

AD613553

January 29, 1965
DMIC Memorandum 201

COMPATIBILITY OF MATERIALS WITH ROCKET
PROPELLANTS AND OXIDIZERS

Best Available Copy

DEFENSE METALS INFORMATION CENTER
BATTELLE MEMORIAL INSTITUTE
COLUMBUS, OHIO 43201

REPRODUCED BY
NATIONAL TECHNICAL
INFORMATION SERVICE
U. S. DEPARTMENT OF COMMERCE
SPRINGFIELD, VA. 22161

The Defense Metals Information Center was established at Battelle Memorial Institute at the request of the Office of the Director of Defense Research and Engineering to provide Government contractors and their suppliers technical assistance and information on titanium, beryllium, magnesium, aluminum, refractory metals, high-strength alloys for high-temperature service, corrosion- and oxidation-resistant coatings, and thermal-protection systems. Its functions, under the direction of the Office of the Director of Defense Research and Engineering, are as follows:

1. To collect, store, and disseminate technical information on the current status of research and development of the above materials.
2. To supplement established Service activities in providing technical advisory services to producers, melters, and fabricators of the above materials, and to designers and fabricators of military equipment containing these materials.
3. To assist the Government agencies and their contractors in developing technical data required for preparation of specifications for the above materials.
4. On assignment, to conduct surveys, or laboratory research investigations, mainly of a short-range nature, as required, to ascertain causes of troubles encountered by fabricators, or to fill minor gaps in established research programs.

Contract No. AF 33(615)-1121
Project No. 8975

Roger J. Runck

Roger J. Runck
Director

"The information in this report came from many sources, and the original language may have been extensively quoted. Quotations should credit the original authors and the originating agency. Where patent questions appear to be involved, the usual preliminary search is advised before making use of the material, and where copyrighted material is used, permission should be obtained for its further publication."

COPIES AVAILABLE FROM OTS \$.....

**U.S. DEPARTMENT OF COMMERCE
National Technical Information Service**

AD-613 553

**COMPATIBILITY OF MATERIALS WITH
ROCKET PROPELLANTS AND OXIDIZERS**

W. K. Boyd, et al

**Battelle Memorial Institute
Columbus, Ohio**

January 1963

DISCLAIMER NOTICE

**THIS DOCUMENT IS BEST QUALITY
PRACTICABLE. THE COPY FURNISHED
TO DTIC CONTAINED A SIGNIFICANT
NUMBER OF PAGES WHICH DO NOT
REPRODUCE LEGIBLY.**

*Code 23
QSP*

Unclassified

Security Classification

DOCUMENT CONTROL DATA - R&D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author) Battelle Memorial Institute Defense Metals Information Center 505 King Avenue, Columbus, Ohio 43201		2a. REPORT SECURITY CLASSIFICATION Unclassified	
		2b. GROUP —	
3. REPORT TITLE Compatibility of Materials With Rocket Propellants and Oxidizers			
4. DESCRIPTIVE NOTES (Type of report and inclusive dates) DMIC Memorandum			
5. AUTHOR(S) (Last name, first name, initial) Boyd, W. K., Berry, W. E., and White, E. L.			
6. REPORT DATE January 29, 1965		7a. TOTAL NO. OF PAGES 40	7b. NO. OF REFS 302
8a. CONTRACT OR GRANT NO. AF 33(615)-1121		8b. ORIGINATOR'S REPORT NUMBER(S) DMIC Memorandum 201	
8c. PROJECT NO. 8975			
8d.		8d. OTHER REPORT NO(S) (Any other numbers that may be assigned this report) —	
10. AVAILABILITY/LIMITATION NOTICES Copies may be obtained from DMIC at no cost by Government agencies and by Government contractors, subcontractors, and their suppliers. Others may purchase copies from: Clearinghouse for Federal Scientific and Technical Information, U. S. Department of Commerce, Springfield, Virginia 22151.			
11. SUPPLEMENTARY NOTES		12. SPONSORING MILITARY ACTIVITY United States Air Force Research and Technology Division Wright-Patterson Air Force Base, Ohio 45433	
13. ABSTRACT Compatibility data are summarized for the storage and handling of metals and nonmetals in the following rocket propellants and oxidizers: ammonia, HiCal-3, pentaborane, trialkyl boranes, fluorine, TiOX, oxygen difluoride, ozone difluoride, chlorine trifluoride, bromine trifluoride, bromine pentafluoride, iodine pentafluoride, perchloryl fluoride, halogenated hydrocarbons, hydrazine, monomethyl hydrazine, unsymmetrical dimethyl hydrazine, Aerozine-50 hydrogen, hydrogen peroxide, methylene chloride, red fuming nitric acid, white fuming nitric acid, concentrated acid, nitrogen tetroxide, oxygen, ozone, nitronium perchlorate, and solid propellant ANP-2639 AF. (Author)			

DD FORM 1 JAN 64 1473

Unclassified

Security Classification

Unclassified

Security Classification

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Fuels Oxidizers Compatibility Light metals Refractory metals High-strength steels Stainless steels Superalloys Other specific metals Metals (in general) Nonmetallics						

INSTRUCTIONS

1. **ORIGINATING ACTIVITY:** Enter the name and address of the contractor, subcontractor, grantee, Department of Defense activity or other organization (*corporate author*) issuing the report.

2a. **REPORT SECURITY CLASSIFICATION:** Enter the overall security classification of the report. Indicate whether "Restricted Data" is included. Marking is to be in accordance with appropriate security regulations.

2b. **GROUP:** Automatic downgrading is specified in DoD Directive 5200.10 and Armed Forces Industrial Manual. Enter the group number. Also, when applicable, show that optional markings have been used for Group 3 and Group 4 as authorized.

3. **REPORT TITLE:** Enter the complete report title in all capital letters. Titles in all cases should be unclassified. If a meaningful title cannot be selected without classification, show title classification in all capitals in parenthesis immediately following the title.

4. **DESCRIPTIVE NOTES:** If appropriate, enter the type of report, e.g., interim, progress, summary, annual, or final. Give the inclusive dates when a specific reporting period is covered.

5. **AUTHOR(S):** Enter the name(s) of author(s) as shown on or in the report. Enter last name, first name, middle initial. If military, show rank and branch of service. The name of the principal author is an absolute minimum requirement.

6. **REPORT DATE:** Enter the date of the report as day, month, year, or month, year. If more than one date appears on the report, use date of publication.

7a. **TOTAL NUMBER OF PAGES:** The total page count should follow normal pagination procedures, i.e., enter the number of pages containing information.

7b. **NUMBER OF REFERENCES:** Enter the total number of references cited in the report.

8a. **CONTRACT OR GRANT NUMBER:** If appropriate, enter the applicable number of the contract or grant under which the report was written.

8b, 8c, & 8d. **PROJECT NUMBER:** Enter the appropriate military department identification, such as project number, subproject number, system numbers, task number, etc.

9a. **ORIGINATOR'S REPORT NUMBER(S):** Enter the official report number by which the document will be identified and controlled by the originating activity. This number must be unique to this report.

9b. **OTHER REPORT NUMBER(S):** If the report has been assigned any other report numbers (*either by the originator or by the sponsor*), also enter this number(s).

10. **AVAILABILITY/LIMITATION NOTICES:** Enter any limitations on further dissemination of the report, other than those

imposed by security classification, using standard statements such as:

- (1) "Qualified requesters may obtain copies of this report from DDC."
- (2) "Foreign announcement and dissemination of this report by DDC is not authorized."
- (3) "U. S. Government agencies may obtain copies of this report directly from DDC. Other qualified DDC users shall request through _____."
- (4) "U. S. military agencies may obtain copies of this report directly from DDC. Other qualified users shall request through _____."
- (5) "All distribution of this report is controlled. Qualified DDC users shall request through _____."

If the report has been furnished to the Office of Technical Services, Department of Commerce, for sale to the public, indicate this fact and enter the price, if known.

11. **SUPPLEMENTARY NOTES:** Use for additional explanatory notes.

12. **SPONSORING MILITARY ACTIVITY:** Enter the name of the departmental project office or laboratory sponsoring (*paying for*) the research and development. Include address.

13. **ABSTRACT:** Enter an abstract giving a brief and factual summary of the document indicative of the report, even though it may also appear elsewhere in the body of the technical report. If additional space is required, a continuation sheet shall be attached.

It is highly desirable that the abstract of classified reports be unclassified. Each paragraph of the abstract shall end with an indication of the military security classification of the information in the paragraph, represented as (TS), (S), (C), or (U).

There is no limitation on the length of the abstract. However, the suggested length is from 150 to 225 words.

14. **KEY WORDS:** Key words are technically meaningful terms or short phrases that characterize a report and may be used as index entries for cataloging the report. Key words must be selected so that no security classification is required. Identifiers, such as equipment model designation, trade name, military project code name, geographic location, may be used as key words but will be followed by an indication of technical context. The assignment of links, rules, and weights is optional.

Unclassified

Security Classification

613-553

DEFENSE METALS INFORMATION CENTER
BATTILLE MEMORIAL INSTITUTE
COLUMBUS, OHIO 43201

DMIC MEMORANDUM 201

COMPATIBILITY OF MATERIALS WITH
ROCKET PROPELLANTS AND GRIDIZERS

ERRATA

In Table 6 on page 12, several entries are in error. The corrections are listed below. In table 29, a rating for Monel is supplied that was inadvertently omitted during copying from the worksheets.

ERRATA FOR TABLE 6

Material	Temperature, F								References
	Gas				Liquid				
	Class 1	Class 2	Class 3	Class 4	Class 1	Class 2	Class 3	Class 4	
309 Stainless Steel	500			570					7,207
309 Cb Stainless Steel	500			570					7,207
310 Stainless Steel	500			660					7,207
347 Stainless Steel	390			500	-310		-320		7,120,207,274
430 Stainless Steel		400	390	600					7,207,211
Azmco Iron	390	500	167						7,159,160,207
Iron (0.004 Si)		200	400	390					82,159,160
Iron (0.79 Si)		100	300	390					82,159,160
Sheet Steel	390	660		500					7,207
SAE 1010	100	200	400	>400					82,160
SAE 1011				570					7,207
SAE 1020				390					7,207
SAE 1030	660		390	500					7,207
Music Wire				570					7,207
A-Nickel		1000	750	>1200					7,73,82,120,143,153,159,160,211,274
Monel		1000	750	>1200					7,73,82,120,143,153,159,160,211,274
Inconel		1000		<750					7,207,211
Deoxidized copper				<400					7,207
Brass 70-30		200		400					82,159,160
Magnesium MA (1.2% Mn)	140	200							82,159,160
Magnesium PS-1A	140	200							82,159,160

ERRATUM FOR TABLE 29

Monel	75	125	100	75	211
-------	----	-----	-----	----	-----

ARCHIVE COPY

TABLE OF CONTENTS

	<u>Page</u>
GENERAL CONSIDERATIONS.	1
CLASSIFICATION OF MATERIALS OF CONSTRUCTION	1
Metals	1
Nonmetals.	1
SOURCES OF INFORMATION.	2
AMMONIA (NH ₃)	2
BORON HIGH-ENERGY FUELS	3
Hi Cal-3	3
Pentaborane (B ₅ H ₉)	3
Trialkyl Boranes	3
FLUORINE COMPOUNDS	3
Fluorine (F ₂)	3
FLOX	4
Oxygen Difluoride (OF ₂)	4
Ozone Difluoride (O ₃ F ₂)	4
Chlorine Trifluoride (CTF) (ClF ₃)	4
Bromine Trifluoride (BTF) (BrF ₃)	4
Bromine Pentafluoride (BPF) (BrF ₅)	4
Iodine Pentafluoride (IPF) (IF ₅)	5
Perchloryl Fluoride (PF) (ClO ₃ F)	5
Mixtures With Perchloryl Fluoride.	5
Halogenated Hydrocarbon Propellants.	5
HYDRAZINES.	5
Hydrazine (N ₂ H ₄)	5
Monomethyl Hydrazine (CH ₃ NNH ₂)	6
Unsymmetrical Dimethyl-Hydrazine (UDMH) [(CH ₃) ₂ NNH ₂]	6
Hydrazine-Unsymmetrical Dimethyl Hydrazine Mixtures.	6
HYDROGEN.	6
HYDROGEN PEROXIDE (H ₂ O ₂)	7
Aluminum Passivation.	7
Stainless Steel Passivation	7
Pretreatment of Plastics.	7
Discussion.	7
METHYLENE CHLORIDE (CH ₂ Cl ₂)	8
NITRIC ACID	8
Red Fuming Nitric Acid	8
White Fuming Nitric Acid	9
Concentrated Nitric Acid	9
NITROGEN TETROXIDE (N ₂ O ₄)	9
OXYGEN.	9
OZONE	10
SOLID PROPELLANTS	10
ANP-2639AF	10
Nitronium Perchlorate (NO ₂ ClO ₄)	10
REFERENCES.	31

COMPATIBILITY OF MATERIALS WITH ROCKET PROPELLANTS AND OXIDIZERS

W. K. Boyd, W. E. Berry, and E. L. White*

GENERAL CONSIDERATIONS

An important consideration in rocket technology is the compatibility of each propellant with the container material. Serious problems arise because many propellants are extremely reactive and their containment is possible only with a few materials of construction. The resistance of many alloys to fuels and oxidizers is dependent entirely on the formation of an inert, corrosion-resistant film or barrier coating. In addition to corrosion problems, the presence of some metals tends to promote decomposition of the propellant. Also, certain metal/oxidizer combinations may ignite if subjected to impact.

Four years ago DMIC Memorandum 65 was issued and included all information available at that time on compatibility of materials of construction with rocket propellants and oxidizers. Since that time additional information on compatibility has been generated for new, as well as the more established, fuels and oxidizers. This report contains these new data combined with the information presented in DMIC Memorandum 65. In order to expand the usefulness of the report, the source of the data is referenced for each material.

This memorandum summarizes the available information on the compatibility of liquid rocket propellants with prominent materials of construction. It is pointed out that compatibility data for materials not ordinarily covered by the Defense Metals Information Center are included. These data were found during the search for information on materials that are within the scope of the DMIC, and are included for convenience. Fuels and oxidizers of current interest are discussed. The corrosion data which are presented will apply to storing, handling, and control equipment outside of missiles and to missile components excluding combustion chamber. The compatibility of materials with reaction products in combustion chambers, nozzles, etc., has not been considered. Included in the summary are data for many nonmetallic materials. These data were collected in conjunction with those obtained for metals but no concerted effort was made to secure compatibility data for nonmetals.

The memorandum is subdivided into sections according to the propellant. Each material of construction is rated for a given medium as belonging to one of four classes, based primarily upon corrosion resistance. Consideration also is given to such factors as catalytic decomposition and sensitivity to impact.

CLASSIFICATION OF MATERIALS OF CONSTRUCTION

Metals

Class 1

The Class 1 materials are those which exhibit a corrosion rate of less than 1 mil per year. The material does not promote decomposition of the propellant or oxidizer and is free from impact sensitivity.

*Chief, Associate Chief, and Research Chemical Engineer, Corrosion Research Division, Battelle Memorial Institute, Columbus, Ohio.

Class 2

The materials falling in Class 2 are similar to those in Class 1, except that the corrosion rate may be as great as 5 mils per year.

Class 3

A material in Class 3 shows only fair corrosion resistance; rates of attack may be of the order of 5 to 50 mils per year. The material may also cause a moderate breakdown of the propellant, but it is not shock sensitive under conditions likely to be encountered in service.

Class 4

Materials in this class are not considered usable for containing the propellant; they have corrosion rates greater than 50 mils per year, cause extensive decomposition of the propellant, cause spontaneous ignition, or react on impact.

These classifications are summarized in Table 1.

TABLE 1. COMPATIBILITY CLASSIFICATIONS FOR METALS^(a)

Class	Rating	Corrosion Resistance	Decomposition of Propellant	Shock Sensitivity
		Penetration Rate, mils/year		
1	Excellent	<1	No	No
2	Good	<5	No	No
3	Fair	5 to 50	Some	No
4	Poor	>50	Extensive	Yes

(a) The classification of a material is based on the lowest rating of any one of the three properties.

Nonmetals

Ratings for nonmetals are also somewhat arbitrary but wherever possible they follow those described in the Titan II Storable Propellant Handbook, (169) The classifications are summarized in Table 2.

TABLE 2. COMPATIBILITY CLASSIFICATIONS FOR NONMETALS

	Class			
	1	2	3	4
Volume Change, percent	0 to +25	-10 to +25	-10 to +25	<-10 or >+25
Durometer Reading Change	±3	±10	±10	<-10 or >+10
Effect on Propellant	None	Slight change	Moderate change	Severe
Visual Examination	No change	Slight change	Moderate change	Severely blistered, or cracked, dissolved
General Usage	Satisfactory, general use	Satisfactory for repeated short term use	Satisfactory for short time use	Unsatisfactory

The compatibility data have been tabulated according to the maximum temperature permissible for a given material in Classes 1, 2, and 3. The minimum temperature at which a given material becomes Class 4 (noncompatible) also is listed. For example, a notation of RT under Class 1 means that the material would fall into this classification up to room temperature. It will be noted, in many instances, that no temperature is listed for one of the more resistant classifications. This does not necessarily mean that the material does not fall in Class 1 or 2 at some temperature, but rather that insufficient data are available to assign a temperature limit.

Occasional entries indicate that a material has a higher rating at higher temperatures, e.g., Class 1 at 160 F and Class 2 at 80 F. These entries reflect a conflict in reported data. In many of these cases, it is recommended that the original references be consulted where possible, to determine which results were obtained under conditions most nearly simulating the application in question.

In many cases, a material does not fit into a classification because (1) there is a scarcity of numerical data, or (2) the decomposition effects on the propellant are of primary concern. Hydrogen peroxide is a good example of a propellant for which it is difficult to classify construction materials. In such a case, the classification used in the table is described in detail for the material in question. Many materials are listed by trade names. Similar materials marketed under other trade names probably would be given the same classification. However, only materials for which actual data are available are listed.

SOURCES OF INFORMATION

The information on which this memorandum is based came from a variety of sources. A list of references is given at the end of the text. Appropriate references for a particular propellant material are listed at the beginning of each section. References are also included for each individual entry. In addition to reference material obtained from published literature, specialists in companies active in the development of rocket propellants were contacted either by letter, by telephone, or in person. The cooperating companies are listed below.

Aerojet-General Corporation
Food Machinery and Chemical Corporation
Becco Chemical Division
Belmont Smelting and Refining Works, Inc.
General Dynamics Corporation
Convair Astronautics Division
Callery Chemical Company
Research and Development Division
Celanese Corporation of America
Columbia-Southern Chemical Corporation
Commercial Solvents Corporation
Douglas Aircraft Company, Inc.
Diamond Alkali Company
The Dow Chemical Company
Texas Division
E. I. du Pont de Nemours and Company, Inc.
Foote Mineral Company
Allied Chemical Corporation
General Chemical Division
Hughes Tool Company
HEF, Inc. - Hooker Chemical Corporation and
Foote Mineral Company

Hercules Powder Company
California Institute of Technology
Jet Propulsion Laboratory
Lockheed Aircraft Corporation
Missile Systems Division
Lithium Corporation of America
Menasco Manufacturing Company
Metal Hydrides, Inc.
Monsanto Chemical Company
Research and Engineering Division
Chemetron Corporation
National Cylinder Gas Division
Union Carbide Corporation
Kinde Company
Union Carbide Metals Company
National Carbon Company
Olin-Mathieson Chemical Corporation
Pennsalt Chemicals Corporation
Thiokol Chemical Corporation
Reaction Motors Division
North American Aviation, Inc.
Rocketdyne Division
Rohm & Haas Company
Stanford Research Institute
Solar Aircraft Company
Sinclair Research Laboratories, Inc.
Titanium Metals Corporation of America
Virginia-Carolina Chemical Corporation
Wyandotte Chemicals Corporation.

General information on compatibility and properties of large groups of propellants are contained in References 3, 23, 81, 102, 110, 151, 196, 198, 211, and 237. Information on handling, safety, and toxicity is included in References 81, 195, 291, and 302.

AMMONIA (NH₃)*

Ammonia is a pungent colorless gas that is alkaline in nature. It can be liquified at room temperature at pressures above 100 psia. The vapor irritates the eyes and respiratory tract. The threshold-limit value of toxicity in the atmosphere is 50 ppm.

Stainless steel, carbon steel, nickel alloys, silver, platinum, gold, and tantalum are sufficiently resistant to anhydrous ammonia to be placed in Class 1, as shown in Table 3. Inconel, gold, platinum, and tantalum are Class 1 materials in moist ammonia. Carbon steel and cast iron are also quite resistant and are normal materials of construction for ammonia service.

The copper alloys are less resistant than steel and have the disadvantage of being susceptible to cracking in ammonia atmosphere.

The upper temperature limit of many metals is related to the initiation of the nitriding process. Inconel is more resistant to nitriding than other nickel alloys, mild steel, or stainless steel.

Many organic materials are suitable for ammonia service. Plastics and elastomers usually resist attack up to their softening point.

Most inorganic construction materials are not attacked by ammonia. Graphitic materials are considered best for handling ammonia gas at very high temperatures.

*Ammonia: see References 80, 81, 82, 94, 102, 109, 110, 127, 128, 151, 181, 199, 211, 214, 217, 221, 287, and 295.

Hi-Cal-3*

The composition and properties of Hi-Cal-3 are classified.

Many of the common construction materials are compatible with Hi-Cal-3. Mild steels, stainless steels, copper alloys, nickel alloys, aluminum, titanium, tantalum, and lead can all be used up to 120 F and are listed as Class 1 in Table 4. Above this temperature, no data are available. Organic materials which are compatible with Hi-Cal-3 are listed in Table 4 as Class 2.

Pentaborane (B_5H_9)**

Pure pentaborane is a clear colorless liquid that possesses an odor similar to that of rotten pumpkin. It is pyrophoric and highly toxic. Maximum allowable exposure is less than 1.0 ppm. It has a vapor pressure of 77 mm at 77 F and boils at 137 F.

Most of the metals used in rocket construction are compatible with pentaborane, including iron, steel, stainless steel, aluminum, copper, brass, magnesium, titanium, etc. Data are presented in Table 5. Teflon, Viton, Kel-F, and fluorosilicon rubber are included among the plastics and elastomers that are compatible with pentaborane. Pentaborane forms shock-sensitive mixtures with most of the chlorinated hydrocarbons that are used as degreasers or solvents.

Trialkyl Boranes***

Materials which have withstood 1 month's exposure in triethylborane [$(C_2H_5)_3B$] (a colorless liquid that boils at 203 F) at 160 F with no apparent attack include:

Metals	Nonmetals
Mild steel	Teflon
Stainless steel	Phenolite
Aluminum	Garlock 900 packing
Brass	Garlock red rubber
Nickel	Koppers 6200
Monel	Super Dylan polyethylene
Inconel	
Lead	
Copper (pitted)	

Materials which have withstood 2 weeks' exposure in tri-n-butyl borane [$(C_4H_9)_3B$] (a colorless liquid that exerts a vapor pressure of 20 mm at 228 F) at 122 F with no apparent attack include:

Metals	Nonmetals
Mild steel	Teflon gasket
Stainless steel	Palmer to gasket
Aluminum	Koroseal
Brass	Kel-F
Nickel	Hycar
Copper	Nylon gasket

*Hi-Cal-3: see Reference 103.

**Pentaborane: see References 56 and 294.

***Trialkyl boranes: See Reference 57.

A number of fluorine compounds are being considered as oxidizers for rocket-propulsion systems. These include fluorine, chlorine trifluoride, bromine trifluoride, bromine pentafluoride, iodine pentafluoride, oxygen difluoride, oxygen difluoride-oxygen mixtures, perchloryl fluoride, perchloryl fluoride-tetrafluoro-hydrazine mixtures, and fluorine-oxygen mixtures (FLOX). All of these materials are extremely active chemically. Under the proper conditions, they will react with almost every known element; hence, they present severe corrosion and compatibility problems. These oxidizers, however, are not for the most part susceptible to thermal and catalytic breakdown and present little or no problem in this respect. Therefore, compatibility ratings are based primarily on the reaction of the medium with the material in question.

Fluorine (F_2)*

Fluorine is a yellowish gas that has a pungent odor and is irritating to the respiratory tract. The threshold limit of toxicity of fluorine in the atmosphere is 0.1 ppm. It is normally handled as a liquid at -310 to -320 F.

Many metals perform well in liquid and gaseous fluorine as can be seen from the data in Table 6. It is believed that a protective fluoride film which forms on the surface of most metals imparts corrosion resistance. On the other hand, some experiments have revealed no increased corrosion on specimens immersed in liquid fluorine and wire brushed to remove any film, suggesting no passivating effect from metal fluorides.(275)

Traces of water in the system react with fluorine to form hydrofluoric acid. This acid tends to attack some of the materials which are resistant to uncontaminated fluorine. Since moisture may be present in many systems, Monel is usually chosen as a construction material because, in addition to being resistant to fluorine, it also is resistant to hydrofluoric acid.

Titanium ignites** in liquid fluorine if subjected to impact or rupture. However, ignition does not propagate as it does in liquid oxygen. Although ignition has occurred in at least one specimen of aluminum alloys, aluminum is not considered to be impact sensitive in liquid fluorine.(275) Dynamite cap explosions against tubes filled with liquid fluorine have failed to cause ignition in Monel, nickel, copper, brass, 304 stainless steel, 316 stainless steel, 347 stainless steel, and 1100 aluminum.(275) Tensile tests to fracture in liquid fluorine have not caused ignition of AM350, 304L stainless steel, 301 stainless steel, ASM 6434, 2014-T6 and 7075-T6 aluminum, Inconel X, and Ti-6Al-4V.(233)

*Fluorine: see References 7, 14, 15, 16, 20, 40, 52, 58, 73, 81, 82, 83, 86, 90, 91, 93, 94, 99, 100, 102, 110, 120, 121, 122, 123, 132, 134, 143, 146, 151, 152, 153, 159, 160, 161, 162, 163, 175, 184, 191, 194, 197, 199, 201, 202, 203, 204, 207, 211, 212, 214, 215, 217, 221, 224, 225, 226, 233, 237, 243, 251, 252, 253, 259, 261, 263, 264, 265, 266, 268, 269, 270, 271, 272, 273, 274, 275, 276, 277, 278, 290, 297, and 299.

**Ignition - fluorine: see References 141, 233, 274, 275, and 276.

Because of its strong oxidizing properties, fluorine reacts readily and often violently with most organic materials. Only the highly fluorinated hydrocarbons such as Teflon and Kel-F withstand continued service.

Cleanliness is essential for fluorine systems. If the metal surfaces in contact with fluorine or for that matter almost any strong oxidizer are contaminated with organic materials, such as traces of oil or grease, local hot spots may form which in turn may cause the violent burning of the encasing material.

It is recommended that equipment to handle fluorine be first thoroughly cleaned to remove all contaminants, e.g., organic matter, and then passivated with fluorine diluted with an inert gas.

FLOX*

Mixtures of liquid fluorine and liquid oxygen (called FLOX) have received some consideration as oxidizers. Typical ratios are 40:60 and 20:80 fluorine:oxygen. The limited compatibility data that are available for FLOX are summarized in Table 7. In general, it appears that any material which performs well in liquid fluorine also performs well in FLOX.

Oxygen Difluoride (OF₂)**

Oxygen difluoride is a colorless gas and a brownish yellow liquid. It boils at -220 F. It is toxic and possesses about the same lethal characteristics as phosgene.

The limited data on the compatibility of materials with oxygen difluoride and oxygen difluoride-oxygen mixtures are summarized in Tables 8 and 9. In general, the materials behave as well as, or better than, in fluorine. No detonation has been observed in steel cylinders when filled with OF₂ liquid or gas and struck by 0.22-caliber long rifle bullets fired from 50 feet. (124)

Ozone Difluoride (O₃F₂)

Ozone difluoride is a viscous blood-red liquid at -297 F. At -250 F it decomposes into oxygen and oxygen difluoride.

There is little published information on O₃F₂. The corrosive effect of 0.05 percent O₃F₂-LOX on stainless steel is reported to be about the same order of magnitude as that of fluorine. (83) Compatibility data are summarized in Table 10.

Chlorine Trifluoride (CTF)(ClF₃)***

Like fluorine, chlorine trifluoride is among the most active chemicals known. It is a nearly colorless gas at atmospheric pressure and room temperature, but can be liquified by the application of slight pressures. CTF reacts violently with water and many organic compounds. It attacks the respiratory tract. The threshold-limit value of toxicity for CTF in air is 0.1 ppm.

*FLOX: see References 224, 266, and 267.

**Oxygen difluoride: see References 83, 124, 224, 238, 282, and 283.

***Chlorine trifluoride: see References 17, 23, 40, 81, 82, 106, 110, 111, 112, 113, 114, 115, 116, 117, 118, 119, 151, 158, 200, 211, 243, 244, 269, and 286.

Chlorine trifluoride can be handled in many of the common metals shown in Table 11. As with fluorine, a coating is formed on metals, which provides protection from corrosive attack. Among the metals which are resistant to CTF are copper, brass, steel, Monel, and nickel. Of these, Monel and nickel are preferred because of their resistance to hydrogen fluoride and hydrogen chloride, which are formed by reaction of CTF with water. The organic materials that are compatible are limited to Teflon and Kel-F.

Although some surface staining has occurred in tests employing impact, shock, and perforation, there has been no ignition of low-carbon steel, stainless steel, aluminum, copper, magnesium, or titanium in liquid or gaseous CTF. (114, 115)

Cleaning and passivating treatments similar to those described for metals that are used to contain fluorine must be used for CTF systems to reduce the possibility of rapid reactions.

Bromine Trifluoride (BTF)(BrF₃)*

Bromine trifluoride is a colorless liquid that boils at 275 F. Its vapor pressure at 70 F is 0.15 psia. It is toxic and has a threshold limit value for toxicity in the atmosphere of 0.1 ppm.

Bromine trifluoride reacts violently with many organic compounds and vigorously with water. BTF, like CTF, appears to react with some metals to form a protective coating of the metal fluoride. As shown in Table 4, this coating permits the use of nickel up to about 1300 F, copper to 750 F, and steel to 480 F. The data are not sufficiently detailed to permit a more extensive classification than that shown in Table 12.

Metals which do not form protective coatings are vigorously attacked. Examples of this type of condition are molybdenum and tungsten, either as the pure metal or in an alloy. Titanium is also attacked by BTF. Boron, silicon, columbium, and sulfur all burn in BTF (liquid).

Materials of construction, equipment design, cleaning, passivation, and general handling practice for bromine trifluoride are the same as for chlorine trifluoride.

Bromine Pentafluoride (BPF)(BrF₅)**

Bromine pentafluoride is a colorless liquid that boils at 105 F. Its vapor pressure at 70 F is 7 psia. The toxicity threshold-limit value of BrF₅ in the atmosphere is 0.1 ppm.

Bromine pentafluoride reacts with most of the known elements except nitrogen, oxygen, and the rare gases. Under the proper conditions, it will react with most inorganic compounds except those containing fluorine in their highest valence state. Most organic compounds react violently with BPF at room temperature and atmospheric pressure. Detailed corrosion data for metals are not available.

Recommended materials of construction for BPF are the same as those for chlorine trifluoride. The same precautions for cleaning and passivation must be followed.

*Bromine trifluoride: see References 82, 94, 106, 151, 211, 243, and 269.

**Bromine pentafluoride: see References 243 and 269.

Iodine Pentafluoride (IPF)(IF_5)*

Iodine pentafluoride is a colorless liquid. It boils at 207 F. and has a vapor pressure of 0.4 psia at 70 F. Its toxicity threshold-limit value is 0.1 ppm.

Iodine pentafluoride is the least reactive of the halogen fluorides. Very few quantitative corrosion data for common materials of construction in IPF are available. However, it is reported that most metals are only slightly attacked by it at ordinary temperatures. The recommended materials of construction are the same as those for chlorine trifluoride.

IPF reacts violently with water. It also reacts with most organic compounds. Those rich in hydrogen will yield hydrogen fluoride and tend to ignite. Reaction with chlorine-containing compounds tends to release free iodine.

Perchloryl Fluoride (PF)(ClO_3F)**

Perchloryl fluoride is a colorless gas with a sweet odor. It can be liquified at room temperature at pressures in excess of 150 psia. PF affects the respiratory tract and causes "burns" if the liquid is splashed onto the body. The toxicity threshold-limit for PF in air is 3 ppm.

Anhydrous PF is normally shipped in liquid form in steel containers. Table 13 shows other materials which resist PF quite well.

Reactions of PF with water are very slow up to temperatures of about 575 F. However, in the presence of water, PF becomes more corrosive as indicated in Table 14. Under moist conditions, Types 304, 310, and 314 stainless steels have shown relatively good resistance at room temperatures. Short-time tests also have shown the nickel alloys, Hastelloy C, titanium, and tantalum to have good resistance.

Grenade or cylinder-perforation tests resulted in detonation of titanium in liquid and gaseous perchloryl fluoride. (114,115) Titanium also ignited under impact in perchloryl fluoride but the burning was not sustained. Other metals which underwent these same tests but did not ignite were: steel, stainless steel, copper, magnesium, and aluminum. (114,115)

Teflon and Kel-F are very resistant to attack by PF. Other plastics which are suitable are unmodified phenolic resins and epoxy resins. Rubbers which are compounded with carbon black tend to be inflammable, while those with iron oxide fillers are not inflammable. The large surface areas of sponge rubbers make them inflammable. Ordinary oils, greases, and waxes should never be used with PF, however, fluorocarbon compounds are compatible. Many organic materials do not react with PF at room temperature, but if ignited will burn violently. Some inorganic materials react rapidly, e.g., mercury and "indicating" Drierite.

Mixtures With Perchloryl Fluoride

Compatibility data for materials in 25 percent perchloryl fluoride-75 percent chlorine trifluoride

*Iodine pentafluoride: see References 243 and 269.

**Perchloryl fluoride: see References 81, 82, 83, 110, 111, 112, 113, 114, 115, 116, 117, 118, 119, 151, 211, 219, and 224.

are summarized in Table 15. With the exception of columbium, molybdenum, and titanium, most metals perform well.

Compatibility data for materials in 50 percent perchloryl fluoride-50 percent tetrafluorohydrazine are presented in Table 16. All of the usual metals of rocket construction appear compatible in both the liquid and gas at -109 F. (Tetrafluorohydrazine boils at -100 F. It can be liquified at room temperature at pressures greater than 600 psi.)

Halogenated Hydrocarbon Propellants*

Halogenated hydrocarbon propellants are chiefly fluorinated and chlorinated methane and ethane. Many are well known as refrigerants under the trade names of Freon, Genetron, etc. They range from gases to liquids at room temperature with boiling points of about -200 F to about +200 F.

Compatibility data for some five propellants are summarized in Tables 17 to 21. Most of the common structural materials can be used satisfactorily with the halogenated hydrocarbons. At high temperatures, some metals promote catalytic breakdown of the propellants. The general order of this tendency is: Inconel<18-8 stainless steel<nickel<copper<1340 steel<aluminum<bronze<brass<silver. (68) Aluminum alloys containing more than 2 percent magnesium and magnesium alloys are not recommended for use in halogenated hydrocarbons containing water.

Impact tests at 70 ft-lb in Propellants 113 and 114B2 have not caused ignition of aluminum, aluminum plus alumina sand, titanium, titanium plus titanium filings, or titanium plus alumina sand.

Tetrafluoroethylene and chlorotetrafluoroethylene plastics and orlon acrylic are generally suitable for use in halogenated hydrocarbon propellants. Polyvinyl alcohol resists these propellants but is sensitive to water. Phenolics, Delrin acetal resin, nylon, polyethylene and vinyls are suitable for use in many applications, but the behavior of different types may vary in different propellants, and thus should be thoroughly tested before use. Methacrylates and polystyrene are generally not suitable. No single elastomer has been found to be compatible in all halogenated hydrocarbon propellants, but a satisfactory combination can usually be found. (68)

HYDRAZINES

Hydrazine (N_2H_4)**

Hydrazine is a clear oily liquid with an odor similar to that of ammonia. Its vapor pressure at 80 F is 0.31 psia and it boils at 236 F. Hydrazine vapors affect the respiratory tract, nervous system, liver, and kidney, and cause "burns" when spilled on the skin. The toxicity threshold-limit value in the atmosphere is 1 ppm.

The information regarding the compatibility of various metals and nonmetals with hydrazine and

*Halogenated hydrocarbon propellants: see References 51, 53, 68, 84, 136, 214, and 279.

**Hydrazine: see References 3, 4, 7, 23, 70, 81, 82, 102, 110, 135, 145, 149, 151, 170, 171, 172, 173, 174, 183, 196, 211, and 216.

hydrazine-water mixtures is not completely consistent. These differences appear to be related to the specific application. For example, a metal may be satisfactory if air oxidation of the surface can be prevented. On the other hand, this same metal may be unacceptable for service in which prolonged exposure to air cannot be avoided.

In assessing the compatibility of a material with hydrazine, two major factors must be considered for any given exposure condition. They are:

- (1) The corrosion behavior of the material in contact with hydrazine
- (2) The effect of the material and/or corrosion products on the rate of decomposition of hydrazine.

This is particularly true for carbon and low-alloy steels, copper alloys, and molybdenum. From the corrosion standpoint, they are satisfactory. On the other hand, these metals and/or their corrosion products catalyze hydrazine decomposition at elevated temperatures. Explosions may occur. At one time, it was believed that Type 316 stainless steel (containing molybdenum) caused explosions when contacted by hydrazine at elevated temperature. However, it is now generally agreed that the hazard from misoperation in hydrazine and unsymmetrical hydrazine is no greater with 316 stainless steel than with any of the other 300 series stainless steels. (254)

Most metallic materials of construction are compatible with hydrazine. Data are summarized in Table 22.

Many plastics and rubbers are compatible with hydrazine at room temperature. Graphite and Graphitar are not suitable, since they tend to promote decomposition.

Monomethyl Hydrazine (CH_3NNH_2)*

Monomethyl hydrazine is a clear liquid with the odor of ammonia. It has a vapor pressure of 1 psia at 80 F and boils at 189.5 F. Its toxic properties are somewhat similar to those of hydrazine. The recommended threshold limit is 0.5 ppm in the atmosphere.

The following materials can be used in the storage and handling of monomethyl hydrazine:

Metals

303 stainless steels
304 stainless steels
321 stainless steels
347 stainless steels
4130 steel
Aluminum alloys to 160 F
Aerobrazed-I

Nonmetals

Tetrafluoroethylene resins
High-density polyethylene
Some silicone rubbers
Some unplasticized trichlorofluorethylene

*Monomethyl hydrazine: see Reference 154.

Copper, lead, zinc, and alloys containing more than 0.5 wt% molybdenum are not compatible with monomethyl hydrazine.

Unsymmetrical Dimethyl Hydrazine (UDMH) $[(\text{CH}_3)_2\text{NNH}_2]$ *

UDMH is a clear liquid with the odor of ammonia. Its vapor pressure at 80 F is 8.4 psia and it boils at 146 F. Its toxicity is similar to that of hydrazine but not so severe. The toxicity threshold-limit value of UDMH is 0.5 ppm.

In general, unsymmetrical dimethyl hydrazine affects materials in much the same manner as hydrazine. Of the metals, low-alloy steels, aluminum, and stainless steels are commonly used to contain UDMH. Aluminum is attacked by UDMH if water is present with the attack being in direct proportion to the amount of water. Teflon, Kel-F (unplasticized), nylon, polyethylene, and Havig 60 are among the plastic materials which are not attacked by UDMH.

Lubricants such as APS C-407, Parkerlube 5 PB, Molykote, and Peraline 12-4 may cause decomposition. On the other hand, litharge and glycerine paste, X-Pando, and Q-seal are compatible and can be used for thread compounds and other similar applications. Petroleum and silicone greases do not react, but are dissolved by the UDMH. Data for all materials are summarized in Table 23.

Hydrazine-Unsymmetrical Dimethyl Hydrazine Mixtures**

Much of the information on properties and compatibility of 50:50 N_2H_4 :UDMH (Aerozine 50) is summarized in the Titan II Storable Propellant Handbook. (167,168,169) Most of the common metallic materials of construction are compatible with N_2H_4 :UDMH at room temperature, including aluminum alloys, steel, stainless steel, nickel alloys, and titanium alloys. As described under "Hydrazine", Type 316 and molybdenum-containing stainless steels are no longer believed to pose an explosion hazard with 50:50 N_2H_4 :UDMH. (254) Of the plastic materials only some of the fluorocarbons, polyethylene, polypropylene and polyolefins are Class 1 materials. Compatibility data are summarized in Tables 24 and 25.

HYDROGEN***

Liquid hydrogen boils at -423 F. Hydrogen is not toxic in the usual sense but will cause "burns" if the cold liquid contacts the skin. Hydrogen is readily ignited in air at concentrations of 4 to 74 vol%.

Liquid hydrogen and gaseous hydrogen at low temperatures are both considered to be noncorrosive. Embrittlement of metals by the low temperature of the liquid or gas is a more important factor. As can be seen in Table 26, a number of metals can be

*Unsymmetrical dimethyl hydrazine: see References 3, 7, 23, 24, 54, 60, 61, 62, 63, 79, 81, 82, 92, 102, 110, 145, 151, 155, 156, 157, 164, 171, 172, 173, 174, 182, 196, 198, 211, 227, 228, 281, and 296.

**Hydrazine-unsymmetrical dimethyl hydrazine mixtures: see References 4, 31, 47, 48, 49, 50, 165, 166, 167, 168, 169, 170, 198, 205, and 254.

***Hydrogen: see References 34, 46, 74, 80, 81, 82, 93, 151, 181, 199, 211, and 221.

rated compatible (Class 2) with liquid hydrogen; among these are the 300 series stainless steels, Type 410 stainless steel, aluminum and most of its alloys, some nickel alloys, cobalt alloys, and molybdenum. The use of organic materials is limited because of the effect of the low temperature on their physical properties. To avoid this temperature effect, "warm joints" are used, in which the gasket material is kept at a higher temperature so that only hydrogen gas contacts a joint. Table 26 lists some of the organic materials that can be used with liquid hydrogen.

HYDROGEN PEROXIDE (H_2O_2)*

Hydrogen peroxide is a colorless liquid that boils at 303 F. Its toxicity threshold-limit value in the atmosphere is 1 ppm.

When considering materials of construction for handling and containing concentrated hydrogen peroxide, both the effect of the H_2O_2 on the construction material and the effect of the construction material on the H_2O_2 must receive equal attention. If corrosion of the material takes place, usually the H_2O_2 will also decompose, although the reverse is not true, for some materials catalytically decompose H_2O_2 without much corrosive attack occurring.

One means of reducing the decomposition is to passivate the construction material before use.

Aluminum Passivation

An accepted passivation procedure for aluminum consists of several steps.

Step 1, thoroughly clean the metal. This step consists of degreasing with trichlorethylene, perchlorethylene, or a detergent wash, or both, depending upon the type of contaminating dirt, followed by thorough rinsing with clean water.

Step 2, treat with 5 percent nitric acid for 1 or 2 days. Rinse with tap water. Spots or areas which are not passivated can be readily identified. These spots will not have the uniform dull, velvety finish characteristic of passivated aluminum.

Step 3, reclean unpassivated areas and dig out areas containing iron or other inclusions in the aluminum.

Step 4, repeat the cleaning and nitric acid treatments until the aluminum is satisfactorily passivated.

Step 5, treat with stabilized 35 percent H_2O_2 for 1 to 3 days. The passivity of the aluminum can be checked by the amount of decomposition of the 35 percent H_2O_2 , by gas bubbles, and by the warming of the solution.

Step 6, rinse with distilled or deionized water.

Step 7, expose to 90 percent H_2O_2 . During the first 16 to 24 hours of exposure to strong H_2O_2 , equipment must be carefully watched to be sure that the H_2O_2 is not decomposing.

*Hydrogen peroxide: see References 23, 28, 35, 36, 37, 38, 41, 44, 75, 76, 77, 81, 82, 94, 101, 102, 105, 108, 110, 129, 144, 147, 148, 149, 151, 186, 187, 198, 206, 208, 210, 211, 213, 221, 229, 230, 234, 245, 246, 249, 250, 258, and 293.

Modifications of the procedure and other treatments which produce the same result may be used.

Stainless Steel Passivation

The passivating procedure for the 300 series stainless steels is similar to that for aluminum.

Step 1, clean with appropriate solvents and detergent solutions to remove dirt, grease, and other contamination and rinse with tap water.

Step 2, treat with 70 percent nitric acid for 4 or 5 hours and rinse with distilled water. An alternative treatment for 17-7PH steel uses a 2 percent $Na_2Cr_2O_7 \cdot 2H_2O$ -20 percent HNO_3 solution for 1/2 hour at 120-130 F.

Step 3, condition the stainless steel in H_2O_2 of the concentration it will be required to handle. This operation should be observed closely to determine whether decomposition is taking place.

Step 4, if decomposition takes place, repeat the cleaning and passivating steps.

Some stainless steels may not respond to passivating treatments without prior cleaning by pickling in a 3% HF-10% HNO_3 solution.

Pretreatment of Plastics

Plastic materials must be cleaned with the appropriate solvents or detergent solutions and rinsed. Next, they should be pre-exposed for 16 to 24 hours in the H_2O_2 solution in which they will be used.

Discussion

Another method which effectively reduces the decomposition is the addition of sodium stannate to H_2O_2 in about 2.0 ppm concentration. This treatment is effective in reducing decomposition after refilling a container with fresh stannate-free H_2O_2 .

In general, the acceptability of a material for H_2O_2 service is based mostly upon the amount of active oxygen that is lost by decomposition rather than upon a corrosion rate of the construction material. Accordingly, the "class" ratings used for materials for H_2O_2 have been based on decomposition limits. Table 27 describes these limits in detail for four classes of materials. The table lists the material in each class immediately under the description.

Aluminum, some of its alloys, tantalum, and zirconium are the only metals included in Class 1.

Many aluminum alloys, stainless steel alloys, silicon, and tin fall into Class 2.

Class 3 contains other aluminum alloys, a variety of stainless steel alloys, Inconel X, Alloy H-075, and Refractalloys 26 and 70.

In general, the presence of copper in an aluminum alloy greatly reduces its compatibility with H_2O_2 . The 1060 alloy is most widely used in 90 percent H_2O_2 service; however, several other alloys are considered to be Class 1 materials.

The attack of an aluminum alloy is usually of the smooth overall type, but pitting occurs

occasionally. Pitting is usually attributed to the presence of impurities which cause local breakdown of the H_2O_2 . Chloride ions also accelerate the pitting attack. The addition of small amounts of nitrate ion, such as sodium nitrate, tends to reduce the action of the chloride ion. However, the presence of 10 mg Cl^- per liter causes accelerated attack even with nitrate present. Anodizing of the metal also reduces the attack by H_2O_2 with chloride, but damage of the anodic coating localizes the pitting in the damaged area. The addition of compounds to H_2O_2 which change the pH in either direction from the neutral point may accelerate attack.

Galvanic coupling of aluminum to stainless steel results in increased attack on the aluminum. Chloride ions in turn increase the galvanic effect.

Many of the higher strength aluminum alloys are not compatible with H_2O_2 ; therefore, one alternative is to use a strong alloy clad with a compatible grade. Of course, special attention must be given to welds, to insure complete covering of the base alloy.

Many cases of decomposition of H_2O_2 in aluminum or other compatible metals is traced to soluble or suspended contamination of the H_2O_2 and not to an effect of the container material.

The table shows that the 300 series stainless steels cannot be rated as Class 1, but give very good Class 2 service. The 300 series steels are used for high-pressure flowing systems and may be welded. Chloride contamination, at the 10-mg-per-liter level, does not appear to cause pitting in stainless steels. The galvanic effect in aluminum-stainless steel couples tends to protect the steel. The 17-7PH grades of stainless steel are satisfactory with H_2O_2 , but the 400 series is not. A 120-grit finish on the 17-7PH steels improved their service.

Lower concentrations of H_2O_2 (52 to 90 percent) require the same materials of construction as 90 percent H_2O_2 . Higher strength peroxide (98 percent) is, in general, more stable than 90 percent H_2O_2 in contact with metals. Aluminum alloys 1060, 5052, and 7072 are rated Class 1. Stainless steels Types 304, 316, and 347, and aluminum alloys 6061 and 356 are rated Class 2.

In the transporting of high-strength H_2O_2 , 1060 aluminum has been used in tank cars and 43 aluminum or 300 series stainless steels in self-priming centrifugal pumps, while valves, fittings, and instruments are usually made of 300 series stainless steel. (208)

Of the plastics and rubbers, molded Teflon, Kel-F, and Mylar B are rated Class 1 (unrestricted use). Koroseal 700 has been used extensively as gasketing material. Many lubricants exhibit impact sensitivity in H_2O_2 . The fluorinated and chlorinated lubricants appear most promising with a Class 2 rating and no impact sensitivity. Compatibility data for nonmetals in H_2O_2 are presented in Table 28.

METHYLENE CHLORIDE (CH_2Cl_2)*

Methylene chloride is a colorless liquid. It boils at 104 F and exerts a vapor pressure of 380 mm at 72 F. The toxicity threshold limit for CH_2Cl_2 in the atmosphere is 500 .

*Methylene chloride: see References 127, 129, and 211.

Liquid methylene chloride is compatible with copper, steel, austenitic stainless steels, Hastelloy B, Hastelloy C, asbestos, and graphite. Gaseous methylene chloride is more corrosive, being compatible with Northite and Durimet 20. Compatibility data are summarized in Table 29.

NITRIC ACID (HNO_3)*

The nitric acid used for propellants is usually in the concentrated form referred to as "fuming nitric acid". In general, the fuming acids contain less than 5 percent water. If the acid contains dissolved oxides of nitrogen, it is known as "red fuming nitric acid" or "RFNA". The NO_2 content normally varies from 7 to 30 percent.

Nitrogen dioxide is not present in "white fuming nitric acid" or "WFNA", which contains a minimum of 97 percent HNO_3 .

Hydrofluoric acid may be added to either RFNA or WFNA as a corrosion inhibitor. Listed below are the Military Specification compositions of inhibited and noninhibited acid (MIL-N-7254 C, July 19, 1956):

	<u>White Fuming Nitric Acid</u>	
	<u>Type I</u>	<u>Type I A (WFNA)</u>
Nitric acid (HNO_3)	97.5% min.	96.8% min.
Nitrogen dioxide (NO_2)	0.0 + 0.5%	0.0 + 0.5%
Water (H_2O)	2.0% max.	2.0% max.
Hydrofluoric acid (HF)	0.0	0.6 ± 0.1%
	<u>Red Fuming Nitric Acid</u>	
	<u>Type III</u>	<u>Type III A (RFNA)</u>
Nitric acid (HNO_3)	82.0 - 85%	81.3-84.5%
Nitrogen dioxide (NO_2)	14.0 ± 1.0%	14.0 ± 1.0%
Water (H_2O)	2.5 ± 0.5%	2.5 ± 0.5%
Hydrofluoric acid (HF)	0.0	0.6 ± 0.1%

Red Fuming Nitric Acid

Red fuming nitric acid is a highly corrosive material; therefore, the choice of construction materials is based upon the corrosion resistance of the material rather than on the catalytic decomposition of the acid. Aluminum and stainless steel alloys are usually used to handle RFNA. The compatibility data in Table 30 indicate that at room temperature, the corrosion rate for aluminum alloys is slightly higher than for the 300 series stainless steels. It should be noted that at 160 F, aluminum alloys are more resistant than stainless steels. Stainless steels and aluminum alloys are usually attacked in a uniform manner. However, selective attack in the heat-affected zone near welds is sometimes produced. Knife-line attack at welds may occur in aluminum alloys above 120 F. The 1060 alloy appears to be free from this attack to higher temperatures. The low-carbon grades of the 300 series stainless steels and those containing columbium or titanium are less susceptible to attack at welds than are the regular grades. Aluminum, when coupled to stainless steel, acts as a sacrificial anode to protect the steel.

*Nitric acid: see References 18, 19, 29, 30, 32, 39, 64, 69, 81, 82, 87, 89, 93, 95, 96, 97, 102, 104, 110, 127, 128, 130, 133, 135, 150, 151, 179, 181, 185, 188, 189, 190, 192, 193, 198, 204, 211, 214, 221, 222, 223, 239, 240, 241, 242, 248, 260, 287, 298, and 300.

As little as 0.1 percent HF added to RFNA greatly reduces the corrosion rate of both aluminum and stainless steel. If this change from RFNA to IRFNA is made in stainless steel equipment and selective attack has already started, the inhibitors are not effective. The HF inhibitor reduces the selective attack at welds, permitting use at higher temperatures.

Titanium and tantalum are both resistant to RFNA; however, caution must be used with the titanium alloys. A pyrophoric reaction may occur with titanium alloys in RFNA which contains less than 1.5 to 2.0 percent H_2O . Both titanium and tantalum are attacked much more rapidly by IRFNA than by the acid without the HF addition.

A number of other alloys are compatible with red fuming nitric acid. These include cobalt alloys, Types 430 and 446 stainless steels, chromium, and for some applications, nickel and some nickel alloys. Platinum, gold, tin, and zirconium may be used. Low-alloy steels, lead, copper, and magnesium are rapidly attacked by either RFNA or IRFNA.

White Fuming Nitric Acid

White fuming nitric acid is similar to red fuming nitric acid with respect to compatibility with construction materials. It is not so stable as RFNA, but compatibility is largely dependent upon corrosion properties rather than on decomposition.

The corrosion behavior of metals in white fuming nitric acid is much the same as that in RFNA. The same materials are resistant and the same materials are severely attacked. However, Table 31 shows that the temperature limits are somewhat lower in the white fuming nitric acid.

Concentrated Nitric Acid

Table 32 has been included to show the compatibility of materials in somewhat less concentrated acids than the fuming grades. It can be seen that acids from 80 percent up to the fuming range are much more corrosive than the more concentrated ones. Stainless steels are the best materials of construction for these acids.

NITROGEN TETROXIDE (N_2O_4)*

Nitrogen tetroxide is an equilibrium mixture of dinitrogen tetroxide and nitrogen dioxide ($N_2O_4 \rightleftharpoons 2NO_2$). It is a heavy brown liquid that boils at 70.1 F. The liquid causes severe burns on body tissue. The toxicity threshold-limit value in the atmosphere is 5 ppm as NO_2 or 2.5 ppm as N_2O_4 .

Much of the information on properties and compatibility of N_2O_4 is summarized in the Titan II Storable Propellant Handbook. (167,168,169)

Dry (less than 0.2 percent H_2O) nitrogen tetroxide can readily be contained by several metals and their alloys. It is normally handled in aluminum, mild steel, cast iron, or stainless steel, although there have been reported instances of intergranular attack in welded 2014-T6 aluminum. Compatibility data are summarized in Table 33.

*Nitrogen tetroxide: see References 3, 9, 10, 11, 12, 13, 23, 31, 47, 48, 49, 50, 59, 72, 81, 82, 88, 102, 110, 126, 131, 137, 145, 151, 165, 166, 167, 168, 169, 170, 171, 172, 173, 174, 181, 196, 198, 205, 211, 220, 221, 245, 256, 257, 287, 288, and 292.

Titanium is resistant to N_2O_4 except under impact. It has been found that titanium impacts sporadically under reasonably well controlled test conditions; the ignition frequency is increased markedly by titanium filings or glass particles on the impact surface; increasing the impact-energy level increases the ignition frequency; and increasing the water content of the N_2O_4 to 2 to 5 percent lowers the ignition frequency. (256,257,292) The ignitions do not spread beyond the impact area.

Moist N_2O_4 is, in general, more corrosive because of the nitric acid formed. As shown in Table 34, at levels of up to 1 percent moisture in N_2O_4 , most common metals are still Class 1 at room temperature. With 3.2 percent moisture in N_2O_4 the corrosion resistance of steel and aluminum alloys drops off markedly even at slight increases in temperature. Data for the latter are summarized in Table 35.

Limited data on the compatibility of materials with flowing N_2O_4 are presented in Table 36.

The most resistant plastic materials are polymerized fluorinated hydrocarbons such as Teflon and unplasticized Kel-F. Other plastics such as Koro-seal, Saran, polyethylene, and Tygon are suitable for short-time exposures. Vinyl plastics, in general, do not hold up well in N_2O_4 .

Asbestos and graphite are satisfactory for packing materials and graphite-waterglass for thread compound.

Impact tests at 60 ft-lb in liquid N_2O_4 have resulted in detonations of polydimethylsiloxane. Similar tests at 70 ft-lb did not cause detonation in polychloroprene, branched or linear polyethylene, polypropylene, polyvinylidene fluoride, polyvinylidene fluoride-hexafluoropropylene copolymer. (126)

OXYGEN*

Oxygen is a light blue transparent liquid at -297.4 F. In the liquid state it can cause "burns" if spilled on the skin. Oxygen supports combustion and accidental contact should be avoided with oxidizable materials.

Of the elemental materials, oxygen is next to fluorine in reactivity. It will form compounds with all elements except the rare gases. However, the reactivity of liquid oxygen is very low compared with that of gaseous oxygen.

Liquid oxygen is considered to be noncorrosive to most metals. In particular, nickel, Monel, Inconel, copper, aluminum, the 300 series of stainless steels, brass, and silver solder are used in liquid-oxygen-handling equipment.

Several instances have been reported of violent reactions of titanium and liquid oxygen which appeared to be related to impact. The impact sensitivity of titanium in LOX has been investigated rather extensively.** It appears that the ignition of titanium under impact occurs in the following sequence: (139,140)

* Oxygen: see References 1, 5, 6, 7, 8, 21, 22, 25, 26, 27, 33, 42, 43, 45, 65, 66, 67, 71, 78, 80, 81, 82, 98, 102, 107, 125, 126, 138, 139, 140, 141, 142, 151, 176, 177, 180, 181, 195, 198, 209, 211, 218, 231, 232, 235, 236, 255, 259, 262, 284, and 285.

** Ignition in LOX: see References 7, 22, 27, 42, 43, 65, 66, 71, 78, 126, 138, 139, 140, 141, 142, 176, 177, 180, 198, 218, 235, and 236.

- (1) The impact exposes fresh metal and results in some gaseous oxygen being formed at the point of impact.
- (2) The gaseous oxygen reacts with the fresh metal in an exothermic reaction.
- (3) The heat generated raises the metal temperature sufficiently to result in localized dissolution of any TiO_2 film that might form.
- (4) Thus a protective oxide film does not build up and the reaction proceeds rapidly between the base metal and oxygen.

Ignition of massive titanium is observed in gaseous oxygen at liquid-oxygen temperatures at pressures of about 100 psi and above. This critical pressure limit is lowered only slightly as the temperature of the oxygen is raised to ambient temperature.

Massive aluminum exhibits ignition under severe detonation in LOX. The frequency is not so great nor is the propagation so severe as it is with titanium under the same conditions. Magnesium also ignites under detonation at shock levels higher than those for titanium but lower than those for aluminum.

Organic materials should be avoided with both liquid and gaseous oxygen because of possibilities of explosions. Currently, there is no single test or group of tests which gives a reliable compatibility rating for organic materials in liquid oxygen service. It is recommended that organic materials be avoided wherever possible and used only with caution. No completely compatible lubricants have been found. Thread antiseize sealants of graphite in chlorinated organic carrier and halogen paraffin oils with pour points as low as -100 F have been used in LOX systems. Teflon, Mylar, and certain chloroprene and Buna-N compounds have been used as static seals while Kel-F-300, Kel-F-500, Kel-F-240, Fluorothene FYTD, Fluorothene FYTS, and certain chloroprene and Buna-N compounds have been used in dynamic seals. (284,285)

Many organic and plastic materials exhibit impact sensitivity in LOX including: (71,126)

- (1) Synthetic elastomers and Thiokols
- (2) Cellulose-based papers
- (3) Silicone- and silicate-based oils and greases
- (4) Thermoplastics such as nylon and phenolics
- (5) Thermo-setting resins (phenolics, silicones, epoxies, etc.)
- (6) Petroleum-based oils and greases.

The fluorocarbon plastics are probably the best choice with respect to impact sensitivity. These, however, should not be used with aluminum. A number of other organic materials might be used, but specific conditions should be carefully studied. The list of references on ignition in LOX contains the results of many impact tests on organic materials, which can be used as a guide to selection.

OZONE

Ozone is colorless in gaseous and liquid state. It boils at -168 F. The toxicity threshold-limit value for ozone in the atmosphere is 0.1 ppm.

There are few data on the compatibility of materials with ozone. It has been shown that 100 percent gaseous ozone can be stored up to 50 days at 5 atm pressure and dry ice temperature (-109 F) in stainless steel, aluminum, and glass with no decomposition of the ozone. (280)

SOLID PROPELLANTS

ANP-2639AF

There are few or no data published in the open literature on the compatibility of materials with solid propellants. Bent beam specimens of the following materials bonded to propellant ANP-2639AF and stressed to 75 percent of the 0.2 percent off-set yield strength have survived over 100 days' exposure at room temperature and 180 F. (289)

Ladish D6AC
300 M
Vascojet 1000
AM-355 (longitudinal)
PH 15-7Mo
BI20VCA titanium
(longitudinal and transverse)

Nitronium Perchlorate (NO_2ClO_4)

Nitronium perchlorate is a white crystalline powder at room temperature which has a faint odor of chlorine and nitrogen oxide. Its vapor pressure is less than 0.05 mm at 68 F. It melts and decomposes at 250 to 285 F.

The following materials are reported to be compatible with nitronium perchlorate: (55)

Metals:	stainless steel (mild steel if system is dry)
Nonmetals:	glass, Teflon, unplasticized polyvinyl chloride, polyethylene
Lubricants:	Hooker Fluorolube Grease GR-54 Hooker Fluorolube Oil X-30 3M Kel-F Polymer Oil, Grade No. 1 Halocarbon Oil Series B-21.

TABLE 3. COMPATIBILITY OF MATERIALS WITH AMMONIA

Material	Temperature, °F								References
	Gas				Liquid				
	Class 1	Class 2	Class 3	Class 4	Class 1	Class 2	Class 3	Class 4	
Metals									
Aluminum	212	100	175	>175			175	175	211, 224, 287
302 Stainless Steel	75			<900					82
304 Stainless Steel	600			<900					58, 73, 109, 217, 221, 287, 288, 3, 217, 221
316 Stainless Steel	400			<900					221
347 Stainless Steel			75						109
410 Stainless Steel	600			800					58, 73, 221
430 Stainless Steel	600			<900					58, 73, 221, 221
Marbrite	75			<900					82
Durimet 20	75			<900					221
Carpenter 20	600			<900					58
Mild Steel	600			<900		75			211, 221, 287
Cast Iron	600			<900		75			211, 221, 287
St-Iron	212	75					75		211, 287
Mt-Cast Irons, Low Cu	75					160			211, 287
Mt-Cast Irons, High Cu	75								All 211, 287
Nickel	500		500	<1100					75
Inconel	700		1100	<1100		75			211, 221, 287
Monel	500		500	<1100					75
Hastelloy A	600	600		<1100					58, 127, 128, 211
Hastelloy C	600	600		<1000					58, 127, 128, 211
Hastelloy D	600	600		<1000					58, 127, 128, 211
Hastelloy F		600		<1000					127, 128
Chlorimet 2-1	75								221
Nickel-Copper	75								82
Copper		75		High					Low 127, 217, 221, 287
Yellow Brass		75		High					Low 127, 221, 287
Red Brass		75		High					Low 127, 221, 287
Tin Bronze		75		High					Low 127, 221, 287
Al Bronze		75		High					Low 127, 221, 287
Si Bronze		75		High					Low 127, 221, 287
Cu-Nickel		75		High					Low 82, 127, 221, 287
Gold	212				High				211, 221
Lead		75		>160		75			211
Dow Metal C		Low							82
Dow Metal F		Low							82
Dow Metal H		Low							82
Dow Metal J		Low							82
Dow Metal M		Low							82
Platinum	212				High				211, 221
Ir-Platinum	High				High				221
Rh-Platinum	High				High				221
Silver	75								211
Ag-Cu					All				82
Titanium	175								211
Tantalum	212				High	212		High	221
Zinc	75								211
Zirconium	175								211
Organic Materials									
Rubber, Hard Linings				75					82
Rubber, Soft Linings				75					211
Rubber, Natural		75		Hot					82
GRS		75		Hot					82
Neoprene		75		Hot					82
Butyl Rubber		75		Hot					82
Thiokol			Cold						82
Glass Fabric and Silicone Elastomers*		Hot							82
Silicone Greases		Hot							82
Neveg 41 Epon	212								211
Silicone Elastomer		75							82
Silicone Resins									82
Teflon		Hot							82
Corb									82
Vinyl Copolymers		Hot				Hot			82
Phenolics		Hot				Hot			82
Purans		Hot				Hot			82
Polyethylene		Hot				Hot			82
Kel-F		Hot				Hot			82
Vinylidene Chloride			Cold				Cold		82
Sulfur Cement			Cold				Cold		82
Bituminous Composition			Cold				Cold		82
Polystyrene				75					211
Polyesters				75					211
Phenol Formaldehyde				75					211
Nonmetals									
Glass	212								211
Stoneware	212								211
Silicate	>2000								82
Carbon	>2000								82
Graphite	>2000								211

* Glass Fabric and Silicone Rubber

TABLE 4. COMPATIBILITY OF MATERIALS WITH HI-Cal-3 (82)

Material	Remarks
Class 1	
Mild steel	Below 120 F, probably higher
40/50 carbon steel	Below 120 F, probably higher
Hot-rolled primer steel	Below 120 F, probably higher
Type 304 stainless steel	Below 120 F, probably higher
Beryllium copper	Below 120 F, probably higher
Cupro-nickel	Below 120 F, probably higher
Naval brass	Below 120 F, probably higher
Phosphor-bronze	Below 120 F, probably higher
Phosphorized copper	Below 120 F, probably higher
Nickel	Below 120 F, probably higher
Inconel	Below 120 F, probably higher
Monel	Below 120 F, probably higher
Niobel	Below 120 F, probably higher
Incoloy	Below 120 F, probably higher
Aluminum	Below 120 F, probably higher
Lead	Class 2 at 120 F
Titanium	Below 120 F, probably higher
Tantalum	Below 120 F, probably higher
Class 2	
Organics	
Bakelite	No change at 120 F
Easton PVC plastic pipe	No change at 120 F
Epoxy resin	No change at 120 F
Graphite bearing	No change at 120 F
Kel-F 300	No change at 120 F
Kel-F 500	No change at 120 F
Teflon	No change at 120 F
Hycar 1001-520-39-5-4	No change at 120 F
Viton 4411A-58	No change at 120 F
Hycar 1000x88-520-39-20-3	No change at 120 F
Hycar 1001-520-37-83-1	No change at 120 F
IF4 Fluororubber	No change at 120 F
LS-53 Fluorosilicone rubber	Slightly less resilient at 120 F
Hycar 1001-520-37-83-5	No change at 120 F
X-Pando pipe dope	No change at 120 F
Nylon Zytel 101-KC-10	No change at 120 F
Class 3	
Organics	
Hycar 1001-520-39-5-2	120 F, Slightly stiffened
Polyethylene tubing	120 F, Turns yellow
Garlock 8748 (Buna-W binder)	120 F, Stiffened
Garlock 7021 (GRS - high sulfur binder)	120 F, Stiffened and roughened
Garlock 900 (GRS binder)	120 F, Stiffened
African Blue Asbestos packing	120 F, Darkened
Teflon asbestos packing	120 F, Weight gain
Class 4	
Organics	
Hycar 1001-520-39-5-3	120 F, Blistered
Compressed asbestos gasket	120 F, Fibers loosened
Garlock 7228 (neoprene binder)	120 F, Blistered
Hycar 1042-520-24-144-1	120 F, Brittle, crazed
Tygon tubing	120 F, Hardened
Garlock 7705 (GRS - blue asbestos)	120 F, Stiffened
Plexiglas	120 F, Became soft and sticky
Fairprene 5051 (neoprene on duck)	77 F, Stiffened
Fairprene 5039 (neoprene on nylon)	77 F, Became brittle
Natural rubber	120 F, Softened, easily torn
National 846, O-ring	120 F, Stiffened
Neoprene	120 F, Softened
Hycar 1001-520-39-5-1	120 F, Stiffened
Hycar 1001-520-39-5-3	120 F, Stiffened
Silicone rubber	120 F, Deteriorated to a powder

TABLE 5. COMPATIBILITY OF MATERIALS WITH PHTHALONITRILE (204)

Material	Temperature, F								References
	Gas				Liquid				
	Class 1	Class 2	Class 3	Class 4	Class 1	Class 2	Class 3	Class 4	
Metals									
Aluminum, 2024 T-3					75				
Aluminum, 3003 H-14					75				
Aluminum, 5052 H-14					75				
Aluminum, 6061 T7-6					75				
Aluminum, 7075 T-6					75				
Aluminum, 356 T-6					75				
Aluminum, Chromated					75				
Cadmium-Plated Steel					75				
Cadmium-Coated Aluminum					75				
Copper					75				
Brass					75				
Iron					75				
Steel					75				
302 Stainless Steel					75				
304 Stainless Steel					75				
321 Stainless Steel					75				
347 Stainless Steel					75				
Magnesium Alloy, Fed QQ					75				
Nickel					75				
Nickel Alloy, X125H					75				
Titanium, C-110H					75				
Titanium, C-130H					75				
Nonmetals									
Asbestos, Graphite					75				
Asbestos, Hercules No. 571 K					75				
Pure Carbons					75				
Graphite, No. 39					75				
Nylon					75				
Nylon A					75				
Nylon B, No. 500C					75				
Polycarbonate and Glass Cloth					75				
Polystyrene					75				
Fluorinated Rubber					75				
Foamglass									75
Dow Corning R-7502 Foam									75
Dow Corning R-7003 Foam									75
Mopco F 10 Foam									75
Mopco B 40									75
Natural Rubber									75
Nitrile Rubber or Nylon									75
Dow Corning 9483 Rubber									75
Low-Density Plastic 25G									75
Low-Density									75
Baron									75
Nylon									75
Nylon									75
Nylon									75
Nubatek G-20/27N									75
Nubatek A-103J									75
Pierreflex, No. XSR									75
Pierreflex, No. 51P									75
Dow Corning Silastic									75
No. 80-24-48C									75
General Silastic No. 240									75
Lubricants									
Rockwell Nordtron Lube					75				
No. 92					75				
Molybdenum Disulfide					75				
Rockwell Nordtron Lube									75
No. 833									75
Rockwell Nordtron Lube									75
No. 8-21									75
Rockwell Nordtron Lube									75
No. 840									75
Rockwell Nordtron Lube									75
No. 356									75
Rockwell Nordtron Lube									75
No. 824G									75
Rockwell Nordtron Lube									75
No. 8-20									75
Rockwell Nordtron Lube									75
No. 942-B									75
Water-Based Lubricants									75

TABLE 6. COMPATIBILITY OF MATERIALS WITH FLUORINE

Material	Temperature, F								References
	Gas				Liquid				
	Class 1	Class 2	Class 3	Class 4	Class 1	Class 2	Class 3	Class 4	
Metals									
Aluminum 1100	500	600	800	<673	-320			-310	7,73,132, 143,153,159, 207,211,274
Aluminum 2017						-320		-310	143
Aluminum 3003	700	>1000	1000	>1000		-320		-310	120,143
Aluminum 5052	700	700	1000	>1000		-320		-310	120,274
Aluminum 5154	700	>1000	1000	>1000		-320		-310	143,274
Aluminum 6061						-320		-310	153
Aluminum 7075						-320		-310	274
Beryllium				75					269
304 Stainless Steel	400	400	500	>900	-320	-320	-310		58,211,274
304 L Stainless Steel	270		400	>900					143
309 Stainless Steel	570		750						7
309 Co Stainless Steel	500		750	>900					207
316 Stainless Steel	570	660	750						7,207
321 Stainless Steel	400				-320				58,211,274
347 Stainless Steel	390	570	750		-320		-310		120,274
410 Stainless Steel				75	-320		-310		58,153,211
430 Stainless Steel	400	400	500	600	-320				7,207,211
Carpenter 20	400				-320				58
PH15-NiFe					-320				153,274
AM-350-C					-320				274
AM-350-CK					-320				274
AM-350-D					-320				274
AM-350-DE					-320				274
Cast Iron				75					211
Armco Iron	750		500	>900					7,159,163,207
Stellite Iron				75					211
Iron (S.304S1)		200	400	>900					159,160
Iron (S.74S1)		100	300	>900					159,160
Sheet Steel	750	840		930					7
SAE 1010	100	200	400	>900			-310		207
SAE 1015	300	400	570	>900					7,159,163, 207,211
SAE 1020	390			930					7,159
SAE 1130	750		840	930					7,159
Carbon Steel	750		840	930					82
Mild Steel		570							7
Al-Nickel	1200	900	1300	>1300	-320		-310		7,73,120,143 153,159,160, 211,274
Al-Nickel		1200	1300	>1300			-310		82
Nickel (Low Carbon)	1100	1200	1300	>1300					82
Nickel (Electrolytic)	1100	1200	1300	>1300					82
Dynalene	1100	1200	1300	>1300					82
Monel	1200	1300	1400	>1400	-320	-320	-310		7,73,143, 153,159,160, 207,211,274
Cast Monel	400	800	1000	>1000			-310		82
Al-Nickel	600	800	1200	>1200			-310		82
Inconel	930	1170	500	>900			-310		7,207,211
Hastelloy B		75	212						58,127,128, 211
Hastelloy C	95		212						58,127,128, 211
Hastelloy D			212						58,211
Copper	200	400	800	>800	-320		-310		7,153,159, 207,211,274
Deoxidized Copper		230	1290						7
Copper ETP	200	400	800	>800					82
Brass (70-30)	200								159,160
Brass (Red)	230	400	600	>600			-310		73,211
Brass (24)	230		500	>900					82
Brass (Low-leaded)					-320				120
Brass (Yellow)					-320				274
Brass (Cartridge)					-320				274
Brass (Castings)									73,159,160, 211
Brass	200	400	700						73,159,160, 211
Copper-Nickel	200	400		>800	-320				155
Copper-20% Nickel					-320				274
Copper-30% Nickel					-320				274
Everdur 1010					-320				274
Chromium Plate	400								159,160
Lead			100	>100					211
Magnesium		500	700						82
Magnesium M1A	653	<1000							143
Magnesium AZ1A-T6	691	<1000							143
Magnesium ZK21G-T6		400					-310		82
Magnesium AZ91G-T6	<1000								143
Magnesium HE-31			1100		-320				82
Magnesium HE-31A-M24							-310		82
Magnesium HE-31 (Coated with Dow-17)							-320		274
Magnesium HE-31					-320				153,274
Magnesium AZ-31					-320				274
Magnesium AZ-31 (Coated with Dow-17)					-320				274
Magnesium MA (1.205n)		200							159,160
Magnesium PS-1A		200							159,160
Magnesium J-1H	140								159,160
Magnesium H-1A		600	1000				-310		82
Magnesium Dow Metal G	570	600							7,207

TABLE 6. (Continued)

Material	Temperature, F								References
	Gas				Liquid				
	Class 1	Class 2	Class 3	Class 4	Class 1	Class 2	Class 3	Class 4	
Molybdenum	212			75					94, 199
Platinum	212								211
Gold	212								211
Silver	700								211
Silver Solder (Eutectic)		100							82
Tantalum	212		100	>100			-310		211
Ti-6	212		100	>100					211
Titanium A-35	212	100		>350					211
Titanium A-70									211
Titanium Alloy 6Al-4V		250			>325 (+/- 325)				211
Titanium A-110AT					>325 (+/- 325)				211
Titanium Alloy B-120VCA		300		>350					211, 274
Titanium Alloy 16V-2 Sn		300							86, 153, 274
Titanium Alloy 8Al-8Sn		300							86
Titanium 70%									86
Columbium				75					86
Zirconium		100	400	>700					86
Stainless Steel			400	>700			-310		86
ORGANIC MATERIALS									
Rub. (Al ₂ O ₃)	75	140							225, 226
Alumina	392	1400							159, 160
Alumina		1400							82
Sintered Alumina		1400							82
Refractory Alumina		1400							82
Activated Alumina		400		>400					82
Soda Glass	212	300		>300					211
Pyrex	212	400		>400					211
Silica		480		>480					82
Titanite		100							159, 160
Alabaster		100							82
Amorphous Carbon		400		>400					159, 160
Metal Fluorides		No limit							82
CaF ₂ -Al ₂ O ₃ Based	400	400		>400					159, 160
Sulfur Carbons				>32					82
ORGANIC MATERIALS									
Alcohols									225, 226
Kel-F No. 10		ORT							225, 226
M-43 (Glycol) 3N		ORT							225, 226
Carboxylic Acid			All temp						159, 160, 211
Glycol			All temp						211
Oil-Containing Fluids 200			All temp						225, 226
Utility Solvent 178			All temp						225, 226
Lean Ice			All temp						225, 226
Carbon Tetrachloride			All temp						159, 225, 226
GLASSES AND POLYMERS									
Kel-F Mod. Max		ORT							225, 226
Kel-F No. 1 Grease		ORT							225, 226
Fluoropolymer LG and MG		ORT							225, 226
Paralene No. 3		ORT							225, 226
Quelac		ORT							225, 226
Blue Gelp		ORT							225, 226
Mylar		ORT							225, 226
Plastic-Seal		ORT							225, 226
Paralene Nos. 1 and 2		All temp							225, 226
White Lead		All temp							225, 226
RESINS									
Kel-F	390 (d)		>390						225, 226
Kel-F	RT		>RT						225, 226
Nacryl (Glass Filled)			>RT						225, 226
Nacryl		All temp							225, 226
Rubber	75		All temp						159, 160, 211
ORS Rubber			All temp						82
PVC			>RT						225, 226
Plastic			>RT						225, 226
Typ-F			>RT						225, 226
Permalloy POC and PCI			>RT						225, 226
Polystyrene			All temp						225, 226
Polyethylene			All temp						225, 226
Oil-Containing Elastomer			All temp						225, 226
Mylar No. 2			All temp						225, 226
Urethane and Glycol			All temp						225, 226
Phenolic Plastic (F-100)			All temp						225, 226
Phenolic Cement			All temp						225, 226
Phenol Formaldehyde			75						225, 226
Polyethyl Alcohol			All temp						82
Polyethyl Methacrylate			All temp						82
Polyethylene			All temp						82
Polyester			All temp						225, 226
Graphite			All temp						159, 211, 215
Pressed Carbon (C-1)	75								274

(a) See Reference 82 also.

(b) Glass is Class 4 at all temperatures if fluorine is contaminated with hydrofluoric acid.

(c) Titanium alloys exhibit impact ignition but flame does not propagate.

(d) Material is pressure sensitive. Class 2 below 390 F and 15-psi pressure. Higher pressures can be tolerated at room temperature.

TABLE 7. COMPATIBILITY OF MATERIALS WITH FLOX

Material	Temperature, F								References
	Gas				Liquid				
	Class 1	Class 2	Class 3	Class 4	Class 1	Class 2	Class 3	Class 4	
FLOX-40 (40% F ₂ -60% O ₂)									
Aluminum, 2014-T6					-320				224, 266
Aluminum, 5052-H34					-320				266
Aluminum, 6061-T6					-320				266
4340 Steel					-320				266
301 Stainless Steel					-320				266
304 Stainless Steel					-320				266
347 Stainless Steel					-320				266
Ni-60					-320				266
Inconel X					-320				266
Teflon PTFE	RT								267
Teflon PMP	RT								267
Kel-F 81	RT								267
Armalon POK 7700				RT					267
Asbestos-Stainless Steel Gasket				RT					267
Oxylic TGI on 347 SS						-320			82
FLOX-20 (20% F ₂ -80% O ₂)									
Aluminum, 2014					-320				224
Cadmium Plated 4137 Steel					-320				224
Oxylic TGI on 347 SS						-320			224

TABLE 8. COMPATIBILITY OF MATERIALS WITH OXYGEN DIFLUORIDE (OF₂) (224)

Material	Temperature, F								References
	Gas				Liquid				
	Class 1	Class 2	Class 3	Class 4	Class 1	Class 2	Class 3	Class 4	
Metals									
Aluminum, 1100-C	-109				-109				
Aluminum, 2014-T6	-109				-109				
Aluminum, 2024-T351	-109				-109				
Aluminum, 2219-T6	-109				-109				
Aluminum, 5456-H343	-109				-109				
Aluminum, 6061-T6	-109				-109				
Aluminum, 7070-T6	-109				-109				
Aluminum, 7079-T6	-109				-109				
Stainless Steel, 301	-109				-109				
Stainless Steel, 316	-109				-109				
Stainless Steel, 347	-109				-109				
Stainless Steel, 410	-109				-109				
PHS-7M	-109				-109				
Al-350	-109				-109				
Al-355	-109				-109				
Nickel 200	-109				-109				
Nickel 400	-109				-109				
Inconel X	-109				-109				
Wasp 45	-109				-109				
Duralco, 40	-109				-109				
Duralco 40 with Electroless Ni Plate	-109				-109				
Copper	-109				-109				
Brass 7030	-109				-109				
Titanium, A-110AT	-109				-109				
Titanium, 6AL-4V	-109				-109				
Columbium	-109				-109				
Tantalum	-109				-109				
Magnesium	-109				-109				
Nelco 100 FEP	-109				-109				
Nelco 827 FEP	-109				-109				
Fluoroflex I Teflon	-109				-109				
ral-F 542V	-109				-109				
Graphite AGSP	-109				-109				
Dynalco 701 on 347 SS	-109				-109				

TABLE 9. COMPATIBILITY OF MATERIALS WITH 75 PERCENT OF₂ 20 PERCENT OF₂ (1 ATMOSPHERE)(124)

Material	Temperature, F								References
	Gas				Liquid				
	Class 1	Class 2	Class 3	Class 4	Class 1	Class 2	Class 3	Class 4	
<u>Metals</u>									
Aluminum, 2024-T4	212								
Aluminum, 2017-T8	212								
Copper	212								
Brass	212								
Mild Steel	212								
303 Stainless Steel	212								
304 Stainless Steel	212								
316 Stainless Steel	212								
318 Stainless Steel	212								
Niobium	212								
Lead	212								
Magnesium, Domestic, FS14	212								
Magnesium, Domestic, FS1A	212								
Magnesium, Domestic, MA	212								
Nickel	212								
Ni Monel	212								
P Monel	212								
304 Monel	212								
5 Monel	212								
6 Monel	212								
CR Monel	212								
Inconel	212								
Hastelloy D	212								
Platinum	212								
<u>Nonmetals</u>									
Teflon	212								
Kel-F			212						

TABLE 10. COMPATIBILITY OF MATERIALS IN OZONE DIFLUORIDE-LIQUID OXYGEN (CLASS 3 OF 2 - BALANCE LOX)(83)

Material:	Temperature, F								References
	Gas				Liquid				
	Class 1	Class 2	Class 3	Class 4	Class 1	Class 2	Class 3	Class 4	
304 Stainless Steel	-297				-297				
316 Stainless Steel	-297				-297				
304 Stainless Steel	-297				-297				
316 Stainless Steel		-297				-297			
316L-Ti	-297					-297			
AM-356	-297				-297				

TABLE 11. COMPATIBILITY OF MATERIALS WITH CHLORINE TRIFLUORIDE (ClF₃)

Material	Temperature, F								References
	Gas				Liquid				
	Class 1	Class 2	Class 3	Class 4	Class 1	Class 2	Class 3	Class 4	
Metals									
Aluminum, 1000					85				111,115
Aluminum, 1100	85		644		85				111,115, 112,113, 113,211
Aluminum, 1000, Welded	85				85				111
Aluminum, 2024, Welded	85				85				111,115
Aluminum, 2024	85				85				111,115
Aluminum, 3003	85				85				111,115
Aluminum, 5052	85				85				111,115
Aluminum, 6061, Welded	85				85				111,115
Aluminum, 7075	85				85				111,115
Columbium									1105
Copper, ETP	85		500		85				111,115, 113
Copper, DHP					85				111,115
Beryllium Copper, 2% Phosphor Bronze, 98					85				111,115
Aluminum Bronze, 95	85				85				111,115
Yellow Brass	85				85				111,115, 211
Red Brass					85				111,115, 211
tin Bronze	75				85				111,115
303 Steel	85		640		85				211
304 Steel (Coated with Fosbond 40)					85				111,115
304 Steel (Coated with Fosbond 21)					85				111,115
304 Stainless Steel	85				85				111,115
304 Stainless Steel					85				111,115, 211
316 Stainless Steel	85				85				111,115
316 Stainless Steel					85				111,115
AM-300									82
A-286									82
Carpenter 20					85				82,111,115
PH15-7Mo (H 950)					85				117
PH15-7Mo (H 1050)					85				117
410 Stainless Steel (Welded)	85				85				117
304 Stainless Steel (Welded)	85				85				117
AM-300 (Welded)	85				85				117
PH15-7Mo (Welded)	85				85				117

TABLE 11. (Continued)

Material	Temperature, F								References
	Gas				Liquid				
	Class 1	Class 2	Class 3	Class 4	Class 1	Class 2	Class 3	Class 4	
Metals									
Magnesium, AZ-31B	85				85				111,115
Magnesium, HK-21A					85				111,115
Magnesium, HK-31A					85				111,115
Aluminum	85				85				111,115, 211
Monel	85				85				111,115, 211
Inconel					85				111,115
Inconel X					85				81
Incoalloy					85				111,115
Hastelloy X									82
Werk 41									82
Copper-Nickel, 90%					85				111,115
Nickel 200 (Welded)					85				111,115
Monel 400 (Welded)					85				111,115
Nickel-Silver, 18% (Alloy A)					85				111,115
Thorium									82
Titanium, 100A					75				82,111,115
Titanium, G-102AV									111,115
Titanium, A-110AT									111,115
Lithium					400				82
Zirconium					645				82
Nonmetals									
Glass									211
Pyrex Glass									82
Stoneware									211
Neoprene Rubber									111,115
Carbon, Karsate #1514									111,115
Graphite, Karsate #1514									111,115
Graphite Graphite 59									111,115
Graphite 6"									111,115
Graphite Activated									111,115
Teflon					85				111,115, 211
Kel-F									211
Polysulfone Fluoride (K-2025)					85				111,115, 115
					85				111,115

TABLE 12. COMPATIBILITY OF MATERIALS WITH PERCHLORYL FLUORIDE (ClO₂F)

Material	Temperature, F								Reference
	Gas				Liquid				
	Class 1	Class 2	Class 3	Class 4	Class 1	Class 2	Class 3	Class 4	
Metals									
Aluminum, 1060					85				111,115
Aluminum, 1100	160				85				111,115,219
Aluminum, 1100 (Welded)	85				85				117
Aluminum, 2014 (Welded)	85				85				111,115,219
Aluminum, 2024	160				75				111,115
Aluminum, 3003	160				85				111,115,219
Aluminum, 5052	160				85				219
Aluminum, 6061	160				85				117
Aluminum, 6061 (Welded)	85				85				111,115
Aluminum, 7075					85				111,115
Copper, ETP	85				85				111,115
Copper, D16					85				111,115
Beryllium Copper, 25					85				111,115
Phosphor Bronze, 85					85				111,115
Aluminum Bronze, 85	85				85				111,115
Yellow Brass	85				85				111,115
White Brass					85				111,115
101C Steel	85				85				111,115
101C Steel (coated with Passbond 40)					85				111,115
101C Steel (coated with Passbond 27)					85				111,115
Carbon Steel	160				85				219
403 Stainless Steel	85				85				111,115
43C Stainless Steel	160								219
531 Stainless Steel	160								219
202 Stainless Steel	160								219
302 Stainless Steel	160								219
304 Stainless Steel	160				85				111,115,219
310 Stainless Steel	160								219
314 Stainless Steel	160								219
316 Stainless Steel	160				85				111,115,219
321 Stainless Steel	75	160							219
347 Stainless Steel	160				85				111,115
347 Stainless Steel (Welded)	85				85				117
41C Stainless Steel (Welded)	85				85				117
41C-20C (Welded)	85				85				117
PH15-7Mo (RHPS)					85				111,115
PH15-7Mo (TH10A)					85				111,115
PH15-7Mo (Welded)	85				85				111,115
Carperite 20-40					85				111,115
Lead	75	85							219
Magnesium AZ31B		85			85				111,115
Magnesium HK21A		85			85				111,115
Magnesium HK31A		85			85				111,115
Al-Mg-Zn	160				85				111,115,219
Monel	85	85			85				111,115,219
Inconel					85				111,115
Incoloy					85				111,115
Hastelloy B	160								219
Hastelloy C	85	85			85				117
Nickel 20C (Welded)	85				85				117
Monel 40C (Welded)	85				85				111,115
Cupro-Nickel, 30%					85				219
Silver Silver	75	85							219
Nickel Silver, 10%					85				111,115
Tin	75	85							219
Titanium-100A	95	85			85				111,115,219
Titanium G-120AY	95				85				111,115,219
Zinc	75								111,115,219
Organic Materials									
Teflon	75	390							82,111,115
Kel-F	75	390							82,111,115
Phenolic Resins		390							82
Epoxy Resins		390							82
Silicone	75	85							82
Fluorocarbon Rubber (Iron Oxide Filler)		390							82,219
CRS Rubber		390							82
Kel-F Elastomer		390							82
Silicone Rubber (On Glass Cloth)		390							82
Polychlorotrifluoroethylene		390							82
Oil or Grease				85					82
Cellulose				85					82
Cellulose Acetate				85					82
Ethyl Cellulose				85					82
Gum Arabic				85					82
Melamine Formaldehyde				85					82
Methyl Styrene				85					82
Dylon				85					82
Polystyrene				85					82
Polyvinyl Chloride				85					82
Polyethylene				85					82
Polyethyl Methacrylate				85					82
Polyacrylonitrile				85					82
Polyvinyl Pyrrolidone				85					82
Polyisobutylene				85					82
Polyethylene	75			85					82,219
Nylon				85					82
Xylylene Glycol Polyester				85					82
Cellulose	75								82,219
Rayon	75				390				82,219
Plasticize	75				390				82,219
Dacron					390				82
Oxylon					390				82
Neel					390				82
Silk					390				82
Alkyl Resins					390				82
Alkyl Enamel					390				82
Modified Phenolic Resin					390				82
Silicone Glass Cloth					390				82
Varnished Glass Cloth					390				82
Varnished Paper					390				82

TABLE 13. (Continued)

Material	Temperature, F								Reference
	Gas				Liquid				
	Class 1	Class 2	Class 3	Class 4	Class 1	Class 2	Class 3	Class 4	
Butyl Rubber with Carbon					390				82
Natural Rubber					390				82
Form Rubber					390				82
Nylon Carbon Filled					390				82
Neprene Carbon Filled					390				82
Orlon Tape					390				82
Perfluorobutyl Acrylate (Carbon Filled)					390				82
Neolam Rubber (Carbon Filled)					390				82
Silicone Rubber					390				82
Neorax					390				82
Carbide Wax					390				82
Lubricant Grease					390				82
Silicone Stopcock Grease					390				82
Transformer Oil	75				390				82,219
Chlorinated Naphthalene Fluorolube	75				390				82
									82,219
Other Materials									
Kaoline Clay					390				82
Mercury					390				82
Berolite (Indicating)					390				82
Mica Board					390				82
Kraft Board					390				82
Leather	75				390				82,219
White Lead Pipe Dope					390				82
Permatex Pipe Dope					390				82
Champion Pipe Dope					390				82
Loak Back Pipe Dope					390				82,219
Paper	75				390				82
Aluminum		390							82
Activated Silica		390							82
Sodium Metasilicate		390							82
Graphite	75	85							82,219
Glass		390							82
Asbestos Paper		390							82
Transite Board		390							82
Cork	75	85							82,219

(a) Ignites under impact, but burning is not sustained.

TABLE 14. COMPATIBILITY OF MATERIALS WITH PERCHLORYL FLUORIDE CONTAINED IN AIR MOISTURE

Material	Temperature, F								Reference
	Gas				Liquid				
	Class 1	Class 2	Class 3	Class 4	Class 1	Class 2	Class 3	Class 4	
Metals									
Aluminum, 1100			85	75					111,219
Aluminum, 2024				75					219
Aluminum, 3003				75					219
Aluminum, 5052				75					219
Aluminum, 6061				75					219
Copper				80		85			111,219
Brass				75					219
Aluminum Bronze, 85			85			85		85	111
Yellow Brass			85					85	111
101C Steel				85(a)				85	111
Carbon Steel				75					219
403 Stainless Steel				85				85(a)	111
201 Stainless Steel				75					219
202 Stainless Steel				75					219
302 Stainless Steel				160					219
304 Stainless Steel			75		85(a)				111,219
310 Stainless Steel			75		160				219
314 Stainless Steel		75							219
316 Stainless Steel			85(a)		85				111,219
321 Stainless Steel		75							219
347 Stainless Steel				85(a)		85			111,219
Carperite 20-40		85(a)			85				111
Carbon D				75					219
Clutching				75					219
Surimat 20		85		80	85				111,219
Surimat 2		75		160					219
Chlorinat 3				85				85	111
Lead			75		80				219
My AZ 31B			85(a)		75		85		111,219
A-Nickel				85			85		111
Inconel		85(a)		85(a)	85		85		111,219
Incoloy		85			85				111
Hi-Qual		85			85				111
Hastelloy A				75	75				219
Hastelloy B				75	160				219
Hastelloy C (cast)		85		160	85				111
Hastelloy C (wrought)		160		85			85		111,219
Hastelloy D				75	160				219
Illium G			85						111
Illium A			85		85				111
Illium 98			85			85			111
Illium G-134			160						219
Illium G-138			160						219
Cupro-nickel, 3.5				85			85		111
Gold			85			85			111
Platinum			85			85			111
Silver			95			85			111
Nickel Silver, 18%				85				85	111
Tantalum		160							219
Tin			75		80				219
Titanium C-120AY					160			85	111,219
Zinc			75						219

TABLE 15. COMPATIBILITY OF MATERIALS WITH 2M CLF - PW CLP

16

Material	Temperature, P								References
	Gas				Liquid				
	Class 1	Class 2	Class 3	Class 4	Class 1	Class 2	Class 3	Class 4	
Metals									
Aluminum, 1000					85				119
Aluminum, 1100					85				119
Aluminum, 1100 (Welded)	85				85				119
Aluminum, 2014 (Welded)	85				85				119
Aluminum, 2024					85				119
Aluminum, 3003					85				119
Aluminum, 3003					85				119
Aluminum, 6061 (Welded)	85				85				119
Aluminum, 7079					85				119
Columbium								85	111,115
Copper, 99.95					85				119
Copper, 99.99					85				119
Nickel-Copper, 25					85				119
Phosphor Bronze, 55					85				119
Aluminum Bronze, 95					85				119
Yellow Brass					85				119
Red Brass					85				119
304 Steel					85				119
304 Steel (Coated with phosphor 45)					85				119
304 Steel (Coated with phosphor 27)					85				119
304 Stainless Steel					85				119
316 Stainless Steel (Welded)	85				85				119
304 Stainless Steel					85				119
316 Stainless Steel					85				119
347 Stainless Steel					85				119
347 Stainless Steel (Welded)	85				85				119
Carbonyl 20-80					85				119
PH15-70 (H900)					85				119
PH15-70 (H1000)					85				119
PH15-70 (Welded)	85				85				119
AM-350 (Welded)	85				85				119
Magnesium, AZ31B					85				119
Magnesium, HK31A					85				119
Magnesium, HK21A					85				119
Molybdenum								85	111,115
Nickel					85				119
Nickel 200 (Welded)	85				85				119
Monel					85				119
Monel 400 (Welded)	85				85				119
Inconel					85				119
Incoloy					85				119
Titanium 0-120AV								85	111,115
Nonmetals									
Graphite, Spectroscopic Grade								85	111,115
Teflon								85	119
Teflon, GFL filled					85				119
Kal-F								85	119

TABLE 16. COMPATIBILITY OF MATERIALS WITH 30% CLF, PW, 83,224

Material	Temperature, °F								References
	Gas				Liquid				
	Class 1	Class 2	Class 3	Class 4	Class 1	Class 2	Class 3	Class 4	
Metals									
Aluminum, 1100-0	-109				-109				
Aluminum, 2014-75	-109				-109				
Aluminum, 2024-1351	-109				-109				
Aluminum, 2219-75	-109				-109				
Aluminum, 4046-045	-109				-109				
Aluminum, 6061-75	-109				-109				
Aluminum, 7075-75	-109				-109				
Aluminum, 7079-75	-109				-109				
Columbium	-109				-109				
Carbonyl 40	-109				-109				
Copper	-109				-109				
Brass 70-30	-109				-109				
301 Stainless Steel	-109				-109				
316 Stainless Steel	-109				-109				
304 Stainless Steel	-109				-109				
410 Stainless Steel	-109				-109				
PH15-70	-109				-109				
AM-350	-109				-109				
AM-355	-109				-109				
Magnesium	-109				-109				
Nickel 200	-109				-109				
Monel 400	-109				-109				
Inconel X	-109				-109				
Refr 41	-109				-109				
Tantalum	-109				-109				
Titanium, A-11047	-109				-109				
Titanium, 6Al-4V	-109				-109				
Teflon 100 FEP	-109				-109				
Teflon 6277F				-109					
Fluoropolymer Teflon				-109					
Kal-F 9900 Fluoromer				-109					
Graphite AGSP	-109							-109	

TABLE 17. COMPATIBILITY OF MATERIALS WITH DICHLORODIFLUOROMETHANE (CCl₂F₂) (FREON 12)(211)

Material	Temperature, P								References
	Gas				Liquid				
	Class 1	Class 2	Class 3	Class 4	Class 1	Class 2	Class 3	Class 4	
Metals									
Mild Steel	75				75				
Cast Iron					75				
A1C Stainless Steel					75				
A30 Stainless Steel					75				
A04 Stainless Steel	75								
T10 Stainless Steel	75								
Monel	75								
Durimet 20	75								
Copper	75								
Sn Bronze	75								
Al Bronze	75								
Si Bronze	75								
Red Brass	75								
Yellow Brass	75								
A-Nickel					75				
Monel					75				
Inconel					75				
Aluminum, 1100					75				
Lead									
Gold	75								
Platinum	75								
Tantalum	75								
Nonmetals									
Glass	75								
Stoneware	75								
Rubber					75				
Asbestos	75								

TABLE 18. COMPATIBILITY OF MATERIALS WITH MONOCHLOROTRIFLUOROMETHANE (CClF₃) (FREON 13)(211)

Material	Temperature, P								References
	Gas				Liquid				
	Class 1	Class 2	Class 3	Class 4	Class 1	Class 2	Class 3	Class 4	
Metals									
Mild Steel			75						
304 Stainless Steel	75	70							
316 Stainless Steel	75	70							
Monel	75								
Durimet 20	75								
Cu-Ni	75								
Platinum	75								
Tantalum	75								
Ni-Cu-Ni		70							
Nonmetals									
Glass	75								
Stoneware	75								

TABLE 19. COMPATIBILITY OF MATERIALS WITH TRICHLORONITROFLUOROMETHANE (CCl₃FN) (FREON 113)(211)

Material	Temperature, P								References
	Gas				Liquid				
	Class 1	Class 2	Class 3	Class 4	Class 1	Class 2	Class 3	Class 4	
<u>Metals</u>									
Mild Steel	75				75				
Cast Iron	75				75				
304 Stainless Steel	75				75				
316 Stainless Steel	75				75				
Monel	75				75				
Durimet 20	75				75				
Copper	75				75				
Si-Nickel	75				75				
Al Bronze	75				75				
Red Brass	75				75				
Yellow Brass	75				75				
Aluminum, 1100	75				75				
Gold	75				75				
Platinum	75				75				
Tantalum	75				75				
<u>Nonmetals</u>									
Glass	75				75				
Stoneware	75				75				

TABLE 20. COMPATIBILITY OF MATERIALS WITH TRICHLOROFLUOROMETHANE (CCl₃F-CCl₂F₂) (FROM 113)

Material	Temperature, °F								References
	Gas				Liquid				
	Class 1	Class 2	Class 3	Class 4	Class 1	Class 2	Class 3	Class 4	
Metals									
Aluminum, 1100	762								136, 211
Aluminum, 6061	75								75
Copper	75		192						136, 211
Sn Bronze	75								211
Al Bronze	75								7-1
Si Bronze	75								2-1
Red Brass	75								211
Yellow Brass	75								211
Mild Steel									
Cast Iron	75								136, 211
NI-Resist	75								211
Aluminum	75								75
410 Stainless Steel	75								211
430 Stainless Steel	75								211
304 Stainless Steel	75								211
316 Stainless Steel	75								211
430 Steel	75								136
Marble	75								2-1
Durite 20	75								211
Acrylic	75								211
Monel	75								211
Inconel	75								211
Gold	75								211
Platinum	75								211
Tantalum	75								211
Nickel			211						136
Titanium 70A	75								136
Titanium, 6Al4V	75								136
Nonmetals									
Glass	75								211
Stoneware	75								7-1

TABLE 2. COMPATIBILITY OF MATERIALS WITH DIBROMOTETRAFLUOROETHANE (CBrF_2 - CF_2)
(FROM 11482) (136)

Material	Temperature, °F								References
	Gas				Liquid				
	Class 1	Class 2	Class 3	Class 4	Class 1	Class 2	Class 3	Class 4	
Metal:									
Aluminum	24R			592					
Aluminum, 6061	75								
Copper	20C		342						
Brass	24B	24R							
Steel	24B	24B							
4130 Steel	75								
17-7 Ph	75								
Magnesium	75								
Titanium 70A	75								
Titanium, 241-4V	75								

TABLE 22. COMPATIBILITY OF MATERIALS WITH HYDRAZINE (N_2H_4)

Material	Temperature, °F								References
	Gas				Liquid				
	Class 1	Class 2	Class 3	Class 4	Class 1	Class 2	Class 3	Class 4	
Metals									
Aluminum, 1100	140				140		140		7, 149, 174, 211, 212
Aluminum, 2020							160		82
Aluminum, 2014					80			160	174
Aluminum, 2017					160				174
Aluminum, 2024					66				174
Aluminum, 3003					80		140	80	7, 174, 211
Aluminum, 4043					160				174
Aluminum, 5052					80				7, 174
Aluminum, 5426	140				80				174
Aluminum, 6061	140				160				174
Aluminum, 6066					80				174
Aluminum, 7070							160	75	7, 174
Aluminum, 408					0		160		149, 174
Aluminum, 356					160				174
Aluminum, 716					140		160		174
Cadmium								RT	174
Chromium Plating						RT			174
Cobalt								75	
Crustite							77		145
Steellite 21					75				174
Copper					68	80		140	7, 174, 216
Brass					80	140			7, 174, 216
Brass								RT	174
Gold					75			212	211
Pure Iron								80	7
Mild Steel								80	7, 149, 211
10% Steel								75	216
410 Stainless Steel					200	80	77		7, 174
410 Stainless Steel					200				174
410 Stainless Steel					200 (min)				7

TABLE 22. (Continued)

Material	Temperature, F							Reference	
	Gas			Liquid					
	Class 1	Class 2	Class 3	Class 4	Class 5	Class 6	Class 7		
430 Stainless Steel					68			68	7,174,216
304 0 Stainless Steel					80			75	
302 Stainless Steel					80	140			174,216
303 Stainless Steel					80	75			7
304 Stainless Steel	140				140				7,174
316 Stainless Steel	200				200			160	7,174
317 Stainless Steel					80				174
321 Stainless Steel	140				140			68	7,174,216
347 Stainless Steel	200				200				7,174
Stainless W					75		160		149,174
17-4PH	140				140			160	174
17-7PH					75				174
44-300					140				174
44-300					160				174
Graphite	75								211
Durlec 20	75								211
Lead					68				149,211,216
90Pb-10Sn			77		75				149,174
Magnesium								77	7,174
Magnesium, AM100A				140					174
Aluminum					75			80	7,149,174
Nickel					140			140	7,149,174
Electroless Nickel									211,216
Monel					60			68	174
Nicro-1				200	140			80	211,216
Inconel				200	200		140		7,149,174
Inconel X					80		140		211,216
Nichrome					80				149,174
Chromel A					80			80	149,174
Hastelloy C					125				211
Silver					80			75	7,174,211
Silver Solder					75		140		149,174
Tantalum					80			212	7,211
Tin					80		140		7
Titanium, Ti-6Al-4V					160				82
Titanium, AZ101A	140				140				174
Tungsten						75			7
Zinc								87	7,174
Zirconium					75				211
Nonmetals									
Carbon					140				7,149,174
Kaol-F					80			160	211,216
Kaol-M-1								140	7,82
Kaol-M-2								140	174
Kaol-F-300 (10% Glass Filled)								140	174
Polyethylene					80			140	174
Savon								68	210
Woolite						80			149
Epon							75		7
Nylon							75		7
Polystyrene, Chloride								75	68
Polystyrene, Alcohol								75	7
Vinylite						75			82
Polyester								75	7
Cellulose Acetate								75	7
Ethyl Cellulose								75	7
Lactoprene								75	7
Phenolic								140	174
Nylar, Type A								140	82
Buna N Rubber						80	130		174,216
Neprene Rubber						75	75	68	7,211,216
Natural Rubber						80			2
Silicone Rubber						75			149
N.S. Rubber 17825						77			174
Buffy Rubber Compound					140				174
N.S. Rubber M-20795						77			149
SBR					75	160		160	23
Polybutadiene						75			23
Hydrocol						100			23
Stycolic 157						75			149
Stycolic 158-53								140	174
Silicone DC-710									143
Koroseal							75		82
Durlec 61							200		174
Delantum				140					174
Exaltex Gasket MC						200			174
Arduo C							75		174
Ceram 200								140	174
Duper 35									174
Oxyneal								75	7
Arduo-53								140	7,211
Glasfite					80	75			7,149,216
Glasfite					140				7,82,174
Glasfite 2 and 50					80			75	7,211,216
Asbestos								80	

TABLE 23. COMPATIBILITY OF MATERIALS WITH UNSYMMETRICAL DIMETHYL HYDRAZINE (UDMH)

Material	Temperature, F								Reference	
	Gas				Liquid					
	Class 1	Class 2	Class 3	Class 4	Class 1	Class 2	Class 3	Class 4		
Metals										
Aluminum, 1100					160			174,296		
Aluminum, 1100-H14					145			7,92,227		
Aluminum, 1350-H14					140			92,227		
Aluminum, 2014	140		160		140			174,296		
Aluminum, 2017	75	160			75	160		174,296		
Aluminum, 2024	75				145			7,92,227		
Aluminum, 2024-T3					66			174		
Aluminum, 2024-T3 (T4)					66	160		174,296		
Aluminum, 5053	75	160			145			92,227		
Aluminum, 5053-H14					145			92,227		
Aluminum, 5053-H16					140			92,174,227, 296		
Aluminum, 5053	140				140			92,227		
Aluminum, 5053-H14					145			174		
Aluminum, 5053-H16					145			92,227		
Aluminum, 5053-H18					145			92,227		
Aluminum, 5053-H19					145			92,227		
Aluminum, 5053-H20					145			92,227		
Aluminum, 5053-H21					145			92,227		
Aluminum, 5053-H22					145			92,227		
Aluminum, 5053-H23					145			92,227		
Aluminum, 5053-H24					145			92,227		
Aluminum, 5053-H25					145			92,227		
Aluminum, 5053-H26					145			92,227		
Aluminum, 5053-H27					145			92,227		
Aluminum, 5053-H28					145			92,227		
Aluminum, 5053-H29					145			92,227		
Aluminum, 5053-H30					145			92,227		
Aluminum, 5053-H31					145			92,227		
Aluminum, 5053-H32					145			92,227		
Aluminum, 5053-H33					145			92,227		
Aluminum, 5053-H34					145			92,227		
Aluminum, 5053-H35					145			92,227		
Aluminum, 5053-H36					145			92,227		
Aluminum, 5053-H37					145			92,227		
Aluminum, 5053-H38					145			92,227		
Aluminum, 5053-H39					145			92,227		
Aluminum, 5053-H40					145			92,227		
Aluminum, 5053-H41					145			92,227		
Aluminum, 5053-H42					145			92,227		
Aluminum, 5053-H43					145			92,227		
Aluminum, 5053-H44					145			92,227		
Aluminum, 5053-H45					145			92,227		
Aluminum, 5053-H46					145			92,227		
Aluminum, 5053-H47					145			92,227		
Aluminum, 5053-H48					145			92,227		
Aluminum, 5053-H49					145			92,227		
Aluminum, 5053-H50					145			92,227		
Aluminum, 5053-H51					145			92,227		
Aluminum, 5053-H52					145			92,227		
Aluminum, 5053-H53					145			92,227		
Aluminum, 5053-H54					145			92,227		
Aluminum, 5053-H55					145			92,227		
Aluminum, 5053-H56					145			92,227		
Aluminum, 5053-H57					145			92,227		
Aluminum, 5053-H58					145			92,227		
Aluminum, 5053-H59					145			92,227		
Aluminum, 5053-H60					145			92,227		
Aluminum, 5053-H61					145			92,227		
Aluminum, 5053-H62					145			92,227		
Aluminum, 5053-H63					145			92,227		
Aluminum, 5053-H64					145			92,227		
Aluminum, 5053-H65					145			92,227		
Aluminum, 5053-H66					145			92,227		
Aluminum, 5053-H67					145			92,227		
Aluminum, 5053-H68					145			92,227		
Aluminum, 5053-H69					145			92,227		
Aluminum, 5053-H70					145			92,227		
Aluminum, 5053-H71					145			92,227		
Aluminum, 5053-H72					145			92,227		
Aluminum, 5053-H73					145			92,227		
Aluminum, 5053-H74					145			92,227		
Aluminum, 5053-H75					145			92,227		
Aluminum, 5053-H76					145			92,227		
Aluminum, 5053-H77					145			92,227		
Aluminum, 5053-H78					145			92,227		
Aluminum, 5053-H79					145			92,227		
Aluminum, 5053-H80					145			92,227		
Aluminum, 5053-H81					145			92,227		
Aluminum, 5053-H82					145			92,227		
Aluminum, 5053-H83					145			92,227		
Aluminum, 5053-H84					145			92,227		
Aluminum, 5053-H85					145			92,227		
Aluminum, 5053-H86					145			92,227		
Aluminum, 5053-H87					145			92,227		
Aluminum, 5053-H88					145			92,227		
Aluminum, 5053-H89					145			92,227		
Aluminum, 5053-H90					145			92,227		
Aluminum, 5053-H91					145			92,227		
Aluminum, 5053-H92					145			92,227		
Aluminum, 5053-H93					145			92,227		
Aluminum, 5053-H94					145			92,227		
Aluminum, 5053-H95					145			92,227		
Aluminum, 5053-H96					145			92,227		
Aluminum, 5053-H97					145			92,227		
Aluminum, 5053-H98					145			92,227		
Aluminum, 5053-H99					145			92,227		
Aluminum, 5053-H100					145			92,227		
Aluminum, 5053-H101					145			92,227		
Aluminum, 5053-H102					145			92,227		
Aluminum, 5053-H103					145			92,227		
Aluminum, 5053-H104					145			92,227		
Aluminum, 5053-H105					145			92,227		
Aluminum, 5053-H106					145			92,227		
Aluminum, 5053-H107					145			92,227		
Aluminum, 5053-H108					145			92,227		
Aluminum, 5053-H109					145			92,227		
Aluminum, 5053-H110					145			92,227		
Aluminum, 5053-H111					145			92,227		
Aluminum, 5053-H112					145			92,227		
Aluminum, 5053-H113					145			92,227		
Aluminum, 5053-H114					145			92,227		
Aluminum, 5053-H115					145			92,227		
Aluminum, 5053-H116					145			92,227		
Aluminum, 5053-H117					145			92,227		
Aluminum, 5053-H118					145			92,227		
Aluminum, 5053-H119					145			92,227		
Aluminum, 5053-H120					145			92,227		
Aluminum, 5053-H121					145			92,227		
Aluminum, 5053-H122					145			92,227		
Aluminum, 5053-H123					145			92,227		
Aluminum, 5053-H124					145			92,227		
Aluminum, 5053-H125					145			92,227		
Aluminum, 5053-H126					145			92,227		
Aluminum, 5053-H127					145			92,227		
Aluminum, 5053-H128					145			92,227		
Aluminum, 5053-H129					145			92,227		
Aluminum, 5053-H130					145			92,227		
Aluminum, 5053-H131					145			92,227		
Aluminum, 5053-H132					145			92,227		
Aluminum, 5053-H133					145			92,227		
Aluminum, 5053-H134					145			92,227		
Aluminum, 5053-H135					145			92,227		
Aluminum, 5053-H136					145			92,227		
Aluminum, 5053-H137					145			92,227		
Aluminum, 5053-H138					145			92,227		
Aluminum, 5053-H139					145			92,227		
Aluminum, 5053-H140					145			92,227		
Aluminum, 5053-H141					145			92,227		
Aluminum, 5053-H142					145			92,227		
Aluminum, 5053-H143					145			92,227		
Aluminum, 5053-H144					145			92,227		
Aluminum, 5053-H145					145			92,227		
Aluminum, 5053-H146					145			92,227		
Aluminum, 5053-H147					145			92,227		
Aluminum, 5053-H148					145			92,227		
Aluminum, 5053-H149					145			92,227		
Aluminum, 5053-H150					145			92,227		
Aluminum, 5053-H151					145			92,227		
Aluminum, 5053-H152					145			92,227		
Aluminum, 5053-H153					145			92,227		
Aluminum, 5053-H154					145			92,227		
Aluminum, 5053-H155					145			92,227		
Aluminum, 5053-H156					145			92,227		
Aluminum, 5053-H157					145			92,227		
Aluminum, 5053-H158					145			92,227		
Aluminum, 5053-H159					145			92,227		
Aluminum, 5053-H160					145			92,227		
Aluminum, 5053-H161					145			92,227		
Aluminum, 5053-H162					145			92,227		
Aluminum, 5053-H163					145			92,227		
Aluminum, 5053-H164					145			92,227		
Aluminum, 5053-H165					145			92,227		
Aluminum, 5053-H166					145			92,227		
Aluminum, 5053-H167					145			92,227		
Aluminum, 5053-H168					145			92,227		
Aluminum, 5053-H169					145			92,227		
Aluminum, 5053-H170					145			92,227		
Aluminum, 5053-H171					145			92,227		
Aluminum, 5053-H172					145			92,227		
Aluminum, 5053-H173					145			92,227		
Aluminum, 5053-H174					145			92,227		
Aluminum,										

TABLE 24. (Continued)

Material	Temperature, °F								References
	Gas				Liquid				
	Class 1	Class 2	Class 3	Class 4	Class 1	Class 2	Class 3	Class 4	
Rubbers									
Chicago Reshite-Silvrene 9623								145	92
Chicago Reshite-Silvrene 9694								145	92
Chicago Reshite-Silvrene 9617								85	92
Chicago Reshite-Silvrene 20316								85	92
Commercial Hard Rubber Company 3601								85	92
Enjay 035					80	75		85	92
Enjay 218						140		140	92
Enjay 268								60	165, 169
Enjay 551							60	92	
Enjay CR617						85		92	
Pirestone Rubber D-404								85	92
Pirestone Rubber D-430								85	92
Pirestone Rubber D-431								85	92
Pirestone Rubber D-432								85	92
Pirestone Rubber D-406								145	92
Pirestone Rubber D-408								145	92
Pirestone Rubber D-409								145	92
Pirestone Rubber D-410								145	92
Parker Appliances 37-014						85		92	
Parker Appliances 37-024						85		92	
Plastics and Rubber Products 805-70								85	92
Plastics and Rubber Products 805-90								85	92
Precision Rubber Products 907-90								85	92
Precision Rubber Products 925-70								85	92
Stillman SR 613-75					80	100		85	92, 169
Sturmer Rubber 85-05								85	92
Synthetic Rubber Products 5028605								85	92
Synthetic Rubber Products 50223								85	92
Thiokol C 42986-1						85		145	92
Thiokol C 55935								85	92
D. Pont Neoprene (1156)								100	92
D.F. Goodrich Neoprene 091						100		92	
Neoprene								60	50, 169
Myar 2202							60	85	50, 92, 169
Myar 520-41-125-1								85	92
Myar 1043 Std. B. 1								85	92
Myar 4001								85	92
Myar G4								100	92
Chemigum 86 12								100	92
Chemigum 86								75	92
Kal-F 3790								75	92
Kal-F 5000								75	92
Fluororubber 184								60	50, 92, 169
Via rel								60	50, 92, 169
Viton A								60	50, 92, 169
Viton A-247B								60	50, 92, 169
Viton A-44-11 A-35								85	92
Viton B								85	92
Stillman Fluororubber 81 821-470								60	165, 169
Precision Rubber 18007, 18057								60	50, 169
Hydropol Y						140		160	169
Hydropol T						145		160	92
Tresan X3603								75	92
Saran Rubber 300 Unhard								75	92
Saran Rubber 300 Cured								100	92
Dow Silicone LB-63								100	92
Dow Silicone DC-132								100	92
G.E. Nitrile Silicone MS205402								75	92
G.E. Nitrile Silicone 52750								85	92
Nichols Teflon A								130	92
Silicone LB-63								85	92
Parco 823-70								80	165, 169
Parco 805-70								80	165, 169
Precision Rubber 9357								80	165, 169
Precision 214-607-9								80	169
Precision Rubber 9407								80	165, 169
940 X 399								160	169
Parker 8480-7								80	169
Parker 8496-7								60	169
Parker 318-7								160	169
Cusman 1357								80	169
Linear 7806-70								80	169
Hammer 22800-71								100	169
Formula 120 (Resin Cured)								140	169
Formula 121 (Resin Cured)								140	169
Acushnet 88E-442								160	169
Acushnet 88E-449								160	165, 169
Acushnet 88E-450								160	169
Acushnet 88E-451								160	169
Stillman EX 904-90								160	169
LP3								160	165, 169
Hammer 56789-2307								60	165, 169
Thiokol 300C St.								130	92
Derlock 900								60	169
Derlock 22								60	92, 169
Derlock 500								60	92, 169
Parco 8318-7								60	169
Adiprene 81136								100	92
Adiprene 81157								100	92

TABLE 24. (Continued)

Material	Temperature, °F								References
	Gas				Liquid				
	Class 1	Class 2	Class 3	Class 4	Class 1	Class 2	Class 3	Class 4	
Lubricants and Sealants									
LSM Lube							80		169
S No. 50-4							80		169
LOK Safe							80		169
Andok C							80		169
DD-11			80				80		169
Microseal 100-1 (Dry Lube)					80				169
Rockwell Nordstrom 147						75			92
Rockwell Nordstrom 421								75	92
Rockwell Nordstrom 501								75	92
Rockwell Nordstrom 921								75	92
Rockwell Nordstrom 950							80		169
Microseal DC-224-A								75	92
Valve Seal A						80			169
Flase Graphite					80				169
DC-35							80		169
DC-41 Vacuum		80					60		169
Molykote 2								60	165, 169
Kal-F 40								75	92
Kal-F 80							75		92, 165, 169
Kal-F 200								75	92
Drilube 703								60	165, 169
Bayco-32								60	169
Electrofilm 66-C							60		169
Polyglycol Oils							60		169
Flu-45							80		169
Polyslon L							80		92, 169
SC 150							80		169
Fluorolube 80-600								80	169
Fluorolube 80-1200									75
Fluorothene G								80	169
Andok L237									75
Canus 200								75	92
Fluoropack									75
Lubri-Seal							75		92
Worm Stopcock Grease								75	92
Microseal 15								75	92
Silicone DC 11									92
Kaddy Lube 100					80				169
Kaddy Lube 200					80				169
Water Glass Graphite					80				169
Drylube Sealant						80			169
Vydex A						80			169
Teflon Tape					80				169
Painting Compounds									
PR 1422								60	169
RTV 20								60	169
Paraplex P-43								60	169
Proseal 703								60	169
Polyprene 5159								60	169
Crystal 1807								60	50, 169
Adhesives									
Armstrong A-6								60	169
BT 847								60	169
BT 434								60	50, 169
Apcon 422					80				169
Apcon 4-3								80	169
Ceramics									
Temporel 1300					60				50, 169
Sauerstein P-1					60				50, 169
Sauerstein 31					60				50, 169
Sauerstein 47							75		169
Basaltus									169
Coatings									
Epoxy No. 1								60	169
Modified Epoxy No. 1								60	169
Epoxy No. 7								60	169
Epoxy No. 9								60	169
Epoxy No. 6809								60	169
Alkyd No. 4								60	169
Polyurethane								60	169
Acrylic Nitrocellulose								60	169
Vinyl								60	169
Primer MIL-P-6889								60	169
Enamel								60	169
Typr-K								160	169
Copolymer P-2000								160	169
CA 9747 Primer								160	169
Corrosite Clear 361								160	169
Proseal 323								160	169
Marbel DA-6							80		169
Aluminum								80	169
Granules									
Graphiter 14								160	169
Graphiter 39								160	169
Graphiter 84					80				169
Graphiter 86					80				169
National Carbon CDP-72					160				169
Purebon P28					160				169
Purebon P28							160		169
Gravel and Packing Material									
Vytech 83-HSS (with Teflon)							75		92
Delanum							75		92
Neoprene								75	92
Carlson 900								130	92
Du Verre 22									75
Neveq 30									75
Neveq 41									75
Neveq 50									75
Neveq 60									75
Neveq 61									75
Neveq 62									75
Neveq 63									75
Neveq 64									75
Neveq 65									75
Neveq 66									75
Neveq 67									75
Neveq 68									75
Neveq 69									75
Neveq 70									75
Neveq 71									75
Neveq 72									75
Neveq 73									75
Neveq 74									75
Neveq 75									75
Neveq 76									75
Neveq 77									75
Neveq 78									75
Neveq 79									75
Neveq 80									75
Neveq 81									75
Neveq 82									75
Neveq 83									75
Neveq 84									75
Neveq 85									75
Neveq 86									75
Neveq 87									75
Neveq 88									75
Neveq 89									75
Neveq 90									75
Neveq 91									75
Neveq 92									75
Neveq 93									75
Neveq 94									75
Neveq 95									75
Neveq 96									75
Neveq 97									75
Neveq 98									75
Neveq 99									75
Neveq 100									75
Neveq 101									75
Neveq 102									75
Neveq 103									75
Neveq 104									75
Neveq 105									75
Neveq 106									75
Neveq 107									75
Neveq 108									75
Neveq 109									75
Neveq 110									75
Neveq 111									75
Neveq 112									75
Neveq 113									75
Neveq 114									75
Neveq 115									75
Neveq 116									75
Neveq 117									75
Neveq 118									75
Neveq 119									75
Neveq 120									75
Neveq 121									75
Neveq 122									75
Neveq 123									75
Neveq 124									75
Neveq 125									75
Neveq 126									75
Neveq 127									75
Neveq 128									75
Neveq 129									75
Neveq 130									75
Neveq 131									75
Neveq 132									75
Neveq 133									75
Neveq 134									75
Neveq 135									75
Neveq 136									75
Neveq 137									75
Neveq 138									75
Neveq 139									75
Neveq 140									75
Neveq 141									75
Neveq 142									75
Neveq 143									75
Neveq 144									75
Neveq 145									75
Neveq 146									75
Neveq 147									75
Neveq 148									75
Neveq 149									75
Neveq 150									75
Neveq 151									75
Neveq 152									75
Neveq 153									75
Neveq 154									75
Neveq 155									75
Neveq 156									75
Neveq 157									75
Neveq 158									75
Neveq 159									75
Neveq 160									75
Neveq 161									75
Neveq 162									75
Neveq 163									75
Neveq 164									75
Neveq 165									75
Neveq 166									75
Neveq 167									75
Neveq 168									75
Neveq 169									75
Neveq 170									75
Neveq 171									75
Neveq 172									75
Neveq 173									75
Neveq 174									75
Neveq 175									75
Neveq 176									75
Neveq 177									75
Neveq 178									75
Neveq 179									75
Neveq 180									75
Neveq 181									75
Neveq 182									75
Neveq 183									75

TABLE 25. COMPATIBILITY OF MATERIALS WITH 50:50 HYDRAZINE (UNSYMMETRICAL DIMETHYL HYDRAZINE) PLUS UP TO 3% WATER (50)

Material	Temperature, F								References
	Gas				Liquid				
	Class 1	Class 2	Class 3	Class 4	Class 1	Class 2	Class 3	Class 4	
Metals									
Aluminum, 1100-O					>60				
Aluminum, 5656H321					>60				
Aluminum, 7075-T6					>60				
Aluminum, 356-T6	>60								
Ni-Span-C					>60				
Titanium, 5A1-4V					>60				

TABLE 26. COMPATIBILITY OF MATERIALS WITH LIQUID HYDROGEN (82,211,221)

Class 1 or 2 Materials		Class 4 Materials
Aluminum, 1100	Inconel	Aluminum, 40 E
Aluminum, 5052	Low-Carbon Steel	Magnesium
Aluminum, 4043	High-Nickel Steels	Lead
Aluminum, 2024-T3	Titanium	Zinc
Aluminum, 1100-T	Nitrile Rubber	Iron
300 Series Stainless Steel	Silicone Rubber	High-Carbon Steel
410 Stainless Steel	Teflon	Natural Rubber
Haynes 21	Gerrick Packing	Neoprene Rubber
Molybdenum	Bavelite	Cork
Nickel	Micarta	Wood
Monel	Lucite	Polyvinyl Chloride
	Graphite	Saran
		Polyvinyl Alcohol

TABLE 27. COMPATIBILITY OF METALS WITH 90 PERCENT HYDROGEN PEROXIDE

Aluminum Alloys	Stainless Steel Alloys	Nickel Alloys	Cobalt Alloys	Other Alloys	Other Pure Metals	Reference
Class 1 Metals						
Maximum per cent of active oxygen loss (AOL) by H ₂ O ₂ in 1 week: at 30 C (76 F) - 0.2%, at 66 C (150 F) - 5.0%						
Minimum stability of H ₂ O ₂ after test - 95% stable in 24-hour test at 212 F in glass						
No other effect on H ₂ O ₂ or metal						
1060	None	None	None	None	Tantalum	35,36,37, 38,149,210
1100					Zirconium	35,36,132, 149,210
1160						35,210
1260						35,210
7072						35,36,37, 38,210
B-356						35,36,38, 210
Class 2 Metals						
Maximum per cent of active oxygen loss (AOL) by H ₂ O ₂ in 1 week: at 30 C (76 F) - 6.0%, at 66 C (150 F) - 80%						
Minimum stability of H ₂ O ₂ after test - 90% stable in 24-hour test at 212 F in glass						
No other effect on H ₂ O ₂ ; slight bronzing of the metal allowable but no corrosion						
3003	Type 202	None	None	None	Silicon	35,36,210
4043	Type 302				Tin (cp)	35,36,149, 210
5052	Type 304					35,36,37, 38,149,210
5054	Type 304 ELC					35,210
5056	Type 309					35,210
5652-0	Type 310					35,36,210
5254-0	Type 316					35,36,37, 38,210
6061	Type 316 ELC					35,36,37, 38,210
3063	Type 317					35,210
6363	Type 318					35,36,210
150	Type 321					35,210
214E	Type 322					35,36,37, 38,210
214F	Type 347					35,36,210
356F	17-7PH, 37-45 R _c					35,36,37, 210
5052	17-7PH, 45 R _c					35,210
(anodized)	(buffed)					
6061	17-7PH					35,210
(anodized)	(unhardened)					
6061	Hasco-O-Seven					35,210
(HNO ₃ Pass.)						
6061	Malin-Wilabrite					35,36,210
(detergent wash)						
6061						35
(WFNA Pass.)						

Table 27. (Continued)

Aluminum Alloys	Stainless Steel Alloys	Nickel Alloys	Cobalt Alloys	Other Alloys	Other Pure Metals	Reference
<u>Class 3 Metals</u>						
Maximum per cent of active oxygen loss (AOL) by H ₂ O ₂ in 1 week: at 30 C (76 F) - 11.0%, at 66 C (150 F) - 100% in 24 hours Minimum stability of H ₂ O ₂ after test - 15% after 30 C (76 F) test Bronzing and staining, but no rusting or other corrosion products; slight attack may be allowed.						
2024	329	Inconel X	None	H-975	None	35, 37, 38, 210
B214F	AM 350			Refractalloy 26		35, 210
A360	17-7PH, 45 Rc			Refractalloy 70		35, 210
6061	17-7PH, 45 Rc					35
(anodized)	(electropolished)					
2017	17-4PH					35
(anodized)						
2024	Carpenter 20					35, 36, 210
(anodized)	Durimet 20					35, 210
6061	AM 355					35, 210
(hard coat)	19-9DL					35, 210
	16-25-6					35
	Preloy Type					35, 210
	302 porous wire					
	Worthite					35, 210
<u>Class 4 Metals</u>						
Maximum per cent of active oxygen loss (AOL) by H ₂ O ₂ in 1 week - not specified Minimum stability of H ₂ O ₂ after test - not specified. Pitting or corroding during or after test						
2014	AM 350	Nickel	Cobalt	Mild steel	Copper	35, 36, 149, 210
2017	410	Inconel	Haynes 25	Be-bronze	Zinc	35, 36, 149, 210
7075	416	Monel	Star "J"	Chromaloy H-3	Tungsten	35, 149, 206, 210
40E	420	Hastelloy	Haynes 3	Duriron	Titanium	35, 36, 210
218	430	"B"	Haynes 6	(cast)	Sodium	35, 36, 210
355F	431	Hastelloy	Haynes 12	Fanweld "O"	Magnesium	35, 38, 149, 210
		"C"				
A750	440		S-588	Ni-Resist	Beryllium	35, 210
B750	443	Hastelloy	S-590	Tantung	Cadmium	35, 149, 210
2024	446	"D"		Dow metal JIA	Chromium	35, 149, 210
(anodized)	Rigimesh J	Be-nickel		Dow metal MA	Gold	35, 210
	SS porous	Illum "G"		Kennametal	Iron	35, 36, 210
	wire	Chlorimet		K-138	Lead	35, 36, 210
	300 series SS			Kennametal	Manganese	35, 210
	powder compact			K-3H	Mercury	35, 210
	Type 302			Kennametal	Molybdenum	35, 94, 149, 210
	powder compact			K-501		
					Platinum	35, 210
	Type 316			Kennametal	Silver	35, 36, 210
	powder compact			K-M		
	Type 302B			Multimet N-155		35, 210
	powder compact					
	Type 316 + Cb					35
	powder compact					
	Utiloy 3					35, 210
	Utiloy 20					35, 210
	Utiloy H					35, 210
	Utiloy NH					35, 210
	Elgiloy					35, 210

TABLE 28. COMPATIBILITY OF NONMETALS WITH 90 PERCENT HYDROGEN PEROXIDE AT 150 F⁽³⁵⁾

Material	Classification
<u>Plastics - Polyethylene and Halogenated Polyethylene Type</u>	
Fluoroflex I-TP1001	1
Fluoroflex I-TP1000 (black)	2
Fluran B-4100	3
Halgene	2
Hypalon S-2	4
Hypalon Gasket	4
Hypalon V-54-B (gray)	4
Hypalon V-56-A (gray)	4
Hypalon V-163-4 (black)	4
Hypalon "O" Ring (GRC 90-5)	3
Irrathene 101 (irradiated polyethylene)	2
Kel-F (unplasticized)	1
Kel-F 800 (Lot 5649)	1
Kel-F 820 (G4028)	2
Kel-F 3700 gum	3
50% Kel-F 3700-50% Kel F 800	2
Kel-F 5500 (unpigmented)	2
Kel-F 5500 gum	3
Kel-F 5500-121	2
Kel-F 5500-61	2
50% Kel-F 5500-50% Kel-F 800	1
75% Kel-F 5500-25% Kel-F 800	1
Kel-F O-Ring (CPD. 7761-70)	2
Polyethylene	2
Rulon (Teflon Base)	2
Teflon (white)	1
Viton A (411A4) (black)	3
<u>Plastics - Polyvinylchloride and Copolymers</u>	
Alanol tubing	3
Boltron 6200 (gray)	2
Geon 118	4
Geon 404 (yellow)	3
Koroseal 116	3
Koroseal 117 (molded)	3
Koroseal 700	2
Lucoflex (translucent)	3
Lucoflex (white)	3
Marvinol 218-200	4
Marvinol 218-201	4
Marvinol NG-3005	4
Marvinol NR-6010	4
Saran	2
Saran Rubber Q-187	4
Transflex Tubing	4
Tygon B-20	3
Tygon B-32	3
Tygon B-63	3
Tygon B-71	3
Tygon B-72	3
Tygon B-136	3
Tygon S-22-1	4
Tygon TL-103	4
Tygon 2807	4
Tygon 3400	4
Tygon 3603	4
Tygon 3604A	2(a)
Tygon 3604B	2(a)
Vinyl 79139	2
Vinylite VG 1914	2
Vinylite VU 1940	2
Vinylite VS 1310	3
Vinylite VU 1900	3
Vinylite UE 1907	3
Vinylite VU 1920	3

TABLE 28. (Continued)

Material	Classification
<u>Plastics - Polyvinylchloride and Copolymers</u>	
Vinylite VU 1930	3
Vinylite VU 1940	3
<u>Plastics - Silicone Rubber Compounds</u>	
Fluorosilicone LS-53	2
GE 407B-217-1	4
GE 1240	2
GE 81223	2
GE 12601	4
GE 12602	3
GE 12650 (unpigmented)	2
GE 12650 (pigmented red)	3
GE 12670	4
GE 12670 (pigmented brown)	4
GE 15060 (pigmented)	3
GE 15080	3
GE X-7181	3
Parkone White 467-1 O-ring	4
SE 450 (unpigmented)	2
Silastic 152	3
Silastic 160	3
Silastic 160 O-ring	4
Silastic 161	3
Silastic 181	3
Silastic 240	2
Silastic 250	4
Silastic 261	3
Silastic 675	3
Silastic 6-128	2
Silastic 7-180	3
Silastic 9711	2
Silastic HR-9711	2
Silastic 9711 welded with S-2200	2
Silastic S-2000-4-480	2
Silicone 407-B-217-1	3
Silicone 407-B-437-1	2
Silicone HT 656	3
Silicone SR 5550	2
Silicone SR 5570	2
SR 5550	2
SR 5570	2
X-7181	3
Silicone Y-1749	2
<u>Rubbers and Plastics - General</u>	
Acrylon Rubber BA-12	4
Acrylon EA-5	4
Adiprene C	4
Bisilon No. 50	2
Buna N	4
Butyl Rubber A 3405	4
Butyl Rubber SR-384	4
Cyclocac (natural color)	4
Garlock No. 5681 (Teflon-impregnated asbestos)	4
Hycar PA 478-1-1 (black)	4
Haveg 41 (Asbestos filled phenolic)	4
Haveg 60 (phenolic)	4
Hysol 4-77C (clear)	4
Hysol 4-77D (amber)	4
Hysol 4-77E	4
Hysol 4-77F	4
Hysol 4-78A (white)	4
Hysol 4-78B (brown)	4
Hysol 4-78C (amber)	4
Hysol 4-78D (amber)	4
Hysol 6000 B (amber)	4

TABLE 28. (Continued)

Material	Classification
<u>Rubbers and Plastics - General (continued)</u>	
Kralite	3
Melmac No. 1077	4
Mylar A	1
Mylar B	1
Neoprene Pure Gum	4
Neoprene SR 365-B	4
Nylon	4
Phenol-Formaldehyde	4
Plexiglas	4
Polystyrene (Polyflex)	2
Thiokol EC-801-LP2	4
Thiokol 3000 FA	4
Thiokol 3000 ST	4
Thiokol 1620 AH	4
<u>Plastics - Laminates, Diaphragm</u>	
<u>Materials and Adhesives</u>	
Chemeloc MI-411 (Teflon Fiberglass)	2(b)
Duroid 5600 (fiber-reinforced Teflon)	3
Fairprene PS57-167 (Viton A, 116 Glass)	3
Fairprene PS57-168 (Viton A, Dacron)	2
Fairprene (Viton A)	
5806	2
5807	2
5809	2
Kel-F-Dacron Diaphragm-VL-1101m4	4
Kel-F 5160 Diaphragm	2
Kel-F 5500 (gray) Diaphragm	2
Kel-F 5500 (gray) on Dacron diaphragm	2
Korda Flex (Teflon-coated glass fabric)	2
Silastic DC-9711 on Dacron diaphragm	3
Vinyl coated Fiberglass (gray-green)	3
9711 Silicone seal washer DC A 4094	3
adhesive (Dow Corning Silicate base)	
on aluminum	
9711 Silicone seal washer DC Chemloc	3
607 adhesive on aluminum	
<u>Porous Materials</u>	
Al-Si-Mag, Porous Ceramic No. 393	3
Aluminum Oxide, Porous-RA-98	2
Armalon-Teflon Felt (impregnated)	3
Armalon-	3
Dacron Cloth	2
Dac-2100	
Dac-2101	2
Dac-2102	2
Filtros C Stone (55 Micron)	2
Glass Cloth G-206-C	2
Poroloy--302SS Wire	3
Porous Kel-F (15-Micron Pore)	2
Porous Porcelain (1.4 Micron)	2
Porous Teflon (9-Micron Pore)	2
Rigimesh J SS, Wire	4
Sintered 300 Series SS Powder Compact	4
Sintered 302 SS Powder Compact	4
Sintered 316 SS Powder Compact	4
Sintered 302B SS Powder Compact	4
Sintered 316 and Cb SS Powder Compact	4
Teflon Cloth (25 Grade)	3
Teflon Cloth-Repeat (25 Grade)	2
Teflon Cloth (40 Grade)	3
Teflon Felt (impregnated)	
Teflon Cloth T-2300	3
Teflon Cloth T-2305	2

TABLE 28. (Continued)

Material	Classification	Impact Sensitive
<u>Lubricants</u>		
Alkaterge C	4	Yes
Amino Silane Oil and Grease	4	Yes
Apiezon Hardwax W	4	
Arochlor 1221	4	Yes
Arochlor 1232	4	Yes
Arochlor 1242	4	Yes
Arochlor 1248	4	Yes
Arochlor 1254	4	Yes
Bardahl	4	Yes
Carum 200	4	Yes
Ceresin Max	4	Yes
CFB-1	4	Yes
Dichloro-bis-tri-fluoromethyl benzene	3	No(c)
Dichlorohexafluorobutene	3	No(c)
Fluorolube FS	2	No(c)
Fluorolube FS plus 5% fluorolube light grease	2	No(c)
Fluorolube heavy grease 10214	2	No(c)
Fluorolube oil 10213	2	No(c)
Fluorolube S	2	No(c)
Fluorolube T	2	No(c)
Fluorolube Oil, S-30	2	No(d)
Fluorolube Grease, Hg-1200	2	No(d)
Fluorolube Grease, GR-660	2	No(d)
Formulation		Yes
F-9	4	
OS-16	4	Yes
OS-22	4	Yes
OS-23	4	Yes
OS-27	4	Yes
OS-28	4	Yes
OS-30	4	Yes
OS-32	4	Yes
OS-33	4	Yes
OS-34	4	Yes
OS-35	4	Yes
OS-37	4	Yes
CP-3898-2	4	Yes
Skydrol (uncolored)	4	Yes
Halocarbon Oil 8-25 AV	2	No(c)
Halocarbon Grease, Series 25-10	2	No(d)
Halocarbon Hi-Temp Stopcock Grease	2	No(d)
Halocarbon Oil 10-21	2	No(c)
Halocarbon Oil 11-14	2	No(c)
Halocarbon Stopcock Grease	2	No(c)
Hexachlorobutadiene	3	No(d)
Hexachloropropylene	4	No(c)
Hydraulic fluid RPM	4	
Hydraulic Oil Houghton Safe 620	3	Yes
Kel-F Alkane	2	
Kel-F Oil Cut No. 1	2	No(d)
Kel-F Oil No. 10	2	No(c)
Kel-F No. 90 Grease	2	No(c)
Lindol HF (tricresyl phosphate)	4	Yes
Lindol HFX	4	Yes
Liqui-Moly Concentrate	4	Yes
Lubri-Seal	4	Yes
Mineral Oil	4	Yes
Paraffin	4	Yes
Perfluorolube Grease FCD-759	2	Yes
Perfluorolube Oil FC-331	2	No(c)
FC-332	2	No(c)
FC-333	2	No(c)
FC-334	2	No(c)
FC-335	2	No(c)
Petrolatum	4	Yes
Polychloropentane (stabilized)	4	Yes
Renex	4	Yes
Silicone XF 224	4	Yes
Silicone Oil DC-7	4	Yes
DC-44	4	Yes
DC-200	4	Yes
DC-550	4	Yes
DC-701	4	Yes
DC-702	4	Yes
DC-710	4	Yes
Silicone Oil GE 2V3733	4	Yes
GE 51346	4	Yes
Tectyl	4	Yes
1,1,2,2, tetrafluoroethyl dodecylether	4	Yes
Tributyl Phosphate	4	Yes
Ucon Hydrolube U-4	4	Yes

TABLE 28. (Continued)

Material	Classification
Ceramics, Refractories, and Miscellaneous	
Agate (natural)	3
Agate (polished)	3
Al-Si-Mag (porcelain)	2
Alundum LA 116	2
Boron Nitride	4
Carboloy 44-A	4
Carboloy 55-A	4
Carboloy 78	4
Carboloy 999	4
Ceramic AB-2	2
Ceramic Al-200	2
Charcoal	4
Crystalor. (Silicon Carbide)	4
Graphitar No. 30	4
Graphite P5A6 Silver impregnated	4
Graphite P-55 Copper impregnated	4
Graphite P-59L Copper impregnated	4
Graphite P-692	4
Karbate	4
Norbide	2
Synthetic Sapphire (polished)	1

Protective Coatings

(A. Recommended for Long-Time Contact and Splash Resistance)

Teflon	1(e)
Kel-F	1(e)
Kel-F on 1060 Aluminum	1
Kel-F on 5234 Aluminum	1
Kel-F on 5652 Aluminum	1
Glass-lining (Clear) Light-Gray	1
Glass-lining (Cobalt) Cobalt-Colored Glass	1

(B. Recommended for Splash Resistance Service Only)

Tygon Paint 7286 TP-81-Clear	3(e)
Tygon Paint 71253 TP-107B	3(e)
Corrosite No. 521	3(e)
Corrosite No. 551	3(e)
Corrosite No. 581	3(e)
Plastic Metal No. 22	3(e)
Saran Rubber Q-1875	3(e)
Mv-Type No. 150	3(e)
Amercoat No. 1262	3(e)
Hellex	3(e)
P-5, Copolymer	3(e)
Neolac Gray No. 8588	3(e)
Steelcote Stainless Steel	3(e)

(C. Not Recommended for 90% H₂O₂ Service)

Geon Latex 31X	4(e)
Flexcoat No. 1 Black	4(e)
Lithgow LC-600 (Gray)	4(e)
Amercoat Red	4(e)
Prufcoat Medium Gray	4(e)
Lithgow LC (600) (Brown)	4(e)
Veloform F-10 CPP304	4(e)
Cordo -255A	4(e)
Cordo Plastic Coating (E-1 Resin + H-26 Activator)	4(e)
Chromalloy	4(e)
Unichrome Drum Lining B-124-17	4(e)
Uclon, System E Coating	4(e)
EX63B Paint	4(e)
Sealer EC8C1 With Accelerator	4(e)

TABLE 28. (Continued)

Material	Formulation	Classification	Impact Sensitive (f)
Joint Sealing Compounds			
"Althion" E	Polyethylene resin	1(e)	Non-impact sensitive
Dispersite 1820	Butyl rubber in alkaline dispersion	2(e)	Non-impact sensitive
Duxseal	Teflon	4(e)	Non-sensitive Impact
Calmar CB Pipe Seal		4(e)	Sensitive
Crane Thread Lub.	Oxidizable Oil	4(e)	1 doubtful impact from 10 trials
Fel-Pro, C-5	Colloidal Copper	4(e)	Impact sensitive 1 of 4 trials
Graphite Paste	Graphite dispersion	4(e)	Non-impact sensitive
Goop (Blue)		4(e)	Positive
Goop (Silver)		4(e)	Positive
Cyl-Seal		4(e)	Non-impact sensitive
Molybdenite Pipe Dope		4(e)	Not tested
Permatex, Aviation Form A Gasket No. 3		4	Not tested
CS-18 Lubricant	Skydrol + 3% benton 34	4(e)	Impact
Pecora Cpd.		4(e)	Impact
Plastic Metal	No. 22-aluminum filler, latex base. No. 333-55 filler, latex base	4(e)	Impact
Rutland Pipe Dope		4(e)	Sensitive when met
Skydrol	Mixture Skydrol (P-801) and talc	4(e)	Sensitive 2 of 3 trials
T-Film	Teflon-water dispersion	4(e)	Impact sensitive
Weco No-Gel.	No. 50 metallic zinc base	4(e)	Impact
X-Pardc		4(e)	Non-impact sensitive
Kel-F Grease No. 90	Polychlorotrifluoroethylene		Non-sensitive
Tin Plating On Aluminum 6061		4(e)	
Alcone Thread Lubricant		4(e)	Not tested
Radco-Seal No. 15		4	Not tested

(a) Based on service experience.

(b) After 24-hour screening at 66°C (150°F).

(c) Non-impact sensitive to 1 kg at room temperature.

(d) Non-impact sensitive to 3 kg at room temperature.

(e) Tested at room temperature.

(f) One-kg impact at room temperature.

TABLE 29. COMPATIBILITY OF MATERIALS WITH METHYLENE CHLORIDE (CH₂Cl₂)

Material	Temperature, F								References
	Gas				Liquid				
	Class 1	Class 2	Class 3	Class 4	Class 1	Class 2	Class 3	Class 4	
Metals									
1100 Aluminum			125				75	100	211
Copper			125		100		75		211
Br Bronze			125				75		211
Al Bronze			125				75		211
St Bronze			125		100		75		211
Red Brass			125				75		211
Yellow Brass			125				75		211
Mild Steel			125		75		75		211
Cast Iron							75		211
Mi-Resist							75		211
Si-Iron							75		211
410 Stainless Steel							75		211
430 Stainless Steel					100		75		211
304 Stainless Steel					75		75		211
316 Stainless Steel					75		75		211
Monel	175		212						211
Worthite	175		212						211
Durimet 20					100				211
Carpentay 20									211
A-Nickel			75			100	75		211
Monel			125			100	75		211
Inconel			75				75		211
Hastelloy B					100				127, 129, 211
Hastelloy C					100	100			127, 129, 211
Ni-O-nel					75				211
Lead							75		211
Gold							75		211
Platinum							75		211
Tantalum							75		211
Silver							75		211
Nonmetals									
Glass							75		211
Stoneware							75		211
Rubber								75	211
Asbestos					75				211
Graphite					75				211

TABLE 10. (Continued)

Material	Temperature, F								Reference
	ASTM Type III				ASTM Type IIIA				
	Class 1	Class 2	Class 3	Class 4	Class 1	Class 2	Class 3	Class 4	
Asphalt									
Starfast Severe Gr. No. 1		75							149
Asphalt 100				212					149
Asphalt 125				212					149
Asphalt 150				212					149
Dom. Gravel Fluid				75					149
Gravel No. 1				75					149
Gravel No. 2				75					149
Carbonyl				75				160	149
Plastics									
Polystyrene					75				223
Polystyrene 30								75	223
Polystyrene 40								75	223
40 Styrene Sheet								75	223
Styrene								75	223
Styrene 11								75	223
Styrene 12								75	223
Styrene 13								75	223
Styrene 14								75	223
Styrene 15								75	223
Styrene 16								75	223
Styrene 17								75	223
Styrene 18								75	223
Styrene 19								75	223
Styrene 20								75	223
Styrene 21								75	223
Styrene 22								75	223
Styrene 23								75	223
Styrene 24								75	223
Styrene 25								75	223
Styrene 26								75	223
Styrene 27								75	223
Styrene 28								75	223
Styrene 29								75	223
Styrene 30								75	223
Styrene 31								75	223
Styrene 32								75	223
Styrene 33								75	223
Styrene 34								75	223
Styrene 35								75	223
Styrene 36								75	223
Styrene 37								75	223
Styrene 38								75	223
Styrene 39								75	223
Styrene 40								75	223
Styrene 41								75	223
Styrene 42								75	223
Styrene 43								75	223
Styrene 44								75	223
Styrene 45								75	223
Styrene 46								75	223
Styrene 47								75	223
Styrene 48								75	223
Styrene 49								75	223
Styrene 50								75	223
Styrene 51								75	223
Styrene 52								75	223
Styrene 53								75	223
Styrene 54								75	223
Styrene 55								75	223
Styrene 56								75	223
Styrene 57								75	223
Styrene 58								75	223
Styrene 59								75	223
Styrene 60								75	223
Styrene 61								75	223
Styrene 62								75	223
Styrene 63								75	223
Styrene 64								75	223
Styrene 65								75	223
Styrene 66								75	223
Styrene 67								75	223
Styrene 68								75	223
Styrene 69								75	223
Styrene 70								75	223
Styrene 71								75	223
Styrene 72								75	223
Styrene 73								75	223
Styrene 74								75	223
Styrene 75								75	223
Styrene 76								75	223
Styrene 77								75	223
Styrene 78								75	223
Styrene 79								75	223
Styrene 80								75	223
Styrene 81								75	223
Styrene 82								75	223
Styrene 83								75	223
Styrene 84								75	223
Styrene 85								75	223
Styrene 86								75	223
Styrene 87								75	223
Styrene 88								75	223
Styrene 89								75	223
Styrene 90								75	223
Styrene 91								75	223
Styrene 92								75	223
Styrene 93								75	223
Styrene 94								75	223
Styrene 95								75	223
Styrene 96								75	223
Styrene 97								75	223
Styrene 98								75	223
Styrene 99								75	223
Styrene 100								75	223
Styrene 101								75	223
Styrene 102								75	223
Styrene 103								75	223
Styrene 104								75	223
Styrene 105								75	223
Styrene 106								75	223
Styrene 107								75	223
Styrene 108								75	223
Styrene 109								75	223
Styrene 110								75	223
Styrene 111								75	223
Styrene 112								75	223
Styrene 113								75	223
Styrene 114								75	223
Styrene 115								75	223
Styrene 116								75	223
Styrene 117								75	223
Styrene 118								75	223
Styrene 119								75	223
Styrene 120								75	223
Styrene 121								75	223
Styrene 122								75	223
Styrene 123								75	223
Styrene 124								75	223
Styrene 125								75	223
Styrene 126								75	223
Styrene 127								75	223
Styrene 128								75	223
Styrene 129								75	223
Styrene 130								75	223
Styrene 131								75	223
Styrene 132								75	223
Styrene 133								75	223
Styrene 134								75	223
Styrene 135								75	223
Styrene 136								75	223
Styrene 137								75	223
Styrene 138								75	223
Styrene 139								75	223
Styrene 140								75	223
Styrene 141								75	223
Styrene 142								75	223
Styrene 143								75	223
Styrene 144								75	223
Styrene 145								75	223
Styrene 146								75	223
Styrene 147								75	223
Styrene 148								75	223
Styrene 149								75	223
Styrene 150								75	223
Styrene 151								75	223
Styrene 152								75	223
Styrene 153								75	223
Styrene 154								75	223
Styrene 155								75	223
Styrene 156								75	223
Styrene 157								75	223
Styrene 158								75	223
Styrene 159								75	223
Styrene 160								75	223
Styrene 161								75	223
Styrene 162								75	223
Styrene 163								75	223
Styrene 164								75	223
Styrene 165								75	223
Styrene 166								75	223
Styrene 167								75	223
Styrene 168								75	223
Styrene 169								75	223
Styrene 170								75	223
Styrene 171								75	223
Styrene 172								75	223
Styrene 173								75	223
Styrene 174								75	223
Styrene 175								75	223
Styrene 176								75	223
Styrene 177								75	223
Styrene 178								75	223
Styrene 179								75	223
Styrene 180								75	223
Styrene 181								75	223
Styrene 182								75	223
Styrene 183								75	223
Styrene 184								75	223
Styrene 185								75	223
Styrene 186								75	223
Styrene 187								75	223
Styrene 188								75	223
Styrene 189								75	223
Styrene 190								75	223
Styrene 191								75	223
Styrene 192								75	223
Styrene 193								75	223
Styrene 194								75	223
Styrene 195								75	223
Styrene 196								75	223
Styrene 197								75	223
Styrene 198								75	223
Styrene 199								75	223
Styrene 200								75	223
Styrene 201								75	223
Styrene 202								75	223
Styrene 203								75	223
Styrene 204								75	223
Styrene 205								75	223
Styrene 206							</		

TABLE XI. COMPATIBILITY OF MATERIALS WITH WHITE FUMING NITRIC ACID

Material	Temperature, F								References
	Gas				Liquid				
	Class 1	Class 2	Class 3	Class 4	Class 1	Class 2	Class 3	Class 4	
Metals									
Aluminum 1060						130			249
Aluminum 1089						85	185		82
Aluminum 1100					75	85	160		75, 149, 211, 298
Aluminum 2014					110	75	100		29, 298
Aluminum 2017							100		82
Aluminum 2024					110	75		160	29, 298
Aluminum 3003					110	75	130		29, 249, 298
Aluminum 3052					110	75	160		29, 298
Aluminum 6061					110	75	120	160	29, 298
Aluminum 6061 (Welder)					75	100	130	140	82
Aluminum 6061					110	75	160		29, 298
Aluminum 7075					110	75		160	29, 298
Aluminum 43								160	29, 149
Aluminum 356								160	29
301 Stainless Steel				75				4120	29
302 Stainless Steel				75					149
304 Stainless Steel				75	70		85	120	21, 29, 30, 50, 149, 249
304 E.C. Stainless Steel				75				120	29, 30
304 E.C. Stainless Steel (Welder)				75		120	140		150
309 Stainless Steel				75			120	4160	29, 149, 249
310 Stainless Steel				75			120	4160	29, 149, 249
316 Stainless Steel				75			85	120	29, 56, 149, 211
316 E.C. Stainless Steel						75		4160	29
318 Stainless Steel						75		4160	29
321 Stainless Steel				75		75		4120	29
322 Stainless Steel								4160	29
347 Stainless Steel						75	120	120	149, 249, 298
347 Stainless Steel (Welder)						120	140		150
410 Stainless Steel				75				75	29, 56, 149, 211
410 Stainless Steel (Welder)								75	150
420 Stainless Steel								411	82
430 Stainless Steel				75			10		29, 56, 149, 211, 249
440 Stainless Steel								411	82
446 Stainless Steel							130	41	149, 249
Carpenter 20				75				125	50
SAB 1030						75		75	29, 149, 239
Mild Steel								411	149, 211
Steel 20M								411	149, 211
Mn-20Cr								411	149, 211
Cr-20Fe								411	82
Stainless						75			149, 211
St-Mn 20Cr						185			82
Inconel				75			125	130	149, 211
Nickel								411	149, 211
Ni-Mo-Fe Alloys								411	149
Ni-Cu Alloys								411	82
Ni-Si Alloys								411	82
Monel								75	149, 211
Ni-Cu-Ni					70			160	149
Copper								411	211
Cu-Ni Alloys								411	211
Other Copper Alloys								411	211
Brass								411	211
17-7PH								120	211
Martens								125	211
Duralmet 20									211
Stainless 8						75		130	149
Haynes 25						160			29
Gold						175			211
Lead								411	82
Soft Solder						75			149
Platinum						175			211
Silver Alloys								411	82
Silver Solder								75	149
Tantalum							175		211
Niobium								75	149
Titanium					160	160			29, 211, 249
Titanium 470					75				30
Titanium Cu-10M					75				39
Zirconium					160				29, 211
Nonmetals									
Teflon							80		149
Epoxy Resins								411	82
Phenolic Resins								411	82
Rubbers								411	149
Kel-F Dispersion Coating						75			82
3M-87NA Sealer						75			82
AGC-1 System E								411	82
Epon 470								411	82
Epon 470								411	82
Vinyl Mastic								411	82
DEL Series A								411	82
Prufcoat A								411	82
Stonewall RMA					75 (a)				82
Lanoket-40					75 (a)				82
Fluorline 100					75 (a)				82
Phenoline 315 Plus					75 (a)				82

TABLE 31. (Continued)

[illegible]

(c) Intermittent contact, such as espionage

TABLE 12. COMPATIBILITY OF MATERIALS WITH 80 TO 95 PERCENT NITRIC ACID

Material	Temperature, F								References
	90 to 915 F (30 to 500 C)				90 to 915 F (30 to 500 C)				
	Class 1	Class 2	Class 3	Class 4	Class 1	Class 2	Class 3	Class 4	
Metals									
Aluminum 1060		130							248
Aluminum 1080		85	185			85	140	140	287
Aluminum 1100	75	85	185	175		85	75	140	211, 221, 287
Aluminum 3003		130	185			85	140	140	211, 287
Aluminum 6061		85	185			85	140	140	248
304 Stainless Steel	75	130	125	212	75	120	160	160	58, 211, 248, 287
305 Stainless Steel		130	160			120	160	160	248, 287
312 Stainless Steel		130	160			120	160	160	248, 287
316 Stainless Steel	75	120	160	160	75	120	160	160	58, 287
321 Stainless Steel		120	125	212		120	120	212	211, 221
347 Stainless Steel	75	130	125	212	75		125	212	211, 248
416 Stainless Steel				A11			75	125	58, 211, 287
430 Stainless Steel								A11	82
434 Stainless Steel		130	75	130			75	125	58, 211, 248, 287
44C Stainless Steel		130	160	160		120	160	160	248
Carperter 20	75		212		75		212		58
Mild Steel				A11				A11	211, 287
Cast Iron				A11				A11	211, 287
W-Irons				A11				A11	211, 287
Co-Irons				A11				A11	287
St-Irons	212				212	185			211, 287
Bi-Mc-Irons						185			287
Nickel			185	A11				A11	211, 287
Monelloy B				A11					82
Monelloy C	75			75					
Copper				A11				A11	211, 221, 287
All Copper Alloys				A11				A11	211, 221, 287
Gold	212	185			212	185			211, 221
Lead				A11				A11	211, 287
All Lead Alloys				A11				A11	287
Platinum	212	185			212	185			211
Magnesium				A11				A11	287
All Magnesium Alloys				A11				A11	287
Silver				A11				A11	287
Zirconium	75								214
Tantalum	212	185			212	185			211
Titanium	75								214
Colubium	75				75				93
Nonmetals									
Glass	212				212				211
Siliconware	212				212				287
Rubber				75				75	211
Graphite				75				75	211

TABLE 83. COMPATIBILITY OF MATERIALS WITH NITROGEN TETRACIDE (N_2O_4) (<0.2% MOISTURE)

Material	Temperature, F								References
	Gas				Liquid				
	Class 1	Class 2	Class 3	Class 4	Class 1	Class 2	Class 3	Class 4	
410 Stainless Steel	65				100				169, 174
410 Stainless Steel (Welded)					65				169
416 Stainless Steel	65				65				169, 174
440C Stainless Steel					100				169, 245
302 Stainless Steel					100				169
303 Stainless Steel					100				169, 174
304 Stainless Steel	65			K2155	140				68, 169, 174, 220
304L Stainless Steel					145				17, 56, 169
304L Stainless Steel (Welded)					65				169
316 Stainless Steel	65				65				169
321 Stainless Steel	65				65				50, 169
321 Stainless Steel (Welded)					65				169
347 Stainless Steel	65				130				50, 169, 174
347 Stainless Steel (Welded)					65				169
A-286 (Annealed)					100				50, 169
A-286 (Aged)					60				50
AM-35C (Annealed)					60				169
AM-35C (Condition A)					65				169
17-4PH (W100C)					100				169
17-4PH (W100C)					100				169
17-7PH (TW50C)	60				100				169, 174
17-7PH (RW50C)					100				169
PH15-7 Mo (Condition A)					180				12
16-25-6 Lead					85				174
MoSibrenum				K2112		80	80	80	174, 220
Magnesium, 100A	41	45			60	44			169, 174
Magnesium, AZ31C	61	65			60	65	50		169, 174
Magnesium, HM21A-T8					60				50, 174
Al-Nickel	60				65			75	169, 174
Nickel Electroplate					60				165
Electroless Nickel Plate	65				100				169, 174
A-Nickel (Welded)					65				169
Inconel	65				65			75	169, 174
Monel	65				65			75	169, 174
N-Monel					65			75	174
Ni-Span-C					60				169
Inconel X					75				174
Hastelloy Alloys					75				174
Niivar					60				50, 169
Platinum					75	75			21
Silver								75	174, 221
Silver Paste								50	169
Silver Solder								50	50, 169
Easy Flo 45								80	169, 245
St. Feel 55Co, 15Ag, 5Pb								80	245
Metco Hard Facing Alloy W							100	100	169
Metco Hard Facing Alloy 100							100	100	169
Metco Hard Facing Alloy 510							100	100	169
TE Spec Bzaze							80		245
Microseal 100-1 on AMCO A Mg				100			100		169
Microseal 100-1 OD on AZ31C Mg				75			75		169
Microseal 100-1 on 2014-T6 Al	100				100		100		169
716 Bzaze 60Co-70 Al					65				169
Pure Tin Solder on 303 SS					65				169
Easy Flo Bzaze on 347 SS					65				169
AMS 4775 Microbrazz on 347 SS					65				169
Cu-60 Bzaze (Mo-Mi-Co) on 347 SS						100			169
Tantalum	65			K2021	75				68, 169, 174, 211, 220
Tin					80				174, 220
Tin Plate					60				169
Titanium, 6SA					100				169
Titanium, 7SA					105				17, 169, 220
Titanium, Alloy 4	65(6)				65				169, 174
Titanium, B122(2SA)					60				50, 169
Titanium, C122(2AV)					185				69, 174
Titanium, RC133AM	50(6)				150				169
Titanium, 6Al-4V					150				17, 50
Tungsten Carbide	65					65			169
Zinc								80	174, 220
Zinc Plate								50	169
Zirconium								75	220
FLUORIDES									
Teflon					75				50
Teflon FFE					75	60			169
Teflon FEP					100	60		60	23, 169
Teflon Graphite					75	50			23, 50, 169
Teflon PPS					75	50			50, 169
Teflon Asbestos					75				50, 169
Teflon Filled With Glass					80				23, 169
Teflon Filled With CaF ₂					80				23, 169
Teflon (Silica Primed)								75	23
FPE-Resit					75			60	50, 169
Armoform 7700					75	60			50, 169
Armoform 7700B					75	50			50, 169
Fluorobaktes					60				50, 169
Fluorogreen					60				50, 169

Material	Temperature, °F								References
	Gas				Liquid				
	Class 1	Class 2	Class 3	Class 4	Class 1	Class 2	Class 3	Class 4	
Kel-F								75	50
Kel-F 300 (unplasticized)								60	169
Kel-F 300 (Annealed)								60	169
Genetron GC						80		160	23, 169
Genetron CCK-38					65			160	169
Genetron M-25					65			160	169
Trilthane A						80		75	23, 169
Alcor 191					67				169
Polyethylene								75	23, 50
Polyethylene (low density)						60		60	169
Polyethylene (high density)						60		60	169
Polyethylene (irradiated)							60	60	50, 169
Raythane N (irradiated)					65			65	169
Polypropylene						60		60	50, 169
Nylon								65	50
Zytel 101								65	50
Copren 591								60	23, 169
Nylar								60	169
Saran								60	23, 50, 169
Synar					80			80	50, 169
Delrin								60	169
Luxon								60	50, 169
Tedlar					67			80	50, 169
Marlex 50								75	50, 169
MI Fox								75	23
Spondite								75	23
Kodapak II								75	23, 169
Mycon 20								60	169
H-File								60	169
Epon 1031 (with PMCA)								80	169
Plexiglas II								75	50
Plexiglas CR-39								75	50, 169
Plexiglas 55								75	50
Silicone Laminate								50	50, 169
Therocil Laminate						60		75	50, 169
Epon Laminate								50	50, 169
Polyester Laminate								60	50, 169
TM-1571 Laminate								75	50
Polyvinylchloride								75	50
Ultron						80		80	50, 169
Opalon 1219							60	60	169
Opalon 1220								60	169
Opalon 1221								60	169
Opalon 1222								60	169
W-plate								60	169
Elastomers									
Peristaltic 14 Extruded Polypropylene Rubber								65	169
Formula 132 (Ethylene Propylene Rubber, ILC)								67	169
E-42-2								65	169
E-422-1								65	169
X-7000-1 to 7 and 9 to 11								65	169
Parker 805-70								80	169
Parker 846-80								80	169
Parker 846-7								80	169
Parker 846-10								80	169
E-14, 258								65	50, 169
Exlar 551								65	169
Hycar 2202								65	50, 169
Stillman SR613-75								65	169
Stillman 11502-34								65	169
Stillman TC4, 9, 1A								65	169
Precision 1390K20								70	169
Precision Formula 120								67	169
Precision Formula 121								67	169
Parker XV-1235-2								80	169
Parker XV-1235-4								80	169
Parker KB-1235-10								80	169
Trifluorohydrofluoroketane tetrafluoroethylene (TFM-TFE)								80	169
Viton A								67	50, 169
Viton B								60	50, 169
Stillman Extruded Omni X FBE-4								67	169
Fackel V424-1								67	169
Parker 77-045								60	169
EX921-A70								60	169
Kel-F Elastomer								80	169
Kel-F-370C								75	50, 169
Kel-F-9500								60	169
Stillman Thicon Fluorel								65	169
LS 52								60	50, 169
LS 63								80	169
Nature Rubber									
Buna N								60	50, 169
B-318-7								80	169
Chlorbutyl 500 (Silicone)								60	50, 169
Gerlock 22								65	50, 169
Gerlock 90C								65	50, 169
Neoprene								60	50, 169
Hypalon 20								75	50
Polybutadiene								75	50
Ty-lac 1650								75	50
Ty-lac 1640C								75	50
Ty-lac 1640								75	50
Penton								75	50
Chloroprene								75	50

Material	Temperature, F								References
	Gels				Liquids				
	Class 1	Class 2	Class 3	Class 4	Class 1	Class 2	Class 3	Class 4	
Lubricants									
DC 11		67				67			160
DC 55						80			160
DC PL VAC		67				67			160
DC 150									160
Rayco-DC Grease					65				160
Nel-P 90								60	160
Polyglycol Oil						60			160
FX 45								67	160
Molykote Z						67			160
DiLube 703					60				160
Electrofil 86-C							60		160
Rayco-30 Grease							60		160
Halocarbon Grease						67		60	160
Nordseal 1475 and 421						90			160
Microseal 100-1									160
PD-88					67				160
LOX Safe								67	160
Flake Graphite					80				160
Johns Manville No. 40					80				160
Graphiter 2,14,29,30, and 86								60	160
CCP-72					67				160
Purebor P3M and P3N					67				160
Valve Seal A						67			160
Aplon L							60		160
Fluorolube M6600					80				160
Fluorothene G					80				160
Sealants and Potting Compounds									
Reddy Tube 100	67				160				160
Reddy Tube 200	67				160				160
Waterglass-Graphite	67				67				160
Vulcan A			67				67		160
Dry-Lube Sealant									160
Taffin Tape (Unstretched)					80				160
78-1422								60	50, 160
RTV 20								60	50, 160
Epoxy 928								60	50, 160
Tetraplex P-43								60	50, 160
Proseal 703								60	50, 160
Paltrane 5256								60	50, 160
Crystal M & CF					60			60	50, 160
DC Potting								75	50
Epoxy 92								75	50
Epoxy 921								75	50
Epoxy 422								75	50
Epoxy 921								75	50
Epoxy 101								75	50
Epoxy 921-9								75	50
EC 105								75	50
EC 106								75	50
Resinex SC1008								75	50
Resinex SC1013								75	50
Reinhold P120-15								75	50
US Polymeric 1000								75	50
Adhesives									
Armstrong A-6								60	50, 160
EC 647								60	50, 160
HT 426								60	50, 160
3M-AF-10								60	160
A-15					60				160
Epoxy 422								60	50, 160
Ceramics									
Temperal 1500									50, 160
Saceralene P-1				60	75				50, 160
Saceralene 11					60				50, 160
Saceralene 47							75		160
Coatings									
Rotaflex									160
Resistal 1, 2, and 3							75		160
Aluminum									
Epoxy No. 1							80		160
Epoxy No. 5							60		160
Epoxy No. 7							60		160
Epoxy No. 9							60		160
Epoxy 6809							60		160
Modified Epoxy No. 5							60		160
Axyd No. 4							60		160
Four-Jet-48							60		160
Catalac Primer and Filler on Steel							67		160
Catalac Improved							67		160
Acrylic Nitrocellulose Vinyl							60		160
Primer M1-P-6889							60		160
Type 7							60		160
Co-Flo Max P-2000							75		160
CA 974 Primer							75		160
Corrosite Clear 581							75		160
Proseal 333							75		160
Metal: DAB, DAB, DAB, DAB				60					160
Gray							75		160

(e) Personal communication.

(b) Titanium ignites under impact, but ignition does not spread.

TABLE 34. COMPATIBILITY OF MATERIALS WITH NITROGEN TETRoxide CONTAINING FROM 0.2 TO 1.0 PERCENT WATER

Material	Temperature, F								References
	Gas				Liquid				
	Class 1	Class 2	Class 3	Class 4	Class 1	Class 2	Class 3	Class 4	
Metals									
Aluminum, 1050					80				82
Aluminum, 1100-H14					80				90
Aluminum, 2014-T6					80				90
Aluminum, 2024					140				82
Aluminum, 2219-T81					80				90
Aluminum, 5052					130	140			90
Aluminum, 5086-H34					70	15	165		12
Aluminum, 5086 Welded					70	12	165		12
Aluminum, 5456-H34					60				70
Aluminum, 5456-H321					60				90
Aluminum, 6061-T6					130		160		90
Aluminum, 7075-T6					60				90
Aluminum, 356-T6					80				90
Copper						80			86
Yellow Brass								80	82
Red Brass								80	82
1020 Steel					130				90
Carbon Steel, ASTM-A285, Grade C					70	165			12
Carbon Steel						80	170		82
Mild Steel					130	140			82
AISI Steel					140				82
304 Stainless Steel					80				82
304 Stainless Steel					140				82
304 Stainless Steel					165				12, 90
307 Stainless Steel					130				82
308 Stainless Steel					80				82
A-286 (Annealed)					60				90
PH15-7Mo					165				12
Al-Span-40					60				90
Ti-6Al-4V						80			82
Titanium, 75A					165				12
Titanium, 6Al-4V					165				12, 90
Nonmetals									
Silicone Rubber						80			82
Kel-F (unplasticized)					150				82
Kel-F (plasticized)								160	82
Koroseal						80			82
Polyethylene						80			82
Selen					190				82
Teflon						80			82
Tygon									82
U. S. No. 2090								80	82
Graphite Waterglass						80			82

TABLE 35. COMPATIBILITY OF MATERIALS WITH NITROGEN TETRoxide CONTAINING 3.2% WATER (12)

Material	Temperature, F								References
	Gas				Liquid				
	Class 1	Class 2	Class 3	Class 4	Class 1	Class 2	Class 3	Class 4	
Metals									
Aluminum, 5086-H34						15	70	120	
Aluminum, 5086, Welded						15	70	120	
Carbon Steel, ASTM-A285, Grade C					15				
304L Stainless Steel					165		70	120	
PH15-7Mo					165				
Titanium, 75A					165				
Titanium, 6Al-4V					165				

TABLE 36. COMPATIBILITY OF MATERIALS WITH NITROGEN TETRoxide FLOWING AT 10 FEET PER SECOND (12) (12) (12) (12) (12) (12) (12) (12) (12) (12)

Material	Temperature, F								References
	Gas				Liquid				
	Class 1	Class 2	Class 3	Class 4	Class 1	Class 2	Class 3	Class 4	
Metals									
Aluminum, 5086					90				
Carbon Steel, ASTM-A285, Grade C					90				
304L Stainless Steel					90				
PH15-7Mo					90				
Nonmetals									
Nel-P									90
Teflon									90
Koroseal									90
Alathon									90
PVC									90
John-Manville Service Asbestos									90
African Blue Asbestos					90				
Teflon Impregnated Asbestos - Palmetto 133C					90				

31 REFERENCES

- (1) Abramson, B. N., Brandwein, D. S., and Menes, H. C., "The 250,000-Pound Thrust Rocket Test Stand at Lake Denmark, N. J.", Jet Propulsion, 24 (5), 291-296 (1954).
- (2) "Survey of Hazards of Handling Liquid Oxygen", Accident and Fire Prevention Information, AEC, Issue 76 (January 23, 1958).
- (3) "Compatibility of Six Selected Materials in Eight Propellants", Report M-1856, Aerojet-General Corporation, Materials Department.
- (4) "Storable Liquid Propellants Nitrogen/Aerozine 50", Report No. LRP 198, Second Edition, Aerojet-General Corporation, Sacramento, California (June, 1962).
- (5) Africano, A., "Specification (Tentative) Lubricant, Antiseize, and Sealing for Liquid Oxygen Systems", Report GM-676-9A, Space Technology Laboratories, Inc., Los Angeles, California (Revised October 10, 1958).
- (6) Africano, A., "General Guidance for the Preparation of Specifications for Fabrication, Assembly, and Operation of Components and Facilities Utilizing LOX and Associated Gases and Materials", Report GM-TM-178A, Space Technology Laboratories, Inc., Los Angeles, California (October 10, 1958).
- (7) Agricola, K. R., "The Usefulness of Materials Used in Booster Structures", paper presented at the Symposium, The Application and Properties of Materials Used in Aerospace Vehicle Design, sponsored by The Martin Company, Denver, Colorado, May 4-6, 1960.
- (8) Allen, S., "Liquid Oxygen as a Rocket Propellant", Journal of the British Interplanetary Society, 14 (3), 165-168 (1955).
- (9-11) Preliminary information and private communication from Allied Chemical Corporation, Hopewell, Virginia.
- (12) Alley, C. W., Hayford, A. W., and Scott, H. F., Jr., "Nitrogen Tetroxide Corrosion Studies", Report No. TR-60-384 under Air Force Contract AF 33(616)-6568, Allied Chemical Corporation, Hopewell, Virginia (July, 1960).
- (13) Alley, C. W., Hayford, A. W., and Scott, H. F., Jr., "Effect of Nitrogen Tetroxide on Metals and Plastics", Corrosion, 17 (10), 479t-484t (October, 1961).
- (14) "Product Information Technical Bulletin TA-85413, Fluorine", Allied Chemical Corporation, Hopewell, Virginia (October, 1961).
- (15) "Product Data Sheet PD-TB-85411, Liquid Fluorine Unloading Procedure", Allied Chemical Corporation, Hopewell, Virginia (July, 1958).
- (16) "Product Information Technical Bulletin TC-85411, Handling Elemental Fluorine Gas in the Laboratory", Allied Chemical Corporation, Hopewell, Virginia (October, 1961).
- (17) "Product Information Technical Bulletin TA-8532-3 Chlorine Trifluoride (CTF)", Allied Chemical Corporation, Hopewell, Virginia.
- (18) "Product Data Sheet PD-TA-70751, Nitric Acid, Fuming", Allied Chemical Corporation, Hopewell, Virginia (February, 1959).
- (19) Ambrose, P. M., and Barrett, J. C., "Investigation of Accident Involving Titanium and Red Fuming Nitric Acid, Bureau of Mines Information Circular 7711, U. S. Department of the Interior (September, 1954).
- (20) Arbellot, L., "Behavior of Nickel and Its Alloys in the Presence of Halogens", Corrosion et Anticorrosion, 2 (4), 112-118 (April, 1957).
- (21) Ashmead, R. R., "Static Seals for Missile Applications", Jet Propulsion, 25, pp 331-333, 340, 346 (1955).
- (22) Austin, C. M., Rohrer, C. S., and Selfert, R. L., "Explosive Hazard of Aluminum-Liquid Oxygen Mixtures", Journal of Chemical Education, 36 (2), 54-57 (February, 1959).
- (23) Preliminary information, The Connecticut Hard Rubber Company, New Haven, Connecticut.
- (24) Baldrige, J. H., "The Resistance of Elastomers and Plastics to Rocket Propellants", Report No. WADC 57-472, The Connecticut Hard Rubber Company, New Haven, Connecticut (January, 1958).
- (25) Balis, E. W., "Behavior of Liquid Oxygen", Report No. 45783, General Electric Company, Schenectady, New York (June, 1946).
- (26) Baum, J. V., Goobich, B., and Trainer, T. M., "An Evaluation of High-Pressure Oxygen Systems", Final Technical Report ASD under Air Force Contract AF 33(616)-8267, Battelle Memorial Institute, Columbus, Ohio (August 3, 1962).
- (27) Beane, A., "Results of Impact Testing of Titanium with Liquid Oxygen", Report No. WADC TN 59-175, Wright Air Development Center, Propulsion Laboratory, Wright-Patterson Air Force Base, Ohio, AD 232573 (April, 1959).
- (28) "Development and Standardization of Peroxide Handling Techniques and Devices", Report No. HR-24, Becco Chemical Division, Food Machinery and Chemical Corporation, Buffalo, New York (January, 1955).
- (29) Beck, F. H., Holzworth, M. L., and Fontana, M. G., "Materials for Handling Fuming Nitric Acid", Report No. AF TR 6519, Part I under Air Force Contract AF 33(038)-10381, The Ohio State University Research Foundation, Columbus, Ohio, AD 159418 (March, 1952).
- (30) Bergdorf, W. H., and Kinsey, E. J., Jr., "Investigation of Corrosion Inhibitors for Fuming Nitric Acid", Report No. WADC TR 57-302 under Air Force Contract AF 33(616)-3056, Wright Air Development Center, Materials Laboratory, Wright-Patterson Air Force Base, Ohio, AD 151116 (April, 1958).
- (31) Berman, L. D., "Compatibility of Materials With Storable Propellants", The Martin Company, Denver, Colorado, paper presented at the Fourth National SAMPE Symposium, Los Angeles, California, November 13-15, 1962.

- (32) Bernard, M., "Inhibitors of Nitric Acid Corrosion of Steel and Light Alloys", Corrosion et Anticorrosion, 4 (4), 126-134 (April, 1956).
- (33) Binder, W. O., "Effect of Cold Work at Low Temperature on Austenitic 18-8", Metal Progress, 58 (2), 201-207 (August, 1950).
- (34) Birmingham, B. W., Brown, E. H., Class, C. R., and Schmidt, A. F., "Vessels for the Storage and Transport of Liquid Hydrogen", Paper 2757, Journal of Research of the National Bureau of Standards, 58 (5), 243-253 (May, 1957).
- (35) Bloom, R. J., Jr., Weeks, L. E., and Raleigh, C. W., "Materials of Construction for Equipment in Use with Hydrogen Peroxide", Bulletin of Technical Information, Bulletin No. 104, Becco Chemical Division, Food Machinery and Chemical Corporation, Buffalo, New York (1959 Edition).
- (36) Bloom, R. J., Jr., Nowak, J. H., Raleigh, C. W., and Weeks, L. E., "Hydrogen Peroxide and Materials of Construction", Corrosion, 16 (4), 164t-170t (April, 1960).
- (37) Bloom, R. J., Jr., Davis, N. S., and Levine, S. D., "Hydrogen Peroxide as a Propellant", Journal of the American Rocket Society, (80), pp 3-17 (March, 1950).
- (38) Bloom, R. J., Jr., and Brunsvold, N. J., "Anhydrous Hydrogen Peroxide as a Propellant", Chemical Engineering Progress, 53 (11), 541-547 (November, 1957).
- (39) Bomberger, H. B., "Titanium Corrosion and Inhibition in Fuming Nitric Acid", Corrosion, 13 (5), 287t-291t (May, 1957).
- (40) Booth, P., "The Halogen Fluorides", Chemical Reviews, 41, pp 421-439 (1947).
- (41) Bowers, T. K., "Naval Handling Manual", Report PR MONGF-P 31, U. S. Naval Gun Factory, Washington, D. C. (January, 1953).
- (42) Boyd, W. K., "Summary of Present Information on Impact Sensitivity of Titanium When Exposed to Various Oxidizers", DMIC Memorandum 89, Defense Metals Information Center, Battelle Memorial Institute, Columbus, Ohio (March 6, 1961).
- (43) Boyd, W. K., Campbell, J. E., Fink, F. W., Jackson, J. D., Miller, P. D., Rice, L. P., and Simmons, F. W., "The Evaluation of Effects of Very Low Temperatures on the Properties of Aircraft and Missile Metals and A Study of the Titanium-Liquid Oxygen Pyrophoric Reaction", Report under Air Force Contract AF 33(616)-6345, Battelle Memorial Institute, Columbus, Ohio (August 31, 1959).
- (44) Bradley, P., and Waite, G. C., "The Techniques of Welding Aluminum and Aluminum Alloy Vessels for Use with Concentrated Hydrogen Peroxide", Technical Note R.P.D.-157, Royal Aircraft Establishment, England (November, 1957).
- (45) Brennan, W. H., "Failure of Titanium Helium Bottle", Rocketdyne Letter 59RD9330, North American Aviation, Canoga Park, California.
- (46) Brown, E. H., Class, C. R., and Schmidt, A. F., "Vessels for the Storage and Transport of Liquid Hydrogen", Report NBS-3529, National Bureau of Standards (April, 1955).
- (47-50) Preliminary information and private communication, The Martin Company, Denver, Colorado.
- (51) Brown, J. A., "Effect of Propellants on Plastic Aerosol Valve Components", Soap and Chemical Specialties, 36 (3), 87, 88, 91, 206, 207 (March, 1960).
- (52) Brown, P. E., Crabtree, J. M., and Duncan, J. F., "Corrosion of Copper by Elementary Fluorine", Report AERE-C/R-1241, Atomic Energy Research Establishment, England (April 27, 1953).
- (53) Butts, W. H., and Williams, M. F., "Vector II Tank Contamination", Engineering Report No. 128, Lockheed Aircraft Corporation, Missiles and Space Company, Sunnyvale, California (September 8, 1961).
- (54) Campbell, J. W., "Compatibility of Various Materials with Unsymmetrical Dimethylhydrazine", Report M544, Aerojet-General Materials Division.
- (55) "Nitrogen Perchlorate", Technical Bulletin C-1200, Callery Chemical Company, Callery, Pennsylvania (September 4, 1962).
- (56) "Pentaborane", Technical Bulletin CI-1300, Callery Chemical Company, Callery, Pennsylvania (October 1, 1961).
- (57) "Trialkyl Boranes", Technical Bulletin C-311, Callery Chemical Company, Pittsburgh, Pennsylvania (March 1, 1959).
- (58) "Corrosion Control", Report I.D. 113A, Carpenter Steel Company, Reading, Pennsylvania, (1960).
- (59) Cassidy, F. H., "Materials for Use With Various Rocket Propellants", Report MA 158, Aerojet-General Corporation, Materials Division (July, 1953).
- (60) Cassidy, F. H., "Effect of Unsymmetrical Dimethylhydrazine and JP-X on Nylon, Type FM-10001", Report MA-263, Aerojet-General Corporation, Materials Division.
- (61) Cassidy, F. H., "Compatibility of Various Materials With Unsymmetrical Dimethylhydrazine", Report MA-255, Aerojet-General Corporation, Materials Division (August, 1954).
- (62) Cassidy, F. H., "Compatibility of O-Ring Materials for Use in Unsymmetrical Dimethylhydrazine JP-X", Report MA-252, Aerojet-General Corporation, Materials Division (June, 1954).
- (63) Cassidy, F. H., "Compatibility of Dimethylhydrazine with Usual Construction Materials", Report M-232, Aerojet-General Corporation, Materials Division.
- (64) Cawthorne, E. W., DMIC, memorandum to R. J. Runck, Director, Defense Metals Information Center, Battelle Memorial Institute, Columbus, Ohio (October 15, 1959).

- (65) Chafey, J. E., Witzell, W. E., and Scheck, W. G., "Titanium-Oxygen Reactivity Study", Report 4E-62-0674 under NASA Contract NAS 8-2664, General Dynamics/Astronautics, San Diego, California (July 2, 1962).
- (66) Christian, J. L., Chafey, J. E., Hurlich, A., Watson, J. F., and Witzell, W. E., "Compatibility of Metals and Cryogenic Liquids", Metal Progress, 83 (4), 100-103, 122, 124 (April, 1963).
- (67) Clark, A. M., "Tonnage Oxygen Process", Chemical and Process Engineering, 41 (6), 243-246 (June, 1950).
- (68) "Freon Technical Bulletin B-2", E. I. du Pont de Nemours and Company, Inc., Wilmington, Delaware (1962).
- (69) Clark, J. D., and Walsh, M. E., "The Corrosivity of Fuming Nitric Acid", Transactions of New York Academy of Science, 17, pp 279-288 (1955).
- (70) Clegg, J. W., and Peterseim, F. D., "Behavior of Commercial Hydrazine in Contact With Various Materials", Research Memo RM 504, Battelle Memorial Institute, Columbus, Ohio (August, 1950).
- (71) Clippinger, D. E., and Morris, G. J., "Impact Sensitivity of Organic Materials on Exposure to Liquid Oxygen", Aircraft Engineering, 31, (365), 204, 205 (July, 1959).
- (72) Cole, L. G., "The Nitrogen Oxides as Rocket-Fuel Oxidants Including the Theoretical Performances of Propellant Systems Employing Nitrogen Tetroxide", CIT-JPL Progress Report No. 9-23, California Institute of Technology, Jet Propulsion Laboratory, Pasadena, California (October, 1948).
- (73) Committee T-5B, "High Temperature Corrosion Data", Corrosion, 11 (5), 59-63 (May, 1955).
- (74) Coplen, H. L., "Large-Scale Production and Handling of Liquid Hydrogen", Journal of the American Rocket Society, 22, pp 309-322 (1952).
- (75) Davis, N. S., and Levine, S. D., "Storage and Handling of Hydrogen Peroxide", Final Report under Army Contract W18-108-OM-652, Army Chemical Center, Maryland.
- (76) Davis, N. S., and Keefe, J. H., "Concentrated Hydrogen Peroxide as a Propellant", Industrial and Engineering Chemistry, 48 (4), 745-748 (April, 1956).
- (77) Davis, N. S., and Bloom, R., Jr., "Newer Techniques in the Transfer of Hydrogen Peroxide at High Pressures", paper presented at the American Rocket Society Meeting (December, 1954).
- (78) "Preliminary Data on the Reaction Sensitivity of Titanium and Oxygen", Technical Note, Defense Metals Information Center, Battelle Memorial Institute, Columbus, Ohio (August 14, 1959).
- (79) Diamond, L. H., "Unsymmetrical Dimethylhydrazine", Chemical Engineering Progress, 57 (7), 87, 90, 92 (July, 1961).
- (80) "The Handling and Storage of Liquid Propellants", Office of the Director of Defense Research and Engineering, Washington, D. C. (March, 1961).
- (81) "The Handling and Storage of Liquid Propellants", Office of the Director of Defense Research and Engineering, Washington 25, D. C. (January, 1963).
- (82) Boyd, R. K., and White, E. L., "Compatibility of Rocket Propellants With Materials of Construction", Unreferenced data from DMIC Memorandum 65, Defense Metals Information Center, Battelle Memorial Institute, Columbus, Ohio (September 15, 1960).
- (83) Preliminary information, Astropower, Inc., Newport Beach, California.
- (84) "Parlage for Profit", E. I. du Pont de Nemours and Company, Inc., Wilmington, Delaware (1956).
- (85) English, J. L., "Corrosion by Nitric Acid", Corrosion, 12 (6), 65-68 (1956).
- (86) Ericson, G. L., Boyd, W. K., and Miller, P. D., "Corrosion of Titanium and Titanium Alloys in Liquid and Gaseous Fluorine", Titanium Metallurgical Laboratory Memorandum 152, Battelle Memorial Institute, Columbus, Ohio (April 30, 1958).
- (87) Everhart, J. L., "Mafnium Metal--Its Properties and Future", Materials and Method, 36 (5), 95-97 (November, 1952).
- (88) Farber, M., Darnell, A. J., and Ehrenberg, D. M., "High Temperature Corrosion Rates of Several Metals With Nitric Oxide", Journal of the Electrochemical Society, 102 (9), 446-453 (1955).
- (89) Feiler, C. E., and Morrell, G., "Investigation of Effect of Fluoride on Corrosion of 25-O Aluminum and 347 Stainless Steel in Fuming Nitric Acid at 170 F", Report NACA RM53L17b, NASA-Lewis Research Center, Cleveland, Ohio (February, 1954).
- (90) Fink, F. W., and White, E. L., "Materials of Construction for Handling Fluorine", Battelle Memorial Institute, Columbus, Ohio, from the Proceedings of the Propellant Thermodynamics and Handling Conference, held at The Ohio State University, Columbus, Ohio, on July 20-21, 1959.
- (91) Fink, F. W., and White, E. L., "Corrosion Effects of Liquid Fluorine and Liquid Oxygen on Materials of Construction", Corrosion, 17 (2), 58t-60t (February, 1961).
- (92) "Compatibility of Materials With Dimazine", Food Machinery and Chemical Corporation, Princeton, New Jersey.
- (93) Francis, E. L., "Niobium Data Manual", English Report IGR-R/R-304, United Kingdom Atomic Energy Authority (October 16, 1958), and Amendment Sheets (April, 1961).

- (94) Freeman, R. R., and Briggs, J. Z., "Corrosion Resistance of Molybdenum and Molybdenum Base Alloys", Technical Notes, Climax Molybdenum Company (November, 1959).
- (95) Fulmer, D., "Investigation of Fuming Nitric Acid Contaminants", Report No. 8002-981-006, Bell Aircraft Corporation, AD 156224 (October, 1957).
- (96) Fulmer, D., "Investigation of Fuming Nitric Acid Contaminants", Report No. 8002-981-007 Bell Aircraft Corporation (November, 1957).
- (97) Fulmer, D., "Investigation of Fuming Nitric Acid Contaminants", Report No. 8002-981-012, Bell Aircraft Corporation (April, 1958).
- (98) Gakle, P. S., and Grush, R. E., "Minutes of Symposium on Liquid Oxygen Contamination", Aerojet-General Corporation (April 28, 1959).
- (99) Gall, J. F., "Fluorine-Derived Chemicals as Liquid Propellants", Industrial and Engineering Chemistry, 49 (9), 1331-1332 (September, 1957).
- (100) Gall, J. F., "Recent Advances in Fluorine Chemistry and Technology", Journal of the American Rocket Society, 22, pp 95-103 (February, 1959).
- (101) Gelman, S. I., "Use of Rocket Oxidizers", Report TR-55219, General Electric Company, (August, 1947).
- (102) Geiger, R. A., Schuler, F. T., and Mowers, R. E., "Corrosion Considerations in Selection of Rocket Engine Materials", Corrosion, 16 (1), 20 (January, 1960).
- (103) Gibson, W. R., "Evaluation of Materials of Construction for Boron High Energy Production", Callery Chemical Company, paper presented at NACE Meeting in Chicago, Illinois (March 16-20, 1959).
- (104) Gilbert, L. L., and Funk, C. W., "Explosions of Titanium and Fuming Nitric Acid Mixtures", Metal Progress, 70 (5), 93-96 (November, 1956).
- (105) Gillig, F. J., "Effects of Concentrated Hydrogen Peroxide on Mechanical and Corrosion Properties of Structural Aluminum Alloys", Report No. KC-1164-M-11, Cornell Aeronautical Laboratories, Inc., Buffalo, New York (February, 1959).
- (106) Glocker, G., and Popov, A. J., "Observations on the Fluorination of Praseodymium and Neodymium Compounds", Journal of the American Chemical Society, 74 (5), 1357-1358 (March 5, 1952).
- (107) Goalwin, D. S., "Techniques for Transferring Cold Liquids", Refrigerating Engineering, 59 (3), 251-255 (1951).
- (108) Goldschlag, L., and Brunsvold, N. J., "Effect of Coupling of Aluminum or Stainless Steel Alloys to Aluminum on Corrosion by 90% Hydrogen Peroxide", Report 91:49-4, Food Machinery and Chemical Corporation, Princeton, New Jersey (October, 1959).
- (109) Gordon, J. N., Jr., "Comments on the Corrosion of Stainless Steel in Liquid Ammonia Cleaning Solution", US AEC Report NP-6432, Mine Safety Appliance Company, Callery, Pennsylvania (August 20, 1953).
- (110) Grelecki, C. J., and Tannenbaum, S., "Survey of Current Storable Propellants", ARS Journal, 32, pp 1189-1195 (August, 1962).
- (111-114) Preliminary information and private communication, Pennsalt Chemical Corporation, Wyndmoor, Pennsylvania.
- (115) Grigger, J. C., and Miller, H. C., "The Compatibility of Materials With Chlorine Trifluoride, Perchloryl Fluoride and Mixtures of These", Report TR 61-54 for WADD under Air Force Contract AF 33(616)-6796, Pennsalt Chemical Corporation, Wyndmoor, Pennsylvania (April, 1961).
- (116) Grigger, J. C., and Miller, H. C., "The Compatibility of Materials With Chlorine Trifluoride, Perchloryl Fluoride and Their Mixtures", Materials Protection, 3 (9), 53-58 (September, 1964).
- (117-119) Preliminary information and private communication, Pennsalt Chemical Corporation, Wyndmoor, Pennsylvania.
- (120) Gundzik, R. M., and Feller, C. E., "Corrosion of Metals of Construction by Alternate Exposure to Liquid and Gaseous Fluorine", Report NACA TN-3333, NASA-Lewis Research Center, Cleveland, Ohio (December, 1954).
- (121) Haendler, H. M., Bartram, S. F., Becker, R. S., Bernard, W. J., and Bukata, S. W., "Reaction of Fluorine With Titanium, Zirconium and the Oxides of Titanium, Zirconium and Vanadium", Journal of the American Chemical Society, 76 (8), 2177-2178 (April 27, 1954).
- (122) Haendler, H. M., Bartram, S. F., Bernard, W. J., and Kippax, D., "Reaction of Fluorine With Tin", Journal of the American Chemical Society, 76 (8), 2179-2180 (1954).
- (123) Haendler, H. M., Towle, L. H., Bennet, E. F., and Patterson, W. L., "Reaction of Fluorine With Copper", Journal of the American Chemical Society, 76 (8), 2178-2179 (1954).
- (124) Halbedel, H. S., and Swinehart, C. F., "Final Summary Report for Rocket Propellant Oxidizers" under Contract NDA(s)-10249(c), Laurel Research Laboratory, Marshaw Chemical Company, Cleveland, Ohio (April 25, 1950).
- (125) Hauser, R. L., and Peckham, H. M., "Compatibility of Materials With Liquid Oxygen", Report No. M-M-MI-58-66, The Martin Company, Denver, Colorado (November, 1958).
- (126) Hauser, R. L., Sykes, G. E., and Rumpel, W. F., "Mechanically Initiated Reaction of Organic Materials in Missile Oxidizers", ASD Technical Report 61-324 under Air Force Contract AF 33(616)-7271, The Martin Company, Denver, Colorado, (October, 1961).

- (127) "Corrosion Resistance of Haynes Alloys", Haynes Stellite Company, Kokomo, Indiana (November, 1958).
- (128) "Hastelloy, Corrosion-Resistant Alloys", Haynes Stellite Company, Kokomo, Indiana (May, 1957).
- (129) Heep, H., "Experiences With Hydrogen Peroxide at the Engineering Experiment Station", United States Navy Engineering Experiment Station, Annapolis, Maryland, paper presented at the Second Inter-Bureau Technical Committee on Guided Missile Propellants (November 4, 1949).
- (130) Henderson, P., "Storage and Handling of White Fuming Nitric Acid", Report CRL-372, Chemical and Radiological Labs, Army Chemical Center, Maryland (August, 1954).
- (131) Holt, C. W., and Turley, R. E., "Cell Apparatus Checks Resistivity of Nitrogen Peroxide Propellant to Control Corrosion in Missiles", Corrosion, 17 (12), 26-27 (December, 1961).
- (132) Horst, R. L., "Aluminum", Chemical Engineering, 52 (5), 300, 302, 304, 308-310, 312-314 (May, 1952).
- (133) Horst, R. L., "Aluminum Versus Fuming Nitric Acids", Corrosion, 12 (10), 77 (October, 1956).
- (134) Huckel, W., "New Fluorine Compounds", Nachr. Akad. Wiss Gottinger, Math-Physik, Klasse, pp 36-37 (1946).
- (135) "Materials of Construction Data", Industrial and Engineering Chemistry, 42 (10), 2026-2076 (October, 1950).
- (136) Jackson, J. D., and Boyd, W. K., "Compatibility of Propellants 113 and 114B2 With Aerospace Structural Materials", DMIC Memorandum 151, Defense Metals Information Center, Battelle Memorial Institute, Columbus, Ohio (April 27, 1962).
- (137) Jackson, J. D., Miller, P. D., and Boyd, W. K., "Reactivity of Titanium With Gaseous N_2O_4 Under Conditions of Tensile Rupture", DMIC Memorandum 173, Defense Metals Information Center, Battelle Memorial Institute, Columbus, Ohio (August 1, 1963).
- (138) Jackson, J. D., Miller, P. D., Boyd, W. K., and Fink, F. W., "A Study of the Mechanism of the Titanium-Liquid Oxygen Explosive Reaction", ASD-Technical Report 61-479 under Air Force Contract AF 33(616)-7595, Battelle Memorial Institute, Columbus, Ohio (September, 1961).
- (139) Jackson, J. D., Miller, P. D., Boyd, W. K., and Fink, F. W., "A Study of the Titanium-Liquid Oxygen Pyrophoric Reaction", Report WADD-TR 60-258 under Air Force Contract AF 33(616)-6345, Battelle Memorial Institute, Columbus, Ohio (March, 1960).
- (140) Jackson, J. D., Boyd, W. K., Brisbane, A. W., and Miller, P. D., "The Reactivity of Titanium With Liquid and Gaseous Oxygen", paper presented at the 19th Annual Conference NACE, New York, New York, March 11-15, 1963, Materials Protection, 4 (1), 30-33 (January, 1965).
- (141) Jackson, J. D., "Corrosion in Cryogenic Liquids", Chemical Engineering Progress, 57 (4), 61-64 (April, 1961).
- (142) Jackson, J. D., Boyd, W. K., and Miller, P. D., "Reactivity of Metals With Liquid and Gaseous Oxygen", DMIC Memorandum 163, Defense Metals Information Center, Battelle Memorial Institute, Columbus, Ohio (January 15, 1963).
- (143) Jackson, R. B., "Corrosion of Metals and Alloys by Fluorine", Final Report under Air Force Contract AF 04(611)-3389, Allied Chemical Corporation, General Chemical Division, Hopewell, Virginia (March, 1960).
- (144) Johnston, D. H., "Handling and Storage of Concentrated H_2O_2 ", Report 3F(2)966707, United States Naval Engineering Experiment Station, Annapolis, Maryland (July, 1952).
- (145) Jones, R. L., Mikus, E. B., and Gorton, L. D., "Properties of AM-355 for Use in Ultra-Light Weight Tankage for Storable Liquid Propellant Missile Systems", Report MRG 238, General Dynamics/Astronautics, San Diego, California (July 7, 1961).
- (146) Kates, L. W., "Rhenium Metal - Its Properties and Future", Materials and Methods, 32 (3), 88-91 (March, 1954).
- (147) Katz, H. L., and Kline, H. A., "Storage Characteristics and Passivation of Experimental Aluminum Tanks for Use With 90% Hydrogen Peroxide", Report 4319-A, Philadelphia Naval Shipyard, Philadelphia, Pennsylvania, AD 2150481 (April, 1959).
- (148) Keefe, J. H., and Raleigh, C. W., "Field Transportation of Concentrated Hydrogen Peroxide", Jet Propulsion, 27 (6), 663-665, 677, 737 (June, 1957).
- (149) "6000 Pound Thrust Jet Propulsion Unit; Part II, Materials Corrosion Data", Report SPD 121 under Air Force Contract AF W33(038)-ac-13916, M. W. Kellogg Company (March, 1948).
- (150) Kinsley, E. J., and King, E. J., "The Rate of Change of Corrosion and Physical Properties of Types 410, 347, 304, 304 ELC Stainless Steels and 61ST-6 Aluminum at Ambient Temperatures, 100, 120, 140, and 160 F", Report No. 56-987-081 under Contract W33-038-ac-14169, Bell Aircraft Corporation, Buffalo, New York (March, 1954).
- (151) Kit, B., and Evered, D. S., Rocket Propellant Handbook, Macmillan Company, New York, New York (1960).
- (152) Preliminary information, Air Products and Chemical Company, Allentown, Pennsylvania.
- (153) Preliminary information, Air Products and Chemical Company, Allentown, Pennsylvania.
- (154) Knight, O. A., Jr., "Monomethyl Hydrazine", Hydrocarbon Processing and Petroleum Refiner, 41 (2), 179-184 (February, 1962).

- (155) Knight, W. P., "Progress Report Number Six on Evaluation of Fuels for Gas Generator and Starter Motor for AJ-23-8 Rocket Engine", Report No. AC-101, Aerojet-General Corporation (January, 1954).
- (156) Knight, W. P., "Progress Report Number Seven on Evaluation of Fuels for Gas Generator and Starter Motor for the AJ-23-8 Rocket Engine", Report No. AC-101, Aerojet-General Corporation, (March, 1954).
- (157) Knight, W. P., "Progress Report Number Five on Evaluation of Fuel for Gas Generator and Starter Motor for AJ-23-8 Rocket Engine", Report No. AC-101, Aerojet-General Corporation (October, 1953).
- (158) Kukin, I., and Rochow, E. G., "The Use of Chlorine Trifluoride as a Fluorinating Agent", *Journal of the American Chemical Society*, 74 (6), 1615-1616 (March 20, 1952).
- (159) Landau, R., "Corrosion by Fluorine and Fluorine Compounds", *Corrosion*, 8 (8), 283-288 (August, 1952).
- (160) Landau, R., and Rosen, R., "Industrial Handling of Fluorine", *Industrial and Engineering Chemistry*, 39 (3), 281-286 (March, 1947).
- (161) Lanier, L. F., "U. S. Atomic Energy Commission Reports on Elemental Fluorine", Report No. TID-3507, U. S. Atomic Energy Commission (May, 1957).
- (162) Lee, M. E., "General Information Concerning Fluorides", Report No. ORNL-1252, Oak Ridge National Laboratory, Oak Ridge, Tennessee (February, 1952).
- (163) Leech, H. R., "The Development of Fluorine Production", *Research*, 5, pp 108-115 (March, 1952).
- (164) Leonard, C. A., and Knight, W. P., "Summary Report on Projects Undertaken for the Nike Program", Report No. AC-211, Aerojet-General Corporation (September, 1954).
- (165) Lewis, S., and Cooper, J. P., "Materials Compatibility With Storable Propellants", *Space/Aeronautics R&D Technical Handbook C-18 to C-20* (1962-1963).
- (166) Preliminary information, Bell Aerosystems Company, Buffalo, New York.
- (167) Liberto, R. R., "Titan II Storable Propellant Handbook", Report TR 61-32 under Air Force Contract AF 04(611)-6079, Bell Aerosystems Company, Division of Bell Aerospace Corporation, Buffalo, New York (June, 1961).
- (168) Liberto, R. R., "Titan II Storable Propellant Handbook", Report No. AFBSD-TR-62-2, Revision A under Air Force Contract AF 04(694)-72, Bell Aerospace Company, Division of Bell Aerospace Corporation, Buffalo, New York (March, 1962).
- (169) Liberto, R. R., "Titan II Storable Propellant Handbook--Final Handbook--Revision B", Report No. AFBSD-TR-62-2, No. 8182-933004 under Air Force Contract AF 04(694)-72, Bell Aerospace Company, Bell Aerospace Corporation, Buffalo, New York (March, 1963).
- (170) Liberto, R. R., "Storable Propellant Data for the Titan II Program", Fourth Progress Report, Status Report BSD-TDR-163-51 under Air Force Contract AF 04(694)-72, Bell Aerosystems Company, Division of Bell Aerospace Corporation Buffalo, New York (March, 1963).
- (171- Preliminary information and private communication, Bell Aircraft Corporation, Buffalo, New York.
- (173)
- (174) Liberto, R. R., "Research and Development on the Basic Design of Storable High-Energy Propellant Systems and Components", Final Report IR 60-61 under Air Force Contract AF 33(616)-6689, Bell Aerosystems Company, Division of Bell Aerospace Corporation, Buffalo, New York (May 19, 1961).
- (175) Lingnau, Von. E., "Das Verhalten der Werkstoffe Gegenuber Fluor", *Werkstoffe und Korrosion*, 7 (11), 634-641 (November, 1956).
- (176) Littman, F. E., and Church, F. M., "Reactions of Titanium With Water and Aqueous Solutions", Final Report under Atomic Energy Commission Contract W-7045-ENG-26, Stanford Research Institute, Menlo Park, California (June 15, 1958).
- (177) Littman, F. E., and Church, F. M., "Reactions of Metals With Oxygen and Steam", Final Report AECU-4092, Stanford Research Institute, Menlo Park, California (February 15, 1959).
- (178) Logan, S. E., "Static Seal for Low-Temperature Fluids", *Jet Propulsion*, 25 (7), 334-340 (July, 1955).
- (179) Long, S. A., Bergdorf, W. H., and Kinsley, E. J., "The Development of Corrosion Inhibitor for Fuming Nitric Acids", Bell Aircraft Corporation, Buffalo, New York, from the Proceedings of the Propellant Thermodynamics and Handling Conference, held at The Ohio State University, Columbus, Ohio, July 20-21, 1959.
- (180) Lucas, W. R., and Riehl, W. A., "An Instrument for the Determination of Impact Sensitivity of Materials in Contact With Liquid Oxygen", Report DSN-TR-2-58, Army Ballistic Missile Agency, Redstone Arsenal, Alabama (October 15, 1958).
- (181) Lyman, I., *Metals Handbook*, American Society for Metals, Cleveland, Ohio (1948).
- (182) Maloney, C. J., and Kidwell, A. S., "Effect of Potential Rocket Fuels and Oxidizers on Elastomers and Development of Elastomeric Compounds Suitable for Retention of These Materials", WADC 56-351, The Connecticut Hard Rubber Company, New Haven, Connecticut (November, 1956).

- (183) Mandell, B., "Effect of Hydrazine Hydrate on Plastic Materials", Work Report MA-21, Aerojet-General Corporation (June, 1950).
- (184) Mandleberg, C. J., "Apparatus for Handling Fluorine in the Laboratory", Report AERE-c/M-172, Atomic Energy Research Establishment, England (February, 1953).
- (185) "Chemical Safety Data Sheet SD-5, Nitric Acid", Manufacturing Chemists Association, 1825 Connecticut Avenue NW, Washington 9, D. C. (1947).
- (186) "Chemical Safety Data Sheet SD-53, Hydrogen Peroxide", Manufacturing Chemists Association, 1825 Connecticut Avenue NW, Washington 9, D. C. (1955).
- (187) "First Progress Report on the Effect of Concentrated Hydrogen Peroxide on Various Elastomers", Report No. 112-3, Mare Island Naval Shipyard, Rubber Laboratory, Vallejo, California (February 3, 1958).
- (188) Marine, G. L., "A Study of Three Candidate Protective Coatings for Use in the Storage and Handling of Fuming Nitric Acid", Memorandum Report, Army Chemical Center, Chemical and Radiological Laboratory, Maryland (February 1, 1955).
- (189) Mason, D. M., and Rittenhouse, J. B., "Mechanism of Inhibiting Effect of Hydrofluoric Acid in Fuming Nitric Acid on Liquid-Phase Corrosion of Aluminum and Steel Alloys", Corrosion, 14 (7), 345t-347t (July, 1958).
- (190) Mason, D. M., and Rittenhouse, J. B., "Study of Chemical Factors Affecting Corrosion of Carbon Steel AISI 1020 by Liquid-Phase Fuming Nitric Acid", Corrosion, 15 (5), 245t-250t (May, 1959).
- (191) Mason, R. W., and Staiti, J. J., "Study of the Corrosion of Metals in Fluorine", Report under Air Force Contract AF 04(611)-3380, Allied Chemical Corporation, General Chemical Division, Morristown, New Jersey (February 7, 1959).
- (192) Mason, D. M., Taylor, L. L., and Keiler, H. F., "Storability of Fuming Nitric Acid", California Institute of Technology, Jet Propulsion Laboratory, Pasadena, California (December 28, 1953).
- (193) Mason, D. M., Taylor, L. L., and Rittenhouse, J. B., "Inhibiting Effect of Hydrofluoric Acid in Fuming Nitric Acid on Liquid and Gas Phase Corrosion of Several Metals", Corrosion, 13 (12), 821t-827t (December, 1957).
- (194) McBride, R. H., "Metering of Hydrofluoric Acid and Fluorine" Report AECD-369C, E. I. du Pont de Nemours and Company, Inc., Wilmington, Delaware (1945).
- (195) McCamy, C. S., "Survey of Hazards of Handling Liquid Oxygen", Industrial and Engineering Chemistry, 49 (9), 81A-82A (September, 1957).
- (196) McDonough, J. M., Jackson, W. W., and Rubin, A., "Liquid Propellants Handbook - Compatibility of Materials With Various Liquid Propellants", Aerojet-General Corporation (April, 1959).
- (197) McNamee, J. P., "Natural and GR-S Rubber vs Corrosion", Chemical Engineering, 61 (8), 234-248 (August, 1954).
- (198) Messina, J., "Greases Nonreactive with Missile Fuels and Oxidizers", Frankford Arsenal, paper presented at Fourth National SAMPE Symposium, Los Angeles, California, November 13-15, 1962.
- (199) "Molybdenum", Metallwerk Plansee, Gesellschaft M.B.H., Reutte, Tirol.
- (200) Michaelsen, J. D., and Wall, L. A., "Further Studies on the Pyrolysis of Polytetrafluoroethylene in the Presence of Various Gases", Journal of Research of the National Bureau of Standards, 58 (6), 327-331 (June, 1957).
- (201) Miles, F. T., et al, "Progress Report of the Reactor Science and Engineering Department", Report BNL-176, Brookhaven National Laboratory, Long Island, New York (March 31, 1952).
- (202) Milford, R., "Engineering Design of Oak Ridge Fluoride Volatility Pilot Plant", Industrial and Engineering Chemistry, 50 (2), 187-191 (1958).
- (203) Millaway, E. E., and Covington, L. C., "Resistance of Titanium to Gaseous and Liquid Fluorine", Progress Report No. 3, Titanium Metals Corporation of America (March, 1959).
- (204) Mogerman, W. D., "Missiles and Metals, Part II", The International Nickel Company, Inc., New York, New York, Corrosion Reporter, 6 (2) (October, 1959).
- (205) Mowers, R. E., "How the New Propellants Affect Plastics and Elastomers", Materials in Design Engineering, 50 (3), 89-91 (September, 1959).
- (206) Múrau, F. C., "Dissolution of Tungsten by Hydrogen Peroxide", Analytical Chemistry, 33 (18), 1125-1126 (July, 1961).
- (207) Myers, W. R., and DeLong, W. B., "Fluorine Corrosion", Chemical Engineering Progress, 44 (5), 359-362 (1948).
- (208) Naistat, S. S. and Ryan, J. H., "Handling and Storage of High-Strength Hydrogen Peroxide", Chemical Engineering Progress, 57 (8), 76, 78-80 (August, 1961).
- (209) "Liquid Oxygen Data Sheet" D-283, National Safety Council, 425 North Michigan Avenue, Chicago 11, Illinois (1955).
- (210) "Field Handling of Concentrated Hydrogen Peroxide", U. S. Department of the Navy, Bureau of Aeronautics, AD 208977 (January 15, 1957).
- (211) Nelson, G. A., Corrosion Data Survey, Shell Development Company, Emeryville, California (1960).
- (212) Neumark, H. R., and Holloway, F. L., "Fluorine Tamed for Rockets", Missiles and Rockets, 2 (9), 97-100 (September, 1957).
- (213) Nielson, P., Jr., and Milligan, S., "Naval Loading Depot", Department of the Navy, Bureau of Naval Ordnance Report No. 543 (July, 1953).
- (214) Corrosion Data Sheets, Technical Service Bulletin No. 101, The Nooter Corporation, St. Louis, Missouri (1960).

- (215) Oliver, J. P., "Carbon and Graphite", Chemical Engineering, 59 (9), 276-278, 280, 282, 284 (September, 1952).
- (216) Ordín, P. M., Miller, R. O., and Diehl, J. M., "Preliminary Investigation of Hydrazine as a Rocket Fuel", NACA Report No. E7H21, National Advisory Committee for Aeronautics, Washington, D. C. (May 24, 1948).
- (217) "Corrosion and Corrosion Protection of Metals", Pamphlet ORDP 20-311, Ordnance Materials Handbook, Ordnance Corp (July, 1957).
- (218) Orr, W. M., "Results of LOX-lubricant Impact Sensitivity Cooperative Test Program No. 1, WADC Technical Note 58-344, Wright Air Development Division, Wright-Patterson Air Force Base, Ohio (November, 1958).
- (219) "Perchloryl Fluoride", Booklet DC-1819, Pennsalt Chemicals Corporation, King of Prussia, Pennsylvania (1957).
- (220) Preliminary information, Bell Aerospace Company, Buffalo, New York.
- (221) Perry, J. H., Chemical Engineers Handbook, 3rd Edition, McGraw-Hill Book Company, New York, New York (1950).
- (222) Phillips, J. D., "Coating Material Survey - Protection of Metals and Nonmetals from Nitric Acid", Report CWLR 2072, Army Chemical Center, Maryland (October, 1956).
- (223) Phillips, J. D., and LeCompte, S. W., "Evaluation of Candidate Coating Materials for the Protection of Metals and Nonmetals from Fuming Nitric Acid", Report CWLR-2210, Army Chemical Center, Maryland, AD 158706 (January, 1958).
- (224) Preliminary information, Astropower, Incorporated, Newport Beach, California.
- (225) Price, H. G., Jr., and Douglass, H. W., "Material Compatibility with Gaseous Fluorine", NACA-RM-E56K21, National Advisory Committee for Aeronautics, Washington, D. C. (January, 1957).
- (226) Price, H. G., Jr., and Douglass, H. W., "Non-metallic Material Compatibility With Fluorine", NACA-RM-E57G18, National Advisory Committee for Aeronautics, Washington, D. C. (October, 1957).
- (227) Raleigh, C. W., and Derr, P. F., "Compatibility of Materials With Unsymmetrical Dimethylhydrazine Rocket Fuel", Corrosion, 16 (10), 507t-511t (October, 1960).
- (228) Raleigh, C. W., and Derr, P. F., "Compatibility of Materials With Unsymmetrical Dimethylhydrazine Rocket Fuel", Food Machinery and Chemical Corporation, Westvaco Chlor-Alkali Division, preprint of paper presented at the Sixteenth Annual Conference, National Association of Corrosion Engineers, Dallas, Texas, March 14, 1960.
- (229) Reichert, J. S., and Pete, R. H., "Materials of Construction vs Hydrogen Peroxide", Chemical Engineering, 58 (10), 253, 265, 267 (October, 1951).
- (230) Rex, C. B., "Welding in the Fabrication or Repair of Pure Aluminum Naval Tanks for H₂O₂ Service", U. S. Naval Torpedo Station ITM-133 (August, 1950).
- (231) Reynales, C. H., "Compatibility of Materials With Oxygen", Report DB1-444, Douglas Aircraft Company, Inc., Long Beach, California (October 1, 1958).
- (232) Reynales, C. H., "Safety Aspects in the Design and Operation of Oxygen Systems", Engineering Paper No. 741, The Dow Chemical Company Meeting, Tulsa, Oklahoma, January 20-21, 1959.
- (233) Richards, H. T., and Hanson, M. P., "Influence of Fluorine Environments on the Mechanical Properties of Several Sheet Alloys", NASA TN D-1706, NASA-Lewis Research Center, Cleveland, Ohio (April, 1963).
- (234) Riehl, W. A., and Curry, J. E., "A Peroxide-Resistant Coating for Steel", Report No. D5N-TR-1-59, Redstone Arsenal, Alabama (March 31, 1959).
- (235) Riehl, W. A., Key, C. F., and Gayle, J. B., "Reactivity of Titanium With Oxygen", MTP-P & VEM-62-13, NASA-George C. Marshall Space Flight Center, Huntsville, Alabama (November 30, 1962).
- (236) Riehl, W. A., Key, C. F., and Gayle, J. B., "Reactivity of Titanium With Oxygen", NASA-George C. Marshall Space Flight Center, Huntsville, Alabama, paper presented to the Fourth National SAMPE Symposium, Los Angeles, California, November 13-15, 1962.
- (237) Riehl, W. A., "How To Pick Liquid Tank Materials", Missiles and Rockets, 2 (10), 35 (October 19, 1959).
- (238) Riehl, W. A., Perkins, H., Stokes, C. S., and Kirshenbaum, A. D., "Ozone Fluoride for Rocket Propulsion", American Rocket Society Journal, 32 (3), 384-387 (March, 1962).
- (239) Rittenhouse, J. B., and Mason, D. M., "Study of Chemical Factors Affecting Corrosion of Carbon Steel AISI 1020 by Liquid-Phase Fuming Nitric Acid", Corrosion, 15 (5), 245t-250t (May, 1959).
- (240) Rittenhouse, J. B., Stolica, N. D., Vango, S. P., Whittick, J. S., and Mason, D. M., "Corrosion and Ignition of Titanium Alloys in Fuming Nitric Acid", WADC-TR 56-414 under Air Force Contract AF 33(616)-3066, California Institute of Technology, Jet Propulsion Laboratory, Pasadena, California (February, 1957).
- (241) Rittenhouse, J. B., and Papp, C. A., "Inhibition of Titanium in Fuming Nitric Acid", Corrosion, 14 (6), 283t-284t (June, 1958).
- (242) Rittenhouse, J. B., "Corrosion Pyrophoricity and Stress-Corrosion Cracking of Titanium Alloys in Fuming Nitric Acid", digest of ASM Preprint No. 68, 1958, published in Metal Progress, 74 (4), 220, 226 (October, 1958).

- (243) Rogers, M. T., and Katz, J. K., "Fluorine-Exchange Reactions Between Hydrogen Fluoride and the Halogen Fluorides", *Journal of the American Chemical Society*, **74** (6), 1375-1377 (March 20, 1952).
- (244) Rogers, M. T., Speirs, J. L., and Panish, M. B., "The Chlorine Trifluoride-Hydrogen Fluoride System; Some Vapor Pressure and Conductance Measurements", *Journal of Physical Chemistry*, **61** (3), 366 (1957).
- (245) Rosenthal, F., "Resistance of Silver Solder-Stainless Steel 18-8 Combinations", Analysis Laboratory Report No. 58-1, California Institute of Technology, Pasadena, California (January 23, 1958).
- (246) Roth, E. M., Jr., and Shanley, E. S., "Stability of Pure Hydrogen Peroxide", *Industrial and Engineering Chemistry*, **45** (10), 2343-2349 (October, 1953).
- (247) Rudge, A. J., "Preparation, Properties, and Handling of Elementary Fluorine", *Chemistry and Industry*, **16** (4), 247-253 (April 16, 1949).
- (248) Sands, G. A., "Transportation and Storage of Strong Nitric Acid", *Industrial and Engineering Chemistry*, **40** (10), 1937-1945 (October, 1948).
- (249) Satterfield, C. N., and Schumb, W. C., "Status Report of the Hydrogen Peroxide Laboratories for Office of Naval Research", DSR 5-7576 (September 30, 1957).
- (250) Satterfield, C. N., Schumb, W. C., and Wentworth, R. L., *Hydrogen Peroxide*, ACS Monograph No. 128, American Chemical Society (1955).
- (251) Schmidt, H. W., "Reaction of Fluorine With Carbon as a Means of Fluorine Disposal", NACA-RM-E57E02, National Advisory Committee for Aeronautics, Washington, D. C. (July 18, 1957).
- (252) Schmidt, H. W., "Compatibility of Metals With Liquid Fluorine at High Pressures and Flow Velocities", NACA-RM-E58D11, National Advisory Committee for Aeronautics, Washington, D. C., AD 162732 (1958).
- (253) Schmidt, H. W., and Rothenberg, E. A., "Some Problems in Using Fluorine in Rocket Systems", NASA-Lewis Research Center, from the Proceedings of the Propellant Thermodynamics and Handling Conference, held at The Ohio State University, Columbus, Ohio, July 20-21, 1959.
- (254) Shultz, R. B., "Minutes of Meeting To Discuss Suitability of Type 316 Steel for Titan II Propellant Transfer Systems Components", WDFN/R. Shultz/2845 (August 17, 1960).
- (255) Schumaker, H. J., "The System Ozone-Oxygen and Its Behavior at Various Pressures and Temperatures", *Anal. Assoc. Quim. Argentina*, **41**, pp 203-207 (1953).
- (256) Preliminary information, Allied Chemical Corporation, Hopewell, Virginia.
- (257) Scott, H. F., Jr., Alley, C. W., Gerry, H. I., and Hayford, A. W., "Impact Sensitivity of Metals (Titanium) Exposed to Liquid Nitrogen Tetroxide", TN 61-175 under Air Force Contract AF 33(616)-7114, Allied Chemical Corporation Hopewell, Virginia (May, 1961).
- (258) Seals, W., "Corrosion Rate Index of Titanium Alloys MST-621 in 90% H₂O₂ at 77 F and 160 F", Report No. EML-1038, Reaction Motors, Inc.
- (259) Schmidt, H. W., and Rothenberg, E. A., "Some Problems in Using Fluorine in Rocket Systems", NASA-Lewis Research Center, from the Proceedings of the Propellant Thermodynamics and Handling Conference, held at The Ohio State University, Columbus, Ohio, July 20-21, 1959.
- (260) Sidall, D. F., Hillier, E., Garling, R., and Gunther, M., "The Development of a Protective Coating Resistant to Nitric Acid and Hydrocarbons", WADC 54-527, U. S. Stoneware Company (June, 1956).
- (261) Siegmund, J. M., "Transportation-Transfer-Storage of Liquid Fluorine", Allied Chemical Corporation, General Chemical Division, Hopewell, Virginia, from the Proceedings of the Propellant Thermodynamics and Handling Conference, held at The Ohio State University, Columbus, Ohio, July 20-21, 1959.
- (262) Simpson, G. E., "Handling of Liquid Oxygen", *Journal of the American Rocket Society*, (80), pp 18-23 (March, 1950).
- (263) Preliminary information and private communication, Air Products, Incorporated, Allentown, Pennsylvania.
- (264) Spicer, D. R., "Liquid Fluorine and Flox Immersion Tests of Alloys Under Static Stress", Laboratory Report No. MP 30,450, Douglas Aircraft Company, Inc., Santa Monica, California (March 3, 1964).
- (265) Spicer, D. R., "Static Immersion of Non-Metallic Materials in Gaseous Flox", Laboratory Report No. MP30,451, Douglas Aircraft Company, Inc., Santa Monica, California (March 23, 1964).
- (266) Steele, J. R., "Beryllium Corrosion", *Materials Protection*, **1** (7), 59-62 (July, 1962).
- (267) Stein, L., and Vogel, R. C., "The Behavior of Uranium, Thorium, and Other Selected Materials in Bromine Trifluoride, Bromine Pentafluoride, Chlorine Trifluoride, and Fluorine at Elevated Temperatures", Report ANL-5441, Argonne National Laboratory, Chicago, Illinois (May, 1955).
- (268) Stein, L., and Vogel, R. C., "Behavior of Uranium and Other Selected Materials in Fluorinating Reagents", *Industrial and Engineering Chemistry*, **48** (3), 418-421 (1956).
- (269) Stindler, M. J., and Vogel, R. C., "Corrosion of Materials in the Presence of Fluorine at Elevated Temperatures", Report ANL-5662, Argonne National Laboratory, Chicago, Illinois (January, 1957).

- (272) Sterner, C. J., "Compatibility of Liquid Fluorine With Various Structural Metals and Carbon", Bi-Monthly Progress Report No. I under Air Force Contract AF 33(616)-6515, Air Products, Inc., Allentown, Pennsylvania (July, 1959).
- (273) Sterner, C. J., "Compatibility of Liquid Fluorine With Various Structural Metals and Carbon", Bi-Monthly Progress Report No. II under Air Force Contract AF 33(616)-6515, Air Products, Inc., Allentown, Pennsylvania (September, 1959).
- (274) Sterner, C. J., and Singleton, A. H., "Compatibility of Various Metals and Carbon With Liquid Fluorine", TR 60-436 under Air Force Contract AF 33(616)-6515, Air Products, Inc., Allentown, Pennsylvania (August, 1960).
- (275) Sterner, C. J., and Singleton, A. H., "The Compatibility of Various Metals With Liquid Fluorine", TR 60-819 under Air Force Contract AF 33(616)-6515, Air Products, Inc., Allentown, Pennsylvania (March, 1961).
- (276) Sterner, C. J., and Singleton, A. H., "Impact-Ignition Sensitivity of Titanium and Aluminum in Liquid Fluorine", Air Products, Inc., Allentown, Pennsylvania, paper presented at the National Association of Corrosion Engineers, Missile Industry Corrosion Symposium, Buffalo, New York, March 13-17, 1961.
- (277- Preliminary information, Air Products, Inc.,
278) Allentown, Pennsylvania.
- (279) Stormer, W. C., "Compatibility of Freon 114 Used in Mercury Support Equipment With Various Hose Materials, Aerospace Engineering, 20 (6), 28-29, 84 (June, 1961).
- (280) Streng, A. G., and Grosse, A. V., "Storing Gaseous Ozone Under Pressure", Industrial and Engineering Chemistry, 53 (5), 61A-64A (May, 1961).
- (281) Terlizzi, P. M., and Streim, H., "Liquid Propellant, Handling, Transfer and Storage", Industrial and Engineering Chemistry, 48 (4), 774-777 (April, 1956).
- (282) Preliminary information, Astropower, Inc.,
283) Newport Beach, California.
- (284) Tomlinson, E. M., "Materials Selection for Liquid Fuel and Oxidizer Services", Aerojet-General Corporation, Sacramento, California, paper presented at the Materials Symposium, Denver, Colorado, on May 4, 1960.
- (285) Tomlinson, E. M., "Materials Selector for Propellant Systems", Aircraft and Missiles, 4 (2), 24-27 (February, 1961).
- (286) Trevorrow, L. E., Fischer, J., and Steunenbergh, R. K., "The Preparation and Properties of Vanadium Pentafluoride", Journal of the American Chemical Society, 79 (19), 5167-5168 (October 5, 1957).
- (287) Uhlig, H. H., The Corrosion Handbook, John Wiley and Sons, Inc., New York, New York (1948).
- (288) "Nitrogen Dioxide as an Oxidizer for Liquid Fuel Rockets", NAVORD Report 1021, Note 138, U. S. Naval Ordnance Test Station, China Lake, California (June, 1949).
- (289) Preliminary information, Aerojet-General Corporation, Azusa, California.
- (290) Vavalides, S. P., Cable, R. E., Henderson, W. K., and Powell, C. A., "High-Capacity, Long-Life Fluorine Cell", Industrial and Engineering Chemistry, 50 (2), 178-180 (February, 1958).
- (291) Volz, H. A., "Handling and Hazards of Propellant Fuels", Industrial and Engineering Chemistry, 53 (3), 69A, 70A, 72A (March, 1961).
- (292) Wallner, R. L., and Williams, B. B., "Nitrogen Tetroxide Compatibility With Titanium Alloy 6Al-4V", North American Aviation, Inc., Downey, California, preprint of paper presented at NACE Western Conference, Disneyland Hotel, California, on September 25-27, 1963.
- (293) Walter, H., "Experience With the Application of Hydrogen Peroxide for Production of Power", Jet Propulsion, 24 (3), 166-169 (May-June, 1954).
- (294) Ward, E. D., "Pentaborane Handling and Safety Procedures", Paper No. 1638-61, American Rocket Society, New York, New York, paper presented at the Missile and Space Vehicle Testing Conference, Los Angeles, California, on March 13-16, 1961.
- (295) Weisman, M. H., "Elevated Temperature Stress Rupture and Fatigue Properties of Inconel and Inconel X in Ammonia Atmosphere", ASME Paper 61-AV-21, presented at the Aviation Conference, Los Angeles, California, on March 12-16, 1961.
- (296) "Storage and Handling of Unsymmetrical Dimethylhydrazine", Third Edition, Sales Department, Westvaco Chlor-Alkali Division, Food Machinery Company, South Charleston, West Virginia.
- (297) Whitaker, G. C., "Corrosion of Metals in Fluorine and Hydrofluoric Acid", Corrosion, 6 (9), 283-285 (September, 1950).
- (298) Willging, J. F., Hirth, J. P., Beck, F. H., and Fontana, M. G., "Corrosion and Erosion of Some Metals and Alloys by Strong Nitric Acid", Corrosion, 11 (2), 71t-79t (February, 1955).
- (299) Wray, K. L., and Hornig, D. F., "Dissociation Energy of Fluorine", Journal of Chemical Physics, 24 (6), 1271-1272 (June, 1956).
- (300) Yee, T. B., "Effect of Inhibitors in Fuming Nitric Acid on Corrosion and Oxidation", Corrosion, 14 (2), 82t-84t (February, 1958).
- (301) Yelton, E. B., "Applications of Plastics in Chemical Equipment", Chemical Engineering Progress, 44 (1), 89-92 (1948).
- (302) Sax, N. I., Dangerous Properties of Industrial Materials, Second Edition, Reinhold Publishing Company, New York, New York (1963).

PARTIAL LIST OF DMIC MEMORANDA ISSUED

Number	Title
*160	Identification of Microconstituents in Superalloys, November 15, 1962 (AD 289664, \$0.75)
*161	Electron Microscopic Fractography, December 21, 1962 (AD 295029, \$1.00)
162	Report on Meeting to Review Maraging Steel Projects, December 28, 1962 (AD 296040, \$0.75)
163	Reactivity of Metals with Liquid and Gaseous Oxygen, January 15, 1963 (AD 297124, \$0.75)
164	A Discussion of the Fracture Toughness of Several Stainless Steels in Sheet Form, January 31, 1963 (AD 298204, \$3.60)
165	Review of Uses for Depleted Uranium and Nonenergy Uses for Natural Uranium, February 1, 1963 (AD 299705, \$0.75)
166	Literature Survey on the Effect of Sonic and Ultrasonic Vibrations in Controlling Grain Size During Solidification of Steel Ingots and Weldments, May 15, 1963 (AD 410538, \$1.00)
167	Notes on Large-Size Furnaces for Heat Treating Metal Assemblies, May 24, 1963 (A Revision of DMIC Memorandum 63) (AD 410282, \$0.50)
168	Some Observations on the Arc Melting of Tungsten, May 31, 1963 (AD 409824, \$0.50)
169	Weldability Studies of Three Commercial Columbium-Base Alloys, June 17, 1963 (AD 415203, \$0.75)
170	Creep of Columbium Alloys, June 24, 1963 (AD 424097, \$2.25)
171	A Tabulation of Designations, Properties, and Treatments of Titanium and Titanium Alloys, July 15, 1963 (AD 424412, \$0.50)
172	Production Problems Associated with Coating Refractory Metal Hardware for Aerospace Vehicles, July 26, 1963
173	Reactivity of Titanium with Gaseous N_2O_4 Under Conditions of Tensile Rupture, August 1, 1963 (AD 419555, \$0.50)
174	Some Design Aspects of Fracture in Flat Sheet Specimens and Cylindrical Pressure Vessels, August 9, 1963 (AD 420376, \$0.75)
175	Consideration of Steels with Over 150,000 psi Yield Strength for Deep-Submergence Hulls, August 16, 1963 (AD 420873, \$0.50)
176	Preparation and Properties of Fiber-Reinforced Structural Materials, August 22, 1963 (AD 422242, \$0.75)
177	Designations of Alloys for Aircraft and Missiles, September 4, 1963 (AD 424998, \$1.75)
178	Some Observations on the Distribution of Stress in the Vicinity of a Crack in the Center of a Plate, September 18, 1963 (AD 422463, \$1.00)
179	Short-Time Tensile Properties of the Co-20Cr-15W-10Ni Cobalt-Base Alloy, September 27, 1963 (AD 425922, \$2.75)
180	The Problem of Hydrogen in Steel, October 1, 1963 (AD 425124, \$1.00)
181	Report on the Third Maraging Steel Project Review, October 7, 1963 (AD 425125, \$1.50)
182	The Current Status of the Welding of Maraging Steels, October 16, 1963 (AD 425714, \$1.00)
183	The Current Status and 1970 Potential for Selected Defense Metals, October 31, 1963 (AD 425604, \$1.25)
184	A Review and Comparison of Alloys for Future Solid-Propellant Rocket-Motor Cases, November 15, 1963 (AD 430165, \$1.25)
185	Classification of DMIC Reports and Memoranda by Major Subject, January 15, 1964
186	A Review of Some Electron-Microscopic Fractographic Studies of Aluminum Alloys, February 5, 1964 (AD 434212, \$0.50)
187	Some Observations on the Electron-Microscopic Fractography of Embrittled Steels, February 19, 1964 (AD 602288, \$2.25)
188	A Review of Available Information on the Welding of Thick Titanium Plate in the USSR, March 6, 1964
189	A Review of Dimensional Instability in Metals, March 19, 1964
190	Continued Observations on the Distribution of Stress in the Vicinity of a Crack in the Center of a Plate, April 14, 1964
191	Observations on Delayed Cracking in Welded Structures of Unalloyed Titanium Sheet, April 29, 1964
192	Summary of the Eighth Meeting of the Refractory Composites Working Group, April 20, 1964
193	Mechanical and Physical Properties of Three Superalloys--MAR-M200, MAR-M302, and MAR-M322, May 6, 1964
194	Porosity in Titanium Welds, June 1, 1964
195	The Production of Powder-Metallurgy Tungsten Sheet and Plate, July 20, 1964
196	Report on the Fourth Maraging-Steel Project Review, August 19, 1964
197	Electrodeposited, Electroless, and Anodized Coatings on Beryllium, September 1, 1964
198	Surface Damage in Machined Beryllium, January 4, 1965
199	Machining of Titanium Alloys, February 2, 1965
200	Summary of the Ninth Meeting of the Refractory Composites Working Group, March 3, 1965

* DMIC supply exhausted; copies may be ordered from CFSTI.