V. QUALIFICATION PROCEDURES FOR ENGINE AND FUEL SYSTEM COMPONENTS

In the previous chapter the engine and fuel-system components were discussed relative to their interface with the fuel, i.e., materials compatibility which was further reduced to elastomer compatibility. Buna N was found in numerous applications most of which were static seals, but a few included dynamic seals and disphragms where increased swelling could cause problems in performance or durability.

Although Buna N can be affected by aromatics depending on the composition of the elastomer, it is the specific application that determines the suitability, depending on temperatures, pressures, design, etc. The military uses standard qualification procedures for all engines, fuel system hardware, and elastomeric materials to ensure compatibility with fuels with the application and utilization of the components. For the discussion here the important military specifications are:

MIL-E-8593A	Engines, Aircraft, Turboshaft and Turboprop General Specification for (15 Oct 1975)
MIL-F-8615D	Fuel System Components, General Specification for (29 March 1976)
MIL-H-7061A	Hose, Rubber: Aircraft, Self-Sealing, Aromatic Type (6 June 1968)
MIL-T-5578C	Tank, Fuel, Aircraft, Self-Sealing (1 March 1974)
MIL-T-6396D	Tanks, Fuel, Oil, Water-Alcohol, Coolant, Fluid, Aircraft, Nonself-sealing, Removable Internal (30 August 1974)
MIL-P-5315B	Packing, Preformed, Hydrocarbon Fuel Resistant (2 December 1964)
MIL-R-6855	Rubber, Synthetic, Sheets, Strips, Molded For Extruded Shapes (8 September 1977)

MIL-R-25988	Rubber, Fluorosilicone Elastomers, Oil- and Fuel-Resistant, Sheets, Strips, Molded Parts, and Extruded Parts (4 June 1975)
MIL-R-83248	Rubber, Fluorocarbon Elastomers, High Temperature, Fluid and Compressor Set Resistant (15 January)
TT-S-735	Standard Test Fluids; Hydrocarbon (11 March 1964)

These specifications along with other documents itemized in them control the qualification/certification procedures for all the engines, fuel system components, fuel cells, hoses, and elastomeric seals used in the Army aircraft.

A. Engine Qualification

The qualification procedures for turboshaft and turboprop engines stress a variety of operational and environmental problem areas such as the performance of hydraulic, lubrication, and control systems; endurance of rotating and hot sections; and temperatures and vibrations. Most of these areas have little or no interface with the fuel. The requirements which are directly related are component tests for the fuel pump and fuel control, the low- and high-temperature starting tests, and the alternate and emergency fuel tests. Also, minimum performance requirements are established for the engine fuel system in terms of fuel temperatures, viscosities, and vapor/liquid ratios. Fuel contamination is also addressed in the specification but is not really pertinant to this discussion as that is a fuel handling problem totally independent of the fuel properties with which this study is concerned.

For reference, the primary, alternate, and emergency fuels are defined in section 3.7.3.2 of the engine specification as follows:

Primary Fuel. "The engine shall function satisfactorily throughout its environmental conditions and operating envelope for all steady-state and transient operation conditions when using fuel conforming to and having any of the variations in characteristics permitted by MIL-T-5624 of the grades specified in the engine specification."

Alternate Fuel. "When required by the Using Service, the engine shall also start and operate using the alternate fuels specified. The operating limits, power outputs and power transients specified in the engine specification shall not be adversely affected when using alternate fuel. The effects on the engine performance characteristics, changes in SFC, changes in starting and stopping time, and effects on the aircraft missions when using alternate fuels shall be specified. There shall be no effect on the established time between overhaul for the engine from that specified in 3.2.4.2. Only those external adjustments permitted in 3.7.2.3.1.1 shall be allowed in order to meet this requirement. The engine shall function satisfactorily with the alternate fuels specified containing anti-icing additive conforming to MIL-I-27686 and added in a concentration up to 0.15 percent by volume."

Emergency Fuel. "When required by the Using Service, the engine shall also start and operate using the emergency fuels specified. The engine shall function satisfactorily for a time period of at least 6 hours from sea level to 10 km altitude, at least throughout a range from idle to 90 percent of maximum power, at no greater than 120 percent of the specification rated or estimated specific fuel consumption when using fuels conforming to MIL-G-5572, MIL-G-3056, and VV-G-1690. Only the external control adjustments permitted in 3.7.2.3.1.1 will be allowed to meet this requirement. If applicable, operating limitations, special inspections or maintenance actions required as a result of using this fuel shall be specified."

The main differences are that an "alternate fuel" shall not adversely affect the operating limits, the power outputs, the power transients, and the overhaul time; "emergency fuels" are allowed to cause performance and power degradations within specified limits. Since the Army does not specify emergency fuels for its aircraft turbine engines, they will not be further addressed here.

Several requirements are placed on the fuel system to establish minimum performance criteria under temperature and pressure extremes. At low temperature this means the system must operate with fuels of higher viscosity and lower vapor pressure than on a standard day; typical problems would be engine starting and control. At high temperatures, the system must be able to accomodate high vapor pressures and hence high vapor/liquid ratios; problems in priming pumps and fuel control are typical.

The fuel pump and fuel control systems have specific qualification tests. Other engine fuel system components are addressed in more general terms. "Accelerated aging" and "high temperature" tests are specified for fuel compatibility of all components containing non-metallic parts. They are first dried and placed in an oven at 71°C (160°F) for 168 hours. The components are then subjected to a 100-hour or 600-cycle test (whichever is longer) during which the ambient temperature is cycled between 71°C and the maximum temperature for the component. The fuel used is the specified primary fuel doped with toluene to give an aromatics content of at least 25%, representing the most detrimental fuel allowed by the fuel specification.

Other testing is done at low and room temperatures, but these are for elastomer performance and fuel contamination respectively and do not stress fuel compatibility.

For overall engine performance and compatibility, a 60-hour cycle test run is made on each of the alternate fuels specified in the engine specification. "The test is considered satisfactory when, in the judgement of the Using Service, engine performance meets the requirements specified...and the results of the hot section inspection do not reveal abnormal hot section distress."

B. Fuel System Component Qualification

The discussion here will focus only on the fuel compatibility requirements of the pertinent specifications. To begin with, the standard hydrocarbon test fluids used in the qualification tests are defined in TT-S-735. Four test fluids for fuel systems are defined and have the following composition:

Ingredient Material	Volume%			
	Type I	Type II	Type III	Type VII
Iso-octane	100	60	70	10
Benzene	0	5	0	0
Toluene	0	20	30	30
Xylene	0	15	0	0
Cyclohexane	0	0	0	59
Butyl disulfide (tertiary)				1
Total Aromatics	0	40	30	30

Types I and III are the two test fluids most commonly required for fuel resistance and aging qualification tests. They represent extremes of aromatic content, 0 and 30%. (Note: the fuel specifications for JP-4, JP-5, and JP-8 allow maximums of 25% aromatics while Jet-A allows only 20%.) Furthermore, the aromatics used, i.e., toluene, have a low molecular weight representing about the lowest weight aromatics of JP-4 type fuels and much lower than the aromatics found in JP-5. Recalling from Figure 8 on page 30 that the lower weight aromatics have a higher solvent activity and that the aromatics found in JP-5 have relatively low solvent compared to JP-4, it is concluded that the Type III test fluid is a conservative test fluid for fuel compatibility.

Type II fluid is required in the fuel resistance, aging, and gunfire tests for the self-sealing hoses along with Type I fluid. Here an even more extreme case of 0 and 40% aromatics are used. (The reasoning for the use of the Type II fluid was not determined in this study.)

The Type VII fluid is used primarily as a qualifying fluid for the polysulfide sealants used in wet-wing fuel tanks, none of which are found on Army aircraft.

Figure 17 shows the effects of aging time on six major properties of O-rings; the materials are two nitrile rubbers of different fuel resistance, and two aromatic levels are shown. The conclusion from this data is that in every case with the exception of "hardness," all of the changes stabilized in less than two days regardless of aromatic content. Table 14 reproduces the "Temperature Classifications" and "Soak Period/ Test Fluid" requirements from MIL-F-8615D, to general specification for fuel system components. Alternating soak and dry periods are very determental to elastomers. The first high temperature soak period is 96 hours or four days which according to the data of Figure 17 should be sufficient to stabilize the degradation. The components are also required to pass an endurance test simulating the operating consitions of the component for its design operational life between overhauls; at least 20% of this test must be at the high temperature and using the test fluid in accordance with the classifications shown in Table 14. It is the concerted opinion of design and test engineers from component

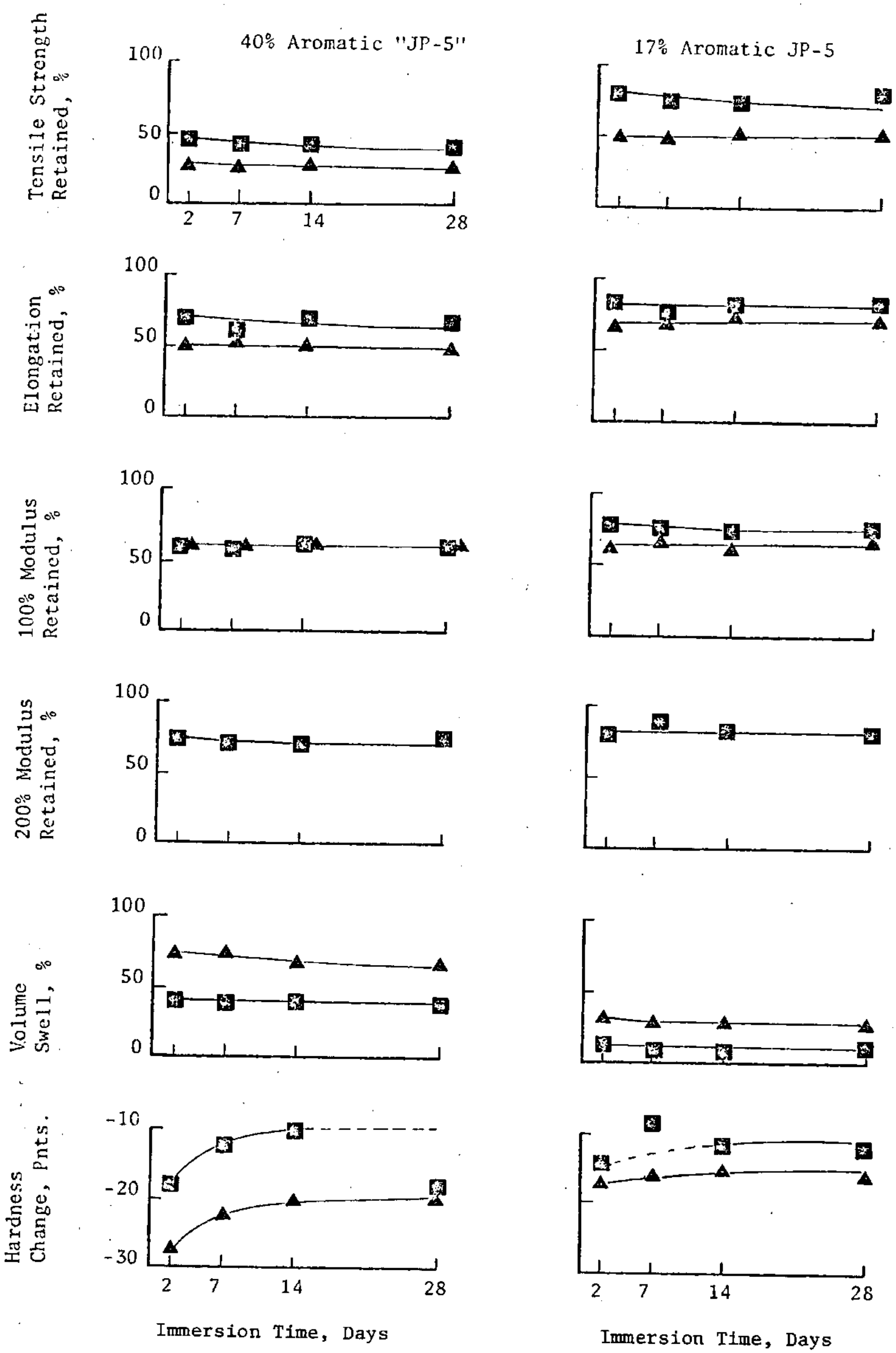

FIGURE 17. EFFECT OF IMMERSION TIME IN PHYSICAL PROPERTIES OF HIGH (▲) AND LOW (■) ACRILONITRILE RUBBERS (BUNA N)

Table 14. Temperature Classifications and Soak Tests for Fuel System Component Qualification

Temperature classification.

Class	High Temperature °C			Low Temperature Fuel and Air °C
	T	T_t	T_a	
A	60°C ±3	75°C ±5	75°C ±5	-57°C ±4
B	95°C ±5	115°C ±5	175°C ±5	-57°C ±4
C	150°C ±5	180°C ±7	315°C ±10	-57°C ±4

T - High operational fuel temparature

T_t - High fuel test temperature

T_a - High ambient temperature

TEST FLUIDS AND SOAK PERIODS

Test Period	Phase I		Phase II		Phase III
	Soak	Dry	Soak	Dry	Soak
Ambient and fluid test temperature (Table I)	T_t	T_a	T_t	T_a	-57° ±4°C
Test Fluid During Soak					
Class A	Type III		Type III		Type I
Class B	Type III		Type III		Type I
Class C	JP-5		JP-5		Type I
Period Duration	96 hours minimum	24 hours	18 hours minimum	30 hours	18 hours minimum
Test fluids to be used for tests immediately after period	Type III	Type I	Type III	Type I	Type I

manufacturers that from their experience most elastomer degradation occurs in less than 50 hours and that any fuel/elastomer incompatibilities will show up in the test life of the qualification tests.

In summary it is felt by component design and test engineers that the components tests for fuel compatibility are not accelerated tests and hence that their components are, in fact, compatible with the 30% toluene test fluid and therefore 30% aromatic fuels.

VI. SUMMARY

There are no significant pressures to change the JP-4 fuel specifications especially in the areas of hydrogen content, aromatics, and boiling point distribution. Futhermore the Air Force projects that JP-4 derived from shale oil should meet the current JP-4 fuel specification, and the hydrogen content may be higher than the average JP-4 today; however, there may be a problem with aromatic contents that are too low. The "alternative fuels" JP-5, JP-8, and Jet-A have the obvious difference of reduced volatility and higher viscosity; JP-5 is seen as generally a worst case because of its higher flash point requirement and historically higher viscosity. There are pressures to increase the aromatic limit on JP-5 to improve availability in some marketing areas. End point increases also improve availability if the higher freeze point could be accepted; this could also lead to a higher viscosity. No differences are seen in thermal stability. Lubricity could be a problem that will have to be solved by additives.

If low aromatic concentrations prove to be a problem the Air Force, which controls the JP-4 specification, will also experience difficulties and will undoubtedly establish a minimum aromatic content in the specification. The potentially higher aromatics in JP-5 are not seen as a problem to Army systems. The higher molecular weight makes them less detrimental to elastomers than the aromatics found in JP-4; futhermore, the higher limit would have to be compatible with Navy aircraft which have components and elastomer systems similar to Army systems.

Projections were made on the impact of reduced hydrogen content fuels on the relative low-cycle-fatigue life of the combustors. The T700 combustor was seen as the least affected by reduced hydrogen content. The results could be improved by using actual mission profiles.

The higher viscosity and lower volatility of the alternative fuels will affect the cold start capabilities but the problems will not be any different than is being experienced today. Combustor tests to determine the sensitivities to volatility and viscosity of various combustors are desirable; T63 tests are currently planned for FY82 and T700 tests are being considered.

With the exception of some recent field problems with the T700 engine, no current maintenance problems were found that were related to fuel properties nor were any potential problems identified that could be aggrevated by synthetic or alternative fuel usage other than those mentioned above. Some coking has been seen in the fuel nozzles of the T700 engines recently. While no details were available for this study, it is a problem that would be aggrevated by deteriorating fuel thermal stability.

Qualification procedures for engines and fuel system components stress compatibility with a current fuel specification rather than the sensitivity of a design to changing fuel properties. The test fuels are designed to be worst cases however and are believed adequate for currently identified problems.

VII. RECOMMENDATIONS

This study addressed only fuels that met current specifications for JP-4, JP-5, JP-8, and Jet A and potential modifications to those specifications; these fuels are the ones currently authorized as "primary" or alternate" fuels for Army aircraft gas turbine engines. During combat or in other periods of extreme emergency, specification fuels may not be available. It is therefore recommended that a similar study be conducted to address the potential use of emergency specification and off-specification fuels; the scope of the study should include the impact of such fuels on aircraft performance, durability, and safety; it should also attempt to define allowable limits for critical properties and identify inspection and maintenance procedures to be taken following the use of such fuels. Since very little sensitivity data was found relating performance and durability to fuel properties, experimental programs to develop such a data base will be necessary to support the above recommendation. It is also recommended that a methodology for qualifying future Army aviation fuels be developed to reduce the level of full scale engine and airframe testing necessary to ensure compatibility between new fuel specifications and aircraft designed to operate the current fuel specifications.

REFERENCES

1. Moses, C.A., Sefer, N.R., and Valtierra, M.L., "An Alternate Test Procedure to Qualify New Fuels for Navy Aircraft," Draft Final Report submitted to Naval Air Propulsion Center, Trenton, New Jersey, March 1981.

2. U.S. Army Regulation 703-1, "Coal and Petroleum Products Management: Coal and Petroleum Products Supply and Management Activities," 15 November 1978.

3. Shelton, E.M. "Aviation Turbine Fuels, 1980," Report No. DOE/BETC/PPS-81/2, Bartlesville Energy Technology Center, Bartlesville, Oklahoma, March 1981.

4. Personal communication with Mr. Art Churchill, Branch Chief, Fuels Branch Air Force Aero Propulsion Laboratory, Wright-Patterson AFB, Ohio.

5. Dickson, J.C. and Karvelas, L.P., "Impact of Fuel Properties on Jet Fuel Availability," Report No. AFAPL-TR-76-7, April 1976.

6. McClelland, C.C. "Effects of Jet Fuel Constituents on Combustor Durability," Naval Air Engineering Center Report, NAEC-AEL-1736, AD #404 084, 1963.

7. Macaulay, R.W., and Shayeson, M.W., "Effects of Fuel Properties on Liner Temperatures and Carbon Deposition in the CJ 805 Combustor for Long-life Applications," ASME Paper 61-W-304, 1961.

8. Shirmer, R.M. and Quigg, H.T., "Effects of JP Fuel Composition on Flame Radiation and Hot Corrosion," Phillips Petroleum Co., Research Division Report 4230-65R, 1965.

9. Gleason, C.C., Oller, T.L., Shayeson, M.W., and Bahr, D.W., "Evaluation of Fuel Character Effects on J79 Engine Combusion System," Air Force Aero Propulsion Laboratory Report No. AFAPL-TR-79-2015, June 1979.

10. Gleason, C.C., Oller, T.L., Shayeson, M.W., and Bahr, D.W., "Evaluation of Fuel Character Effects on the F101 Engine Combustion System," Air Force Aero Propulsion Laboratory Report No. AFAPL-TR-79-2018, June 1979.

11. Blazowski, W.S. "Combustion Considerations for Future Jet Fuels," Sixteenth Symposium (International) on Combustion, p. 1631, The Combustion Institute, 1976.

12. Gleason, C.C., Oller, T.L., Shayeson, M.W. and Kenworthy, M.J., "Evaluation of Fuel Character Effects on J79 Smokeless Combustor," Air Force Aero Propulsion Laboratory Report No. AFAPL-TR-80-2092, November 1980.

13. Moses, C.A. and Naegeli, D.W., "Fuel Property Effects on Combustor Performance," ASME Paper 79-GT-178, 1979.

14. Blazowski, W.S. and Jackson, T.A., "Evaluation of Future Jet Fuel Combustion Characteristics," Air Force Aero Propulsion Laboratory Report No. AFAPL-TR-77-93, July 1978.

15. Naegeli D.W., and Moses, C.A., "Effects on Fuel Properties on Soot Formation in Turbine Combustion," SAE Paper 781026, November 1978.

16. Vogel, R.E., Troth, D.L. and Verdow, A.J., "Fuel Character Effect on Current High Pressure Ratio Can-Type Turbine Combustion Systems," Air Force Aero Propulsion Laboratory Report No. AFAPL-TR-2072, February 1980.

17. Parker O-Ring Handbook, Parker Seal Co., 2360 Palumbo Drive, Lexington, Kentucky, issued January 1975.

18. Powell, F.P., Knutson, K., and Touchet, P., "Elastomeric Material Compatibility With Navy Fuels," Report No. 09463 UCBY, Rubber and Coated Fabrics Research Group, U.S. Army MERADCOM, Ft. Belvoir, Virginia, February 1980.

19. Berner, W.E. and Angello, L.C., "Behavior of Non-metallic Materials in Shale Oil Derived Jet Fuels and in High Aromatic and High Sulfur Petroleum Fuels," AD No. A060322, University of Dayton Research Institute, Dayton, Ohio, July 1978.

20. Nadler, C., "Effect of Oxidizing Fuels on Aircraft Fuel System Elastomers and Sealants," contained as an appendix in "Aircraft Systems Fleet Support/Organic Peroxides in JP-5 Investigation," NAPC-LR-78-20, Naval Air Propulsion Center, Trention, New Jersey, September 1978.

21. Personal communication with Mr. Phil House, Air Force Materials Laboratory Wright-Patterson AFB, Dayton, Ohio.

22. Personal communication with Mr. Coleman Nadler, U.S. Naval Air Development Center, Warminster, Pennsylvania.

23. Personal communication with Mr. John Bley, Polysar, Ltd., Sarnia, Ontario, Canada.

24. Personal communication with Mr. Bert Reime, U.S. Army Aviation Research and Development Command, St. Louis, Missouri.

25. Personal communication with Messrs. Wayne Priest, Manager Hose Division and Earl Larkin, Stratoflex, Inc., Fort Worth, Texas.

26. Personal communication with Mr. Oren Linger, Technical Manager, B.F. Goodrich Company, Green Camp, Ohio.

27. Personal communication with Mr. John Etcheverry, Manager of R,D,&E and Mr. John Fogelson, Director of Marketing, ITT/General Controls, Aerospace Division, Glendale, California.

28. Maintenance Instructions Self-sealing Bladder Type Fuel, Oil, and Water Alcohol Cells, NAVWEPS 03-10-513, 1 September 1966.