5.15	65	10.2	6.2	-5.9	18.5	-6.0
PR-1422	Control	407	-	173	-	70	-	-	-	-	-
	Aged in JRF	530	30.2	133	-23.1	79	12.9	3.4	-8.0	9.5	-11.3
	Aged in JRF-2	512	25.8	150	-13.3	76	8.57	4.0	-7.1	9.6	-10.5

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Table G2 - New JRF cross test (JRF-2)
14-day immersion test

		Tensile Strength (psi)	% Change	Elongation (%)	% Change
PS 890	Control	346	-	258	-
	Aged in JRF	388	12.1	193	-25.2
	Aged in JRF-2	303	-12.4	173	-32.9
PS 899	Control	416	-	233	-
	Aged in JRF	294	-28.8	195	-16.3
	Aged in JRF-2	266	-36.1	165	-29.2
PR-1422	Control	407	-	173	-
	Aged in JRF	324	-20.4	88	-49.1
	Aged in JRF-2	362	-11.6	102	-41.0

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APPENDIX H[6] - TEST REPORT
JRF ROUND ROBIN TEST

Table H1

Property	PR-1422 B-2	PR-890 B-2	PR-899 B-2
7-Day Immersion Test			
7 Days at 140 °F in JRF			
Weight change (swollen)	+7.3%	+7.5%	+9.0%
Volume change (swollen)	+15.7%	+18.7%	+20.9%
Weight change (dried)	-5.5%	-6.2%	-5.3%
Volume change (dried)	-7.4%	-9.5%	-8.2%
Hardness (dried)	67	55	55
Tensile Strength (dried)	450	390	400
Elongation (dried)	280	390	490
7 Days at 140 °F in JRF-2			
Weight change (swollen)	+5.1%	+4.6%	+5.7%
Volume change (swollen)	+10.3%	+13.0%	+14.9%
Weight change (dried)	-4.4%	-5.1%	-4.3%
Volume change (dried)	-5.6%	-6.7%	-6.0%
Hardness (dried)	65	55	55
Tensile Strength (dried)	430	370	380
Elongation (dried)	250	380	460
14-Day Immersion Test			
14 Days at 140 °F in JRF			
Tensile Strength	230	230	220
Elongation	200	290	360
14 Days at 140 °F in JRF-2			
Tensile Strength	290	250	250
Elongation	200	280	340

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[6]From Products Research & Chemical Corp. Research and Development Laboratories, Glendale, CA. 1982.

Table H2

Property Chalking Test at 77 °F Days to slight chalking						
Cu,Cd. ppm	0.3	0.4	0.5	0.6	0.7	1.0
PR-1422						
JRF-2	14	10	10	9	7	7
JRF-2 without tertiary dibutyl disulfide	14	10	8	8	7	7
Pro Seal 890						
JRF-2	11	7	7	3	3	3
JRF-2 without tertiary dibutyl disulfide	11	9	7	4	2	2
Pro Seal 899						
JRF-2	15	14	7	7	7	7
JRF-2 without tertiary dibutyl disulfide	14	11	11	10	7	7

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Table H3 - JRF versus JRF-2: effect on polysulfide sealants

	JRF					JRF-2				
	Shore A Hardness inst./3 s	Tensile Strength psi	Ultimate Elongation %	Δ Weight %	Δ Volume %	Shore A Hardness inst./3 s	Tensile Strength psi	Ultimate Elongation %	Δ Weight %	Δ Volume %
PR-1422 B2-7/80										
As Received	71/68	464	220	-	-	71/68	464	220	-	-
After 14 days at 140 °F	48/46 (-32/32%)	309 (-33%)	210 (-5%)	-	-	55/52 (-23/24%)	334 (-28%)	210 (-5%)	-	-
PR-1422 B2-5/83										
As Received	63/60	355	440	-	-	63/60	355	440	-	-
After 14 days at 140 °F	41/40 (-35/-33%)	235 (-34%)	347 (-21%)	-	-	50/49 (-21/-18%)	317 (-11%)	250 (-43%)	-	-
7 days at 140 °F (Wet)	43/40 (-32/-33%)	-	-	+6.1	+13.7	48/45 (-24/-25%)	-	-	+3.7	+9.5
72 hours at 120 °F (Dry)	68/65 (+8/+8%)	448 (+2.6%)	327 (-26%)	-6.4	-8.3	68/65 (+8/+8%)	457 (+29%)	323 (-27%)	-6.1	-7.8
Pro-Seal 890 B2-7/82										
As Received	55/52	436	377	-	-	55/52	436	377	-	-
After 14 days at 140 °F	40/37 (-27/-29%)	308 (-29%)	290 (-23%)	-	-	39/36 (-29/-31%)	312 (-28%)	343 (-9%)	-	-
Pro-Seal 899 B2-7/82										
As Received	55/52	444	400	-	-	55/52	444	400	-	-
After 14 days at 140 °F	35/33 (-36/-37%)	290 (-35%)	310 (-23%)	-	-	37/35 (-33/-38%)	293 (-34%)	380 (-5%)	-	-

NOTE: The number following the material label indicates the month and year that the material was received. Some discoloration (i.e., chalking) occurred in the Pro-Seal material with a more pronounced effect being exhibited in the 899 material. This whitening (chalking) phenomenon occurred for the most part toward the edges of the specimens in JRF-2 only.

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APPENDIX I - JRF-2 EVALUATION

Two sealants, Chem Seal 3204 B-2 and Goal Chemical 408 B-2, were evaluated according to MIL-S-8820E using the new formulation of Jet Reference Fluid, JRF-2. A comparison of the compositions of JRF and JRF-2 is shown in Table I2.

Testing consisted of:

a. Tensile strength and elongation

b. Weight loss and flexibility

c. Chalking (only test using JRF-2 with metal ions)

d. Resistance to thermal rupture

e. Adhesion and corrosion

f. Peel strength

Results obtained in tests a through e for both sealants are summarized in table I3. Peel strength data for CS 3204 B-2 are shown in Table I4. Peel strengths obtained using GC 408 B-2 are shown in Table I5.

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Table I1 - Jet reference fluid composition (JRF)

	JRF	JRF-2
Toluene (TT-T-548)	30 Volumes	25 Volumes
Cyclohexane (Tech Grade)	60 Volumes	35 Volumes
Iso-Octane (TT-S-735, Type 1)	10 Volumes	40 Volumes
Tertiary Dibutyldisulfide	1 Volume	1 Volume
Tertiary Butyl Mercaptan	0.015 weight % ± 0.0015 weight % of other four components	0.015 weight % ± 0.0015 weight % of other four components
Copper Ions		0.50 ppm by weight
Cadmium Ions		0.50 ppm by weight

Table I2 - MIL-S-8802 sealant compatibility with JRF-2

Sealant	Aging 140 °F (60 °C) in JRF-2	Tensile Strength (psi)	Elongation (%)	Weight Loss (%)	Flexibility	Chalking	Pressure Rupture	Adhesion Corrosion
CS 3204 B-2	Control	355	282				Passed	
	7 days			5.94	Passed		Passed	
	9 days					Slight		
	14 days	298	216					
	20 days							Passed
GC 408 B-2	Control	348	334				Passed	
	7 days			4.2	Passed		Passed	
	9 days					Passed		
	14 days	261	305					
	20 days							Failed

Table I3 - MIL-S-8802 sealant compatibility with JRF-2 peel strength 7 days at 140 °F (60 °C) in JRF-2

		JRF-2		JRF-2		Saltwater	
Sealant	Substrate	Load (lb./in)	Cohesion (%)	Load (lb./in)	Cohesion (%)	Load (lb./in)	Cohesion (%)
CS-3204 B-2	QQ-A-250/13 T6 Aluminum	30.4	100	28.7	100	29.9	95
	Aluminum, MIL-C-5541 Chemical Treated	34.3	100	36.9	100	33.7	100
	Aluminum, MIL-A-8625 Anodized	32.0	100	32.3	100	40.0	100
	MIL-S-5059, Stainless Steel	22.6	100	21.3	90	29.8	90
	MIL-T-9046, Titanium	28.7	100	20.2	50	10.1	10
	MIL-C-27725	0	0	31.7	85[1]	35.9	100[2]
	MIL-C-27725, Plus PR-148	30.1	100	35.6	100	32.7	100
	MIL-P-23377, Standard Cure	48.8	100[2]			47.9	100
	MIL-P-23377	34.7	100[2]			49.7	100

[1]Sealant fell off two panels.
[2]Distilled water immersion.

Table I4 - MIL-S-8802 sealant compatibility with JRF-2 peel strength 7 days at 140 °F (60 °C) in JRF-2

		JRF-2		JRF-2		Saltwater	
Sealant	Substrate	Load (lb./in)	Cohesion (%)	Load (lb./in)	Cohesion (%)	Load (lb./in)	Cohesion (%)
GC-408 B-2	QQ-A-250/13 T6, Aluminum	0	0	0	0	0	0
	MIL-C-5541, Aluminum	29.5	100	35.5	100	41.8	100
	MIL-A-8625, Aluminum	31.2	100	32.4	100	40.7	100
	MIL-S-5059, Stainless Steel	33.6	100	13.0	30	15.5	30
	MIL-T-9046, Titanium	31.4	100	39.2	100	49.4	100
	MIL-C-27725	0	0	0	0	0	0
	MIL-C-27725, Plus PR-148	31.4	100	37.8	100	49.8	100
	MIL-P-23377, Standard Cure	57.6	100[1]			64.7	100
	MIL-P-23377, 200 °F Cure	61.0	100[1]			63.8	100

[1]Distilled water immersion.

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APPENDIX J - JRF-3-1 SHORT-TERM EVALUATION

Table J1 - Adhesives

Material Description	Test	Conditioning	Pass/Fail Criteria	Results	Change
FM 47 (Vinyl Phenolic)	Lap Shear	Unaged 28d/200 °F/JP-8 (POSF 4751) 28d/200 °F/JRF-3-1	N/A >1500 psi >1500 psi	3755 psi 3509 psi 3300 psi	N/A -7% -12%
Epon 828/DTA (Epoxy)	Lap Shear	Unaged 28d/200 °F/JP-8 (POSF 4751) 28d/200 °F/JRF-3-1	N/A >1500 psi >1500 psi	4294 psi 3566 psi # 3123 psi #	N/A -17% -27%
Scotchweld AF-10 (Nitrile Phenolic)	Lap Shear	Unaged 28d/200 °F/JP-8 (POSF 4751) 28d/200 °F/JRF-3-1	N/A >1500 psi >1500 psi	3132 psi 2900 psi # 2544 psi	N/A -7% -19%
Loctite 609 (Methacrylate)	Static Shear	Unaged 28d/200 °F/JP-8 (POSF 4751) 28d/200 °F/JRF-3-1	N/A >1500 psi >1500 psi	2474 psi 2281 psi 2440 psi	N/A -8% -1%
Loctite 495 (Cyanoacrylate)	Static Shear	Unaged 28d/200 °F/JP-8 (POSF 4751) 28d/200 °F/JRF-3-1	N/A >1500 psi >1500 psi	2199 psi 1474 psi 903 psi #	N/A -33% -59%

= retested results

Table J2 - Bladder tanks

Material Description	Test	Conditioning	Pass/Fail Criteria	Results	Change
EF 51956 (Nitrile)	Tensile Strength/ Elongation	Unaged 28d/160 °F/JP-8 (POSF 4751) 28d/160 °F/JRF-3-1	N/A >1500%/>300% >1500%/>300%	2441 psi/568% 2222 psi/345% 1912 psi/354%	N/A -9%/-39% -22%/-38%
	Volume Swell	Unaged 28d/160 °F/JP-8 (POSF 4751) 28d/160 °F/JRF-3-1	N/A <25% <25%	N/A -4.7% 8.4%	N/A N/A N/A

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EF 5904C (Polyurethane)	Tensile Strength/ Elongation	Unaged 28d/200 °F/JP-8 (POSF 4751) 28d/200 °F/JRF-3-1	N/A >1500%/>300% >1500%/>300%	3292 psi/449% 2607 psi/490% 2640 psi/594%	N/A -21%/+9% -20%/+32%
	Volume Swell	Unaged 28d/200 °F/JP-8 (POSF 4751) 28d/200 °F/JRF-3-1	N/A <25% <25%	N/A 23.2% 40.7%	N/A N/A N/A

Table J3 - Coatings

Material Description	Test	Conditioning	Pass/Fail Criteria	Results	Change
MIL-S-4383 (EC 776) (Nitrile)	Pencil Hardness	Unaged 28d/200 °F/JP-8 (POSF 4751) 28d/200 °F/JRF-3-1	>3B >3B >3B	2H 2B # 4B #	N/A -5 -7
	Tape Adhesion	Unaged 28d/200 °F/JP-8 (POSF 4751) 28d/200 °F/JRF-3-1	Passed Passed Passed	Passed Passed Passed	N/A 0% 0%
MIL-C-27725 (Polyurethane)	Pencil Hardness	Unaged 28d/200 °F/JP-8 (POSF 4751) 28d/200 °F/JRF-3-1	>6H >6H >6H	>6H >6H >6H	N/A +0 +0
	Tape Adhesion	Unaged 28d/200 °F/JP-8 (POSF 4751) 28d/200 °F/JRF-3-1	Passed Passed Passed	Passed Passed Passed	N/A 0% 0%
BMS 10-20 (Epoxy)	Pencil Hardness	Unaged 28d/200 °F/JP-8 (POSF 4751) 28d/200 °F/JRF-3-1	>6H >6H >6H	>6H >6H >6H	N/A +0 +0
	Tape Adhesion	Unaged 28d/200 °F/JP-8 (POSF 4751) 28d/200 °F/JRF-3-1	Passed Passed Passed	Passed Passed Passed	N/A 0% 0%

6B – 5B – 4B – 3B – 2B – B – HB – F- H – 2H – 3H – 4H – 5H – 6H
Softer Harder

- retested results

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Table J3 - Coatings (continued)

Material Description	Test	Conditioning	Pass/Fail Criteria	Results	Change
BMS 10-39 (Epoxy)	Pencil Hardness	Unaged	>6H	>6H	N/A
		28d/200 °F/JP-8 (POSF 4751)	>6H	>6H	+0
		28d/200 °F/JRF-3-1	>6H	>6H #	+0
	Tape Adhesion	Unaged	Passed	Passed	N/A
		28d/200 °F/JP-8 (POSF 4751)	Passed	Passed	0%
		28d/200 °F/JRF-3-1	Passed	Passed #	0%
MIL-P-24441 (Epoxy Polyamide)	Pencil Hardness	Unaged	>6H	>6H	N/A
		28d/120 °F/JP-8 (POSF 4751)	>6H	>6H	+0
		28d/120 °F/JRF-3-1	>6H	4H #	-2
	Tape Adhesion	Unaged	Passed	Passed	N/A
		28d/120 °F/JP-8 (POSF 4751)	Passed	Passed	0%
		28d/120 °F/JRF-3-1	Passed	Passed	0%
	Taber Test [1] (Wear Index)	Unaged	<0.090 [2]	0.085 [2]	N/A
		28d/120 °F/JP-8 (POSF 4751)	<0.090 [2]	0.15	+.065
		28d/120 °F/JRF-3-1	<0.090 [2]	0.13	+.045

6B – 5B – 4B – 3B – 2B – B – HB – F- H – 2H – 3H – 4H – 5H – 6H
SofterHarder

1 = 1000 gm weights and CS-17 abrasive wheels used; wear index is relative measure of material weight loss per cycle.
2 = unknown what standards were used for this result.

= retested results

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Table J4 - Sealants

Material Description	Test	Conditioning	Pass/Fail Criteria	Results	Change
PR-1422 B-2 (MIL-S-8802) (Polysulfide)	Tensile Strength/ Elongation	Unaged	>200 psi/150%	518 psi/507%	N/A
		28d/200 °F/JP-8 (POSF 4751)	>200 psi/150%	406 psi/347%	-22%/-32%
		28d/200 °F/JRF-3-1	>200 psi/150%	264 psi/269%	-49%/-47%
	Volume Swell	Unaged	<8%	N/A	N/A
		28d/200 °F/JP-8 (POSF 4751)	<8%	4.0%	N/A
		28d/200 °F/JRF-3-1	<8%	7.5% #	N/A
	Shore A Hardness	Unaged	>35	62	N/A
		28d/200 °F/JP-8 (POSF 4751)	>35	62	+0
		28d/200 °F/JRF-3-1	>35	45 #	-17
	Peel Strength (MIL-PRF-27725)	Unaged	>20 lb/100%	36 lb/100%[1]	N/A
		28d/200 °F/JP-8 (POSF 4751)	>20 lb/100%	40 lb/100%	+4 lb
		28d/200 °F/JRF-3-1	>20 lb/100%	42 lb/100%	+6 lb

1 = Data taken from *Small Particulate Emission Control Fuel Additives Materials Compatibility Study,* UDR-TR-2005-00181 (Sept, 2005).
# - retested results

Table J4 - Sealants (continued)

Material Description	Test	Conditioning	Pass/Fail Criteria	Results	Change
PR-1440 B-2 (MIL-S-8802) (Polysulfide)	Tensile Strength/ Elongation	Unaged	>200 psi/150%	395 psi/271%	N/A
		28d/200 °F/JP-8 (POSF 4751)	>200 psi/150%	415 psi/195%	+5%/-28%
		28d/200 °F/JRF-3-1	>200 psi/150%	349 psi/265%	-12%/-2%
	Volume Swell	Unaged	<8%	N/A	N/A
		28d/200 °F/JP-8 (POSF 4751)	<8%	-2.1%	N/A
		28d/200 °F/JRF-3-1	<8%	1.9%	N/A
	Shore A Hardness	Unaged	>35	62	N/A
		28d/200 °F/JP-8 (POSF 4751)	>35	56	-6
		28d/200 °F/JRF-3-1	>35	49	-13
	Peel Strength (MIL-PRF-27725)	Unaged	>20 lb/100%	52 lb/100%[1]	N/A
		28d/200 °F/JP-8 (POSF 4751)	>20 lb/100%	44 lb/100%	-8 lb
		28d/200 °F/JRF-3-1	>20 lb/100%	44 lb/100%	-8 lb

1 = Data taken from *Small Particulate Emission Control Fuel Additives Materials Compatibility Study,* UDR-TR-2005-00181 (Sept, 2005).

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Table J4 - Sealants (continued)

Material Description	Test	Conditioning	Pass/Fail Criteria	Results	Change
Q4-2817/1200 Primer	Tensile Strength/ Elongation	Unaged 28d/200 °F/JP-8 (POSF 4751) 28d/200 °F/JRF-3-1	>200 psi/150% >200 psi/150% >200 psi/150%	643 psi/355% 394 psi/173% 213 psi/182% #	N/A -39%/-51% -67%/-49%
	Volume Swell	Unaged 28d/200 °F/JP-8 (POSF 4751) 28d/200 °F/JRF-3-1	<8% <8% <8%	N/A 1.1% 0.4%	N/A N/A N/A
	Shore A Hardness	Unaged 28d/200 °F/JP-8 (POSF 4751) 28d/200 °F/JRF-3-1	>35 >35 >35	45 40 45	N/A -5 +0
	Peel Strength (MIL-PRF-27725)	Unaged 28d/200 °F/JP-8 (POSF 4751) 28d/200 °F/JRF-3-1	>10 lb/100% >10 lb/100% >10 lb/100%	14 lb/100%[1] 11 lb/100% 24 lb/100%	N/A -3 +10

1 = Data taken from *Small Particulate Emission Control Fuel Additives Materials Compatibility Study,* UDR-TR-2005-00181 (Sept, 2005).

= retested results

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Table J4 - Sealants (continued)

Material Description	Test	Conditioning	Pass/Fail Criteria	Results	Change
PR-2911 (Polythioether/ Polyurethane)	Tensile Strength/ Elongation	Unaged 28d/200 °F/JP-8 (POSF 4751) 28d/200 °F/JRF-3-1	>200 psi/150% >200 psi/150% >200 psi/150%	451 psi/863% 654 psi/615% # 260 psi/220% #	N/A +45%/-29% -42%/-75%
	Volume Swell	Unaged 28d/200 °F/JP-8 (POSF 4751) 28d/200 °F/JRF-3-1	<8% <8% <8%	N/A 13.9% 18.5% #	N/A N/A N/A
	Shore A Hardness	Unaged 28d/200 °F/JP-8 (POSF 4751) 28d/200 °F/JRF-3-1	>35 >35 >35	67 52 # 51	N/A -15 -16
	Peel Strength (MIL-PRF-27725)	Unaged 28d/200 °F/JP-8 (POSF 4751) 28d/200 °F/JRF-3-1	>20 lb/100% >20 lb/100% >20 lb/100%	27 lb/100%[1] 25 lb/28% 30 lb/100%	N/A -2 lb +3 lb

1 = Data taken from *Small Particulate Emission Control Fuel Additives Materials Compatibility Study*, UDR-TR-2005-00181 (Sept, 2005).

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Table J4 - Sealants (continued)

Material Description	Test	Conditioning	Pass/Fail Criteria	Results	Change
PR-1828 B-2 (Polythioether)	Tensile Strength/ Elongation	Unaged	>200 psi/150%	338 psi/323%	N/A
		28d/200 °F/JP-8 (POSF 4751)	>200 psi/150%	335 psi/178%	-1%/-45%
		28d/200 °F/JRF-3-1	>200 psi/150%	239 psi/180%	-29%/-44%
	Volume Swell	Unaged	<8%	N/A	N/A
		28d/200 °F/JP-8 (POSF 4751)	<8%	7.3%	N/A
		28d/200 °F/JRF-3-1	<8%	11.7%	N/A
	Shore A Hardness	Unaged	>35	48	N/A
		28d/200 °F/JP-8 (POSF 4751)	>35	42	-6
		28d/200 °F/JRF-3-1	>35	31 #	-17
	Peel Strength (MIL-PRF-27725)	Unaged	>20 lb/100%	58 lb/100%[1]	N/A
		28d/200 °F/JP-8 (POSF 4751)	>20 lb/100%	38 lb/100%	-20 lb
		28d/200 °F/JRF-3-1	>20 lb/100%	29 lb/100%	-29 lb

1 = Data taken from *Small Particulate Emission Control Fuel Additives Materials Compatibility Study,* UDR-TR-2005-00181 (Sept, 2005).

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Table J4 - Sealants (continued)

Material Description	Test	Conditioning	Pass/Fail Criteria	Results	Change
PR-1776 B-1/2 (AMS3281) (Polysulfide)	Tensile Strength/ Elongation	Unaged 28d/200 °F/JP-8 (POSF 4751) 28d/200 °F/JRF-3-1	>200 psi/150% >200 psi/150% >200 psi/150%	266 psi/596% 257 psi/258% 127 psi/280% #	N/A -3%/-57% -54%/-50%
	Volume Swell	Unaged 28d/200 °F/JP-8 (POSF 4751) 28d/200 °F/JRF-3-1	<8% <8% <8%	N/A -4.4% 8.9% #	N/A N/A N/A
	Shore A Hardness	Unaged 28d/200 °F/JP-8 (POSF 4751) 28d/200 °F/JRF-3-1	>35 >35 >35	38 43 30 #	N/A +5 -10
	Peel Strength (MIL-PRF-27725)	Unaged 28d/200 °F/JP-8 (POSF 4751) 28d/200 °F/JRF-3-1	>20 lb/100% >20 lb/100% >20 lb/100%	36 lb/100%[1] 30 lb/100% 37 lb/100%	N/A -6 lb +1 lb

1 = Data taken from *Small Particulate Emission Control Fuel Additives Materials Compatibility Study*, UDR-TR-2005-00181 (Sept, 2005).

= retested results

Table J5 - Composites

Material Description	Test	Conditioning	Pass/Fail Criteria	Results	Change
AS 4/3501-6 (Graphite/Epoxy)	Interlaminar Shear	Unaged 28d/200 °F/JP-8 (POSF 4751) 28d/200 °F/JRF-3-1	N/A >5000 psi >5000 psi	11141 psi 6867 psi 7227 psi	N/A -38% -35%
IM 7/5250-4 (Graphite/ Bismaleimide)	Interlaminar Shear	Unaged 28d/200 °F/JP-8 (POSF 4751) 28d/200 °F/JRF-3-1	N/A >5000 psi >5000 psi	12330 psi 10480 psi # 11170 psi	N/A -15% -9%

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Table J6 - Foam

Material Description	Test	Conditioning	Pass/Fail Criteria	Results	Change
MIL-F-87260 (conductive) Foamex Type VI (Polyurethane)	Tensile Strength/ Elongation	Unaged 28d/200 °F/JP-8 (POSF 4751) 28d/200 °F/JRF-3-1	N/A 10 psi/100% 10 psi/100%	15 psi/118% 10 psi/134% 10 psi/135%	N/A -33%/+14% -33%/+14%
	Resistivity	Unaged 28d/200 °F/JP-8 (POSF 4751) 28d/200 °F/JRF-3-1	<1.0E+12 <1.0E+12 <1.0E+12	1.3E+11 2.5E+10 2.6E+10	N/A N/A N/A

Table J7 - O-rings

Material Description	Test	Conditioning	Pass/Fail Criteria	Results	Change
Parker N-602 (MIL-P-5315) (Nitrile)	Tensile Strength/ Elongation	Unaged 28d/160 °F/JP-8 (POSF 4751) 28d/160 °F/JRF-3-1	>1000 psi/>200% >1000 psi/>200% >1000 psi/>200%	1783 psi/309% 1233 psi/251% 1168 psi/259%	N/A -31%/-19% -34%/-16%
	Volume Swell	Unaged 28d/160 °F/JP-8 (POSF 4751) 28d/160 °F/JRF-3-1	N/A 0 to 25% 0 to 25%	N/A 15.5% 26.4%	N/A N/A +10.9%
	Shore M Hardness	Unaged 28d/160 °F/JP-8 (POSF 4751) 28d/160 °F/JRF-3-1	70 pts ± 5 pts ±5 pts ±5 pts	68 69 61 #	N/A +1 -7
	Compression Set	Unaged 28d/160 °F/JP-8 (POSF 4751) 28d/160 °F/JRF-3-1	N/A <50% <50%	N/A 25.7% 17.1%	N/A N/A N/A

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