NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

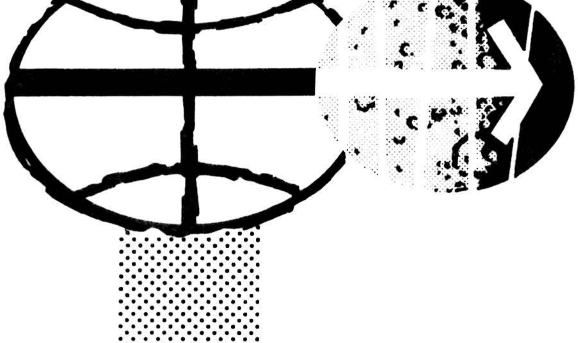
MSC APOLLO 13 INVESTIGATION TEAM

FINAL REPORT

PANEL 8

HIGH PRESSURE OXYGEN SYSTEMS SURVEY

MAY 1970



MANNED SPACECRAFT CENTER
HOUSTON, TEXAS

FINAL REPORT

PANEL 8

HIGH PRESSURE OXYGEN SYSTEM PANEL

MAY 15, 1970

CHAIRMAN, RICHARD S. JOHNSTON

Richard S. Johnston

I. ABSTRACT: As a part of the MSC Apollo 13 Investigation Team, Panel 8 was formed to conduct a survey of the state of the art of breathing oxygen systems design. Typical commercial aviation, military aviation, submarine, aircraft carrier, hospital, and altitude chamber oxygen systems, and the Gemini cryogenic system were reviewed in depth by the panel, and technologies, standards, and criteria were examined for similarities and differences. The panel found no great technological differences or unique problem areas, however, there was considerable common concern for better and improved material selection and testing methods, safety criteria, and means of adapting or controlling electrical interfaces.

Throughout industry there is a heavy reliance on vendors for proper design, safety protection, and material selection. The panel concluded that much specific but incomplete information is available in the literature but there is no single established guide or set of criteria for system design. A general design guide for material selection and oxygen system design is required for use throughout the industry.

II. TABLE OF CONTENTS

III. OBJECTIVE: The objective of Panel 8, "High Pressure Oxygen Systems Panel." of the MSC Apollo 13 Investigation Team was primarily to conduct a comprehensive survey of the state of the art in aircraft and commercial oxygen systems. Although there was very limited time available, the panel also included low pressure gaseous and liquid oxygen systems in its scope to make the survey as complete as possible. Secondary objectives of this survey were considered by the panel to be:

a. The identification of differences, if any, in technology between various oxygen systems.

b. Identification of new technology which is not in general practice and should be considered for application across the industry.

c. The review of various standards and criteria used in the manufacture, service, use, and control of oxygen systems.

IV. APPROACH TAKEN: Panel 8 was established on April 17, 1970, by the Apollo Program Manager to conduct the stated survey. Several administrative meetings were held during the week of April 20, 1970, to develop the survey approach, the overall panel makeup and worksheet questionaires. To maintain the survey in manageable proportions, the panel selected typical oxygen systems from each of several industries and conducted a detailed review of these systems. The typical systems selected were chosen to be representative of commercial aviation, military aviation, submarine, spacecraft, aircraft carrier, hospital and altitude chamber breathing oxygen systems in use today. During the week of April 27, 1970, representatives of the Boeing, McDonnell-Douglas and AiResearch Companies and the Naval Research Laboratory prepared data packages and presented information on their respective oxygen systems to the panel. Presentations and system reviews generally covered the topics listed below:

a. Design standards and system features

b. System performance requirements

c. Component design

d. Test philosophy and experience

e. Process controls and standards

f. Materials control and listings

g. Failure experience

h. Parts lists and suppliers

Information from the presentations and general discussions which followed, and answers to the questionaires were used to make system comparisons. Data submitted by each group is included or referenced in Appendix A.

V. DISCUSSION: Because of variations in design, performance requirements and operating characteristics, it was not possible to make a direct comparison of the systems. The general characteristics of these systems are summarized in Table 1. Appendix A contains the narrative description, system schematic, and results of the panel questionaire on each of the systems reviewed. The presentation and discussion of the various oxygen systems revealed a number of differences between the design methods and needs of the different commercial and governmental groups. However, a common concern for safety was very much in evidence. Discussions of safety considerations indicated that one major concern of each group was the control of fuel (combustible material) and ignitation sources. Fuel was considered to be both metallic and nonmetallic system materials and contaminants in the presence of the oxidizer. Ignition sources were considered to be any phenomenon which could cause a material to reach its ignition temperature.

In design considerations, the hospital, altitude chamber and shipboard systems are not greatly restricted by size, weight, and volume as are the aircraft and spacecraft systems. Therefore, for these ground based systems, design margins for strength and fire resistance are greater. All systems employed relief valves or burst disks to protect lines against overpressure. Only the hospital and altitude chamber systems had all relief lines vented out of the buildings or use area. Static electricity was considered as a potential danger and all systems required electrical grounding during operation and servicing. Contamination control in regard to cleaning, oxygen procurement specification, and particulate filtering was common to all systems but varied greatly in requirement, application, and certification. All systems are cleaned at the time of installation or manufacture except for the hospital which utilized precleaned pipe. All systems except the hospital utilize particulate filtering at the service point as a minimum.

The interfacing of electrical systems to the oxygen system was one of the major ignition sources considered by the various groups. It was found that the military aircraft, the Gemini supercritical tanks, and the MSC altitude chamber had requirements for electrical equipment within the oxygen environments. The military aircraft lox converter contains a capacitance probe in the lox tank as does the Gemini cryogenic tank. The altitude chamber which is similar in some test configurations to spacecraft crew compartments, requires many electrical system interfaces. Wire sizing to load, individual wire fusing, close control of wire insulation and connector potting, and isolating of circuits and power consuming devices by hermetic sealing or nitrogen blamketing are a few of the techniques employed in chamber design. All except the Navy systems

Table 1.–

TABLE OF OXYGEN SYSTEMS

SYSTEM	TYPE O_2	OPERATING PRESSURE psig	OPERATING TEMP. Deg.F	PIPING AND TUBING MAT'L	OTHER METALLIC MATERIAL USED	NONMETALLIC MATERIAL USED	MAT'L AVOIDED	ELECT. (Electrical System from O_2 Environ.)	ENVIRON QUAL. TEST	ACCEPT. TESTING	PERIODIC MAINT.	PERIODIC CLEAN	SINGLE POINT FAIL. Redundant Systems	SINGLE POINT FAIL. Redundant Components
MSC CHAMBER:														
Source	GOX	2200	Ambient	s.s.	Bronze & Brass	Teflon, Viton	Ferrous Metals Hydro-carbons	NO	NO	YES	YES	NO	YES	NO
Distribution	GOX	100	Ambient	s.s., Cu	Bronze & Brass	Kel-F, neoprene		NO	NO	YES	YES	NO	YES	NO
Use	GOX	3.5–20 psia	0 to 100	Al, s.s., Cu	SAME	Beta, PBI Webbing	SAME	YES	NO	YES	YES	NO	YES	NO
MILITARY AIRCRAFT														
Source	LOX	85	-320	s.s	s.s. Cu-Ni s.s. Al Brass	Teflon, Kel–F, Viton, Silicone Rubber	Carbon, Steel, Neoprene	YES	YES	YES	YES	YES	YES	NO
Distribution	GOX	72	-297/90	Al				NO	YES	YES	YES	N/A	YES	NO
Use	GOX	3.5–15 psia	Ambient	Al			N/A	YES, Crew Microphone	YES	YES	YES	N/A	NO	NO
HOSPITAL SYSTEM:														
Source	LOX	70	-290	s.s., Al	Cu, Bronze, silver solder, Aluminum	Teflon Neoprene Cellulose Acetate	Ferrous Metals Hydro-carbons	NO	NO	YES	NO	NO	YES	NO
Distribution	GOX	60	Ambient	Cu				NO	NO	YES	NO	NO	NO (2)	NO
Use	GOX	Ambient	Ambient	Cu, Brass				YES	NO	YES	NO	NO	NO (2)	NO
GEMINI O_2 BOTTLE:														
Source (1)	Super-Critical GOX	900	290	s.s.	718 Inconel Press. Vessel	Silicone Rubber	N/A	YES	YES	YES	YES	NO	YES	NO
SUBMARINES:														
Source	GOX	3000	Ambient	Monel	s.s., pressure vessel, Cu Bronze Brass	Teflon, Kel–F Fluorocarbons Teflon, Nylon	Ferrous Metals Hydro-carbons Rubber Plastics	NO	N/A	YES	YES	YES	YES	NO
Distribution	GOX	100	Ambient	Monel				NO	N/A	YES	YES	YES	YES	NO
Use	GOX	Ambient	Ambient	Monel				NO	N/A	YES	YES	YES	YES	NO
AIRCRAFT CARRIERS:														
Source	LOX	85	approx. -300	s.s.	Cu, Monel Bronze	Teflon, Kel–F	Ferrous Metals Hydro carbons Rubber Plastics	NO	N/A	YES	YES	YES	YES	NO
Distribution (3)	LOX	85	SAME	s.s				NO	N/A	YES	YES	YES	YES	NO
Distribution (6)	GOX	35	Ambient	s.s.				NO	N/A	YES	YES	YES	YES	NO
COMMERCIAL AVN.														
Source	GOX	1850	Ambient	s.s.	Bronze, Al, Brass, Yellow Chromium, Cu, Carbon Steel	Kel–F, Teflon, Nylon, Silicone Rubber, Vinyl Plastic, Silicone Rubber	Titanium Magnesium Rubber Hydro-carbons	NO	YES	YES	YES (4)	YES (4	NO (2)	NO
Distribution	GOX	150–600	Ambient	s.s.				NO	YES	YES	YES (4)	YES (4)	NO (2)	YES (7)
Use	GOX	0 to 150	Ambient	Al				NO	YES	YES	N/A	N/A	NO	YES

(1) Other sections of Gemini oxygen system not considered
(2) Portable bottles available.
(3) Carrier use is by military aircraft.
(4) Periodic maintenance and cleaning performed by aircraft user.
(5) N/A: Data not available
(6) LOX converted to high pressure gas.
(7) Redundancy provided in system actuation only.

contain transducers, remote alarms, solenoid valves, and other electrically operated devices which are not directly in the oxygen environment. In the event of a failure in these components, the internal electrical section of the device could be overheated or exposed to oxygen. The commercial aviation system reviewed requires that all interfacing electrical devices, as mentioned above, be tested to simulate an overvoltage failure. It is required that this type of failure will not result in a loss of integrity of the oxygen system. The panel found no formal government or industry standard which controls electrical interfaces. (see Appendix B)

In all systems reviewed it is required that vendors perform acceptance testing of the component prior to shipment to the major contractor or use facility. Some organizations perform component bench tests prior to system installation. However, all organizations perform installed systems tests for leakage and function although the extent of the functional test varied greatly. Environmental qualification tests are unique to the military and aerospace industry. Periodic maintenance and cleaning are generally not the rule and, primarily, maintenance is performed only as required for failure correction. All systems require batch sampling of the supply oxygen prior to system filling. Only the altitude chamber requires periodic sampling from the use ports. The Navy discussed a problem which it has experienced and was related to sampling. It was found, in some instances, that oxygen sampled from the aircraft lox converter did not meet specifications although the carrier supply was within specification. It was determined that some contaminants would remain in the liquid oxygen when the system is not in use and with repeated partial refilling of the converter, would tend to increase in concentration within the converter. The Navy now requires that each converter be cleaned every 30 days.

The subject of failures was discussed briefly. Although many failures are known, few were of a catastrophic nature and failures were generally related to improper servicing procedures and handling methods. The method for analyzing for failures vary greatly. Critical design reviews, failure modes and effects analysis and experience record for similar systems are used to assure reliability and safety.

The subject of nonmetallic material use was discussed, and it was generally accepted that this area needs standardization of testing and selection criteria. (See Appendix D). The system participants indicated that both the government and prime contractors purchase component parts from vendors with experience in manufacturing oxygen system components and great reliance is made on these vendors to choose "oxygen compatible" nonmetallic materials. Also, no adequate vendor, contractor, or government list of acceptable materials was presented or known. Much of the time, material selection was based upon experience or limited test data. The use of nonmetallics is often compensated by the selection of metals which will contain fire should it occur in the nonmetallic material as a result of heating from without or within the system. For some new designs nonmetallic material selected for commercial aircraft use cannot have a burning temperature which could result in the ignition of the surrounding metal. It should be noted that one commercial airplane manufacturer has undertaken a development program to eliminate all nonmetallic material interfacing the flow stream of the high pressure portion of the oxygen system. Also tests are being developed to demonstrate that a reasonable amount of contaminant can be ignited within components without burning through their housing.

No unique design elements or features were found, however, a device used on some commercial aircraft should be mentioned. This device is called a thermal compensator and it is used before each valve having a nonmetallic seat which could be subjected to rapid pressurization. Rapid repressurization can cause temperatures to increase by compression to the ignition temperature of contaminants which could then lead to burning of the nonmetallic materials. The thermal compensator absorbs and conducts heat from the gas to the surrounding plumbing, thereby preventing the high gas temperature. The device is simply a chromium copper alloy wire brush configuration, approximately 5 inches long, which is placed inside the plumbing at the dead end. This device may be useful to provide additional safety margins for rapid pressurization heating.

VI. CONCLUSIONS:

1. No great technology differences exist among the fields reviewed.

2. Breathing oxygen systems utilized today have been quite successful in meeting their intent. The majority of the relatively few failures which have occurred have been traced to poor handling practices.

3. The success of today's designs has been the result of designing by experience, largely without thorough scientific understanding.

4. Improvement in and standardization of specifications and guidelines are needed in the following areas:

   a. System design requirements as a function of pressure, and use.

   b. Materials requirements and a suitable list of materials for specific applications.

   c. Materials test methods which will verify suitability of materials for the given applications.

   d. Accurate testing methods for determination of a given systems contamination level.

   e. Allowable contamination levels and materials including particle sizes for the various system pressure levels.

VII APPENDIX

A. Operational Oxygen System Reviews

1. Commercial Aviation
by J. Lea and Dr. R. A. Mahugh, Boeing,
and H. H. Jamison, MSC

(a) Description

(b) Operational System Work Sheet

(c) Sketch

(d) Bibliography

Jet Transport Oxygen Systems

With the advent of commercial jet transports in the late 1950's, the maximum cruising altitudes of commercial airplanes was increased from 25,000 to 42,000 feet. The crew oxygen systems were revised to provide diluter demand pressure breathing and a new automatically presented continuous flow oxygen system was developed for the passengers. These systems were designed to handle the emergency descent following a possible rapid decompression at 42,000 feet. The oxygen flow rates in both systems are controlled by aneroids which sense the cabin altitude.

Separate crew and passenger systems are provided in commercial jet transports and these systems are backed up by portable oxygen cylinders. The oxygen supply for all commercial jet transports is provided by 1850 psi ambient temperature gas storage cylinders. A schematic diagram of the crew and passenger oxygen systems for a typical current commercial jet transport is attached. These systems are generally quite similar on all jet transports.

Some aircraft now in development will have passenger oxygen systems supplied by chlorate candles. In these systems, separate candles are provided for each group of seats in a seat row. Candles will be ignited mechanically when the mask is removed from stowage. The crew oxygen systems will be gaseous as on other jets.

In the all-gaseous systems, the pressure is provided by pressure reducers located near the storage cylinders and is further reduced and modulated by the flow control units, additional in-line reducing valves and/or diluter demand regulators as shown on the schematic and reference drawings.

The plumbing in the high pressure systems is stainless steel and valve housings are generally of brass or bronze. Valve seat materials are generally of metal or Kel-F. New valves are being developed which will allow more general use of metal seats in high pressure valves. Medium pressure tubing is also generally of stainless steel and valve seats are generally Kel-F. Low pressure tubing which is normally pressurized is usually stainless steel but distribution tubing in the portions of the system normally unpressurized is generally of aluminum. The reservoir bags and hoses on the passenger masks are of vinyl plastic. Face masks are of silicone rubber.

Boeing recommends replenishment of the crew and passenger oxygen systems by cylinder replacement. However, facilities for external charging are available which control the filling rate and automatically turn off the charging supply when the system has reached the design charging pressure.

Cylinder valves are slow-opening to limit pressurization heating. On Boeing airplanes a heat sink device is added to reduce further the possibility of heating at high pressure dead-ends where there are nonmetal materials. The heat sink is called a thermal compensator. It is built in the form of a wire brush made of chromium copper alloy. It limits the heat of compression by providing a heat sink within the hot gas and shortening the distance that the heat must travel within the gas.

A rupture disc is provided in each cylinder valve which is connected to an overboard discharge system which will discharge the oxygen overboard in event of over-pressurizing of the cylinders or fire in the vicinity of the cylinders.

COMMERCIAL AVIATION ☒
MILITARY AVIATION ☐
SUBMARINE ☐
AIRCRAFT CARRIER ☐
MSC CHAMBER ☐
HOSPITAL ☐

DATE 4/28/70

PRESENTER J. M. Lea
R. A. Mahugh

OPERATIONAL SYSTEM REVIEW WORK SHEET

Type of System(s) Lox ____ Lo Pressure Gox x Hi Pressure Gox x

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SYSTEM DESIGN STANDARDS AND FEATURES

Type of Joints/Fittings – MS flareless and pipe threads
High pressure - 18-8 stainless low press. aluminum

Operating Life & Level – Operating life varies with components. Some component specifications indicate 60,000 hour goal.

Shelf Life/Age Life – Cylinders controlled by ICC. No specified limit on most components.

Operating Environment & Limitations – -65 to +160° F.
-40 to +160° F.
-1000' to 45,100' altitude

Special or Unique Component Designs – Several components combined into single housings.

Single Point Failures – Service experience shows high reliability
Backup provided by portable cylinders

Static Electric Charge Precautions – Bonding spec., BAC 5117, "Electrical Bonding and Grounding"

Electrical Interfaces – No wiring exposed to oxygen
Special over-voltage tests for electrical components

Ignition Source Control – 1. Slow-opening valves. 2. Cleanliness control per BAC-5402 and BPS-0-100. 3. Fire resistant materials. 4. Heat sinks (thermal compensators) provided at some dead-end locations to control compression heating.

PROCESS CONTROL SPECIFICATIONS – Electrical Interface/Contamination Levels/Special Handling Requirements/Inspections.

Manufacture: BPS-0-100 "General Engineering Requirements for Breathing Oxygen System Components (3 milligrams hydrocarbon/sq.ft.). (BAC-5402 "Oxygen Systems" (Mfg. & Instl Control)(5 milligrams (of hydro- (carbon/sq.ft
(BAC-5408 "Vapor Degreasing"(Cleaning Methods)

Service, Maintenance & Repair:
Boeing Document D6-22676, "Airplane Servicing, Gaseous Oxygen."
Boeing Maintenance Manuals, Sections 35-11 and 35-21.

PAGE 2 OF 4

GOX	Commercial	Lea/Mahugh
TYPE OF SYSTEM	**COMM., MIL., ETC.**	**PRESENTER**

OPERATIONAL SYSTEM REVIEW WORK SHEET – Continued

MANAGEMENT PROCESSES AND CONTROLS TO ENSURE SAFETY & RELIABILITY

FMEA, etc. – Design groups conduct critical design reviews; meet requirements for certification per FAR 25. (Presented in certification documents for airplane type.)

Configuration Control(s) – MIL Specs, SAE recommendations, vendor proposals, and Boeing Engineering Approval.

Certification/Recertifications – Airplane type certification and model certification per FAR part 25. Airplane certification by airlines per FAR part 121.

Testing/Retesting – Functional test document and maintenance manuals.

Material Control (Procedure) – Boeing operating procedure 6-1000-041 "Aircraft Oxygen Systems and Supporting Equipment", Boeing process spec. No. BAC-5402 "Oxygen Systems", BAC-5408 "Vapor Degreasing"

Parts Control – Individual component specifications, Boeing Parts Specification, BPS-0-100 "General Engineering Requirements For Breathing Oxygen System Components."

TESTING

Philosophy: Environmental qualification tests by vendors, with oxygen, functional test of components and systems in factory with N_2 and system acceptance tests with oxygen are required.

Experience: Development and production testing experience has been routine.

Operational Certification: Only problems during certification were mask-drop reliability.

Test Failures: No system failures during development, production, or certification testing.

SAFETY FEATURES

Relief Valves – On most medium and low pressure systems.

Burst Discs – On high pressure systems.

Redundancies – In system initiation and flow control units in passenger systems only.

Over Design – Aircraft quality for reliability.

Electro Static Charge Control – Boeing process. spec. BAC-5117 "Electrical Bonding and Grounding"

Other – 1. Recommend replenishment by cylinder exchange. 2. Use slow-opening cylinder valves. 3. Filler valve to control flow rates and maximum pressure. 4. Thermal compensators (heat sinks) at some dead-ends susceptible to compression heating.

GOX	Commercial	Lea/Mahugh
TYPE OF SYSTEM	COMM., MIL., ETC.	PRESENTER

OPERATIONAL SYSTEM REVIEW WORK SHEET – Continued

OPERATIONAL FAILURE EXPERIENCE:

Some fires have occurred during system servicing and testing on the ground on earlier models. No system failures have occurred in flight. Some temporary mask "hangups," inadvertent passenger system actuations and valve seat disappearances have been reported.

MAJOR SUPPLIERS:

Scott Aviation Corporation, Lancaster, New York (greater than 80% of equipment)
Puritan Equipment Corporation, Lenexa, Kansas
ARO of California, Los Angeles, California
Carleton Control Corporation, East Aurora, New York
Sierra Engineering, Sierra Madre, California

METALLIC MATERIALS: List Acceptable Materials SEE ATTACHED SHEET

Pressure Range –

Temperature Range –

Design Considerations/Application Limitations –

Screening Tests –

Special Procedures –

Ignition Source Controls –

Failure Experience –

GOX
TYPE OF SYSTEM

Commercial
COMM., MIL., ETC.

Lea/Mabugh
PRESENTER

OPERATIONAL SYSTEM REVIEW WORK SHEET – Concluded

NONMETALLIC MATERIALS: List Acceptable Materials by Category or Use/Range

SEE ATTACHED SHEET

Class One, A, etc.

1. Pressure Range –
2. Temperature Range –
3. Application Limitation –
4. Screening Test(s) –
5. Special Procedure(s) –
6. Ignition Source Controls –

Class Two, B, etc.

1. Pressure Range –
2. Temperature Range –
3. Application Limitation –
4. Screening Test(s) –
5. Special Procedure(s) –
6. Ignition Source Controls –

Class Three, C, etc.

1. Pressure Range –
2. Temperature Range –
3. Application Limitation –
4. Screening Test(s) –
5. Special Procedure(s) –
6. Ignition Source Controls –

LIST OF NO-NO'S IN REGARDS TO MATERIALS

Titanium, magnesium, rubber, hydrocarbons

1

MATERIALS FOR COMMERCIAL TRANSPORT OXYGEN SYSTEMS

Material	Use	Press. Range PSIG	Temp. Range °F.	Design Consid.	Applic. Limits	Screening Tests	Spec. Proc.	Ignition Source Control	Failure Experience
<u>Metals</u>									
18-8 Stainless steel	GOX	0-3000	-65 to +160	Local ignition sources & combustion characteristics	Plumbing, valve housings and parts	Parts & system qualification tests	Limit of 5 mg. hydrocarbon per sq.ft. BAC-5402	Slow opening valves, Electrical bonding & cleanliness control	*Has resisted external fires but has been consumed during internal system fires
Aluminum alloy	GOX	0-3000	-65 to +160	do.	Some fittings & valve housings. Tubing in low pressure systems only	do.	do.	do.	*Has ruptured in external fires & has been consumed during internal fires
Brass - yellow	GOX	0-3000	-65 to +160	Local ignition sources	Valve housings & valve parts	do.	do.	do.	*Has good resistance to external & internal fires
Monel	GOX	0-3000	-65 to +160	do.	Plumbing housings & valve parts	do.	do.	do	New application, no experience
Bronze	GOX	0-3000	-65 to +160	do.	Valve housings, valve parts & filter elements	do.	do.	do.	*Has good resistance to external & internal fires

*No failures directly attributed to use of this material in oxygen systems

MATERIALS FOR COMMERCIAL TRANSPORT OXYGEN SYSTEMS

Material	Use	Pres. Range PSIG	Temp. Range °F.	Design Consid.	Applic. Limits	Screening Tests	Spec. Proc.	Ignition Source Control	Failure Experience
<u>Metals (cont.)</u>									
Carbon steel	GOX	0-3000	-65 to +160	Local ignition sources	Generally limited to storage cylinders	Parts & system qualification tests	Limit of 3 mg. hydrocarbon per sq.ft. BPS-0-100	Slow presurization rate, electrical bonding & cleanliness control	*Has good resistance to external fires. No experience with interior fires
<u>Nonmetal</u>									
Kel-F 81	GOX	0-3000	-65 to +160	Local ignition sources, quantity & location of material	Valve seats and seals	Parts qualification tests	Limit of 3 mg. hydrocarbon per sq ft BPS-0-100	Slow opening valves & dead-end heat sinks BPS-0-100 & BAC-5402	*Burned when ignited by external fire. Spontaneous "disappearance" of valve seats has been reported
Teflon	GOX	0-3000	-65 to +160	do.	Valve seats & seals & low pressure hoses	do.	do.	do.	*Burned when ignited by external fire.
Silicone rubber	GOX	0-3000	-65 to +160	do.	Static seals, low pressure diaphragms & face masks	do.	do.	do	* do.

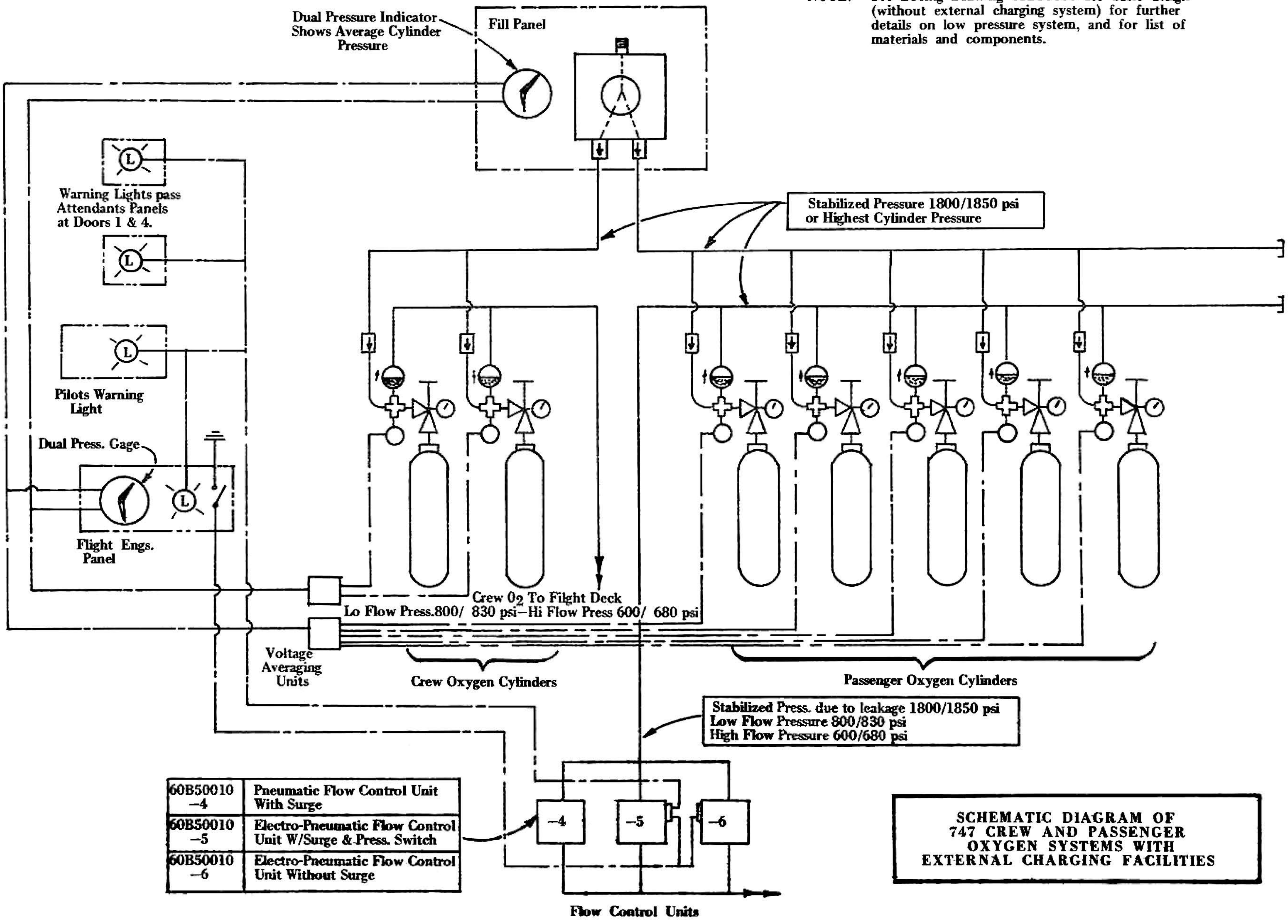
***No failures directly attributed to use of this material in oxygen systems.**

MATERIALS FOR COMMERCIAL TRANSPORT OXYGEN SYSTEMS

Material	Use	Pres. Range PSIG	Temp. Range °F.	Design Consid.	Applic. Limits	Screening Tests	Spec. Proc.	Ignition Source Control	Failure Experience
Nonmetal (cont.)									
Thread sealant MIL-T-5542	GOX	0-3000	-65 to +160	Local ignition sources, quantity & location of material	Apply to male threads only, per BAC 5402	Parts qualification tests	Apply sparingly to first three male threads only per BAC-5402	Slow opening valves & dead end heat sinks BPS-0-100 BAC-5402	* "Disappeared" when heated by external fire.
Vinyl plastic	GOX	0-150	-40 to +160	Local ignition sources & design requirements	Reservoir bags and tubing--low pressure system only	do.	Limit of 3 mg. hydrocarbon per sq. ft BPS-0-100	Prevent smoking during use	*No failure experience.

*No failures directly attributed to use of this material in oxygen systems.

NOTE: See Boeing Drawing 65B50300 for basic design (without external charging system) for further details on low pressure system, and for list of materials and components.



60B50010 –4	Pneumatic Flow Control Unit With Surge
60B50010 –5	Electro-Pneumatic Flow Control Unit W/Surge & Press. Switch
60B50010 –6	Electro-Pneumatic Flow Control Unit Without Surge

SCHEMATIC DIAGRAM OF
747 CREW AND PASSENGER
OXYGEN SYSTEMS WITH
EXTERNAL CHARGING FACILITIES

Bibliography - Commercial Aircraft Oxygen System (Boeing)

BAC-5402	Oxygen Systems - Process Specification (2/26/70)
BAC-5408	Vapor Degreasing - Process Specification (2/17/69)
BPS-0-100	General Engineering Requirements for Breathing Oxygen System Components (10/15/69)
AS-1066	SAE - Aerospace Standard - Minimum Standard for Valve, High Pressure Oxygen, Cylinder Shut-Off, Manually Operated (12/1/68)
D6-13329	Oxygen System Description and Failure Analysis - Model 747 (12/31/69)
D6-22676	Airplane Servicing - Gaseous Oxygen (4/14/69)
6-1000-041	Operating Procedure - Directive: Aircraft Oxygen Systems and Supporting Equipment (3/9/70)
D6-15452	Oxygen System Description and Failure Analysis of Model 737 (5/2/67)
D6-13911 pps 109-112	Flight Crew Oxygen System - 747
35-11-00, pps 5-12	Maintenance Manual - 747 Oxygen System (6/15/69)
35-21-00, pps 9-12	Maintenance Manual - 747 Oxygen System Description (6/15/69)
60B50189	Specification Control Drawing - Valve, Oxygen Filler, Model 747 (7/2/69)
60B50087	Specification Control Drawing - Cylinder Assembly, Oxygen, High Pressure, Stationary or Portable, Model 747 (8/29/68)
OPN 1019	Functional Standard - Airplane Servicing - Gaseous Oxygen D6-22676 (4/7/69)
	Oxygen Systems For Jet Transports 4/24/70 (viewgraph presentation by J. M. Lea to Panel 8)
5-2781-HOU-96	List of Specifications, Standards, Handbooks, and Documents Covering LOX Storage, Compatibility, Handling, Etc. April 22, 1970

Scott 10850	Sketch - Valve, Oxygen Cylinder
ASME-66-WA/PID-2	Rapid Filling of a Cylinder With a Compressible Fluid A. E. Schmidlin (12/1/66)
AIAA 67-965	Oxygen Safety - Submarine to Aircraft, <u>J. Aircraft</u>, Vol. 5, No. 6
	Controlling Cleanliness In the Saturn V First Stage, <u>Contamination Control</u>, March 1968
CGA-G-4.1	Equipment Cleaned for Oxygen Service, March 1959
AMRL-TDR-64-76	Compatibility of Materials with 7,500 psi Oxygen, Nihart and Smith, (Oct. 1964)

Drawings

Scott Aviation Dwg. 801335	Coupling Assembly
Scott Aviation Dwg. 801333	Body and Gage Assembly
Carleton Controls Corp. Dwg. 2278501	Regulator, Oxygen, Pressure Reducing
Carleton Controls Corp. Dwg. 2279501	Valve Assembly, Oxygen Filler
The Boeing Co. Dwg. 65-80299	Oxygen Diagram, 727-200
The Boeing Co. Dwg. 65-79192	Oxygen Diagram, 727-100
The Boeing Co. Dwg. 65-36773	Oxygen Diagram, 707-320C
The Boeing Co. Dwg. 65-53535	Oxygen Diagram, 737-247
The Boeing Co. Dwg. LOPPS-747	Oxygen Supply Syst.-AA-747
The Boeing Co. Dwg. 65B54809 2/2	Regulator Ass'y, High Pressure Oxygen Supply System
The Boeing Co. Dwg. sketch	747 Oxygen System
D6-13923 R1	The 747 Passenger Airplane
The Boeing Co. Dwg. 65B50300	Oxygen System Diagram PA-PASS (RA-001-RA099)

Douglas Process Standards

DPS 1.14	Closure of Openings
DPS 1.22	Anti-Seize Lubricants for Mating Parts
DPS 3.22	Identification of Fluid Lines - Aircraft
DPS 3.27	Marking Methods and Materials
DPS 3.310	Preparing Military Parts for Shipment
DPS 3.572	Aircraft and Missile Hose and Hose Assembly
DPS 3.80	Fluid Piping and Fittings
DPS 3.80-5	Fluid Piping and Fittings - Fabrication
DPS 3.80-6	Fluid Piping and Fittings - Couplings
DPS 3.80-7	Fluid Piping and Fittings - Installation
DPS 4.50-36	Epoxy (FR) Coating System
DPS 4.8000	Handling Instruments and Equipment
DPS 4.901	Breathing Oxygen Specs
DPS 4.901-1	Low Pressure Oxygen System (400 psi)
DPS 4.901-2	High Pressure Oxygen System (1800 psi)
DPS 4.901-3	Installed Oxygen Equipment
DPS 4.901-4	Oxygen Units
DPS 4.901-5	Use of Halogen Detector
DPS 4.901-6	Liquid Oxygen Breathing System
DPS 4.902	Bottled Gases
DPS 4.903	Storing and Handling Liquid Breathing Oxygen
DPS 9.318	Ultrasonic Cleaning
DPS 9.341	Vapor Degreasing
DPS 9.45	Conversion Coatings for Aluminum

2. Military Aircraft

by Don Hughes, MSC
and C. Ramsey, McDonnell-Douglas

(a) Description

(b) Operational System Work Sheet

(c) Sketch

(d) Bibliography

General Description of System:

The liquid oxygen system consists of the liquid oxygen converter and its associated components, a warmup plate, diluter demand oxygen regulators, supply and vent lines, supply line filters, and supply line relief valve. The basic unit of the system is the liquid oxygen converter. The liquid oxygen converter is a quick-removable unit that contains space for liquid oxygen storage, a combination fill, buildup and vent valve, a pressure control valve, a capacitance probe, a relief valve, and a buildup coil. During normal operation, the conversion of liquid to gaseous oxygen is automatically accomplished within the converter and its components. The rate at which liquid oxygen is converted to gaseous oxygen depends upon the demands placed upon the system by the flight crew. A capacitance type quantity indicating system is utilized to inform the crew of the amount of oxygen contained in the converter. A warning light located on the vertical panel forward of the pilot's right console warns of low oxygen supply. Gaseous oxygen generated by the converter is extremely cold and must be warmed before the oxygen, can be breathed by the crew members. The oxygen, received from the converter, is warmed by a warmup plate. Normal servicing is accomplished with the converter in the aircraft; however, the quick removable feature of the converter enables the unit to be filled in a remote area away from the aircraft, which reduces the hazards involved with servicing the converter while installed in the aircraft. Turnaround time is also reduced by replacing any empty converter with a full converter.

Normal oxygen is diverted from the supply line through the diluter demand oxygen regulators to the right consoles and to the crew members' oxygen masks. See Figures 1 and 2. A filter in each diluter demand oxygen regulator removes contaminants acquired through improper handling or storage of liquid oxygen.

Liquid oxygen quantity is indicated on the quantity indicators, which are located in the forward and aft cockpits. These indicators enable the pilot and radar pilot to determine the amount of liquid oxygen (in liters) that remains in the oxygen converter at all times during flight. The indicators are automatically operated by the gaging system which consists of a capacitance probe and an amplifying unit. The capacitance probe, located within the converter, serves as the sensing element for the system and supplies electrical variations to the amplifying unit. A preflight test of the indicators is accomplished with the oxygen quantity test switch. This push type switch is located on the pilot's left utility panel. When the switch is depressed, thd pointer of the quantity indicator rotates toward zero. As the pointer passes the 1-liter mark, the oxygen low warning light illuminates and the indicator pointer continues to rotate to zero. When the pointer reaches zero, and the test switch is released, the pointer rotates to the same reading that was registered on the indicator before the test switch was depressed, and the warning light extinguishes.

AIR FORCE LIQUID OXYGEN SYSTEM
(Without Pressure Suit Capability)

THEORY OF OPERATION

General System Operation. The liquid oxygen system is automatically operated by controlling the rate ofevaporation of liquid oxygen with pressure operating valves. Evaporation of liquid oxygen is accomplished by adding heat to the liquid which causes it to expand and, therefore, raise its pressure. A buildup coil is incorporated in the system which provides the necessary heat transfer to the liquid.

The pressure closing valve controls the rate of liquid evaporation during flow. A relief valve is provided to relieve excess pressure caused from repeated cycling or low demand on the system. General system operation involves several phases or modes of operation which are explained below.

Filling. See Figure 1. Filling the system is generally required prior to each flight to ensure that an adequate supply of liquid oxygen is available in the system at all times. During the filling operation, liquid oxygen is transferred to converter from the servicing trailer through the transfer hose. The hose contains a nozzle that attaches to the fill, buildup and vent valve of the system. The hose nozzle when attached to the fill, buildup and vent valve, actuates a plunger within the valve which places the valve in the vent position. The valve, when in the vent position, provides an opening from the top of the converter to the atmosphere which is utilized to vent gaseous oxygen during filling and liquid after the converter is full. During liquid transfer, liquid oxygen flows into the converter through a passage located in the bottom of the converter. This arrangement allows gaseous oxygen to vent through the converter top as it is being displaced by liquid flow in the bottom. When the converter is completely full, liquid flows overboard through the vent line. Removal of the transfer hose nozzle from the fill, buildup and vent valve automatically places the system in the buildup phase.

Buildup. See Figure 1. The buildup phase of operation provides a rapid pressure buildup to normal operating pressure. During this phase, liquid oxygen from the liquid container fills the buildup coil by gravitational feed. Liquid in the coil absorbs heat from the coil and vaporizes which causes a pressure buildup. Gaseous oxygen formed in the coil then circulates through the pressure closing valve and back to the top of the converter which enables more liquid to flow into the buildup coil. This circulation and pressure buildup continues until approximately 72 psi is reached, at which time the pressure closing valve closes, preventing rapid liquid evaporation and consequent fast boil-off (venting).

Normal Operation. Normal operation begins during the buildup phase and continues until all liquid oxygen has evaporated from the system. When system pressure is low and a demand by the aircrewman creates a pressure drop in the supply line, liquid oxygen is drawn from the bottom of the converter. As the liquid travels through the supply line and warmup coil, vaporization occurs which provides gaseous oxygen for breathing and also aids pressure buildup in the system. As system pressure increases to approximately 72 psi, the pressure closing valve closes which prevents rapid pressure buildup to continue. As the pressure is lowered by crew consumption, the pressure closing valve opens allowing the pressure to again buildup. When oxygen is not being used, the pressure continues to increase by normal evaporation until it reaches a value equal to the relief valve setting. At this point the relief valve opens allowing excess pressure to escape from the system.

SYSTEM PRESSURE SUPPLY

Standard Flight Gear Normal Operation. See Figure 2. Normal system operation with standard flight gear is primarily controlled by the diluter demand oxygen regulator ON/OFF valves. With the valve lever placed on the ON position, gaseous oxygen from the liquid oxygen converter passes through the diluter demand regulator inlet filter and is then automatically mixed with cabin air at a ratio dependent upon cabin altitude. This mixture is then delivered upon demand through the system lines and hoses to the crewmember's oxygen mask.

Standard Fligh Gear Emergency Operation. The emergency oxygen cylinder is attached inside the aft left corner of the seat bucket. See Figure 2. Upon actuation by the emergency oxygen manual release control (10), the oxygen flows from the cylinder to the standard flight gear adapter assembly. During seat ejection, emergency oxygen is automatically actuated by the trip lever (11) being rotated by hitting the emergency oxygen automatic release striker plate (7).

Diluter Demand Oxygen Regulator Emergency Function. In situations where oxygen supply is available from the liquid oxygen converter, the diluter demand oxygen regulator will furnish an emergency nondiluted supply of oxygen to the crewmember's mask. By placing the EMERGENCY-NORMAL-TEST MASK selector to the EMERGENCY position, 100% oxygen coupled with an increase in pressure is automatically supplied to the crewmember (100% oxygen will be furnished regardless of the position of the 100% NORMAL selector). This emergency function of the regulator can be utilized in situations such as loss of a canopy in flight, smoke in the cockpit, or suspected insufficient normal oxygen supply.

PAGE 1 OF 4

COMMERCIAL AVIATION ☐
MILITARY AVIATION ☒
SUBMARINE ☐
AIRCRAFT CARRIER ☐
MSC CHAMBER ☐
HOSPITAL ☐

DATE 4/28/70

PRESENTER C. M. Ramsey

OPERATIONAL SYSTEM REVIEW WORK SHEET

Type of System(s) Lox X Lo Pressure Gox X Hi Pressure Gox ______

SYSTEM DESIGN STANDARDS AND FEATURES

Type of Joints/Fittings – Metal-to-metal, 5052-0 Al., Al. Tubing, AN fittings & B-nuts

Operating Life & Level – System operating life varies with components. with as required replacement of failed components.

Shelf Life/Age Life – Elastomer components, except silicones, not more than 12 months.

Operating Environment & Limitations – Alt. - Sea level to 70,000 ft. with pressure suit
45,000 ft. with standard gear
Temp. - -65° F to +160° F Vibration & shock per MIL-E-5272 and MDC Rpt. 8738

Special or Unique Component Designs – Standard per MIL-C-19803D and MIL-I-19376B (AER)

Single Point Failures – No formal review made, emergency system provides redundancy except for oxygen mask.

Static Electric Charge Precautions – Bonding per MIL-B05087 Jumpers

Electrical Interfaces – Capacitance O_2 quantity gaging system

Ignition Source Control – Material selection control by applicable specifications and drawings. Hardware and fluid systems contamination control by quality assurance:
MDC-PS 12020
12300
20021
17009

PROCESS CONTROL SPECIFICATIONS – Electrical Interface/Contamination Levels/Special Handling Requirements/Inspections.

Manufacture: See attached documentation sheet

Service, Maintenance & Repair: AFTO IF-4C-2-7, part 2

Liquid/Gaseous Oxygen — TYPE OF SYSTEM
Military — COMM., MIL., ETC.
C. M. Ramsey - MDC — PRESENTER

OPERATIONAL SYSTEM REVIEW WORK SHEET – Continued

MANAGEMENT PROCESSES AND CONTROLS TO ENSURE SAFETY & RELIABILITY

FMEA, etc. – Equivalent analysis achieved by contractor and customer system design reviews to insure safety and reliability.

Configuration Control(s) – Part No. changes for all hardware change

Certification/Recertifications – Qualification testing per design requirements and environmental requirements per MIL-E-5272 and MDC Rpt. 8738

Testing/Retesting – Retesting or certification by analysis

Material Control (Procedure) – Nonmetallic materials usage reviewed by materials dept.

Parts Control – See configuration control(s)

TESTING

Philosophy: To comply with applicable military and company specifications and demonstrate acceptability of system for mission performance.

Experience: Approximately 3,800 F-4 series aircraft.

Operational Certification:

Test Failures: Failure to conform to MIL-C-19803D, para. 4.8.9, Evaporation Loss Tests, due to leakage through buildup and vent valve or loss of vacuum insulation due to container leakage.

SAFETY FEATURES (No real redundancy)

Relief Valves – Converter Relief Valve 100-110 psig, System Relief Valve 120-140 psig

Burst Discs – Converter outer shell - rupture point 3/8 in. dia. area, rupture pressure 20% less than burst pressure of outer shell.

Redundancies – Emergency Oxygen System, 50 cu. in. @ 1,800 psi

Over Design –

Electro Static Charge Control – Bonding per MIL-B-5087

Other –

LOX - GOX	Military	C. M. Ramsey
TYPE OF SYSTEM	**COMM., MIL., ETC.**	**PRESENTER**

OPERATIONAL SYSTEM REVIEW WORK SHEET – Continued

OPERATIONAL FAILURE EXPERIENCE:

1. No known fires, explosions, or catastrophic failures.
2. See documentation list for failure data.

MAJOR SUPPLIERS: (GFAE) Converters: Bendix, ARO-Firewel, Essex Cryogenics
Relief Valve : Bendix, A.R.D.C. (Airborne Research & Devel. Corp.)
(GFAE) MS27599 Regulators : Bendix, ARO-Firewel
Breathing Flex. Hoses : R. E. Darling Co.
Metallic Flex Hose : Tite Flex (SCD 32-85014)

METALLIC MATERIALS: List Acceptable Materials (SEE ATTACHED SHEET)

Pressure Range –

Temperature Range –

Design Considerations/Application Limitations –

Screening Tests –

Special Procedures –

Ignition Source Controls –

Failure Experience –

LOX - GOX	Military	C. M. Ramsey
TYPE OF SYSTEM	**COMM., MIL., ETC.**	**PRESENTER**

OPERATIONAL SYSTEM REVIEW WORK SHEET – Concluded

NONMETALLIC MATERIALS: List Acceptable Materials by Category or Use/Range (SEE ATTACHED SHEET)

Class One, A, etc.

1. Pressure Range –
2. Temperature Range –
3. Application Limitation –
4. Screening Test(s) –
5. Special Procedure(s) –
6. Ignition Source Controls –

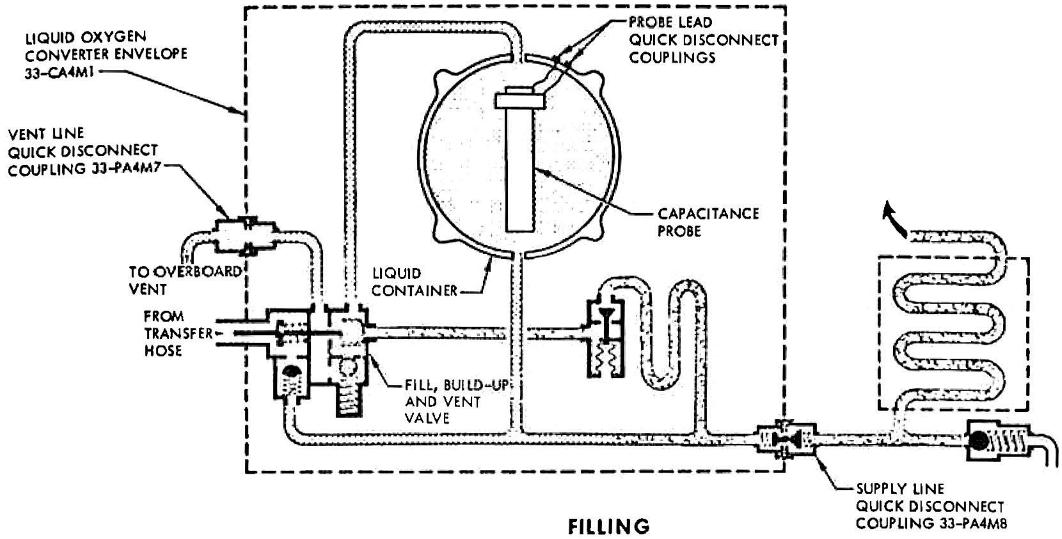
Class Two, B, etc.

1. Pressure Range –
2. Temperature Range –
3. Application Limitation –
4. Screening Test(s) –
5. Special Procedure(s) –
6. Ignition Source Controls –

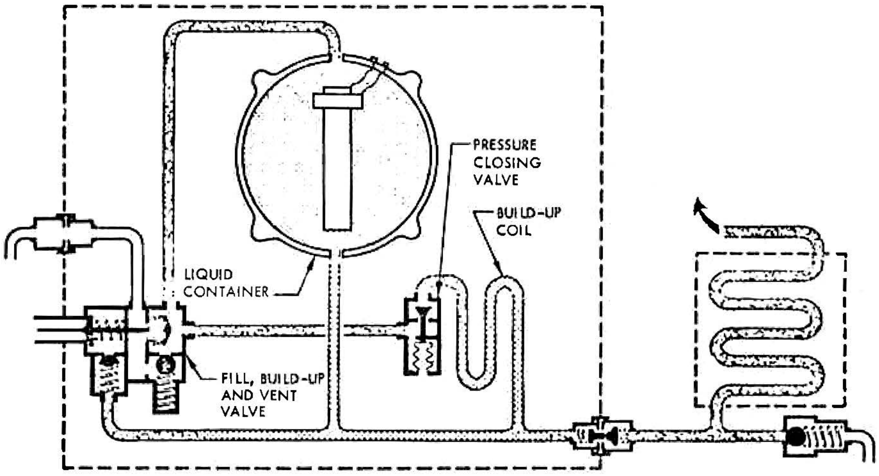
Class Three, C, etc.

1. Pressure Range –
2. Temperature Range –
3. Application Limitation –
4. Screening Test(s) –
5. Special Procedure(s) –
6. Ignition Source Controls –

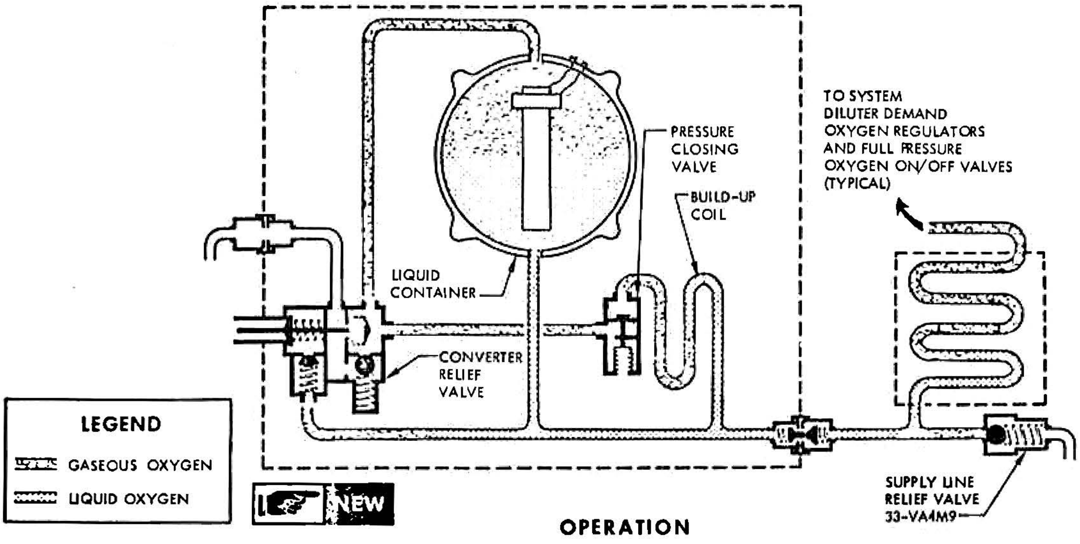
LIST OF NO-NO'S IN REGARDS TO MATERIALS



FILLING

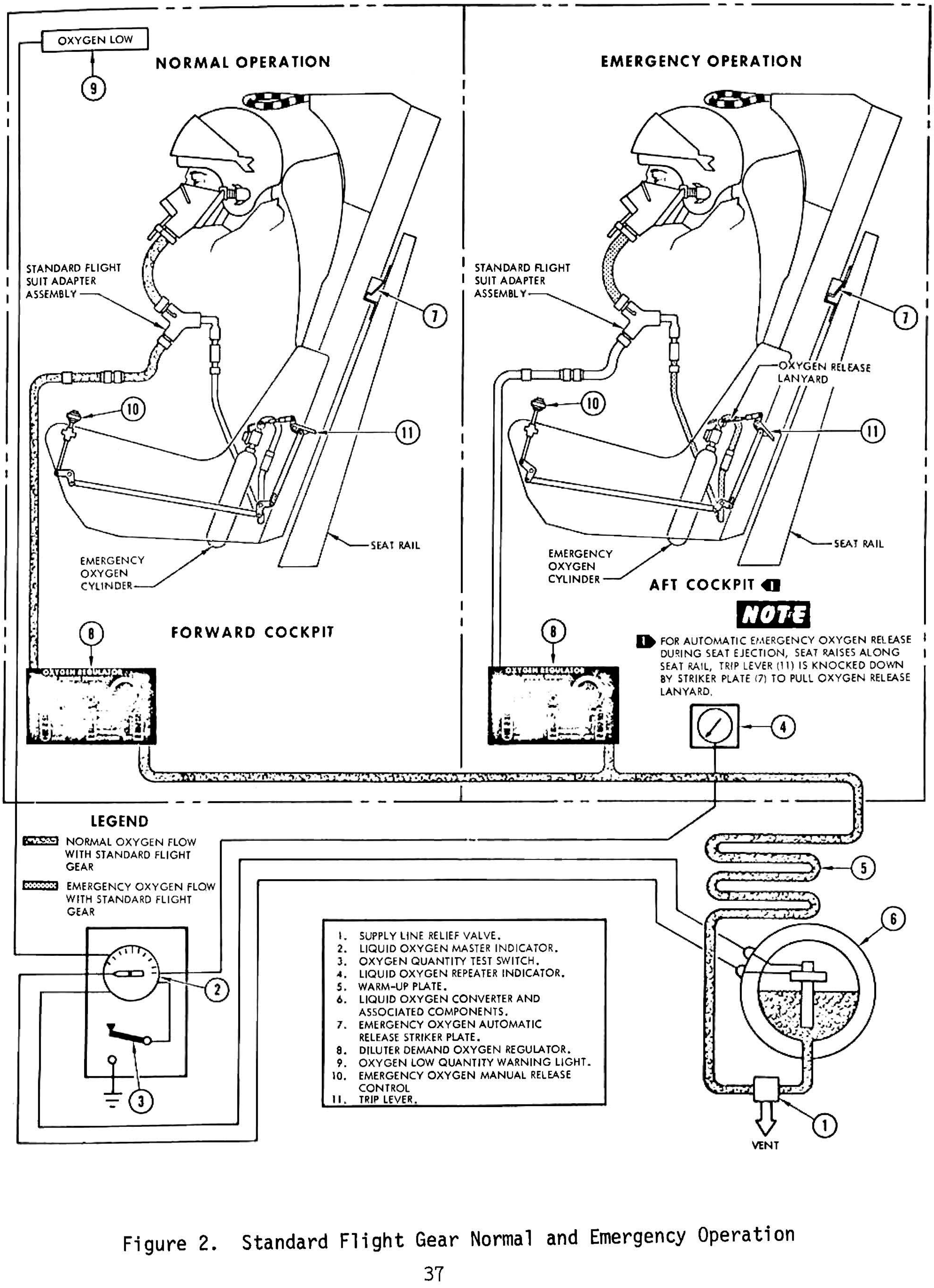


BUILD-UP



OPERATION

Figure 1. Liquid Oxygen System Schematic



NOTE

1 FOR AUTOMATIC EMERGENCY OXYGEN RELEASE DURING SEAT EJECTION, SEAT RAISES ALONG SEAT RAIL, TRIP LEVER (11) IS KNOCKED DOWN BY STRIKER PLATE (7) TO PULL OXYGEN RELEASE LANYARD.

1. SUPPLY LINE RELIEF VALVE.
2. LIQUID OXYGEN MASTER INDICATOR.
3. OXYGEN QUANTITY TEST SWITCH.
4. LIQUID OXYGEN REPEATER INDICATOR.
5. WARM-UP PLATE.
6. LIQUID OXYGEN CONVERTER AND ASSOCIATED COMPONENTS.
7. EMERGENCY OXYGEN AUTOMATIC RELEASE STRIKER PLATE.
8. DILUTER DEMAND OXYGEN REGULATOR.
9. OXYGEN LOW QUANTITY WARNING LIGHT.
10. EMERGENCY OXYGEN MANUAL RELEASE CONTROL
11. TRIP LEVER.

Figure 2. Standard Flight Gear Normal and Emergency Operation

MATERIALS SATISFACTORY FOR USAGE IN AN OXYGEN ENVIRONMENT

METALS:

Aluminum Alloy 5052
Aluminum Alloy 6061T6
Stainless or corrosion-resistant steels - 301, 302, 347
70-30 cupro-nickel alloy
AMPCO-24 alloy
Copper
Beryllium copper alloy 25
Cadmium, copper, nickel and chrome plating

NON-METALLIC:

Plastics, Elastomers:
- KEL-F 81, 800
- Viton A, B
- Rulon A, B, C
- Fluorel KX2141
- Teflon
- Aclar 33C

Thread Lubricants:
- Halocarbon oil series 13-21
- Halocarbon grease series 25-10
- KEL-F 90 grease
- KEL-F oil No. 1
- Molykote 2
- Fluorolube S-30
- Teflon tape per MIL-7-27730

MATERIALS NOT RECOMMENDED:

Metals:
- Titanium
- Magnesium
- Zirconium alloys
- Indium

Non-Metallic:
- Polyethylene
- Buna N
- Nylon
- Neoprene
- Polypropylene
- Fluorosilicone Rubber
- Polyurethane Insulation

McDonnell-Douglas Documentation - F4 Series Aircraft

MIL-D-19326D	Design and Installation of Liquid Oxygen Systems In Aircraft, General Specification For
MIL-C-19803D	Converter, Liquid Oxygen, 10 Liter, GCU-24/A (Process Spec.) P.S. 17009 - Oxygen Systems, Liquid: Installation and Testing of
P.S. 12300	Cleaning and Capping of Fluid Carrying Parts and Assemblies
P.S 20031	Storage and Handling of Liquid Oxygen
P.S. 12020	Cleaning, Solvent Vapor Degreasing
P.S. 17001	Lines, Fluid (Except Oxygen) Installation Of
P.S. 23600	AGE Control Requirements
P.S. 17009	Oxygen Systems: Liquid, Install & Testing Of

Drawings

32-85018	Equipment Installation -LOX System
53-81042	Oxygen Installation - Forward Cockpit (USAF)
53-81043	Oxygen Installation - Aft Cockpit (USAF)
53-81033	Pressure Suit Panel - Fwd. Cockpit (USAF)
53-81063	Oxygen and Utility Panel - Aft Cockpit (USAF)
32-85013	Oxygen Warm-up Plate (USAF/USN)
MS 27599	Diluter Demand Oxygen Regulator (USAF)
32-85055	Spec. Control Dwg. - 10 Liter Oxygen Converter
32-85014	Spec. Control Dwg. - Flexible Metal Lines Assembly
32-85001	Oxygen Installation - Cockpit (USN)
32-85002	Oxygen System Installation - Radar Operator
32-81019	Panel Assembly - Oxygen and Utility

McDonnell Douglas Documentation

32-90173	Acceptance Test Procedure - 10 Liter Converter Excerpt from T.O. IF-4C-2-7 - Oxygen System Description and Schematic
32A-483	Final Report - Test and Inspection of Two Discrepant LOX Converters
NAVWEPS 03-50GCB-7	I.P.B. LOX Converter 21170-3 (ARO)
NAVWEPS 03-50GDB-9	I.P.B. LOX Converter 29073-81 (Bendix) 29073-C1 (Bendix)

W. L. Maddox Memo R-0225 24 April 1970
Failure Data on F-4 Oxygen System

Reference Data:

MIL-I-5585 - Installation of Low Pressure Oxygen Equipment in Aircraft, General Specification for

MIL-I-8683 - Installation of Oxygen Equipment in Aircraft

MIL-I-9745 - Installation Design of Liquid Oxygen Systems in Aircraft, General Specifications for

MIL-I-19326- Installation and Tests of Liquid Oxygen Systems in Aircraft, General Specification for

NASA Report	TM-X-985 TM-X-53052 TM-X-53773 TM-X-53533
USAF (WADC)	TM Report WCRD-TM-55-76

3. Gemini O_2 Bottle

by J. Kennedy, Garrett Corp

(a) Description

(b) Operational System Work Sheet

(c) Sketch

GEMINI SUPERCRITICAL OXYGEN SYSTEM OPERATION

The Gemini supercritical oxygen system consisted of two cryogenic tanks and their associated controls and conditioning components. One tank provided oxygen for the environmental control system and the other provided oxygen for the fuel cell. The operation of the two tanks was essentially identical. The sequence was as follows:

Loading: Oxygen was loaded as a liquid at one atmosphere through the fill valve. The gas generated during this process was released through the vent valve. These two valves were then capped.

Pressure Buildup: The pressure within the storage system was increased from one atmosphere to operating pressure (nominal 850 psia) by the addition of heat. This heat came either from heat transfer across the annulus insulation or from the operation of the internal heaters.

Fluid Delivery: Oxygen is supplied to the using systems (ECS or fuel cell) on demand by the action of the pressure regulators. The supply pressure within the cryogenic tanks is maintained by the addition of heat. Some of this heat is supplied by the heat transfer across the annulus insulation and the remainder is supplied by the internal electrical heaters. These heaters can be operated either manually or automatically.

The storage containers themselves have several design features of special interest. The inner pressure vessel is fabricated of Inconel 718. Inside this vessel is a stainless steel capacitance probe and a copper extended surface heater. The electrical leads to the capacitance probe are brought into the tank swaged in magnesium oxide encased in stainless steel. These are two separate lines which terminate in glass to metal seals inside the inner tank. Bare wires are run from this seal to the capacitance probe. The insulators on the probe itself are all ceramic.

The heater leads are also brought into the tank swaged in magnesium oxide encased in stainless steel. They are joined to the heater element in a sealed boss on the inner tank. The heater is a resistance element swaged in magnesium oxide and encased in stainless steel. This is brazed to the copper extended surface. These are the only electrical elements exposed to oxygen in the Gemini cryogenic system.

COMMERCIAL AVIATION ☐
MILITARY AVIATION ☐
SUBMARINE ☐
AIRCRAFT CARRIER ☐
MSC CHAMBER ☐
HOSPITAL ☐
GEMINI O_2 BOTTLE

DATE April 27, 1970

PRESENTER John Kennedy

OPERATIONAL SYSTEM REVIEW WORK SHEET

Type of System(s) Lox X Lo Pressure Gox ____ Hi Pressure Gox ____

SYSTEM DESIGN STANDARDS AND FEATURES

Type of Joints/Fittings — Welds, brazes, B-nuts

Operating Life & Level — 336 hrs. @ 100 naut. mi. orbit

Shelf Life/Age Life — 18 months/18 months

Operating Environment & Limitations — Titan II launch followed by low earth orbit

Special or Unique Component Designs — No

Single Point Failures — All except pressure control valve

Static Electric Charge Precautions — None

Electrical Interfaces — Piping connectors at interfaces but no insulation exposed to oxygen

Ignition Source Control — Cleanliness and no nonmetals in storage container

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PROCESS CONTROL SPECIFICATIONS — Electrical Interface/Contamination Levels/Special Handling Requirements/Inspections.

Manufacture: Internal specs on all manufacturing materials and processes.

Service, Maintenance & Repair: None

PAGE 2 OF 4

Lox	Gemini O_2 Bottle	John Kennedy
TYPE OF SYSTEM	COMM., MIL., ETC.	PRESENTER

OPERATIONAL SYSTEM REVIEW WORK SHEET — Continued

MANAGEMENT PROCESSES AND CONTROLS TO ENSURE SAFETY & RELIABILITY

FMEA, etc. — Complete

Configuration Control(s) — Complete

Certification/Recertifications — Formal qualification and reliability

Testing/Retesting — In-process testing and acceptance testing

Material Control (Procedure) — Complete traceability on all significant materials

Parts Control — Serial numbering and traceability

TESTING

Philosophy: Qualification testing demonstrates design adequacy. Acceptance testing demonstrates proper fabrication

Experience: 100 containers in Gemini, approximately 150 other space tanks

Operational Certification: Qualification report

Test Failures: None significant, i.e., no structural failures, fires, or other catastrophic events

SAFETY FEATURES

Relief Valves — Yes

Burst Discs — No. But outer shell pinch tube serves as burst disc for outer shell

Redundancies — On control functions only

Over Design — 1.67 proof 2.22 burst

Electro Static Charge Control — No special precautions

Other — All electrical wires which are in contact with oxygen are bare. Whenever possible, electrical wires are encased in swaged stainless steel tubing with MgO insulation

Lox	Gemini O_2 Bottle	John Kennedy
TYPE OF SYSTEM	COMM., MIL., ETC.	PRESENTER

OPERATIONAL SYSTEM REVIEW WORK SHEET — Continued

OPERATIONAL FAILURE EXPERIENCE: GT-5 heater circuit (See Attached)

MAJOR SUPPLIERS: Honeywell - capacitance gauge
Bourns - pressure transducer

METALLIC MATERIALS: List Acceptable Materials INCO 718, 347 S.S, 304 S.S, 321 S.S. Cu. Ni braze, Ag braze, Au Braze, Ti (5.0 AL, 2.5 Si).

Pressure Range — 0-1,000 psia

Temperature Range — 140° Rankin - 2,200° Rankin

Design Considerations/Application Limitations — INCO 718 pressure vessel S.S. fittings and lines, cu. heat transfer surfaces.

Screening Tests — None for flammability

Special Procedures — Vacuum melt material, complete CMR on all material

Ignition Source Controls — Absolute cleanliness

Failure Experience — No material failures

Lox — **TYPE OF SYSTEM**

Gemini O_2 Bottle — **COMM., MIL., ETC.**

John Kennedy — **PRESENTER**

OPERATIONAL SYSTEM REVIEW WORK SHEET – Concluded

NONMETALLIC MATERIALS: List Acceptable Materials by Category or Use/Range

Class One, A, etc. Teflon, silicone rubber

1. Pressure Range – 150 - 1,000 psia
2. Temperature Range – -300 - +160° F.
3. Application Limitation – Valve seats and O-rings
4. Screening Test(s) – High pressure GOX cycling
5. Special Procedure(s) – None in storage containers
6. Ignition Source Controls – No insulated electrical leads

Class Two, B, etc. Teflon, silicone rubber, Viton

1. Pressure Range – 50 - 150 psia
2. Temperature Range – -65 to +160° F.
3. Application Limitation – Valve seats and O-rings
4. Screening Test(s) – High pressure GOX cycling
5. Special Procedure(s) –
6. Ignition Source Controls – No electrical wiring

Class Three, C, etc.

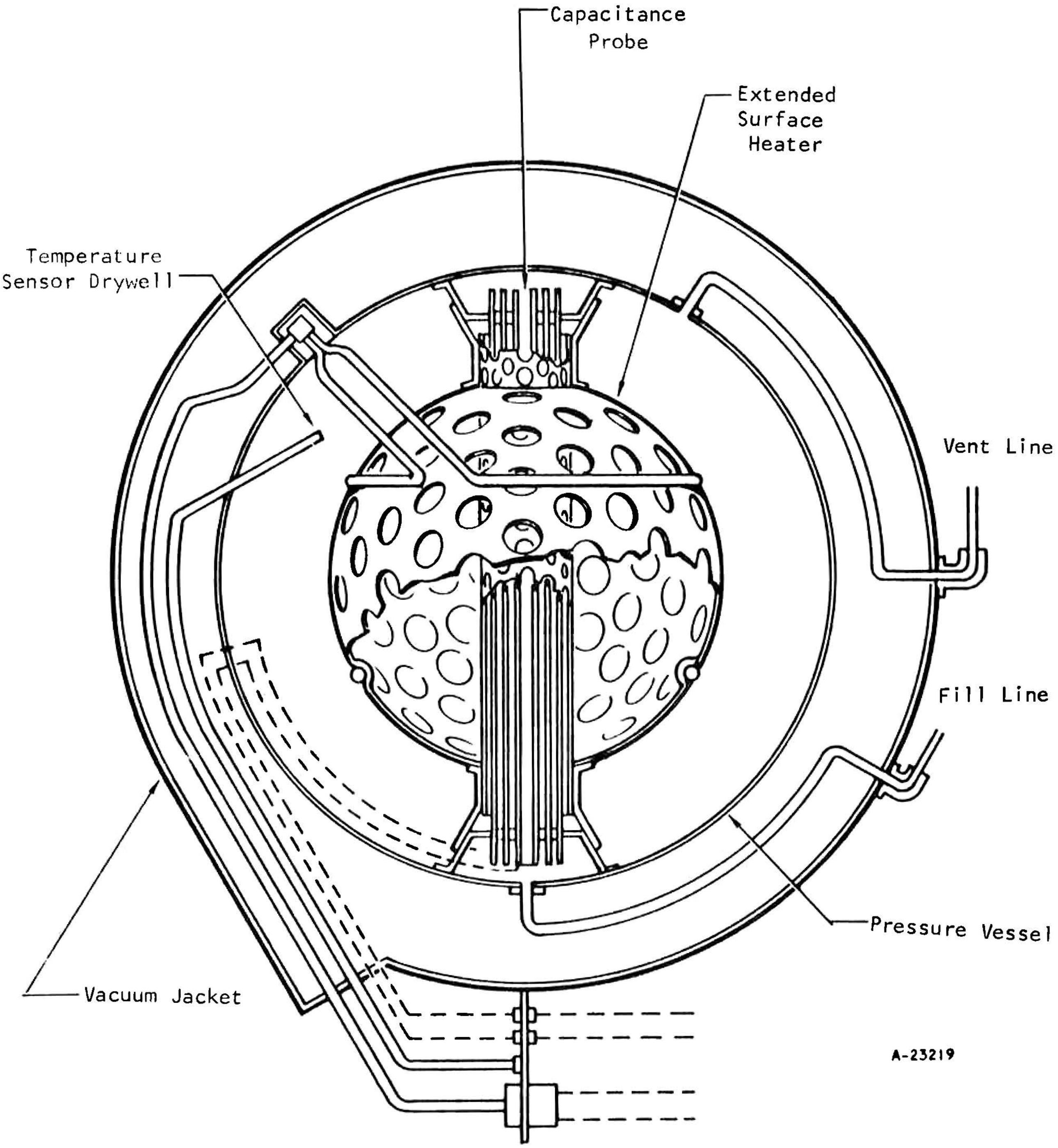
1. Pressure Range –
2. Temperature Range –
3. Application Limitation –
4. Screening Test(s) –
5. Special Procedure(s) –
6. Ignition Source Controls –

LIST OF NO-NO'S IN REGARDS TO MATERIALS

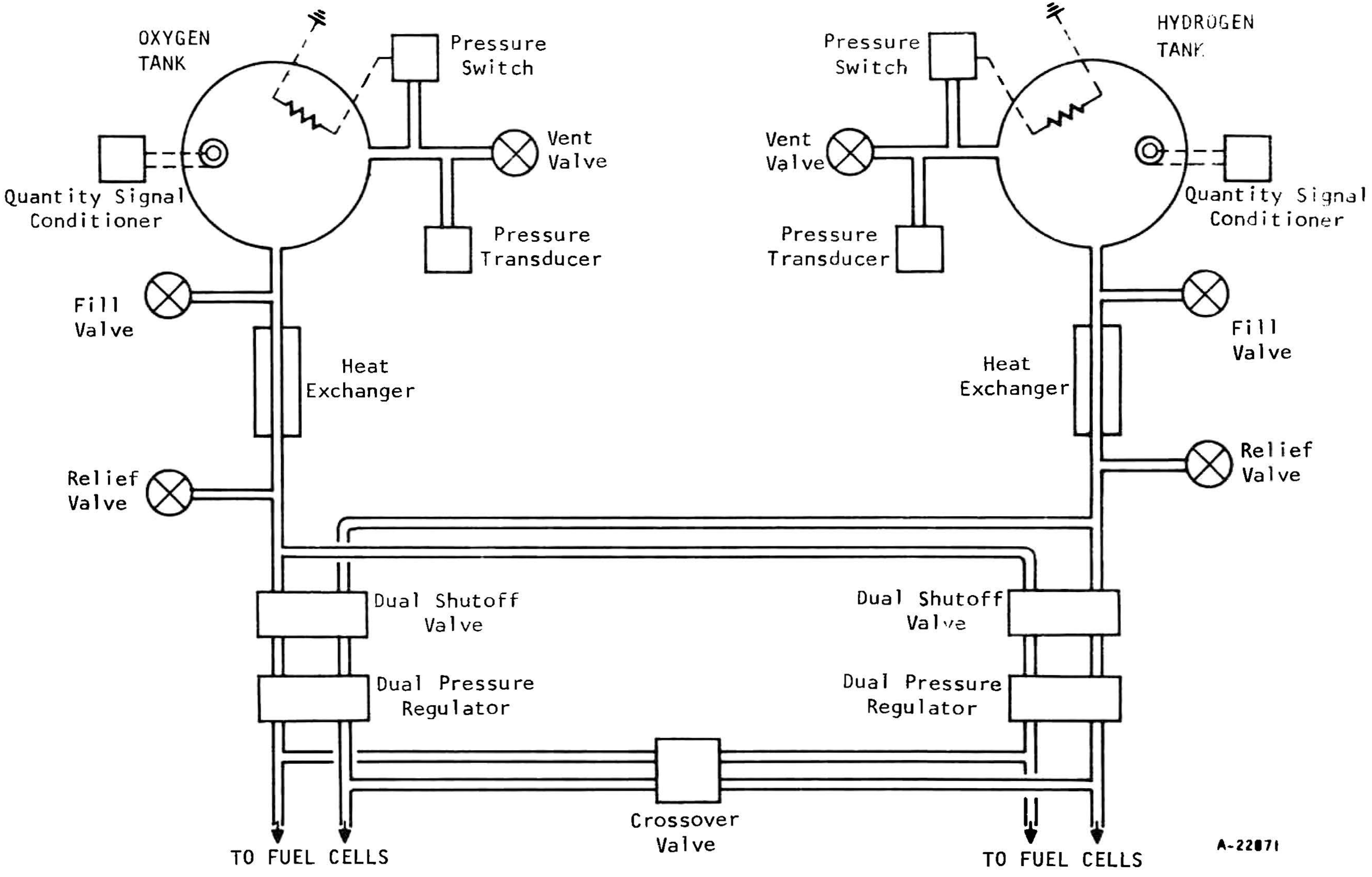
GT-5 Heater Failure

The one operational failure which occurred during the Gemini cryogenic tankage program occurred on GT-5. GT-5 launched with the Reactant Supply System (RSS) oxygen tank heater on in the automatic mode. At approximately 28 minutes GET a current spike occurred and the circuit breaker apparently tripped. When the pressure was observed to be dropping below the automatic control band, the circuit breaker was reset by the crew. This did not activate the heater nor did an attempt to operate in the manual mode. The actual failure was never identified since the adapter section which contains the cryogenic tanks is not recovered. It was established from the review of the available data that the most probable cause was a short circuit to ground of a 28 volt high lead some place before the heater element. This could have been either tank wiring or vehicle wiring.

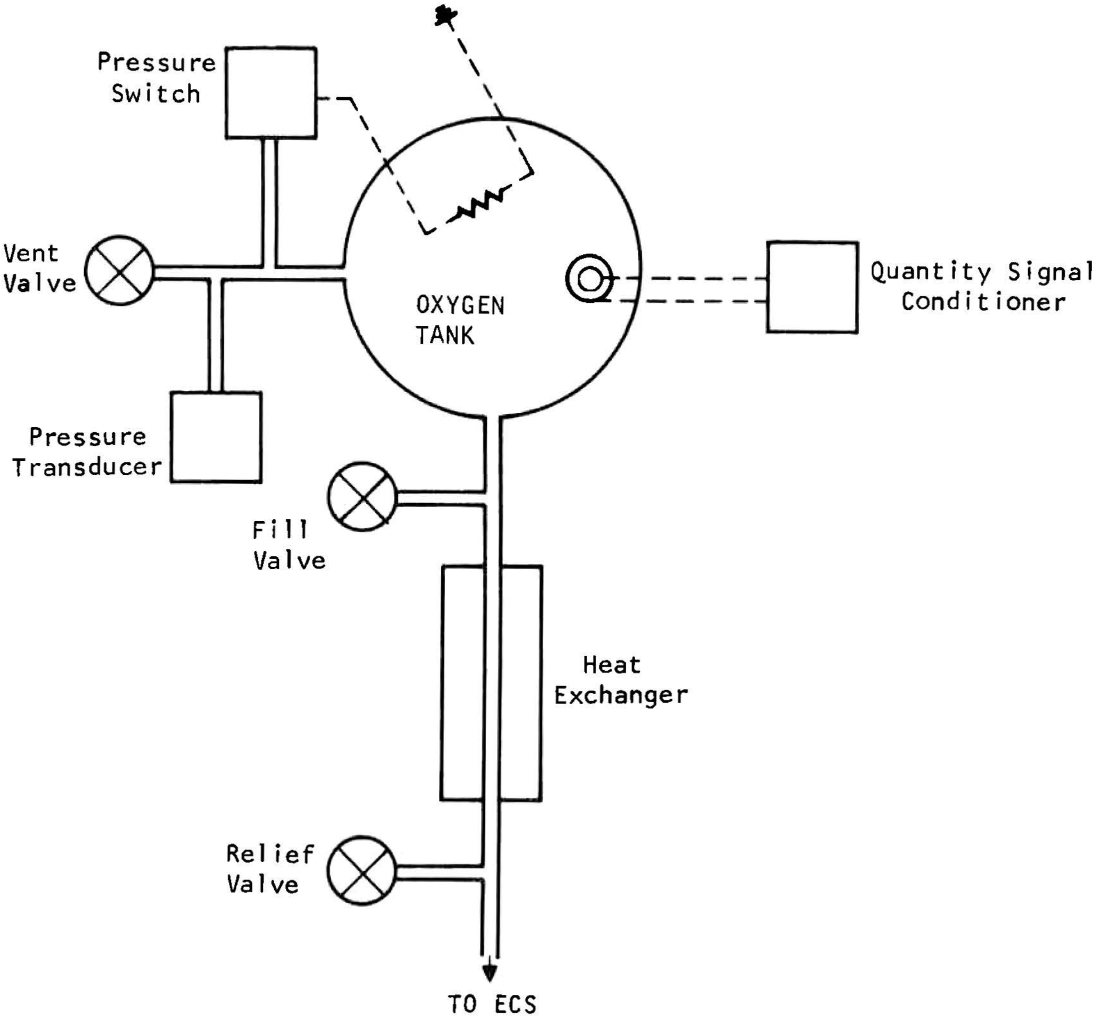
This failure left the tank with no source of pressurization energy other than heat leak through the insulation. This was not adequate to maintain supercritical operation and the pressure in this tank fell from more than 800 psia to 65 psia over a period of several hours. At this pressure, the fluid in the tank became two-phase and the energy requirements for isobaric operation changed dramatically. The energy required for liquid delivery under these conditions is such that the pressure stabilized and began to rise. After a powered down period of less than 24 hours, the normal mission was resumed. The tank pressure continued to rise throughout the mission and had reached 251 psia at the end of the mission. This occurred because the fluid in the tank was oriented by surface tension effects such that the withdrawal port saw liquid throughout the mission.


Capacitance Probe
Extended Surface Heater
Temperature Sensor Drywell
Vent Line
Fill Line
Pressure Vessel
Vacuum Jacket
A-23219

GEMINI REACTANT SUPPLY SYSTEM



GEMINI ECS SUPERCRITICAL OXYGEN CONTAINER



A-22869

4. Submarines

by Dr. J. E. Johnson,
Naval Research Lab

(a) Description

(b) Operational System Work Sheet

(c) Sketch

(d) Bibliography

Submarine Oxygen System

Oxygen gas is stored in the submarine in large flasks which are 18 inches in diameter and up to 15 feet long with a maximum volume of 21 cu. ft. Liquid oxygen is not normally carried in the submarine. Gaseous oxygen is charged to 3,100 psi in the flasks from LOX either from the air plant in the submarine tender (AS) which is identical to the plants on aircraft carriers, or from dockside facilities.

A charging line is prepared to transfer the evaporated LOX into the submarine gaseous oxygen storage system. The line must be copper tubing, single piece as short as possible, with connectors only at the ends. Connections are made with silver brazing couplings. Alternatively, lengths of monel pipe together with two or three lengths of flexible metal hose and monel couplings may be used. In either case, the entire charging line shall be welded or silver brazed so that the only threaded connections are at the ends. The charging line is hydrostatically tested to 4,500 psi and cleaned with R-113, purged with dry, oil-free nitrogen. During charging, applicable compartments in submarine are monitored with portable oxygen analyzers. (Details of preparations, charging, and shut down are given in BUSHIPS INSTRUCTION 9230.16)

In addition to external sources described above, oxygen is supplied from electrolysis of water in plants aboard some nuclear submarines (Treadwell generators). The oxygen is generated at 2100 psig pressure and the by-product hydrogen gas also generated at 2,100 psig is discharged directly to sea. The oxygen is carried either to storage banks or directly to disposal. 120 SCFH of O_2 is normally produced by one plant, which is usually enough to supply the continuous demand for personnel breathing. Various safety features are built into the operation of the oxygen generator.

Oxygen gas is dropped by regulators to 100 psig or lower for dispersal. Dispersal is normally accomplished by bleeding oxygen through needle valves into the submarine at several points using special diffusers at 2 to 3 psig.

An important aspect of the gaseous oxygen storage and distribution facilities is maintaining them contaminant-free. When contamination of any part of system is suspected, or repairs and replacement parts are required, cleaning and purging is done using trichlorotrifluoroethylene according to MIL-STANDARD-1330 (SHIPS). The trend is to use only nickel-copper or copper-nickel alloys for all parts of the high pressure gaseous oxygen system including piping, fittings, and valves. A recent change is to replace stainless steel end plugs in oxygen flasks with monel plugs whenever cleaning of the flasks is accomplished. Flasks themselves are still fabricated of corrosion resistant steel in accordance with MIL-F-22606B(SHIPS).

A single line schematic flow diagram of the submarine oxygen distribution system is attached. Additional specific details are included in the attached specifications and documentation.

PAGE 1 OF 4

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AIRCRAFT CARRIER ☐
MSC CHAMBER ☐
HOSPITAL ☐

DATE 4/28/70

PRESENTER Johnson/Kitts

AIRCRAFT CARRIER GOX SYSTEMS USE IDENTICAL COMPONENTS FOR PIPING

OPERATIONAL SYSTEM REVIEW WORK SHEET

Type of System(s) Lox Only loading from tender Lo Pressure Gox 100 psi Hi Pressure Gox 3,000 psi

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SYSTEM DESIGN STANDARDS AND FEATURES

Type of Joints/Fittings – 3,000 psi - Pipe, valves, fitting of nickel-copper alloy (monel). Diaphragm valves with Teflon Kel-F disc inserts. All valves have welded nipples. Pipe threads shall not be used. Socket ends for silver brazing

Operating Life & Level – Components will be scrapped if inspection reveals excessive corrosion or thread galling.

Shelf Life/Age Life – Indefinitely long - no scheduled retirement.

Operating Environment & Limitations – External environment 65-80° F., 50-60% r.h., 1.0 atm. press.

Special or Unique Component Designs – Keep all joints and interfaces to minimum.

Single Point Failures – Redundance of system precludes SPF.

Static Electric Charge Precautions – Permanently grounded

Electrical Interfaces – No electrical penetration for instrumentation
Isolation from electrolytic O_2 plant.

Ignition Source Control – Quality control on O_2 to eliminate metallic and organic sources of ignition. Electrical grounds.

PROCESS CONTROL SPECIFICATIONS – Electrical Interface/Contamination Levels/Special Handling Requirements/Inspections.

Manufacture: Systems are assembled from components mfd. to mil. specs.

Service, Maintenance & Repair: Cleaning of oxygen banks, piping systems, and components by flushing with trichlorotrifluoroethylene (ultra-clean) only. Testing for residual flushing solvent required. For any repair work, cleaning process must be repeated. All oxygen flasks shall have CRES plugs replaced by monel plugs at next opportunity. ALL COMPONENTS AND COMPLETED SYSTEMS TESTED TO 1.5 TIMES MAX. OPERATING PRESSURE.

Submarine Hp GOX	Military	Johnson/Kitts
TYPE OF SYSTEM	**COMM., MIL., ETC.**	**PRESENTER**

OPERATIONAL SYSTEM REVIEW WORK SHEET – Continued

MANAGEMENT PROCESSES AND CONTROLS TO ENSURE SAFETY & RELIABILITY

FMEA, etc. – Based on experience and use

Configuration Control(s) – Modifications to systems incorporated during overhaul.

Certification/Recertifications – Quality assurance maintained by Govt. inspectors.

Testing/Retesting – Pressure tests required every time system is opened or system integrity is in doubt.

Material Control (Procedure) – Actual material is specified in mil. spec. for each component.

Parts Control – All parts for replacement shall be of materials in strict accordance with material spec. shown of approved drawing.

TESTING

	SYSTEM	COMPONENT
Philosophy:	Test for contamination level--pressure test for leaks using N_2 gas.	According to spec. requirements.
Experience:	Systems can be operated safely if kept clean and properly maintained.	
Operational Certification:	After inspection, repair & cleaning, 15 min. hydrostatic test to 1.5 times max. op. pres. using cleaning solvent. Next pressure test with N_2/Freon-12 mixed gas for 7 days. Max. allowable press. drop is 5 psig (at 3,000 psi). Purge to free of Freon-12.	Tested as part of system
Test Failures:		Repair or replace defective component

SAFETY FEATURES

Relief Valves – For oxygen service, relief valves are used: body and spring housing are of monel, springs of bronze, monel, copper-nickel alloy; valve disc inserts of Teflon (MIL-V-22549D(SHIPS)).

Burst Discs –

Redundancies – No single point failure

Over Design –

Electro Static Charge Control – All systems are to common ground

Other – Contamination and quality control of oxygen. Strict control of materials and components according to mil. specs.

submarine Hp GOX	military	Johnson/Kitts
TYPE OF SYSTEM	COMM., MIL., ETC.	PRESENTER

OPERATIONAL SYSTEM REVIEW WORK SHEET – Continued

OPERATIONAL FAILURE EXPERIENCE:

MAJOR SUPPLIERS: From numerous sources

(See Next Page Also)

METALLIC MATERIALS: List Acceptable Materials Copper, nickel-copper alloy, copper-nickel (for oxygen flasks use HY-80 or F-22 (of ASTM A336) steel.

Pressure Range – 3,000 psi op. pressure; 4,500 psig hyprostatic test pressure

Temperature Range – normal 65 - 80°F

Design Considerations/Application Limitations – Compatibility with HP O_2

Screening Tests – Experience

Special Procedures – Surfaces must be clean to eliminate oil and hydrocarbons.

Ignition Source Controls – Controlled by specific metal permitted

Failure Experience – Few. Have experienced at least one O_2 bottle fire in which CRES end plug was burned almost completely.

Submarine Hp GOX	Military	Johnson/Kitts
TYPE OF SYSTEM	**COMM., MIL., ETC.**	**PRESENTER**

OPERATIONAL SYSTEM REVIEW WORK SHEET – Concluded

NONMETALLIC MATERIALS: List Acceptable Materials by Category or Use/Range

Class One, A, etc.	Teflon, Kel-F	Fluorolubes, Teflon tape, Kel-F oil
1. Pressure Range –	3,000 psi HP GOX	3,000 psi HP GOX
2. Temperature Range –	Normal, 60-85° F.	Normal, 60-85° F.
3. Application Limitation –	Flange gaskets, valve disc inserts	Lubricants and thread compounds
4. Screening Test(s) –		
5. Special Procedure(s) –		Avoid direct contact with flowing oxygen
6. Ignition Source Controls –		

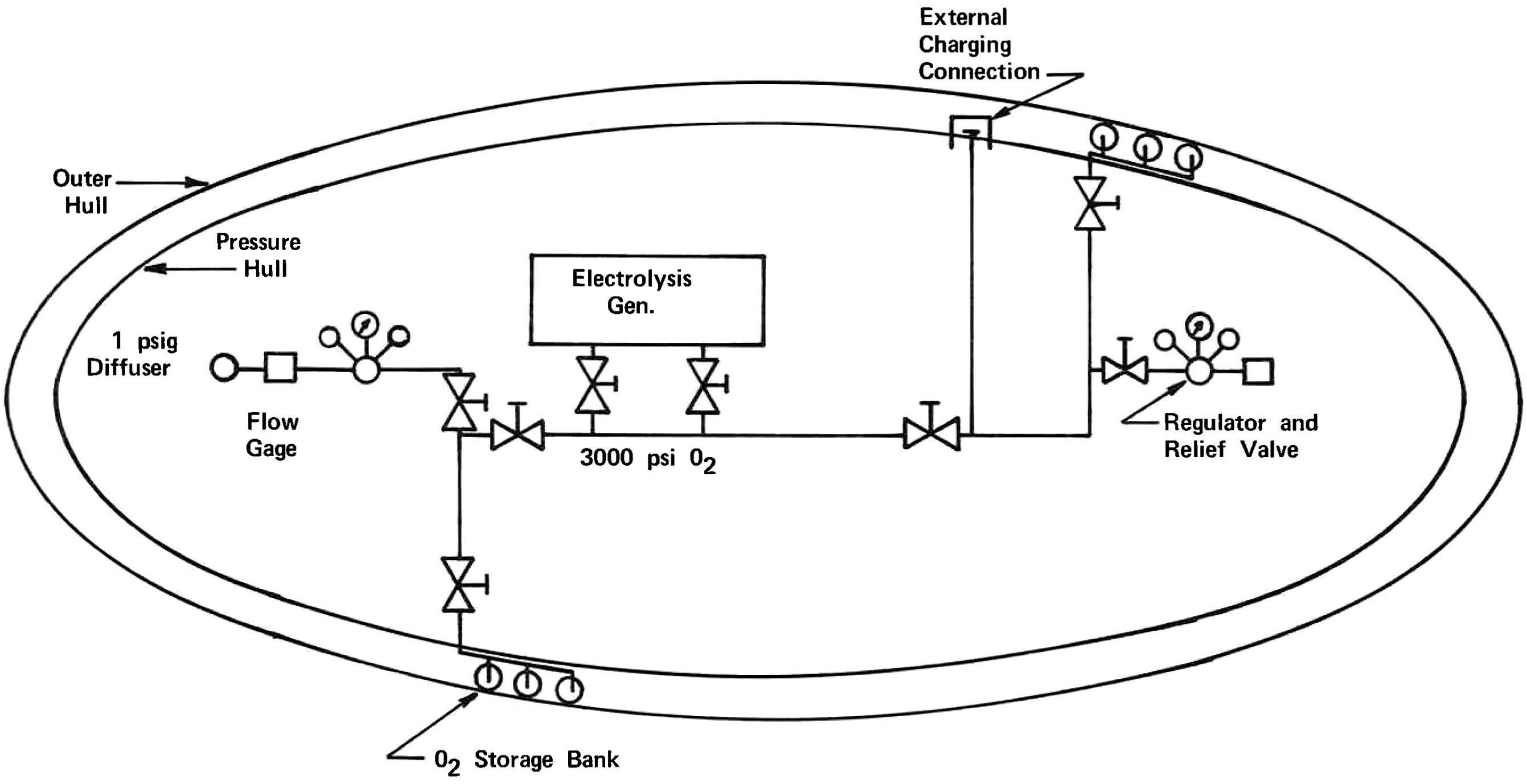
Class Two, B, etc.

1. Pressure Range – 0-100 psig
2. Temperature Range – Ambient
3. Application Limitation – Stem packing--Teflon disc washer--Teflon or nylon
4. Screening Test(s) –
5. Special Procedure(s) –
6. Ignition Source Controls –

METALS
Class ~~Three~~/~~C~~, etc.
Two Copper, bronze, Naval brass

1. Pressure Range – 0-100 psig
2. Temperature Range – Ambient
3. Application Limitation – pipe, valves, fittings
4. Screening Test(s) –
5. Special Procedure(s) –
6. Ignition Source Controls –

LIST OF NO-NO'S IN REGARDS TO MATERIALS Plastics (other than flouorocarbons), rubber, cast iron, carbon steel, organic compounds. No greases with a petroleum base.



SUBMARINE OXYGEN SYSTEM

Reference Material On Submarine Oxygen Systems (Received 4/27/70)

1. Naval Ships Technical Manual, chapter 9230 "Industrial Gases; Generating, Handling and Storage," NAVSHIPS 0901-230-0002, September 1967 edition.

2. General Specifications for Ships of the United States Navy, Department of the Navy, Naval Ship Engineering Center, section 9230-1, "Compressed Gas Systems" draft copy, supersedes section S23-1, dated 1 May 1958.

3. BUSHIPS Instruction 9230.12A, "Oxygen and Nitrogen Piping Systems, Cleaning and Inspection of," BUSHIPS 9230.12A, Ser 648F-188, 8 Feb. 1961.

4. BUSHIPS Instruction 9230.15B, "High Pressure Air, Oxygen and Dry, Oil-Free Nitrogen Systems, approved Lubricants and Thread Compounds for," BUSHIPS 9230.15B Ser 648F-2475, 27 Dec. 1962.

5. BUSHIPS Instruction 9230.16, "Submarine Oxygen Systems, Dockside and Tender (AS) Charging and Off-Loading of," BUSHIPS 9230.16, Ser. 648F-1300, 20 Aug. 1962.

6. Military Standard, "Cleaning and Testing of Oxygen and Nitrogen Gas Piping Systems, " Mil-STD-1330(SHIPS), 10 May 1968.

7. Military Standard, "Schedule of Piping, Valves, Fittings, and Associated Piping Components for Submarine Service," MIL-STD-438D(SHIPS), 30 Oct. 1969. (See Category K-1 and K-2)

8. Mil. Spec. "Flask, Compressed Gas and End Plugs for Air, Oxygen and Nitrogen," MIL-F-22606B(SHIPS), 12 June 1964 (with Amendment -4)

9. MIL SPEC "Indicators, Pressure, Bourdon Type," and others.
MIL-I-18997/1(SHIPS), 7 Mar. 1967
MIL-I-18997/2(SHIPS), 7 Mar. 1967
MIL-I-18997C(SHIPS), 6 Mar. 1967 and SUPPLEMENT-1.

10. MIL SPEC, "Bronze, Valve: Castings," MIL-B-16541B(WP) 3 Dec. 1964 (plus Amend.-1)

11. MIL SPEC, "Valves, Pressure Reducing, for Oxygen Service," MIL-V-24336 (SHIPS), 20 May 1968 (plus Amend.-1).

12. MIL SPEC "Valves, Angle, Relief, for Gas and Oxygen Service (Sizes 2-inches IPS and Below); Naval Shipboard," MIL-V-22549D(SHIPS), 20 Sept. 1968.

13. MIL SPEC "Tube, Copper (Seamless)," MIL-T-24107(SHIPS), 10 Mar. 1965.

14. MIL SPEC "Fittings, Tube, Cast Bronze, Silver-Brazing," MIL-F-1183E, 24 July 1961, (plus Amend.-1).

15. MIL SPEC "Tube, 70-30 and 90-10 Copper-Nickel Alloy, Seamless and Welded," MIL-T-16420J(SHIPS), 4 Mar 1965 (plus Amend.-3).

16. MIL SPEC "Pipe, Stainless Steel, (Corrosion-Resistant), Seamless or Welded," MIL-P-1144B(SHIPS), 18 Oct. 1962 (plus Amend.-1).

17. MIL SPEC "Tube and Pipe, Nickel-Copper Alloy, Seamless and Welded," MIL-T-1368C, 2 June 1965, (plus Amend.-2).

18. FED SPEC "Nickel-Copper Alloy Bar, Plate, Rod, Sheet, Strip, Wire, Forgings, and Structural and Special Shaped Sections," QQ-N-281b, Oct. 31, 1966.

19. FED SPEC "Brass, Naval, etc.," QQ-B-637a, Mar. 14, 1967.

20. NRL Ltr. Rpt. "Fire in oxygen make-up system for pressure chambers used for manned exposures," 6180-48A:FWW:JEJ:ec of 3 May 1968.

21. NRL Ltr. Rpt. "Aviators breathing oxygen from aircraft converters, evaluation of:" 6180-176A:FWW:ec of 20 Nov. 1968.

DRAWINGS

Diagram, "SS(N)637-501-2142136.
(Newport News S.&D.D. No. 273-325).

Diagram, "ASR21-513-4369845, Rev. B" Sheet 1 and 2.
Submarine Rescue Ship, ASR21, "Compressed Gas System Diagram."
Alabama Dry Dock and Shipbuilding Co., Mobile, Ala.

Miscellaneous BuShips Drawings
- 1385941, Sheets 1 and 2, "Fittings, Silver Brazed, WOG, for 3000 PSI Service".
- 1385943, Sheets 1 and 2, " Unions, Sil Brzg, 3000 PSI Service".
- 1385946, "Unions, Bronze, Silver Grazing, WOG".
- 1385950, "Bosses, Non-Ferrous Piping, 3000 PSI Service".
- 1385963, Sheets 1 and 2, "Fittings, Silver Brazing Ni-Al-Brz for 1500 & 3000 PSI".
- 1385846, Sheets 1-4, "Oxygen Systems, Submarines, Replenishment" Schematic Piping Diagram.
- 1385859, "Union, Bronze, Silver Brazing Alloy, Low Pressure Service 800-1500 PSIG".

5. Aircraft Carriers

by W. Kitts, MSC

(a) Description

(b) Operational System Work Sheet

(c) Systems Schematic

(d) Bibliography

Aircraft Carrier Oxygen System (CVA)

The source of oxygen on the Navy aircraft carrier is the air separation plant which produces, by distillation, liquid oxygen and liquid nitrogen. Each aircraft carrier is equipped with two such air separation plants which are located on the hangar deck level, one forward and one aft in outboard compartments. The liquid products are transferred from the air separation plant to storage as liquid or gaseous products. Each air separation plant is capable of producing liquid oxygen at the rate of 110 lbs./hr. or 1.32 tons/day or producing liquid oxygen and liquid nitrogen simultaneously.

The cryogenic storage system consists of two liquid tanks suspended inside a single outer shell. The insulating space between the tanks and shell are filled with perlite insulating material and evacuated to provide insulation against heat leakage. The storage systems piping includes pressurizing controls to each tank to permit increasing the gas pressure over the liquid for liquid withdrawal or transfer. Each tank is equipped with pressure controls, instrumentation, valves, relief valves, burst discs, liquid level gages, and vacuum gages to permit ease of operation and to prevent dangerous pressure levels from building up in the storage tanks. The normal capacity of the liquid oxygen storage tank is 750 gallons of LOX with a 10 percent vapor space provided for the expansion of the stored liquid as it vaporizes.

A liquid oxygen fill bench is provided to fill removed aircraft liquid oxygen converters at a remote compartment adjacent to the oxygen plant on the hangar deck level. The aircraft converters can also be filled in the aircraft on the flight deck level by utilizing portable 50-gallon storage tanks. The portable storage tanks are replenished from the main 750 gallon LOX storage tank on the hangar deck level.

Each oxygen plant is equipped with a liquid oxygen pump and vaporizing system to produce high pressure (3,000 psig) gaseous oxygen from the liquid product. The pump is a single cylinder, positive displacement reciprocating pump driven by a crosshead connecting rod, crankshaft, and electric motor assembly. The pump and vaporizer assembly is capable of producing gaseous oxygen at a maximum rate of 25,000 standard cubic foot per hour at ambient temperature and at a maximum pressure of 3,500 psig. The gaseous oxygen is pumped into the ships storage system wherein it is manifolded into connecting piping which distributes the gaseous product to the ships oxygen piping system for various uses as high and low pressure gas throughout the ship. A single line schematic flow diagram of the aircraft carrier's oxygen distribution system is attached.

Additional specific details are included in the attached specifications and documentation.

COMMERCIAL AVIATION ☐
MILITARY AVIATION ☐
SUBMARINE ☐
AIRCRAFT CARRIER ☒
MSC CHAMBER ☐
HOSPITAL ☐

DATE 29 April 1970

PRESENTER Kitts/Johnson

OPERATIONAL SYSTEM REVIEW WORK SHEET

Type of System(s) Lox x Lo Pressure Gox _____ Hi Pressure Gox _____

SYSTEM DESIGN STANDARDS AND FEATURES

Type of Joints/Fittings – Pipe, valves, and fittings of stainless steel; socket weld fittings and joints are composed of 316L stainless steel.

Operating Life & Level – Components replaced when inspection reveals defects or damaged in use.

Shelf Life/Age Life – Indefinite.

Operating Environment & Limitations – -297° F. to 120° F., exposed to salt or sea spray sea level pressure, maximum internal operating pressure - 3,500 psig.

Special or Unique Component Designs – Cryogenic transfer lines of double wall or vacuum-jacketed construction. Keep all connections, welds, and interfaces to a minimum.

Single Point Failures – Redundancy of the system precludes SPF.

Static Electric Charge Precautions – LOX transfer lines are grounded.

Electrical Interfaces – No electrical interfaces required for instrumentation.

Ignition Source Control – Electrical grounds, acetylene tests required for LOX storage tanks at 90 day intervals.

PROCESS CONTROL SPECIFICATIONS – Electrical Interface/Contamination Levels/Special Handling Requirements/Inspections.

Manufacture: Components assembled to meet military specifications.

Service, Maintenance & Repair: All oxygen systems shall be cleaned in accordance with requirements of MIL-STD-1330. Freon 113 solvent is used. All repair parts shall be identical in material and quality of those originally furnished with the valve or component.

Aircraft carrier LOX	military	Kitts/Johnson	**PAGE 2 OF 4**
TYPE OF SYSTEM	**COMM., MIL., ETC.**	**PRESENTER**	

OPERATIONAL SYSTEM REVIEW WORK SHEET – Continued

MANAGEMENT PROCESSES AND CONTROLS TO ENSURE SAFETY & RELIABILITY

FMEA, etc. – Based on experience while in use.

Configuration Control(s) – Modifications to the systems are made during the normal overhaul period at the shipyard.

Certification/Recertifications – QA coverage provided by Naval inspectors. The original oxygen plant certification is accomplished at the shipbuilders yard with Navy surveillance and recertified during the normal overhaul period.

Testing/Retesting – Compone

Material Control (Procedure) – Components are procured to meet mil. spec. requirements. The basic oxygen plant must demonstrate satisfactory performance to Navy shipboard specifications.

Parts Control – Quality control is provided to assure that parts are cleaned and are of identical materials for LOX service as the original.

TESTING

Philosophy: A gas sample is obrained from the system to ascertain the system cleanliness level and to meet the criteria and requirements for LOX. The system integrity must be verified by leak testing and free of contaminants.

Experience: Experience indicates that safety cannot be over-emphasized and is a prime consideration in safe handling and production of cryogenic liquids.

Operational Certification: For new ships plant certification for LOX is obtained at the shipyard under naval inspector scrutiny to assure that the plant produces LOX to the purity and quantity required by the specificatiosn.

Test Failures: During overhaul periods, the carrier's LOX plants are cleaned, purged, leak tested and operated to verify plant performance for recertification.

SAFETY FEATURES

Relief Valves – For oxygen service relief valves and burst discs are used for overpressure conditions. Burst discs are used as a second level of protection on LOX tanks.

Burst Discs –

Redundancies – Two complete plants are installed on each aircraft carrier.

Over Design –

Electro Static Charge Control – All LOX and GOX systems are grounded.

Other – An automatic sprinkling system is activated by thermostatic controls located in the floor of the LOX plants on carriers. In the event of mass spillage of LOX, the system is actuated when the floor temperature reaches 0° F.

Aircraft carrier LOX	military	Kitts/Johnson
TYPE OF SYSTEM	COMM., MIL., ETC.	PRESENTER

OPERATIONAL SYSTEM REVIEW WORK SHEET – Continued

OPERATIONAL FAILURE EXPERIENCE:

MAJOR SUPPLIERS: From several sources to meet the applicable military specifications for LOX and GOX service.

METALLIC MATERIALS: List Acceptable Materials Copper, nickel copper, bronze, CRES type 316 L

Pressure Range – 3,000 psi for LOX pump and vaporizer

Temperature Range – -297° F. to 120° F.

Design Considerations/Application Limitations – System must be compatible for LOX and have pump and vaporizing capability to supply gaseous oxygen for the carriers requirement.

Screening Tests –

Special Procedures – Cleaning to rigid requirements to eliminate oil, grease, and hydrocarbons. Procedures are used to limit and prevent acetylene buildup in LOX storage tanks.

Ignition Source Controls –

Failure Experience –

LOX, aircraft carrier	military	Kitts. Johnson
TYPE OF SYSTEM	**COMM., MIL., ETC.**	**PRESENTER**

OPERATIONAL SYSTEM REVIEW WORK SHEET – Concluded

NONMETALLIC MATERIALS: List Acceptable Materials by Category or Use/Range

Class One, A, etc. Teflon, Kelf

1. Pressure Range – 0 - 3,000 psi in pump and vaporizing unit, reduced to 100 psi or less for specific uses.
2. Temperature Range – -297° F. to 120° F.
3. Application Limitation – Valves seats and packing
4. Screening Test(s) –
5. Special Procedure(s) –
6. Ignition Source Controls –

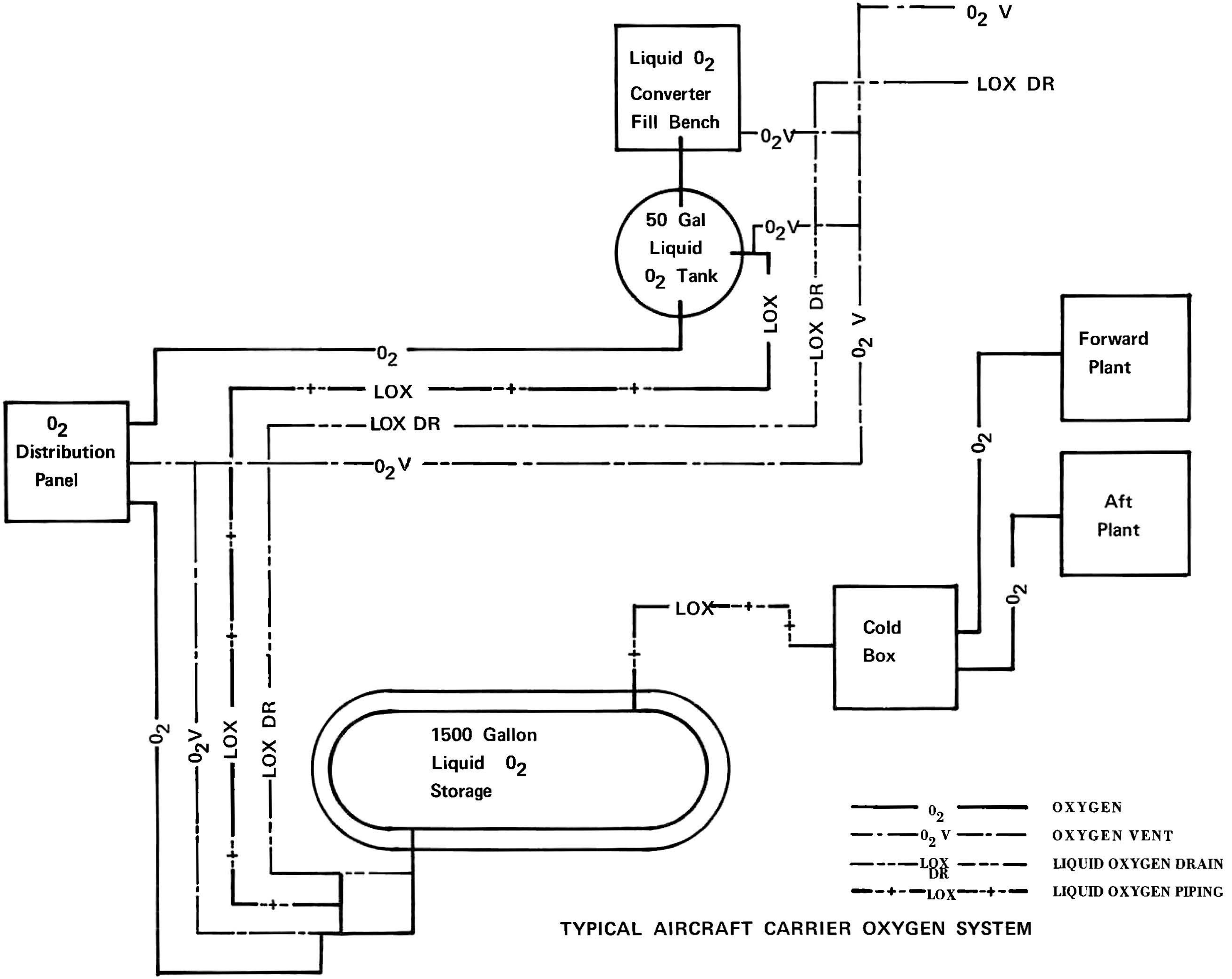
Class Two, B, etc.

1. Pressure Range –
2. Temperature Range –
3. Application Limitation –
4. Screening Test(s) –
5. Special Procedure(s) –
6. Ignition Source Controls –

Class Three, C, etc.

1. Pressure Range –
2. Temperature Range –
3. Application Limitation –
4. Screening Test(s) –
5. Special Procedure(s) –
6. Ignition Source Controls –

LIST OF NO-NO'S IN REGARDS TO MATERIALS Plastics (other than fluorocarbons) rubber, cast iron, carbon steel, organic compounds are not permitted. No grease, oils, or petroleum base products can be used.



TYPICAL AIRCRAFT CARRIER OXYGEN SYSTEM

REFERENCE MATERIAL OR AIRCRAFT CARRIER OXYGEN SYSTEMS

Received 4/24/70 from Ships Command, Military Spec's.

1. MIL-P-23638A (Ships) 11 October 1963
   Plant; for Producing, Storing, Pumping and vaporizing Liquid Oxygen and Liquid Nitrogen (Shipboard type)

2. MIL-S-23639A (Ships) 11 October 1963
   System for Liquid Oxygen and Liquid Nitrogen Storage and Charging; (Shipboard type)

3. MIL-D-19326D; 29 September 1966
   Design and Installation of Liquid Oxygen Systems in Aircraft, General Specification for

4. MIL-C-19803D; 18 January 1968
   Converter, Liquid Oxygen, 10 Liter, GCU-24A

5. MIL-V-25514C (USAF); 28 September 1965
   Valve, Oxygen Check, for 70-psi Oxygen Converters

6. MIL-V-25513A (ASG); 21 November 1956
   Valve, Oxygen Check, for 300-psi Oxygen Converters

7. MIL-I-81387 (AS); 18 July 1966
   Indicators, Liquid Oxygen Quantity

8. MIL-R-25410F; 15 January 1968
   Regulators, Oxygen, Diluter-Demand, Automatic-Pressure Breathing

9. MIL-O-23678A; 29 September 1966
   Oxygen Systems, Portable

10. MIL-H-22343A (AS); 16 January 1968
    Hose Assemblies, Metal, Liquid Oxygen

11. MIL-S-81018A (AS); 5 August 1966
    Survival Kit Container, Aircraft Seat, with Oxygen; General Specification for

12. MIL-O-27210D (ASG); 16 May 1969
    Oxygen, Aviator's Breathing, Liquid and Gas

13. MIL-T-27730A(ASG); 15 April 1964
    Tape, Antiseize, Polytetrafluoroethylene, with Dispenser

14. MIL-H-26626A; 1 April 1966
    Hose Assembly, Tetrafluoroethylene, Oxygen

15. MIL-C-25969A (USAF); 19 November 1959
Capsule Emergency Escape Systems General Requirements for

16. MIL-V-25961C (ASG); 21 June 1965 & Amend's 2 & 3
Valve, Fill-Buildup-Vent, Liquid Oxygen Converter, CRU-501A

17. MIL-V-9050D (ASG); 11 April 1968 & Amend 1
Valve, Oxygen, Pressure Relief, Aircraft

18. MIL-T-8506A; 14 December 1966
Tubing, Steel, Corrosion-Resistant, (304), Annealed, Seamless and Welded

19. MIL-V-7908A; 5 March 1965 & Amend 1
Valves, Check, Aircraft Low Pressure Oxygen Systems

20. MIL-H-7138D; 29 September 1966 & Amend 1
Hose Assemblies, Oxygen Breathing, Connector to Regulator

21. MIL-E-5272C (ASG); 13 April 1959 & Amend 1
Environmental Testing, Aeronautical and Associated Equipment, General Specification for

22. MIL-T-38170D (USAF); 26 April 1967 & Amend 3
Tank, Storage, Liquid Oxygen TMU-27/M

23. NAVWEPS 06-30-501; 1 August 1959
Handbook Field Handling of Liquid Breathing Oxygen

1. Technical Manual - NAVSHIPS 323-0049
   Liquid Oxygen Tank 150 Gallon Horizontal
   Model NALO-150S

2. Technical Manual - NAVSHIPS 323-0094
   Liquid Oxygen-Nitrogen Plant
   Model J6287

3. Technical Manual - NAVSHIPS 323-0055
   Shipboard Oxygen-Nitrogen Generating Plant
   Model LGSB 80-30

4. Technical Manual - NAVSHIPS 323-0095
   1500 Gallon Liquid Nitrogen/Oxygen Storage and Charging System
   Model RC-5

DRAWINGS

Diagram, "H-90613-504-4323961, Rev. A"
Aircraft Carrier CVA(N)68, Diagram of 0_2N_2 SYS Showing Hose Coverage on Flight Deck"
(Newport News H594-2732-41).

Diagram, "H-80064-800-2640670, Rev. B"
Attack Aircraft Carrier, CVAN68 Arrangement of Machinery, Forward and Aft, 0_2 and N_2 plant.

Diagram, Nav Ships No. ATS-1,545,2671412, Rev. B
Brooke Marine No. Ship No. 362.
Salvage Tug, ATS-1-Class, Diag. Arrangement of High Pressure Mixed Gas Systems

Nav Ships No. C-90613-504-4323960, Rev. A. Sheets 1-22.
Aircraft Carrier CVAN68, Diag. $0_2/N_2$ System, Notes, Tables and Materials.
Newport News. No. H594-2732-40.

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- 1385941, Sheets 1&2, "Fittings, Silver Brazed, WOG, for 3000 PSI Service".
- 1385943, Sheets 1&2, "Unions, Sil Brzg, 3000 PSI Service".
- 1385946, "Unions, Bronze, Silver Grazing, WOG".
- 1385950, "Bosses, Non-Ferrous Piping, 3000 PSI Service".
- 1385963, Sheets 1&2, "Fittings, Silver Brazing Ni-Al-Brz for 1500 & 3000 PSI".
- 1385846, Sheets 1-4, "Oxygen Systems, Submarines, Replenishment" Schematic Piping Diagram.
- 1385859, "Union, Bronze, Silver Brazing Alloy, low pressure service 800-1500 PSIG"

6. Hospital Oxygen Systems
by Dr. C. K. La Pinta, MSC
and Dr. R. A. Mahugh, Boeing

(a) Description

(b) Operational System Work Sheet

(c) Sketch

(d) Bibliography

OXYGEN SYSTEM
VETERANS ADMINISTRATION HOSPITAL
Houston, Texas
April 24, 1970

Oxygen is normally supplied from a liquid oxygen container in which the pressure is approximately 70 pounds per square inch. From the liquid container the oxygen line is connected to a duplex manifold assembly, to the other side of which is attached 14 each, 300 cu. ft. oxygen cylinders for standby reserve. The manifold arrangement consists of pressure regulators, gages, header valves and relief valves, adjusted in such a manner that oxygen is delivered to the distribution system at 60 pounds per square inch pressure. In the event the pressure should drop to 44 pounds, oxygen is admitted to the system from the reserve cylinders.

When the reserve system is activated as a result of a pressure drop to 44 pounds per square inch, an alarm is sounded in the admitting office and a warning light is activated. The alarm may be silenced, but the warning light will remain on until normal service is restored. In the event pressure should fall to approximately 39 pounds per square inch, an alarm is sounded in each ward and facility where oxygen is used. Simultaneously with the sounding of the alarm a red light is activated, indicating low pressure. In the event of complete loss of pressure another red light is activated, indicating oxygen failure. All of the above alarms may be silenced, but the lights will continue to glow until service is restored to normal.

The relief valve connected to an extension manifold assembly is asjusted to open at approximately 80 pounds per square inch.

The liquid oxygen storage/converter unit is supplied by the GSA contracted vendor. Currently, American Cryogenics (La Porte, Texas) has the contract to supply both liquid and gaseous oxygen as well as a 1,320-gallon LOX facility.

The storage/converter unit is of standard design and was built by the Cosmodyne Corporation (Torrance, Calif.). Construction is of type 304 stainless steel, anodized aluminum, bronze, and brass, with Teflon used as the valve packing material. All joints are either welded (preferred method), all metal fittings (e.g., swagelock), or flanged. Screw connections are avoided as are nonmetal seals. Valves, both relief and shut-off, are of hard-seat (brass or other copper alloy) design with Teflon stem packing. Cosmodyne depends heavily on aircraft and space hardware manufacturers for approved methods and materials recommendations.

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MILITARY AVIATION ☐
SUBMARINE ☐
AIRCRAFT CARRIER ☐
MSC CHAMBER ☐
HOSPITAL ☒

DATE 27 Apr 70

PRESENTER Dr. R. Mahugh
Dr. C.K. La Pinta

OPERATIONAL SYSTEM REVIEW WORK SHEET

Type of System(s) Lox 70 psi Lo Pressure Gox 60 psi Hi Pressure Gox 2200 psi

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SYSTEM DESIGN STANDARDS AND FEATURES

Type of Joints/Fittings – Tubing per Fed Spec WW-T-799 Silver Solder per Fed Spec QQ-S-561, Class 3 Screw joints made with a luting compound.

Operating Life & Level – No information given

Shelf Life/Age Life – No information given

Operating Environment & Limitations – No information given

Special or Unique Component Designs – CGA--D.I.S.S (Diameter Index Safety System) Connector No. 1240. Gages shall be U.L. listed for oxygen service.

Single Point Failures – No Protection (except alarm) beyond automatic reserve switch-over.

Static Electric Charge Precautions – System is all-metal, grounded

Electrical Interfaces – No internal (to oxygen) circuits, components cleaned and prepared for oxygen per cleaning procedure.

Ignition Source Control – Use low pressure (regulated), no rapid pressurization, system grounded, hoses made of conductive neoprene.

PROCESS CONTROL SPECIFICATIONS – Electrical Interface/Contamination Levels/Special Handling Requirements/Inspections.

Manufacture: NFPA 565 shall apply. All items cleaned with Na_2CO_3 or Na_3PO_4 (1 # to 3 gals. H_2O) Water rinsed, dried and packed especially for O_2 service. Tubing-same, with ends sealed with wooden plugs or soldered caps.

Service, Maintenance & Repair:

All work per NFPA 565.

LOX-GOX
TYPE OF SYSTEM

VA HOSPITAL
COMM., MIL., ETC.

DR. R. MAHUGH
DR. C. La Pinta
PRESENTER

PAGE 2 OF 4

OPERATIONAL SYSTEM REVIEW WORK SHEET – Continued

MANAGEMENT PROCESSES AND CONTROLS TO ENSURE SAFETY & RELIABILITY

FMEA, etc. – N.I.G.

Configuration Control(s) – All valves shall be 1/4 turn, of same manufacture andof similar design.

Certification/Recertifications – NONE

Testing/Retesting – Test piping with air at 200 psi or 1½ times (l.p.) working pressure--final test-24 hrs with O_2, no leaks.

Material Control (Procedure) – Specific use of non-ferrous metals, specs call for copper tubing per Fed Spec WW-T-561, class 3

Parts Control – Parts shall be supplied by a mfr of oxygen system components

TESTING

Philosophy: Acceptance test only - for leakage and delivery of approx. 99% O_2 at service outlets. All testing is with soap solution---no leaks are permitted.

Experience: N.I.G.

Operational Certification: N.I.G.

Test Failures: N.I.G.

SAFETY FEATURES

NFPA 565 shall apply

Relief Valves – on each cylinder or LOX **converter**; also on low pressure line, set to 1.5 times system pressure. Must re-seat after relief.

Burst Discs –

Redundancies – Multiple cylinders, check valve isolation for failure--at least two sources of supply at all times, **automatically** switched.

Over Design –

Electro Static Charge Control – Grounded system - hoses (low pressure) of conductive neoprene

Other – High pressure storage or bulk storage shall be located in a separate room or enclosure, per NFPA 566. Quantity and pressure alarm systems, per NFPA 565. All quick-disconnect couplings use C.G.A. D.I.S.S fittings.

LOX-GOX	VA Hospital	Dr. R. Mahugh Dr. C. K. La Pinta
TYPE OF SYSTEM	**COMM., MIL., ETC.**	**PRESENTER**

OPERATIONAL SYSTEM REVIEW WORK SHEET – Continued

OPERATIONAL FAILURE EXPERIENCE: No failures in 17 yrs. at Houston, Texas VA Hospital

---

MAJOR SUPPLIERS: Both storage tank/converter and LOX are on GSA contract. American Cryogenics is the current contractor. Storage vessel / converter unit is manufactured by Cosmodyne--uses gages, regulators, etc., from various manufacturers. Much of the hospital system components are supplied by National Cylinder Gas Co.

METALLIC MATERIALS: List Acceptable Materials Copper and copper alloys, cast bronze, aluminum on low pressure outlets, CRES on outlet boxes.

Pressure Range –

Temperature Range –

Design Considerations/Application Limitations –

Screening Tests –

Special Procedures –

Ignition Source Controls –

Failure Experience – No failures in 17 yrs. at the Houston, Texas VA Hospital

PAGE 4 OF 4

LOX-GOX	VA HOSPITAL	Dr. Mahugh Dr. La Pinta
TYPE OF SYSTEM	COMM., MIL., ETC.	PRESENTER

OPERATIONAL SYSTEM REVIEW WORK SHEET – Concluded

NONMETALLIC MATERIALS: List Acceptable Materials by Category or Use/Range

Class One, A, etc. Hi pressure System

1. Pressure Range – 150-3000 psi
2. Temperature Range – Ambient
3. Application Limitation – May use Teflon seats in valves---no oils or greases permitted
4. Screening Test(s) –
5. Special Procedure(s) –
6. Ignition Source Controls –

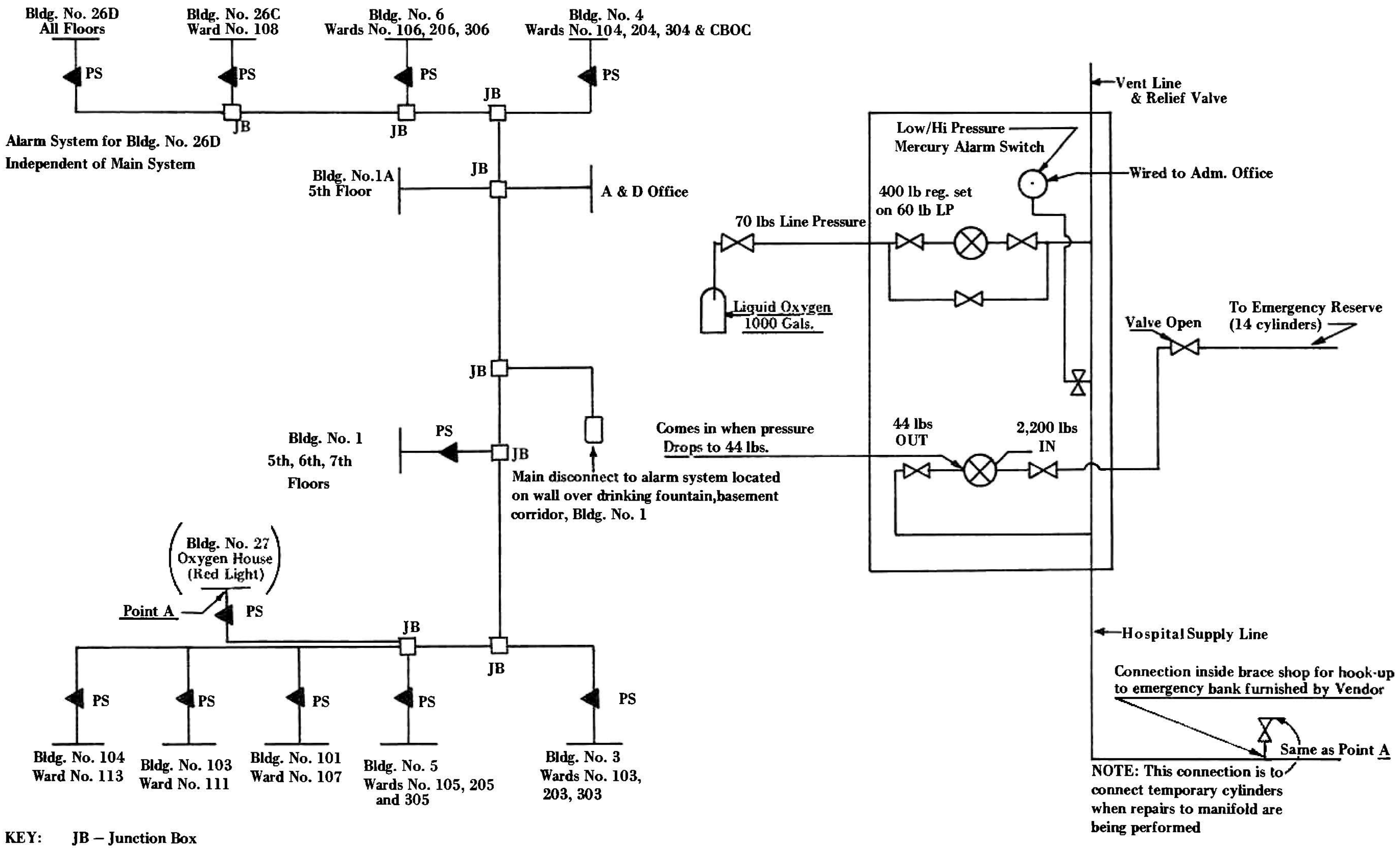
Class Two, B, etc.

1. Pressure Range – 50-150 psi
2. Temperature Range – ambient
3. Application Limitation – May use Teflon or neoprene seats in valves
4. Screening Test(s) –
5. Special Procedure(s) –
6. Ignition Source Controls –

Class Three, C, etc. Low pressure outlets and tents

1. Pressure Range – Up to 50 psi
2. Temperature Range – Ambient
3. Application Limitation – Tents of slow burning material, e.g., cellulose acetate
   Hoses of conductive neoprene
4. Screening Test(s) –
5. Special Procedure(s) –
6. Ignition Source Controls – No electrical devices, no hydrocarbon liquids or gases, signing to prohibit open flame or smoking

LIST OF NO-NO'S IN REGARDS TO MATERIALS

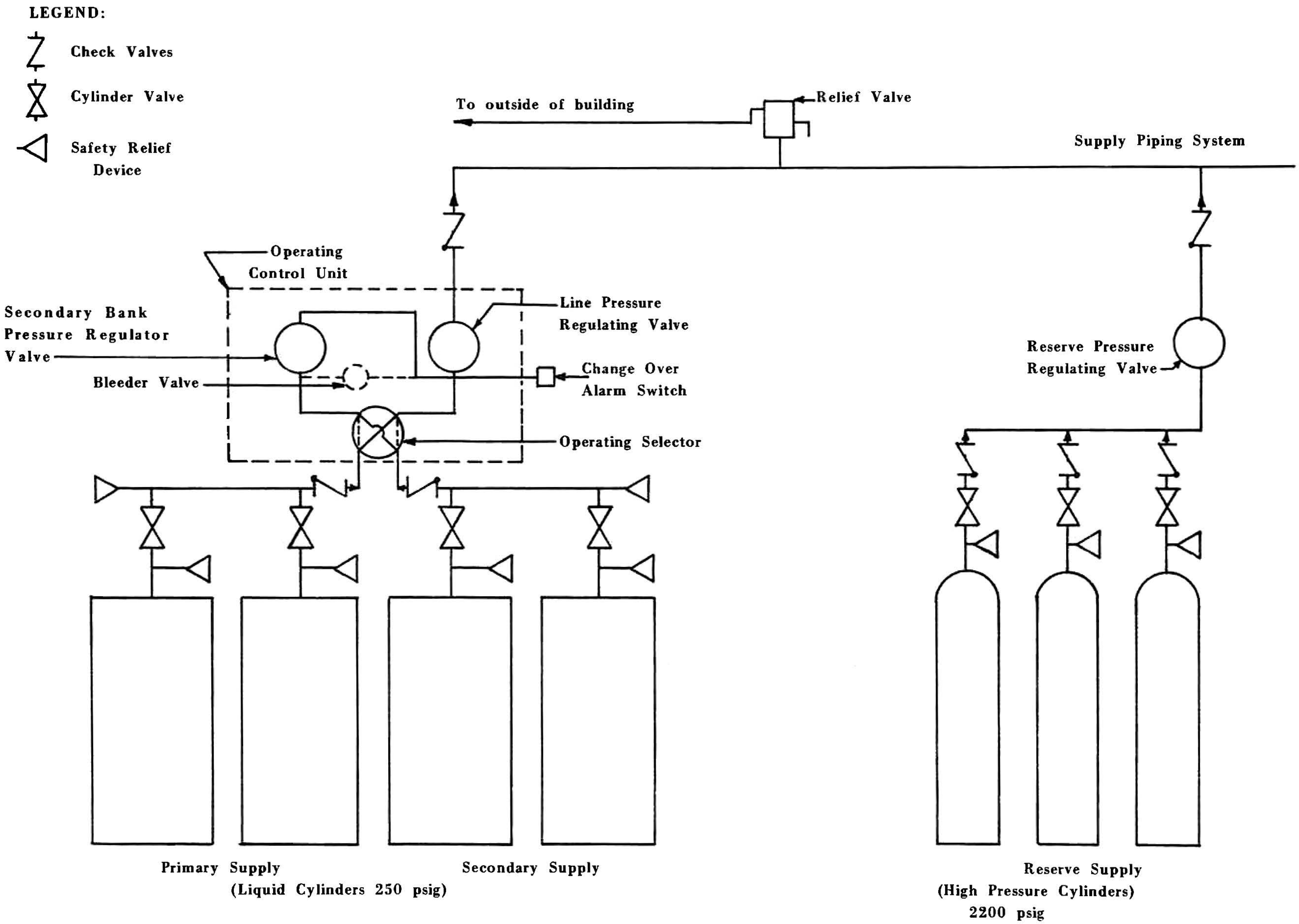


KEY:
JB – Junction Box
PS – Pressure Switch (Wired to alarms in areas where oxygen is used)

NOTE: Setting for all pressure switches – 45 psi

OXYGEN SUPPLY & ALARM SYSTEM AND OXYGEN SUPPLY CONTROL PANEL, BLDG. NO. 27

Veterans Administration Hospital, Houston, Texas



Operating Supply may consist of one or more supply units on each bank.

FIGURE 2.– TYPICAL OXYGEN CYLINDER SUPPLY SYSTEM WITH RESERVE SUPPLY

HOSPITAL DOCUMENTATION

1. Simple Schematic from Houston VA Hospital
2. National Fire Codes, National Fire Protection Association, Vol. 2, 1966-67
   Section 565-1 Nonflammable Medical Gas Systems
   Section 566-1 Bulk Oxygen Systems at Consumer Sites
3. Specifications 691R Hospital Oxygen System
   VA Bulletin, Section 311
4. Narrative of Houston VA Hospital Oxygen System

7. MSC Chamber

by W. H. Bush, MSC

(a) Description

(b) Operational System Work Sheet

(c) Sketch

(d) Bibliography

MSC - Chamber (11-ft. - Bldg. 7)

Description - Bldg. 7 Oxygen Supply and Distribution System and 11-ft. Chamber Open Loop Environmental Control System (OLECS)

The oxygen systems involved in the operations of the 11-ft. chamber will be divided into two major catagories for simplification of description. These are the (I) Bldg. 7 Oxygen Supply and Distribution System and (II) Open Loop ECS.

I. The Bldg. 7 oxygen distribution system is supplied by a high pressure (2,200 psi) gaseous tube trailer as primary, 50,000 cu. ft. capacity, with a 3,750 cu. ft. K bottle secondary bank. The secondary is used in event of component failures or primary supply depletion. The primary oxygen is supplied through high flow regulators in the Bldg. 7 distribution system at a nominal pressure of 100 psi. The primary and secondary systems are plumbed through an automatic source switch-over system, activated by redundant electronic pressure switches, to the chamber and occupants. There are safety relief valves and burst disks on each individual line segment and regulators to provide and insure described working pressure. There is approximately 1,500 cu. ft. of high pressure oxygen (2,200 psi) available at the chamber from an independent K bottle source.

II. The 11-ft. chamber Open Loop Environment Control System (OLECS) is designed to provide an open loop flow of 100% oxygen between 6 and 12 ACFM for each of two space suited test subjects in the chamber at absolute pressures between 3.7 and 21 psia. This system will maintain space suit pressures from a few inches of water above, to 3.7 psi above chamber pressure. The chamber can be evacuated to a few microns of mercury. The open loop gas is discharged into a separate vacuum system. The oxygen flow is used for both breathing and the removal of metabolic heat generated by the suited subjects. The OLECS is supplied by the 100 psig oxygen from the Bldg. 7 oxygen distribution (I) system. In event of a system malfunction 95 psi O_2 is supplied across a limiting orifice to supply 12 ACFM to the suit, also barostats sensing suit pressure will automatically repressurize the chamber to a safe level in the event of a suit pressure failure.

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MSC CHAMBER ☒
HOSPITAL ☐

DATE 4-29-70

PRESENTER L. O. Casey

OPERATIONAL SYSTEM REVIEW WORK SHEET

Type of System(s) Lox ____ Lo Pressure Gox X Hi Pressure Gox X

0-100 psig 0-2200 psig

SYSTEM DESIGN STANDARDS AND FEATURES

Type of Joints/Fittings — V threaded, welded, & flared. Permanent larger joints welded. Small tubing flared.

Operating Life & Level — Permanent facility with scheduled and unscheduled maintenance capability. Can operate nearly continuously.

Shelf Life/Age Life — Replace components when they fail only - routine checkout procedures identify failures.

Operating Environment & Limitations — Normal laboratory building environments in regards to temperature & humidity. Relative clean and vibration free.

Special or Unique Component Designs — None - off the shelf commercial equipment used through out the system

Single Point Failures No credible (not considering structural & wire breakage) single point failures allowed by failure modes and effects

Static Electric Charge Precautions — Building grounded and system tied to ground. Ground GOX trailer prior to connection to.

Electrical Interfaces — None other than crew compartments or space suit interiors

Ignition Source Control — Dynamic system analysis, nonmetallic material usage location review & control. Electrical component minimization and fusing of all wires. Hermetically seal electronics.

PROCESS CONTROL SPECIFICATIONS — Electrical Interface/Contamination Levels/Special Handling Requirements/Inspections.

Manufacture: Electrical: Fusing each wire, wire sizing, teflon insulation, potting hermetically sealing electronic circuits, grounding. No switching, no motors, etc.
Nonmetallic Materials: Selecting & screening, covering, testing. Cleaning & Sampling:
Service, Maintenance & Repair: Inspect all work; control all work on configuration and quality documents, periodically system cleanliness is sampled and certified. Quality and cleanliness of all oxygen and connections is maintained.

GOX	MSC Chamber	L. O. Casey
TYPE OF SYSTEM	COMM., MIL., ETC.	PRESENTER

OPERATIONAL SYSTEM REVIEW WORK SHEET – Continued

MANAGEMENT PROCESSES AND CONTROLS TO ENSURE SAFETY & RELIABILITY

FMEA, etc. – Formal analysis per written FMEA procedures. No single point failures allowed.

Configuration Control(s) – Work, documentation & materials are all controlled and inspected to show current status and instruction adherence.

Certification/Recertifications – Certified as an operating system by periodic testing in all modes. Recertified operational prior to each manned test by written checklists

Testing/Retesting –

Material Control (Procedure) – All nonmetallic materials are selected, per established criteria

Parts Control – Procurement inspection for nonmetallic material compliance. Control of quality of oxygen (batch sampling).

TESTING

Philosophy: Test system in all modes to insure workability. Overpressure to 1.5 operating pressure and determine leaks.

Experience: No major problems. Sections of 100 psi header made of copper was very difficult to make leak tight.

Operational Certification: Operational readiness inspection and manned test readiness review boards.

Test Failures: None significant.

SAFETY FEATURES

Relief Valves – On each individual line segment

Burst Discs – In series with relief valves to eliminate single point failures

Redundancies – Supplies, regulators, & check valves where a single item would create a single point failure

Over Design – ASME code

Electro Static Charge Control – Grounding of system and supply trailers

Other – All overpressure reliefs are vented out of the building

GOX	MSC Chamber	L. O. Casey
TYPE OF SYSTEM	**COMM., MIL., ETC.**	**PRESENTER**

OPERATIONAL SYSTEM REVIEW WORK SHEET – Continued

OPERATIONAL FAILURE EXPERIENCE:

None of a catastrophic nature.

Miscellaneous components fail from time to time due to wear. None have occurred while system was in use. All failures are picked up in pretest system verifications. No fire or explosive type failures have been recorded.

MAJOR SUPPLIERS:

Jamesbury, Victor, Rego, Hoke, Whitey

METALLIC MATERIALS: List Acceptable Materials

All applications are generally within room or habitat environments with pressure limited

Pressure Range – to 2,500 psi. (This applies to all items below.)

Temperature Range –

Design Considerations/Application Limitations –

Screening Tests –

Special Procedures –

Ignition Source Controls –

Failure Experience –

Stainless steel is chosen for all high pressure applications. Stainless steel is also desired for for all low pressure (115 to 20 psia) applications, although copper is used occasionally and is acceptable. Aluminum is used in applications below 20 psia. Metallic materials are chosen so as to prevent galvanic action and sized structurally to ASME code. (This applies to all items listed above.)

GOX	MSC Chambers	L. O. Casey
TYPE OF SYSTEM	**COMM., MIL., ETC.**	**PRESENTER**

OPERATIONAL SYSTEM REVIEW WORK SHEET – Concluded

NONMETALLIC MATERIALS: List Acceptable Materials by Category or Use/Range

Class ~~One~~ A Crew Compartments or suit interiors

1. Pressure Range – 0-20 psia
2. Temperature Range – $0-100^{\circ}$ F.
3. Application Limitation –
4. Screening Test(s) – Flame impingement and flame propogation
5. Special Procedure(s) – 100% water spray available on all exposed surfaces
6. Ignition Source Controls – All wires fused at 1¼ of rated load, wires Teflon insulated and limited to 500 cir-mil/amp hermetical.

(Teflon
(Beta
(PBI Webbing
(Silicon Rubber
(Nylon (Limited)
(Asbestos

Class ~~Two~~ B High Pressure

1. Pressure Range – 100 - 2,200 psi
2. Temperature Range – Room temp.
3. Application Limitation – Each use is examined
4. Screening Test(s) – MSC STD
5. Special Procedure(s) – Routine cleaning
6. Ignition Source Controls – No electrical interfaces--slow opening valves

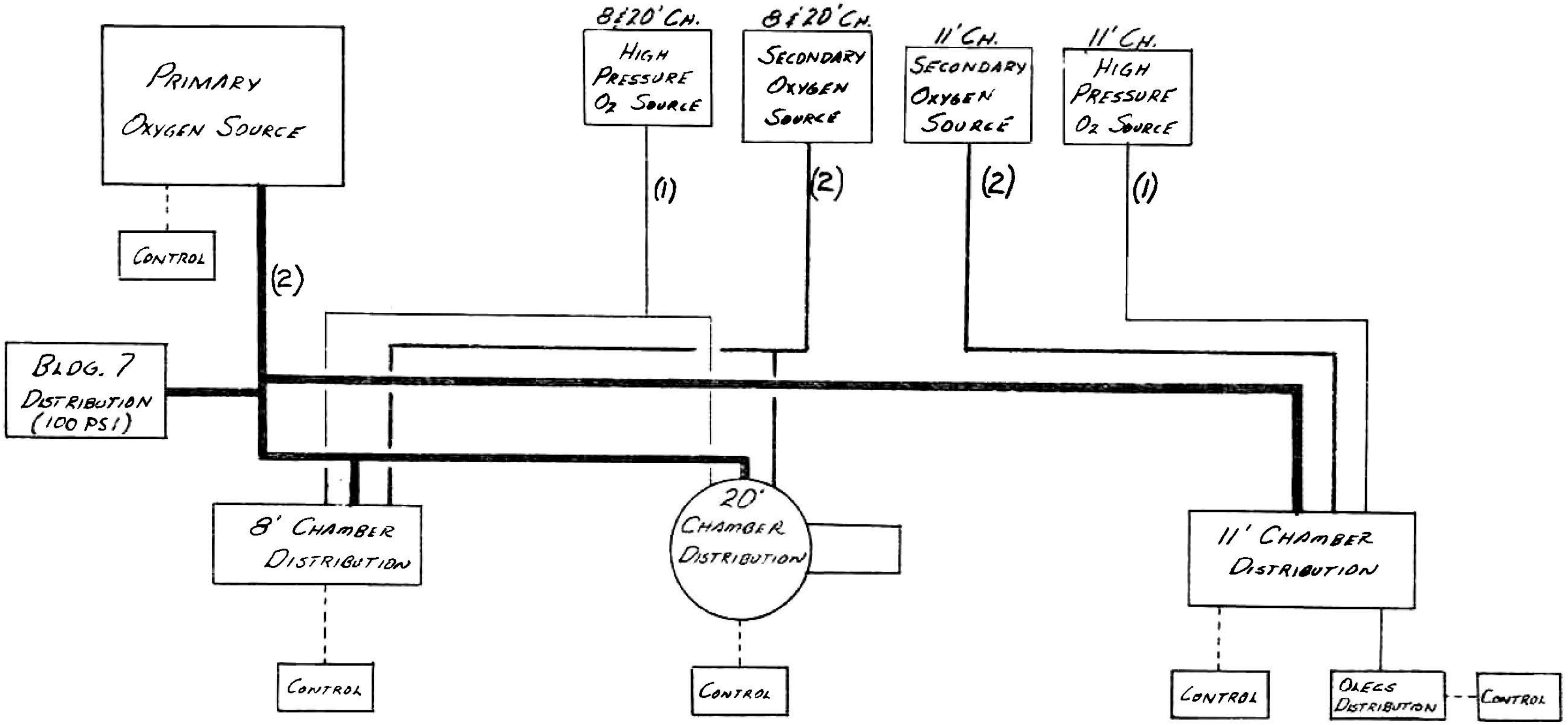
(Teflon
(Viton
(Nylon (Limited

Class ~~Three~~ C. Low Pressure

1. Pressure Range – Below 100.0
2. Temperature Range – Room temp.
3. Application Limitation – Each use is examined
4. Screening Test(s) – MSC STD
5. Special Procedure(s) – Routine cleaning
6. Ignition Source Controls – No electrical interfaces

(Teflon
(Viton
(Kel-F
(some neoprene

LIST OF NO-NO'S IN REGARDS TO MATERIALS Iron, oil



MSC

(1) HIGH PRESSURE - 2200 PSI
(2) NOMINAL PRESSURE - 100 PSI

NOTE: (A) ALL SUPPLIES ARE GASEOUS AT 2200 PSI
(B.)

SIGNATURES	DATE
	4-28-70
AUTH	4-28-70

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
MANNED SPACECRAFT CENTER · HOUSTON, TEXAS

BLOCK DIAGRAM
BLDG. 7 OXYGEN SYSTEM

CODE IDENT NO.	SIZE	DWG NO.
21356	A	SKE-BRN-0004
SCALE None		SHEET 1 of 1

MSC Form 1616 A (REV OCT 65)

MSC 11-Ft. Chamber Oxygen System Documentation

1. STB-SOPM 5.2.2 Cleanliness Spec. For Precision Cleaning
2. STB-F-037 - 11-ft. Chamber O_2 System Checkout Procedure
3. STB-F-047 - 11-ft. Chamber Suit Engineering O_2 and Overpress. Relief System Checkout Procedure
4. STB-F-053 - FMEA O_2 Source and Dist. System, Bldg. 7
5. STB-F-032 - FMEA O_2 Source and Dist. System, 11-ft. chamber
6. STB-SOPM 6.9 - Nonmetallic Material Program for STB
7. PMTO - ME-A-450 - Maintenance task on O_2 system
8. PMTO - ME-A-440 - Maintenance task on O_2 system
9. FMU-5 - 11-ft. Chamber O_2 system pretest checklist
10. FMU-6 - 11-ft. Chamber O_2 system posttest checklist
11. STB-F-064 - OLECS Operation Manual
12. STB-F-058 - FMEA - 11 ft. chamber OLECS
13. STB-SOPM 5.7.1 - Electrical Guidelines and Design Criteria for O_2 rich environments
14. PMU-16 - 11 ft. chamber OLECS pretest and checklist
15. PMU-17 - 11-ft. chamber OLECS posttest checklist
16. NAS-TO-03-0764-EC11 - R&D "Engineering Analysis for Oxygen Compatibility of Materials Use In The PLSS Test Console, 8-ft. Chamber, and 20-ft. Chamber Oxygen Manifold."

B. CRITERIA AND STANDARDS REVIEW

by John Conlon and J. H. Kimzey, MSC

Specifications and Standards

A listing of specifications and standards for oxygen has been prepared and is enclosed as Appendix A. This list includes those that are used by the Manned Spacecraft Center for its own facilities and those proscribed for contractors' use in building spacecraft.

It is noted that thousands of specifications exist and the list, therefore, is not intended to be complete. It is however, a listing of the major documents from which others are referenced, except that many contractors such as North American-Rockwell, Grumman, McDonnell-Douglas, Martin, Boeing, and others have their own in-house documents which are prepared for their procurement and shop use and include, in some cases, proprietary data and techniques.

There are many manufacturers and suppliers of spacecraft components. The Beech Aircraft Company, for example, makes cryogenic vessels under contract to North American-Rockwell. They, in turn, buy parts such as motors from the Globe Co. No attempt has been made to obtain identification of all the specifications involved, much less copies of these documents.

Categories of specifications include the raw material, design and fabrication, cleaning, labeling, assembly, packaging, and environmental test requirements. There are also specifications on assembly areas, such as clean rooms, clothing worn by operators, and test equipment to describe screening procedures to enable a new material to be included, as appropriate.

Another category of standards specifically excluded from Appendix A is those prepared by organizations; such as, the Society of Automotive Engineers, Inc., (for example, Aerospace Standard "Minimum Standards for Valve High Pressure Oxygen, Cylinder Shut-Off, Manually Operated AS1066"), and other professional groups.

Despite the many standards and specifications reviewed by this panel, it has become obvious that a void exists in several areas. One area of major concern is the apparent lack of sufficient detail on nonmetallic materials and their application for high pressure oxygen systems to enable a designer to select the proper material for his system.

The reason for this is that a comprehensive test program has yet to be defined and accomplished. Although some work has been started in this area, it appears that the required effort is a major one and should begin with developing a standard approach to the problem on the part of both Government and industry so that all data developed can ultimately be universally used without the requirements for interpolating test results from a many faceted approach.

The second area of concern is that no standards and/or specifications appear to exist on a total system which points out the hazards resulting from misapplication of a component which may serve its function well in some applications, but may be trigger mechanism of disaster in another application.

The NASA attempts to do these kinds of analyses in their required hazards and system safety analysis. This effort undoubtedly has served the NASA well, but these type analyses are not the generally accepted practice of industry since we have been unable to find documentation to indicate that this practice exists during any of the panels work.

S/C and GFE-O_2 System Related Specifications

1. MSC-NA-D-68-1(F), Nonmetallic Materials Design Guidelines and Test Data Handbook, 11/26/69

2. MSC-SPEC-C-11, Precision Cleaning Specification for

3. MSC-SPEC-C-6B, Apollo S/C Fluid Cleanliness Specification for

4. MSC-SPEC-C-7, Apollo S/C Fluid Systems Surface Cleanliness, Specification for

5. MSC-SPEC-C-9, Cleanliness of Non-airborne Breathing Systems, Specification for

6. MSC-SPEC-C-15, Pressure Garment Assembly, Specification for

7. MSC-SPEC-C-27, Apollo EMO Cleanliness, Specification for Fluid Specifications used for Procurement of O_2

8. MIL-O-27210C, Oxygen, Aviator's Breathing, Liquid + Gas Specification, Specification for

9. MSFC-SPEC-399, Gaseous and Liquid Oxygen

10. MSC-PD-D-67-13, Apollo Spacecraft Nonmetallic Materials Requirements

11. Spec No. 4046-1, Pressure Vessel Specification - Testing and Cleaning of Pressure Vessels Valves, Fittings, and Piping June 14, 1966

12. MSC-SPEC-C-11A, Precision Cleaning, Specification for

13. TTA SPEC 01, Cleaning Requirements for Oxygen and Hydrogen Systems, July 6, 1965

14. MSFC SPEC 164, Amendment 4, Cleanliness of Components For Use In Oxygen Fuel and Pneumatic Systems

Contractor Specifications

Grumman

15. GAC LSP-14-0011B, Surface Cleanliness Levels, General Specification for

North American

16. MAO 610-017, Precision Cleaning Methods and Cleanliness Requirements For Parts and Assemblies of Apollo Fluid Systems

17. MA 0110-018, Cleaning Components of Propellant, Pressurizing and Circulating Systems, 1/17/64

18. MA 0115-005, Testing Compatability of Materials For Liquid Oxygen Systems, 2/12/64

19. MB0110-011, Oxygen, Liquid and Gas, 10/16/64

MSC FLIGHT SAFETY INFORMATION BULLETIN

SUBJECT	NO.
Titanium in Contact with Anhydrous Methanol or Methanol-Freon Mixtures	3-1
Use of Breathing Oxygen as a Pressure Source	6-3
Stress Reduction of 4340 Steel Exposed to Ammonium Fluorocoborate	18-2
Explosion Hazard - Metals/Halogenated Hydrocarbons	18-3
Use of Nonmetallic Materials in the Presence of Medium to High Pressure Gaseous Oxygen	19-2
Lubricants Composed of Chloro-Fluoro Chemical Bonds in the Presence of Aluminum and/or Magnesium	19-3
Corrosion of Aluminum Alloys By Solvent Mixtures of Methanol and Trichlorotrifluoroethane	19-4

MSC DESIGN STANDARDS BULLETIN

TITLE	NO.
Systems Accessibility for Maintenance	DS-1
Separation of Redundant Paths	DS-4
Systems Checkout Provisions	DS-7
Flow Restriction Requirements - Pressurized Sources	DS-17
Titanium or its Alloys - Prohibited Use With Oxygen	DS-26
Service Points - Positive Protection From Interchangeability of Fluid Service Lines	DS-30
Service Points - Fluid Systems	DS-35
Fluid Systems - Design for Flushing	DS-38
Fluid Lines - Separation Provisions	DS-42
Capping of Servicing and Test Ports Which Are Not Required To Function In Flight	DS-47
Fluid Line Components Whose Function Is Dependent On Direction of Flow-Protecttion Against Incorrect Installation	DS-49
Threaded Fittings - Restriction On Release Of Particles and Foreign Material	DS-62
Metals and Metal Couples - Restriction on Use	DS-63
Fluid Supplies - Verification Tests	DS-71
Protection of Pressurized Systems From Damage Due To Pressurant Depletion - Ground Support Equipment	DS-77
Cabin Pressure - Venting Restriction	DS-78
Pressure-Sensor Line Installation	PS-1
Control of Time - Sensitive Components	PS-2
Cleanliness of Flowing Fluids and Associated Systems	PS-3
Procurement Document Identification for Manned Space Flight Vehicle Items	PS-4, Rev. B
Brazed Joints - Identification Marks	PS-7
Non-Destructive Testing - Radiographic Inspection of Brazed Joints	PS-12

Toxicity - Requirements for Nonmetallic Materials Proposed For Use Within Crew Compartments	PS-14
Pressure Relief Valves - Standardization of Functional Test	PS-17
Protection for Tubing, Fittings, and Fluid System Components- Flight Hardware and Associated Equipment	PS-18
Fluid System Cleanliness - Verification in Draining, Purging, and Flushing Operations	PS-19
Fluid Systems - Flushing Requirements	PS-22
Equipment Failure and Replacement - Verification of Flight Readiness	PS-25
Leak Detectors - Wetting Agents	PS-36
Pressure Vessel Material - Stress Corrosion	PS-38, Rev. A
Pressure Vessels - Qualification Tests	PS-39
Fluid Systems - Review of Cleaning, Flushing, and Purging Procedures	PS-42
Purge Gases - Temperature and Humidity Requirements	PS-43

C. Oxygen Specifications Comparison

VII. APPENDIX:

C. Oxygen Specifications Comparison

Four specifications used to procure oxygen for various uses were compared to determine the relative requirements. These specifications and priority requirements are shown on table II . From this date the following observations can be made.

1. The specification used is procuring oxygen for the (Grade A MSC - Spec-C-6B) Apollo command module fuel cells has the most stringent purity requirement of the specifications reviewed. This high priority requirement is required to insure proper fuel cell operation; however compliance with these requirements greatly reduces the hazards associated with oxygen contamination.

2. The grade B oxygen MSC-Spec-C-6B is used in the lunar module or for other non fuel cell uses. It compares very close to the oxygen used for aviator breathing oxygen.

3. Specification BB-O-9252 is used for procuring oxygen for industrial uses and does not contain requirement for trace contaminate levels other than an odor test.

TABLE II - Oxygen Specification Requirements

Characteristic	S/C Fuel Cell O_2 Grade A (MSC-SPEC-C-6B)	S/C Breathing O_2 Grade B (MSC-SPEC-C-6B)	*Aviator's Breathing O_2 (MIL-O-27210D) Type I (Gas)	*Aviator's Breathing O_2 (MIL-O-27210D) Type II (Liq.)	**Aviator's Breathing O_2 (MIL-O-27210C)	Commerical O_2 BB-O-925a
Purity	99.995 percent by Vol. Min.	99.60 percent by Vol. Min.	99.5 percent by Vol. Min.	99.5 percent by Vol. Min.***	99.5 percent by Vol. Min.	99.5 percent by Vol.
Methane	10 ppm	25 ppm	50 ppm	25 ppm	25 ppm	
Ethane	2 ppm	2 ppm				
Propane	1 ppm (Higher Hydrocarbons as Propane)	1 ppm				
Alkyne Hydrocarbons	0.05 ppm (As Acetylene)	0.05 ppm (As Acetylene)	0.10 ppm (As Acetylene)	0.05 ppm (As Acetylene)	0.05 ppm (As Acetylene)	
Total Hydrocarbons	14.0 ppm (As Methane)	29.0 ppm (As Methane)	6 ppm for ethane and others	3 ppm for ethane and others	3 ppm for ethane and others	
Moisture	3.0 ppm	3.0 ppm	0.005 mg H_2O/liter (Approx. 7 ppm)	0.005 mg H_2O/liter (Approx. 7 ppm)	Same as Type I and II	
Nitros Oxide (N_2O)	1.0 ppm	1.0 ppm	2.0 ppm	1.0 ppm	1.0 ppm	
Halogenated Hydrocarbone	1.0 ppm	1.0 ppm	2.0 ppm As Freons 0.2 ppm as Solvent	1.0 ppm as Fresons 0.0 ppm as Solvent	1.0 ppm as Freons 0.1 ppm as Solvent	
Odor	None	None.	None	None	None	None
Ethylene (C_2H_4)			0.4 ppm	0.2 ppm	0.2 ppm	
CO and CO_2	1 ppm total	5.0 ppm CO 5.0 ppm CO_2	10 ppm CO_2	5.0 ppm CO_2	5.0 ppm CO_2	

* MIL-O-27210D - dated May 16, 1969

** MIL-O-27210C - dated June 22, 1966

*** As Gas

As Refrigerants

D. OXYGEN SYSTEM FAILURE EXPERIENCE SURVEY

by Meyer Cook, MSC R&QA (GE)

A LITERATURE SURVEY OF REPORTS OF UNEXPECTED INCIDENTS IN THE PRESENCE OF OXYGEN AT CONCENTRATIONS AND PRESSURES HIGHER THAN THAT OF THE NORMAL ATMOSPHERE

MSC R&QA

MAY 14, 1970

Meyer Cook

Meyer Cook
MSC R&QA (GE)

DOCUMENT SUMMARY

Oxygen Bottle Explosion
Title

McDonnell-Douglas Aircraft Company, Inc., MP10, 171 McD/D Co.
Source

J. O. Weber, C. A. Seil
Author

January 17, 1956
Date

SUMMARY Code 4(D) (B)

Full cause of explosion and fire not determined because too much damage was done to leave enough equipment to examine. Cause attributed to litharge-glycerol cement in the cylinder.

Oxygen/1800 psi
Gas Constituents/Pressure

Aircraft oxygen breathing equipment
Equipment

Property damage
Nature of Damage/Injuries

Key Words

oxygen litharge glycerol cement materials
explosion fire property damage

DOCUMENT SUMMARY

Aircraft Fire
Title

NFPA 53M #3265 P27
Source

NA
Author

1969 Edition
Date

SUMMARY Code 4D

Fire started while crew's oxygen system was preflight checked. Cause not stated.

Oxygen Pressure bottles and ambient
Gas Constituents/Pressure

707 Aircraft
Equipment

Property Damage
Nature of Damage/Injuries

Key Words

Oxygen Fire Unknown origin Property Damage

DOCUMENT SUMMARY

Oxygen Supply System Mishaps (Letter)
Title

Dept. of the Air Force Letter, AFIAS-F3
Source

Lt. Col. Paul A. Bergerot, USAF
Author

April 24, 1970
Date

SUMMARY Code 4C

Serviceman used improper procedure which resulted in an explosion when the oxygen system pressure relief was compromised.

Oxygen 800 PSI
Gas Constituents/Pressure

T33A Aircraft Oxygen System
Equipment

$122,810 property damage (aircraft damage)
Nature of Damage/Injuries

Key Words

oxygen pressure relief procedure explosion fire property damage

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DOCUMENT SUMMARY

Oxygen Supply System Mishaps (Ltr)
Title

Dept. of the Air Force Letter, AFIAS-F3
Source

Lt. Col. Paul A. Bergerot, USAF
Author

April 24, 1970
Date

SUMMARY Code 4D

Explosion in oxygen service cart - cause not determined - still under investigation.

Oxygen 425 PSI
Gas Constituents/Pressure

T37 Aircraft
Equipment

Injuries Property damage
Nature of Damage/Injuries

Key Words

Oxygen leak explosion fire injuries property damage

I. Summary

A limited survey has been made of the available literature of unexpected occurrences (incidents) involving oxygen at concentrations and pressures higher than that in a normal atmosphere of 14.7 pounds per square inch.

The results of the survey are reported herein, covering 44 separate incidents. Twenty-three of the incidents occurred in the presence of 100% oxygen at greater than 14.7 PSI pressure. Of these:

- 3 were caused by equipment failures
- 13 were caused by the presence of noncompatible materials
- 1 was caused by failure of personnel to observe procedures and/or precautions
- 2 had unknown causes or were still under investigation as of the date of the report
- 2 were attributed to accident
- 2 were the result of the presence of 100% oxygen without the knowledge of the participants.

About half of the foregoing were attributed to multiple causes.

A tabulation of the causes of incidents are shown in Table II, and an individual summary of each incident is contained in Section V.

NOTE: Categories above are as used in the original reports.

II. Introduction

The purpose of this survey was to classify and summarize incidents such as fires and explosions which occurred in the presence of a combination of 100% oxygen and a pressure of approximately one atmosphere (14.7 pounds per square inch) or greater. The literature available for this survey consisted of documents and reports from the NASA Manned Spacecraft Center Library, plus additional documents and information obtained from several information services. (See Section IV)

III. Discussion

During the initial screening search of the library and information services listed in Section IV, document titles, and summaries where possible, were examined. In the search, the key words "oxygen," "fire," "explosion," "property damage," "injuries," and the phrase "pressure greater than atmospheric" were used as search criteria. This search yielded a total of 250 incidents; upon further examination, it was found that only 44 incidents occurred at initial pressures greater than one atmosphere in the presence of 100% oxygen or where the heavy oxygen concentration seemed to be the controlling factor. These 44 incidents have been categorized in Table II, and each incident is further identified and described in Section V.

The coding used in Table II is shown in Table I below.

TABLE I - Explanation of Coding Used in Table II

Cause of Incident

A. Equipment Failure

B. Presence of Flammable Contaminants

C. Failure of personnel to observe procedures/precautions

D. Causes unknown (or unresolved - still being investigated as of the date of the document or incident report)

E. Accident

F. Participants did not know oxygen was present

TABLE II - Tabulation of Causes of Incidents

Location of Incident or Type of Surroundings	Cause of Incidents		
	100% Oxygen	Oxygen + Inert Gasses	Oxygen + Active Fluids
1. Space Vehicles (including Ground Support Equipment)	A (1)		
2. Missiles (including Ground Support Equipment)	A (1) B (1) C (1)	A (1)	A (1)
3. Laboratories/Test Chambers	B (4) D (1)	A (1) F (1)	A (1)
4. Aircraft (including Ground Support Equipment)	B (3) D (3) E (1)	C (3) E (1)	E (1)
5. Medical (Hospitals, Hyperbaric Chambers, Etc.)	B (1) F (1)		
6. Industrial (Welding, Transportation, Etc.)	A (6) B (4) C (1) D (2) E (1) F (2)		
TOTAL	34*	7	3

* Eleven of the 34 were mixed high/low pressure.

NOTES: See Table II for explanation of categories A, B, etc.
Numbers in parentheses show total number of incidents in that category.

IV. Sources of Documentation and Reports

(1) NASA MSC Industrial Safety Office

(2) NASA MSC R&QA Technical Retrieval Information Service (General Electric)

(3) U. S. Department of the Interior, Bureau of Mines

(4) U. S. Navy

(5) NASA MSC Technical Library Bibliography Service

(6) The Boeing Company Technical Bibliography Service

(7) The Martin Marietta Company (Denver) Bibliography Service

(8) IDEP (Interagency Data Exchange Program)

(9) U. S. Air Force

(10) Douglas Aircraft Company, Inc.

V. Summaries of Individual Incidents

The following 11 pages are summaries of the 44 incidents which form the basis of this report. Four incident summaries appear on each page.

The code classifications used on the summary sheets are the same as those used in Table II.

DOCUMENT SUMMARY

Spacecraft Command Module Fire
Title

NFPA 53M #3253 P22
Source

NA
Author

1969 Edition
Date

SUMMARY Code 1A

Summary of Apollo SC 204 fire.

Oxygen 16 PSI
Gas Constituents/Pressure

Spacecraft
Equipment

Three fatalities
Nature of Damage/Injuries

Key Words

oxygen spacecraft 16 PSI 3 fatalities fire

DOCUMENT SUMMARY

Titan Missile & Silo Accident
Title

NFPA 53M Page 21 #3250
Source

NA
Author

1969 Edition
Date

SUMMARY Code 2A

Liquid Oxygen line leak caused oxygen enriched atmosphere to support rapid combustion after a spark ignited combustibles.

LOX
Gas Constituents/Pressure

Titan Missile in a Launch Silo
Equipment

$7,186,000.00 property loss
Nature of Damage/Injuries

Key Words

Oxygen	Missile	Silo	Titan
Leak	Line	Spark	Combustibles
Property loss			

DOCUMENT SUMMARY

Oxygen Supply System Mishaps (Letter)
Title

Dept. of the Air Force Letter, AFIAS-F3
Source

Lt. Col. Paul A. Bergerot, USAF
Author

April 24, 1970
Date

SUMMARY Code 2B

Hydrocarbon contaminants inside filter case adjudged cause of explosion. Probably through:

1. Wicking through flange gaskets.
2. Contamination of vent plugs during maintenance.
3. Contaminated LOX supply

LOX ?
Gas Constituents/Pressure

SM-65 F Missile (L15 Filter)
Equipment

Silo & Missile destroyed
Nature of damabe/injuries

$10,300,000 damage
Nature of Damage/Injuries

Key Words

LOX
SM-65F
Missile
L-15
Filter
No fatalities
Property damage

DOCUMENT SUMMARY

Oxygen Supply System Mishaps (Letter)
Title

Dept. of the Air Force Letter, AFIAS-F3
Source

Lt. Col. Paul A. Bergerot, USAF
Author

April 24, 1970
Date

SUMMARY Code 2A

Most probable cause of failure was combination of faulty welds and misdrilled holes in fuel passageway plate. Overstress caused rupture permitting premature mixing of fuel and oxidizer.

O_2 Fuel ?
Gas Constituents/Pressure

COM-10A Missile
Equipment

Injector assembly

$2,026.17 property damage
Nature of Damage/Injuries

Key Words

Weld Fracture
Misdrilled Holes
Injector Plate
Manufacturing Fault
Weld Embrittlement

DOCUMENT SUMMARY

Oxygen Supply System Mishaps (Letter)
Title

Dept. of the Air Force Letter AFIAS -F3
Source

Lt. Col. Paul A. Bergerot, USAF
Author

April 24, 1970
Date

SUMMARY Code 2C

Deviation from Technical order checklist allowed the boil-off valve to remain closed for an extended period of time. "LOX Growth" occurred, oxygen boil-off followed and fire and explosions resulted

LOX 29.5 PSI
Gas Constituents/Pressure

HGM-16F Missile
Equipment

$11,500,000 property damage
Nature of Damage/Injuries

Key Words

Oxygen boil-off valve checklist procedures LOX-growth fire
explosion property damage

DOCUMENT SUMMARY

Final Report of the WSTF Fire Investigation Board Altitude Simulation System LOX Pump Number One at NASA White Sands Test Facility on December 11, 1968
Title

NASA/ MSC, WSTF, Code SC
Source

B. C. Ingels, K. B. Gilbreath, J. A. Mathis
Author

12 December 1968
Date

SUMMARY Code 3B

Accident attributed to use of valves having materials in-compatible with pure Oxygen atmospheres.

LOX 980 PSIG Maximum
Gas Constituents/Pressure

LOX Pump driven by 250 HP Motor
Equipment

No Injury Estimated $17,300.00 Property damage
Nature of Damage/Injuries

Key Words

LOX Buna-Rubber Particle Fire
Explosion Valve Material Incompatible
Oxygen

DOCUMENT SUMMARY

Decompression Chamber Fire
Title

NFPA 53M #3257 P24
Source

NA
Author

1969 Edition
Date

SUMMARY Code 3A

Portable CO_2 scrubber single-phased, overheating line cord, causing ignition.

Oxygen/Helium/Nitrogen 40 PSIG
Gas Constituents/Pressure

Decompression Chamber
Equipment

2 fatalities, 2 injuries, $20,000 property damag
Nature of Damage/Injuries

Key Words

Oxygen helium nitrogen decompression chamber scrubber single-phase
motor overheated line cord fire 2 deaths 2 injuries property damage

---

DOCUMENT SUMMARY

Rocket Engine Test Laboratory Fire
Title

NFPA 53M #3251 P21
Source

NA
Author

1969 Edition
Date

SUMMARY Code 3A

LOX line broke during test on a heat exchanger. Hot surfaces ignited oxygen - fuel mixture

LOX
Gas Constituents/Pressure

Laboratory
Equipment

$65,000 property damage
Nature of Damage/Injuries

Key Words

oxygen LOX line rupture break fuel heat fire property damage

DOCUMENT SUMMARY

Fire in oxygen pipe line
Title

NFPA 53M #3241 P21
Source

NA
Author

1969 Edition
Date

SUMMARY Code 3B

Contamination by halogenated hydrocarbon caused explosion in high pressure pipe line.

Oxygen 2200 PSI
Gas Constituents/Pressure

Laboratory Systems
Equipment

$215,000 property damage
Nature of Damage/Injuries

Key Words

Oxygen Pipe line hydrocarbon contamination explosion property damage

---

DOCUMENT SUMMARY

Static Inverter Flammability Test
Title

North American Rockwell Corp., Report #ATR 142007
Source

Several
Author

7 July 1967
Date

SUMMARY Code 3D

This was a test under controlled conditions. No conclusions can be drawn from the test results other than that the re-design of the equipment was necessary.

Oxygen 16.5PSIA
Gas Constituents/Pressure

Static Inverter in Test Chamber
Equipment

Not assessable.
Nature of Damage/Injuries

Key Words

Oxygen Test Chamber
Igniter Ignition Fire

DOCUMENT SUMMARY

Accident Report on ECS Module C-59, Building 32, January 14, 1966
Title

NASA/MSC Safety Office BM3
Source

J. H. Chappee, J. E. Powell, M. G. Simmons
Author

21 June, 1966
Date

SUMMARY Code 3B

Accident was attributed to either the cummulative build-up of contamination on the valve seat or the sudden entrapment of a contaminant between the ball and seat of the valve. In either case, the accident investigation resulted in the replacement of DELRIN as valve seats with TEFLON and the redesign of the system to prevent the possibility of operating the valves at high pressures. Procedures were also re-written

Oxygen 2250PSI Max
Gas Constituents/Pressure

ECS Module High Pressure System
Equipment

Second and Third Degree Burns
Nature of Damage/Injuries Property Damage not mentioned

Key Words

Oxygen DELRIN TEFLON Contaminant
Valve Seat Fire Explosion
Injuries

DOCUMENT SUMMARY

Final Report of the WSTF Fire Investigation Board Altitude Simulation System LOX Pump Number Three at NASA MSC White Sands Test Facility on September 16, 1966
Title

NASA/ MSC, WSTF, Code SC
Source

D. J. Fitts, E. J. Burke, R. J. Sturtz
Author

15 October, 1966
Date

SUMMARY Code 3B(A)

Cause of accident not definitely determined. Attributed to one the three following causes in order of probability.

- Chip of piece of impeller flew off and was ground between housing and impeller creating heat and sparks.
- Inboard Thrust Bearing failure
- A foreign particle of unknown composition entering into the pump.

LOX 500 to 600 PSI
Gas Constituents/Pressure

LOX Pump driven by 250 HP Motor
Equipment

No Injuries. Dollar value of damage
Nature of Damage/Injuries not stated

Key Words

LOX Pump Particle Fire
Chip Metal Bearing Failure
Material Incompatible

DOCUMENT SUMMARY

Report of Investigation -- Damage to Pulse X-Ray Equipment July 24, 1969 Building 31
Title

NASA/MSC Industrial Safety Office, Code SC
Source

Author

8 October, 1969
Date

SUMMARY Code 3F

Explosion caused by capacitor discharge in pure Oxygen mis-labeled "Compressed Air, 79% Nitrogen, 21% Oxygen"

99% Oxygen 2015 psi internal flask 240 psi working
Gas Constituents/Pressure

Febetron Pulsed Electron-Beam X-Ray System
Equipment

No Injury. Less than $10,000.00 Property damage.
Nature of Damage/Injuries

Key Words

Oxygen	Explosion	240 PSI	Mis-label
2015 PSI Flask		Capacitor	Discharge

DOCUMENT SUMMARY

Aircraft Fire
Title

NFPA 53M #3260 P26
Source

NA
Author

1969 Edition
Date

SUMMARY Code 3 (E)

Short circuit ignited fuel leaking from line. Fire caused aluminum fitting to melt from oxygen control panel, releasing O_2.

Oxygen Pressure Bottle
Gas Constituents/Pressure

Aircraft
Equipment

$177,000 property damage
Nature of Damage/Injuries

Key Words

oxygen short circuit fuel fire property damage

DOCUMENT SUMMARY

Oxygen Supply System Mishaps (Letter)
Title

Dept. of the Air Force Letter, AFIAS-F3
Source

Lt. Col. Paul A. Bergerot, USAF
Author

April 24, 1970
Date

SUMMARY Code 4B(D)

Grease or oil contamination suspected as cause of explosion and fire evidence destroyed in accident.

Oxygen 250 PSI
Gas Constituents/Pressure

T-33 Aircraft
Equipment

1 Fatality Property damage
Nature of Damage/Injuries

Key Words

Oxygen contamination explosion fire fatality property damage

DOCUMENT SUMMARY

Oxygen Supply System Mishaps (Letter)
Title

Dept. of the Air Force Letter, AFIAS F-3
Source

Lt. Col. Paul A. Bergerot, USAF
Author

April 24, 1970
Date

SUMMARY Code 3B (C)

Combination of:
(a) Contamination by hydrocarbons
(b) Overtorquing of connections
(c) Improper servicing procedures generating excessive heat
caused fire and explosion during servicing of aircraft oxygen system

Oxygen 400 PSI
Gas Constituents/Pressure

T33A Aircraft Gaseous oxygen system
Equipment

$19,600 property damge
Nature of Damage/Injuries

Key Words

oxygen contamination hydrocarbon procedures overtorquing
fittings fire explosion property damage

DOCUMENT SUMMARY

Aircraft Fire
Title

NFPA 53M #3261 P26
Source

NA
Author

1969 Edition
Date

SUMMARY Code 4D

During inspection, opening of valve triggered fire. Unknown cause - possible impurity or temperature rise caused by adiabatic pressure of pure oxygen.

Oxygen Pressure Bottle
Gas Constituents/Pressure

Aircraft
Equipment

Property damage
Nature of Damage/Injuries

Key Words

oxygen adiabatic pressure impurity fire property damage

DOCUMENT SUMMARY

Aircraft Explosion
Title

NFPA 53M #3321 P30
Source

NA
Author

1969 Edition
Date

SUMMARY Code 4F

Oxygen cylinder mistakenly used to "inert" fuel manifold lines in an aircraft instead of nitrogen. Explosion killed 3 men and damaged aircraft extensively.

Oxygen High
Gas Constituents/Pressure

Aircraft Fuel System
Equipment

3 fatalities, extensive damage to aircraft
Nature of Damage/Injuries

Key Words

Oxygen fuel manifold nitrogen explosion 3 fatalities property damage

---

DOCUMENT SUMMARY

Oxygen Bottle Explosion
Title

McDonnell-Douglas Aircraft Company, Inc. MP 11, 477 McD/D Co.
Source

R. P. Colburn, J. R. Hollinger
Author

8/26/59
Date

SUMMARY Code 4E

Loose Nylon poppet moving under 1800 psi pressure or heat generated by compression, ignited the poppet in the valve, causing fire and explosion

Oxygen/1800 psi
Gas Constituents/Pressure

DC-8 Aircraft oxygen supply bottle
Equipment

Personnel bogey, bottle destroyed
Nature of Damage/Injuries

Key Words

oxygen valve explosion fire injury
aircraft

DOCUMENT SUMMARY

Aircraft Fire
Title

NFPA 53M #3262 P26
Source

NA
Author

1969 Edition
Date

SUMMARY Code 4E

Spark ignited flammables being used to remove linoleum. Fire caused oxygen relief valves to vent, intensifying flames.

Oxygen Pressure Bottles
Gas Constituents/Pressure

Aircraft
Equipment

Property damage
Nature of Damage/Injuries

Key Words

Oxygen spark flammables valves fire property damage

DOCUMENT SUMMARY

Pressure Regulator Valve Fire
Title

NFPA 53M #3216 Page 19
Source

NA
Author

1969 Edition
Date

SUMMARY Code 5B

During transfer of the pressure regulator valve from one Oxygen supply bottle to another, the valve components ignited.

Accident attributed to non-compatible material in regulator.

Oxygen Cylinder pressure
Gas Constituents/Pressure

Incubator Oxygen Tent
Equipment

Infant fatality, 5 persons injured
Nature of Damage/Injuries

Key Words

Oxygen Regulator Fatality Injuries
Material Lint Oil

DOCUMENT SUMMARY

Oxygen Cylinder Fire
Title

NFPA 53M #3222 P20
Source

NA
Author

1969 Edition
Date

SUMMARY Code 6A

Fire attributed to failure of a valve on an acetylene cylinder. Heat fused valves on oxygen and acetylene cylinder.

Oxygen High
Gas Constituents/Pressure

Welding
Equipment

Six Deaths $1,123,000 property damage
Nature of Damage/Injuries

Key Words

oxygen acetylene valve failure fire property damage fatilities (6)

DOCUMENT SUMMARY

Operating Room Explosion
Title

NFPA 53 M #3300 Page 27
Source

NA
Author

1969 Edition
Date

SUMMARY Code 5F (E)

Series of events in an operating room resulted in explosion & fire which destroyed room and caused several deaths, permanent injuries and large property loss. Accident attributed to:

A. Cyclopropane bottle partially loaded with Oxygen.

B. Too-rapid opening of valve on bottle. Heat of friction ignited mixed gas. (Probably would not have occurred had bottle contained only cyclopropane)

Oxygen/Cyclopropane Etc.
Gas Constituents/Pressure

Operating Room Anaesthesia equipt.
Equipment

6 deaths, 3 amputations, severe trauma, property loss.
Nature of Damage/Injuries

Key Words

Oxygen Cyclopropane Valve Ether
Fire Explosion Fragmentation
Nitrous Oxide

DOCUMENT SUMMARY

Pressure Gage Explosion
Title

NFPA 53M #3224 P20
Source

NA
Author

1969 Edition
Date

SUMMARY Code 6A

Pressure gage from a hydraulic system installed on oxygen system caused explosion.

Oxygen High
Gas Constituents/Pressure

Welding
Equipment

Injuries
Nature of Damage/Injuries

Key Words

oxygen gage hydraulic system explosion personnel injuries

DOCUMENT SUMMARY

Oxygen Transfer Pump Explosion   Transfer Pump Explosion
Title

NFPA 53M 3202 Page 17
Source

NA
Author

1969 Edition
Date

SUMMARY   Code 6A (B)

Nitrogen Seal in crosshead section of transfer pump failed, permitting contamination of oxygen with lube oil. Heat of compression evidently caused ignition and explosion.

Oxygen 1000 PSI
Gas Constituents/Pressure

Reciprocating Oxygen Transfer Pump
Equipment

$20,000.00 Property Damage
Nature of Damage/Injuries

Key Words

oxygen	Pump	Nitrogen	Seal
Transfer	Failure	Explosion	

DOCUMENT SUMMARY

Compressor
Title

NFPA 53M 3207 Page 17
Source

NA
Author

1969 Edition
Date

SUMMARY   Code 6A(B)

Worn TEFLON rider rings on a compressor piston rod permitted lubricating oil to escape into an oxygen cylinder where it spontaneously ignited.

Oxygen Not Specified (Higl
Gas Constituents/Pressure

Compressor
Equipment

$125,000.00 Property Damage
Nature of Damage/Injuries

Key Words

Oxygen	High Pressure	TEFLON	Rider rings
Lubricating oil	Piston	Explosion	Fire

DOCUMENT SUMMARY

Oxygen/Acetylene Piping System Explosion/Fire
Title

NFPA 53M #3220 P19
Source

NA
Author

1969 Edition
Date

SUMMARY   Code 6A

Electric arc ruptured on acetylene pipe line and ignited gas. Explosion ruptured oxygen line.

Oxygen 1200 PSI
Gas Constituents/Pressure

Welding Equipment (Shipyard)
Equipment

$760,000 property damage
Nature of Damage/Injuries

Key Words

oxygen	Property damage
explosion	
acetylene	
piping	
fire	
electric arc	

DOCUMENT SUMMARY

LOX Delivery Truck Tank Rupture
Title

NFPA 53M #3201 P16
Source

NA
Author

1969 Edition
Date

SUMMARY   Code 6A

Tank ruptured during delivery. Oxygen reached noncompatible material resulting in ignition.

LOX
Gas Constituents/Pressure

Delivery Truck
Equipment

$1,000,000 property damage
Nature of Damage/Injuries

Key Words

LOX	Tank	Rupture	Material	Noncompatible	property damage

DOCUMENT SUMMARY

Fire in Oxygen Cylinder Storage Area
Title

NFPA 53M #3215 P18
Source

NA
Author

1969 Edition
Date

SUMMARY Code 6A

Fire in storage shed caused explosion of Oxygen Cylinders. Considerable property damage

Oxygen, 2250 PSI (Cylinders)
Gas Constituents/Pressure

Oxygen Cylinders in Storage Area
Equipment

Property Damage - unspecified
Nature of Damage/Injuries

Key Words

Oxygen Cylinders Fire Explosion Storage

DOCUMENT SUMMARY

High Pressure Oxygen Pump Equipment Explosion & Fire
Title

NFPA 53M #3203 P17
Source

NA
Author

1969 Edition
Date

SUMMARY Code 6B

Glycerine or other flammable material residue in bottom of filter ignited during operation.

Oxygen High
Gas Constituents/Pressure

Pump/Filter
Equipment

Property Damage
Nature of Damage/Injuries

Key Words

Oxygen ignition pump property damage filter glycerine noncompatible material residue

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DOCUMENT SUMMARY

3,800 gal. capacity LOX Truck
Title

NFPA 53M #3200 P16
Source

NA
Author

1969 Edition
Date

SUMMARY Code 6A(E)(B)

Leak in transfer hose released oxygen. Static spark (or other) ignited grease or tires. Heat caused LOX tank to rupture.

LOX
Gas Constituents/Pressure

LOX delivery truck
Equipment

$100,000 property damage
Nature of Damage/Injuries

Key Words

hose leak static spark tank rupture LOX property loss

DOCUMENT SUMMARY

Rupture of a high pressure Oxygen valve
Title

NFPA 53M Page 21 #3240
Source

NA
Author

1969 Edition
Date

SUMMARY Code 6A (E)

Accident attributed to either:

Rupture of a high pressure valve, or
Short circuit of 300 VDC cable to Oxygen pipe, resulting in ignition of pipe and rupture of valve.

Oxygen High Pressure (NS)
Gas Constituents/Pressure

Not Specified
Equipment

No Injuries $160,000.00 property loss.
Nature of Damage/Injuries

Key Words

Oxygen Fire High Pressure Property Loss Valve Rupture High Voltage

DOCUMENT SUMMARY

Oxygen Compressor Fire
Title

NFPA 53M #3204 P17
Source

NA
Author

1969 Edition
Date

SUMMARY Code 6B(D)

Fire attributed to metal "feathers" or "fingers" left in compressor cylinder, or oil seepage into cylinder or rupture of cylinder wall. Damage was so extensive, exact cause not determined.

Oxygen
Gas Constituents/Pressure

Compressor
Equipment

Property damage $375,000
Nature of Damage/Injuries

Key Words

oxygen fingers property damage compressure cylinder metal rupture feathers fire

---

DOCUMENT SUMMARY

Oxygen Cylinder Fire
Title

NFPA 53M #3223 P20
Source

NA
Author

1969 Edition
Date

SUMMARY Code 6C (G)

Fire started in oily rags ignited by sparks from a grinder. Spread to oxygen tank.

Oxygen High
Gas Constituents/Pressure

Welding
Equipment

$35,000 property damage
Nature of Damage/Injuries

Key Words

oxygen rags oil sparks grinder property damage

DOCUMENT SUMMARY

Oxygen Distillation Column Explosion
Title

NFPA 53M #3206 P17
Source

NA
Author

1969 Edition
Date

GE - M. Cook
File Location and Accession Number

SUMMARY Code 6B

Hydrocarbon build-up in the refracter column believed to have caused explosion.

Oxygen
Gas Constituents/Pressure

Refracter Column
Equipment

$830,000 property damage
Nature of Damage/Injuries

Key Words

oxygen hydrocarbon explosion property damage

DOCUMENT SUMMARY

Distillation Column Explosion
Title

NFPA 53M #3205 P17
Source

NA
Author

1969 Edition
Date

SUMMARY Code 6B (D)

Foreign matter (undetermined) in distillation column exploded.

Oxygen
Gas Constituents/Pressure

Distillation Column
Equipment

$400,000 property damage
Nature of Damage/Injuries

Key Words

oxygen foreign matter explosion property damage

DOCUMENT SUMMARY

Ship's Compartment Fire
Title

NFPA 53M #3332 P30
Source

NA
Author

1969 Edition
Date

SUMMARY Code D (G)

Fire of unknown origin aggravated by use of oxygen to blow out ship's suction lines instead of compressed air.

Oxygen
Gas Constituents/Pressure

Ship's equipment
Equipment

5 fatalities
Nature of Damage/Injuries

Key Words

Oxygen compressed air blowing fire 5 fatalities

DOCUMENT SUMMARY

Diesel Engine Starter Explosion
Title

NFPA 53M #3330 P30
Source

NA
Author

1969 Edition
Date

SUMMARY Code 6F

Oxygen used instead of compressed air to start a diesel engine resulted in explosion and fire.

Oxygen 150 PSI
Gas Constituents/Pressure

Diesel Engine
Equipment

One fatality Property damage
Nature of Damage/Injuries

Key Words

Oxygen diesel starter explosion fatality property damage fire

---

DOCUMENT SUMMARY

Fire in Ethylene-Oxygen Reactor feed.
Title

NFPA 53M Page 20 #3230
Source

NA
Author

1969 Edition
Date

GE - M. Cook
File Location and Accession Number

SUMMARY Code 6D

Unexplained explosion following adjustment by operators at the Oxygen Plant.

Oxygen Not specified
Gas Constituents/Pressure

Oxygen Compressor
Equipment

$ $650,000.00 Property Damage and Production interruption
Nature of Damage/Injuries

Key Words

Oxygen Compressor Explosion Fire
Industrial Accident Losses Ethylene
Detonation

DOCUMENT SUMMARY

Accident in Oxygen/Ammonia Plant
Title

NPPA 53 M Page 20 3231
Source

NA
Author

1969 Edition
Date

SUMMARY Code 6E (A)

Electrical Failure opened reducing valve. Compressors, idling to maintain pressure against shut-off valve, permitted hot oil to enter Oxygen line after 3½ hours.

Case of no "fail safe" design.

Oxygen Pressure unspecified"
Gas Constituents/Pressure

Compressors
Equipment

$485,000.00 property damage
Nature of Damage/Injuries

Key Words

Oxygen Nitrogen Compressors Valve
Electrical Failure Oil Contamination

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