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Propellant/Material Compatibility Program and Results

Ten-Year Milestone

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ABSTRACT

This report details the analyses and results of a test program to establish the effects of long-term (10 years or more) contact of materials with earth-storable propellants for the purpose of designing chemical propulsion system components which can be used for current as well as future planetary spacecraft. This report covers the period from the publication of JPL TM 33-779 in 1976 through the testing accomplished in 1981.

The following propellants are reported herein: hydrazine, monomethylhydrazine and nitrogen tetroxide. Materials included the following: aluminum alloys, corrosion resistant steels and a titanium alloy. The results of the testing of more than 80 specimens are included. Material ratings relative to the ten-year milepost have been assigned.

Some evidence of propellant decomposition was found. Titanium is rated as acceptable for ten-year applications. Aluminum and stainless steel alloys are also rated as acceptable with few restrictions.

1. OBJECTIVES

The basic objective of the NASA propellant/material compatibility program is to obtain detailed compatibility data for periods up to 10 years or longer. Concommitant objectives are the development of (1) a standard test methodology, (2) basic procedures for compatibility testing and analysis, and (3) a system of rating the materials for compatibility in long-term applications.

The scope of the test program was established to serve the needs of long-term planetary spacecraft. The "real-time exposure testing" approach was chosen as the most productive method of determining the acceptability of materials of construction for chemical propulsion systems.

The test program is comprehensive. Materials are tested unstressed and stressed in each propellant. Groups of materials are tested in (1) bimetal separated, (2) bimetal contact, (3) welded, (4) brazed, (5) plated and (6) coated configurations. In addition there are control units containing only propellants to monitor the behavior of the propellant itself.

A summary of the specimens remaining in storage is presented in Appendix A. The metals include aluminum alloys, corrosion-resistant steels and titanium alloy. Nonmetals include fluorocarbon coating or grease, ethylene propylene terpolymer and butyl rubber compound elastomer. Whenever possible, these were procured and certified to meet military specifications or equivalent specifications used in aerospace applications. A detailed description of these is given in Ref. 1. The emphasis has been on materials appropriate to small liquid-propellant thrusters. Most of the materials originally placed into storage were those typically used in the Viking Orbiter 1975 propulsion system.

II. PRETEST ACTIVITIES

Preparation of specimens and the assembly of the test units are detailed in Ref. 1. The procedures used for capsule loading are outlined in Fig. 1. The pretest propellant assays are given in Appendix B.

The test container was made of borosilicate glass ("Pyrex"). The design was such that it could be completely sealed with the propellant and specimen in contact with only the glass. Internal pressure in the glass capsules is monitored by attached strain gauges. Earlier capsule designs utilizing an attached bourdon gauge had the disadvantage of propellant interaction with gauge material.

Capsule loading was accomplished under clean room conditions. The specimen was inserted into the capsule and a glass transition section fused to the capsule opening. Propellant was admitted either by the use of a glass syringe or by distillation. The propellant was frozen; the nitrogen used to blanket the propellant was evacuated, and the capsule tipped off by fusing the glass.

After completing the final seal, the capsules with specimens in place were maintained with the propellant frozen. This allowed for safer handling and shipping, and also inhibited any premature chemical reaction. The capsules were shipped to ETS and placed in storage in a special test facility held at a constant temperature of 43° $\pm$1°C (110 $\pm$2°F).

Under the general program plan, a few test units were due to be removed semiannually for posttest analysis. However, this schedule was not adhered to, and capsules were removed on an irregular basis. The criteria for removal from test were (1) to obtain periodic data points for certain, widely used metals, e.g., CRES 304L, (2) to analyze those test units in which the propellant was discolored, thereby indicating a high degree of corrosion, and (3) to remove from test for safety reasons those units indicating pressures greater than 34.4N/cm^2(50 psia). The last criterion proved unsatisfactory because the strain gauges often gave spurious results, especially as they aged.

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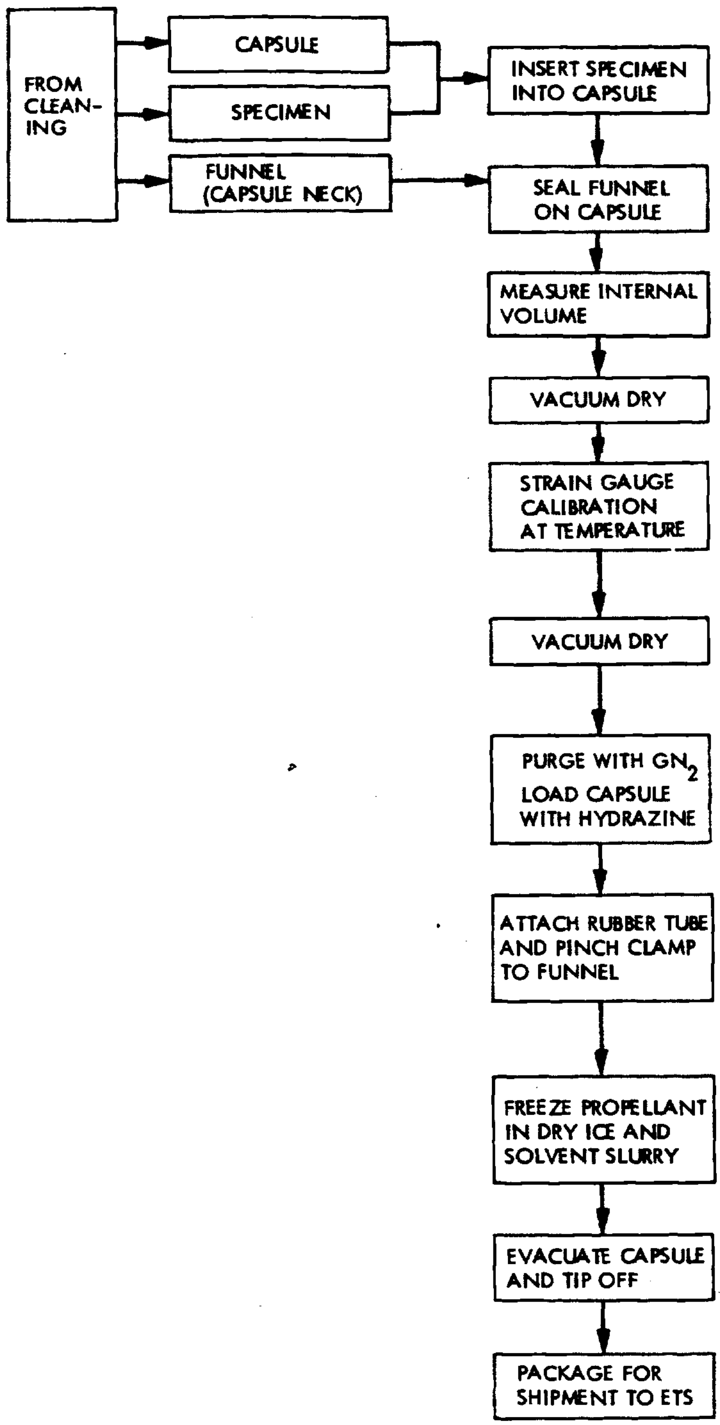

Fig. 1. Procedure for capsule filling (strain gauge type)

III. POSTTEST ANALYSIS

Since the publication of Ref. 1 in 1976 a considerable number of test capsules have been subjected to posttest analysis. Material evaluation and propellant characterization have been accomplished with more than 80 test units. The results of these analyses are included in this report and in Appendix C. The previously published report was primarily directed toward the investigation of fuels (hydrazine, MMH and hydrazine-hydrazine nitrate). The present report includes the analyses of 32 test units containing an oxidizer - nitrogen tetroxide.

The fuel, hydrazine-hydrazine nitrate, has not been included herein because of problems with rapid and excessive corrosion, particularly with CRES specimens, and the rapid evolution of dangerously high pressures in the test capsules. Most of these specimens were removed from test storage within months of their initial exposure period. Many exploded in the test rack. A few capsules containing either titanium (6Al-4V) alloy or aluminum alloys remain in test but no decision has yet been made as to their disposition.

A. POSTTEST CHEMICAL ANALYSIS

The procedures used for posttest chemical analysis of propellants are detailed in Ref. 1. An outline of the procedure for hydrazine is shown in Fig. 2; monomethylhydrazine was tested in a similar manner (Fig. 3). The procedure for nitrogen tetroxide is outlined in Fig. 4.

The propellant was frozen by immersing the capsule in liquid nitrogen. The capsule was placed in an opening fixture, attached to a high vacuum line, and then the glass tip was broken and the noncondensible gas removed and measured in a calibrated volume. This gas was analyzed for N_2, H_2, and, in the case of MMH, CH_4. The propellant was then thawed; hydrazine and MMH were removed from the capsule with a syringe. Nitrogen tetroxide was distilled from the capsule into a preweighed glass vial. Each propellant sample was analyzed for purity, contaminants and dissolved metals.

B. POSTTEST SPECIMEN ANALYSIS

The procedures used for the posttest analysis of the metal specimens were the same as those detailed in Ref. 1. Each specimen was examined to determine the physical or metallurgical changes which had taken place. Surface conditions were examined at low magnifications with an optical microscope and selected surfaces were examined at higher magnification with a scanning electron microscope (SEM) (Appendix D). Figure 5 outlines the general procedures.

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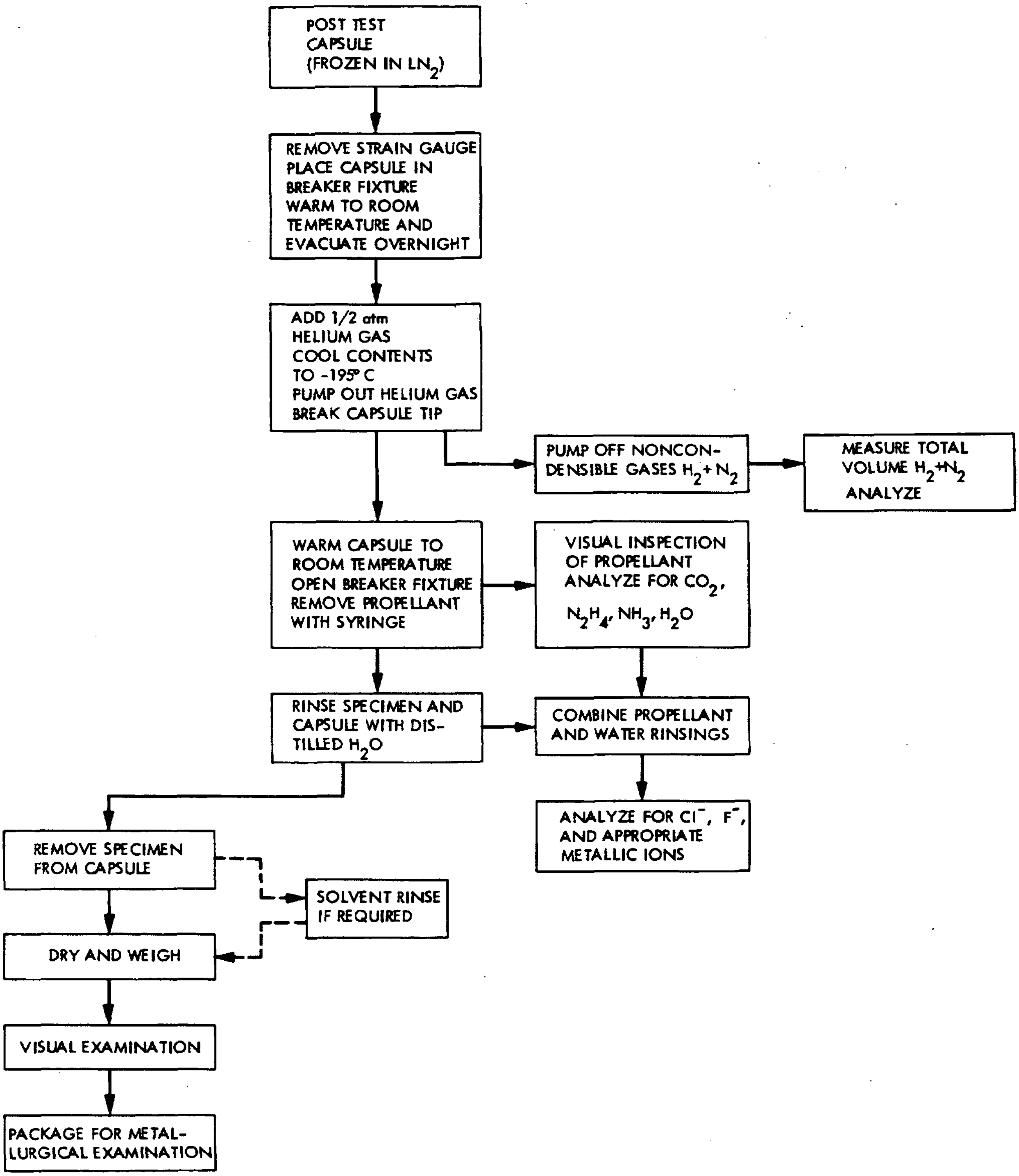

Fig. 2. Procedure for posttest chemical analysis, hydrazine

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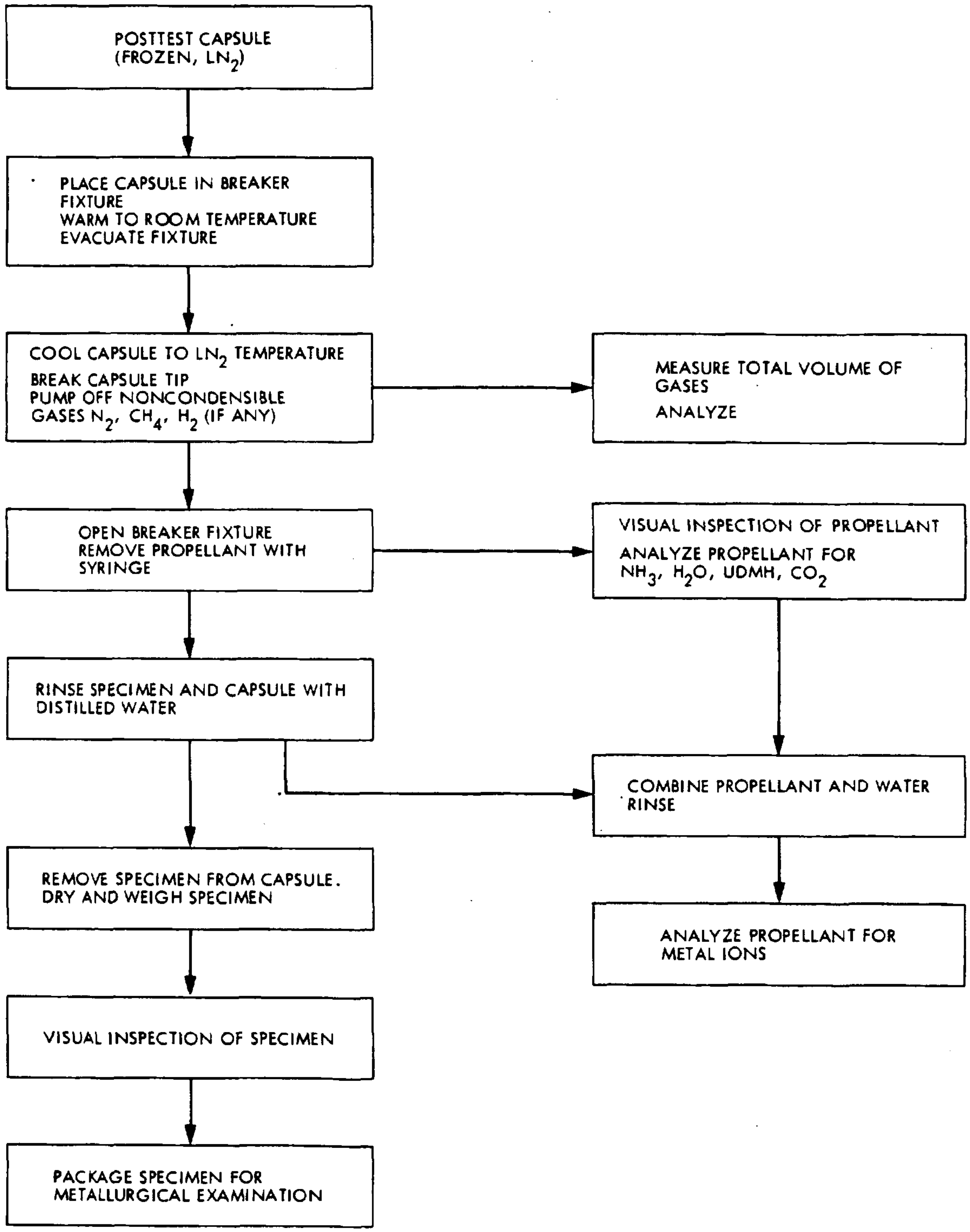

Fig. 3. Procedure for posttest chemical analysis, monomethylhydrazine

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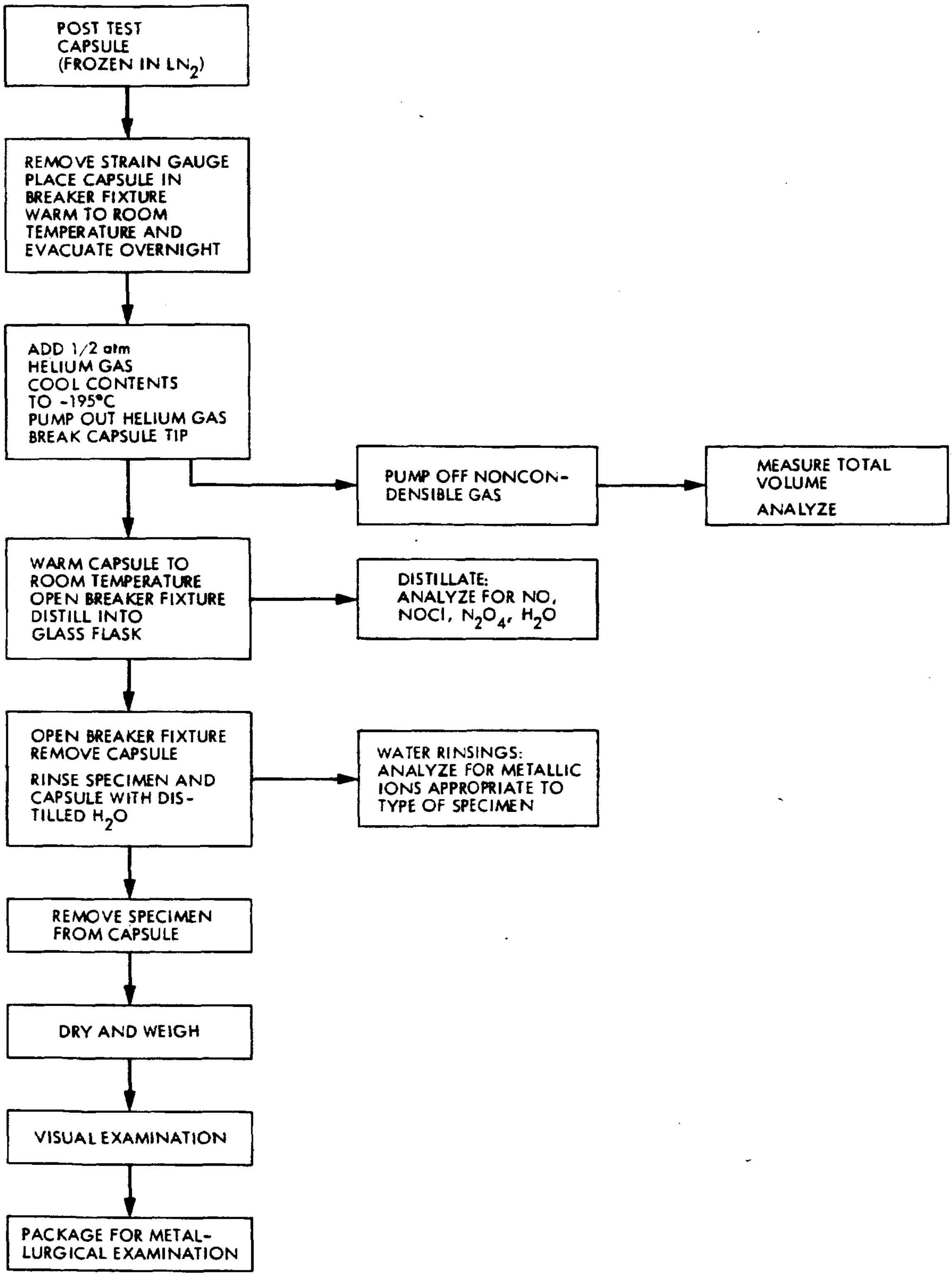

Fig. 4. Procedure for posttest chemical analysis, nitrogen tetroxide

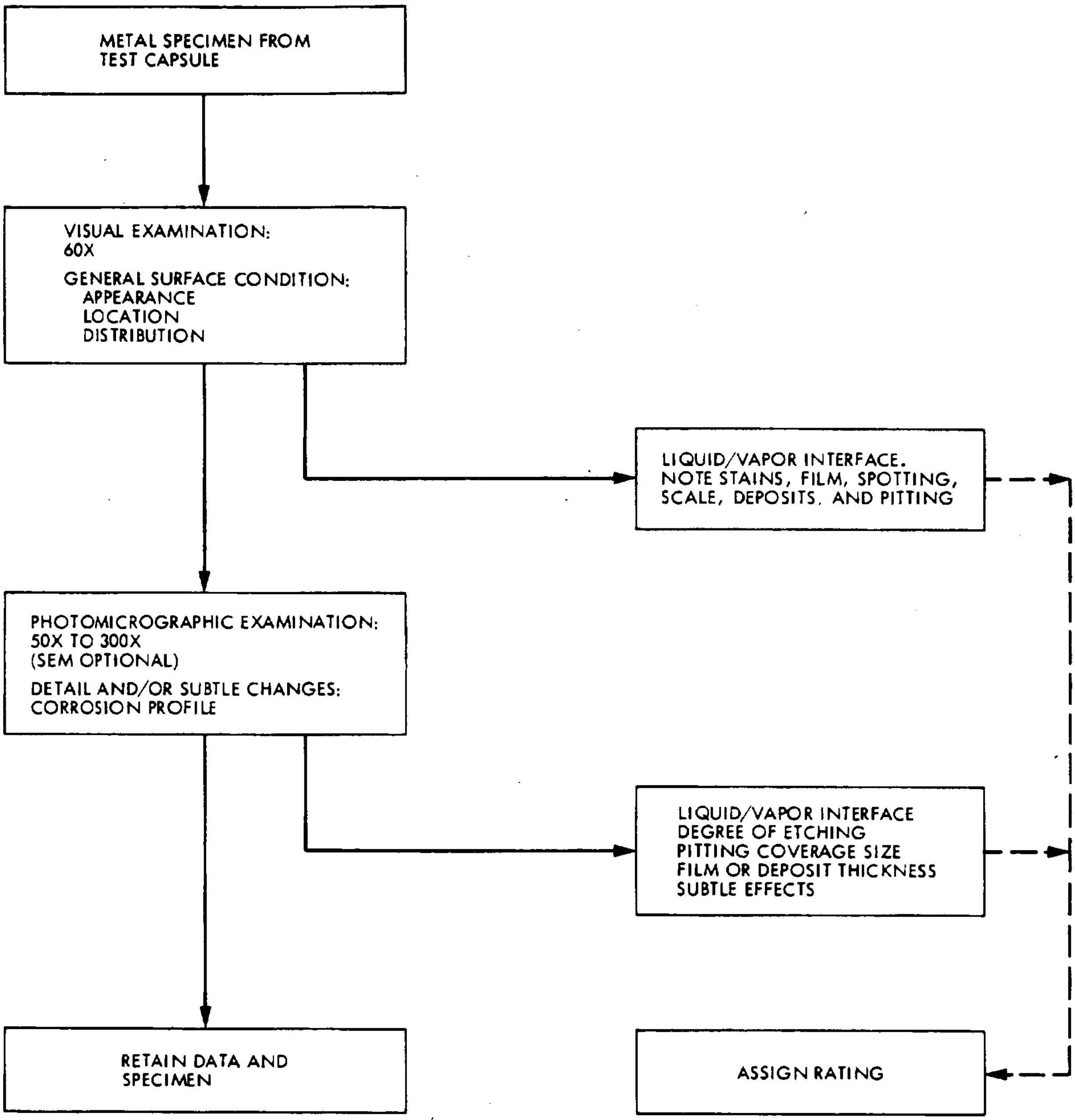

Fig. 5. Procedure for metallic specimen analysis

The important observations are listed:

(1) Weight.

(2) Appearance and location of the liquid/vapor interface boundary.

(3) Presence and distribution of deposits, stain or film.

(4) Streaks, mottling or spotting of surfaces.

(5) Crystalline deposits.

(6) Flaking and/or cracking of films.

(7) Extent and location of etching.

(8) Extent and location of pitting, size of pits.

(9) Extent and location of cracking.

IV. MATERIAL RATINGS

The criteria for the determination of long-term propellant/material compatibility ratings are fully covered in Ref. 1. The general scheme for determining the final ratings is shown in Fig. 6. The materials rating system has been established to derive engineering information and design guidelines for JPL test programs. The system provides for:

(1) A basis for selecting structural or component material candidates based on the application and operating environment.

(2) A basis for rating the acceptable materials in terms of the best data currently available.

The classification and symbols used are:

A = acceptable

N = not acceptable

I = incomplete compatibility data with respect to conditions or duration of exposure

R = restricted compatibility due to corrosion of materials or propellant degradation at conditions that could influence the mission, component or operating specifications.

A. HYDRAZINE/MATERIALS, 10-YEAR COMPATIBILITY RATINGS

Based upon the rating system discussed in the previous section, the compatibility ratings for materials in contact with hydrazine for 10 years at 43°C (110°F) are summarized as follows:

Material	Rating	Qualification
Propellant only	A	R
Aluminum alloys 6061-T6, 2014-T6	A	R
Corrosion resistant steel 302 and 303	N	
304L, 316, 347, 17-7 430, 446, 355	A	R
350	N	I
Titanium alloy 6Al-4V	A	

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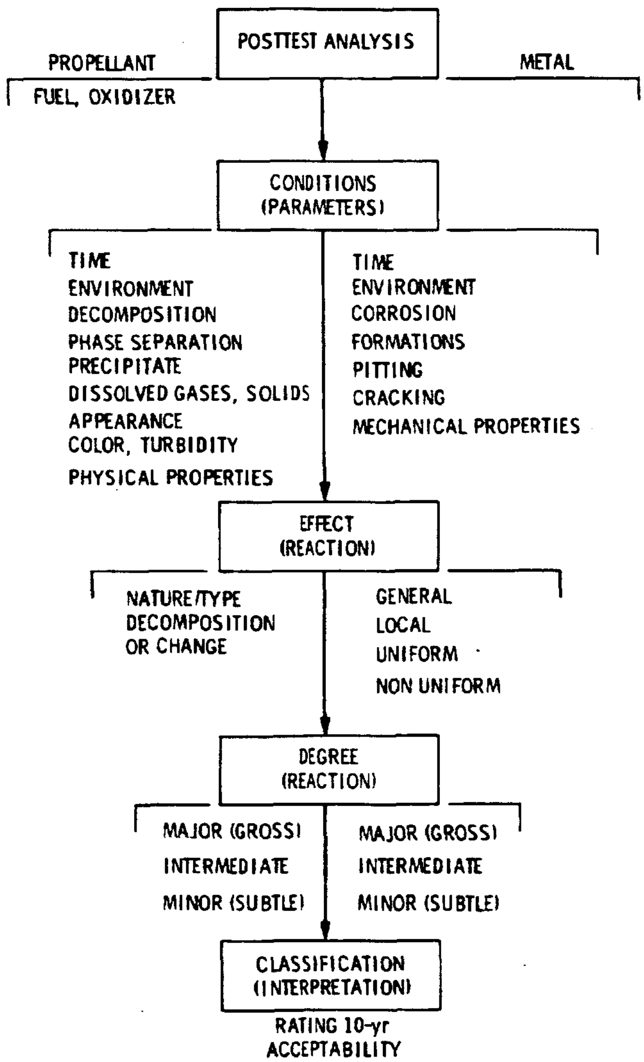

Fig. 6. Materials rating system

Material	Rating	Qualification
Others		
Braze	A	I
Gold plate	A	I
Polymers		
AFE-332	A	I

1. Hydrazine

Decomposition of the propellant resulted mainly from contaminants in solution and the catalytic effects of metals, and, generally, the rate of decomposition was acceptably low, i.e., less than 0.1% per year for both the MIL-P-26536B specification grade and the purified hydrazine. The hydrazine rating is restricted only in presence of contamination and/or catalyzing metal ions.

2. Aluminum Alloy, Type 6061-T6, 2014-T6

During analysis of this aluminum alloy, the main features noted were moderate corrosion and the formation of a surface film, some of which flaked off. The film did not appear to catalyze propellant decomposition. The aluminum alloy rating is restricted because of the possibility of oxide layer flaking and plugging filters.

3. Corrosion-Resistant Steel, Types 302 and 303

All capsules with these alloys were found to contain excessive pressure. These CRES alloys are rated not acceptable because of excessive catalysis of the propellant.

4. Corrosion-Resistant Steel, Types 304L, 316, 347, 17-7, 430, 476, 355, 301

These specimens were found to contain some random corrosion and discrete pitting, with only a thin film formation. A quantity of iron was transferred to the solution, and this can catalyze hydrazine decomposition. However, except for a few anomalies, e.g., the 347 weld stress and a 304L weld-stress, the hydrazine decomposition rates were low. These CRES alloys are restricted only because of possible contamination problems and possibly a catalytic interaction in weld-stress specimens.

5. Corrosion-Resistant Steel, Type AM 350

This alloy produced unacceptably high levels of propellant decomposition and is rated not acceptable. However, the rating is considered incomplete because of insufficient data.

6. Titanium Alloy, Type 6Al-4V

The general effects noted in this alloy were the irregular formation of corrosion products on the surfaces — particularly in the vapor exposed area — and minor pitting. Film buildup was very thin. Apparently none of the titanium dissolved in hydrazine, and the catalytic activity was very low.

7. Others

a. Braze. A 301 Cryo/304L tank-to-diaphragm weld showed no evidence of corrosion; however, the rate of propellant decomposition was 0.2% per year. This alloy is given an acceptable rating; however, these are incomplete data because only one specimen was tested.

b. Gold plating. Imperfections (pitting or porosity) in the plating allowed the propellant to interact with the substrate. This produced nonuniform blisters and to a minor extent, affected the bonding integrity of the plating to the metal. The acceptable rating is incomplete because of insufficient data.

8. Polymeric, Type AFE 332

No serious degradation of this polymer was observed after a three-year exposure, even in the stressed configuration. The acceptable rating is incomplete because data is lacking for 10-year period.

B. MONOMETHYLHYDRAZINE/MATERIALS 10-YEAR COMPATIBILITY RATINGS

Compatibility ratings for materials in contact with monomethylhydrazine for 10 years at 43°C (110°F) are summarized as follows:

Material	Rating	Qualifier
Propellant only	A	
Aluminum alloy 6061-T6	A	I
Corrosion-resistant steel 304L, 347	A	
Titanium alloy 6Al-4V	A	I

1. Monomethylhydrazine

The rate of decomposition of this propellant in contact with any of the materials tested was acceptably low for the 10-year period, i.e., less than 0.1% per year.

2. Aluminum Alloy, 6061-T6

The primary effect noted on the surface of this alloy was a very thin, even oxide coating which did not appear to flake. Although up to 100 ppm of aluminum was found to be dissolved in the propellant, no catalytic effect was noted. The acceptable rating is incomplete because at this point only two specimens have been tested.

3. Corrosion-Resistant Steel, Types 304L and 347

Both types of stainless steel alloys exhibited only minor corrosion with a surface film formation. Considerable iron was dissolved (100 ppm) but the catalytic effect was small.

4. Titanium Alloy, Type 6Al-4V

Corrosion of this alloy was light, but corrosion products were deposited in the vapor-exposed area and at the liquid-vapor interface. A small quantity of very fine sediment was found in a capsule that also contained chloride contamination. The acceptable rating is incomplete because only two specimens have so far been tested.

C. NITROGEN TETROXIDE/MATERIALS 10-YEAR COMPATIBILITY RATINGS

Compatibility ratings, for materials in contact with nitrogen tetroxide MON-1 for 10 years at 43°C (110°F) are summarized as follows:

Material	Rating	Qualifier
Propellant only	A	
Aluminum alloy 6061-T6	A	R
Corrosion-resistant steel 302, 303, 304L, 316, 321, 347, 17-4, 17-7	A	R
Titanium alloy 6Al-4V	A	
Nickel	N	

1. Nitrogen textroxide MON-1

This propellant was found to be stable when in contact with any of the materials tested.

2. Aluminum Alloy - 6061-T6

The primary effects noted in this alloy were corrosion and formation of a surface film. Corrosion was minor because of the protective nature of the film. The rating of this alloy is restricted only because of the possibility of the oxide layer flaking and plugging filters.

3. Corrosion-Resistant Steel, Types 302, 303, 304L, 316, 321, 347, 17-4 and 17-7

In all CRES alloys, only very minor corrosion was seen. However the rating is restricted due to the iron nitrate dissolved from the surface of the metal with possible flow decay problems in certain applications.

4. Titanium Alloy, Type 6Al-4V

Only minor corrosion was seen in this alloy, usually as a spotty grey appearance. Oxide formations were nonuniform and showed signs of cracking, but not flaking. Thin film appeared to adhere tenaciously and did not dissolve in the propellant.

5. Other: Nickel

Extensive corrosion was observed with flaking of the oxide coating leaving a heavily etched surface. The propellant also contained dissolved nickel.

V. CONCLUSIONS

A. HYDRAZINE

Under the controlled environmental conditions, and in the absence of metal surfaces and degrading contaminants, the rate of decomposition of hydrazine in these tests was determined to be 0.015% per year. In the presence of metal specimens, the decomposition of hydrazine was within an order of magnitude of the rate of the propellant control samples, i.e., less than 0.15% per year. The few exceptions to this were all CRES alloys and the reasons for the greater rate of decomposition were not readily apparent. In general, however, none of the tested materials would, with few exceptions, excessively catalyze the decomposition of hydrazine during long-term (10-year) missions.

B. MONOMETHYLHYDRAZINE

The rate of decomposition of propellant, MMH, in those tests was quite small: 0.02 to 0.10% per year. The corrosion products of aluminum appeared to cause only an insignificant amount of decomposition, whereas the metal ions or corrosion products of CRES alloys or titanium seemed to catalyze the decomposition somewhat more.

The dissolved iron from CRES was higher in MMH than is generally seen in the hydrazine propellants, but the catalytic effect of this ferric ion was obviously less with MMH. Even the highest concentration of iron — 100 ppm — yielded a decomposition of only 1.1% in 11 years. It would appear that the materials tested would not excessively catalyze the decomposition of monomethylhydrazine during long term (10-year) missions.

C. NITROGEN TETROXIDE MON-1

No evidence of propellant decomposition has been found. Given the chemical nature of NTO, about the only change possible would be disproportionation into various other oxides of nitrogen, and this disproportionation usually requires more severe conditions (very much higher temperature) than were present in these tests. The CRES alloys, however, did provide enough dissolved iron to cause a possible flow decay problem in certain systems.

GLOSSARY OF TERMS

AES	auger electron spectroscopy
CRES	corrosion-resistant steel
ELI	extra-low interstitial grade
EPT	ethylene-propylene terpolymer
ETS	JPL Edwards Test Station
FEP	Fluorinated ethylene-propylene polymer
MMH	monomethylhydrazine
MON-1	mixed oxides of nitrogen (NTO with 1% NO)
NTO	nitrogen tetroxide
SEM	scanning electron microscope
SIMS	secondary ionization, mass spectroscopy
TFE	tetrafluoroethylene

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1. Toth, L. R., et al., Propellant/Material Compatibility Program and Results, Technical Memorandum 33-779, Jet Propulsion Laboratory, Pasadena, California, August 15, 1976.

2. Tolberg, W. E., et al., Chemical and Metallurgical Analysis of 6Al-4V Titanium Test Specimen Exposed to Hydrazine Liquid Propellant, Report 951586-11; Stanford Research Institute, Menlo Park, Calif., April 15, 1971.

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Appendix A

Summary of Specimens Remaining in Storage

Table A-1. Specimens in hydrazine (MIL-P-26536B)

Material	Slug	Bimetal contact W/304L	Bimetal contact W/347	Bimetal contact W/2219-T81	Bimetal contact W/6061	Bimetal contact W/6-4Ti	Bimetal separated W/347	Bimetal separated W/6061	Bimetal separated W/6-4Ti	Stressed (stressed to 67% of yield) Slug	Stressed Weld	Stressed Bimetal weld	Welded Self	Coatings Gold plate	Coatings Chrome plate	Coatings Anodize	Coatings Krytox 240 AC	Controls	Total
304L	3												1						4
316	1		1				1		1										4
347								1	1										2
430	1														3				4
446															2				2
17-4																	1		1
17-7	1																1		2
355	1																		1
356-T6Al																	2		2
2014-T6										5						1	2		8
2219-T81	2																		2
5052																2	2		4
6061T6	13	2	1			5	1			3	1			2		3	3		34
7075T6																	1		1
6Al-4V Ti	27				2		2			14	16						8		69
6Al-4V ELI	3									6									9
Niobium																	2		2
EPT-10	2		2	3		4													11
Teflon LRV-448	2																		2
N_2H_4																		28	28
Total	56	2	4	3	2	9	4	1	2	28	17		1	2	5	6	22	28	192

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Table A-2. Specimens in purified hydrazine (VL-75)

Material	Slug	Bimetal contact	Stressed (stressed to 67% of yield)				Welded		Brazed	Controls	Total
		W/6-4 Ti	Slug	Weld	Bimetal weld/17-4 PH	Bimetal weld/347	Self	Bimetal/304L	Self		
301 CRYO								2			2
304L CRES	1		3	3	2	1	3				13
316									1		1
446				4			1				5
6Al-4V Ti	1		1								2
AFE-332	4	26									30
EPT-10		6									6
N_2H_4										4	4
Total	6	32	4	7	2	1	4	2	1	4	63

Table A-3. Specimens in hydrazine-hydrazine nitrate

Material	Slug	Bimetal contact		Stressed (stressed to 67% of yield)		Welded	Total
		W/6061	W/6-4Ti	Slug	Weld	Self	
6061-T6 Al			1	1		2	4
6Al-4V Ti	1	1		3	3	4	12
Total	1	1	1	4	3	6	16

Table A-4. Specimens in monomethylhydrazine (MIL-P-27404A)

Material	Slug	Bimetal contact			Stressed (stressed to 67% of yield)		Welded	Brazed	Controls	Total
		W/347	W/6061	W/6-4Ti	Slug	Weld	Self	Self		
303 CRES	3	2	2	1	2	2		2		14
304L	2	2	2	2		2	1			11
316	3	2	4	2	2	2	2			17
347	2		2	2	1	2	2			11
6061-T6 Al	3	1			1	2	1			8
6Al-4V Ti		2	2		3	3	3			13
Teflon-FEP	2									2
Teflon-TFE	4									4
MMH (control)									2	2
Total	19	9	12	7	9	13	9	2	2	82

Table A-5. Specimens in nitrogen tetroxide (MON-1) (MSC-PPD-2B)

Material	Slug	Bimetal contact			Stressed (stressed to 67% of yield)		Welded	Coatings			Controls	Total
		W/347	W/6061	W/6-4Ti	Slug	Weld	Self	Chrome plate	Anodize	Krytox 240 AC		
302 CRES	3	1	1		1							6
303	4	2										6
304L	4	2			1		1			2		10
316	3											3
321	3	1			1		2					7
347	2		7	3	2			2		2		18
416	3											3
17-4	4									1		5
17-7	3									2		5
5052Al	4											4
6061T6	2	2		4	4				4	3		19
7075	3											3
6Al4VTi	8				16	8				3		35
Nickel	5									2		7
N_2O_4											5	5
Total	51	8	8	7	25	8	3	2	4	15	5	136

Appendix B

Pretest Propellant Assays

Table B-1. Assay of hydrazine

Constituent of property	MIL-P-26536B[a] specification limits	Drum H-3155[b]	Purified hydrazine[c]
Hydrazine assay, % by weight	97.5 min	98.7	99.2
Water, % by weight	2.5 max	0.50	0.60
Density at 298 K (77°F), g/cm^3	1.004 ±0.002	1.004	1.004
Particulate, μg/cm^3	10 max	4.6	0.5
Ammonia, % by weight	Not required	0.07	0.06
Aniline, % by weight	Not required	0.25	<5 ppm ND[d]
Carbon dioxide, μg/g (ppm)	Not required	35	19
Nonvolatile residue (ash) μg/g (ppm)	Not required	60	<5 ND
Dissolved metals, μg/g (ppm)	Not required		
Iron		0.5	0.38
Aluminum		0.05	<0.05 ND
Nickel		1.10	0.03
Manganese		0.35	0.04
Cobalt		<0.5 ND	<0.02 ND
Chromium		0.16	0.02
Copper		0.09	0.04
Zinc		0.13	0.01
Silicon		<0.5 ND	<0.5 ND
Magnesium		<0.01 ND	0.01
Sodium		0.20	0.06
Potassium		0.05	0.04
Calcium		0.04	<0.04 ND
Barium		<0.2 ND	<0.2 ND
Boron		<10 ND	<10 ND
Dissolved anions, μg/g (ppm)	Not required		
Fluoride		<0.5 ND	<0.5 ND
Chloride		0.3	<0.3 ND
Sulfate		<0.5 ND	<0.5 ND
Nitrate		<0.5 ND	<0.5 ND

[a]Version of hydrazine specification in force at the start of program.

[b]JPL assay replaces SRI assay (Ref. 2) erroneously reported in Ref. 1.

[c]Martin Marietta Corp. Lot No. 51, JPL assay.

[d]Not detectable by method of analysis used.

Table B-2. Assay of monomethylhydrazine used in material compatibility test program

Constituent or property	MIL-P-2740A Amendment 2 specification limits	Assay of $N_2H_3CH_3$ prior to filling capsules
Monomethylhydrazine ($N_2H_3CH_3$) assay, % by weight	98.3 min	99.42
Water, % by weight	1.5 max	0.48
Particulate, milligram per liter	10.0 max	0.97
Density, grams per milliliter at 77°F (25°C)	0.870 to 0.874	0.872
Ammonia (NH_3), % by weight	Not required	0.10

Table B-3. Assay of nitrogen tetroxide used in material compatibility test program

Constituent or property	MSC-PPD-2B specification limits	Assay of N_2O_4 prior to filling capsules
Nitrogen tetroxide (N_2O_4) assay, % by weight	98.50	99.36
Nitric oxide (NO) assay, % by weight	0.8 ± 0.20	0.60
Water equivalent, % by weight	0.10 max	0.06
Chloride (NOCl), assay, % by weight	0.08 max	<0.01 ND
Ash, % by weight	—	<0.01 ND

Appendix C

Summary of Posttest Analyses and Results

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Table C-1. Summary of posttest analyses and results – hydrazine

Specimen number	Duration of test, days	Specimen				Capsule pressure, N/cm^2 at 43°C	Propellant		
		Material	Configuration	Remarks	Weight change, mg		Decomposition, %	Remarks	Halide content,[a] mg
0007	3939	6061-T6 Al	Slug	Light corrosion; overall thick white film with cracking at the L/V area; light etching and no pitting.	1.8	7.45	0.53	Slight decomposition; water-white.	2.0
0053	3939	Ti6Al-4V	Slug	No corrosion; overall thin film; no pitting.	5.1	13.75	0.88	Slight decomposition; water-white.	2.20
0073	4233	2014-T6Al	Slug	Light corrosion; overall thick film; light etching; no pitting.	-6.9	16.83	1.16	Slight decomposition; water-white.	0.60
0191	3986	Ti6Al-4V ELI	Slug	Light corrosion; overall thick film with cracking; light etching in the L/V and L areas; light pitting in the L/V and V areas approximately 1×10^{-6} in. in diameter with none in the L area.	3.2	3.98	0.35	Slight decomposition; water-white.	0.20
0533A	4038	6061-T6Al	Bimetal STD	Light corrosion; thin film in the L and V areas and thick in the L/V area; light etching and no pitting.	1.8	—	--	Severe decomposition; pale pink.	1.80
0533B		302 CRES	Bimetal	Moderate corrosion and thick film in the L/V and L areas; light corrosion and a thin film in the V area; light etching; moderate pitting in the L/V and L areas and none in the V area.	1.4				
0559A	4027	Ti 6Al-4V	Bimetal STD	Light corrosion; overall thick film, with cracking in the L/V area; light etching and no pitting.	1.0	12.99	0.84	Slight decomposition; water-white.	2.60
0559B		6061-T6Al	Bimetal	No corrosion; overall thick film, with cracking in the L/V area; no pitting.	-2.1				

Table C-1 (contd)

Specimen number	Duration of test, days	Specimen: Material	Specimen: Configuration	Specimen: Remarks	Specimen: Weight change, mg	Capsule pressure, N/cm^2 at $43^\circ C$	Propellant: Decomposition, %	Propellant: Remarks	Propellant: Halide content, mg
0585A	4027	Ti6Al-4V	Bimetal STD	Light corrosion in the L/V and L areas and moderate in the V area; thick film in the L/V and V areas and thin in the L area; light etching; moderate pitting in the L and V areas and none in the L/V.	2.1	47.55	2.50	Moderate decomposition; pale blue.	0.04
0585B		303 CRES	Bimetal	Light corrosion in the L/V and L areas and moderate in the V area; thick film in the L/V and V areas and thin in the L area; light etching; light pitting in the L/V; moderate in the V and none in the L area.	0.9				
0765	3954	Ti6Al-4V	Slug-stress	Light corrosion; overall thick film with cracking in the L/V area; light etching; moderate pitting in the L/V and V areas (1 x 10^{-5} in.), and light pitting in the L area.	0.2	7.30	0.54	Slight decomposition; water white.	0.60
0767	3954	Ti6Al-4V	Slug-stress	Light corrosion; thick overall film with cracking in the L/V area; light etching; moderate pitting in the L/V and V areas (1 x 10^{-6} in.) and none in the L area.	-0.5	11.20	0.73	Slight decomposition; water-white.	6.80
1091	4053	6061-T6Al	Slug-anodized	Light corrosion; thick film overall with cracking in the L/V and V areas; no pitting.	-10.2	11.11	0.80	Slight decomposition; white sediment.	ND
1099	2980	6061-T6Al	Slug-gold plated	Severe blistering of surface.	1.3	11.80	0.73	Slight decomposition, light brown color.	6.9
1853	3689	347 CRES	Slug	No corrosion; thin overall film; no pitting.	0.7	4.76	0.33	Slight decomposition, water-white.	ND

Table C-1 (contd)

		Specimen					Propellant		
Specimen number	Duration of test, days	Material	Configuration	Remarks	Weight change, mg	Capsule pressure, N/cm^2 at $43^{\circ}C$	Decomposition, %	Remarks	Halide content, mg
1875	3689	316 CRES	Slug	Light corrosion in the L/V area only; thin overall film; light etching in the L/V area; no pitting.	-3.5	7.44	0.50	Slight decomposition; water-white.	ND
1899A	3788	347 CRES	Bimetal STD	Light corrosion; thin overall film; light pitting overall approximately 1×10^{-5} in.	--[b]	10.13	0.55	Slight decomposition; water-white.	ND
1899B		316 CRES	Bimetal	No corrosion; very thin overall film; no pitting.	--[b]				
1911	3788	6061-T6Al	Bimetal STD	No corrosion; very thin overall film; no pitting.	0.4	4.97	0.40	Slight decomposition; water-white.	ND
		347 CRES	Bimetal	No corrosion; thin overall film; no pitting.	6.5				
1923	3788	6061-T6Al	Bimetal STD	No corrosion; very thin overall film; no pitting.	-0.3	43.40	3.20	Moderate decomposition; water-white.	ND
		303 CRES	Bimetal	Light corrosion; thin overall film; light etching and no pitting.	-3.7				
1929	3788	Ti6Al-4V	Bimetal STD	No corrosion; thick overall film; no pitting.	-7.5	3.17	0.23	Very low decomposition; water-white.	ND
		347 CRES	Bimetal	No corrosion; very thin overall film; no pitting.	1.3				
1937	3788	Ti6Al-4V	Bimetal STD	Light-to-moderate corrosion; thin overall film; moderate pitting of about 1×10^{-5} in. diameter.	-1.9	5.15	0.30	Very low decomposition; water-white.	0.04
		316 CRES	Bimetal	No corrosion; thin overall film; no pitting.	0.0				
1971	3689	304L CRES	Slug-stress	No corrosion; thin overall film in the L/V and L areas and a thick film in the V area; no pitting.	1.3	58.12	4.58	Severe decomposition; water-white.	ND

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Table C-1 (contd)

Specimen number	Duration of test, days	Specimen					Propellant		
		Material	Configuration	Remarks	Weight change, mg	Capsule pressure, N/cm^2 at 43°C	Decomposition, %	Remarks	Halide content, mg
1975	3759	347 CRES	Weld stress	No corrosion; thin overall film and no pitting seen in the weld zone. Light corrosion; thin overall film in the L and V areas and a thick film in the L/V area; no pitting seen in the heat-affected zone.	-1.2	32.13	2.0	Moderate decomposition; water-white.	ND
3047	3593	17-7 PH CRES	Slug	No corrosion; thin overall film and no pitting.	0.0	16.12	1.09	Slight decomposition; water-white.	ND
3057A	3563	6061-T6 Al	Bimetal STD	No corrosion; no film; no pitting.	0	5.22	0.40	Slight decomposition; water-white.	ND
3057B		304L CRES	Bimetal	Light corrosion and etching in the L/V and V areas but not in the L area; thin overall film and no pitting.	-0.3				
3065	3578	430 CRES	Slug	No corrosion; thin film on the L/V area and very thin on the L and V areas; no pitting.	0.1	. . .	. . .	Slight decomposition; water-white.	. . .
3075	3578	446 CRES	Slug	No corrosion; thin film on the L/V area and very thin on the L and V areas; no pitting.	0.0	. . .	. . .	Slight decomposition, water-white.	. . .
3093	3578	AM 350	Slug	Light corrosion; thin film and light etching on the L/V and V areas, no corrosion; very thin film and no etching on the L area; no pitting.	0.1	. . .	. . .	Moderate decomposition; water-white.	. . .
3099	3562	AM 355	Slug	No corrosion; very thin overall film; no pitting.	-0.3	2.77	0.21	Very low decomposition; water-white.	ND
3155	3562	304L CRES	Slug	No corrosion; very thin overall film; no pitting.	-0.4	2.03	0.19	Very low decomposition; water-white.	ND
3157	3562	304L CRES	Slug	No corrosion; very thin overall film; no pitting.	0.1	. . .	. . .	Very low decomposition; water-white.	. . .

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Table C-1 (contd)

Specimen number	Duration of test, days	Specimen: Material	Configuration	Remarks	Weight change, mg	Capsule pressure, N/cm^2 at 43°C	Propellant: Decomposition, %	Remarks	Halide content, mg
3223[c]	2645	304L CRES	Slug-stress	Light corrosion; thin film on the L/V and V areas and very thin on the V area; light etching and no pitting.	-12.9	2.45	0.25	Very low decomposition; water-white.	ND
3239	3061	Ti6Al-4V	Slug	Light corrosion; thick overall film; light etching and no pitting.	0.3	2.58	0.19	Very low decomposition; water-white.	ND
3257	2550	Ti6Al-4V	Slug-stress	No corrosion; thin overall film; no pitting.	-0.2	3.67	0.21	Very low decomposition; water-white.	
3261	1112	AFE-332	"O" rings stressed on a Ti6Al-4V fixture		- - -	3.86	0.26	Very low decomposition; no residue; water-white.	- - -
3267	2672	304L CRES	Tube welded	Light corrosion; thick overall film; light etching and no pitting.	-1.0	- - -	- - -	- - -	- - -
3277	2709	304L CRES/ 304L CRES	Weld, stress	Light corrosion; thin film in the L/V and L areas and thick in the V area; light etching in the L/V and V areas and none in the L area; no pitting seen in the weld zone. Light corrosion, thin film in the L/V and L areas and thick in the V area; light etching and no pitting seen in the heat affected zone.	-0.7	47.39	3.73	Moderate decomposition; water-white.	ND
3305	2597	301 CRYO/ 304L CRES	Tank/diaphragm weld	Light corrosion; thin film in the L-Weld and L/V areas and a thick film in the V and V-Weld areas with cracking in the V area; light etching and no pitting.	-5.1	16.31	1.38	Slight decomposition; water-white.	ND
3323	1129	AFE-332	ASTM dog-bone double fold in glass sleeve	- - -	-0.3	2.48	0.22	Very low decomposition	- - -

Table C-1 (contd)

[a]Chloride (halide) introduced as contamination during improper cleaning and preparation procedures.

[b]Pretest specimen weight in error.

[c]Specimens numbered greater than 3200 were exposed to VL-75 grade purified hydrazine.

ND = none detected; less than quantity detectable by analytical technique used.

--- = not measured; data not available

L = liquid exposed region.

V = vapor exposed region.

L/V = liquid-vapor interface.

Table C-2. Detailed posttest analyses and results – hydrazine

Specimen number	Specimen weight: Initial, g	Specimen weight: Change, g	Analysis of propellant: Fe + Cr + Ni + Mn, mg	Al, mg	Ti + V, mg	Total metal, mg	$Cl^- + F^-$, mg	CO_2, ug/g	H_2O, %	NH_3, %	Aniline, %	Purity, %	Analysis of gas: $N_2 + H_2$, cc STP	NH_3, cc STP	N_2, mole %	H_2, mole %	NH_3, mole %
0007	1.8696	0.0018	...	...	...	...	2.00	...	0.24	0.36	0.24	...	27.78	94.87	22.15	0.50	77.35
0053	3.2636	0.0051	...	...	0.21	0.21	2.20	...	0.39	0.52	0.27	...	56.45	137.04	28.85	0.32	70.83
0073	1.8928	-0.0069	0.10	...	...	0.10	0.60	...	0.44	0.75	0.25	...	67.27	197.65	24.88	0.51	74.61
0191	3.1796	0.0032	...	...	0.03	0.03	0.20	...	0.66	0.28	...	...	11.75	73.78	13.43	0.30	86.26
0533A	0.8266	0.0018	0.01	0.70	...	0.71	1.80	...	1.09	1.44	...	...	...	379.48	...	...	...
0533B	2.7230	0.0014															
0559A	1.4202	0.0010	...	2.60	<0.02	2.60	2.60	...	0.54	0.52	...	.	52.62	137.04	26.91	0.83	72.25
0559B	0.9314	-0.0021															
0585A	1.3950	0.0021	0.13	...	<0.02	0.13	0.04	...	0.79	1.48			208.60	390.02	26.59	8.26	65.15
0585B	2.7202	0.0009															
0765	3.1844	0.0002	...	...	<0.02	...	0.60	...	0.32	0.37	0.26	...	26.81	97.51	21.53	0.04	78.43
0767	3.2366	-0.0005	...	...	...	...	6.80	...	0.34	0.45	0.24	...	44.96	118.59	27.41	0.08	72.51
1091	1.9480	-0.0102	...	8.60	...	8.60	ND	...	0.49	0.54	...	...	42.59	142.31	22.34	0.69	76.97
1099	2.3425	0.0013	...	0.65	...	0.65	6.9	<50	0.50	0.56	0.25	98.7	48.30	147.80	13.20	11.50	75.30
1853	5.7875	0.0007	...	<0.01	...	...	ND	...	0.46	0.22	0.24	...	17.01	57.98	22.68	...	77.32
1875	5.9380	-0.0035	...	...	...	...	ND	...	0.24	0.34	0.24	...	28.11	89.60	22.23	1.65	76.12
1899A	...	...	0.04	...	...	0.04	ND	...	2.85	0.33	...	...	42.04	86.96	27.36	5.23	67.41
1899B	...	...															
1911A	0.9156	0.0004	0.03	<0.01	...	0.03	ND	...	0.69	0.28	...	...	18.58	73.79	20.11	...	79.89
1911B	2.7552	0.0065															
1923A	0.9155	-0.0003	0.06	<0.01	...	0.06	ND	...	0.58	2.18	...	...	172.41	574.49	21.70	1.38	76.92
1923B	2.7277	-0.0037															
1929A	1.3544	-0.0075	0.01	...	<0.02	0.01	ND	...	0.49	0.17	...	...	9.95	44.80	18.17	...	81.83
1929B	2.7394	0.0013															
1937A	1.2723	-0.0019	0.02	...	<0.02	0.02	0.04	...	1.20	0.20	...	...	19.42	52.71	22.21	4.71	73.09
1937B	2.8080	0															
1971	5.8589	0.0013	0.17	...	...	0.17	ND	...	0.21	3.17	0.20	...	226.43	835.39	21.28	0.04	78.67
1975	6.7811	-0.0012	0.09	...	...	0.09	ND	25	0.59	1.16	...	...	136.69	305.69	30.19	0.71	69.10
3047	5.7443	0	0.10	...	...	0.10	ND	...	0.61	0.70	...	...	64.75	184.47	24.83	1.15	74.02
3057A	0.9022	0	0.12	<0.01	...	0.12	ND	...	0.40	0.28	...	...	18.10	73.79	19.70	...	80.30
3057B	2.7653	-0.0003															
3065[b]	5.7952	0.0001											62.78		...	...	...
3075[b]	5.2220	0											29.92		...	...	...
3093[b]	5.8131	0.0001											121.61		...	...	...
3099	5.7739	-0.0003	0.02	...	...	0.02	ND	...	0.63	0.16	...	...	8.12	42.16	16.15	...	83.85
3155	5.7873	-0.0004	0.01	...	...	0.01	ND	...	0.32	0.16	...	...	4.35	42.16	9.35	...	90.66
3157[b]	5.8026	0.0001								...	...		2.87		...	...	...
3223	5.7286	-0.0129	...	...	...	...	ND	...	0.86	0.22	...	...	5.17	57.98	8.19	...	91.81
3239	3.1147	0.0003	...	...	<0.02	...	ND	...	0.96	0.14	...	...	7.62	36.89	17.11	...	82.88
3257	3.2821	-0.0002	...	...	<0.02	...	ND	...	0.24	0.13	...	...	13.32	...	34.26	27.99	72.00
3261	...	...	...	...	<0.01	0.22[c] (Zn+Si)	...	39	0.92	0.26	...	98.8	12.01	68.00	15.00	<0.01	85.00
3267[a]	1.7418	-0.0010															
3277	6.4497	-0.0007	0.36	...	...	0.36	ND	...	1.00	2.59	...	...	183.91	682.54	21.06	0.17	78.77
3305	19.2021	-0.0051	0.28	...	...	0.28	ND	...	0.44	1.02	...	...	58.38	268.80	17.81	0.04	82.16
3323	4.301	-0.003	...	...	...	0.17 (Zn+Si)	...	ND	0.88	0.17	...	98.9	7.6	44.8	14.3	0.2	85.5

[a] Capsule broke in fixture while warming.
[b] Hydrazine samples lost.
[c] Total metals include those listed in parentheses.
ND = none detected

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Table C-3. Posttest analyses of hydrazine controls

Specimen number	Duration of test, days	Pressure, N/cm^2 43°C	Analysis of propellant: Decom-position, %	$Cl^- + F^-$, mg	CO_2, mg/g	H_2O, %	NH_3, %	Analysis of gas: $N_2 + H_3$, cc STP	NH_3, cc STP
2071[a]	3788	1.47	0.14	ND	48	0.43	0.13	2.14	34.26
2097[a]	3619	1.41	0.14	ND	52	0.58	0.13	1.83	34.26
2099[a]	3633	1.63	0.17	ND	---	0.54	0.16	2.29	42.16
3351[b]	2641	2.63	0.14	ND	35	0.65	0.14	3.25	73.78
3353[b]	2641	2.73	0.14	0.02	32	0.77	0.13	3.85	68.52

[a]20 cc of MIL-P-26536B hydrazine.

[b]40 cc of VL-75 purified hydrazine.

ND = none detected.

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Table C-4. Summary of posttest analyses and results — monomethylhydrazine

Specimen Number	Duration of test, days	Specimen: Material	Specimen: Configuration	Specimen: Remarks	Specimen: Weight change, mg	Capsule pressure, N/cm^2 at 43°C	Propellant: Decomposition, %	Propellant: Remarks	Propellant: Halide content, mg
1493	3996	347 CRES	Slug	Light corrosion; thick overall film; light pitting approximately 1×10^{-6} in. diameter.	0.7	10.59	0.57	Slight decomposition; light brown color.	3.70
1499	3996	6061-T6Al	Slug	Light corrosion; thick overall film with cracking in the L/V and V areas; light etching and no pitting.	0.8	6.28	0.63	Slight decomposition.	2.82
1527	3996	304L CRES	Slug	Light corrosion; thin film in the L area and thick in the L/V and V areas with cracking in the L/V area; light etching in the L/V and V areas and none in the L area; light pitting in the L area and moderate in the L/V and V areas of about 1×10^{-6} in. diameter.	0.2	5.54	0.23	Slight decomposition; light yellow color.	0.14
1559	3996	Ti-6Al-4V/ Ti-6Al-4V	Weld, as is	Light corrosion; thick overall film; light pitting approximately 1×10^{-6} in. diameter.	-0.1	10.00	0.57	Slight decomposition; light yellow color.	0.35
1573	3996	304L CRES 304L CRES	Weld, as is	Light corrosion; thick overall film with cracking in the L/V area; light etching and no pitting.	-0.8	16.19	0.97	Slight decomposition.	0.70
1637	3989	6061-T6 Al	Slug-stress	No corrosion; thin film in the L area and thick in the L/V and V areas with cracking in the L/V area; no pitting.	1.5	6.56	0.23	Slight decomposition.	0.70
1645	3996	Ti-6Al-4V	Slug-stress	Light corrosion in the L/V and V areas and none in the L area; thick overall film; light etching in the L/V and V areas and none in the L area; no pitting.	1.0	10.68	0.55	Slight decomposition; yellow-green color; dark sediment.	2.29
1661	3996	304L CRES	Slug-stress	No corrosion; thin film in the L and V areas and thick in the L/V area with cracking; no pitting.	0.5	16.62	1.13	Slight decomposition; light brown color.	3.17

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Table C-4 (contd)

Specimen number	Duration of test, days	Specimen			Weight change, mg	Capsule pressure, N/cm^2 at 43°C	Propellant		
		Material	Configuration	Remarks			Decomposition, %	Remarks	Halide content,[a] mg
1793	3989	347 CRES	Slug-stress	Light corrosion; thin overall film with cracking in the L/V area; light etching in the L/V and V areas but none in the L area; light pitting.	-0.2	10.16	0.57	Slight decomposition.	0.35

[a]Chloride (halide) introduced as contamination during improper cleaning and preparation procedures.

L = liquid exposed region

V = vapor exposed region

L/V = liquid/vapor interface

Table C-5. Detailed posttest analyses and results – monomethylhydrazine

	Specimen weight		Analysis of propellant[a]							Analysis of gas					
Specimen number	Initial, g	Change, g	Fe, mg	Al, mg	Ti, mg	Total metal, mg	$Cl^- + F^-$, mg	H_2O, %	NH_3, %	CH_4, cc STP	N_2, cc STP	NH_3, cc STP	N_2, mole %	CH_4, mole %	NH_3, mole %
1493	5.7651	0.0007	0.58	---	---	0.58	3.70	2.07	0.30	0.33	38.69	69.57	35.63	0.30	64.07
1499	1.9680	0.0008	---	1.41	---	1.41	2.82	0.47	0.54	<0.01	11.71	125.23	8.55	<0.01	91.45
1527	5.7548	0.0002	0.37	---	---	0.37	0.14	0.50	0.10	0.08	17.50	23.19	42.92	0.20	56.88
1559	3.8351	-0.0001	---	---	0.06	0.06	0.35	0.70	0.31	0.13	35.67	71.89	33.12	0.12	66.75
1573	6.7187	-0.0008	1.28	---	---	1.28	10.70	0.27	0.53	0.10	62.48	122.91	33.68	0.05	66.26
1637	1.8281	-0.0015	---	0.48	---	0.48	0.70	0.82	0.07	0.35	23.10	16.23	58.22	0.88	40.90
1645	3.2293	0.0010	---	---	0.37	0.37	2.29	0.16	0.25	0.28	40.05	59.98	39.91	0.28	59.79
1661	5.9349	0.0005	1.95	---	---	1.95	3.17	0.43	0.70	<0.01	61.05	162.33	27.33	<0.01	72.67
1793	5.8252	-0.0002	1.02	---	---	1.02	0.35	0.38	0.32	0.26	36.22	74.21	32.70	0.23	67.04

[a]Analysis based on 20 cc of MMH, weighing 17.6 g.

--- not measured; data not available.

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Table C-6. Summary of posttest analyses and results — nitrogen tetroxide (MON-1)

		Specimen				Propellant	
Specimen number	Duration of test, days	Material	Configuration	Remarks	Weight change, mg	Remarks	NOCl content, mg
0004	4213	347 CRES	Slug	Light corrosion; thin overall film; light etching and no pitting.	0.3		ND
0010	3249	347 CRES	Slug	No corrosion; thin overall film; no pitting.	-1.0		0.2
0012	2443	347 CRES	Slug	No corrosion; thin film in the L/V area and very thin in the L and V areas; no pitting.	0.0		0.03
0016	3379	6061-T6 Al	Slug	Light corrosion; thick overall film and cracking; light etching and no pitting.	-5.3		0.02
0018	4147	6061-T6 Al	Slug	Light corrosion; thick overall film; light etching and no pitting.	-0.4		ND
0050	4213	Ti 6Al-4V	Slug	Moderate corrosion; thin overall film; light etching; moderate pitting approximately 1×10^{-4} in. diameter.	0.6		ND
0054	3444	Ti 6Al-4V	Slug	Moderate corrosion; thin overall film; light etching; moderate pitting approximately 1×10^{-4} in. diameter.	1.2		0.06
0070	2251	6Al-4V Ti	Slug	Moderate corrosion; thick overall film; light etching, 1×10^{-5} in. diameter pitting.	-38.6		0.03
0134	4022	302 CRES	Slug	Light corrosion; thin overall film; light etching; no pitting.	1.4		ND
0142	3199	302 CRES	Slug	No corrosion; very thin overall film; no pitting.	0.8		0.02
0146	4147	303 CRES	Slug	Light corrosion; thin overall film; light etching and no pitting.	0.8		ND
0160	4017	304L CRES	Slug	Light corrosion; thin overall film; light etching in the L/V area only; no pitting.	0.7		ND
0162	2251	304L CRES	Slug	Light corrosion; thin overall film; light etching; light pitting of 1×10^{-6} in. diameter.	1.5		<0.03
0178	4147	316 CRES	Slug	Light corrosion; thin film in the L/V and L areas and very thin in the V area; light etching in the L/V and L areas; no pitting.	0.2		ND
0180	3255	316 CRES	Slug	No corrosion; thin overall film; no pitting.	0.8		0.06
0218	2246	17-4 PH CRES	Slug	No corrosion; thin overall film; no pitting.	1.5		<0.03

Table C-6 (contd)

		Specimen				Propellant	
Specimen number	Duration of test, days	Material	Configuration	Remarks	Weight change, mg	Remarks	NOCl content, mg
0220	4017	17-4 PH CRES	Slug	Light corrosion; thin film and light etching in the L/V area; no corrosion, very thin film and no etching in the L and V areas; no pitting.	1.6		ND
0232	4017	17-7 PH CRES	Slug	Light corrosion; thin film and light etching in the L/V area; no corrosion, very thin film and no etching in the L and V areas; no pitting.	1.2		ND
0234	3199	17-7 PH CRES	Slug	Light corrosion, thin film and light etching in the L/V area; no corrosion; very thin film and no etching in the L and V areas; no pitting.	1.5		<0.02
0272	2196	NICKEL	Slug	Moderate corrosion; thick overall film; light etching; light pitting of about 1 x 10^{-5} in. diameter.	-9.6		0.03
0588	2196	347 CRES	Bimetal STD	Light corrosion; thick overall film; light etching and no pitting.	0.9		<0.03
		6Al-4V Ti	Bimetal	Light corrosion; thick overall film; light etching and no pitting.	1.2		
0618	3199	347 CRES	Bimetal STD	Light corrosion; thick overall film; light etching and no pitting.	1.9		0.04
		321 CRES	Bimetal	No corrosion; very thin overall film; no pitting.	0.8	White residue.	
0730	2237	347 CRES	Bimetal	No corrosion; very thin overall film; no pitting.	0.7		0.03
		6061-T6 Al	Bimetal	Light corrosion; thick overall film; light etching and no pitting.	-1.8		
0896	4009	Ti 6Al-4V	Slug-stress	Moderate corrosion; thick overall film with cracking in the L/V and V areas; light etching and moderate pitting of about 1 x 10^{-4} in. diameter.	-23.4		ND
0950	3968	304L CRES	Slug-stress	Light corrosion; very thin overall film; light etching in the L/V area only and no pitting.	0.5		ND
0956	2237	321 CRES	Slug-stress	No corrosion; very thin overall film; no pitting.	0.1		<0.03
1016	3968	Ti 6Al-4V	Weld-stress	Moderate corrosion; thick overall film with cracking; light etching and moderate pitting of approximately 1 x 10^{-5} in. diameter.	-11.6		ND

Table C-6 (contd)

Specimen number	Duration of test, days	Specimen			Weight change, mg	Propellant	
		Material	Configuration	Remarks		Remarks	NOCl content, mg
1018	3199	Ti6Al-4V/ Ti6Al-4V	Weld-stress	Light corrosion and thin film in the L area; moderate corrosion and thick film in the L/V and V areas; light etching; light pitting in the L/V and V areas only of about 1×10^{-5} in. diameter.	-13.5		<0.02
1130	3968	304L CRES	Weld	Light corrosion; thin overall film with cracking in the L/V and L areas; light etching and light pitting of about 1×10^{-6} in. diameter.	0.3		ND
1184	2246	6061-T6 Al	Slug Krytox 240AC	Moderate corrosion; thick overall film; light etching and no pitting.	-1.3	White specks (Krytox residue)	0.03
1404	2246	17-4 PH	Slug Krytox 240AC	No corrosion; thin film in the L/V and V areas and very thin in the L area; no pitting.	-0.2	White specks (Krytox residue)	0.03
1556	4017	N_2O_4 ONLY		.....	...		0.05

L = liquid exposed region.

V = vapor exposed region.

L/V = liquid-vapor interface.

ND = none detected.

... = not measured, data not available.

Table C-7. Detailed posttest analyses and results – nitrogen tetroxide

Specimen number	Specimen Weight		Analysis of propellant								
	Initial, g	Change, g	Fe, mg	Al, mg	Ti, mg	Total metal, mg	NOCl, mg	Propellant wt,[a] g	H_2O, %	NO, %	Purity, %
0004	5.8655	0.0003	0.46	---	---	0.46	ND	33.5	0.08	0.60	100.10
0010	5.8166	-0.0010	0.09	---	---	0.09	0.02	33.5	0.15	0.33	100.9
0012	5.8602	0.0000	0.47	---	---	0.48 (Cu)[b]	0.03	28.88	---	0.70	99.08
0016	1.8784	-0.0053	---	0.95	---	0.95	0.02	33.5	0.05	0.85	100.16
0018	1.9561	-0.0004	---	1.54	---	1.54	ND	33.5	0.12	0.60	99.75
0050	3.2532	0.0006	---	0.05	<0.01	0.05	ND	33.5	0.21	0.51	99.42
0054	3.2258	0.0012	---	0.02	<0.01	0.02	0.06	33.5	0.13	0.58	99.84
0070	3.1796	-0.0386	---	0.14	0.95	1.10 (Cu)	0.03	32.78	---	0.46	99.38
0134	5.8840	0.0014	0.39	---	---	0.39	ND	33.5	0.15	0.67	99.93
0142	5.7152	0.0008	0.10	---	---	0.10	0.02	33.5	0.06	0.50	100.16
0146	5.8333	0.0008	<0.18	---	---	<0.18	ND	33.5	0.12	---	99.43
0160	5.8312	0.0007	0.33	---	---	0.33	ND	36.64	0.11	0.52	99.58
0162	5.8578	0.0015	0.31	---	---	0.32 (Cu)	<0.03	33.08	---	0.33	99.39
0178	5.8317	0.0002	0.24	---	---	0.24	ND	33.5	0.21	0.77	99.65
0180	5.9042	0.0008	0.02	---	---	0.02	0.06	33.5	0.10	0.59	99.64
0218	5.6646	0.0015	0.27	---	---	0.31 (Cu)	<0.03	33.20	---	0.69	98.97
0220	5.6563	0.0016	0.28	---	---	0.28	ND	33.5	0.11	0.36	100.10
0232	5.7228	0.0012	0.22	---	---	0.22	ND	35.65	0.16	0.59	100.05
0234	5.7372	0.0015	0.02	---	---	0.02	<0.02	33.5	0.06	0.45	100.20
0272	6.4978	0.0096	11.70	---	---	11.71 (Cu)	0.03	34.46	---	0.63	99.30
0588A	2.6871	0.0009	0.19	0.04	0.06	0.29	<0.03	35.20	---	0.63	99.09
0588B	1.4930	0.0012									
0618A	2.6857	0.0019	0.02	---	---	0.02	0.04	33.5	0.05	0.62	100.13
0618B	2.7263	0.0008									

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Table C-7 (contd)

Specimen number	Specimen Weight: Initial, g	Specimen Weight: Change, g	Analysis of propellant: Fe, mg	Al, mg	Ti, mg	Total metal, mg	NOCl, mg	Propellant wt,[a] g	H_2O, %	NO, %	Purity, %
0730A	2.6847	0.0007	0.07	1.47	---	1.56 (Cu)	0.03	31.71	---	0.67	99.07
0730B	0.9243	0.0018									
0896	3.1650	-0.0234	---	0.06	0.05	0.11	ND	33.78	0.14	0.60	100.00
0950	5.8221	0.0005	0.37	---	---	0.37	ND	33.5	0.30	0.40	99.62
0956	5.8083	0.0001	0.49	---	---	0.50 (Cu)	<0.03	27.52	---	0.64	98.90
1016	3.4109	-0.0116	---	0.03	0.09	0.12	ND	33.5	0.25	0.15	99.56
1018	3.7420	-0.0135	---	0.01	<0.01	0.01	<0.02	33.5	0.07	0.64	99.88
1130	6.5896	0.0003	0.62	---	---	0.62	ND	33.5	0.10	0.42	100.00
1184	1.9323	-0.0013	---	2.07	---	2.08 (Cu)	0.03	30.64	---	0.65	99.06
1404	5.7193	-0.0002	0.95	---	---	0.99 (Cu)	0.03	30.91	---	0.54	99.09
1556	---	---	0.03	<0.01	<0.01	0.03	0.05	35.01	0.12	0.61	99.74

ND = none detected; less than quantity detectable by analytical technique used.

--- = not measured; data not available.

[a]Propellant weight:

4 significant figures = accurately weighed during analysis.
3 significant figures = weight estimated.

[b]Total metals include those listed in parentheses.

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Appendix D

Scanning Electron Microscope Examination of Specimens

These photomicrographs show typical surface appearances after exposure to propellant.

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Surfaces Exposed to Nitrogen Tetroxide

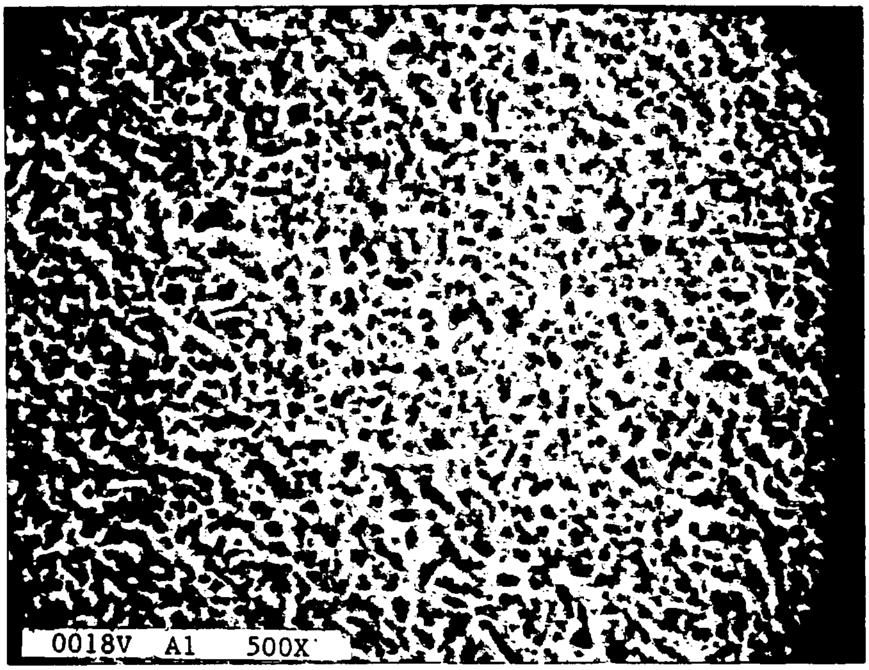

Fig. D-1. Specimen 0018, 6061-T6Al, 500X. Unbroken surface film

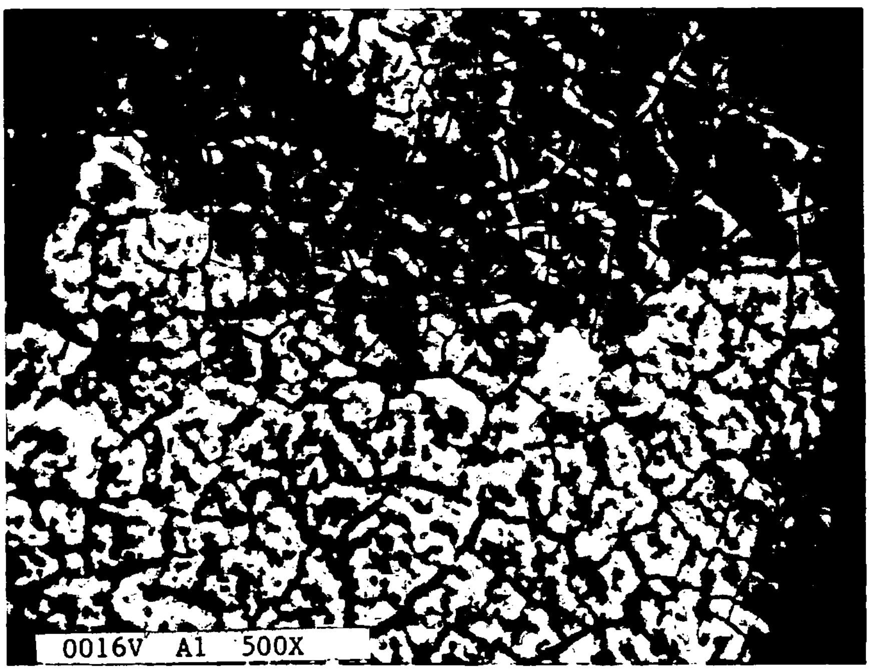

Fig. D-2. Specimen 0016, 6061-T6Al, 500X. Cracked and flaking film

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Surfaces Exposed to Nitrogen Tetroxide

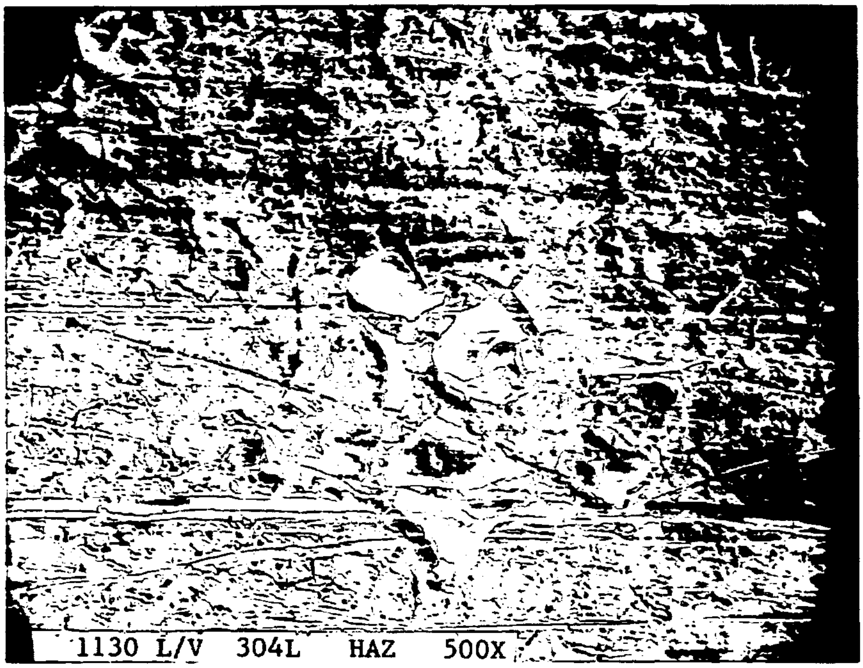

Fig. D-3. Specimen 1130, 304L, heat affected zone, 500X. Thin, irregular film

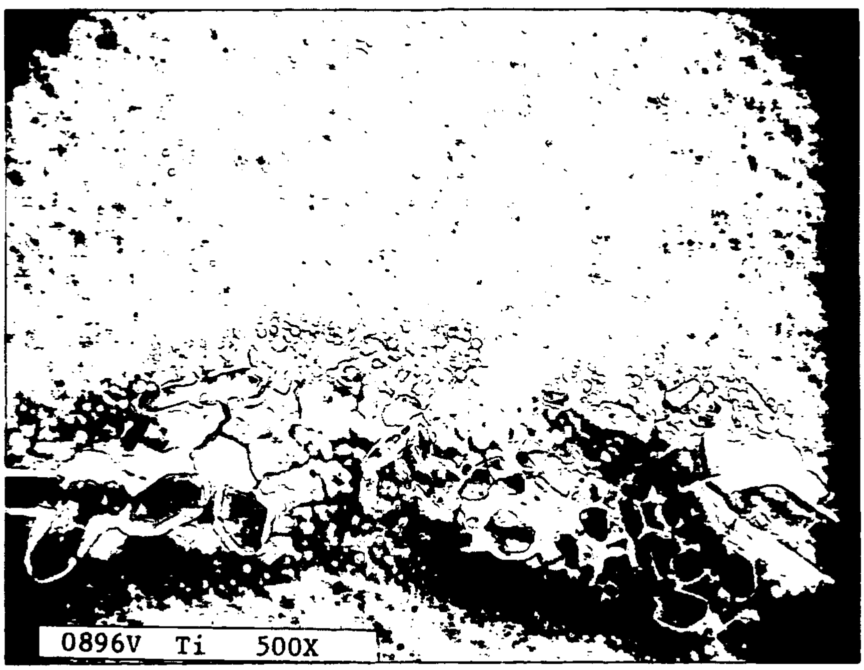

Fig. D-4. Specimen 0896, Ti6Al-4V, 500X. Thin, irregular film, minor cracking and pitting

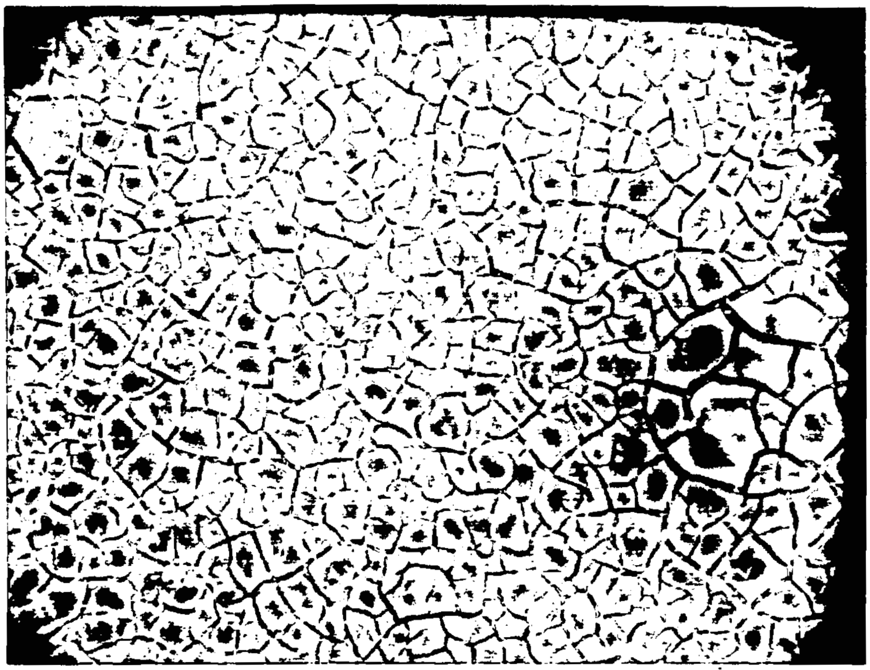

Fig. D-5. Specimen 1499, 6061-T6Al, 500X. Thin film with cracking and flaking

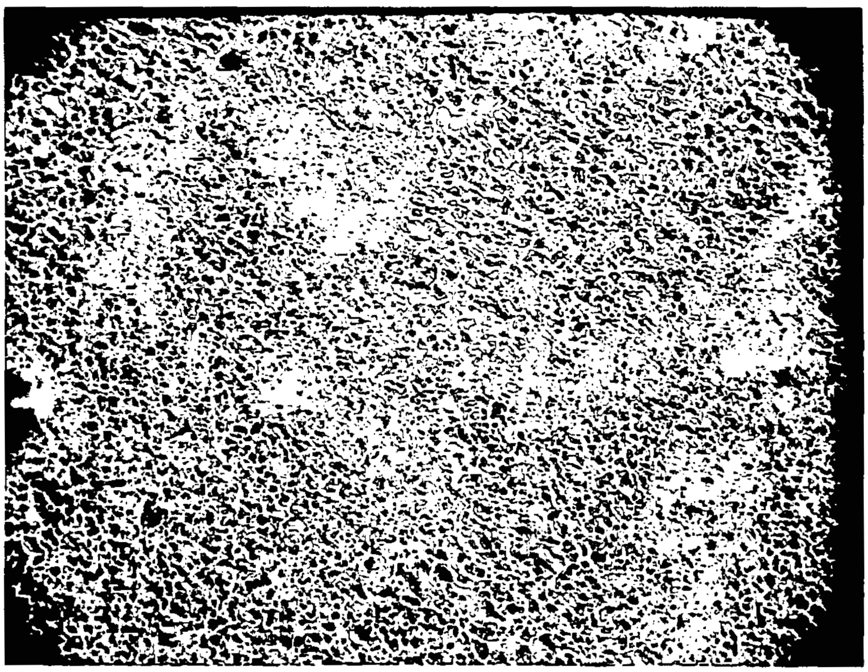

Fig. D-6. Specimen 1527, 304L, 500X. Unbroken surface film

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Surfaces Exposed to Hydrazine

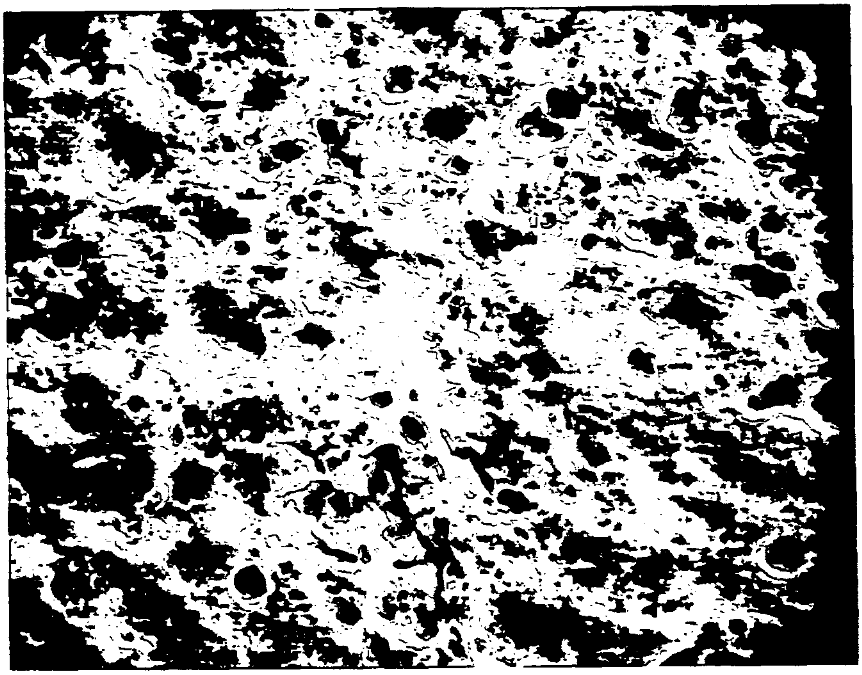

Fig. D-7. Specimen 0073, 2014-16Al, 500X. Thin-to-moderate film showing evidence of erosion, not surface pitting

Fig. D-8. Specimen 3155, 304L, 500X. Surface virtually untouched

Surfaces Exposed to Hydrazine

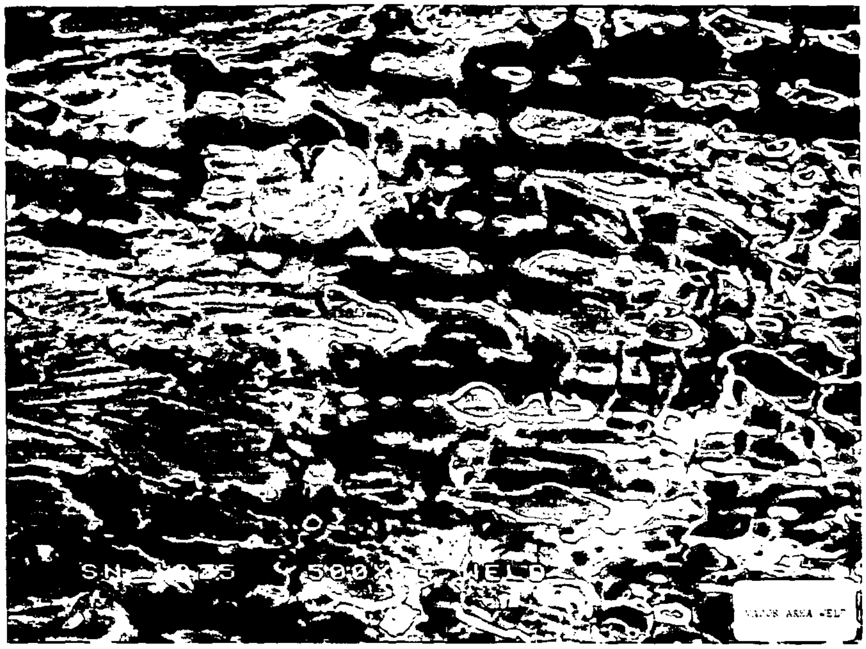

Fig. D-9. Specimen 1975, 347, 500X. Corrosion at area of highest stress

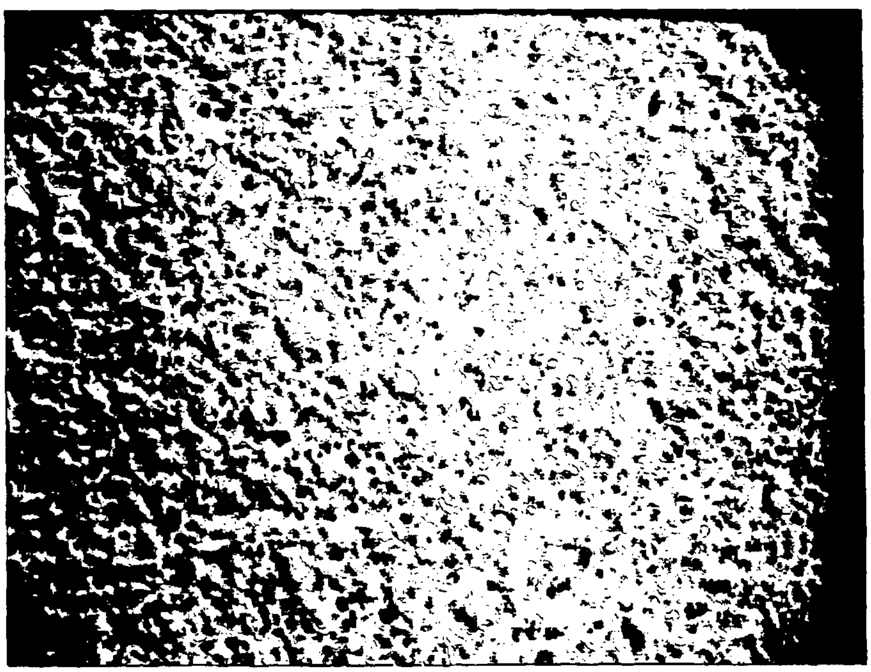

Fig. D-10. Specimen 0191, Ti6Al-4V, 500X. Unbroken surface film

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