the ELS Sequencer Controller Pressure Stimuli Generator (C14-451) would have interfored with hatch close-out.

D. The purpose of OCP-K-0021 was changed to add, "C. To verify astronaut emergency egress procedures (unaided egress)."

E. On this date, review comments from 21 September were sent to keypunch for a second set of flimseys.

4 October 1966	-Third set of flimseys printed for mark-up.
19 October 1966	- Distributed printed preliminary hard copies of procedure for review. Had been submitted for printing on 14 October.
30 October 1966	- Formal review meeting held. Attended by all systems except G&N.
31 October 1966	- In accordance with Astronaut and checkout team desires, and following a technical investigation, it was agreed to delete the ELS Sequencer Controller Pressure Stimuli Generator from the test thus allowing the

following test philosophy changes:

A. Allow performance of normal flight crew countdown. (OCP-K-5117) (This is the astronaut procedure from wake-up to arrival at the launch complex.)

B. Back-up crew to perform their normal launch day functions.

C. Prime crew to ingress and run entire test as on launch day.

D. Emergency egress test to be performed by prime crew after simulated landing.

E. Normal cabin hatch close-out and running of the test on O_2 were results from these decisions

7 November 1966 - Crew Systems Stowage was added to be performed as part of the test set-ups per request of local MSC crew support personnel.

15 November 1966 - G&N information available. Coordination with L/V procedures in progress.

21 November 1966 - Received the mats for printing the basic issue of OCP-K-0021.

7 December 1966 - Six copies of the final master flimsy were presented to Systems Engineering for final review.

10 December 1966	- Final mats approved, cover sheet signed, sent to print shop.
13 December 1966	- Procedure published and released formally.
13 January 1967	- Meeting held at KSC attended by the prime crew Pilot (MSC), Lou DeWolf (FCSD), Tom Grier (FCSD), Don Nichols (KSC), and F. J. Powell (NAA), the following items were discussed and tentatively agreed to:

A. Back-up crew was to perform a panel-by-panel check of all C/M controls during "Back-up Crew Pre-Launch Checks." (See sequence 8.5, 8.6, and 8.7 of OCP-K-0021.) These checklists were to be conducted on a switch-by-switch basis over the intercom.

B. After ingress, the prime crew was to perform a panel sweep of the display console and associated panels which can be reached from couches (lower equipment bay not to be re-checked). This checklist was not to be called out over the intercom.

C. The information to be contained in the switch lists in Items A and

and B above, were discussed and mutually agreed upon. This information was subsequently provided to FCSD for incorporation in Section 1 and Section 2 of the Crew Abbreviated Checklist.

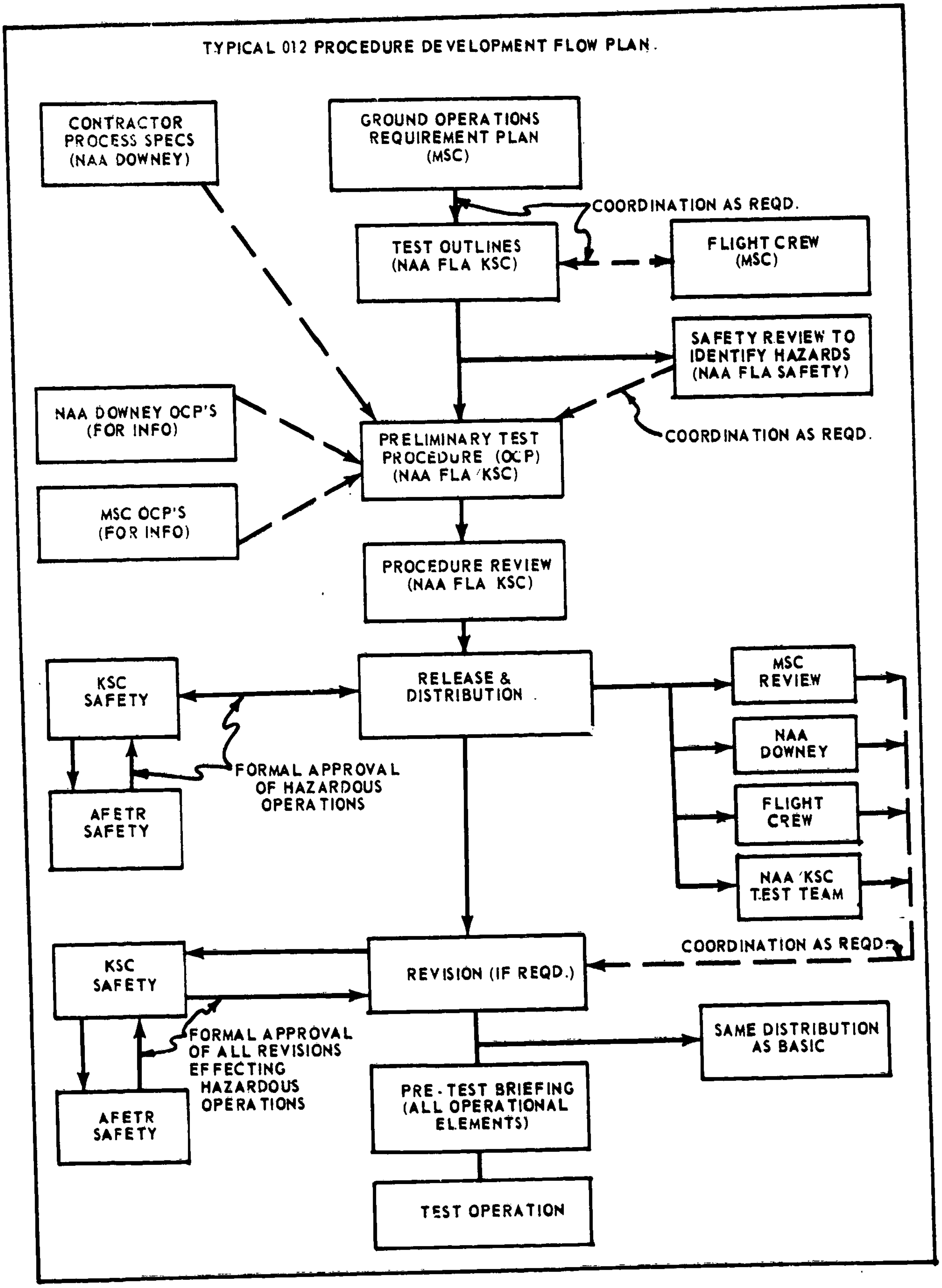
D. Panel nomenclature was called out in all switch lists. In a case where simplification of call outs could be made, the Test Conductor was to combine such call outs as "Main A", "Main B", and other similar switch nomenclatures.

E. Plugs In, Plugs Out, Flight Readiness, and Countdown test procedures were revamped to a standard minus time operation from approximately T-2 hours to liftoff.

F. All S/C 012 OCP's had been written utilizing the 14 November 1966, S/C 012 Crew Checklist (SM-2A-03) as a reference document.

From this date (1/13/67), NAA was in the process of updating procedures to the 5 January 1967, version plus the changes that would be supplied by FCSD in their 16 January 1967, revision.

23 January 1967	- Preliminary Launch Countdown, OCP-K-0007, was published. This procedure provided a baseline from approximately T-3 hours to T-Zero for use in the Plugs Out Test.
26 January 1967	- (5:30 p.m.) Rev. -1 consisting of 209 pages was released with update from OCP-K-0006, Plugs In Test experience, plus 4 weeks information accumulations and incorporation of agreements made in the 13 January meeting. See Attachment 7-3 for details and dates related to the reasons for the -1 Revision of OCP-K-0021.
27 January 1967	-(10:00 a.m.) -1 Revision A delivered. All changes affected plus time sequences only. (Four typed pages in lieu of having to write on-station deviations.)



ENCLOSURE 7-4

OPTIONAL FORM NO. 10
MAY 1962 EDITION
GSA FPMR (41 CFR) 101-11.6

UNITED STATES GOVERNMENT

Memorandum

TO : Apollo 204 Review Board Panel - Task No. 7
Test Procedures Review/Attn: Nichols, Chairman

DATE: February 13, 1967

FROM : Chief, Safety Office, RE

RE-1/1Q6/Barnett:mr
867-3973

SUBJECT: Test Procedures Review for Hazardous Operations

1. The requirement for the KSC Safety Office and the Air Force Range Safety review of test procedures for hazardous operations is specified in Section I, paragraph 3, page A-1 of KMI 1710.1, Attachment A, dated October 4, 1966, and Section C, paragraph 3, page C-5 of AFETRM 127.1 Range Safety Manual dated 1 November 1966.

2. Some operations that have been specified as hazardous in nature are as follows:

a. Propellant servicing

b. Pressure testing

c. Pyrotechnic (ordnance) work

d. Radioactive and toxic material operations

e. Operations with hazardous gases

3. The responsibility of submitting hazardous test procedures for Safety approval is with the contractor. A test to be conducted on Cape Kennedy requires 5 copies of the Test Procedure to be submitted to the KSC Safety Office. One of these copies is retained by the KSC Safety Office and one is sent to Bendix Systems Safety for comment; three copies are then forwarded through the Apollo/Saturn I-V Requirements Branch, DK-3, to Air Force Range Safety (ETOSH) for review and approval.

4. Comments from ETOSH and Bendix Systems Safety are submitted to the KSC Safety Office, who in turn transmits the comments to the contractor for incorporation into the OCP.

5. It should be noted that the AFETRM 127-1 Range Safety Manual requires a minimum of 30 days for review of documents. Apollo Procedure submittals have been very delinquent in meeting this time requirement. The late submittal of procedures has repeatedly been brought to the attention of North American and Spacecraft Operations in various meetings and correspondence. Some procedures have been submitted with as little as two days

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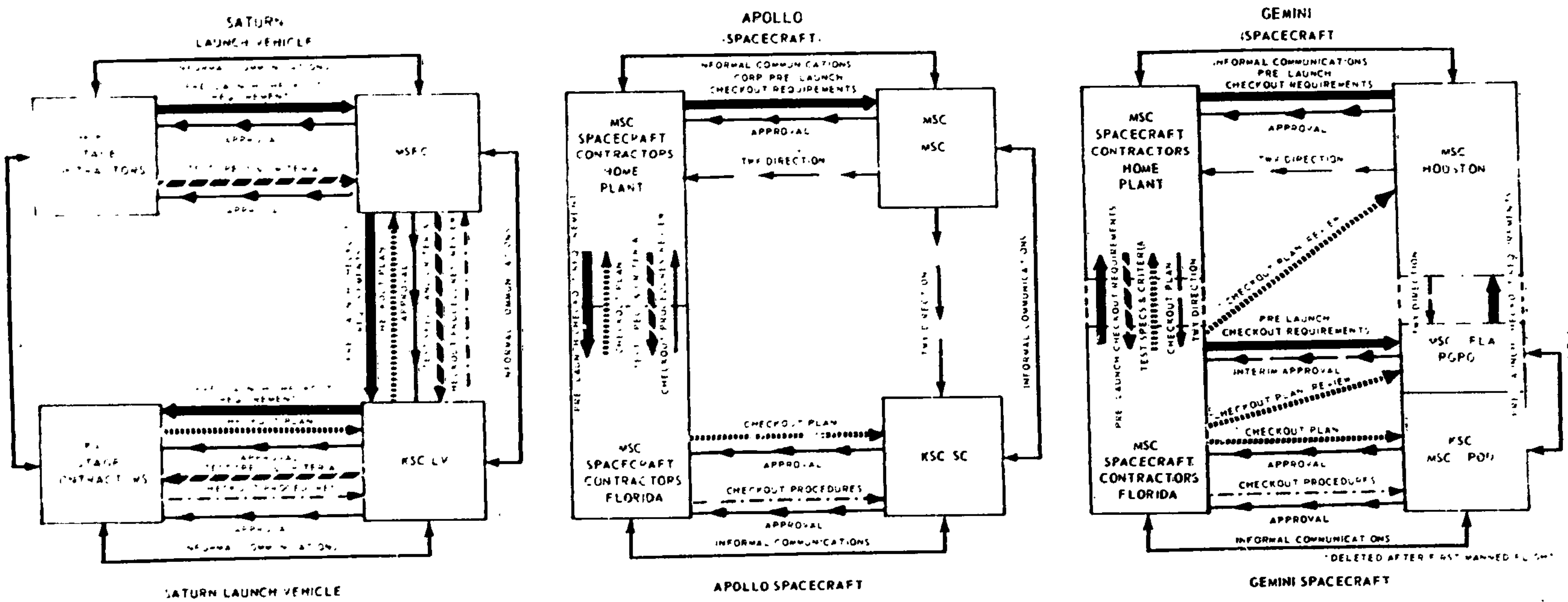
allowable Safety review time. Also, changes to an approved procedure have been published on the day of the test, thereby eliminating any allotted time for Safety review.

6. OCP-0021, S/V Plug Out Integrated Test was reviewed for S/C 009 and was classified as a non-hazardous test, thereby eliminating required Safety approval. This type procedure is not again submitted to KSC Safety for review unless it is changed in such a way as to make the operating hazardous. OCP-0021 for S/C 012 was not submitted to the KSC Safety Office for approval.

for John R. Atkins

PROGRAM CONTROL OF PRE LAUNCH TEST REQUIREMENTS



SATURN LAUNCH VEHICLE

1. DELEGATION OF PRE LAUNCH CHECKOUT AND LAUNCH IMPLEMENTATION RESPONSIBILITY TO KSC FROM MSFC
   - A. FORMAL INTER CENTER AGREEMENTS
   - B. KSC CONTROLLED SUPPLEMENTAL CONTRACTS TO IMPLEMENT DELEGATION

APOLLO SPACECRAFT

1. CENTRALIZED AUTHORITY RETAINED AT MSC
   - A. SLOW RESPONSE LOOP
   - B. MSC APPROVAL CONSTRAINS NORMAL PRELAUNCH ACTIVITY
2. INTER CENTER AGREEMENTS NOT FORMALIZED
   - A. INTERFACE OF CENTERS ROLES AND MISSIONS NOT CLEARLY DEFINED

GEMINI SPACECRAFT

1. LAUNCH SITE AUTHORITY WITH QUICK RESPONSE CAPABILITY TO MEET DYNAMIC NEEDS OF REAL TIME OPERATIONS
2. MSC CONTRACTUAL LOOP NON RESTRAINING WITH AFTER THE FACT CLOSURE ON QUARTERLY BASIS

ENCLOSURE 7-6

D-7-59

FLIGHT VEHICLE TEST DOCUMENTATION

SATURN LAUNCH VEHICLE	APOLLO SPACECRAFT	GEMINI SPACECRAFT

PRELAUNCH CHECKOUT REQUIREMENTS

PURPOSE: Defines and Levies General Checkout and Operations Requirements.

PRELAUNCH TEST AND AND CHECKOUT REQUIREMENTS	GROUND OPERATIONS REQUIREMENTS PLAN	SEDR 9882
1. Class I Document (KSC)	1. Class I Document (S/C Contractor)	1. Class I Document (S/C Contractor
2. Prepared by MSFC Stage Contractor for MSFC	2. Prepared by A. S/C Contractor (Home Plant) B. KSC Informal Inputs to MSC	2. Prepared by A. S/C Contractor (Florida) (with KSC Inputs for MSC)
3. Approved by MSFC Stage Manager	3. Approved by MSC Contracting Officer	3. Approved by MSC Contracting Office (after GPO Agreement)
4. Content A. System Oriented B. Treats System Functions not Methods or Sequences C. Launch Site Oriented	4. Content A. Operations Outlined in Detail B. Specific System Operation Defined C. Flow Oriented – Factory thru Launch Site	4. Content A. Program Document with Table Showing Requirements per Vehicle B. Treats Test Objectives, not Methods or Sequences C. Launch Site Oriented
5. Format – Tabular	5. Format – Tabular	5. Format – Tabular
6. Delivery Schedule A. Original – 1 to 2 Months Prior to Vehicle Delivery B. Revisions – as Required	6. Delivery Schedule A. Original – 18 Months Prior to Delivery Due to Its Utilization as a GSE Provisioning Document B. Revisions – Continuous	6. Delivery Schedule A. Original – 1 to 2 months Prior to Delivery B. Revisions – Updated at 3 month Intervals (Includes after the Fact Changes)
SUMMARY: Requirements are Levied without Restraining Sequence or Method of Implementation.	SUMMARY: Optimum Effectiveness not Achieved as a Test Requirements Document Due to its Utilization as a GSE Provisioning Document and the Excessive Level of Detail in its Contents.	SUMMARY: Prepared at Launch Site with Real Time Approval Allowing after-the-fact Contract Revision.

TEST SPECIFICATIONS AND CRITERIA

PURPOSE: To Furnish Specs and Criteria Applicable to System Performance During Prelaunch and Launch Operations.

PRELAUNCH CHECKOUT SPECIFICATIONS AND CRITERIA (KSC)

1. Class I Document (KSC)
2. Prepared by MSFC Stage Contractor for MSFC
3. Approved by MSFC
4. Content
   A. Systems Information by System
   B. Field Tolerances by System
5. Format - Tabular
6. Delivery Schedule 1 to 2 Months Prior to Vehicle Delivery

SUMMARY: One Integrated Document Per Stage Scoped to Cover Normal Testing, Troubleshooting, And/or Detailed Testing.

PROCESS SPECIFICATION MA0201-XXXX (BLOCK I)

1. Class III Document
2. Prepared by S/C Contractor (Home Plant) Engineering For External Use
3. Approved by Contractor Proj. Engr.
4. Content
   A. Step-by-step Like a Checkout Procedure
   B. One Integrated Document Per Test
5. Format - Written Like Launch Site Checkout Procedures
6. Delivery Schedule Four Months Prior to Test

SUMMARY: Scoped by Test in a Format Which Makes Its Use, As a Reference Document for Specific System Values, Difficult.

PERFORMANCE AND CONFIGURATION SPECIFICATION (MAC REPORT A-900)

1. Class I Document (S/C Contractor)
2. Prepared by S/C Contractor (Home Plant) for MSC
3. Approved by MSC Contracting Office
4. Content
   A. Mission Performance Specification by System
   B. Configuration by System
5. Format - Narrative/Tabular
6. Delivery Schedule Two Months Prior to Spacecraft Delivery

SUMMARY: One Integrated Document Per S/C, Scoped to Cover Normal Testing Level. Troubleshooting And/or Detailed Testing Required is Referenced to Lower Level Documents.

CHECKOUT PLAN

PURPOSE: To Provide an Outline of the Testing and Checkout to be Performed.

CATALOG OF LAUNCH VEHICLE TESTS

1. Class I Document (KSC)
2. Prepared by KSC Stage Contractor for KSC
3. Approved by MSFC Upon Submission
4. Content
   - A. Test Objectives
   - B. Brief Test Description
   - C. Test Support Requirements
5. Format – Narrative
6. Delivery Schedule
   - A. Original - 6 Months Prior to Vehicle Arrival

SUMMARY: KSC Response to the MSFC Prelaunch Test and Checkout Requirements.

FLORIDA FACILITY TEST FLOW PLAN

1. Class III Document
2. Prepared by MSC S/C Contractor (Florida) for KSC
3. Approved by
   - A. S/C Contractor (Florida)
   - B. KSC
4. Content
   - A. Test Objectives
   - B. Brief Test Description
   - C. Detailed SC/GSE Configuration Matrices
   - D. Detailed Outline of Each Test and Operation
   - E. Safety Requirements
5. Format – Narrative and Tabular
6. Delivery Schedule
   - A. Original - 2 Months Prior to SC Arrival

SUMMARY: Locally Generated at KSC To Define Scope and Method of Spacecraft Checkout at KSC.

TEST OPERATIONS PLAN (SEDR 301)

1. Class III Document (S/C Contractor)
2. Prepared by S/C Contractor (Florida) for KSC
3. Approved by
   - A. S/C Contractor (Florida)
   - B. KSC
4. Content
   - A. Test Objectives
   - B. Brief Test Description
   - C. SC/GSE Configuration
   - D. Brief Test Outline
   - E. Hazards (Safety)
5. Format – Narrative
6. Delivery Schedule
   - A. Original - 7 Months Prior to SC Arrival

SUMMARY: Document Replaced After First Manned Launch By Test Matrix Containing Similar Information.

CHECKOUT PROCEDURE

PURPOSE: To Provide Detailed Step-by-step Procedure for Performing Each Test and Operation.

DETAILED OPERATING PROCEDURE (DOP)	OPERATION CHECKOUT PROCEDURE (OCP)	SERVICE ENGINEERING DEPARTMENT REPORT (SEDR)
1. Prepared by Local Contractor for Local NASA 2. Approved by Local Contractor and Local NASA 3. Content – Detailed, Step-by-step Procedure 4. Delivery Schedule – A. Preliminary - 30 Days Prior to Use B. Final - 5 Days Prior to Use C. Revisions - As Required	SAME	SAME

DOCUMENTS REQUIRED IN DIRECT SUPPORT ON THE PLUGS OUT TEST

1. Spacecraft Plugs Out Procedures FO-K-0021 S/C 012/014
2. Launch Vehicle Plugs Out Procedure
3. Space Vehicle Plugs Out Procedure, I-20015-SA204
4. GSE Checklist FO-K-10011 S/C 012
5. Crew countdown FO-K-5117 S/C 012

ENCLOSURE 7-8

AO-67-32

INTERNAL LETTER
North American Aviation, Inc.

Date 23 February 1967

TO Apollo Supervision
Address 42-820, 818, 41-696/697

FROM J. L. Pearce, 42-818 ZK1A
Address S. M. Treman, 41-696-697 HC3

Phone 867-6151
923-1121

Subject Memorandum of Understanding - Coordination of Preparation of Engineering Test Specification and Major Test Outline Document for Florida Facility Block II Apollo Spacecraft Test Operations

The purpose of this memorandum is to record understanding of responsibilities for coordinated preparation between the Florida Facility and Downey Spacecraft Design of the test specification and criteria and FF Major Test Outline documents for Block II Apollo spacecraft operations at KSC.

Specifically, C/O Integration and Combined Systems (D/697-400) is responsible for the preparation of a document to provide requirements for Block II spacecraft functional test and servicing operations to be performed at KSC. The document is to be modular in form and generally system-oriented. It shall be consistent with the requirements of the applicable Block II S/C GORP.

The document will be prepared with the direct support of Florida Facility Apollo Engineering (D/820) and Apollo Operations (D/818). Active coordination channels will be established to assure that the form, content, and details of the document meet the needs of Apollo S/C operations as planned and scheduled by the Florida Facility organization.

Florida Facility Apollo Operations (D/818) is responsible for the preparation of the Major Test Outline document applicable to Block II S/C KSC operations in coordination with D/820. This document will meet requirements contained in the test specification and criteria document and will be in accordance with the applicable Block II S/C GORP. The document will be submitted to D/820 for review and concurrence. The document will simultaneously be provided to D/696 and 697 for review and comments. These comments will be provided to D/820. D/697-400 will provide technical support to D/818 as necessary during document preparation. A summary of the contents of the FF Major Test Outline document is enclosed (See Attachment 1).

D/820 is responsible for assuring that OCP outlines satisfy the requirements of the test specification and criteria document. D/820 will take necessary action to assure that these documents are compatible. D/820 will, in this capacity, directly support

ENCLOSURE 7-9

D/697-400 in the timely on-the-spot assurance of test specification/OCP outline compatibility.

Following initial EO release of the test specification, Downey changes must be implemented utilizing existing Engineering procedures. Copies of EDC's will be supplied to FF for advance information. Changes initiated by FF must be implemented utilizing the FEO/FCA system.

A flow chart depicting the channels of communications and coordination is enclosed (See Attachment 2).

To facilitate coordination and implementation of the provisions of the memorandum, single point contacts will be named in Departments 818, 820, and 697-400. The prime coordination contact at KSC for interfacing with D/696 and 697 will be provided by D/820.

J. L. Pearce
Director CSM
Florida Facility

S. M. Treman
Director
Spacecraft Design

cc: G. W. Jeffs
R. L. Benner
A. B. Kehlet
G. R. Merrick
L. G. Rochester
M. Karp
J. P. Proctor
R. E. Barton

Attachment 1

DEFINITION OF SECTIONS OF THE FLORIDA FACILITY MAJOR TEST OUTLINE DOCUMENT

SECTION A .

Internal Power Configuration Plan

A chart showing usage of batteries, battery substitute units, fuel cells, fuel cell simulators and fuel cell substitute units as a function of various major KSC tests.

SECTION B

GSE Utilization Plan

A chart showing usage of GSE models and DTT's on a per test basis.

SECTION C

Spacecraft Test Plan

1. A chart showing types of missions and aborts on a per test basis.

2. A prose description of each test defining the test objectives and clarifying the goals of the days activities.

SECTION D

Test Limitations

1. References appropriate placards and limitations guide.

2. References appropriate KSC and ETR safety limitations.

3. Describes the limitations of the allocations of activities per test to insure that total KSC testing does not exceed limits.

SECTION E

Spacecraft Flow Plan

A sequential listing of the details of the test flow plan intended as a guide to checklist preparation.

Attachment 1

SECTION F

Plan of System Testing

Either a prose description or a matrix, as appropriate, showing the plan for all KSC test on a per system basis. It is intended to be a convenient guide to all parochial interests to examine the plot of each system in Florida. This section also includes a table of measurements tested and on-board display correlation with telemetry on a per test basis.

SECTION G

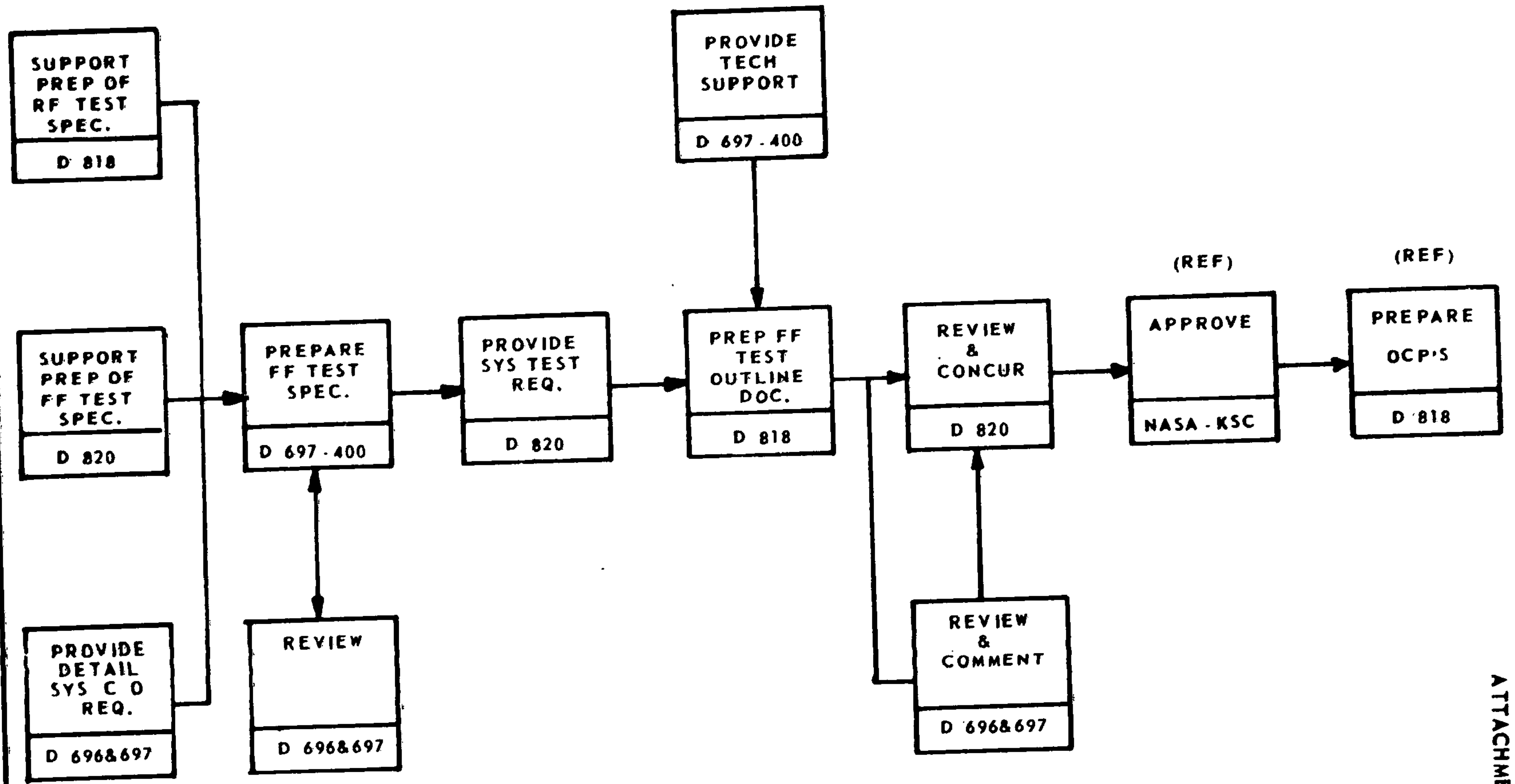
Mission Test Sequence

A sequential listing of all normal or backup event blocks. Does not conform to the flight plan. The intent is to detail all items occurring while going thru an exercise. Test outlines would then pick out selected blocks for performance as appropriate considering the primary test objectives.

SECTION H

Test Outlines

A detailed step by step outline of each OCP from beginning to end. Each item in the outline would be the same as a block title in either the Appendices or the Mission Test Outlines.



ENGINEERING C/O REQUIREMENTS FLOW TO FF

AO-67-34

INTERNAL LETTER

North American Aviation, Inc.

Date 2 March 1967

TO Apollo Supervision
Address 42-820, 818, 41-696/697

FROM J. L. Pearce, 42-818 ZK1A
Address S. M. Treman, 41-696/697 HC30

Phone 867-6151
923-1121

Subject Memorandum of Understanding - Concerning the Form, Content, and Intent of the Block II Florida Facility Engineering Checkout Process Specification

REFERENCES: (a) Memorandum of Understanding, J. L. Pearce and S. M. Treman, Coordinated Preparation of Engineering Test Specification and Major Test Outline Document for Florida Facility Block II Apollo Spacecraft Test Operations, dated 23 February 1967

(b) Meeting at Florida Facility, 28 February 1967, Attended by E. E. Dale, W. F. Cahill, W. L. Eckmeier, W. F. Edson, H. E. Heilman, R. H. Jones and T. H. Linsday

The purpose of this memorandum is to describe the format and objectives of Sections 4.0 and 5.0 of the CSM Checkout Process Specification being prepared for Florida Facility Block II spacecraft prelaunch checkout operations by D/697-400, Checkout, Integration and Combined Systems. This memorandum is an addendum to Reference (a) in order to provide the details of the Process Specification.

The proposed specification, in consonance with the Vehicle Plan (GORP) for Block II Apollo spacecraft, is the logical extension of Part II of the Contract End Item Specification in that the latter document contains only Downey located post-manufacturing checkout operations.

Florida Facility D/820 Systems Engineers and D/818 Operations Integration Engineers and Publications Analysts require firm, accurate, and timely engineering documentation from Downey Spacecraft Design in order to plan and prepare mission oriented Operational Checkout Procedures (OCP's) for those Apollo CSM spacecraft intended for checkout and launch from the KSC. The following stipulations and definitions defined at the Reference (b) meeting will produce a readily usable document to satisfy this requirement:

A. Stipulations -

1. The specification should provide Downey Engineering CSM checkout requirements; and these should be compatible with the applicable GORP. Tests subsequently identified at the Florida Facility as special or additional requirements will be coordinated with Engineering and EO's generated for permanent specification changes.

Form 131 R Rev 2 63

2. For KSC checkouts required, it should provide requirements and planning constraints in Section 4.0 and specifications and criteria including operational constraints in Section 5.0. These data should be in the form of hardware performance values and tolerances relative to a specific operating condition.

3. The specification should be subsystem oriented and must be approved by Subsystems Design Groups.

4. It should include a definition of relationship to other documents and will take precedence over subsystem level process specifications. Subsystem specs are not effective at F/F.

5. It should be controlled by the Engineering change system including field change procedures.

6. An EO on a subsystem process specification will not be effective on this specification. However, changes applicable to this specification must be generated immediately to keep the specifications compatible.

7. Initial issue of Section 4.0 should be five (5) months before CSM arrival at KSC. Initial issue of Section 5.0 should be four (4) months.

8. It should be updated 30 days before CSM arrival at KSC; subsequent updating at 30 day intervals should be accomplished until a final EO incorporation is accomplished after launch.

9. A tabular form should be used for stimuli and measurement tolerances, torque values, etc (with respect to system condition).

10. The Launch Mission Rules will take precedence for launch.

B. Definitions -

<u>Section 4.0</u> - "Checkout Requirements" (Definition of the Engineering requirements per subsystem for checkout at KSC.)

Presents the following: (See Exhibit No. 1 attached)

1. Test code number

2. Brief description of the required subsystem checkout.

3. Statement of major checkout planning constraints (e.g. is a prerequisite to another checkout; time/cycle limitations).

Release date for this portion of the specification will be five (5) months prior to spacecraft delivery. Subsequent updating at 30 day intervals.

Section 5.0 - "Specifications" (A statement of hardware performance values per subsystem with respect to a specific input or operating condition.)

Presents the following: (See Exhibit No. 2 attached)

1. Brief system functional performance description.
2. Measurement number and title.
3. Stimuli characteristics (e.g. amplitude, frequency, duration, pressure, etc.).
4. Performance (output characteristics with tolerance expressed as nominal +/-XX, in engineering units; also may involve other characteristics such as acceptable leakage rate, as applicable and should be compatible with Launch Rules.)
5. Operational constraints affecting specified performance values.
6. Critical spacecraft configuration and interface requirements.

Release date for this portion of the specification will be four (4) months prior to spacecraft delivery.

This memorandum states the mutual agreement of the undersigned to the form, content and intent of a single checkout process specification for each Block II Apollo CSM that will receive a prelaunch checkout at KSC.

J. L. Pearce
Director CSM
Florida Facility

S. M. Treman
Director
Spacecraft Design

cc: G. W. Jeffs
R. L. Benner
A. B. Kehlet
G. B. Merrick
L. G. Rochester
M. Karp
J. P. Proctor
R. E. Barton

EXHIBIT NO. 1

EXAMPLE

CHECKOUT REQUIREMENTS

(Section 4.0 of C/O Spec for Florida Facility)

TF0001 ENVIRONMENTAL CONTROL SYSTEM SERVICING, ACTIVATION, AND VERIFICATION

Perform an ECS servicing, activation, and verification of the primary and secondary water-glycol loops, oxygen system, and suit loop system..

Performance of this checkout is a prerequisite to CSM system activation and verification operations.

TH0012 STABILIZATION AND CONTROL SYSTEM FREQUENCY RESPONSE

Perform an SCS frequency response checkout to demonstrate capability to gimbal the SPS engine, using both primary and seocndary gimbal motors, with the proper magnitude, rate, and direction.

Frequency and step response must be verified in both the LEM OFF and LEM ON operating conditions.

EXHIBIT NO. 2

EXAMPLE

CHECKOUT SPECIFICATIONS

(Section 5.0 of C/O Spec for Florida Facility)

ENVIRONMENTAL CONTROL SYSTEM

The specifications applicable to ECS servicing are as follows:

FFS026P	W/G Supply Pressure	55 +/- 15 PSIA
FFS027Q	W/G Flow	200 +/- 20 Lb/Hr
FFS028P	W/G Diff Pressure	35 +/- 20 15 PSID
FFS029T	W/G Return Temp	55 +/- 10 Deg. F
FFS030T	W/G Supply Temp	35 +/- 10 15 Deg. F

The above specifications apply after system stabilization.

STABILIZATION AND CONTROL SYSTEM

The specifications applicable to SCS/SPS engine frequency response are as follows:

INPUT AMP (Deg./Sec.)	FREQ. (CPS)	TIME (Sec.)	MEAS.	NOMEN.	VALUE (W/ TO L)
3.0	0.318	15	CH3517	Gimbal Pos, Pitch	(XXX+/-X)

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
APOLLO 204 REVIEW BOARD

IN REPLY REFER TO

TO: NASA Manned Spacecraft Center
Houston, Texas 77058

Attn: Dr. Joseph F. Shea
Apollo Program Manager

John F. Kennedy Space Center
Kennedy Space Center, Florida 32899

Attn: General John G. Shinkle
Apollo Program Manager

Mr. Rocco A. Petrone
Director of Launch Operations

FROM: MA/Apollo Program Director

SUBJECT: Minutes of Meeting at KSC, January 26, 1967

Attached for necessary action is a copy of the minutes of the meeting held at Kennedy Space Center on January 26, 1967 to consider possible improvements in spacecraft checkout based on experience of the past year.

/S/ Samuel C. Phillips
Major General, USAF

Attachments (3)

DISTRIBUTION:
See attached list

ENCLOSURE 7-11

MINUTES OF MSC/KSC/OMSF MEETING AT KSC
JANUARY 26, 1967

1. In accordance with an OMSF TWX 362 2204, dated December 22, 1966, a meeting was held at KSC (attendees listed in Attachment 2) to review spacecraft checkout experience over the past year and discuss actions that might be taken to improve checkout of subsequent spacecraft. Items discussed were those submitted by MSC and KSC prior to the meeting (Attachment 3).

2. The discussion of the agenda items resulted in the following agreements or actions:

   a. MSC and KSC to continue to track the 7 configuration verification discrepancies found by KSC on a spot check of 30 odd pieces of hardware to assure that the configuration control paperwork eventually reflects the "as is" condition and review the time lag between the hardware reconfiguration and the time this reconfiguration is reflected in the paperwork. A similar type spot check will be made on S/C 020.

   b. MSC and KSC will review the Cape receiving inspection records on 017 and consider the preparation or modification of inspection criteria for those items where the presence of well written criteria would tend to reduce inspection variances among Quality Control personnel.

   c. KSC will provide a Quality Control inspector to participate in the final inspection of subsequent spacecraft at Downey through spacecraft 102. MSC will also provide a NASA Quality Control inspector to participate in spacecraft receiving inspections at the Cape through 102. Data collected during these inspections will be used to refine and improve inspection methods and criteria.

   d. MSC will provide direction to see that all contractor and GFE non-flight hardware is clearly marked and so identified in the spacecraft paperwork.

   e. KSC will bring to the appropriate Program Manager's personal attention any non-flight hardware that is installed on a space vehicle and not clearly marked.

   f. KSC and MSC will arrange a subsequent meeting to discuss the other actions recommended in the KSC handout to improve overall quality and review the use of the Engineering Disposition Book.

   g. MSC indicated that PAR closeout action by NAA reflects the engineering order number or other specific written corrective action that has been taken to correct the problem.

   h. MSC will check to determine why EO number E15-420603 and 604 were not incorporated in spacecraft 017 before delivery to the Cape.

i. MSC will check recurrence control applied to the cabin relief valve (part number ME-284-0149-0021) to assure that the system is operating as it should.

j. KSC will provide MSC a specific list of areas where it would be helpful to consolidate several process specifications into a single process specification which summarizes requirements.

k. MSC will review MSC and NAA non-metallic crew bay material requirements documents to update them and assure they are compatible.

l. MSC will review NAA documentation on functional checkout and/or PIA time cycles on spare components and provide written guidance to KSC.

m. MSC will review the list of hardware problems presented by KSC in discussing design problems (electrical switch, communications cables, bi-metallic interfaces, DSE recorder, signal conditioner fuses, hand controller cable covering, water glycol and O_2 line installation) and assure that appropriate corrective action is in process.

n. MSC is preparing a revised flow plan and is reviewing the technical requirements to which the system and subsystem is tested as it progresses from assembly through checkout at the Cape. This system will be implemented for Block 2 spacecraft and will provide a better overview of the total testing done on flight hardware before launch. It will also assist in providing better visibility into the test status of hardware when the DD 250 is signed.

o. MSC will recheck the list of items indicated under Part VI, Level of Testing, in KSC handout to assure that the problems indicated have been fed back into NAA for appropriate corrective action.

p. MSC and KSC will take action to arrange for a joint review of the classes of problems found during checkout of each particular spacecraft after it has flown and discuss corrective action that can be taken to reduce the same type of problem on subsequent spacecraft.

q. MSC is taking action to assure closer control over the listing of engineering orders in the Configuration Verification Records of the appropriate spacecraft in accordance with the effectivity point in the EO.

r. MSC and KSC will have a meeting the week of February 13 and formally coordinate the Block II CSM, the LEM and the integrated Ground Operation Requirements Plans (GORP). Any unresolved problems will be presented to the KSC Program Manager and the MSC Program Manager for decision or submission to higher management levels for resolution. KSC will formally sign the basic GORP documents and approve all subsequent changes in writing. Coordination and sign-off on the GORP will be binding on both parties. Additional testing of the type specified in the GORP will not be added at the Cape without formal coordination. Changes recommended by either party will be officially submitted to the otherparty for approval. Contractual direction to the contractors will not be provided by CCA until coordination has been accomplished. As a part of the meeting during the week of February 13, MSC and KSC will develop a written change procedure to permit expeditious revision of the GORP. During this meeting consideration will also be given to reviewing a proposed system for controlling operational checkout procedures (OCP's) including the necessary interface with engineering orders.

s. MSC (Mr. Kapryan) and KSC (Mr. McCoy and Mr. W. Williams) will develop a proposed procedure for integrating into a single Board the present MSC Configuration Control Board at the Cape and the KSC Spacecraft Change Implementation Board. This proposal will include membership, responsibilities, appeal procedures, documentation, signatures, and other appropriate items. This proposal will be prepared for coordination and approval of the KSC Program Manager and the MSC Program Manager. After completion of FRT approval to remove or replace spacecraft flight hardware (components, panels, cables, etc.) will require approval of appropriate KSC and MSC personnel. KSC will develop written procedures to implement this basic policy, and coordinate it with MSC (Mr. Kapryan).

t. A discussion of the procedure for processing of failed hardware led to reconfirmation that MSC makes the decision as to where failure analysis is to be conducted.

u. MSC will review the paperwork associated with the expeditious return of failed hardware to a vendor for repair and return to the Cape and make appropriate changes to facilitate the process.

v. The return of ACE Station No. 5 from GAEC to the Cape will not take place before August 1, 1967. Therefore checkout at the Cape through the summer of 1967 will be limited to 4 ACE stations. KSC will review ACE program development verification, number and experience of maintenance personnel and other factors associated with utilization of their ACE equipment and will develop by March 1, 1967, any necessary recommendations to assure checkout schedule will support the OMSF official working schedule. MSC (Dr. Lanzkron) will provide necessary assistance in considering the use of MSC ACE equipment to assist in software development.

w. The Apollo Program Office (OMSF) is developing revised schedules which will show a working schedule based on an earliest possible launch date and assuming clean hardware is delivered from the factory. These dates are to serve as objectives for everyone to work toward in an effort to launch as early as hardware will permit and still assure mission success. This schedule will receive further review and discussion during the time period February 8-10.

/S/ Samuel C. Phillips
Director, Apollo Program
OMSF

/S/ Joseph F. Shea
Manager, Apollo Spacecraft
Program Office, MSC

/S/ John G. Shinkle
Manager, Apollo Programs Office
KSC

/S/ Rocco A. Petrone
Director, Launch Operations
KSC

SPACECRAFT CONFIGURATION

Altitude Chamber (K0034A) Versus Pad 34 Plugs Out (K0021)

ALTITUDE CHAMBER

- Umbilical In
- Carry-on Disconnected
- WaterGlycol - Internal Circulation
- H_2 Tank Pressurized with GN_2
- Cryogenic O_2 Supplied by GSE
- Water Tanks Filled
- Inner Hatch Installed
- Outer Hatch Not Installed.
- LV Simulator Attached
- GSE Power Supplied Through S/C Umbilical
- Boost Protective Cover Not Installed

PAD 34

- Umbilical In
- Carry-on Disconnected
- Water-Glycol - Circulated Through Spacecraft From GSE
- Gaseous O_2 Supplied by GSE
- Water Tanks Empty
- Inner Hatch Installed
- Outer Hatch Installed
- Mated to Booster
- Fuel Cell Substitute Unit Utilized

GENERAL INFORMATION (ALTITUDE CHAMBER RUN)

During the altitude chamber run, the spacecraft was powered up and all systems verified prior to crew ingress. After crew ingress, suit integrity tests are made and the inner hatch is closed.

The following functions were performed in the listed order after inner hatch closure.

a. Cabin purge and leak check.
b. Sleep switches installed in cobra cables (not applicable to plugs out, pad 34)
c. Post ingress switch list performed.
d. Logic and pyro busses armed
e. VHF FM, C-band transponder and S band checked.
f. Coolant temperature lowered to 45 ± 5 degrees F and the water glycol trimmed
g. Gas chromatograph signal checked.
h. Battery bus ties placed from off to auto.
i. Battery relay bus, battery A and B, circuit breakers closed.
g. Guidance system put in gyro compassing mode
k. The spacecraft was taken up to altitude. All testing and mission functions from here on were performed under altitude conditions (cabin pressure 5.71 psia, suit pressure 6.14 psia).

This points out that during the altitude runs, minimum testing is accomplished at sea level pressures. Whereas during the pad operation all testing is accomplished at sea level pressure.

The following list itemizes system tests performed on K0034 and K0021 prior to hatch closure

	K0034	K0021
G&N		
AGC Operational Test	X	X
DSKY Pushbutton Check	X	X
Uplink Downlink Check	X	X
Bank Sum Check	X	
C-Relay Alarm Checks	X	X
G&N Operations Test	X	X
Optics Power-on Test	X	X
GMC CLock Alignment	X	X
Negative Delta T	X	
SCS		
SCS Activate	X	X
BMAG Warm up	X	X
RF		
RF System VHF FM Test	X	X
C Band Test	X	X
Recovery Beacon	X	
VHF AM Test	X	X
HF Test	X	
S Band and TV	X	X
UDL UHF	X	
UDL		
End to end	X	
INSTRUMENTATION		
DSE	X	X
Flight Qual Recorder	X	X

ECS (See General ECS Configuration)

The following list itemizes system tests and general configuration deltas between K0034 and K0021 after hatch closure and prior to lift off for mission run. Coded (a) designates test is performed at altitude.

	K0034	K0021
Cabin Purge and Leak Test	X	X
Auto Water Boiling	X(a)	
SPS Abort and Reset	X(a)	
EDS Test		X
Normal Mission Preps	X(a)	X
Sleep Switches Installed in Umbilicals	X	
SPS Engine Gimbaled (MTVC)		X
RCS Static Firing		X
Floodlights On		X
FCSM SCS in SCS Mode		X
FCSM G&N Mode	X	
RCS Prop Isolation Circuit Breakers Closed		X
TVC Power 1 and 2 On	X	
Direct RCS On	X	
SCS Channel A/C Mode	X	
2 Engine Ops in Auto Mode	X	

LV Rates in Auto mode	X	
Water Accumulator in Auto Mode	X(a)	X
Non-Essential Telecon on AC 1	X	
Non-Essential Telecon on AC 2		X
Cryogenic Quantity Amplifiers On	X	
Drinking Water Sepply On	X	
Gas Chromatograph Panel On	X	
(Not Installed for K0021)		
Battery C to Main Bus A - Open	X	
Battery C to Main Bes B - Open	X	X
Battery Vent in Vent	X	
O_2 Heaters in Auto	X	
H_2 Fans in Auto	X	

ECS PREPARATION PROCEDURE AND SYSTEM TEST

Comparison of ECS configuration in the manned altitude chamber run OCP KOO34 and L/C 34 OCP KOO21 Plugs Out Test.

	K0034	K0021
GSE WATER GLYCOL ADJUSTMENTS		
ECS Prep (GSE)	X	X
Trim Unit No. 1 and 2 Verification (GSE)		X
Refrigeration Unit 1 and 2 Verification (GSE)		X
Adjust R1 on S14-140 (GSE)	X	X
Transfer Trim and Refr Units to ACE control		X
Transfer accum. quantity to remote (GSE)		X
Transfer Trim and Refr units to manual (GSE)		X
S/C SYSTEM VERIFICATION		
Cabin Air Fan Checks	X	X
Suit Compressor Checks	X	X
ECS Pump Check	X	X
ECS Coolant Loop Check	X	X
Pressurize H2 Tanks with N2	X	
Cabin Temp Control Checks	X	
Glycol Pump Deadhead Check	X	
O2 Tank Purge	X	
Suit Circuit Purge 98% O2 (Note 1)	X	X
Cabin Press Using S14-079 at Hatch Adap	X	X
O2 Press Relief Valve Crack Press	X	X
O2 Press Relief Valve Reseat Press	X	X
O2 Purge 20 Min at 14.7 psia	X	X
O2 Purity (Note 3) % in Cabin	X	X
Increase O2 Pressure to (Note 2) Press and Perform Leak Check	X	X
Install Hatch Plug	X	X
Install Outer Hatch		X
ECS CONFIGURATION PRIOR TO LIFT OFF		
ECS Radiators On	X	X
Battery Vent	X	X
Glycol Compressor Pump 1 on AC	X	X
Cabin Air Fans On	X	X
Suit Compressor Pump 1 on AC 1	X	X
Gas Chromatograph Cabin Auto	X	
Gas Chromatograph Start	X	
Waste Tank Inlet Auto	X	X
Potable Tank Inlet Open	X	X
Press Relief Both	X	X
Waste Tank Servicing Valve Closed	X	X
Cabin Repress Closed	X	X
Direct O2 Flow Reg Off	X	X
Pot H2O Heater Off	X	X

Cabin Temp Auto (R4) Full Decrease	X	X
Cabin Temp (S12) Manual	X	X
Steam Press (S23) Auto		X
Steam Press (S24) Incr/Decr Enter (OFF)	X	X
Temp in (S25) Manual (Note 4)	Auto	X
Glycol Evap H2O Flow (S22) OFF (Note 5)	X	X
H2O Ind (S10) Potable	X	X
Suit Evap (S8) Manual	X	X
Waste H2O Tank Refill (S36) OFF	X	X
H2O Accum (S26) Auto 1	X	X
H2O Accum (S22) OFF (CTR)	X	X
H2 Fans OFF	Auto	X
O2 Fans OFF	X	X
O2 Heaters OFF	Auto	X
O2 Pressure Ind Surge Tank (S28)	X	X
H2 Heaters OFF	X	X
Suit Ht Exch Gly-Evap	Note 6	X
Demand Reg Selector 1 and 2	Note 6	X
Demand Reg (Suit Test) OFF	X	X
Oxygen Surge Tank ON	X	X
O2 S/M Supply ON	X	X
O2 Entry ON	X	X
Glycol Reservoir Inlet Open	X	X
Water and Glycol Tank Press Regulator and Relief Normal	X	X
Glycol Reservoir Bypass Close	X	X
Glycol Reservoir Outlet Open	X	X
Glycol to Rad Open	X	X
Safety Latch OFF	X	X
Cabin Press Relief Right (Boost Entry)	X	X
Emergency Cabin Pressure OFF	X	X
PLSS Fill Valve Closed	X	X
O2 Main Regulator Normal	X	X
Suit Evap OFF	X	X
Evap H2O Auto	X	
Glycol Reserve OFF	X	X
H2O Accumulator 1 and 2 Remote	X	X
Glycol Evap Temp in Full Cool	X	X
Suit Flow Relief OFF	X	X
Suit Evap Glycol ON	X	X
Glycol Accumulator ON	X	X
Glycol Evap H2O Control Bypass OFF	X	Bypass
Suit Circuit Return Air Manual Valve Close	X	X
Surge Tank Press Relief Valve Auto	X	X
Glycol Press Bypass 1 and 2 ON	X	X
Louvers Cabin Open	X	
Drinking Water Supply ON	X	No Info
Cabin Temp As Is Battery Vent	X	No Info

NOTES. 1. Suit loop purge is performed twice prior to crew ingress in 0034.
2. 3-3.5 PSIG OCT 0021 and 5±.2 PSIG in OCP 0034.
3. 75% O2 purity required OCP 0034 and 95% O2 purity required OCP 0021 prior to crew ingress.
4. Difference is at 180 K altitude performing water boiling.
5. On for 3 minutes and then off in OCP K0034.
6. Removed by deviation 13-01 to update OCP to latest SW list configuration.

LIST OF REFERENCES

Reference documents used in the preparation of this report are as follows:

References	
7-1	Spacecraft Operational Checkout Procedure FO-K-0021 - S/C 012/014, updated Jan. 25, 1967. Titled: "Space Vehicle Plugs Out Integrated Test", dtd Dec. 13, 1966
7-2	GSE Checklist FO-K-10011-S/C 012. Titled: "LC 34 Checklist", dtd Oct. 25, 1966
7-3	Crew Countdown FO-K-5117-S/C 012. Titled: "Flight Crew Countdown", dtd Jan. 26, 1967
7-4	Vehicle Plan for Spacecraft 012 & 014 Section II, Part 1, Ground ooperations Requirements Plan (NAS 9-150), SID65-304-2-1, dtd June 19, 1966
7-5	Process Specification MA 0201-3214, Titled: "Overall Test No. 2 with Plugs Out Checkout Requirements for Spacecraft 012 & 014, Florida Facility, Launch Complex 34", dtd August 19, 1966
7-6	Spacecraft Operational Checkout Procedure FO-K-0034-A-1. Titled: "CSM Altitude Chamber Test", dtd Dec. 20, 1966
7-7	Apollo Pre-Flight Operations Procedure T-501, Pages 4 & 5. Titled: "Work Authorization - TPS", dtd June 27, 1966
7-8	Apollo Pre-Flight Operations Procedure 0-202. Titled. "Operational Checkout Procedure", dtd May 13, 1966.
7-9	Interim Discrepancy Report (IDR) No. 001 for OCP-K-0021, dtd Jan. 27, 1967
7-10	Daily Status Reports, Titled: "Status Report Spacecraft 012", dtd Jan. 23, 1967 and Jan. 27, 1967.
7-11	S/C 012 Test Outline, SP-64. Titled: S/C 012 - S/C 014 Florida Facility Test Flow Plan, dtd Aug. 10, 1966
7-12	Space Vehicle Plugs Out Procedure, I-20015-SA-204, Titled: "Space Vehicle Systems Plug Drop Test", dtd Jan. 18, 1967
7-13	Apollo Crew Abbreviated Checklist Mission AS-204, dtd Jan. 23, 1967
7-14	KSC Prelaunch Test and Checkout Requirements for S-IU-206 and Subsequent, NAS 8-14000, dtd Dec. 5, 1966
7-15	Prelaunch Test and Checkout Requirements for Saturn S-IB Stages, SDES-66-424, dtd Aug. 12, 1966
7-16	Catalog of Launch Vehicle Tests, Saturn V, Apollo Saturn 501, Section III of III Sections, Standby Procedures, GP-307, dtd Jan. 15, 1967
7-17	Catalog of Launch Vehicle Tests, Saturn V, Apollo Saturn 501, Section I of III Sections, Test Procedures, dtd Jan. 15, 1967
7-18	Apollo Saturn V Checkout Plan (AS-500F), K-V-041, dtd May 1, 1966
7-19	Test Specification and Criteria, KSC Prelaunch Checkout and Launch Operations, S-IVB-206, 1B67207, dtd Dec. 8, 1966
7-20	S-IVB-502 Stage End Item Test Plan, 1B63789, dtd Nov. 18, 1965
7-21	KSC Prelaunch Test and Checkout Requirements, S-IVB 1B, 1B66258, dtd May 24, 1966
7-22	Annotated Copy OCP FO-K-0021-1
7-23	EDS Overall Countdown Test, FO-K-0042
7-24	Spacecraft Launch Preparation Test Outlines, Report No. 9882, McDonnell Aircraft Corp., SEDR 9882, dtd Dec. 14, 1964
7-25	Gemini Spacecraft Number 12 Performance Configuration Specification, A900-12, dtd July 30, 1965
7-26	Project Gemini, Production Spacecraft Test Plan for Spacecraft Number 2, SEDR 301-2, dtd Feb. 25, 1964
7-27	Test Operations Production Spacecraft at AMR Facility, SEDR 309-1, dtd July 26, 1963
7-28	Project Gemini Test Operations Production Spacecraft at AMR Facility, SEDR 309 X, dtd Aug. 30, 1963
7-29	Titan III Test Procedure Manual, MC-66-2, dtd Feb. 1, 1966

ENCLOSURE 7-13

REPORT OF PANEL 8
MATERIALS REVIEW
APPENDIX D-8
TO
FINAL REPORT OF
APOLLO 204 REVIEW BOARD

A. TASK ASSIGNMENT

The Apollo 204 Review Board established the Materials Work Panel, 8. The task assigned for accomplishment by Panel 8 was prescribed as follows:

Assemble and summarize data and analyses related to flammability of spacecraft materials. Results of other programs as well as Apollo shall be considered. Requirements for additional testing shall be recommended. Review Apollo test conditions for adequacy. Make recommendations for materials or configuration changes to alleviate fire hazard. Perform analyses as appropriate to determine overall energy balance, correlations with temperature and pressure buildup, etc.

In addition to the above briefly summarized Work Statement, a detailed Work Statement was prepared and submitted to the Board on February 1, 1967, which contained the following salient features in keeping with above Work Statement:

1. Assemble, summarize, compare and interpret requirements and data describing the flammability of nonmetallic materials exposed to the crew bay environment of the spacecraft and in related applications.
2. Specify and authorize performance of tests and/or analyses to furnish additional information as to flammability characteristics of these materials alone, and in combination with fluids known or postulated to have been in the Spacecraft 012 cabin.
3. This panel, in support of Panel 5 - Origin and Propagation of Fire shall interpret and implement the requirements for analyses of debris removed from the spacecraft.

B. PANEL ORGANIZATION

1. MEMBERSHIP

The assigned task was accomplished by the following members of the Materials Work Panel:

Mr. W. Bland, Chairman, Manned Spacecraft Center (MSC), NASA
Mr. A. Busch, Kennedy Space Center (KSC), NASA
Dr. A. Staklis, Manned Spacecraft Center (MSC), NASA
Mr. W. Riehl, Marshall Space Flight Center (MSFC), NASA
Mr. A. Archer, North American Aviation, Inc., KSC
Mr. R. Olsen, North American Aviation, Inc., Downey
Mr. E. Welhart, McDonnell Company, St. Louis

2. COGNIZANT BOARD MEMBER

Dr. M. Faget, Manned Spacecraft Center (MSC), NASA, was assigned to monitor the Materials Work Panel.

C. PROCEEDINGS

1. APPROACH

The activities of the Materials Panel were divided into three major categories in implementing the panel work statement (Ref. 8-74, 8-75, and 8-76):

a. Determine the nonmetallic materials configuration of Spacecraft (S/C) 012.
b. Determine combustion characteristics and properties of these materials.
c. Conduct special tests and investigations.

The special tests and investigations conducted are separated into four broad areas:

a. Fire Initiation
b. Fire Propagation
c. Materials Criteria and Controls
d. Displays and Information

Within the fire initiation investigation, several studies were undertaken. These dealt with potential spark ignition sources, spontaneous ignition sources, and impact ignition sources.

The fire propagation investigation was divided into six subcategories. These included the usage and properties of flammable materials on S/C 012 and a theoretical analysis of materials combustion. Temperature mapping of S/C 012, the flammability of water/glycol, simulated mockup testing of materials configurations similar to S/C 012 and an evaluation of substitute materials for flammability were also included.

The criteria and controls investigation was directed to an evaluation of existing acceptance criteria for spacecraft nonmetallic materials located in the crew bay and to a determination of the effectiveness of controls of materials usage in design and fabrication.

The displays and information activity was directed to a determination of methods for presenting materials location and usage information, alternate nonflammable materials and materials properties and characteristics in graphical and usable form.

Status of the Materials Panel investigation program and special displays were maintained at KSC for use by Materials Panel Members and supporting personnel and by other Apollo 204 Review Board activities.

2. SCOPE OF THE REPORT

The scope of this report includes the following major categories of investigations:

a. Configuration of nonmetallic materials, including changes, in S/C 012.

b. Results of routine materials tests to determine combustion properties.

3. DETAILED TASK PROCEDURES

The following sections present technical results of Materials Panel investigations. The presentations include the objectives of the study, methods utilized and details of the results. The proceedings presented in this report are in general abstracted from more detailed reports referenced in Section E, Supporting Data.

4. NONMETALLIC MATERIALS CONFIGURATION OF S/C 012 COMMAND MODULE

a. OBJECTIVE

The nonmetallic materials configuration of S/C 012 was an essential element to evaluate materials combustibility data, potential ignition sources, propagation paths and intensity. A review of existing documentation was undertaken to develop a list of S/C 012 materials and test data.

b. APPROACH

A format containing required data was prepared. Data covering as-designed materials configuration, as-installed materials configuration from Discrepancy Report Squawks (DRS's) and Test Preparation Sheets (TPS's) and test data were included in compiling the S/C 012 nonmetallic materials list.

c. DATA FORMAT

The format is divided into four major sections: material description, location in the S/C, test information and quantity of material used. A sample data page is provided in Enclosure 8-2, Section E.

d. SOURCES OF DATA

(1) Design configuration data. Supporting References 8-1 through 8-13 were utilized.

(2) Test data. Supporting data References 8-14 through 8-27 were utilized. In addition, data available from the activities described in 5., "Routine Materials Tests", were added as they became available. Test data at oxygen (O_2) pressures to 21 psia covering the major combustible materials which contributed to the fire were available (Reference 8-91).

(3) Test conditions for existing data are shown in Table 1.

(4) Configuration changes. Documentation covering materials added to S/C 012 at KSC was reviewed. The documents reviewed included Discrepancy Reports (DR's), DRS's, and TPS's. The nonmetallic materials were identified and the amount used was noted. Photographs of the S/C as received at KSC and photographs of the S/C shortly before the fire were also reviewed for materials location and quantity.

(5) The crew bay materials usage lists of all contractors and suppliers were assembled into a master usage list. This list contains all of the materials that could have been used on S/C 012 but is not an as-built configuration list. This means that some of the materials on the list may not have been used and others may appear more than once. (Reference 8-28). See Enclosures 8-11 to 8-17 for location.

TABLE 1. SOURCE AND TEST CONDITIONS FOR EXISTING MATERIALS DATA

Note: All vertical tests are downward.

Source	Test	O_2 Pressure (psia)	Number of Tests
Collins (5-64)	Flash	15	
	Fire	15	
	Autogenous Ignition	15	
			61
Mass. Inst. of Tech. (1-67)	Flash	5	
	Fire	5	
	Combustion Rate (Vertical)	5	
			31
Hamilton Standard	Flash	5	
	Fire	5	
	Autogenous Ignition	5	
	Combustion Rate (Horizontal)	5	
			200
NAA (Hughes) (to 1-67)	Spark Ignition to 400°F	15	
			102
NASA (to 12-66)	Combustion Rate (Vertical)	5	
			112
Brooks	Combustion Rate (Vertical) (Horizontal)	5	
			66
Grumman	Autogenous Ignition	5	
	Combustion Rate (Horizontal)	5	
			48

e. MATERIALS USAGE SUMMARY

A summary of the nonmetallic materials used or suspected of being used in the Command Module (C/M) of S/C 012 is presented in Table 2 (Ref. 8-28).

TABLE 2. MATERIA LS USAGE SUMMARY

Generic Type	Products Identified
Solvents	18
Lubricants	86
Foams	82
Thermal Insulations	7
Fabrics	395
Tapes	123
Encapsulants	164
Electrical Insulations	185
Plastics	394
Elastomers/Rubbers	238
Paints and Coatings	222
Laminates	78
Adhesives	322
Glass	39
Command Module, Coolant	1
Miscellaneous	174
Total	2,528

f. MATERIALS ADDED AT KSC

Of the listing in Table 2, the following materials shown in Table 3 were added at KSC. (Ref. 8-55 and 8-64).

TABLE 3. MATERIALS USED IN THE C/M AFTER DELIVERY

Material Category	Number of Material Types	Quantities (Approximation)
Adhesives	9	32 ounces
Lubricants	8	10 ounces
Paint and Coatings	6	9 ounces
Encapsulants	6	12 ounces
Tapes	13	80 square inches
Solvents	4	Unknown
Miscellaneous	29	Several instances of large quantities, Ex: 960 in^3 polyurethane foam, 7 lb. Velcro, etc.

The complete documentation of all DR's, DRS's, TPS's used in preparing this compilation are available and were bound int· vo ..ies by categories.

g. ESTIMATED TOTAL QUANTITIES OF MATERIALS

In addition to the document review a determination was made of the appropriate mass of major combustible materials which were directly exposed to the cabin environment (not in closed boxes or stowage compartments) in S C 012 at the time of the accident (Ref. 8-57, 8-64) see Table 4.

TABLE C-4, ESTIMATED QUANTITIES OF MAJOR COMBUSTIBLES EXPOSED TO CABIN ENVIRONMENT ON S/C 012 AT THE TIME OF PLUGS OUT TEST

Material	Function	Total Weight (lbs)	Portion Installed at KSC (lbs)	Portion which was non-flight (lbs)
NON - GFE MATERIALS				
Velcro Pile	Zero-G attachment mechanism	3.9	1.1	
Velcro Hook	Zero-G attachment mechanism	5.9	4.5	
Uralane 577	ECU Insulation Pads on floor	5.2	2.4	2.4
Trilock	Couch Pads	2.7		
Green Nylon	Covering for O_2 suit hoses	0.2		
Raschel Knit (nylon)	Debris Net	2.4	1.3	
Cotton Cloth	Remove-before-flight tags	0.5	0.5	0.5
Plexiglas	Display panels Flood lamp covers	1.8		
Nylon Webbing	Tie-down straps Couches Storage Compartments	3.9		
Nylon oxford cloth	GSE Window covers	1.0	1.0	1.0
Nylon cord	Electrical cable tie wrap	9.1		
Nylon tape	Crew provisions equipment Binding for debris nets	5.7		
Paper (non-flight)	OCP, Note paper	6.9	6.9	6.9
Paper (flight)	Flight/Preflight checklists	1.0	1.0	
Velostat	Covering for Uralane floor pads	0.1	0.1	0.1
Silicone foam	ECS Line insulation	5.0		
GFE MATERIALS				
Cotton cloth	Garments	4.3		
Lexan	Visors	3.0		
Nomex fabric	Garments	6.4		
Nylon Oxford	Garments	3.5		
TOTAL		72.5	18.8	10.9

Displays have been prepared showing the location of Velcro, Uralane Foam, Raschel Knit and Space Suits used in S/C 012 and their location (See enclosures 8-11 to 8-17).

h. Nonmetallic Materials Status

A review of the acceptability and test status of materials identified on this list to the NAA MC999-0058 criteria was accomplished. The approved and waiver status of materials in Government Furnished Equipment (GFE) to MSC-A-D-66-3 (Ref. 8-85), was also determined. The results are reported in a subsequent section on Criteria and Controls.

i. SUMMARY

The nonmetallic (potentially combustible) materials configuration for the major elements of the as-designed configuration of S/C 012 and for the modifications actually installed at KSC was obtained (Ref. 8-28). Results have been tabulated in a standard format and reviewed for status. Tests have been initiated where data were not available. (See Paragraph 9). The precise nonmetallic materials configuration of S/C 012 was not obtained. There is some uncertainty about the materials used in the black boxes and materials applied during assembly at Downey.

5. ROUTINE MATERIALS TESTS

a. OBJECTIVE

As the compilation of data described in Section 4, "Nonmetallic Materials Configuration of S/C 012 Command Module" proceeded it became evident that test data were not available on the majority of materials used. A routine testing program was implemented to develop test data on some of these materials at one atmosphere or 16.5 psia oxygen (Ref. 8-31).

b. PROCEDURE

Procedures for testing were prepared and accuracies determined using Nomex cloth as a standard (Ref. 8-80). The following procedures were prepared:

Nonmetallic Materials Combustion (Propagation) Rate Test
Autogenous Fire Point Determination
Flash and Fire Point Determination of Nonmetallic Material
Combined Thermogravimetric Analysis and Spark Ignition Test
Electrical Wire Insulation and Accessory Spark Ignition Test
Electrical Wire Insulation and Accessory Flammability Test

c. STATUS OF MATERIALS TESTING AS OF MARCH 8, 1967 (Ref. 8-80 and 8-98)

2,527 Materials identified and tabulated
665 Materials determined to require testing
474 Materials orders
446 Materials shipped by supplier
429 Materials received at MSC
280 Tests in progress
245 Tests completed

d. REPORTS

Additional test results applicable to this Section of the report will be contained in Appendix G. Test data are logged in to the Materials List (Ref. 8-28) as they are reported.

e. RESULTS

Results obtained on several samples of materials used in large quantities in S/C 012 are listed in Table 5. Prior test data at 5.0 psia oxygen are also shown for comparison (ref. 8-33 and 8-91).

TABLE 5

Average Downward Flame Propagation Rates (In/Sec)			
Material	Oxygen Pressure		Ratio of Burning Rates
	5.0 psia	16.5 psia	
Raschel Knit (Blue)	0.4	1.0	2.5:1
Velcro Hook (Blue)	0.5	0.8	1.7:1
Velcro Pile (Blue)	1.4	2.5	1.8:1
Trilock	1.1	1.8	1.7:1
Polyurethane Foam	2.1	4.5	2.2:1

As stated, the above data are downward rates, i.e., the slowest rate possible at 1 g in 16.5 psia oxygen pressure. Upward rates are much higher. The average overall rate for materials as installed in S/C 012 will be much greater than those shown above.

f. SUMMARY

The materials which probably contributed heavily to the fire burned at least twice as fast at the accident conditions (16.5 psia) than that at which they were evaluated for space flight (5 psia).

6. SPECIAL INVESTIGATIONS AND TESTS - FIRE INITIATION

Early tests were primarily concerned with materials (solvents and liquids) that might ignite with electrostatic sparks or with low energy arcs.

The extremely low energy reported to ignite solvents and gases in 15 psia of oxygen prompted a search for possible presence of solvents in the spacecraft especially as they might be absorbed on flammable solids thereby sensitizing them to ignition and promoting propagation. The approximate spark ignition thresholds of flammable solids with and without absorbed solvents and glycol coolants were evaluated in laboratory tests. The electrostatic charging of materials and the space suit were studied. Arcing of audio circuit connectors in various concentrations of a solvent in 16.5 psia oxygen atmosphere were also tested.

Impact ignition in gaseous 16.5 psia oxygen was suggested from liquid oxygen experience and is being tested.

Water/glycol spillage and cleanup simulations on wire bundles and connectors are in progress to study corrosion-induced short circuits and electrical heating or arc ignitions.

Spontaneous ignition was also evaluated as a potential source mechanism (Ref. 8-33).

a. RETENTION OF SOLVENTS

OBJECTIVE

Investigate the contribution towards the fire of any solvent absorbed by the more widespread non-metallic materials in the cabin by evaluating solvent evaporation data and analysis.

PROCEDURE 1

Air-dried samples were weighed, saturated with liquid solvent, and allowed to air-dry until essentially free of solvent while being weighed.

RESULTS 1

Velcro hook samples soaked in methyl-ethyl-ketone (MEK) for ten minutes absorbed 3.2 x 10^{-5} lb/in^2 of solvent. When evaporated into 50-percent relative humidity 75°F room air, they retained as much as 40-percent of the solvent for 5 hours (Ref. 8-103).

PROCEDURE 2

Tests with samples of Velcro pile, Uralane, Velostat covered Uralane, and couch material saturated with MEK for approximately ½ minute, air-dried for either 15 minutes or for 1 hour and then covered so that evaporation from the material had to take place by diffusion under the edge of an inverted 20 cc conical cover were conducted as described in Ref. 8-41. These tests were designed to determine the likelihood of vapor entrapment by equipment placed on saturated materials.

RESULTS 2

Diffusion of MEK and air under the edge took place rapidly. Vapor concentration fell below the 1.9-percent lean limit of flammability in less than 1 1/2 hours (Ref. 8-103). However, the results would be modified (1) if the edges of the material were sealed, (2) if the materials were not allowed to dry or (3) if the ratio of edge area to volume were very small. In these cases evaporation would be reduced and trapped pockets and/or heavy film layers of flammable mixture solvent vapors could have existed at the time of the fire.

SUMMARY

Velcro hook material can become saturated (after 10 minutes) with small amounts of MEK (3.2×10^{-5} lb/in^2). When exposed to a 50-percent relative humidity, 75°F environment the solvent retention in the sample decreases after 5 hours to 40-percent of the total amount absorbed.

Combustible concentrations of MEK solvent were not released into air from wetted Velcro pile, Uralane foam and couch material except for a short 1 1/2 hour period under conditions which restricted diffusion of vapor and air through the material to an area under the edge of the covering object.

The presence of significant volumes of concentrated solvent vapor in the spacecraft is unlikely. However, the retention of solvents in the surface layers of solid flammable materials could possibly contribute to their ignition (Ref. 8-103).

b. MATERIALS ODOR EVALUATION

OBJECTIVE

Odors resembling "sour milk" and MEK (see Materials Time Line, Enclosure 8-8) were reported. The objective of this analysis was to identify potential sources of these odors.

RESULTS

The evaluation of the "sour milk" odor involved the review of the K-bottle O_2 analyses, the Beckman Analyzer analyses, a gas sample taken at the crew mouthpiece and earlier sample analyses from August 29, 1966 to January 23, 1967. The review of the K-bottle analyses revealed no unusual impurities and the gas analyses met specifications as required. The analysis of gas from the two Beckman Oxygen Analyzers revealed no significant information on "sour milk" odor.

The gas sample taken at the crew mouthpiece on January 27, 1967 revealed approximately 400 ppm of unidentified hydrocarbons which could contribute to an odor condition (lab report Number TS75381 indicated odor to be of human origin).

A summary of previous analyses including earlier manned altitude testing samples revealed no significant information to identify any "sour milk" odor.

Re-Interrogation of witnesses revealed the following:

(1) There were no reports to the contrary that "only very minor amounts of solvent were introduced to the cabin on January 27, 1967" and these were by way of slightly dampened, wiping materials. No "spillage" or "dripping" of solvents was recalled.

(2) There was agreement that no one smelled anything of significance in the cabin during hatch closeout activity.

(3) There was general agreement that the strongest odors were detected at initiation of the first (20 minutes) cabin purge operations, approximately 3:32 pm EST, and decreased toward a "slightly detectable" level at completion of the second (10 minute) cabin purge operation approximately 4:18 pm EST. The odor was detected both within the white room and outside on Level A-8. There is also evidence which tends to indicate that this odor was was emitting from the steam duct just below the lower edge of the cabin hatch. An on-site review revealed that the configuration could allow some of the flow of gas from the steam duct to be deflected up into the white room and some of it could also be deflected downward into the general area of Level A-8. The other emission points of this odor were at the gas analyzer inlet bleed port and at the analyzer squeeze bulb exhaust port. Odors were detected at these points during environmental sample extraction.

(4) Description of the odor by the persons interrogated was that it was (1) MEK, (2) smelled "like" MEK, or (3) smelled like a solvent.

It appears that a fair degree of uncertainty is associated with identification of odors. Data indicate that the first threshold of smell for solvents such as MEK and isopropyl alcohol is approximately 0.01 percent to 0.03 percent by volume. The concentration that might be described as strong, irritating, and/or sickening is in the range of 1 percent to 4 percent by volume.

Samples of gas taken from the Ground Support Equipment (GSE) prior to the accident and also from the reassembled GSE system at the site provided negative results on significant hydrocarbon content. Solvents initially in the GSE would have been purged dry in the process of cabin purging. There is no reason to expect that further investigation will uncover a proof of solvents introduced by the GSE system.

SUMMARY

No particular suspect item was identified as emitting a "sour milk" odor although some of the Room Temperature Vulcanizing (RTV) potting compounds have distinct, pungent odors that probably come closest to fitting this odor description.

It is possible that accumulated solvent vapors could have been expelled through the steam duct during cabin purge.

Since the Command Pilot opened his faceplate for approximately 4 minutes at 6:19 pm EST and did not report significant odor concentrations it is likely that there were no solvent mixture concentrations in open areas (areas where the cabin fan produced reasonable flow). It should be noted that outward flow from the faceplate opening does not preclude cabin odor detection.

There is no evidence that significant concentrations or organic vapors existed in the spacecraft at the time of the accident (Ref. 8-54).

c. ELECTROSTATIC SPARK IGNITION

OBJECTIVE

The objective was to investigate the possibility of generation of sufficient electrostatic energy by movement of a suited astronaut to ignite combustible fuel-oxygen mixtures and materials of the type found in the S/C. Solid materials with remnant solvent had to be evaluated to determine required energy for ignition (Ref. 8-29).

PROCEDURES AND RESULTS

(1) Nylon fabrics, Raschel knits, polyethylene and neoprene were tested by rubbing with nylon. Only the nylon materials had appreciable charges generated on them at 50 percent relative humidity. Those that did not develop charges at 50 percent were tried again at 8 percent relative humidity and found to be still without appreciable charge (Ref. 8-32).

(2) In the laborator a suit on a subject was charged by rubbing with nylon. He sat and then reclined on a linoleum covered metal table used to simulate spacecraft couches. Volt-

ages and energies induced were somewhat higher than the values later obtained in the spacecraft itself.

Capacity measurements were made using a 60 cps capacitance bridge and a radio frequency capacity meter. For the reclining subject they ranged from 500 to 600 picofarads. For the metal parts of the suit an increase over the theoretical values is explainable by coupled capacity of other objects such as the suit neoprene bladder and other metal parts.

TABLE 6

Maximum Voltages Induced and Energies Calculated

Item	Potential, KV	Energy, Millijoules (mj)
Neck ring	2.1	1.36
Exhaust fitting	2.2	0.15
Inlet fitting	2.2	0.15
Zipper	1.7	0.56
Wrist ring	1.9	1.1
Subject and EKG lead	3.3	3.75

Resistances to ground which were measured at 10^9 to 10^{11} ohms would result in some loss of electrostatic energy during the process of measurement.

(3) A suited subject in C/M 014 at 8 percent relative humidity showed it was possible to obtain comparable capacitances to ground as in the laboratory. The subject's motion on the couch resulted in the generation of one (1) KV (Ref. 8-104 and 8-105).

(4) Capacitance spark tests showed that certain materials are ignitable by spark energies as follows (Ref. 8-79):

Material	Dry	Damp
Uralane foam	190 mj	40 mj (MEK and isopropyl alcohol)
Cotton (constant wear garment)	ª	210 mj (dampened with face oil)
Velcro	ª	200 mj (ethylene glycol)

ª No ignition up to 300 mj

SUMMARY

Sufficient electrostatic energy (about 4 mj) can be stored on a suited astronaut to ignite MEK vapor and methane in 14.7 psia O_2 (0.002 to 0.004 mj required) (Ref. 8-42). Samples of suit and other spacecraft materials were not ignited by this energy level even when soaked in combustible fluids which were then allowed to evaporate for about 5 hours in a laboratory environment before being subjected to the spark test.

d. COBRA CABLE SPARK IGNITION TEST

OBJECTIVE

Reports of Cobra Cable connect-disconnect actions immediately prior to the fire were received. A test was designed to investigate the possibility of igniting flammable MEK mixtures in high concentrations of gaseous oxygen. This was accomplished by breaking and mating spacecraft connectors with power applied. For the test, two cables were fabricated using spacecraft approved materials and spacecraft qualified Deutsch Connectors.

PROCEDURE

The test setup consisted of three power circuits routed through the Deutsch Connectors in the pressure chamber to loads outside the chamber. The loads were identical to the circuit loads used in C/M 012. The communications load was an identical impedance (600 ohms) to that of a pressure suit helmet headset. The biomedical load was a physio-simulator. The simulator has a DC-DC converter which is flight-qualified and identical to the three used by astronauts in S/C 012. The converter had an input impedance of 300 ohms when loaded.

The spacecraft microphone amplifiers were powered from a 28-volt DC battery through a series-dropping resistor. Therefore, the spacecraft power source did not present any significant inductance. The test power supplies did present some inductances, since no dropping resistor was used. This test, therefore, presents a more severe arcing condition than the spacecraft system which was simulated.

Three separate AC to DC rectifier/transformer power supplies were used, one for the right microphone 16.8 VDC, one for the left microphone 16.8 VDC and one for the biomedical converter 28.2 VDC (Ref. 8-48 and 8-49).

RESULTS

With the circuit previously described increasing concentrations of solvent were established in the pressure chamber.During the first test the chamber was filled with air at ambient conditions. In the ambient condition the Deutsch Connectors were separated three times under circuit load. During the connector breaks 200-frame-per-second 16 mm pictures were taken to record any sparks or ignition. No sparks or ignitions were noted either visually at the time or on the film.

The second test setup was run with 97-percent oxygen at ambient in the chamber. The oxygen concentration requirement was 96-percent or greater. Chemical analysis revealed the oxygen concentration to be greater than 97-percent. With power on the circuit the connectors were separated a minimum of two times. No sparks were generated with sufficient energy to ignite the connector.

Other tests were performed with MEK concentrations of 2.0-percent, 4.0-percent, 8.0-percent, and saturated (less than 15.4-percent with the remaining atmosphere having an oxygen concentration of greater than 97-percent. A minimum of three separations and remates were performed at each mixture level. No sparks were initiated with sufficient energy to ignite the mixtures.

Modification No. 1 reconfigured the circuitry so that the current was increased to 150 ma. This is 2.5 times maximum operating current which approximates the worse case. Namely, the maximum current drain encountered if the biomedical power were shorted in the spacesuit umbilical. The connectors were separated several times with 4.0-percent gaseous volume of MEK in the chamber. No sparks were generated of sufficient energy to ignite the mixture.

Modification No. 2 configured the circuitry so that single wired pins could be pulled at 60 ma, 28 VDC (normal operating conditions). The pins were pulled twice at MEK concentration of 4.0-percent and once at 15.0 percent. No sparks were generated with sufficient energy to ignite the mixture. No sparks were seen by an observer or recorded on the high speed film (Ref. 8-48 and 8-49).

SUMMARY

Separating simulated Cobra Cable audio and biomed 16-volt circuits produced neither visible arcs nor ignition. Separations of connections at maximum nominal power with MEK-saturated O_2

and at 2.5 times nominal power in MEK concentrations to 4 percent, all in 16.4 psia oxygen produced no ignition. Tests using flight type Cobra Cables with audio center loads and battery power supply will be reported in Appendix G.

e. IMPACT SENSITIVITY OF MATERIALS IN GOX

OBJECTIVE

It is known that many materials in contact with liquid oxygen (LOX) are capable of exploding or igniting when subjected to mechanical shock or some other sudden energy surge. Organic materials of the type used in S/C 012 such as netting, lubricants, foams and Velcro are examples of ignitable substances.

Whether such materials form impact-sensitive hazards in low-pressure gaseous oxygen was unknown. Thus it was decided to investigate the feasibility of this method of fire initiation in gaseous oxygen at 16.5 psia and with typical flammable materials in S/C 012.

RESULTS

A standard method of evaluating the compatibility of materials with LOX has been used by Marshall Space Flight Center. The test equipment is shown in Reference 8-30. The test equipment was modified to permit impact of materials in contact with gaseous oxygen at slightly above atmospheric pressures. This corresponds to spacecraft conditions. Impacts are applied by a 20 lb plummet falling 43 inches and delivered through a 1/4-in. diameter striker pin face (less than 72 foot-pound). The chamber was purged with sufficient oxygen to maintain a 5 psig differential for fifteen minutes then bled off to 16.7 psia prior to impact.

The following materials were tested under impact in contact with gaseous oxygen (GOX). Each was applied to a 1-inch diameter disc of aluminum for test purposes:

- Velcro Hook (pressure-sensitive adhesive backing)
- Velcro Pile (pressure-sensitive adhesive backing)
- Velcro Hook and Pile together (pressure-sensitive adhesive backing)
- Velcro Hook - Cross-cut grooves to expose adhesive
- Velcro Pile - Cross-cut grooves to expose adhesive
- Velcro Hook - Creased intentionally during application
- Velcro Pile - Creased intentionally during application
- Raschel Knit

Six Velcro hook samples were run. No fires resulted but in two of these burnt odors resulted. Three samples of Velcro pile on the hook were run. In these one burnt odor was detected and one sample ignited and burned vigorously. Of three samples of Raschel Knit impacted to date two ignited and burned (Ref. 8-30).

SUMMARY

These tests have shown that mechanical impacts on Velcro or Raschel Knit in contact with 16.5 psia O_2 can produce ignition and burning. A survey of spacecraft loose and movable objects revealed no possible high-impact condition on flammable materials.

f. AUTOGENOUS IGNITION SCREENING TEST OF S/C 012 MATERIALS

OBJECTIVE

Tests were undertaken to determine if combinations of solvents and materials could lead to unusually low spontaneous ignition temperatures in the oxygen atmospheres used in the S/C 012 test.

PROCEDURES

The tests were run in stainless steel pressure vessels equipped with a viewing port, thermocouple and a method of maintaining a 16.5 psi O_2 atmosphere together with a heat source. All samples were exposed to programmed heating, culminating at 400°F for ten minutes. They were then examined. Samples for gas chromatographic analysis were taken.

Materials which have a significant capacity for absorption of solvents such as foams and fabrics were tested in the as-received condition. This was done after soaking in methyl-ethyl-ketone, isopropyl alcohol, 50-50 ethylene glycol/water and in various combinations of these fluids. Samples were allowed to dry for approximately 5 hours prior to testing. Materials exposed to these tests were as follows:

Uralane Foam
Velostat
Velcro (various colors), Hook and Pile
Raschel Knit
Trilock

Materials tested without solvents were as follows: (Ref. 8-46 and 8-93)

Epon 828	Minn Hon 6745A Oil
Mystic Tape	Bray Oil Lube 812
DC 4 Lubricant	PR 240 AC Lubricant
Rayclad Sleeving	Versilube 300
EC 1469 Adhesive	DC 33 Lubricant
Aero Shell Grease	NOPCO Foam A 206
AiResearch Grease	3M, No. 27 Tape
DC 30-121	Nomex-HT-1 Suit Fabric
Epon 828 + Versamid 115	RTV 90 Encapsulant
	RTV 577 Encapsulant
Stycast 1090	RTV 560 Encapsulant
Epon 934	Organoceram
EC 1469	

SUMMARY

No autogenous ignition of materials tested was detected at or below the 400°F test limit even samples treated with cleaning solvents.

g. EFFECT OF WATER/GLYCOL ON WIRE BUNDLES

OBJECTIVE

This task was undertaken to determine the effects of spacecraft cabin environment on electrical wire bundles of S/C 012 types which had been exposed to water/glycol at some previous time.

It has previously been observed that flammable aircraft wire insulation such as polyvinylchloride (PVC) and nylon may burst into sustained flames in air even though adequately protected with circuit breakers. This can occur provided the following conditions are present:

(1) Insulation on adjacent wires is damaged to the conductors.

(2) Sufficient moisture is present to bridge the damaged areas.

(3) An electrical potential exists between the conductors of the damaged wires. (Ref. 8-38, 8-39 & 8-78).

These wet-wire fires were observed without tripping circuit protective devices because the current through the wires may be as low as 10 percent to 20 percent of the regular wire current at the time of ignition. The above results were recorded in a Lockheed Company film (Ref. 8-92 and 8-94).

The present task was undertaken to determine whether spacecraft wire bundles were susceptible to fire initiation and propagation as observed in the Lockheed tests.

PROCEDURE

Tests are in progress at NASA Manned Spacecraft Center on wire bundles. The test procedure includes a method for keeping the wire bundles moist with the water/glycol solution. Several wires in each bundle have intentionally-damaged wire insulation. The tests will be continued for at least several months to verify whether or not the effect of the water/glycol is appreciable.

In a special test Teflon covered shielded wire that had been purposely cut through to the conductor and exposed to ECS coolant caught fire. The fire occurred after about 8 hours in ambient atmosphere with less than 5 amperes passing through the conductor. The coolant was applied as droplets into the damaged area (Ref. 8-107).

SUMMARY

Initial test results show that fire initiation is possible. Additional test results applicable to this section of the report will be contained in Appendix G.

h. EFFECT OF WATER/GLYCOL ON CONNECTOR ASSEMBLIES

OBJECTIVE

Water/glycol coolant spillage occurred on a number of wire bundles and connectors used in S/C 012. The objective of this test program is to evaluate the effect of water/glycol and of the cleaning procedures used on S/C 012 on connectors similar to those used in S/C 012.

PROCEDURE

A series of tests have been defined to determine the effects of water/glycol spillage on wire bundle assemblies with connectors. A total of twenty-nine harness assemblies were ordered from NAA Downey for this testing. The assemblies are as follows:

V16-420337, CO5W5-P91	5 assemblies
V16-420303, CO5W5-P167	5 assemblies
V16-420308, CO3W15-P50	5 assemblies
V16-420307, CO3W15-P58	5 assemblies
V16-420316, CO1W1-J94	5 assemblies
836598-1-1	1 assembly
836600-1-1	1 assembly
836602-1-1	1 assembly
836599-1-1	1 assembly

These wire harness assemblies were selected since they represent harnesses that have been subjected to water/glycol (MBO 110-006, Type II) spillage on S/C 012. These harnesses are ECU cable harnesses, SCS-ECA cable harnesses and spacecraft harness assemblies located under the ECU.

The test environment is 75°F, 100 percent oxygen at 14.7 psia. These types of tests will be carried out as follows: (Ref. 8-83)

(1) Test A - Dip the cables and connectors in water/glycol for 30 seconds and allow to drip dry. Disassemble the connectors and clean per the procedures used on S/C 012. Rejoin the connectors and apply spacecraft voltages and currents and monitor the results.

(2) Test B - Test B is the same as Test A except the connectors are not cleaned and dried.

(3) Test C - Immerse the cables and connectors in a bath of water/glycol in the O_2 atmosphere. Apply spacecraft voltage and currents and record all readings. Allow the wire bundles and connectors to remain immersed in the water/glycol solution and continuously record circuit resistances.

Tests A and C will be run at KSC while Test B will be run at White Sands Test Facility.

SUMMARY

Test results applicable to this section of the report will be contained in Appendix G.

i. REVIEW OF KSC CONNECTOR TEST WITH WATER/GLYCOL

OBJECTIVE

A test conducted during October and November 1966 at KSC on a connector which had been subjected to ethylene glycol in which shorting occurred under DC load came to the attention of the Panel. This test was investigated for applicability ot the fire investigation.

RESULTS

A review as contained in Ref. 8-66 and 8-67 of test requirements, objectives, test techniques and results related to the special test show that test personnel were properly concerned about the effects of water/glycol spillage on spacecraft electrical equipment. To evaluate the effect of water/glycol on S/C connectors they chose to apply a worse-case condition to a worse-configuration spacecraft-type electrical connector in a set of laboratory tests to check the effectiveness of a proposed vacuum-environment cleaning technique. Accordingly, a spacecraft-type connector partially equipped with pins and wires but without plugs in unused pin holes or potting applied to the exposed ends of the connector was dipped in a water/glycol solution of the type used in the C/M. This resulted in water/glycol being introduced directly into the components of the connector. After a number of operations involving resistance measurements, vacuum drying, room air storage, disassembly, cleaning, washing in water/glycol solution, reassembly and "drip drying," the connector was tested with active AC and DC circuits. The DC circuit failed because of an internal short. A later test at less voltage (28 compared to 35) was run for about the same length of time without failure.

SUMMARY

In analyzing test techniques, test results and statements made by the main participants in this test, it appears that the environment and the hardware were not representative of spacecraft equipment or environment but represent an extreme set of conditions which have not been known to exist in S/C operation. Thus, the results are not directly applicable to Apollo S/C equipment. Currently planned laboratory tests of real spacecraft connectors and cables wetted with water/glycol constitute a better source to judge the hazard of such events.

7. RESULTS OF SPECIAL INVESTIGATIONS AND TESTS - FIRE PROPAGATION

This section of the report deals with investigations and tests to evaluate the propagation of the fire.

The effect of foam insulation burning in 16.5 psia oxygen on aluminum oxygen supply lines in causing failure to these lines was evaluated. Investigations of the leakage of water/glycol solutions and residue were also undertaken. Temperature mapping of S/C 012 based on the condition of materials in various locations was investigated. The correlation of Command Module mockup tests with the S/C 012 configuration and condition was also investigated.

An analysis of combustion characteristics of materials was undertaken to evaluate the S/C 012 nonmetallic materials configuration from a combustibility standpoint.

a. EFFECT OF BURNING FOAM INSULATION ON OXYGEN LINES

OBJECTIVE

The objective of these tests was to determine if burning foam insulation on aluminum oxygen supply lines in 16.5 psia oxygen could cause failure of these lines.

PROCEDURE

Uralane foam insulation was placed in separate tests on and under oxygen lines and ignited in 16.5 psia oxygen. Foam thickness and weight was selected to duplicate the amounts used on S/C 012. The oxygen lines were selected to represent lines used in S/C 012 (1/4-inch outer diameter, .035-inch wall thickness).

Normal oxygen flow was maintained in these lines throughout the test. The following specific tests are planned:

(1) Foam insulation around a 100 psia aluminum line.
(2) Foam insulation placed under a 100 psia aluminum line.
(3) Foam insulation near a soldered joint of a 100 psia aluminum line.
(4) Foam insulation placed under a 900 psia aluminum line.
(5) Insulation and lines configured as in S/C 012 per test request.

RESULTS

Tests number 1 and number 2 are completed. No failure of the aluminum lines occurred when the foam insulation was burned (Ref. 8-98).

SUMMARY

Foam insulation representative of a single insulated line as installed in the S/C 012 ECU when burned in a 16.5 psia oxygen does not cause failure of a 1/4-inch, .035-inch wall thickness, 100 psia aluminum oxygen line.

Results from the remainder of the tests pertinent to this section of the report will be reported in Appendix G.

Additional tests are planned to determine the effect of a burning foam on soldered joints and 900 psia oxygen lines and lines configured as in S/C 012. These additional test results applicable to this section of the report will be contained in Appendix G.

b. WATER/GLYCOL LEAKAGE IN SPACECRAFT

OBJECTIVE

It was postulated that water/glycol (Ref. 8-96 and 8-97) leakage in S/C 012 could have contributed to the propagation or initiation of the fire. This study was initiated to determine the instances of water/glycol spillage in S/C 012, 009, 011, 017, and BP 014.

RESULTS

General: A review of documentation was conducted to determine the extent of water/glycol leakage in S/C 008, 009, 011, 012, 017, and BP 014. The records disclose that the water/glycol was MB0110-006 Type II. The following summary is a result of the review:

Vehicle Number	Instances	Total Leakage (Oz.)
S/C 008	1	16
S/C 009	1	2
S/C 011	6	52
S/C 012	6	90
BP 014	14	96 - 160 (est)
S/C 017	7	Unknown

No failures of spacecraft or boilerplate cables, harnesses, components or connectors have been attributed to the effects of water/glycol leakage.

S/C 012 The following instances of water/glycol leakage have been recorded against the ECS of S/C 012.

(1) ECU Removal at Downey - 2 pints. Approximately 2 pints of water/glycol leaked during ECU removal at Downey on August 12, 1966.

(2) Glycol Diverter Valve at KSC - Few tablespoonsful. On September 15, 1966 the glycol diverter valve was noted to be leaking at the rate of "approximately one drop/minute" (DR S/C 0188). This situation was corrected by adjusting the valve mounting bracketry to relieve the side loading effects which apparently were causing the leak. The DR was closed on September 26, 1966. The leakage had not caused other components or wire bundles to become wetted with water/glycol.

(3) Cold Plate IMU Supply Line, Weld Joint at KSC - 1 pint. On September 28, 1966 "three water/glycol leaks" were noted to be in existence "behind inverters - Lower Equipment Bay" (DR S/C 0289). The leakage was corrected by the replacement of existing solder unions with B-nuts and union. Following leak check and re-insulation of the affected lines the area exposed to water/glycol, including electrical connectors, was wiped with distilled water applied from a squeeze bottle, blown dry with GN_2, flushed with "denatured alcohol" from a squeeze bottle and dried again with GN_2. The electrical connectors were cleaned "inside and out". The subject DR (0289) was closed on September 30, 1966. DR-0305 was initiated against the water/glycol contamination to electrical connectors and wire harnesses which resulted from the leak documented on DR-0289. DR-0305 was closed by referencing the cleaning steps which were taken on DR-0289.

(4) Transducer CF0550 Removal/Rotation at KSC-2 pints (Oct. 11, 1966). The spillage of water-glycol which occurred during the operations documented on DR S/C 0436 was controlled to the extent that no water/glycol contamination of components or wire bundles was incurred.

(5) Pump Leak (1st) ECU Servicing at KSC - 1/2 cup (Nov. 30, 1966). Following ECU removal and subsequent investigation at AiResearch it was found that some evidence of leakage existed on the water/glycol pump flanges. Although leakage at this point in the system could not be verified the isolation of the leakage point to the pump flange area was the "best guess" available. (Reference DR S/C 0737).

TPS S/C 418 documents the tests which were performed on the ECU at AiResearch. The only leak source which could be determined was in the area of the pump filter housing. The observed leak was very minor (documented as "one drop" IDR 001, TPS S/C 418).

(6) Pump Leak (2nd) Servicing at KSC - 1/4 cup (Dec. 20, 1966). DR S/C 0811, which is still open, documented a water/glycol leak which "seeped down I-beam and extended to the wire harness on the C/M floor". The area was dried and the water/glycol did not reappear. The DR was to remain open until after the FRT (OCP-K-0028) at which time it would be closed.

The leak source was documented as being "exclusively associated with (water/glycol) servicing". Through 1830 on January 27, 1967 no failures on S/C 012 cables, harnesses, or connectors were attributed to the effects of water/glycol leakage. Total leakage 90 ounces (estimated).

From a review of the referenced documentation it may be concluded that the only water/glycol leak which wetted nearby electrical connectors and components was the leak at the solder joint at the IMU coldplate water/glycol supply line. The other leaks apparently did not contaminate electrical components or wire bundles. The water/glycol from the IMU coldplate leak wetted several connectors. These connectors were demated and cleaned to eliminate the possibility of water-glycol contamination inside the connector. The affected connectors were:

Yaw ECA: J-96, J-95, J-94, J-93, J-92
Auxiliary ECA: J-97, J-98, J-99, J-100
Pitch ECA: J-101, J-102, J-103, J-104, J-105

Each of these connectors was cleaned by water flush-gaseous nitrogen (GN_2) dry-denatured alcohol flush-GN_2 dry method. Each of the referenced connectors was potted.

During the inspection of the area in the C/M which could have been contaminated by the coldplate leak, black boxes were removed in sequence until the inspection of connectors and cables revealed that water/glycol had not reached the specific area being inspected. At that time the ECA units noted were determined to be the only units affected by the leak (Ref.8-70).

SUMMARY

There have been 35 instances of water/glycol leakage on the Spacecraft listed with a total leakage of approximately 320 ounces including the 6 instances and 90 ounces on S/C 012. There have been no failures of cables, harnesses, connectors or components attributed to water/glycol leakage. The 14 connectors which were wetted with water/glycol on S/C 012 were demated and cleaned.

c. FLAMMABILITY OF WATER/GLYCOL RESIDUES

OBJECTIVE

It was desired to determine whether a thin film of water/glycol on a surface (from a drip or stream along the floor or wall) could be ignited at room temperature or slightly above by a flame impinging directly on the liquid surface.

PROCEDURE

Tests were made in which a flame was applied directly on the surface of a thin film of water/glycol/inhibitor mixture, pure glycol and films of the C/M coolant mixtures after exposure to vacuum. All flammability tests were conducted in 14.7 psia oxygen.

RESULTS

(1) Fifty drops of C/M coolant spread onto a 3-inch x 3-inch glass plate and a 1/8-inch x 3-inch x 3-inch aluminum plate would not propagate a flame in 14.7 psia 0_2 when ignited by a 1/2-inch diameter 1-1/2-inch long paper cylinder. Burning of the coolant immediately adjacent to the paper produced small flashes and sparks for about a one-inch radius around the fire.

(2) The same test using C/M coolant fluid was performed using stainless steel plate with a 1/16-inch deep "V" groove. Ten drops of coolant were placed in the groove and five drops on the paper cylinder. The paper burned for 90 seconds and there was some progression along the groove as the plate heated.

(3) A test similar to (2) but using pure ethylene glycol took 3 to 5 seconds to propagate along the groove.

(4) The same test using C/M coolant fluid was performed on aluminum and stainless steel plates after 18, 24, 46, and 48-hour storage in room air. The fire burned out in both cases in about 10 seconds leaving about two thirds of the coolant on the plate. There was some sparking around the flame in all cases.

(5) When the 50 drops of standard coolant fluid on an aluminum plate was held under reduced pressure about 80 hours and then ignited the fire spread to the residue and was visible over the entire surface. The residue burned completely within 15 seconds after ignition. The same test on a stainless steel plate with a coolant exposed to dynamic vacuum for 9-1/2 hours shows partial burning of the coolant film.

(6) Tests performed by Raychem Corporation also showed that the evaporation residue from water/glycol will propagate a flame (Ref. 8-100).

(7) A test was conducted to determine if Teflon insulated wire soaked with water/glycol would propagate a flame. This test simulated the wiring in the SCS junction box which was burned in S/C 012. None of the samples would propagate a flame when ignited (Ref. 8-40 and 8-77).

SUMMARY

In 14.7 psia oxygen:

(1) A pure ethylene glycol film on a stainless steel plate will propagate a flame at room temperature.

(2) Water content in the C/M coolant will prevent flame propagation on thin films. Air drying for 48 hours does not produce a combustible mixture.

(3) Films of C/M coolant placed on horizontal stainless steel or aluminum plates and exposed to vacuum for extended periods at room temperature will propagate a flame if ignited.

(4) Residues from previous C/M coolant spills in S/C 012 could have provided a fuel.

(5) Single wires and three-wire bundles were soaked with water-glycol and either air-dried or vacuum-dried and did not propagate a flame.

d. TEMPERATURE MAPPING OF S/C 012

OBJECTIVE

A study was initiated to determine the major heat zones in S/C 012. Samples of nylon Velcro were used which had been heated to various temperatures. As part of this study the materials in the S/C were evaluated to determine which ones would allow ready comparison of hot and cool zones in the spacecraft.

PROCEDURE

Combustible materials were used throughout the spacecraft including nylon Raschel Knit and some plastic buttons or knobs on panels. Some of these were damaged but not entirely consumed. The reference material selected was Velcro. Samples of nylon Velcro were heated in an oxygen atmosphere at 16 psia at the White Sands Test Facility Laboratories. Each specimen was stopped at its assigned temperature, preserved, and photographed for degree of damage and color. Speciments were obtained for each 50°F increment between 300°F and 600°F.

RESULTS

The evidence that the fire was more intense on the left side than on the right side is summarized as follows:

Material	Type/Degree of Damage	
	Left Side	**Right Side**
Aluminum Panels	Blistered and whitened	No blistering. Some panels almost undamaged.
Velcro	Mostly burned off. Some of the patches are only partially burned.	Largely surface burning. Patches melted and dripped more than they burned.
Teflon Insulation	Extensive damage. On some wires the insulation is completely burned.	Mostly surface damage.

In general combustible materials were burned throughout the spacecraft particularly on the floor and around the sides. The materials listed subsequently which were in the S/C at the time of the fire were evaluated and an estimate of their role in the fire is as follows:

DEBRIS NETS - Virtually consumed or melted. These were probably instrumental in propagating the fire around the S/C.

VELCRO - This was another major material for flame propagation. Combustion varied from complete burning to only surface burning.

VELOSTAT PLASTIC SHEETS - These were consumed in nearly all areas. The material was a fuel but did not appear to be instrumental in spreading the fire.

FOAMS - A major fuel in the fire. The foam on the floor and on the ECU was nearly consumed.

COUCH MATERIALS - These pads and cover materials were partially consumed in the fire.

TEFLON WIRE INSULATION - It did not appear to act as a fuel for the fire by itself and was intact in most areas of the spacecraft. The wire insulation was damaged by the fire in those areas where flame impinged directly on the insulation. Areas where the wires were bare of Teflon reached temperatures in excess of 800°F.

The data from the above summary were combined with the condition of the Velcro observed in the S/C to obtain the temperature chart presented in Enclosures 8-4 and 8-5 (Ref. 8-43). It was observed that the number of conditions in the S/C fire were not all reproduced in the test plan. As a result the temperature ranges in the diagram are approximate (Ref. 8-34, 8-35, 8-36, 8-37, 8-43, and 8-44).

SUMMARY

An estimate was made of temperatures attained at various locations in S/C 012. This was based on burning, melting, and other effects observed on aluminum alloys, Velcro and Teflon wire insulation coupled with calibration type exposures of Velcro materials to various temperatures and times. The most intense heat was in the lower left front area. Over 1000°F was attained on surfaces on the left side. However, in some isolated pockets temperatures did not exceed 400°F.

e. CORRELATION OF C/M MOCKUP TESTS

OBJECTIVE

These tests were made to (1) evaluate the integrated combustibility of materials as they interact in a fire representative of the S/C 012 accident, (2) to correlate test results with observations made on materials in S/C 012 after the accident, and (3) to compare the observation of (1) with tests at lower partial pressures of O_2.

RESULTS

Test	Description	Status
1	Engineering Simulation of S/C 012 16.5 psia O_2	Complete Feb. 26, 1967
2	All-Up Simulation of S/C 012 16.5 psia O_2	Complete Mar. 4, 1967
3	S/C 012 Materials Configuration 5 psia O_2	Complete Mar. 8, 1967
4	New Materials Configuration 14.7 psia Air	Scheduled Mar., 1967
5	New Materials Configuration 5 psia O_2	Scheduled Mar., 1967 (Ref. 8-98)

Comparison of the measured rate of pressure rise and the minimum rate calculated from materials characteristics is discussed in the subsequent section 7 g. "Thermochemical Adiabatic Analysis of Fire Development". The test results are available in documented form. A test report covering material usage and placement forms a portion of the backup data for this report (Ref. 8-11 through 8-17. and 8-28), and in the form of motion picture films (Ref. 8-87 and 8-88). Additional information is contained in film (Ref. 8-99).

The 5 psia tests utilized approximately the same nonmetallic materials configuration except that Velostat-covered foam and nylon coverings on the suit hose were not included. Also, no oxygen was added during the 5 psia tests as was done in the 16.5 psia tests.

SUMMARY

Judging from an initial review of test results and comparing the external appearances of materials from S/C 012 and the mockup tests an effective reproduction of the S/C 012 accident was accomplished.

Review of the films of the 16.5 psia test indicates that after about a 10-second period the fire was propagated very rapidly by the Raschel Knit. Velcro and Uralane foam also were major fuels in the conflagration.

Fire simulation mockup tests at 5.0 psia resulted in a much lower fire propagation rate, less extensive fire damage before 0_2 supply exhaustion and a cabin pressure rise from the fire that was limited by the cabin pressure relief valve. The intensity of the fire in 5 psia 0_2 although less than at 16.5 psia was still incompatible with crew safety and could be fatal to an unsuited crewman.

The results of additional tests applicable to this section of the report will be contained in Appendix G.

f. FIRE PROPAGATION TEST OF RASCHEL KNIT AS INSTALLED.

OBJECTIVE

Determine fire propagation rate for Raschel Knit material in a configuration as installed in C/M 012 along the floor and side wall intersection near the ECU.

PROCEDURE

Raschel Knit was installed in the test chamber with the long dimension (about 2 feet) horizontal and the narrow dimension (about 8 inches) aligned about 20 degrees from the vertical. Ignition was accomplished by a Nichrome wire element touching the Raschel Knit at about the midpoint of the vertical dimension and a measured distance from the end point. The chamber atmosphere was about 100 percent 0_2 and near ambient pressure.

RESULTS

Preliminary results from two tests, reference 8-106, obtained with a visual observation and stop watch technique gave average rates of about 2 inches per second.

SUMMARY

Horizontal flame propagation rates of fairly large pieces of Raschel Knit material as used in C/M 012 below the ECU in oxygen at ambient pressure have been measured at about 2 inches per second. This rate is about twice as fast as the downward rate obtained with small samples in nearly the same environment during materials screening tests. This large increase shows the importance of testing materials in the intended-use arrangement.

g. THERMOCHEMICAL ADIABATIC ANALYSIS OF FIRE DEVELOPMENT

OBJECTIVE

The objective of this analysis is to correlate S/C 012 and boilerplate temperature and pressure changes with time. This will establish energy balance correlations with the combustion characteristics of materials.

SUMMARY

A supporting task showed that the total energy available from complete combustion of the Raschel Knit, Velcro, Trilock, and Uralane foam present in S/C 012 was over 300,000 Btu. Only about 3300 Btu (based on an adiabatic process) would be required to raise the interior pressure of the C/M from 16.5 psia to 36 psia. Thus many times more fuel was available than necessary to provide sufficient heat on burning to reach estimated burst pressure (approximately 20 psi positive differential). The minimum energy (approximately 3300 Btu) could be obtained from only about 4 ounces of Raschel Knit, Velcro, or polurethane foam, or 1/2 pint of Command Module water glycol coolant (ref. 8-61).

Limited theoretical calculations indicate that burning of either Raschel Knit or Velcro alone would probably release a sufficient quantity of heat to raise the cabin pressure from 16.5 to estimated burst pressure (36 psia) in less than fourteen seconds from initiation. By this time a quantity equivalent to a hole of over 14 in. radius would have been burnt in the Raschel Knit and approximately 11 in in the Velcro ,consuming at least 3.8 ounces of either material and less than 2 percent of the available oxygen.

Based upon a number of known and estimated conditions and assumptions the minimum rate of pressure rise as a function of time was calculated (enclosure 8-6). This curve is based primarily on the slowest rate of combustion of Raschel Knit, i.e., in the vertical downward direction and its heat of combustion. For reference purposes pressure measurement from S/C 012 and the estimated curve (from Panels 3, 5, and 10) are also shown for comparison on the same plot. Pressure measurements during the 16.5 psia mockup test (SMD-2B) at MSC (normalized to a zero time base and 16.5 psia starting conditions) are also plotted.

Fire development characteristics vary with initial starting conditions. Thus, similar theoretical analyses were made for space conditions, i.e., assuming external vacuum and internal 5 psia pure 0_2 and using Teflon and Raschel Knit materials as limiting cases. The maximum or most favorable conditions were assumed for the burning of the Teflon.

The approach consisted of calculation of the minimum amount of heat necessary to raise the crew bay pressure from 5 psia to that under consideration. The amount of Teflon or nylon necessary to produce this amount of heat and the times necessary to consume these amounts were then calculated. The baseline burning rate of Teflon (5 mil film) was taken as 0.38 in/sec measured in the upward direction and burning in a semicircular fashion in 1 g. Admittedly, such a favorable condition for Teflon burning probably will never occur. However, even under such conditions at least 80 seconds would be required to reach the estimated burst pressure. In this time frame normal adiabatic expansion of the gas would not occur because the heat sink capability of the structure would be utilized partially. This heat sink capability would give additional time to take corrective action. For example, it would take in excess of 25 seconds to heat the cabin gas to 160°F (assuming that the ECS was inoperative). Thus, the burning of Teflon sheets is not likely to cause overpressurization and structural failure of the Apollo C/M. (Ref. 8-56, 8-59 and 8-47). However, as indicated proviously Teflon can propagate a flame so that its use over wide areas of the S/C should be limited.

h. THEORETICAL COMBUSTION ANALYSIS

OBJECTIVE

The objective of this investigation is to evaluate combustion processes and data from other fire incidents to acquire further insight into initiation and propagation of fire in spacecraft. A second objective is to evaluate proposed remedial approaches involving materials selection and placement.

PROCEDURE

These analyses are being carried out by the Atlantic Research Corporation.

RESULTS

In preparation.

SUMMARY

Test results applicable to this section of the report will be contained in Appendix G.

8. RESULTS OF SPECIAL INVESTIGATIONS AND TEST - DESIGN AND INSTALLATION CRITERIA AND CONTROLS OVER MATERIALS

This action presents investigations undertaken to evaluate design and installation criteria and controls over materials used in S/C 012.

a. NAA CRITERIA AND MATERIALS PROCEDURES

OBJECTIVE

The objective of this investigation was to evaluate existing criteria and controls covering flammability of materials in effect by the prime contractor.

SUMMARY

With respect to the S/C 012 fire, the NAA Specification MC999-0058 (Ref. 8-84) and MAO 155-008 covering the selection and usage of nometallic materials for flight had the following inadequacies

(1) The criteria did not require any combustion rate testing.

(2) There were no restrictions on total quantities of combustibles which could be placed in the cabin.

(3) The criteria did not require any restriction on quantities or location of particular materials.

(4) Material selection flammability criteria were not stringent enough.

(5) Requirements for flammability control of nonflight materials, including the usage of flammable solvents, were not established.

With respect to the implementation of controls, the following inadequacies were determined:

(1) The existing system for controlling installation and usage of materials to the established criteria was not effective.

(2) Controls were design-oriented but were not restrictive.

(3) Control and documentation of subcontractor materials usage was not adequate (Ref. 8-71, 8-72, 8-89, 8-55 & 8-63).

b. NASA/MSC CRITERIA AND MATERIALS CONTROL PROCEDURES COVERING THE SELECTION AND USAGE OF NONMETALLIC MATERIALS FOR FLIGHT OBJECTIVE

The objective of this investigaton was to evaluate existing criteria and controls in effect for government furnished equipment.

SUMMARY

With respect to the S/C 012 fire, the NASA MSC-A-D-66-3 and MSC-A-D-66-4 criteria had the following inadequacies:

(1) The criteria did not require evaluation of ignition and combustion rate at 16.5 psia oxygen. The criteria were oriented toward flight conditions of zero g and 5 psia oxygen.

(2) The criteria which specified combustion rate tests (downward) yielded results at the lowest rate possible in a one-g environment.

(3) The total quantity of combustible materials which could be used in the cabin was not limited.

(4) The materials selection flammability criteria and restrictions on individual quantities and locations were not stringent enough (Ref. 8-85 and 8-86).

(5) Requirements for flammability control of nonflight materials, including usage of flammable solvents were not established.

With respect to the implementation of controls, the following inadequacies were determined:

(1) Many materials used were qualified only by successful usage on prior programs.

(2) The existing system for controlling installation and usage of materials to the established criteria was not effective.

(3) Control of flammable materials installation was exercised by several organizations which tended to act independently.

(4) Control and documentation of contractor materials usage was not adequate. (Ref. 8-8, 8-9, 8-73 & 8-90).

(5) NASA criteria was not contractually imposed on the S/C contractor.

A physical "walk-through" inspection of S/C 012 was conducted at Downey on August 20, 1966 as part of the CARR activity. As a result of that inspection, nylon-Velcro chafe guards were removed from the electrical harness assemblies on the S/C floor and those around the sides and beneath the crew insertion hatch.

Subsequent to that inspection and after delivery the materials identified in tables 3 and 4 were added. Materials added included Raschel Knit debris nets, a large amount of Velcro, and Velostat plastic sheets and foam pads.

A "walk-through" inspection for S/C 012 was schedule for January 29, 1967 to review the arrangements of the large usage materials in the crew bay. (Ref. 8-89). While the results of this planned but not accomplished inspection can only be speculated, it is anticipated that the team made up of the same experienced people who had previously inspected S/C 012 at the factory and S/C 008 at MSC would have been concerned with the extensive use of Velcro and Raschel net (Ref. 8-60).

A similar inspection was made of the S/C 008 crew bay area before the altitude chamber tests were conducted in the Space Environment Simulation Laboratory at MSC. This inspection resulted in a number of changes including removal of the nylon-Velcro chafe guards, polyvinyl bags, a wooden wire bundle stiffener and the rework and qualification testing of a sealed Teflon and beta cloth for the polyurethane floor pads.

"Walk-through" inspections of spacecraft with NASA/NAA personnel have been utilized to perform a check of the installation of the nonmetallic materials visible in the cabins. During such inspections it has been possible for the team to judge on the basis of the NAA criteria and NASA criteria.

As noted the NASA effort to update the existing NAA Nonmetallic Materials criteria and control procedures had not been completed prior to January 27, 1967. Some of the more significant milestones on the updating efforts are listed in Ref. 8-101. Many of the contractor responses to NASA requests were in the form of status reports presented at regular NASA/NAA management meetings. The NAA responses culminated in a January 10, 1967 letter (Ref. 8-102) which was not acceptable to the NASA. Later, agreement was reached as confirmed in NASA TWX's of January 17, 1967 in item 15 and 18 of Ref. 8-101. This resulted in the January 27th revision of MC999-0058(E) which reflected the adoption of NASA criteria (Ref. 8-50 and 8-51).

The adoption of the NASA criteria through change to the contractor's nonmetallic materials criteria (MC999-0058) would not necessarily have prevented this accident because the cause has not been identified and because the NASA criteria also had some shortcomings as noted. However, the relative effectiveness of these two criteria is shown in Enclosure 8-27 by a comparison of the status of the major flammable materials attached to the spacecraft relative to these criteria. The two most significant differences were the restrictions given to the application of Velcro and the Uralane foam in the NASA criteria. Such restrictions would have prevented the installation of these materials any closer than 12 inches to electrical leads. This would have made a significant difference in the amount of both of these materials installed in the spacecraft at the time of the accident. The difference in the amount of permissible Velcro on and by the hatch and on the floor is shown by comparing the Velcro installation in Enclosures 8-17, 8-8 and 8-9. Only the Velcro shown in red in Enclosures 8-8 and 8-9 would have remained. Much of the Velcro used to support the Raschel would have been prohibited. Under the same enforcement assumption, most of the foam would have been removed.

c. REVIEW OF WIRE BUNDLE TESTING

OBJECTIVE

The objective of this analysis was to review the results of government and industry tests on the subject of ignition and flammability of spacecraft wires.

PROCEDURE

Available test and evaluation data on spacecraft wire bundles were reviewed (Ref. 8-95).

SUMMARY

Although flammability by itself may not be in every case the deciding factor, silicone rubber and polyolefin are so flammable that they appear to have limited usefulness at least in an oxygen atmosphere. On the other hand, H-film appears to be relatively fire resistant. Teflon insulation on electrical wiring propagates a flame in high concentrations of oxygen only when heated.

d. AVAILABILITY OF ALTERNATE MATERIALS

OBJECTIVE

The more prevalent flammable materials in the cabin are nylon debris netting, nylon Velcro, polyolefin couch padding, polyurethane foam and suit material. The objective of this task was to determine if nonflammable or less flammable alternate materials are available for replacement of combustible materials in the spacecraft.

RESULTS

The following materials are suitable for strengthening, insulating, cushioning and filling to reduce combustion rate of a bonded product. They are documented in various government, industry and manufacturers' reports as being nonflammable:

Fiberglass	Potassium Titanate
Beta Fabric	Eccospheres
JM Microfibers	Asbestos
Q felt	Silica
Min-K	Cabosil.

Government and industry documents present a great deal of data concluding that fluorinated plastics and elastomers have a very slow burning rate and are difficult to ignite in 5 psia oxygen. It is known that fluorinated polymers will produce harmful gases when subjected to temperatures over 600°F. Gases produced during flaming are not as harmful. The following are candidate fluorinated plastic and elastomeric matrix materials:

Teflon (TFE)	Kynar
Teflon (FEP)	Fluorel
Kel-F (CTFE)	Viton A
Fluorosilicones	

Typical commercial materials with low burning rates comparable to Teflon or which are nonflammable are presented in the following table (Ref. 8-58, 8-59, and 8-69).

Material	**Type**
Kel-F	n-CF2-CFCl
Aluminum Screen	Silicate coated
Metal Net	
Fluorocarbon Elastomers	n-CF2-CF2Cl-n
Fiberglass	
Armalon Felt (PBX-7700B)	Teflon
J.M. Microfiber Felt	
Min-K Felt	Ceramic
H-Film Sellev	Aromatic Polyimide
Inorganic Paper Crystal M, MP, or MG	Ceramic
Saucreisen Cement No.'s 28, 29 or 51	Ceramic (Cold Set)

Displays of available materials are shown in Enclosures 8-18 and 8-19. Attachment methods as replacements for Velcro are shown in Enclosure 8-20.

SUMMARY

Nonflammable (or significantly less flammable) materials which probably will meet the use requirements for most of the flammable materials used in S/C 012 were determined to be available from commercial sources (Ref. 8-59). For example, fiberglass screens or fabrics are essentially nonflammable items which probably can serve as debris traps. Ceramic fiber batts in nonflammable covers are available for use as cushions, insulations, etc. Final choices of materials should be verified by test approximating their applied configurations.

e. CREW COMPARTMENT PROCESSING AND ENVIRONMENT TIME LINE

OBJECTIVE

The objective of this analysis was to determine the history of the materials processes and environment time line for S/C 012 crew compartment during January 1967.

PROCEDURE

A detailed review of certain C/M related documentation, including DR's, DRS's, and TPS's, was undertaken to define those nonmetallic materials, which were installed or utilized within the crew compartment of the C/M since its receipt at KSC. Interviews with personnel who were in attendance during the performance of OCP FO-K-0021-1 (Plugs-Out Test) were undertaken to further describe the actual C/M nonmetallic configuration at the time of the accident. Cabin environment conditions, i.e., 0_2 partial pressure, temperature, flow rate of circulating air were determined and plotted to display a profile of these parameters from the end of OCP FO-K0034a (Manned Sea Level Test) December 30, 1966 to 6:31 pm EST on January 27, 1967.

RESULTS

The tabulation of materials added by DR, DRS, and TPS action in January 1967 (Ref. 8-45, 8-62, 8-63 & 8-64) is shown below:

- Water/glycol (leakage)
- Pressure-sensitive adhesive-backed aluminum foil
- Freon (cleaning)
- RTV 560 (potting)
- Methyl-ethyl-ketone (cleaning)
- Sealing Compound (MBO 130-019) and primer (MBO 125-038)
- Napthalene - Carbon tetrachloride mixture (cleaning)
- White Paint (MBO 125-019)
- Epon 828 with Versamid 125 (potting)
- Glass fabric tape
- Epon 954 (bonding)
- Teflon tape
- Naptha (cleaning)
- PRC 1538 (potting)
- Teflon heat shrink sleeving
- RTV 577 (potting)
- Loctite Grade HV, primer (sealing)
- Isopropyl alcohol (cleaning)
- Leak check soap solution
- Acid paste

Review of these materials against the NAA control specification MC999-0058 showed that 6 were accepted, 4 were rejected but waived, and 10 did not appear (Ref. 8-55).

Solvent usage in S/C 012 is estimated as follows for this time period:

methyl-ethyl-ketone	2 quarts[a]
Freon	1 quart
Leak check soap solution	1 pint
Isopropyl alcohol	1 quart[a]
Acid Paste	0.1 pint

[a] Used as a basis for analysis reported in Section 6.a.

A graphic time line on solvent usage was prepared based on the preceding data. Pertinent excerpts are included in Enclosure 8-7, which depicts the last utilization of solvents, the detection of odors and the basic environmental parameters in the spacecraft cabin. (See "Materials Odor Evaluation", 6.5.). Although etchants were not used in the crew compartment a summary study of the potential effects of various etchants was compiled and is presented in References 8-52 and 8-53. Evaluation of the results reveals that many process materials were added in January, 1967. The process materials noted were either installed in such a manner or in such minute amounts that their contribution to the fire intiation even though possible is considered remote.

Approximately 4.5 quarts of solvent were used in the spacecraft through January, 1967. However, results of a cabin environment air sample taken at 10:15 pm EST on January 26, 1967, indicated less than 1 ppm total hydrocarbons. This result tends to reduce concern that solvent vapors could have been a fuel for the fire.

9. RESULTS OF SPECIAL INVESTIGATIONS AND TESTS -TECHNICAL DATA AND INFORMATION AVAILABILITY

This section deals with investigations of the feasibility of methods for improving technical information availability to primary activities having materials selection, installation and control responsibilities.

a. MATERIALS MAPPING AND CREW BAY DISPLAY OBJECTIVE

The objective of this analysis was to develop S/C 012 materials usage displays and to evaluate the feasibility of maintaining displays of nonmetallic materials usage with the LM and C/M crew bay. The purpose of this display was to locate the nonmetallic materials that may become flammability hazards due to their close proximity to ignition sources. The intent of this display was to graphically illustrate the individual materials, location, approximate amounts, identity of the materials and their status.

RESULTS

The types of displays that were considered are as follows:

(1). Photographs for schematics.

(2). Overlay on schematic.

(3). Display board of actual material samples.

(4). Scale model of crew compartment interior.

A system that worked well during the Apollo 204 accident investigation has been to photograph the interior of the crew bay exhibiting by color photographs the location of the various pieces of associated equipment. This system involved one overall crew bay enlargement with individual "closeup" color photos of pieces of equipment and localized areas (Ref. 8-65 and 8-68).

SUMMARY

Maintenance of spacecraft nonmetallic materials usage displays is feasible and useful.

Preparation of the full-scale mockup of S/C 012 revealed the continuous fire propagation path presented by the placement of Raschel Knit and/or Velcro in the crew bay.

b. MATERIALS INFORMATION CENTER

Objective

The activities of the Materials Panel illustrated the need for:

(1) The rapid availability of materials information including usage and property data.

(2) The availability in graphic form of location and usage of nonmetallic materials in manned spacecraft.

(3) Increased awareness of personnel at all levels of characteristics of nonmetallic materials.

(4) Provide test data and means for getting new materials tested to appropriate criteria.

The objective of this study was to evaluate the feasibility of implementing a more active information interchange system.

RESULTS

An objective review of the materials information program has resulted in a plan for its reorientation toward a more active role in acquiring and distributing vital materials information. The targets for receipt of this information are program management, contractors, and field sites.

Displays covering materials usage in S/C 012 have been prepared. A feasibility study of maintaining individual spacecraft usage data in graphical form has also been prepared.

The existing computerized materials file maintained at MSC was reviewed. The expansion of this system to accommodate test data, usage locations and spacecraft effectivity and material status, including waivers is feasible and is being implemented. The target date is June 1, 1967 (Ref. 8-68, 8-81 & 8-82).

SUMMARY

The results of this study indicate the feasibility of a central data source for acquisition, storage, display and distribution of materials information.

Materials configuration can be maintained in a centralized document. This can be accomplished on each vehicle and reviewed during each Customer Acceptance Readiness Review (CARR), and Flight Readiness Review (FRR). During fabrication and test of each vehicle, configuration control and status can be maintained. Materials information on the use and applications of hazardous materials can be distributed to Program Management, Apollo contractors and field sites. This can be accomplished through workshops, film strips and formal presentations.

10. UNFINISHED BUSINESS

The following items of unfinished business are open.

ITEM	SECTION	EST. COMP. DATE
Routine Materials Testing	5	May 26
Electrostatic Spark Ignition - Suited Man in Spacecraft Tests	6.c	April 15
Effect of Water/Glycol on Wire Bundles	6.g	June 23
Effect of Water/Glycol on Connector Assemblies	6.h	April 21
Effect of Burning Foam Insulation on O_2 Lines	7.a	April 15
Command Module Mockup Tests	7.e	April 15
Theoretical Combustion Analysis	7.h	April 7

D. FINDINGS AND DETERMINATIONS

1. MATERIALS CONFIGURATION

a. FINDING:

Complete documentation which identified potentially combustible nonmetallic materials used in S/C 012 is not available in a single readily usable format. A total of 2,528 different potentially combustible nonmetallic materials which were probably used on S/C 012 were found by a review of available documentation.

DETERMINATION:

The program for identification and documentation of nonmetallic materials used in the S/C, including their weights and surface areas, was not adequate.

There is no system in effect through which nonmetallic materials configuration changes are tracked, reported, evaluated, and controlled in an integrated manner.

b. FINDING:

Test data providing individual combustion properties in environments of 5 psia to 21 psia oxygen were available for 550 of the potentially combustible nonmetallic materials identified as possibly being used. Data on higher pressure testing were available only on suit materials, Velcro and K-10 flight paper.

DETERMINATION:

Flammability test requirements were not standardized at the time the referenced tests were accomplished.

Large numbers of potentially combustible nonmetallic materials were used in the fabrication of S/C 012 without specific correlated combustibility test data. Test data were available at high O_2 pressures (to 21 psia) to define the combustion characteristics of some of the major materials which contributed heavily to the fire.

c. FINDING:

Installation records including photographs and redlined drawings were maintained at KSC which contained descriptions of materials added to S/C 012.

DETERMINATION:

Methods for identifying configuration changes related to materials were operational at KSC.

2. ROUTINE MATERIALS TEST

FINDING:

Raschel Knit, Velcro, Trilock and polyurethane foams burn about twice as fast (in the downward direction) in 16.5 psia as in 5 psia O_2.

DETERMINATION

The primary fuels for the fire burned over twice as fast in the early stages of the fire in accident conditions (16.5 psia) than in space flight atmosphere for which they were evaluated (5 psia).

3. FIRE INITIATION SPECIAL INVESTIGATION

a. Retention of Solvents

FINDING:

Laboratory analyses indicated that solvent retention by test specimens was significant. The analyses also indicate that the evaporation characteristics of the solvent is such that vapor concentration fell below the lean flammability limit after 1½ hours.

DETERMINATION:

The presence of significant volumes of concentrated vapor in the spacecraft is unlikely. However, the retention of solvents in the surface layers of solid flammable materials could possibly contribute to their ignitability.

b. Materials Odor Evaluation

FINDING:

Odors similar to that of sour milk and methyl-ethyl-ketone were reported before the fire during suit and cabin purge operations.

Thresholds of methyl-ethyl-ketone and isopropyl alcohol detection by smell are approximately .01 percent to .03 percent by volume and concentrations described as strong, irritating or sickening range from 1 percent to 4 percent by volume.

DETERMINATION:

There is no evidence that significant concentrations of organic vapors were present in S/C 012 at the time of the fire.

c. ELECTROSTATIC SPARK IGNITION

FINDING:

The maximum electrostatic spark energy generated and measured on a man suited in a space suit was about 4 millijoules.

FINDING:

Ignition of the more flammable S/C 012 solid materials tested required spark energies of 190 millijoules or greater.

FINDING:

Ignition of solvent vapors in oxygen can take place at spark discharge energies as low as 0.002 millijoules. Ignition of methane vapors in oxygen can take place at spark discharge energies as low as 0.004 millijoules. Ignition of solid materials damp with solvents can take place at spark discharge energies as low as 40 millijoules.

DETERMINATION:

Ignition of solid materials by electrostatic discharge is not a probable cause of the S/C 012 fire.

DETERMINATION:

It is possible from an energy consideration that methane and solvent vapor can be ignited by electrostatic discharge. Nevertheless, this is not believed to be a possible cause of the fire.

d. COBRA CABLE SPARK IGNITION

FINDING:

Connecting and disconnecting of spacecraft qualified Cobra connectors at normal loads did not create sufficient energy to ignite concentrations up to saturation (approximately 12 percent) of methyl-ethyl-ketone in 16.4 psia oxygen. An increase in loading to 2.5 times operating amperage in 4.0 percent of MEK yielded no ignition.

DETERMINATION:

Ignition of flammable concentrations of solvent vapors by connecting and disconnecting Cobra connectors is an unlikely ignition source for the S/C 012 fire.

e. IMPACT SENSITIVITY OF MATERIALS IN GOX

FINDING:

Preliminary high energy impact tests on Velcro and Raschel Knit in 16.5 psia oxygen produced ignition and burning.

FINDING:

A survey of similar spacecraft and mockup failed to disclose the possibility of any high impact conditions.

f. SPONTANEOUS IGNITION OF S/C 012 MATERIALS

FINDING:

Results of tests on S/C 012 materials considered to be most flammable with and without solvents (methyl-ethyl-ketone, isopropyl alcohol) and coolants (water/glycol) did not result in spontaneous ignition at or below 400°F in any case.

DETERMINATION:

Spontaneous ignition is an unlikely ignition source for the S/C 012 fire.

g. EFFECT OF WATER/GLYCOL ON WIRE BUNDLES

FINDING:

Conditions required for wet-wire fire ignition through electrolytic action are damaged wire insulation, presence of an electrolyte and electric potential between damaged wires and a flammable substance in the proximity. A test has shown that ECS coolant applied to a purposely damaged wire of a type used in the C/M caused a fire.

DETERMINATION:

The required conditions could have been present in S/C 012.

h. REVIEW OF KSC CONNECTOR TEST WITH WATER/GLYCOL

FINDING:

An unpotted connector with some unused pin channels subjected to water/glycol and placed under DC stress developed a short circuit.

DETERMINATION:

Water/glycol electro-corrosion products and residue are conductive and capable of acting as an electrolyte.

4. FIRE PROPAGATION SPECIAL INVESTIGATION

a. WATER/GLYCOL LEAKAGE IN SPACECRAFT

FINDING:

There have been 35 instances of water/glycol leakage on Block I Spacecraft involving approximately 320 ounces.

DETERMINATION:

The water/glycol distribution system requires corrective action to eliminate leakage.

FINDING:

Prior to the accident there had been no electrical system failures attributable to the water/glycol leaks.

DETERMINATION:

The electrical system has some tolerance to water/glycol spillage.

FINDING:

There is no standard cleaning procedure in effect to remove water/glycol spills or residue.

DETERMINATION:

There is a probability that water/glycol residue is present in areas of all Block I Spacecraft.

FINDING:

Six instances of water/glycol leakage were recorded for S/C 012. Of these, one soaked several SCS connectors and wire bundles. Some corrective action was taken to clean all known spills in S/C 012.

DETERMINATION:

Water/glycol residues may have been present in areas of S/C 012 including on wire bundles and connectors.

b. FLAMMABILITY OF WATER/GLYCOL RESIDUES

FINDING:

Tests in a 14.7 psia oxygen atmosphere on horizontal surface show films of C/M coolant will not propagate a flame before or after air drying for up to 48 hours. Films of coolant will propagate a flame after exposure to reduced pressure for periods of 60 to 80 hours. Pure ethylene glycol will propagate a flame in a similar atmosphere.

DETERMINATION:

Residues from previous standard coolant fluid spills in S/C 012 might have provided a path for flame propagation on materials that were wetted. Spills or leaks in the early stages of the fire would burn when heated.

c. TEMPERATURE MAPPING OF S/C 012

FINDING:

Surface and bulk damage of materials in S/C 012 varied from melting and blistering of aluminum alloys, combustion of Velcro and melting and burning of Teflon wire insulation to slight surface damage and melting of nylon fabrics.

DETERMINATION:

The fire filled the S/C interior. The most intense heat was in the lower left front area around the ECU. Surface temperatures in excess of 1000°F were reached in areas such as the front and left side of the spacecraft. Surface temperatures were less than 400°F in isolated pockets above the right-hand couch.

d. CORRELATION OF C/M MOCKUP TESTS

FINDING:

The condition and appearance of individual materials after the 16.5 psia oxygen boilerplate test approximated materials conditions observed in S/C 012. The pressure rise measured in the boilerplate test approximated that in the S/C 012.

DETERMINATION:

A reasonable simulation of the S/C 012 accident was achieved by the boilerplate tests.

FINDING:

The rate of flame propagation, the rate of pressure increase and the maximum pressures achieved and the extent of conflagration in 5 psia oxygen boilerplate tests was much less severe than observed in the 16.5 psia oxygen boilerplate tests. Burning or charring was limited to approximately 29 percent of the nonmetallic materials by oxygen depletion.

DETERMINATION:

The conflagration which occurred in S/C 012 at 16.5 psia would be far less severe and slower in a spacecraft operating with an environment of 5 psia oxygen if additional large quantities of oxygen are not fed into the fire.

DETERMINATION:

A fire in a spacecraft configured as S/C 012 operating with a 5 psia oxygen environment could be fatal.

FINDING:

The early stages of fire propagation in the boilerplate tests were observed to be dependent upon the combustion rate and location of the materials. The observed rates appeared to have been much greater than the factor of two increase measured downward in the laboratory tests when the oxygen pressure is increased from 5 psia to 16.5 psia. The additional increase in rate in the boilerplate tests most likely occurs because of the combined effect of burning upward and along the continuous paths provided by flammable materials. This is substantiated by preliminary results referenced in 8-106.

DETERMINATION:

The spread of fire at 16.5 psia operating pressures is too rapid for effective remedial action in spacecraft with combustible materials arranged as in C/M 012. The spread of fire at 5 psia operating pressures is probably too rapid for effective remedial action by an unsuited crewman.

e. THERMO-CHEMICAL ANALYSIS OF FIRE DEVELOPMENT

FINDING:

The energy available from about four ounces of Raschel Knit or Velcro could raise the pressure in a closed C/M from 16.5 psia to 36 psia in less than 14 seconds after ignition. (Calculations assume complete combustion and adiabatic conditions).

FINDING:

Teflon materials did not burn appreciably in S/C 012. Calculations based on laboratory data indicate that Teflon could not have contributed appreciably to the rate of pressure rise. The total energy available from the Raschel Knit, Velcro, foam, Trilock and polyurethane materials was much greater than necessary to raise the cabin pressure from 16.5 psia to 36 psia.

DETERMINATION:

Teflon provides an insignificant fire risk.

DETERMINATION:

There was considerable excess combustible material available with which to raise the C/M pressure to the estimated burst pressure.

5. MATERIALS INSTALLATION CRITERIA AND CONTROLS

a. NAA CRITERIA AND MATERIALS CONTROL PROCEDURE

FINDING:

The NAA materials selection specification MAO 155-008 requires only that a material pass a 400°F spark ignition test in 14.7 psia oxygen.

DETERMINATION:

The NAA criteria for materials flammability control were inadequate.

FINDING:

A system for control of nonmetallic materials usage existed at NAA during the design, fabrication and assembly of C/M 012. The NAA materials control system is design oriented.

DETERMINATION:

The system is permissive to the extent that controls over the installation or use of flammable materials are not adequate.

FINDING:

There were nonflight items containing combustible materials in C/M 012 during this test.

FINDING:

No flammability criteria or control existed covering nonflight items installed in C/M 012 for test.

DETERMINATION:

Lack of control of nonflight material could have contributed to the fire.

b. NASA-MSC CRITERIA AND MATERIALS CONTROL PROCEDURES

FINDING:

The NASA materials selection criteria MSC-A-D-63 and MSC-A-D-66-4 requires that a material pass a 400°F spark ignition test and a 0.5 in/sec combustion rate (measure downward in 5 psia O2). Raschel Knit and Velcro (hook) pass this test.

DETERMINATION:

The NASA criteria for materials flammability control are not sufficiently stringent.

FINDING:

The system for control of nonmetallic materials usage at MSC during the design and development of government furnished equipment used in C/M 012 depended on identification of non-compliance with criteria by the development engineers.

DETERMINATION:

The NASA materials control system is permissive to the extent that installation or use of flammable materials were not adequately reviewed by a second party.

FINDING:

The NASA criteria were intended to limit the use of Velcro and Uralane foam to distances greater than 12 inches from wire bundles.

FINDING:

Nonmetallic materials selection criteria utilized by NAA and NASA are not consistent. The NASA criteria, although more stringent, were not contractually imposed on the S/C contractor.

DETERMINATION:

Materials were evaluated and selected for usage in C/M 012 using different criteria. Application of the NASA criteria to the C/M would have reduced the amount of the more flammable materials (Velcro and Uralane foam).

FINDING:

Visual "walk-through" inspections had resulted in removal of combustibles in the proximity of wire bundles on C/M 012 before delivery and on C/M 008 before manned testing. Such inspection had not been made before OCP FO-K 0021-1

DETERMINATION:

Visual inspections have resulted in removal of combustible materials from potential ignition sources (wire bundles).

c. AVAILABILITY OF ALTERNATE MATERIALS

FINDING:

Alternate materials which are nonflammable or significantly less flammable than those used on C/M 012 are available for many applications.

DETERMINATION:

The amount of combustible material used in Command Modules can be limited.

6. TECHNICAL DATA AND INFORMATION AVAILABILITY

MATERIALS INFORMATION CENTER

FINDING:

Current information and displays of the potentially flammable materials configuration of S/C 012 was not available prior to the fire.

FINDING:

A centralized source for materials data was established for the Board Panel 8 (Materials Review).

DETERMINATION:

Maintenance of data and displays at central locations and test sites for management visibility and control of flammable materials is feasible and useful.

E. SUPPORTING DATA

This section contains references to supporting data in the form of reports, lists and other documents. Also included are photographs, tables and graphs essential to provide completeness of this final report.

Items are numbered 8-1, et. seq., for those displays enclosed in this section. Supporting reports and references not included in this report are numbered consecutively.

Supporting data included are listed below:

Enclosure	Description
8-1	Not used
8-2	Sample page from C/M 012 Materials Configuration, March 6, 1967
8-3	C/M 012 Temperature Mapping and Materials Usage Display - Prior to Fire (Neg. No. 166-238C-2)
8-4	C/M 012 Temperature Mapping and Materials Usage Display - After Fire (Neg. No. 166-238C-3)
8-5	C/M 012 Temperature Mapping Overlay (Neg. No. 283-498C-1)
8-6	C/M 012 pPressure vs Burning Time - Velcro or Raschel Knit
8-7	C/M 012 Materials Time Line
8-8	Exposed Nonmetallic Materials Location - Velcro and Wire Bundles 12 Inches Apart on Floor (Neg. No. 329-713C-3)
8-9	Exposed Nonmetallic Materials Location - Velcro and Wire Bundles 12 inches Apart on Aft Bulkhead % Hatch (Neg. No. 329-713C-1)
8-10	Major Exposed Nonmetallic Materials in C/M 012 (Neg. No. 166-238C-1)
8-11	Exposed Nonmetallic Materials Location - Command Module Outline (Neg. No. 216-468C-1)
8-12	Exposed Nonmetallic Materials Location - Velcro (Neg. No. 216-468C-4)
8-13	Exposed Nonmetallic Materials Location - Velcro and Uralane Foam (Neg. No. 216-467C-6)

SAMPLE PAGE FROM C M 012 MATERIALS CONFIGURATION LIST

APOLLO CREWBAY MATERIALS

05 FABRIC

MATERIALS				LOCATION					PRIORITY	TESTS				TEST RESULTS				QUANTITY USED		WAIVER	MSC-A-D-4
NAME	MFGR DESIG	MFGR	SPEC NUMBER	SUB SYST	CONTR	SUB CONTR	INSTL SITE	USE		SPEC.	FACIL-ITY	DATE	O_2 psi	FIRE PT. °F	FLASH PT. °F	COMB. RATE in/sec	AUTO IGNIT. °F	WEIGHT (LBS)	AREA IN²		
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[illegible]	[illegible]	[illegible]	[illegible]																		
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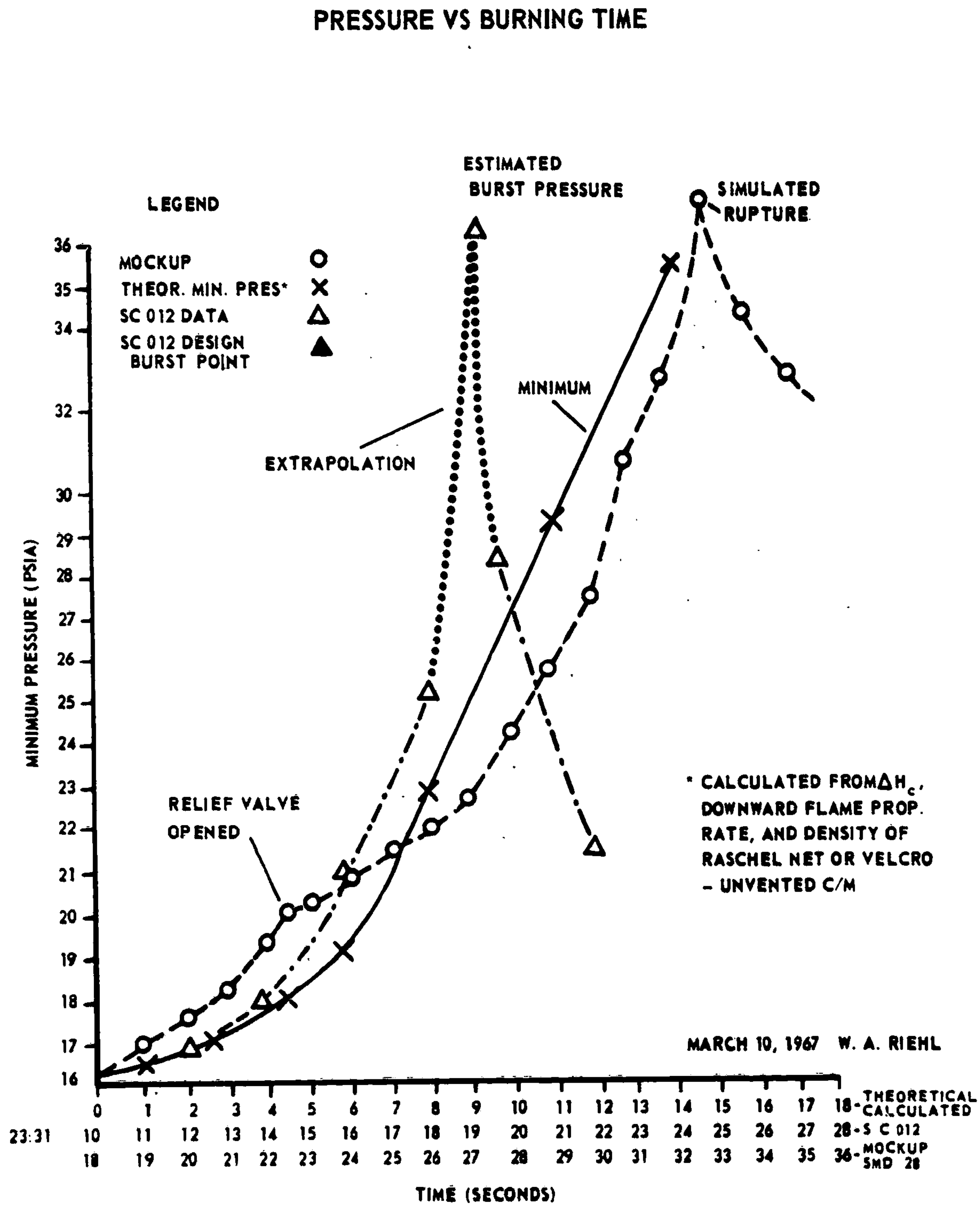
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		[illegible]		6	MSCA-D-66-3	MIT	1967		500	500	.36	N.I.				
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]						MSCA-D-66-3	MIT	1967	[illegible]	500	500	.36	N.I.	.038 gm.	[illegible]	[illegible] D	
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]												.08	169		
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]													.01	[illegible]		
[illegible]	[illegible]	[illegible]	[illegible]						[illegible]												

REMARKS:

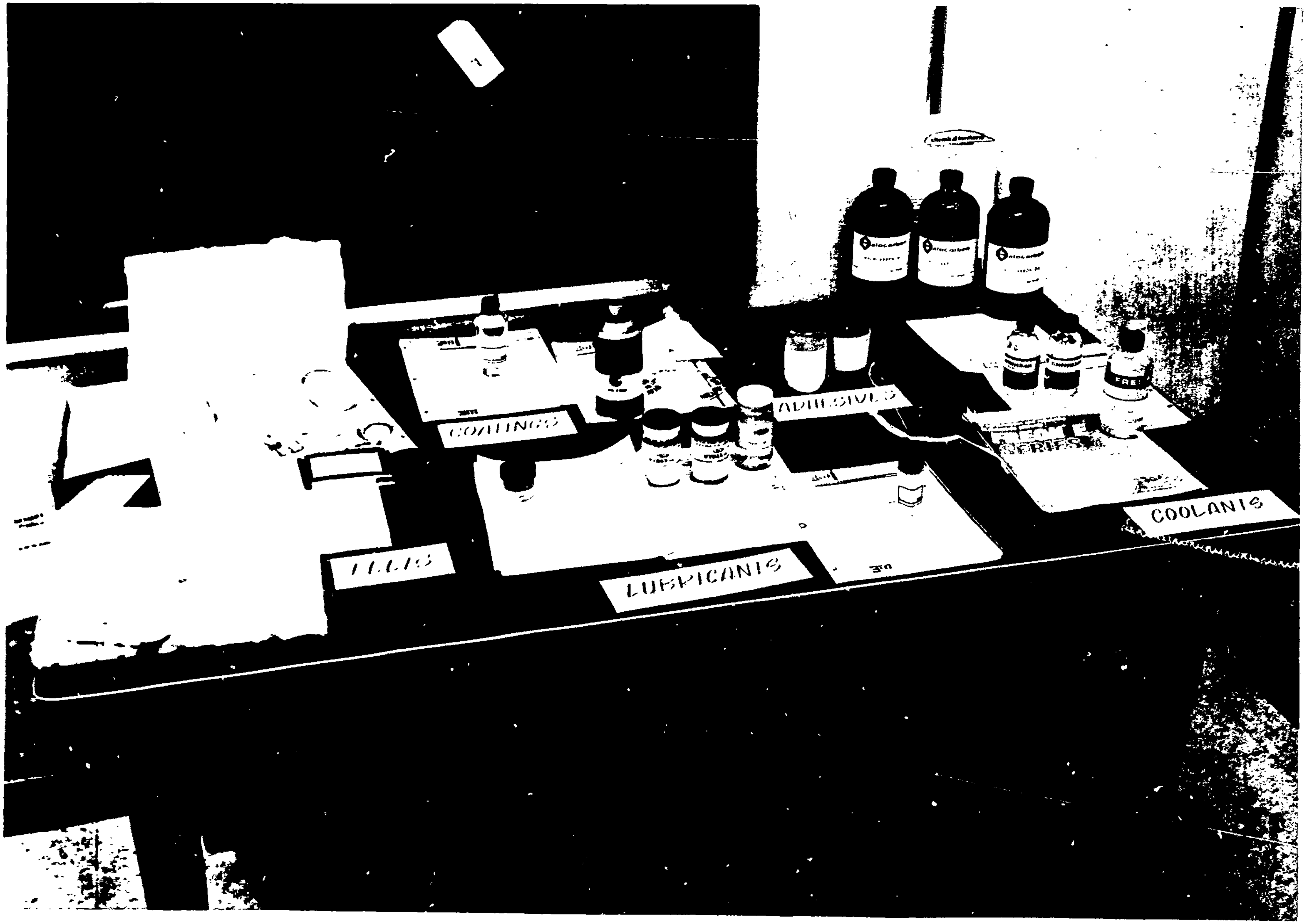
ENCLOSURE 8-2

D.8.37



ENCLOSURE 8-6

ENCLOSURE 8–19



CANDIDATE NON-FLAMMABLE MATERIALS – FELTS, COATINGS, LUBRICANTS, ADHESIVES AND COOLANTS

LIST OF REFERENCES

	TITLE	IDENTIFICATION SOURCE
8-1	Nonmetallic Materials Used in the Interior of the Apollo Command Module, September 1, 1966	Unidentified (30 pgs. 881 materials)
8-2	Subcontractor Material Use List	Unidentified (53 pgs)
8-3	Updated Tab Run of Nonmetallic Materials	NO ID Number
8-4	Stabilization and Control System, Honeywell Inc., Material List, October 25, 1964	A64769A (2)
8-5	Partial List of Materials on S/C 012 by Drawing Number	Unidentified (48 pgs)
8-6	Material Usage G&N 12/50, February 5, 1967	Unidentified (86 materials plus hand-written update of KSC added)
8-7	Apollo Materials Master File Index, December 28, 1967	RPT-X50-98-915
8-8	GFE Equipment - Nonmetallic materials (Addendum to TRIS 020580)	TRIS 020583
8-9	GFE - Flight Crew Support Division Hardware Onboard, January 27, 1967	Unidentified (Survey of cognizant FCSD personnel)
8-10	Acceptable S/C 012 GFE Materials List - Tab Run, February 6, 1967	TRIS 020585
8-11	Bills of Materials, Space Suit Assembly S987-000 Part I	TRIS 020590
8-12	Bills of Materials, Space Suit Assembly, S978-000 Part II	TRIS 020591
8-13	Bills of Materials, Helmet Assembly, A1920-000	TRIS 020592
8-14	Collins Test Data	AR-518-1, January 1965
8-15	Hamilton Std. Test Data	SVHSER 4024,3886
8-16	KSC Data	February 14, 1967
8-17	MSC Data	February 2-9, 1967
8-19	MSC Data	Tech. Note S136, 1966
8-18	MSC Data	February 7-8, 1967
8-20	WSTF Data	February 2, 1967
8-21	GAEC Data	LED-520-3A, January 1966
8-22	S. A. M. Data	TR-65-78, 1965
8-23	MIT G&N Data	Not published, 1967
8-24	NAA/Hughes Data	P64-53, June 1964
8-25	NAA/Hughes Data	P66-06, January 1966
8-26	NAA/Hughes Data	P67-32, February 1967
8-27	NAA/Hughes Data	2748, 06, 56, February 20, 1967
8-28	S/C 012, Materials Configuration	Apollo 204 Review Board Panel 8 Materials Review March 6, 1967
8-29	Spark Ignition Tests	Apollo 204 Review Board Panel 8 Materials Task 2.1
8-30	Determination of Impact Sensitivity of Materials to GOX	Apollo 204 Review Board Panel 8 Materials Task 2.29
8-31	Material Cataloging and Routine Testing	Apollo 204 Review Board Panel 8 Materials, Tasks, 1.1, 1.2 and 1.3
8-32	Electrostatic Spark Generation in Selected Nonmetallic Materials	Apollo 204 Review Board Panel 8 Materials, March 8, 1967
8-33	Flammability of Materials in O_2 (Preliminary)	Apollo 204 Review Board Panel 8 Materials Task 2.3
8-34	Temperature Mapping in S/C 012	Apollo 204 Review Board Panel 8 Materials Task 2.4
8-35	Preliminary Temperature Survey of S/C 012	Apollo 204 Review Board Panel 10, February 28, 1967

8-36	Temperature Changes in S/C 012	Apollo 204 Review Board Panel 3, February 28, 1967
8-37	Temperature Changes in S C 012	Apollo 204 Review Board Panel 1, February 20, 1967
8-38	Wire Bundle Insulation Test Exposed to Water/Glycol	Apollo 204 Review Board Panel 8, Materials Task 2.5
8-39	Studies Underway on Water/Glycol Solutions	Apollo 204 Review Board Panel 8, Dr. A.A. Staklis
8-40	Flammability of Type II Water Glycol Coolant	Apollo 204 Review Board Panel 8, W. A. Riehl
8-41	Absorption - Evaporation Tests	Apollo 204 Review Board Panel 8, Materials Task 2.6
8-42	Data on Flammability Limits and Ignition Energies for Certain Substances	Datafax to A. Busch from W. T. Olson, Lewis Research Center February 2, 1967
8-43	Development of the Maximum Temperature Profile of C/M 012 Inner Cabin	Apollo 204 Review Board Panel 10, February 22, 1967
8-44	S/C 012 Temperature Profile	Apollo 204 Review Board Panel 10, February 18, 1967
8-45	Concentrations of MEK in S/C 012	Apollo 204 Review Board Panel 8, February 18, 1967
8-46	Autogenous Testing of Nonmetallic Materials in the C/M	Apollo 204 Review Board Panel 8, Materials Task 2.7
8-47	Updating of Thermochemical Plots of Pressures vs. Time for S C 012	Memo to W. M. Bland, Panel 8, from W. A. Riehl March 10, 1967
8-48	Final Report - Preliminary Cobra Cable Spark Test, TPS-MA 014	Apollo 204 Review Board, Panel 8 March 7, 1967
8 49	Investigation Report - Preliminary Cobra Cable Spark Test (TPS-MA 014)	Submitted to Panel 8 by J. C. Van Hooser, March 1, 1967
8-50	Approved Nonmetallic Materials for C M Interior	Apollo 204 Review Board, Panel 8 February 22, 1967
8-51	Materials Comparison and Reconcilliation Between NAA Spec. 0058 and MSC Spec. 66-4, March 1, 1967	Apollo 204 Review Board, Panel 8 Materials Task 2.11
8-52	Deleterious Effects of Etchants in S C and Wire Bundles	Apollo 204 Review Board, Panel 8 Materials Task 2.13
8-53	MSFC Tests of Teflon Etchant	Apollo 204 Review Board Panel 8, February 15, 1967 W A. Riehl
8-54	Material Odor Evaluation for S C 012 (Ref. Action Item no. 78)	Apollo 204 Review Board Panel 8, March 7, 1967, Materials Task 2.15
8-55	S C 012 Crew Bay Configurations Time of Delivery to Time of Accident	Apollo 204 Review Board Panel 8, Materials Task 2.16
8-56	Thermochemical Analysis of Fire Development in S C 012 Based on Materials Characteristics	Apollo 204 Review Board Panel 8, March 9, 1967
8-57	Estimates of the Mass of Materials in S C 012 at Time of Accident	Apollo 204 204 Review Board Panel 8, Materials Task 2 18
8 58	Flammable Materials Substitution Program	Apollo 204 Review Board Panel 8. Unissued
8-59	Alternates for the More Prevalent Nonmetallic in the Cabin, March 1, 1967	Apollo 204 Review Board Panel 8, Materials Task 2 19
8 60	Comparison of Nonmetallic Distribution in S C 008 and 012	Apollo 204 Review Board Panel 8, Materials Task 2.21
8 61	Calorimeter Bomb Tests of Selected Materials to Determine Fuel Energy Available	Apollo 204 Review Board Panel 8, Materials Task 2 23
8 62	S C 012 Materials Oriented Timeline Backup Material	Apollo 204 Review Board Panel 8, Materials Task 2.31
8 63	Summary of Solvents, Bonding Agents, Etchants, etc Usage in S C 012	Apollo 204 Review Board Panel 8, Materials Task 2 32
8 64	Quantities of Nonmetallic Materials Installed in CSM 012 at KSC	Memo to W M Bland, Panel 8, from A Lorenz, March 9, 1967, re Task 2 16

8-65	Reconciliation of Materials Usage Geometry in PIB Mockup and Panel 8 Display	Apollo 204 Review Board Panel 8, Materials Task 2.38
8-66	A Special Assessment on Materials Analysis Branch Report of 12/2/66 on Hughes Co. Connector Assembly	Apollo 204 Review Board Panel 8, February 28, 1967
8-67	Materials Evaluation, Connector Assembly Hughes Aircraft Co. P/N 1004250 and P/N 1004251 - MAB-1392-66	Materials Analysis Branch Technical Services Division
8-68	Materials Information Service Plan	Apollo 204 Review Board Panel 8, Materials Task 2.41
8-69	Alternate Materials Follow-up Information Display	Apollo 204 Review Board Panel 8, Materials Task 2.44
8-70	Water/Glycol Leakage History of S/C 009, 011, and 012	Apollo 204 Review Board Panel 8, Materials Task 2.50
8-71	NAA's Criteria and Materials Control Procedures Prior to Jan. 27, 1967	Apollo 204 Review Board Panel 8, Materials Task 2.51
8-72	Contractor Nonmetallic Materials Waiver Status	Apollo 204 Review Board Panel 8, Materials Task 2.52
8-73	GFE Nonmetallic Materials Waiver Status	Apollo 204 Review Board Panel 8, Materials Task 2.54
8-74	Interim Summary Report	Apollo 204 Review Board Panel 8, February 16, 1967
8-75	Responsibility and Schedule for Accomplishment of Panel 8 Materials Tasks, Rev. A	Apollo 204 Review Board Panel 8, February 28, 1967
8-76	Responsibility and Schedule for Accomplishment of Panel 8, Materials Tasks, Rev. B.	Apollo 204 Review Board Panel 8, March 2, 1967
8-77	Study of Flammability Properties of Water/Glycol Mixtures	Apollo 204 Review Board Panel 8 Materials Task 2.27
8-78	Testings of the Effect of Water/Glycol on Apollo S/C Wire Insulation	Apollo 204 Review Board Panel 8, February 27, 1967 Dr. A. A. Staklis
8-79	Activity Report as of February 27, 1967, Spark Ignition Tests per February 6, 1967, Letter by A. Busch	Memo to W. Bland from J. D. Jeter, Chief, Materials Analysis Branch, KSC, February 27, 1967
8-80	Input to Panel 8 - Materials Final Report, Routine Materials Test Status and Boilerplate Test Status	Memo to W. M. Bland, Panel 8, from J. N. Kotanchik, MSC, March 8, 1967
8-81	Selection/Control of Nonmetallic Materials in S/C (Preliminary Outline)	W. M. Bland, ASPO, R. Q&T, March 8, 1967
8-82	Materials Information Service Program Plan	Apollo 204 Review Board Panel 8, Materials, March 6, 1967
8-83	Testing of Water/Glycol Treated Wire Bundles (Connectors) at KSC	Apollo 204 Review Board, Panel 8, Materials, March 10, 1967 (Task 2.12)
8-84	**Approved Materials for Use in the Apollo S/C, General Specifications**	**North American Aviation, Inc., Specification No. 99-0058**

8-85	Procedures and Requirements for the Evaluation of Apollo Crew Bay Materials	NASA-MSC, R. Q&T Div. May 13, 1966, MSC-A-D-66-3
8-86	Crew Bay Nonmetallic Materials Status Report of Unacceptable, Acceptable Materials Rev. F	NASA-MSC, R. Q&T Div. December 30, 1966, MSC-A-D-66-4
8-87	Boilerplate Flammability Tests in 5 psia oxygen	NASA-MSC (Film)
8-88	Boilerplate Flammability Tests in 16.5 psia Oxygen	NASA-MSC (Film)
8-89	Hazardous (Nonmetallic) Materials Control Program	H. M. Lampert, GE-ASD February 17, 1967
8-90	Acceptable S C 012 GFE Materials List, Tab Run, 2 16 67	TRIS 028075
8-91	Flammability Characteristics of Materials in Oxygen	Apollo 204 Review Board, Panel 8-Materials, February 22, 1967
8-92	Investigation Report - Aircraft Wire Harness Fire	Lockheed Film No. 3 (4-1963)
9-93	Spontaneous Ignition of S C 012 Materials	Apollo 204 Review Board, Panel 8, Materials-Task 2.7
8-94	The Lockheed Aircraft Corporation Film on Wet Wire Fire	Memo to PD Chief, Systems Engineering, from PD4 Engineering Branch, February 9, 1967, PD4 M864
8-95	Materials Literature Survey of Wire Bundle Tests Having Application to Apollo 204 Accident Investigation	Apollo 204 Review Board, Panel 8, Materials-Task 2.24
8-96	Flammability of the Higher Boiling Liquids and their Mists	Industrial and Engineering Chemistry, December 1947, p. 1607
8-97	Physical Properties of Ethylene Glycol	GLYCOLS, Curme and Johnston, ACS Monograph 114 Reinhold Publ. Co.
8-98	Test Activities by Structures and Mechanics Division, Manned Spacecraft Center	Apollo 204 Review Board, Panel 8, March 19, 1967
8-99	Boilerplate Flammability Tests in 16.5 psia Oxygen (1st Test)	NASA MSC (Film)
8-100	"Some Experiments on Coolant Mixture"	Raychem Corp. Memo to R. M. Halperin from Heslop & Frisco dated March 11, 1967
8-101	List of Some Significant Correspondence Relative to Nonmetallic Materials Control at NAA	Apollo 204 Review Board, Panel 8 March 17, 1967
8-102	Contract NAS9-150, R&D for Project Apollo S C Toxicity and Flammability Program	Letter to R. W Williams, MSC from G. W. Jeffs, NAA, January 10, 1967
8-103	Final Report-Solvent Evaporation Rates from nonmetallic materials in an ambient environment	Letter to Panel 17 from Chairman, Panel 8, Material Review, Task 2.6
8-104	Results of Electrostatic Ignition Investigation, March 31, 1967	Memo from E. Latchfield to Chairman, Panel 18, with attachment

8-105	Summary of Suit Electrostatic Measurement Data	Memo to Chairman, Panel 8, from KB-6, Whittaker
8-106	Results of Special Tests on Raschel Knit	Preliminary Report, March 31, 1967, W. M. Bland, Panel 8, Materials
8-107	Wet Wire Fire Test No. 1	Apollo 204 Review Board, Panel 8, March 31, 1967

STATUS OF MAJOR NONMETALLIC MATERIALS USED IN S/C 012 CREW BAY

Introduction

The objective of this evaluation was to determine the status of the major combustible materials used in the S/C 012 crew bay.

Results

The table below lists materials status as determined from a review of NAA MC 999–0058 and MSC-A-D-66-4 documents which list acceptable and unacceptable materials.

TABLE
STATUS OF MAJOR NONMETALLIC MATERIALS USED IN
S/C 012 CREW BAY

MATERIAL DESIGNATION	MATERIAL TYPE	STATUS PER NAA-MC-999-0058 Rev. D	STATUS PER MSC-A-D-66-4 Rev. F
Nylon Rachel Knit	Polyamide	Acceptable	Acceptable
Nylon Velcro	Polyamide	Acceptable	Restricted – 12 inches from electrical leads
Trilock Cushions	Woven Cushion. Rubber Based Thread.	Acceptable	Unacceptable
Uralane 577-1	Polyurethene Foam	Acceptable	Restricted – Not to exceed 18 inches lengths or closer than 12 inches from electrical leads

REPORT OF PANEL NO. 9
DESIGN REVIEWS PANEL
APPENDIX D-9
TO
FINAL REPORT OF
APOLLO 204 REVIEW BOARD

DESIGN REVIEW PANEL REPORT

A. TASK ASSIGNMENT

The Apollo 204 Review Board established the Design Review Panel, 9. The task assigned for accomplishment by Panel 9 was prescribed as follows:

Conduct critical design reviews of systems or subsystems that may be potential ignition sources within cockpit or which might provide a combustible condition in either normal or failed conditions. Consider areas such as glycol plumbing configuration, electrical wiring and its protection, physical and electrical, as well as other potential ignition sources such as motors, relays, and corona discharge. Other areas of review include egress augmentation and basic cabin atmosphere concept (one versus two-gas). Document where applicable pro's and con's of design decisions made.

B. PANEL ORGANIZATION

1. MEMBERSHIP:

The assigned task was accomplished by the following members of the Design Review Panel:

Mr. R. W. Williams, Manned Spacecrft Center (MSC), NASA, Chairman
Mr. J. Janokaitis, Kennedy Space Center (KSC), NASA
Mr. Aaron Cohen, Manned Spacecraft Center (MSC), NASA
Dr. John F. McCarthy, North American Aviation (NAA), Downey, California
Mr. R. Pyle, North American Aviation
Mr. F. Sanders, McDonnell Company, St. Louis, Missouri

2. COGNIZANT BOARD MEMBER:

Mr. G. White, NASA Headquarters, Board Member, was assigned to monitor the Design Review Panel.

C. PROCEEDINGS

1. APPROACH:

Panel 9 effort has encompassed the four major sub-divisions as follows:

a. Review of subsystems for sources of ignition or flammable materials.
b. Review of the selection of the cabin atmosphere.
c. Review of the egress process.
d. Review of the flight and ground voice communications.

The object of the review was to:

a. Identify problems and potential problem areas that may provide guidance in determining the cause of the fire.
b. Identify potential problem areas in the design for which design changes may be required.

The review process has been expedited by informal assignment of subtasks to knowledgeable groups of people (Reference 1).

It must be noted that the contemplated spacecraft configuration for the next manned flight (Spacecraft 101, Block II) is different to a significant extent from spacecraft (S/C) 012 (Block I) in which the fire occurred. As a consequence both configurations are involved in the design reviews; the Block I configuration as an aid to determining possible sources for the fire, and the Block II to evaluate the system design characteristics and potential design change requirements to prevent recurrence of fire.

2. DETAILS OF INVESTIGATION

A description of the process leading to the results of the detailed analyses of each of the four major subdivisions listed in Item 1 is presented herein.

a. Ignition and Flammability

(1) SUMMARY

A team of NASA and NAA Subsystem Managers and Systems Engineers conducted a thorough review of the subsystems housed in Block I and II Command Module (C/M) crew compartments. The purpose of the review was (1) to ascertain if any of the subsystems contained ignition sources that might have contributed to the Apollo 204 incident and (2) to identify similar anomalies that might exist in the Block II S/C and document them for input to the overall spacecraft design review activity.

This extensive review culminated in the compilation of a final report (Reference 2) to the Chairman of Panel 9 substantiated by the Design Review summary sheets (Reference 3). Results of the review delineate ignition sources (Blocks I and II) and contiguous non-metallic materials (Block II) for each subsystem. The type of packaging and qualification history was examined and is listed for each component (Block II). A summary of this review is included as Enclosure 9-1 to this report.

(2) CRITERIA FOR REVIEW

(a) IGNITION SOURCES

Search for and identify possible ignition sources of the following types:

Corona discharge

Electrical arcs or sparks from damaged insulation, motor brushes, exposed relay contacts, switches, etc.

Overheating caused by circuit failures

Overheating due to inadequate or improper lubrication

Chemical sources

Miscellaneous (impact, etc.)

(b) COMBUSTIBLE MATERIALS

Identification and location by subsystem of all flammable materials within the crew compartment.

(3) SYSTEM/SUBSYSTEMS FOR REVIEW

(a) Guidance and Navigation (G&N) (including Block II rendezvous radar)

(b) Stabilization and Control System (SCS)

(c) Electrical Power System (EPS) and Sequential Events Control System (SECS)

(d) Controls and Displays

(e) Caution and Warning System (C&WS)

(f) Environmental Control System (ECS)

(g) Emergency Detection System (EDS)

(h) Telecommunications (T/C)

Operational instrumentation

Spacecraft communication

Crew communication

Television (TV)

System instrumentation

(i) Experiments and Scientific Equipment

(j) Crew Personal Equipment

(4) METHOD OF OPERATION

The task was executed in two phases. The first phase consisted of concurrent independent reviews of the C/M subsystems by Subsystem Managers and Systems Engineers at Manned Spacecraft Center (MSC) and by contractor personnel at the North American Aviation (NAA) plant in Downey, California. These independent reviews were conducted in the time period February 6-16, 1967. The second phase consisted of working sessions, involving both MSC and NAA personnel, conducted at MSC during the period February 17-20, 1967. During these sessions, the MSC and NAA inputs were combined to constitute the subpanel report. The two-phase method of task execution was used for many reasons, the principal being optimum utilization of personnel and facilities at both the contractor's and MSC plants, and thoroughness afforded by two independent reviews of the subsystems which separately reflect the contractor and customer rationale.

(5) SPECIAL DESIGN CONSIDERATIONS

The configurations of both Block I and Block II vehicles were examined with a view toward identifying deficiencies in design and compatibility of design with criteria (specified requirements). Many deficiencies in the design could be traced to criteria which changed in the course of the program. The deficiencies can be categorized into those affecting wiring and ECS plumbing.

A number of criticisms of the wiring and ECS plumbing joints for Block I vehicles have resulted from examination of S/C 012, 014, and 017. The criticisms include instances of:

Interference with access for maintenance
Insufficient physical protection
Undesirable routing and terminating
Lack of flexibility for change
Frequent leakage of water, glycol joints
Poor workmanship
Lack of neatness and craftsmanship

The process of spacecraft manufacture, test, and maintenance, which results in the above criticisms, derives from the designs to which the spacecraft are built. The criteria establish the requirements for the design. These criteria continued to evolve after the design had been started and in some instances changed after release of design to manufacturing. Some significant examples follow:

(a) WIRING

(1) Unmanned flights were introduced which required retrofit of the Mission Control Programmer and associated wiring, and interconnecting with C/M flight control and other subsystem circuits. This additional complexity applies to S/C 017 but not to S/C 012 and 014.

(2) Because of the experience of water condensing on electrical equipment during the flight of a Mercury spacecraft, the electrical and electronic components were required to be qualified in a combined environment of water, oxygen and salt instead of oxygen alone. As a result, the environmental-seal concept was introduced which changed the packaging design of the electronic equipment.

(3) The in-flight maintenance concept, on which the initial design was based, was dropped in favor of built-in redundancy after design completion on Block I but prior to the initiation of the design of Block II.

(4) The requirements for in-flight scientific experiments were added after designs were released to manufacture or test.

(5) Additional development and operational instrumentation requirements were introduced after the wiring design was released and in manufacture or test.

(6) The design of displays and controls was based on requirements established by a flight-crew group. Subsequently, minor changes were made to meet the requirements of the assigned flight crew.

(7) The audio communication control equipment on S/C 012 suffered from a series of changes in performance requirements resulting in a number of fixes. The final configuration contained many changed and interrelated switch functions which resulted in a complex matrix of switch positions for proper selection of the different modes.

The initial design for the Block I vehicles failed to accommodate growth and changes typically experienced in research and development programs. The result was that the flexibility for change was quickly saturated, and it was necessary to improvise at the expense of the factors exposed by the criticisms above. (However, the initial design of Block II allowed for a 50 percent growth in wiring.) The Block I wiring runs were laid out without the use of an engineering mockup and wire harnesses were fabricated in two-dimensional rather than three-dimensional fixtures.

Post-fire inspection of S/C 012 revealed deficiencies in the wire installation demonstrating poor practices in design, manufacturing and quality control. The wiring in the spacecraft survived the fire with a small degree of damage overall. The Teflon insulation was found to be damaged only in localized hot spots. The majority of the damage consisted of insulation loss due to heat; however, in practically all instances there remained sufficient insulation or distance between the affected wires, that shorting was not apparent. All enclosures pertaining to this section are photos of S/C 012 after the accident.

During the wire inspection, the following design deficiencies were noted:

(1) The wiring in the Lower Equipment Bay (LEB) was routed through narrow channels having many 90 degree bends. This could cause mechanical stress on the Teflon insulation. Some wiring in these areas was found with damage to the sleeve which covers the shielded wire (Enclosure 9-4).

(2) Wire color coding practices were not always adhered to as evidenced by Enclosure 9-5.

(3) Some areas of wiring exhibited what would be referred to as "rats nests" because of the dense, disordered array of wiring. In some instances excessive lengths of wires were looped back and forth to take up the slack. Also, there were instances where wires appeared to have been threaded through bundles which added to the disorder (Enclosures 9-6, 9-7, 9-8, 9-9 and 9-10).

(4) A circuit breaker panel was pressed so close to a wire harness, that wiring indentions were left in the circuit-breaker potting (Enclosure 9-11).

(5) There were wires routed across and along oxygen and water/glycol lines.

(6) The floor wiring and some connectors in the LEB were not completely protected from damage by test personnel and the astronauts. This is evidenced by mashed 22-gauge wires found in some of the wire harnesses.

The following Manufacturing and Quality Control deficiencies were noted:

(1) Lack of attention during manufacture and/or rework is evidenced by foreign objects found in the spacecraft harnesses. Enclosure 9-12 shows a wrench socket in one of the connector channels, and Enclosure 9-13 shows a metal washer inside a wire bundle.

(2) Some wiring did not have identification tags.

(3) A Hughes connector on communications equipment was broken prior to the fire as evidenced by soot in the crack, Enclosure 9-14.

(4) A chipped Hughes connector was found in a condition exposing female inserts (Enclosure 9-15).

(b) ECS PLUMBING JOINTS

(1) The ECS design criteria, emphasizing minimum weight, resulted in the selection of aluminum piping with soldered joints (Enclosure 9-3). The design approach utilized accounted for the normal operating stresses but failed to account for the loads and stresses introduced by handling and installation.

(2) The proper fabrication of joints requires that the initial alignment of the tubes to be soldered must be established without stress and without benefit of a holding tool. The tool provides support to the joint only during the heat-up and cool-down phase.

(3) The couplings were made too short to provide the joint with strength greater than the tubing. As a result, unanticipated axial, bending or torsional loads cause the joint to develop leak paths.

(4) The installation design does not permit adequate inspection and does not protect the plumbing and the joint from accidental damage, or from use as hand holds. In some areas access of tools is difficult without stressing or springing joints already made.

The development and qualification testing of the ECS extended beyond the original schedule. Units were produced and installed in spacecraft which required modification to eliminate problems later identified during qualification tests. The design failed to provide easy access for removal and replacement of components in the assembled condition. Consequently, the process of rework is difficult, and the design criteria for soldered joints is violated under rework conditions. The leakage of soldered joints in the C/M cabin is traceable primarily to these conditions.

b. CABIN ATMOSPHERE

(1) INTRODUCTION

The process of selection of the cabin atmosphere has been reviewed and a comprehensive bibliography (Reference 4) of all material leading to the decision to use oxygen O_2 in space and at the pad has been compiled. A summary of this material is contained in Enclosure 9-2 to this report. The references contain a retracing of all the steps and considerations leading to the choice of the cabin atmosphere for the spacecraft. Pertinent data are included from cognizant NASA organizations, other government agencies, Mercury, Gemini, and Apollo contractors and subcontractors, other aerospace companies, the medical community, universities, and other research organizations.

(2) DISCUSSION:

Selection of a spacecraft cabin atmosphere involves human physiology constraints, spacecraft and space suit design considerations, flammability characteristics of materials, ground considerations, and considerations of fire extinguishing and suppression.

(a) HUMAN PHYSIOLOGICAL CONSTRAINTS

Human physiology imposes a requirement for a minimum partial pressure of oxygen for respiration, a minimum absolute-pressure environment for respiration and control of body water-vapor partial pressure, and limits to the rate of depressurization to prevent bends from gases emanating from solution in the body. A one hundred percent oxygen atmosphere is physiologically acceptable for continuous use up to thirty days.

NASA physiologists specify that a minimum oxygen partial pressure of 3.5 psia and a minimum absolute pressure of 5 psia be maintained as spacecraft cabin atmosphere. Reduced levels are acceptable for short periods of time (up to eight hours). One hundred percent oxygen pre-breathing is specified for a minimum of three hours prior to launch.

Dysbarism (bends) is avoided by a minimum partial pressure of diluent gas in the spacecraft. The desirable partial pressure of nitrogen in a mixed-gas spacecraft atmosphere has not been formally established. It has been established that the disadvantages will more likely exceed the advantages at nitrogen partial pressures greater than 3.5 psia.

Oxygen toxicity is prevented by avoiding oxygen partial pressures significantly greater than those experienced at sea level (3.5 psia).

Consequently, from the physiological standpoint, acceptable cabin atmosphere ranges from a 5 psia oxygen single-gas environment to a mixed-gas environment with 3.5 psia oxygen and 3.5 psia nitrogen partial-pressures.

(b) SPACECRAFT AND SPACE SUIT DESIGN CONSIDERATIONS

The design parameters for spacecraft involving cabin atmosphere are concerned with the strength of the structure to contain the cabin pressure and the varying complexities of atmosphere-control systems for one hundred percent oxygen or mixed gases. The design parameters for space suits are the same as for the spacecraft with the addition that the effort associated with movement increases with increasing differential pressure.

The Apollo spacecraft atmosphere control system design is based on providing a one hundred percent oxygen environment. Duplication of the atmosphere-control components as well as addition of a mechanism for oxygen partial-pressure control is required to provide diluent gases. These additions introduce additional crew-safety failure modes into the flight systems.

The state-of-the-art in space suit design establishes 3.8 psi as the desirable maximum differential pressure. Freedom of movement is constrained with further increases in differential pressure.

(c) FLAMMABILITY CHARACTERISTICS OF MATERIALS

The flammability characteristics of materials involve interrelationships with chemical and physical properties of the material, the total pressure of the atmosphere and partial pressure of atmospheric constituents, the temperatures of the material and the atmosphere, and the process of ignition utilized to initiate combustion.

There are three flammability characteristics that are generally measured to determine relative flammability of materials:

(1) Linear burning rate in inches per second.

(2) Temperature at which self-ignition occurs.

(3) Temperature at which ignition by spark is achieved.

The tests are performed in the atmospheres of particular interest. These have included oxygen alone at various pressures and oxygen mixed with nitrogen at various pressures with various ratios of partial-pressure.

The linear burning rates and auto-ignition temperatures measured in tests are shown in the tables below:

Relative Propagation Rates (inches/sec, downward)

Atmosphere psia/gas	Material Cotton	Velcro	Nomex	Teflon
$3.5/O_2$	.49	.4	.3	
$5.0/O_2$	.5	.48	.34	
$16.0/O_2$	.55	.7	.43	.003
$3.5/O_2 1.5/N_2$	.4	.33	.22	
Air	.1	.3	.1	

Auto-Ignition Temperature (°F)

Atmosphere psia/gas	Cotton
$3.5/O_2$	1160
$5.0/O_2$	1180
$16.0/O_2$	1280
$3.5/O_2 1.5/N_2$	1040
Air	1000

Downward burning rates of the same material are shown to vary over a range of only 1.4 to 1 with atmosphere changes from 5 psia oxygen to a 7 psia atmosphere of 3.5 psia oxygen and 3.5 psia nitrogen. Downward burning rates in a particular atmosphere vary over a range of 1000 to 1 with material changes from cotton to Teflon. Consequently, the potential for fire in the C/M is much more strongly influenced by the selection of materials than by acceptable variations in atmosphere.

It may be concluded that the selection of 5 psia oxygen as a cabin environment for space flight operations was a reasonable choice. The physiological requirements are totally fulfilled. The requirements on spacecraft structure and systems are minimized. Based on tests of downward-burning propagation, the difference in fire potential between various physically acceptable atmospheres is not large, particularly if easily combustible materials are eliminated.

(d) GROUND CONSIDERATIONS

At any pressure the suitloop must contain only oxygen to avoid the "bends". If cabin atmospheric constituents other than oxygen are used, they should be isolated from the suitloop and expelled from the cabin prior to crew emergency from the suited conditions to avoid anozia. These requirements were fulfilled for Apollo 204 by the use of oxygen without diluents.

Downward burning rates of some materials vary by a factor of 1.3 to 1 for an atmosphere of 16 psia oxygen compared to a 5 psia oxygen atmosphere. If the decision had been made to use the extreme atmosphere for space operation of 3.5 psia oxygen and 3.5 psia nitrogen partial pressures, the burning-rate ratio between 16 psia oxygen and this environment would be only 1.8 to 1.

Tests carried out subsequent to the Apollo 204 accident with full-scale mockups at both 16 psia and 5 psia, one hundred percent oxygen atmospheres have demonstrated that differences in downward burning rates of materials are not indicative of actual fire hazards. Propagation rates and overall fire damage were much greater at the higher pressure. Thus, it appears that the geometric arrangement of the combustibles in their actual installations are much more significant than tests on isolated samples.

If air were used instead of oxygen on the ground (recognizing that spacecraft design changes would be required) a ratio of burning rates of 1 to 2 over 5 psia or 1 to 4 over 16 psia oxygen would be achieved. This reduction in burning rate would provide a reduced hazard for ground operation over space operation, except within the suit loop where 15 psia oxygen is required. These relations are based on downward burning rates for isolated specimens under controlled conditions. The conclusions have not been verified by tests in air with full scale mock-ups.

It must be concluded that burning rates of materials are significantly reduced only when large amounts of diluent are used. The limited quantity of diluent acceptable by physiological criteria contributes very little to the reduction of burning rate over that in pure oxygen.

(e) FIRE EXTINGUISHING AND SUPPRESSION

The established process for extinguishing a cabin fire in space is to evacuate the cabin of oxygen by venting to space. Limited flammability tests indicate that burning generally ceases when oxygen pressure is reduced to a half (0.5) psia. The cabin-venting mechanism design results in cabin pressure reducing from 5.0 psia to 0.5 psia in approximately one minute forty-five seconds.

Cabin depressurization requires that the crew be in their space suits. The donning time is 10-15 minutes.

Alternative extinguishing techniques have been examined, but no really satisfactory technique has so far been found. Effort in this area is continuing. Recent experiments have shown only water to be effective. A better understanding of the burning and extinguishing phenomena is required to properly assess the adequacy of the present and alternative extinguishing processes.

Elimination of contaminants in the cabin by means such as suit purge and cabin venting must be provided. Prior to the venting process, crew protection should be provided by some means such as oxygen masks supplied by a separate fire-proof oxygen supply.

c. REVIEW OF THE EGRESS PROCESS

(1) INTRODUCTION.

A critical review of the egress situation investigated the elements of both Launch Complex (LC) 39 and Launch Complex 34, including the environmental chamber, access arm, elevator, personnel carrier (M-113) (Launch Complex 34 only), escape chute and hardened room (Launch Complex 39 only), lighting, communications, and fire suppression. This review was supplemented by conferences and responsive written reports on suggested design criteria from the following permanent Apollo Saturn Inter-Center Coordination Panels: Apollo Launch Operations Committee (ALOC) Emergency Egress Working Group, Apollo Launch Operations Panel (ALOP) Emergency Egress Subpanel, and Crew Safety Panel, as well as the Ground Emergency Provisions Review Panel No. 13 of the Apollo 204 Review Board.

The Panel No. 9 review and the reports of these associated organizations are contained in the supporting data which has been transmitted to the Apollo 204 Review Board files (Reference 6). This review utilized time lines, simulations, review of drawings, inspection of the Ground Support Equipment (GSE), and a methodical analysis of the egress process all the way from C/M exit to safety.

(2) DISCUSSION:

Based on tests in mock-up configurations, the following times for crew egress were measured. (Average times are used; best times are in parentheses.) Sixty (41) seconds are required for unaided crew egress from the Command Module. Ten (7) seconds are required for all three crewmen to disconnect and for the center crewman to turn around and face the hatch prior to opening. Forty (26) seconds are required for the center crewman to release and stow the inner hatch and release and open the outer hatch and boost-protective-cover hatch. Ten (8) seconds are required for all three crewmen to exit. The hatch cannot be opened with positive cabin pressure above approximately 0.25 psi.

The access arm to the Command Module contains flammable materials, and the doors are not designed to accommodate rapid emergency egress. Correction of these conditions would significantly improve emergency egress capabilities.

Removal of the access arm to allow the escape mode changeover from crew egress to Launch Escape System (LES) pad abort is necessary for maximum flight-crew safety just prior to launch. In the event of a C/M fire in this time period, the access arm could be returned to the C/M in time for safe crew egress if reduced flammability characteristics of the Command Module would greatly increase the allowable time for the egress escape process.

d. REVIEW OF THE FLIGHT AND GROUND VOICE COMMUNICATIONS

(1) INTRODUCTION:

Since the Operational Checkout Procedure (OCP) Plugs-Out Test during the Apollo 204 accident (OCP FO-K-0021-1) experienced communications difficulties, an examination of the design and performance of the total communications network was undertaken. This effort included: a comprehensive review to establish the configuration and operating characteristics of the Apollo 204 system; a system and circuit analysis, a test of the total ground system utilizing detailed measurements (February 21-24, 1967), and analyses of recordings made during the OCP FO-K-0021-1 test.

The supporting data (Reference 7) transmitted to the Apollo 204 Review Board files contain: a description of the on-board system, its test performance, and a discussion of the problems encountered; description and conclusions concerning the ground network; and detailed findings and determinations.

(2) DISCUSSION:

During the OCP FO-K-0021-1 test (Plugs-Out Test during Apollo 204 incident), difficulties were experienced maintaining voice communications. These difficulties included the following:

(a) Voice unintelligible due to very low levels at the listener's position.
(b) Voice unintelligible due to distortion, or "garbling."
(c) Syllables or words not received.

(d) Inability to contact another individual.

(e) Inability to communicate because of noise or other interference, including undesired voice.

These problems did not occur at all stations, or at any one station all the time; however, there were instances when several of the troubles occurred simultaneously. The source of the problems can be divided into two parts, viz., spacecraft and ground.

SPACECRAFT:

The spacecraft experienced a "live mike" situation, first noticed by the crew approximately one hour and five minutes before the accident. The records indicate that the VHF and S-band RF downlinks (exclusive of spacecraft audio and control circuit wiring) from spacecraft to ground operated satisfactorily during the OCP FO-K-0021-1 test.

GROUND:

The Communications Astronaut Console (CAST) on the ground was configured to patch the three voice links together (Astro 1 - Unified "S" Band, Astro 2 - VHF, and Astro 3 - Umbilical). With this configuration any downlink transmission is retransmitted back to the spacecraft on all three links.

The Spacecraft Test Conductor (MSTC) in the Automatic Checkout Equipment (ACE) Control Room in the Manned Spacecraft Operations Building (MSOB) was unable to contact the Command Pilot, Senior Pilot or Pilot at one time because of the Voice Operated Relay (VOX) in the ground link. The back-to-back VOX circuits lock out operation in the reverse direction when a signal appears in the unit.

Any signal coming from the Cape Kennedy Air Force Communications Terminal Building, Eastern Test Range, such as the MSTC or Superintendant of Range (AFETR), going into Launch Complex 34 has priority, with interrupt capability, over a signal originating in the Complex. However, even though it gets into the Complex Operational Intercommunication System (OIS) and the CAST console, it still has no priority to the spacecraft on any link.

System and circuit analyses showed that the difficulties experienced were due to system design deficiencies in the ground communications system, unfamiliarity with the system limitations and unsatisfactory procedures.

The ground communication system is one that has evolved during a series of modifications and additions. Rather than establishing an overall system design, hardware was merely added as new requirements were identified. The result was an overloaded system, with different types of subsystems which were inadequately interfaced.

D. FINDINGS AND DETERMINATIONS

1. A listing of findings and determinations from the information generated in the processes described in in Section C above are listed in Section D.2.

2. To be compatible with Section C above, the findings and determinations are listed according to the major classifications; viz., Ignition and Flammability, Cabin Atmosphere, Review of Egress Process, and Review of the Flight and Ground Voice Communications.

a. IGNITION AND FLAMMABILITY

(1) FINDING:

Flammable, non-metallic materials are used throughout the spacecraft. In the Block I and Block II spacecraft design, combustible materials exist contiguous to potential ignition sources.

DETERMINATION:

In the Block I and Block II spacecraft design, combustible materials are exposed in sufficient quantities to constitute a fire hazard.

(2) FINDING:

Malfunctions and failures can produce ignition sources in the Command Module.

DETERMINATION:

An ignition source in the presence of a combustible in the cabin atmosphere constitutes a fire hazard.

(3) FINDING:

Packaging design for Block II components differs from Block I in that nearly all components in Block II are hermetically or environmentally sealed.

DETERMINATION:

The Block II packaging design practice reduces the probability for the coexistence of an ignition source and flammable material.

(4) FINDING:

The space suit contains power wiring to electronic circuits; also, the astronauts could be electrically insulated.

DETERMINATION:

Both the power wiring and potential for static discharge constitute possible ignition sources in the presence of combustible materials. The wiring in the suit could fail from working or bending.

(5) FINDING:

Eighteen electrical circuits in Spacecraft 012 did not adhere completely to wire size/load/circuit protection design criteria.

DETERMINATION:

The condition was examined from the standpoint of overheating, and no problem was found to exist.

(6) FINDING:

Residues of RS89 (inhibited ethylene glycol/water solution) after drying are both corrosive and combustible. RS89 is corrosive to wire bundles because of its inhibitor.

DETERMINATION:

Because of the corrosive and combustible properties of the residues, RS89 coolant could in itself provide all of the elements of a fire hazard if leakage occurs onto electrical equipment.

(7) FINDING:

Water/glycol is combustible, although not easily ignited.

DETERMINATION:

Leakage of water/glycol in the cabin increases the risk of fire.

(8) FINDING:

Deficiencies in design, manufacture and quality control were found in the post-fire inspection of the wire installation.

DETERMINATION:

There was an undesirable risk exposure which should have been prevented by both the Contractor and the Government.

(9) FINDING:

The environmental control system is plumbed with aluminum tubing in both the water/glycol and oxygen circuits. Joints in the plumbing are made by nickel plating the aluminum and joining the nickel-plated surfaces with a tin-lead solder. Leakage of ECS coolant from these joints has been experienced in the Apollo spacecraft.

DETERMINATION:

The design of the soldered joints is inadequate to cope with all the conditions experienced in the spacecraft.

b. CABIN ATMOSPHERE

(1) FINDING:

NASA physiologists specify that a minimum oxygen partial pressure of 3.5 psia and a minimum absolute pressure of 5 psia be maintained as spacecraft cabin atmosphere.

DETERMINATION:

Acceptable cabin atmosphere ranges from a 5 psia oxygen single-gas environment to a mixed-gas environment with 3.5 psia oxygen and 3.5 psia nitrogen partial pressure.

(2) FINDING:

The spacecraft atmosphere control system design is based on providing a pure oxygen environment.

DETERMINATION:

The complexity of the technology is such that, to provide diluent gases, duplication of the atmosphere-control components as well as addition of a mechanism for oxygen partial-pressure control is required. These additions introduce additional crew-safety failure modes into the flight systems.

(3) FINDING:

Flammability characteristics of non-metallic materials are varied by only a factor of 3 or 4 by diluents in atmospheres containing oxygen at 3 to 5 psi partial pressure.

DETERMINATION:

Previous analyses leading to the decision to use 5 psia pure oxygen cabin environment in space are still valid.

c. REVIEW OF THE EGRESS PROCESS

(1) FINDING:

Sixty seconds are required for unaided crew egress from the Command Module. The hatch cannot be opened with positive cabin pressure above approximately 0.25 psi. The vent capacity was insufficient to accommodate the pressure buildup in the Apollo 204 Spacecraft.

DETERMINATION:

Even under optimum conditions emergency crew egress from Apollo 204 Spacecraft could not have been accomplished in sufficient time.

(2) FINDING:

The access arms to the Command Module in Launch Complexes 34 and 39 contain flammable materials, are removed thirty minutes prior to launch, and their doors open the wrong way for easy egress.

DETERMINATION:

The access arm could constitute a fire hazard and imposes delays to emergency crew egress.

d. REVIEW OF THE FLIGHT AND GROUND VOICE COMMUNICATIONS

(1) FINDING:

The control circuit from the Command Pilot developed a condition of continuous keying during the test.

DETERMINATION:

An anomaly existed in the spacecraft communication system.

(1) FINDING:

During the Apollo 204 test, difficulty was experienced in communicating from ground to Spacecraft and among ground stations.

DETERMINATION:

The ground system design was not compatible with operational requirements.

E. SUPPORTING DATA

The following is a list of enclosures to this section of the report.

Enclosures	
9-1	Summary of Ignition and Flammability Review
9-2	Spacecraft Atmospheres
9-3	Examination of Soldered Joints for Aluminum Tubing
9-4	Wiring Assessment
9-5	Wiring Assessment
9-6	Wiring Assessment
9-7	Wiring Assessment
9-8	Wiring Assessment
9-9	Wiring Assessment
9-10	Wiring Assessment
9-11	Wiring Assessment
9-12	Wiring Assessment

ABBREVIATIONS USED IN APPENDIX D-9

ALOC	Apollo Launch Operations Committee
ALOP	Apollo Launch Operations Panel
AS	Apollo Saturn
C&WS	Caution and Warning System
CM	Command Module
ECS	Environmental Control System
ECU	Environmental Control Unit
EPS	Emergency Detection System
ECP	Electrical Power System
EVA	Extravehicular Activity
G&N	Guidance and Navigation
T/C	Telecommunications
KSC	Kennedy Space Center
LC	Launch Complex
LES	Launch Escape System
LH_2	Liquid Hydrogen
MC	McDonnell Company
MSC	Manned Spacecraft Center
NAA	North American Aviation
O_2	Gaseous oxygen
OCP	Operations Checkout Procedure
OCP-0021	Space Vehicle Plugs Out Overall Test
RF	Radio Frequency
RS89	Inhibited Ethylene Glycol/Water Solution (AiResearch Specification)
S/C	Spacecraft
SCS	Stabilization and Control System
SECS	Sequential Events Control System
SM	Service Module
TV	Television
VHF	Very High Frequency

SUMMARY OF RESULTS OF IGNITION AND FLAMMABILITY REVIEW

This enclosure contains the significant findings of the Ignition Source Review Team for both Block I and Block II equipment installed in the Command Module interior. The possible ignition sources are grouped by subsystem. The information which follows was derived from a detailed review of the approximately 2000 pages contained in the basic ignition source report.

It is important to bring out the fact that neither the MSC, nor the NAA review teams nor the integration team were able to locate any possible sources of ignition in the subsystems under normal operating conditions. In all cases in order to have an ignition source, there must first be some type of failure of the component in question.

When a single failure mode for each component was postulated, twenty-one and fourteen potential ignition sources were identified for the Block I and Block II crew compartment subsystems, respectively. The number of ignition sources noted above does not represent a tally of total individual compartment subsystems, respectively. The number of ignition sources noted above does not represent a tally of total individual components that are suspect because all identical components such as switches and indicators on the display and control panels, all electrical connectors, and all harnesses or cable runs, etc., were treated generically; i.e., each group of suspect items in a category was considered as one potential ignition source. Delineation of ignition sources identified in Block I and II subsystem follows.

BLOCK I
ELECTRICAL POWER SUBSYSTEM

The following components of this subsystem are considered possible sources of ignition under a failure condition:

- General Usage Connectors
- Special Purpose Connectors
- Modular Terminal Boards
- Electrical Wiring

The above listed possible sources are generally generated by procedural and human error problems such as broken wires, damaged insulation, bent connector pins, damaged or lack of, conformal coating on terminal boards, etc. Evaluation of the detailed data in the basic report revealed that there were several cases on S/C 012 where there were deviations taken to the basic criteria for circuit-breaker compatability with wire size. The basic ignition source report contains an analysis of each of the cases of deviation, and evaluation of these analyses reveals a very low probability that these deviations could have been contributory to the S/C 012 accident.

DISPLAYS AND CONTROLS SUBSYSTEM

The following components of this subsystem are considered possible sources of ignition under a failure condition:

- Main Display Console (MDC) Panels
  - (Wiring and Terminal Strips)
- Lower Equipment Bay (LEB) Panels
  - (Wiring and Terminal Strips)

Excessive handling and human error problems associated with these components can lead to damage of wiring and conformally coated terminal strips. This damage could, in turn, lead to an arcing or shorting failure mode.

CAUTION AND WARNING SUBSYSTEM

The following component of this subsystem is considered a possible ignition source under a failure condition:

- Elapsed Time Indicator

This device is removed prior to flight and is, therefore, only a potential ignition source during ground operations. The Block I program has experienced one problem with this indicator on S/C014 during Downey checkout that could have led to it being an ignition source. Smoke was observed in this particular case when over-heating of a spike-suppression capacitor occurred.

ENVIRONMENTAL CONTROL SYBSYSTEM.

The following components of this subsystem are considered possible ignition sources under a failure condition:

- Glycol Evaporator Back Pressure Controller
- Cable Assemblies
- Waste Management System Blower
- Valve Seats in Oxygen Lines

The Controller was considered as a potential source only in that there is some probability that overheating of the controller under an internal failure condition could ignite the encapsulating material. It is not known, whether such a condition could result in ignition of the insulation, so it must be classified as suspect.

The cable assemblies are listed since breakage or abrasion could provide a source of ignition in that some harnesses are in direct contact with the Environmental Control Unit (ECU) foam insulation. The foam insulation was not covered with silicone rubber and thus did not meet the Apollo criteria for ignition temperature characteristics of nonmetallic materials.

The Waste Management System Blower is considered suspect because failures of a shorting or arcing nature within the blower motor have been experienced during the program.

Overheating of regulator and valve seats can occur in high-pressure oxygen lines due to compression waves. Because of this phenomenon, ignition of flammable plastic seats is possible.

GUIDANCE AND NAVIGATION SUBSYSTEM

The following components of this subsystem are considered possible ignition sources under a failure condition:

- Display and Keyboard (DSKY) Electroluminescent Panels
- Guidance and Navigation (G&N) Interconnecting Harness
- Inertial Measuring Unit (IMU) Control Panel Switches
- Eyepiece Heaters

A failure of the sealing for the Electroluminescent lights on the DSKY Panel could allow moisture to provide a shorting path for 250 volts used to excite the luminescent material. These seals did experience failure in qualification testing during low-temperature storage.

Breakage or abrasion of the G&N harness could lead to a possible ignition source.

The IMU Control Panel pushbutton lighted switches which contain bulbs do not constitute an hermetically or environmentally sealed device. These are possible ignition sources in the case of cracked bulbs or poor contact due to corrosion.

An equipment or component is considered hermetically sealed if it is sealed, either via a bonded-metal cover, or a gasketed cover (a molded-in-place elastomer gasket) which is designed to be capable of remaining pressurized or evacuated for the specification life of the equipment or component.

An equipment or component is considered environmentally sealed if it is not hermetically sealed, and is potted, foamed and/or conformally coated such that it will withstand the Apollo qualification environments, particularly with regard to the humidity and salt fog environments. This type of packaging generally "breathes" and is normally enclosed in a metal package.

The Eyepieces contain resistance heaters which operate at 28 volts and 0.1 amps. These eyepieces are subject to much handling before and during flight and are therefore subject to a greater probability of damage than fixed electrical components. Such damage could result in arcing or shorting.

STABILIZATION CONTROL SUBSYSTEM

The following components of this subsystem are considered possible ignition sources under a failure condition:

- Rotational Control
- Velocity Change Indicator (Delta V)

These two components of the Stabilization Control Subsystem contain non-hermetically sealed switches. If a failure occurs in the arc-suppression diodes, there could be a short to ground causing arcing of the contacts.

SPACECRAFT COMMUNICATIONS SUBSYSTEM

The following components of this subsystem are considered possible ignition sources under a failure condition:

- Radio Frequency (RF) Connectors
- Overheating of Equipment due to Loss of Cooling
- Elapsed Time Indicators (See Caution and Warning Subsystem)
- Hughes Connectors

Arcing of RF connectors and pin-to-pin shorting of the Hughes connectors are potential ignition sources under a failure condition. There is a general concern with regards to potential ignition sources if all communications system cooling should be lost. Whether or not ignition temperatures of adjacent non-metallics could be attained is not known.

TELEVISION SUBSYSTEM

The following components of this subsystem are considered possible ignition sources under a failure (procedural) condition:

- Television Bulkhead Connectors and Cable Assemblies

If the TV power switch is left in the "on" position during connection or disconnection of the TV power cable, arcing could occur thereby providing an ignition source.

SUBSYSTEM CONTAINING NO PROBABLE IGNITION SOURCES

Based on the ground rules established for this evaluation, the following subsystems are considered non-suspect from a probable ignition source standpoint:

- Sequential Events Controller
- Mission Control Programmer
- Crew Communications
- Instrumentation
- Experiments and Scientific Equipment

BLOCK II

The number of Block II components considered to be possible ignition sources under failure conditions is fourteen. This is seven fewer components than were listed in the Block I subsystems. The reduction in number is due in all cases to either one of two conditions:

(a) The Block I component is not used in Block II or

(b) The Block II components have been redesigned to eliminate the problem that existed in the Block I component. In many cases non-hermetically sealed components in Block I had been previously redesigned to incorporate hermetic seals due to concern over moisture penetration.

The following is a listing by subsystem of the Block II components that are considered possible ignition sources under failure conditions. The reasons that these are suspect can be found under the previous Block I susystem discussion of the component

ELECTRICAL POWER SUBSYSTEM

General Usage Connectors

Special Purpose Connectors
Modular Terminal Boards
Electrical Wiring

DISPLAYS AND CONTROLS SUBSYSTEM
MDC and LEB Panels (Wiring and Terminal Strips)

ENVIRONMENTAL CONTROL SUBSYSTEM
Glycol Evaporator Back Pressure Controller
Cable Assemblies

GUIDANCE AND NAVIGATION SUBSYSTEM
G&N Interconnecting Harness
Eyepiece Heaters

STABILIZATION CONTROL SUBSYSTEM
Rotational Control

SPACECRAFT COMMUNICATION SUBSYSTEM
RF Connectors
Overheating of Equipment due to Loss of Cooling

TELEVISION SUBSYSTEM
Television Bulkhead Connectors and Cable Assemblies
The following lists subsystems in which there exists no probable source of ignition:
- Caution and Warning
- Sequential Events Controller
- Entry Monitor
- Crew Communications
- Instrumentation
- Experiments and Scientific Equipment

Table I of this Enclosure is a convenient listing of the ignition sources and identifies changes from Block I to Block II.

The type of packaging and qualification history was examined for the components which were reviewed for possible ignition services. The components were treated categorically so the total number portrayed is greatly reduced from the total number actually reviewed (i.e., switches, circuit breakers, terminal boards, etc.)

Total number of components	- 188
Number environmentally sealed	- 95
Number hermetically sealed	- 78
Number not protected by either hermetic or environmental packaging	- 15

Table II of this Enclosure is a listing of all the Block II components which are neither hermetically nor environmentally sealed.

Table III of this Enclosure is a listing by subsystem of non-metallic materials contiguous to the components in Block II which have been identified as possible single-failure ignition sources.

TABLE I OF ENCLOSURE

SUMMARY OF POSSIBLE SOURCES OF IGNITION UNDER A FAILURE CONDITION

- BLOCK I & BLOCK II -

BLOCK I ITEM	DESCRIPTION	STATUS IN BLOCK II
General Usage Connectors	Cabling	Same
Special Purpose Connectors	Cabling	Same
Modular Terminal Boards	Cabling	Same
Electrical Wiring	Cabling	Same
Main Display Console (MDC) Panels (Wiring and Terminal Strips)	Cabling	Same
Lower Equipment Bay (LEB) Panels (Wiring and Terminal Strips)	Cabling	Same
Elapsed Time Indicator	Component	Eliminated
Glycol Evaporator Back Pressure Controller	Component	No Change
Cable Assemblies	Cabling	Same
Waste Management System Blower	Component	Fixed
Display and Keyboard (DSKY) Electroluminescent Panels	Component	Fixed
Guidance and Navigation (G&N) Interconnecting Harness	Cabling	Same
Inertial Measuring Unit (IMU) Control Panel Switches	Component	Fixed
Eyepiece Heaters	Component	No Change
Rotational Control	Component	No Change
Velocity Change Indicator (Delta V)	component	Fixed
Radio Frequency (RF) Connectors	Cabling	Same
Overheating of Equipment due to Loss of Cooling	Condition	Same
Elapse Time Indicators	Component	Eliminated
Hughes Connectors	Cabling	Eliminated
Television Bulkhead Connectors and Cable Assemblies	Cabling	Same

TABLE II OF ENCLOSURE I

BLOCK II COMPONENTS NOT HERMETICALLY OR ENVIRONMENTALLY SEALED

COMPONENT	SUBSYSTEM	TYPE OF PACKAGING	REMARKS
D&C Panel Assemblies (Twenty-eight for Block I) (Fifteen for Block II)	Displays & Controls (D&C)	Conformal Coating	Terminals are potted or conformally coated. All current carrying contacts are within sealed enclosures. Incandescent filaments are doubly sealed within glass bulbs inside sealed envelopes
Eyepiece Stowage	Guidance & Navigation	Stowage	Qualified
Video Coaxial Connector Cable Assemblies	Communications	No seal	These assemblies have been qualified. Voltage and power levels are not considered to be high enough to pose a threat of fire. There are no known failures which have indicated that a fire hazard exists in the video connector cable assemblies

TABLE II OF ENCLOSURE I (Continued)

COMPONENT	SUBSYSTEM	TYPE OF PACKAGING	REMARKS
Bulkhead Receptacle	Communications	Metal housing with plastic dielectric around terminals. No seal	The receptacle has been tested in 100% O at 14 psia with simulated cameral load. No failure has occurred.
Stadimeter	Experiments & Scientific Equipment	Not packaged	Non-electrical component
Data Reduction Tables	Experiments & Scientific Equipment	—Not packaged	Non-electrical component
D009 Container	Experiments & Scientific Equipment	Not packaged	Non-electrical component
Ultraviolet (UV) Stellar Spectrograph Support Structure	Experiments & Scientific Equipment	Not packaged	Non-electrical component
Lens Cover	Experiments & Scientific Equipment	Not packaged	Non-electrical component
UV/X-Ray Solar Spectrograph Cable	Experiments & Scientific Equipment	Connectors Potted	No history of failure
Scientific Airlock	Experiments & Scientific Equipment	Not packaged; provides spacecraft seal	Non-electrical component
Film Magazine for Camera	Experiments & Scientific Equipment	Combustible film is totally enclosed, but not sealed, in metal magazine	No history of failure
1.2 Litre Contingency	Experiments & Scientific equipment	Not packaged	Non-electrical component
Urine Receiver	Experiments & Scientific Equipment	Not packaged	Non-electrical component
Scientific Junction Box	Experiments & Scientific Equipment	Potted internally	No history of failure

TABLE III OF ENCLOSURE 9-1

BLOCK II NON-METALLIC MATERIALS CONTIGUOUS TO COMPONENTS IDENTIFIED AS POSSIBLE SINGLE-FAILURE IGNITION SOURCES

SUBSYSTEM	NON-METALLIC MATERIALS
Electrical Power	Teflon Tetrafluoroethylene (TFE) Silicone Rubber

TABLE III OF ENCLOSURE 9-1 (Continued)

SUBSYSTEM	NON-METALLIC MATERIALS
Stabilization & Control	Phenolic Molding Compound
	Diallylisophthalate (DAIP) Molding Compound
	Expoxy Primer
	Acrylic Enamel
	Epoxy-Syntatic Foam
	Polyurethane Varnish
	Silicone Lubricant
	Silicone Rubber
Sequential Events Control	No Ignition Sources
Mission Control Programmer	Not Applicable
Entry Monitor	No Ignition Sources
Communications	Class A Foamed Polypropylene
	Irradiated Polyolefin
	Irradiated Polyvinylidene Fluoride
	Teflon
Instrumentation	No Ignition Sources
Experiments and Scientific Equipment	No Ignition Sources

TABLE III OF ENCLOSURE 9-1 (Continued)

SUBSYSTEM	NON-METALLIC MATERIALS
	Teflon Tetrafluoroethylene Fluoro Ethylene Propylene (TFE FEP)
	Polyvinylidene Fluoride
	Nomex Acrylic Coated
	Nylon
	Epoxy Polyamide Resin
	Epoxy Adhesive Epon 929
Displays & Controls	Silicone Rubber Grommets
	Room Temperature Vulcanized (RTV) Conformal Coating
	Teflon
	Polyvinylide Fluoride
	Nomex, Acrylic Coated
	Nylon
	Polyurethane
	Fiberglass
	Neoprene
	Epoxy Polyamide Resin
Caution & Warning	No Ignition Sources
Environmental Control	Compounds, Airesearch SPEC Nos 219 081 9001, 219 049 9001, S84711.22, S8952 20 9 008 223 022 9047 219 109 9001
Guidance & Navigation	Polyurethane Foam
	Viton
	Irradiated Polyethylene
	Polytetrafluoroethylene

SPACECRAFT ATMOSPHERES

BACKGROUND

The use of 100% oxygen for spacecraft atmosphere in the U. S. manned space program has been based on extensive research and development in both the fields of biomedical science and engineering. The selection of a pure oxygen atmosphere at a pressure of 5 psia for the Mercury, Gemini, and Apollo Programs resulted from careful consideration of the physiological, safety, and reliability requirements of manned space flight.

The engineering, medical, and safety aspects of the one-gas (100% oxygen) atmosphere have been the subject of widespread investigation in the United States and abroad, by government, university, and industrial research. While the bulk of the research has been over the past ten years, considerable work relating to the use of 100% oxygen in aircraft was done much earlier. Probably one of the most authoritative compilations of this research is contained in a four-part series on "The Selection of Space-Cabin Atmospheres," prepared for NASA by Dr. E. Roth of the Lovelace Foundation for Medical Education and Research, Albuquerque, New Mexico. The series, which was prepared under NASA contract, is comprised of four volumes: (1) "Oxygen Toxicity," (2) "Fire and Blast Hazards," (3) "The Physiological Factors of Inert Gases," and (4) "Engineering Trade-offs of One-Versus-Two-Gas Systems." Volumes (1) and (2) have been published; Volumes (3) and (4) are in the publication process. These studies have been further expanded by the work of the Douglas Company for NASA contained in, "Engineering Criteria for Spacecraft Cabin Atmosphere Selection," Douglas Missile and Space Systems Division, Douglas Report DAC-59169, November 1966.

GENERAL CONSIDERATIONS IN THE SELECTION OF SPACECRAFT ATMOSPHERE

Before discussing the specific aspects of the spacecraft atmospheres used in Mercury, Gemini, and Apollo, the general considerations relating to spacecraft atmosphere should be reviewed. Selection of the atmosphere must consider at least the following factors:

1. Sufficient oxygen content to support life. This requires a minimum partial pressure of oxygen equal to or greater than 3.5 psia.
2. Dysbarism (bends) caused by pressure decreases in a multi-gas system, or in transitions from normal atmosphere to pure oxygen environment at reduced pressures.
3. Total operating pressure, which affects spacecraft structural design as well as dysbarism potential in event of spacecraft decompression in normal or emergency operations.
4. Space suit operating pressure (gauge) which has significant effects on suit design, crew mobility in unpressurized cabin and extra-vehicular activity (EVA) physiological stress levels. In general, suit pressure levels exceeding 3.5 psia result in increasingly severe space suit rigidity.
5. Difference in cabin atmosphere constituents and suit atmosphere constituents which affect the possibility of dysbarism in decompression, or would dictate extended time for crew purging for EVA activities as well as potential leakage problems between suit and cabin atmospheres in redundant operating modes.
6. Pulmonary atelectasis (collapse of lung tissue), which could be caused by inhalation of pure oxygen for extended periods of time which is a function of absolute oxygen pressure level.
7. Differences between cabin atmosphere and suit atmosphere constituents which could produce the possibility of hypoxia! lack of sufficient oxygen! in the event of minor system malfunction or interaction.
8. The hardware complexity of the environmental control system design which is a function of its atmosphere constituents. This extends to consideration of oxygen uses for purposes other than life

its atmosphere constituents. This extends to consideration of oxygen uses for purposes other than life support.

9. The reliability of measuring and controlling the partial pressures of constituent elements of a multigas system. In general, more complex measurement and control systems must be used for a two-gas atmosphere as compared to simply controlling the pressure of an oxygen atmosphere.

10. Crew comfort on a long mission which is significantly affected by continued suit operation in either a pressurized or an unpressurized cabin. This consideration is also a function of confidence in cabin integrity and expected emergency decompression rates.

11. Effect of the atmosphere chosen on ignition temperatures of cabin materials. In general, the ignition temperatures for solids vary only slightly with oxygen partial pressure.

12. Effect of the atmosphere on combustion propagation rates after ignition has begun. Again, in general, the propagation rate is affected by oxygen partial pressure. However, at the relatively low pressures used in spacecraft, this effect appears to be of no significance.

MERCURY AND GEMINI FLIGHT ATMOSPHERES

The guideline for the selection of the atmosphere used in the Mercury Spacecraft was to employ the least complex and lightest approach consistent with reasonable safety. The 5 psia, 100% oxygen environment was selected as the best compromise to preclude anoxia and oxygen toxicity. Another consideration was the selection of a pressure level which, in the event of a cabin decompression, would result in a minimum decrease to the suit pressure, and therefore, the least incidence of dysbarism [bends!. It should be noted that prior to the inception of the Mercury Program, aviators flying high-performance aircraft were breathing 100% oxygen. This aircraft experience was the natural predecessor to the Mercury environment; in effect it constituted the "state of the art" within the aerospace medical community.

Early in the Mercury Program, a NASA Life Sciences Committee, chaired by Dr. W. R. Lovelace, II, reviewed the medical requirements and approved the approach taken by the program.

As a part of the development of the Mercury Environmental Control System (ECS) manned altitude chamber tests were conducted in a boilerplate spacecraft. The first of these manned tests was conducted at McDonnell Aircraft Corporation on April 21, 1960, with Mr. G. B. North, a McDonnell test pilot, as the test crewman.

Mr. North was prepared for the test by pre-breathing oxygen before ingress to the test vessel. The pressure suit circuit had already been purged with oxygen. After the ingress operation was completed, the suit circuit was again purged with oxygen for a time period and rate previously determined to assure an essentially pure oxygen environment in the suit circuit. The hatch was closed and sealed. No oxygen purge of the cabin was conducted, since the space suit was isolated and the Environmental Control System design provided an 80% cabin purge during spacecraft ascent by adding oxygen to the cabin as the cabin relief valve permitted total pressure to reduce from one atmosphere to space operating level.

The altitude chamber was evacuated to 27,000 feet equivalent altitude, and the Environmental Control System operation during the chamber pump down (simulating launch ascent) was as planned.

After approximately forty (40) minutes of operation at 5 psia, the test was aborted because Mr. North became unconscious. This condition was attributed to hypoxia (lack of sufficient oxygen).

Subsequent investigations revealed that leakage of nitorgen from the spacecraft air into the pressure suit circuit had gradually decreased the partial pressure of oxygen below physiologically acceptable limits. This decrease in oxygen partial pressure could occur since certain portions of the suit circuit were at negative pressures relative to the cabin pressure.

Three additional manned tests were conducted on June 2, 2, and 6, 1960. All three tests were aborted because of rapid decreases in the suit circuit oxygen levels.

As a result of these incidents, the prelaunch procedure for all Mercury spacecraft, both astronaut and chimpanzee, was changed to require that the cabin be purged with oxygen prior to launch. This change eliminated the possibility of nitrogen concentration in the suit circuit.

The requirement for purging the cabin with pure oxygen at approximately 15 psia during the prelaunch period of several hours has been continued for all manned spacecraft launched in this country. This same procedure has been used also on all manned spacecraft vacuum chamber tests in the Mercury, Gemini and Apollo Programs.

The Gemini spacecraft atmosphere was selected to be the same as Mercury (5 psia, 100% oxygen). This selection allowed the Gemini program to develop an environmental control system largely based on the Mercury design, and to benefit from the years of previous experience in procedures, specifications, and standards. The Gemini system proved extremely reliable, and performed successfully in 10 manned flights, and in a large number of manned and unmanned altitude chamber tests and prelaunch operations.

APOLLO FLIGHT ATMOSPHERE

Early studies based on NASA's own research and also on a large body of other experimentation on artificial atmospheres, e.g., aircraft and submarine, resulted in a recommendation for a 7 psia oxygen-nitrogen atmosphere for Apollo. This first recommendation was in 1961. The primary reason for this recommendation was concern by physiologists that two-week Apollo missions in a 5 psia 100% oxygen environment (used in the Mercury Program) could cause pulmonary atelectasis (collapse of lung tissue). This condition had been observed after extended inhalation of pure oxygen prior to that time. However, a counter-balancing physiological question concerned dysbarism (bends) in the recommended two-gas system if a rapid cabin decompression should occur.

An extensive test program was, therefore, initiated to resolve these physiological questions for both the Apollo and Gemini atmosphere selections. (5 psia, 100% oxygen) atmosphere was planned for the Gemini spacecraft). The tests showed that a preoxygenation period of at least three hours was required to prevent bends in the event of cabin decompression during, or immediately following launch. Testing in the 5 psia 100% oxygen atmosphere indicated that atelectasis would not be a problem in the two-week Apollo or Gemini missions. (Satisfactory crew performance has not been demonstrated for 30-day periods in 5 psia 100% oxygen atmosphere, including dynamic and static conditions). Based on the results of this test program, NASA decided in 1962 that the Apollo spacecraft would also use the 5 psia 100% oxygen atmosphere used in the Mercury and Gemini Programs. This selection of cabin atmosphere in space has enabled:

1. Continuation of the Mercury and Gemini experience.
2. Avoidance of potential dysbarism problems in avrious modes of space operation.
3. Relatively simple environmental control system hardware with attendant high reliability.
4. A "shirt-sleeve" cabin environment which has enhanced crew comfort and effectiveness.
5. Minimum operational restraints to EVA initiation.
6. Maximum crew mobility within the constraints of present space suit design by utilizing lowest practical absolute pressure.

FLIGHT ATMOSPHERE FOR THE APOLLO APPLICATION PROGRAM

The Apollo Applications Program (AAP) presently plans to use a 5 psia two-gas atmosphere (60% oxygen; 31% nitorgen) only in the airlock module (S-IVBspent stage workshop) for planned mission durations in excess of 30 days. The 5 psia pressure level selected for the long duration missions was dictated by present Apollo pressure vessel capability and system compatibility considerations.

Present program plans continue the utilization of the standard Apollo pure oxygen environment in the Command Service Module and Lunar Modules, which may be associated with AAP missions. While the airlock module will have the capability for a two-gas system on the first AAP mission, present plans are to utilize the two-gas system for the second mission (45 days). Pure oxygen atmosphere would be used on the first mission (30 days).

The primary consideration in utilization of the two-gas system for long duration missions is a desire to avoid physiological uncertainties and the possibility of atelectasis.

FIRE HAZARDS IN THE SPACECRAFT ATMOSPHERE

The possibility that fire could occur in any atmosphere capable of life support has been understood throughout the program. In general, neither ignition temperature nor combustion rate is a strong function of oxygen partial pressure in the range from 3.5 psia to perhaps 7 psia. Mixed gas systems operating with a minimum of 3.5 psia oxygen partial pressure apparently do not have significantly different fire hazard potentials as compared to a pure oxygen atmosphere at the same pressure.

Limited zero-G aircraft testing has indicated that there is a tendency for combustion in a low-pressure pure-oxygen environment at zero-G to be self-limiting. This may occur because of the lack of natural convection to remove products of combustion which no longer contain oxygen from the vicinity of the flame source. However, forced convection in the cabin could nullify this effect.

In orbit, fire on board the spacecraft could be extinguished by venting the cabin to space. This mode of operation would require the crew to be suited prior to the decompression period because physiological constraints dictate that a minimum body pressure of 3.5 psia be maintained. Suit-donning times are on the order of 10-15 minutes. Since the probability of fire was considered sufficiently remote, this mode was not given strong consideration because crew comfort and crew effectiveness in long-duration missions require that the suits be off for extended periods.

Attempts to design fire extinguishers for cabin deluge systems have not been particulary successful. The "fire pockets" between instrument panels and structures complicate the design of any effective fire-extinguishing system for spacecraft use. In addition, there is the potential interaction with crew safety, e.g., toxic fumes. The difficulty of timely detection of a fire and reliable operation of an extinguishing system must be carefully weighed against the potential dangers when considering such a system for spacecraft use.

SUMMARY REMARKS

In summary, the selection of a 100% oxygen atmosphere for manned spacecraft has resulted from the careful consideration of all factors relating to crew safety and mission success. This choice has been based on extensive research, which has included single and multi-gas atmospheres with their attendant advantages and disadvantages.

The 100% oxygen atmosphere has been used successfully in all U.S. manned flights to date, and is considered suitable for missions of 30 days or less.

EXAMINATION OF SOLDERED JOINTS FOR ALUMINUM TUBING

A. Design Selection Rationale

The decision to use aluminum tubing in the Environmental Control System (ECS) for both the water/glycol and oxygen circuits was made on the basis of stringent mission requirements and design limitations (weight, vibration, fluid compatibility, pressure, ect.). These required that:

(1) All joints were to be essentially leak free. The maximum leak rate allowed was 5.6 x 10^{-6} std. cc of helium/sec.

(2). The joints were to be compatible with the various spacecraft fluids without a loss in strength, particulate formation, or fluid degradation.

(3). The joints, and the lines, were to withstand an acoustic environment sustained at a sound pressure level above 143 decibels for 150 seconds.

(4). The joints were to sustain a dynamic in-flight environmental stress of 17,000 psi for 5,000 cycles.

(5). The maximum design pressure was not to exceed 900 psi in the ECS aluminum lines.

Another consideration was that the plumbing system be of minimum weight. The aluminum tube wall thickness was established at .035 inch for strength and to facilitate handling, 304L stainless steel lines would also require 0.035 inch tube wall. On this basis, assuming the various joint configurations would be similar for both steel and aluminum, the steel system would weigh approximately 3 times the aluminum system, a weight penalty of approximately 103 pounds.

Welding of the aluminum joints was also considered, but early in the program it was evident that an extensive and costly development program would be necessary. Therefore, aluminum tube welding was limited to manual welding on the bench and in readily accessible areas on the spacecraft.

Mechanical fittings were utilized, but limited in number for obvious reasons. Mechanical fittings are susceptible to loosening under vibration, and generate the greatest amount of particulate matter during tightening. Therefore, these joints (B-nuts and quick disconnect fittings) were limited to dissimilar metal joining, closeout lines, equipment connectors, etc.

Based upon these considerations, a metallurgical joint was indicated and a soldered union for joining aluminum tubing was considered. The soldered tube-union joint permits the assembly of a plumbing system of minimum weight generates the minimum contamination, has adequate strength to withstand system pressures, is compatible with system fluids, and will sustain spacecraft environments.

When the decision to use solder joints was made in 1962, a program was immediately initiated to select a soldering alloy. This alloy was required to be compatible with the spacecraft fluids, readily available, and applicable to existing processing techniques. This phase of the program involved an intensive literature search, mechanical property determinations, flow and compatibility testing.

The literature survey resulted in 31 candidate alloys from which twenty were selected for fluid compatibility testing. These tests screened out all but two potential alloys. These two alloys were subjected to the following tests:

[1]. Compatibility with N_2O_4
[2]. Alloy wetting and flow characteristics
[3]. Optimem plate thickness (nickel base for solder)
[4]. Optimum gap for capillary flow
[5]. Peel resistance
[6]. Metallurgical analysis (diffusion, erosion of tube)
[7]. Mechanical properties (shear, stress rupture)
[8]. Effects of reheating

Subsequent to these tests, containment of N_2O_4 was not required by the aluminum tubing. This necessitated a re-evaluation of the soldering alloy. Based upon prior development testing, production experience, strength, availability and exceptionally good corrosion resistance, it was decided to test and use the 60 Sn - 40 Pb solder alloy. This solder conformed to Federal Specification QQ-S-571, Type SN 60 RARP2 (activated rosin cored flux). This alloy was subjected to the following tests:

[1!. System and Material Compatibility Tests

a. Exposure and weight loss
b. Metallographic examination
c. Salt spray - 240 hours at 95°F in 20% NaCL
d. Humidity - 240 hours at 120°F in 95% humidity
e. Simulated system exposure to water-glycol for periods up to 8 months
f. Leak tests prior to and subsequent to exposure
g. Joint strength change prior to (control specimen) and subsequent to exposure.

[2!. Mechanical Property Tests

a. Joint shear strength
b. Stress rupture under tensile loading (38% to 90% of joint shear strength).
c. Creep (35% to 95% of joint shear strength)
d. Burst pressure (Hydrostatic)
e. Flexure - Impulse fatigue - Impulse fatigue (pressure 40-60 psi, 17,000 psi fiber stress for 5,000 cycles minimum).

[3!. Structural Environmental Tests

a. Acoustic vibration (143 decibels minimum for 150 seconds).
b. Vibration-flow (Sinusoidal and random vibration - time 5 minutes, Orientation: Both orthogonal axis perpendicular to the longitudinal axis of the tube).

[4!. Leak Testing

a. Mass Spectrometer

1. Internally pressurized joints
2. Evacuated lines and joints

[5!.. Effect of Resoldering Joints

PROCEDURE

a. Solder up to 3 times (joints pulled apart between each resolder operation).
b. Check joint by X-Ray for presence of voids.
c. Leak rate with mass spectrometer
d. Determine change in joint strength.

[6!. Alignment

Where required, a tube alignment fixture shall be attached in such manner that the tubes are held together with a maximum allowable gap of 0.060 inch. The maximum premissible axial misalignment shall be three degrees, and displacement of either tube end from the center of the union shall not exceed 0.060 inch.

TEST RESULT SUMMARY

[1!. Corrosion and Compatibility Testing

a. No evidence of deleterious corrosion or corrosion products were noted in simulated partial ECS systems with inhibited water, glycol after eight months exposure. Aluminum soldered joints removed from SC 011 after flight and recovery revealed only a slight white deposit in the joint area, but no evidence of tube or solder alloy corrosion. The white deposit is believed to be an anhydrous Al (OH)e, but is not considered detrimental in an active system as it is present as a gel and does not clog the system.

b. No deleterious corrosion was evident due to the salt spray and humidity testing. The ak integrity of the joint was maintained with no appreciable loss of strength as measured by the burst tests.

[2!. Mechanical Property and Environmental Stress Testing

a. The joint shear strenght (tensile) is more than adequate for the low pressures used on the Apollo. The tensile load applied by the system pressure is only a fraction of the joint strength. Avg joint strength [1/4 dia.! - 681 pounds Axial load due to pressure [900 psi! - 36 pounds

b. The vibration, flexure-impulse, and burst-test results indicate that the joints do withstand the environmental stresses by at least a factor of 10.

(3). Structural Environmental Testing (Spacecraft Test Sections)

Several test sections of the service module containing numerious soldered joints of all sizes and configuration were acoustically tested with only one leak (out of 51 joints) in a water/glycol tube tee assembly. This test was part of the auxiliary plumbing and not a test item This joint was repaired and the test repeated successfully.

[4!. Leak Testing

The leak tests were performed with a mass spectrometer sensitive to 10-6 std. cc of helium/second using helium as the detectable gas. The leak checks were performed prior to and subsequent to vibration, flexture-impulse, and resoldering tests. Out of 47 joints tested, five leaks were observed. Two of the leaks were in the tubes at the fixture, two did not exceed the allowable limits (3.54 x 10-7 and 1.27 x 10-7 st. cc of helium/sec.) and the fifth had a leak rate of 8.9 x 10-6 std. cc of He/sec.

(5). Burst Testing

The average hydraulic fluid pressure required to burst the aluminum soldered joints ranged from 13,000 psi for the 1/4 inch lines to 5,300 psi for 5/8 inch lines. These fluid pressures are more than adequate for the maximum system pressure of 900 psi. Based on these results the factor of safety at operating pressure is at least six.

(6). The selection of solder for joining aluminum tubes was evaluated further by establishing the magnitude of the midspan deflection of a simply-supported tube specimen stressed in bending to 17,000 psi. This stress was considered to be a minimum safe allowable value. The span was selected by assuring that the natural frequency would be greater than 120 cps. Based on the outer fiber stress of 17,000 psi achieved during the test, the following midspan deflections were obtained.

Tube Diameter (In.)	Span (In.)	Midspan Deflection (In.)
1/4	13.5	0.239
3/8	16.5	0.226
5/8	22.0	0.232

It was assumed that in normal manufacturing and assembly handling these deflections would permit assembly without any undue problems in tube alignment and line movement during equipment installation and removal. These deflections were substantiated by the vibration test which imposed a fiber stress of 17,000 psi for a minimum of 61,200 cycles.

Based upon the foregoing data, the implementation of soldering for joining aluminum tubing is considered to a sound decision provided the procedures for alignment are met, good design practice is exercised, and appropriate criteria for system installation and field maintenance are generated.

B. Program Experience

(1). Union on coupling design.

The union, as presently used in the program, has been designed to minimize weight. In practical use and especially in conjunction with the use of the 6061-T6 hardened aluminum tubing, these unions have proven to be unsatisfactory. Considerable number of leaking joints have been found on all spacecraft. Substantial improvement of this union is required in order to accept normal handling associated with spacecraft checkout and field repairs.

(2). Joint Assembly

Initially, considerable difficulty was experienced in the nickel plating process; however, this problem has apparently been resolved by establishing and maintaining rigid cleaning process specifications.

The present specification allows an additional heat if the joint is unsatisfactory. Criteria for a satisfactory joint has been reduced to leakage only. Joints not meeting the other criteria are often accepted as a result of engineering action if they meet the leakage requirements.

In spite of the allowable reheat and reduced criteria, a ten percent rejection rate still exists.

LIST OF REFERENCE MATERIAL

The supporting data for this report have been transmitted to the Apollo 204 Review Board files. These data are contained in the following references:

REFERENCE

9-1. Williams, R. W., DETAILED INSTRUCTION TO WORKING GROUPS, February 5, 1967.

9-2. Hamblett, E. B., et. al., COMMAND MODULE CREW COMPARTMENT IGNITION SOURCES AND CONTIGUOUS NON-METALLIC MATERIALS, March 15,-967.

9-3. Hamblett, E. B., et. al., DATA SHEETS, BLOCK I AND BLOCK II COMMAND MODULE IGNITION SOURCE AND CONTIGUOUS NON-METALLIC MATERIAL REVIEW.

9-4. CABIN ATMOSPHERE, SUMMARY AND BIBLIOGRAPHY.

9-5 Joslyn, A. W., et. al., OXYGEN SUMMARY, March 15, 1967
Hazards Evaluation, Bibliography
Engineering Tradeoffs [State of the Art! - General, Bibliography
Material Selection, Bibliography
Physiological Considerations - General, Bibliography
MSC Supporting Data [Atmospheric Selection, Safety Considerations!, Bibliography
New Releases, Bibliography.

9-6. Jaderlund, W. W.. et. al., APOLLO 204 PANEL 9 REPORT ON PAD EGRESS, March 10, 1967.

9-7. Beers, C. A., et. al., VOICE COMMUNICATIONS ANALYSIS REPORT, PANEL 9, APOLLO 204 REVIEW BOARD, March 21, 1967.

REPORT OF PANEL 10
ANALYSIS OF FRACTURE AREAS
APPENDIX D-10
TO
FINAL REPORT TO
APOLLO 204 REVIEW BOARD

A. TASK ASSIGNMENT

The Apollo 204 Review Board established the Analysis of Fracture Areas Panel, 10. The task assigned for accomplishment by Panel 10 was prescribed as follows:

Inspect spacecraft for structural failures resulting from the fire. Analyze these failures from standpoint of local pressure, temperature levels, direction of gas flow, etc.

B. PANEL ORGANIZATION

1. MEMBERSHIP:

The assigned task was accomplished by the following members of the Analysis of Fracture Areas Panel:

Mr. P. C. Glynn, Chairman, Manned Spacecraft Center (MSC), NASA
Mr. N. Koenig, Kennedy Space Center (KSC), NASA
Mr. R. E. Johnson, Manned Spacecraft Center (MSC), NASA
Mr. S. Glorioso, Manned Spacecraft Center (MSC), NASA
Mr. L. J. Korb, North American Aviation, Inc. (NAA)
Mr. D. Root, North American Aviation, Inc. (NAA)

Technical support was provided by the Manned Spacecraft Center (MSC) Structures and Mechanics Division (SMD) and North American Aviation structural analysis personnel. The major portion of the on-site task consisted of detailed metallurgical inspection and laboratory analysis. Metallurgists Korb, Glorioso, Root, and Johnson performed the majority of the inspection while Koenig monitored or performed all the laboratory analyses.

2. COGNIZANT BOARD MEMBER:

Mr. E.B. Geer, Langley Research Center (LaRC), NASA, Board Member, was assigned to monitor the NAnalysis of Fracture Areas Panel.

C. PROCEEDINGS

In response to the direction of the Apollo 204 Review Board, the Panel derived detailed objectives. These objectives were:

Inspect the spacecraft structures to determine the extent, origin, mode, and failure sequence of significant structural damage.

Estimate the cabin environment during the fire. Analyze all applicable data and examine the spacecraft for evidence of local temperature and pressure extremes.

Provide metallurgical support to the systems engineers during spacecraft disassembly. Define metallurgical test requirements to determine the cause of system damage.

1. PANEL ACTIVITY

The inspection of the spacecraft structures was conducted in a systematic manner starting with the Command Module (C M) and Service Module (S M) while located at Launch Complex 34 and continued through C M heat shield removal. Structural damage reports were made coincident with the spacecraft disassembly phases. As major sub-systems were removed from the spacecraft, they were visually inspected. Buckles, fractures, cracks, melted areas, localized arcing or pitting in metal components, and obvious direct wire-shorts were noted and documented. Those items which required laboratory analyses were identified and detailed test requirements were defined. Equipment removed from the spacecraft following heat shield removal was inspected in detail at the request of the applicable system engineer. Analyses of results of the monitored laboratory work were provided to Panel 18 Integration Analysis. Metal degradation due to extreme structural temperatures was documented and analyzed. An estimate of the temperature attained in local areas as determined from examination of the metallic components was provided to Panel 8 Materials Review. Support concerning the spacecraft strength and structural configuration was provided to Panel 4, Disassembly Activities Panel. Structural and mechanical subsystem support was provided to the Equipment Screening Committee.

2. INTRODUCTION

The crew compartment of C/M 012 was a pressurized shell fabricated of bonded aluminum honeycomb sandwich structure. The cabin structure was pressurized to a positive pressure of approximately 2 pounds per square inch differential (psid) pressure at the time of the fire. As a result of the fire, portions of the interior and exterior were burned and the primary cabin structure was ruptured.

At the time of the accident, all components of the structural and mechanical subsystem were inactive. No evidence was found which would support a hypothesis of mechanically induced ignition of combustibles within the C/M. The crew equipment subsystem contained combustible material which burned. Examination of film and data from the SMD-2B boilerplate fire simulation test (Reference 10-1) verified that the rupture of the C/M cabin accelerated the propagation of the fire by inducing forced convection.

3. INVESTIGATIVE ACTIVITIES

a. CABIN RUPTURE

(1) TIME OF RUPTURE

The time of cabin rupture was concluded to be between 6:31:19.3 pm EST (23:31:19.3 GMT) and 6:31:19.5 pm EST. This conclusion is supported by analysis of aft heat shield thermocouple data and Stabilization and Control System (SCS) spacecraft angular rate data. The thermocouple data indicated an open circuit at approximately 23:31:19.5 GMT. Inspection of the measurement wire leads near the origin of cabin rupture verified that the leads had been burned through. The induced structural motions at rupture, indicated at 23:31:19.3 GMT by the SCS rate measurements, were analyzed and correlated with the origin of the fracture.

(2) CABIN PRESSURE HISTORY

Atmospheric pressure at the time of the accident was 14.68 pounds per square inch absolute (psia). Direct measurement of the cabin pressure was valid until approximately 6:31:16 pm EST at which time the cabin pressure measurement indicated full scale. However, the Guidance and Navigation System did respond to cabin pressure as discussed in Reference 10-2. AC Electronics Division analyzed the applicable data from OCP FO-K-0021-1 as well as data from a previous C/M 012 cabin pressure test. This and supporting test data obtained by simulation using Spacecraft 008 (Reference 10-3) verified the cabin pressure measurement and provided the additional data points shown in Enclosure 10-2.

An estimate of the minimum cabin pressure history for the time period 6:31:16 to 6:31:19.4 pm EST was calculated. The heat absorbed by the cabin gas was calculated up to the time of pressure transducer saturation. The rate of heat absorbed by the cabin gas was linearly extrapolated and the resulting pressures and average gas temperatures were calculated. Venting of the cabin pressure relief valve and the addition of oxygen to the cabin were included in the analysis (Reference 10-4 and 10-5). Operation of the cabin pressure relief valve was shown to have negligible effect upon the time until cabin rupture. The method of analysis used was judged to yield a minimum pressure history. The estimated minimum pressure at rupture was 29 psia.

Enclosure 10-2 presents the estimated cabin pressure from 6:31:06 to 6:31:22 pm EST. Pressure values plotted for the time of rupture are:

Design ultimate pressure 12.9 psi differential (27.6 psia)
Estimated minimum pressure at rupture 14.3 psi differential (29 psia)
Estimated maximum pressure at rupture (discussed in Section C3c(1))
23 psi differential (37.7 psia)

Average gas temperature at the time of rupture was estimated to be in excess of 700 degrees Fahrenheit (°F). The SMD-2B fire simulation test data (Reference 10-1) and analyses estimate a structural temperature at the time of rupture in the vicinity of the origin of fracture of less than 130° F.

b. C/M PRIMARY STRUCTURAL DAMAGE

(1) C/M EXTERIOR

Inspection of the C/M exterior indicated extensive primary structural damage to the +Y, -Z quadrant exterior structure. Evidence of degradation of the external thermal control coating was most severe in this region. Evidence of C/M crew compartment exterior structural damage was noted in the region between access panels 15 and 17, (Enclosure 10-3) and of the helium pressurization panel bracketry as illustrated in Enclosures 10-4 and 10-5. Inspection following heat shield removal indicated burned and melted secondary structure in this region.

(2) C/M CREW COMPARTMENT

Inspection of the interior of the C/M cabin determined that the primary structure was damaged in several locations. Burned penetrations of the bonded aluminum honeycomb sandwich cabin structure were observed in the aft bulkhead beneath the Environmental Control Unit (ECU) and Water Control Panel and in the aft sidewall behind the Water Control Panel. Rupture of the aft bulkhead was observed as illustrated in Enclosures 10-6 and 10-7. Melting and erosion of the fracture surfaces was evident and is illustrated in Enclosure 10-8.

Much of the fracture surface was not initially visible from the interior of the C/M due to equipment and secondary structure installations. The fracture surfaces are defined in detail in Enclosures 10-9 and 10-10. Exterior definition of the fracture is illustrated in Enclosure 10-11a, 10-11b, and 10-11c.

(3) C/M AFT HEAT SHIELD

The aft heat shield brazed stainless steel honeycomb sandwich structure was melted and eroded in the +Y, -Z quadrant as shown in Enclosures 10-12a, 10-12b, and 10-12c. Evidence of high temperatures and high velocity gas flow is further illustrated by the charred and missing insulation which is installed between the aft heat shield and cabin aft bulkhead. Evidence of impinging hot gas through penetrations in the cabin aft bulkhead in the +Z quadrant was observed. Little evidence of impinging gas was observed at the location of the burned-through area beneath the ECU and Water Control Panel.

c. ANALYSIS OF PRIMARY FAILURES

(1) BACKGROUND

Nondestructive pressure testing of the C/M crew compartment structure performed during the qualification tests of the Apollo Spacecraft structure predicted the observed mode of aft bulkhead rupture. The aluminum sheets forming the inner surface of the cabin are welded to form a pressure tight compartment. Thicker chemically milled sections at the circumferential joint of the aft bulkhead (Enclosure 10-7) are provided to facilitate the welding process and allow for the reduced unit strength of the weld. The junction of the aft sidewall aft bulkhead forms a discontinuity in the shell surface. The critical region of the cabin structure for internal pressure loading occurs in the aft bulkhead inner face sheet at the transition of the weld land to the thinner inner face sheet near this discontinuity.

The predicted failure mode is rupture due to meridional tensile stress of the inner face sheet. Calculation, using strain gage data from the qualification test, yields an estimated upper limit of burst pressure of 37.7 psia.

(2) ORIGIN

Detailed inspection of the bulkhead was correlated with the observed aft heat shield and cabin exterior structural damage. The motion of the structure due to cabin rupture, deduced from the Stabilization and Control System rate data, was consistent with the observed evidence. It was concluded that the cabin ruptured at point A shown in Enclosures 10-9 and 10-10 at the junction of the weld land to the inner face sheet. Enclosures 10-8, 10-9, 10-10, 10-11a, 10-11b, and 10-11c define the total fracture. Most of the fracture surfaces were burned and melted; little metallurgical analysis was attempted.

(3) FAILURE SEQUENCE

It was concluded that the tensile failure of the inner face sheet at point A (Enclosure 10-9) was followed immediately by tensile failure of the outer face sheet at point A (Enclosure

10-10). Rupture then propagated to points B and C. Failure of the inner face sheet to point H and failure of the outer face sheet along lines IJKL and CIJ were deduced from inspection and structural analysis to have occurred following the initial rupture and to have been of secondary significance. The bonded doubler at point K was added as a result of manufacturing process control testing performed during structural assembly. Failure of the inner face sheet along DEFG and delamination of the outer face sheet from the core with burn-through holes in the -Y, +Z quadrant occurred subsequent to the initial rupture at a pressure-structural-temperature combination less than that required to cause failure of the outer face sheet. Burn-through in the area beneath the ECU did not occur until the late stages of the fire at a time when cabin pressure was approximately ambient. Face sheet defects adjacent to this area are a result of the structural temperatures attained in this vicinity. The penetration in the aft sidewall, shown in Enclosure 10-13b, was concluded to be a result of locally impinging hot gas behind the Water Control Panel, occurring in the late stages of the fire.

(4) SECONDARY DAMAGE

Detailed inspection of the C/M inner secondary structure revealed buckled aluminum panels and burned and delaminated aluminum honeycomb sandwich panels. Typical damage is illustrated in Enclosure 10-14 and 10-15.

Aluminum melts at approximately 1200°F. With the exception of the aft bulkhead fracture, melting of aluminum was confined to the left hand (-Y) side of the inner cabin. Melted aluminum was observed in close proximity to plastic which was unmelted, indicating local flame impingement in specific areas.

Damage to the inner face sheet of the aft sidewall adjacent to the melted and deformed CO_2 Absorbers is shown in Enclosure 10-16. The structure shown is located in the -Y, +Z quadrant of the C/M. Significant structural damage was noted to plumbing beneath the ECU and in back of the Water Control Panel. The lines are identified and shown in Enclosures 10-13a, 10-13b, 10-13c, and 10-13d. Aluminum and stainless steel lines were melted in this area. It was also observed that soldered joints at couplings on the aluminum lines had parted.

Melted nickel-plated copper wire was observed in the vicinity of the ECU. Copper melts at approximately 1980°F whereas stainless steel and nickel melt at approximately 2600°F. These materials are distributed throughout the spacecraft and are unmelted at other locations.

d. SERVICE MODULE DAMAGE

The Service Module (S/M) structure was inspected for evidence of structural damage. No evidence of structural failure was observed. Nondestructive tests were defined to determine any degradation in design strength. It was recommended that these tests be accomplished within the normal Apollo program activity.

D. FINDINGS AND DETERMINATIONS

1. FINDING

The structural and mechanical subsystem was inactive at the time of the fire.

DETERMINATION

The structural and mechanical subsystem did not cause the fire.

2. FINDING

Visual inspection of the Service Module structure revealed no structural failures.

DETERMINATION

Verification of the structural adequacy for the design loads would require non-destructive testing.

3. FINDING

The crew compartment structure was a pressurized shell structure during the fire.

a. The resulting fire environment initiated the following sequence of major structural damage:

(1) Rupture of the C/M cabin aft bulkhead.

(2) Melting and erosion of C/M cabin and heat shield honeycomb sandwich face sheets adjacent to the origin.

(3) Penetration of the cabin structure beneath and adjacent to the ECU.

b. Minor structural damage resulting from the fire included:

(1) Honeycomb sandwich delamination

(2) Panel buckling

(3) Melting of metallic components

4. FINDING

Spacecraft data acquired during the OCP-FO-K-0021-1 test gave indications from which a spacecraft cabin pressure history could be estimated.

DETERMINATION

a. The C/M cabin structure ruptured at 6:31:19.4 (±0.1) pm EST at an estimated minimun cabin pressure of 29 psia.

b. The C/M cabin structure sustained cabin pressure in excess of its design ultimate pressure of 12.9 psi differential (27.6 psia). It is probable that the cabin pressure at rupture reached a range of 29 to 37.7 psia.

c. The estimated average gas temperature at rupture exceeded 700°F.

5. FINDING

The C/M cabin ruptured in the aft bulkhead adjacent to its juncture with the aft sidewall.

DETERMINATION

The failure occurred due to excessive meridional tensile stress in the inner face sheet at the weld land to thinner face sheet junction. The fracture was determined to have originated on the right-hand side of the C/M in the vicinity of coordinates Y=+45 inches Z=-30 inches.

6. FINDING

Penetrations of the C/M cabin structure occurred in the aft bulkhead beneath the ECU and in the aft sidewall.

DETERMINATION

a. The loss of structural integrity at these penetrations occurred after the primary rupture.

b. Failure of the water glycol and oxygen lines in the vicinity of the ECU resulted in local burning and melting of the adjacent structure.

7. FINDING

The aft heat shield stainless steel face sheets were melted and eroded.

DETERMINATION

The flame and gas temperature exiting from the fracture origin exceeded 2500°F.

8. FINDING

With the exception of the aft bulkhead fracture surfaces, melting of aluminum was confined to the left-hand side of the C/M. Melting of copper wire, stainless steel and aluminum occurred in the vicinity of the ECU and Water Control Panel on the left side and at the foot of the left-hand couch. These materials are distributed throughout the spacecraft and (excluding aluminum) are unmelted at other locations

DETERMINATION

a. The left-hand side of the inner cabin attained the maximum temperatures.

b. The hottest part of the C/M cabin occurred in the vicinity of the ECU and Water Control Panel.

9. FINDING

Melted aluminum was observed on the left-hand side of the C/M inner cabin in very close proximity to plastic which was unmelted, although the plastic had a much lower melting point than the aluminum.

DETERMINATION

A "blow torch" effect occurred where narrow "tongues of flame" impinged on certain areas at the same time as the general burning.

10. FINDING

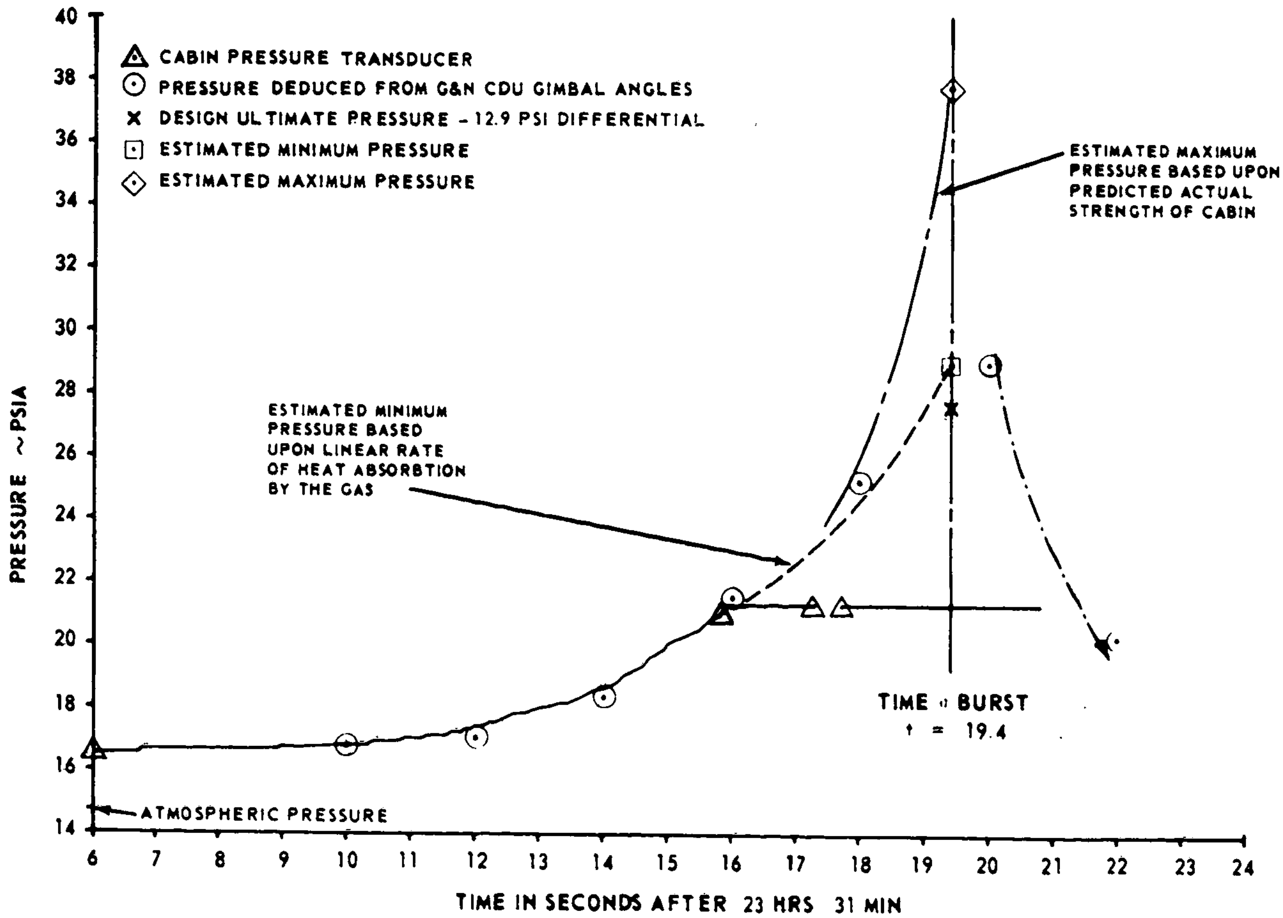
Several aluminum tubes were parted at soldered joints at couplings.

DETERMINATION

The soldered aluminum joints at unions will fail if the solder is raised to its melting point of approximately 360°F. The soldered aluminum joints at couplings were not adequate for the temperatures attained during the fire.

E. SUPPORTING DATA

LIST OF ENCLOSURES



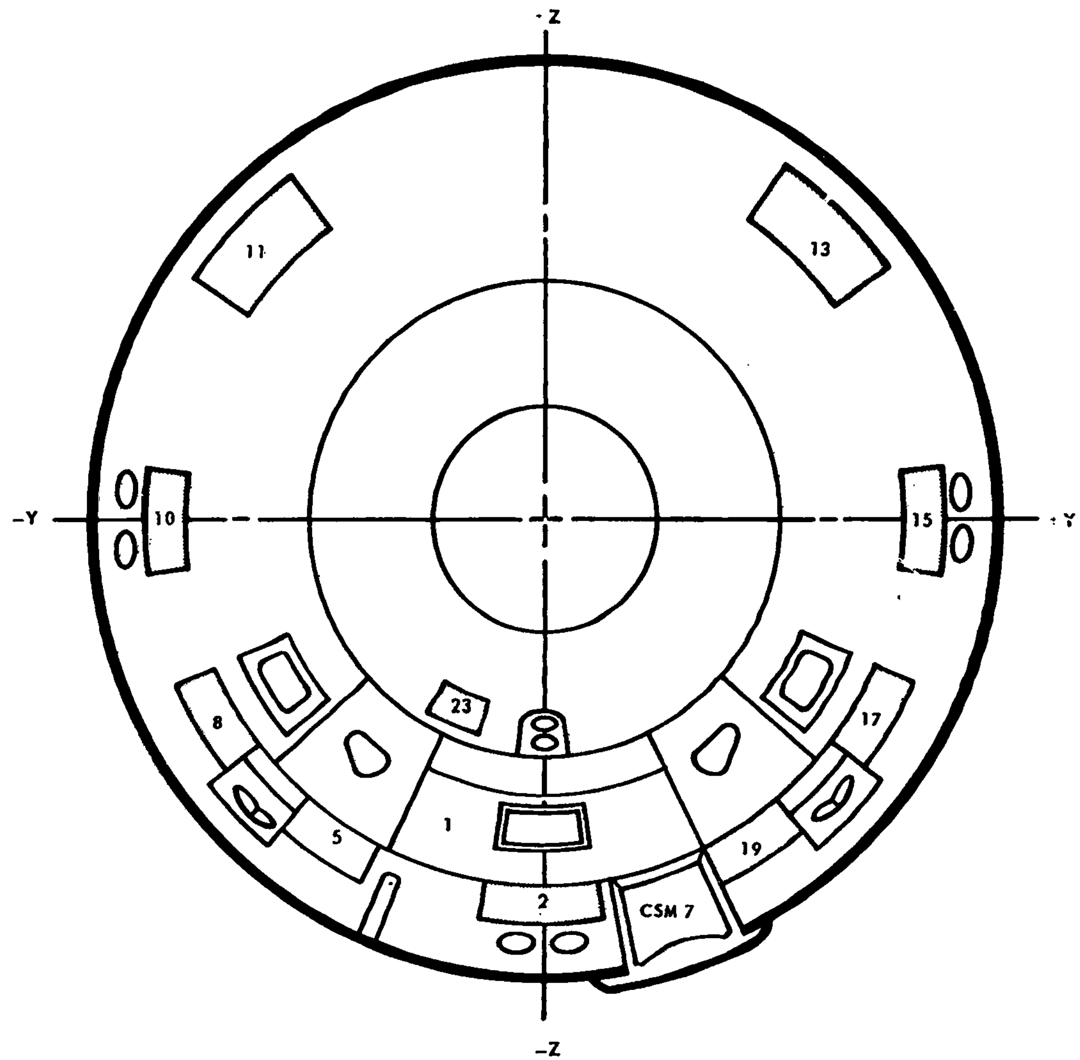
CABIN PRESSURE

ENCLOSURE 10-2

ENCLOSURE 10-3

ACCESS PANEL NOMENCLATURE

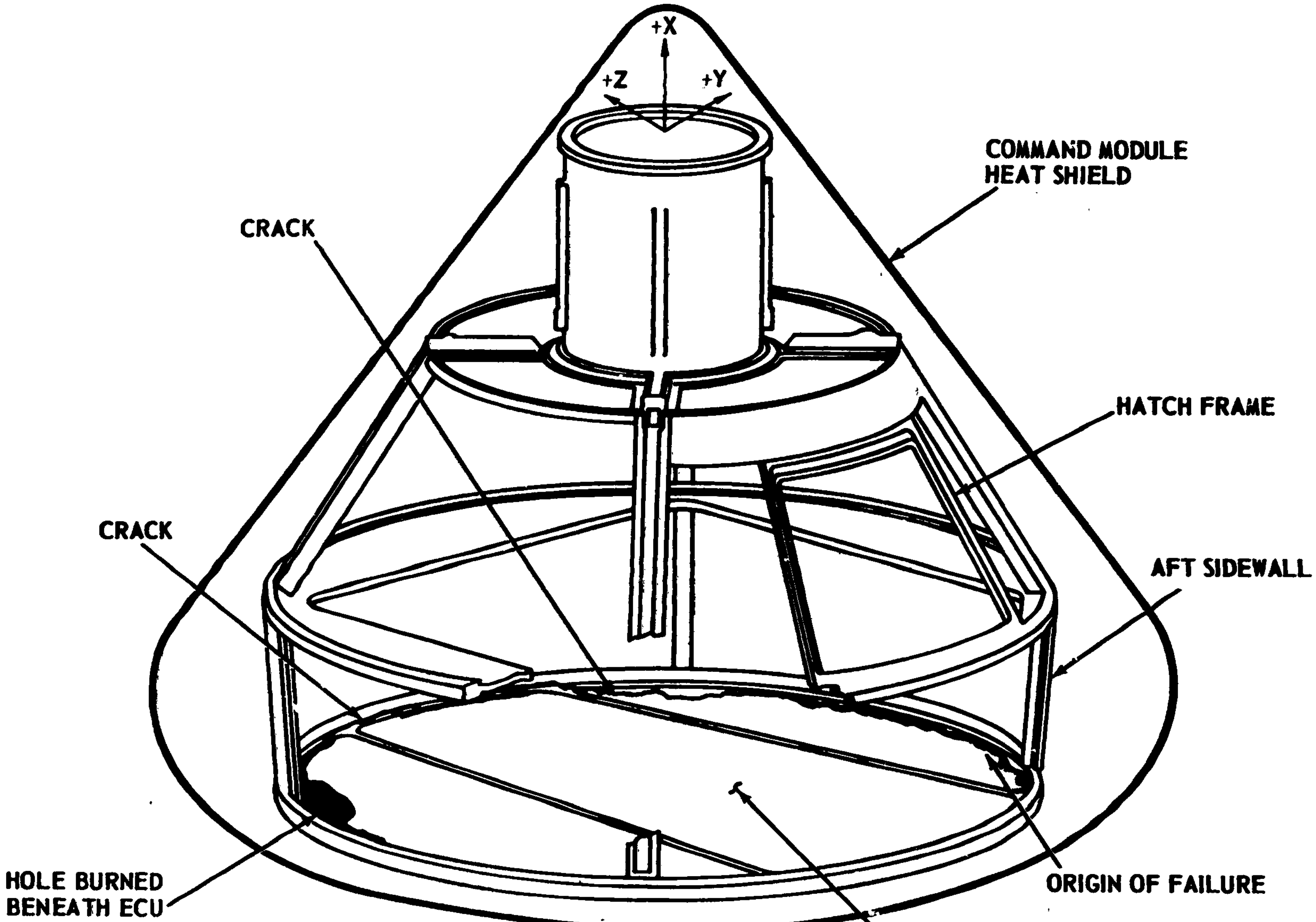
CM 1 CREW HATCHES
CM 2 PITCH ENGINE ACCESS
CM 5 ROLL ENGINE & URINE DUMP PANEL
CM 8 ROLL ENGINE ACCESS
CM 10 YAW ENGINE & He FILL ACCESS
CM 11 FUEL PANEL ACCESS
CM 13 OXYGEN PANEL ACCESS
CM 15 YAW ENGINE & He FILL ACCESS
CM 17 ROLL ENGINE ACCESS
CM 19 ROLL ENGINE ACCESS
CM 23 PITCH ENGINE ACCESS
CSM 7 CM TO SM UMBILICAL



NOTE: SHADED PANELS REPRESENT AREAS OPEN AT THE TIME OF THE ACCIDENT

HEATSHIELD ACCESS PANELS

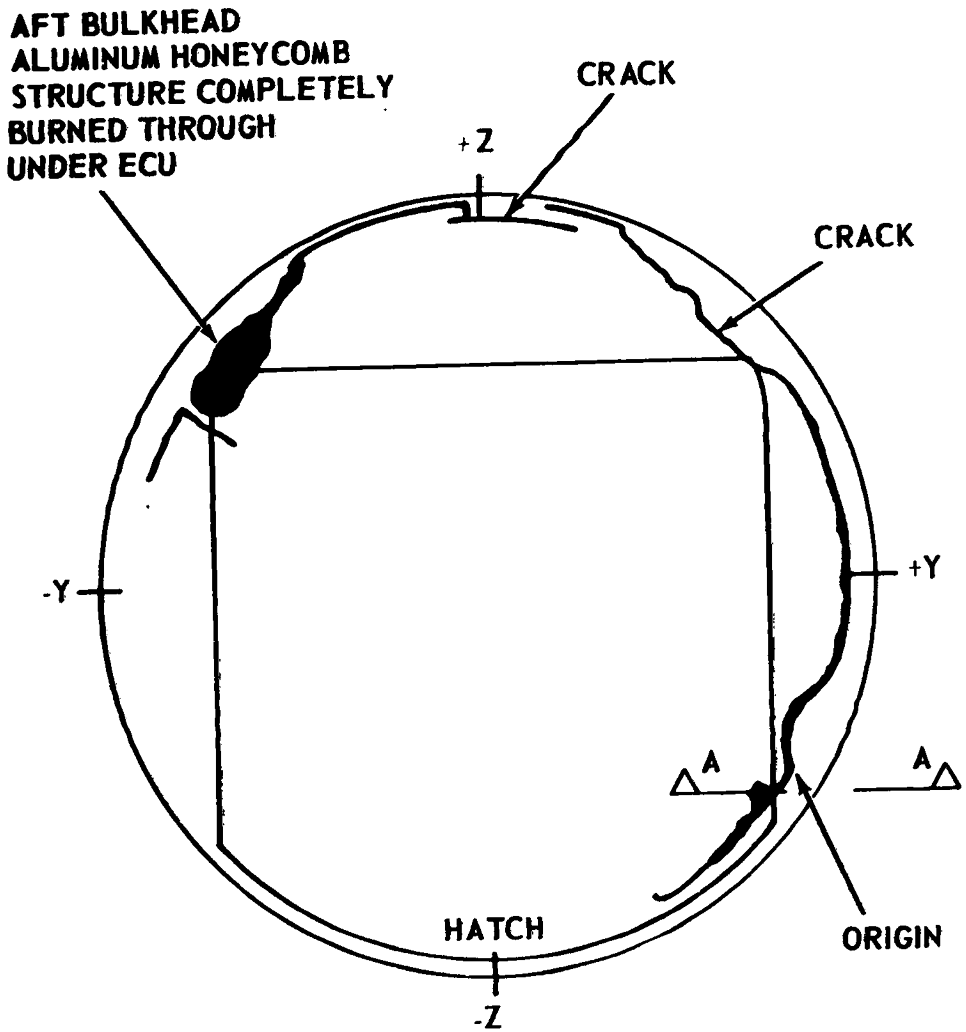
ENCLOSURE 10-6



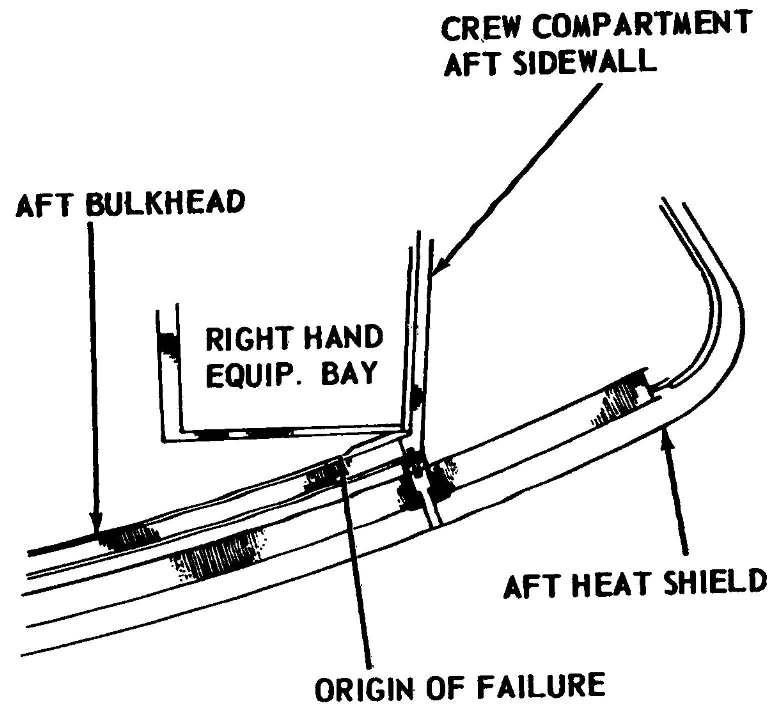
LOCATION OF CABIN FRACTURE
ENCLOSURE 10-6

LOCATION OF CABIN FRACTURE

ENCLOSURE 10-7



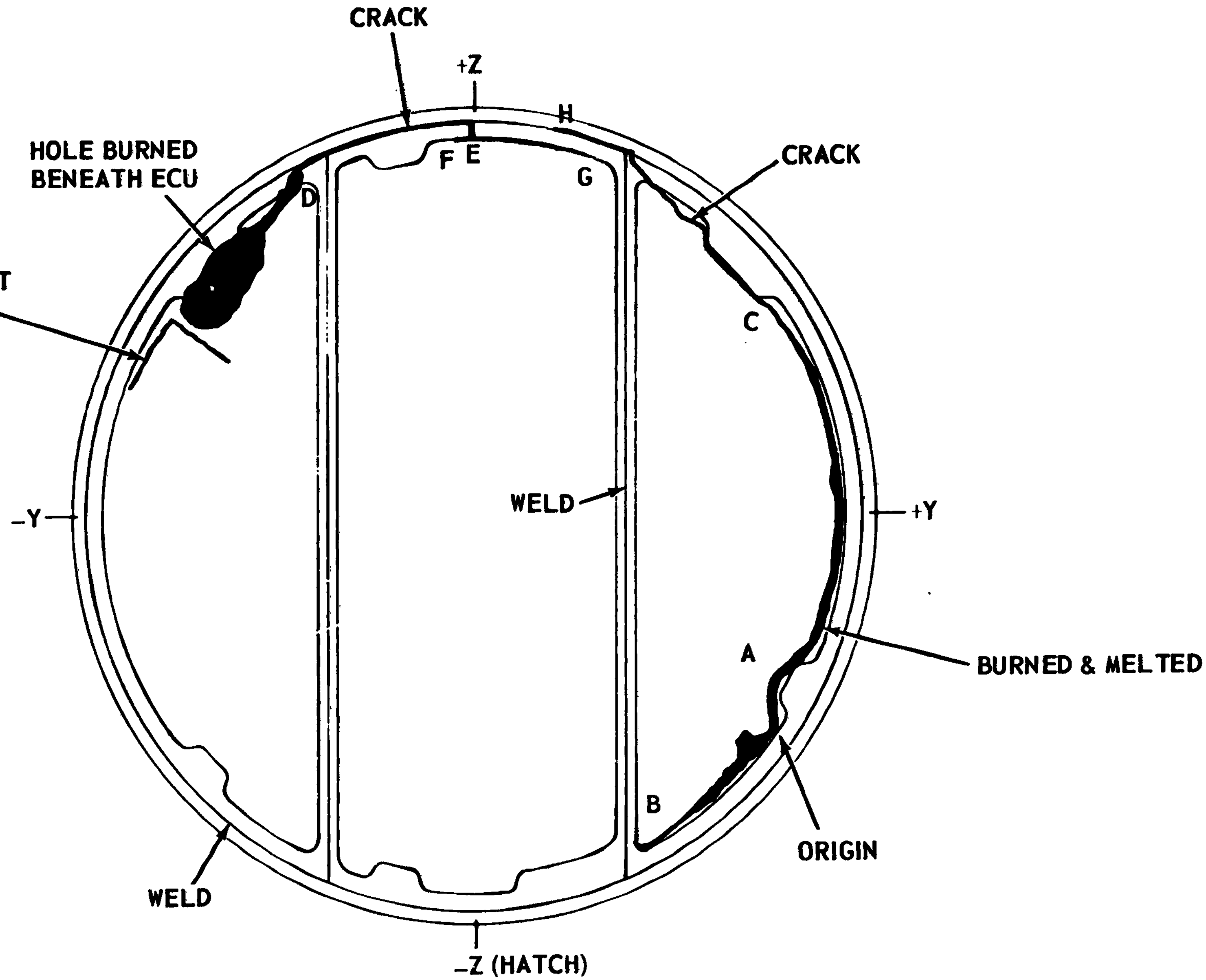
AFT BULKHEAD



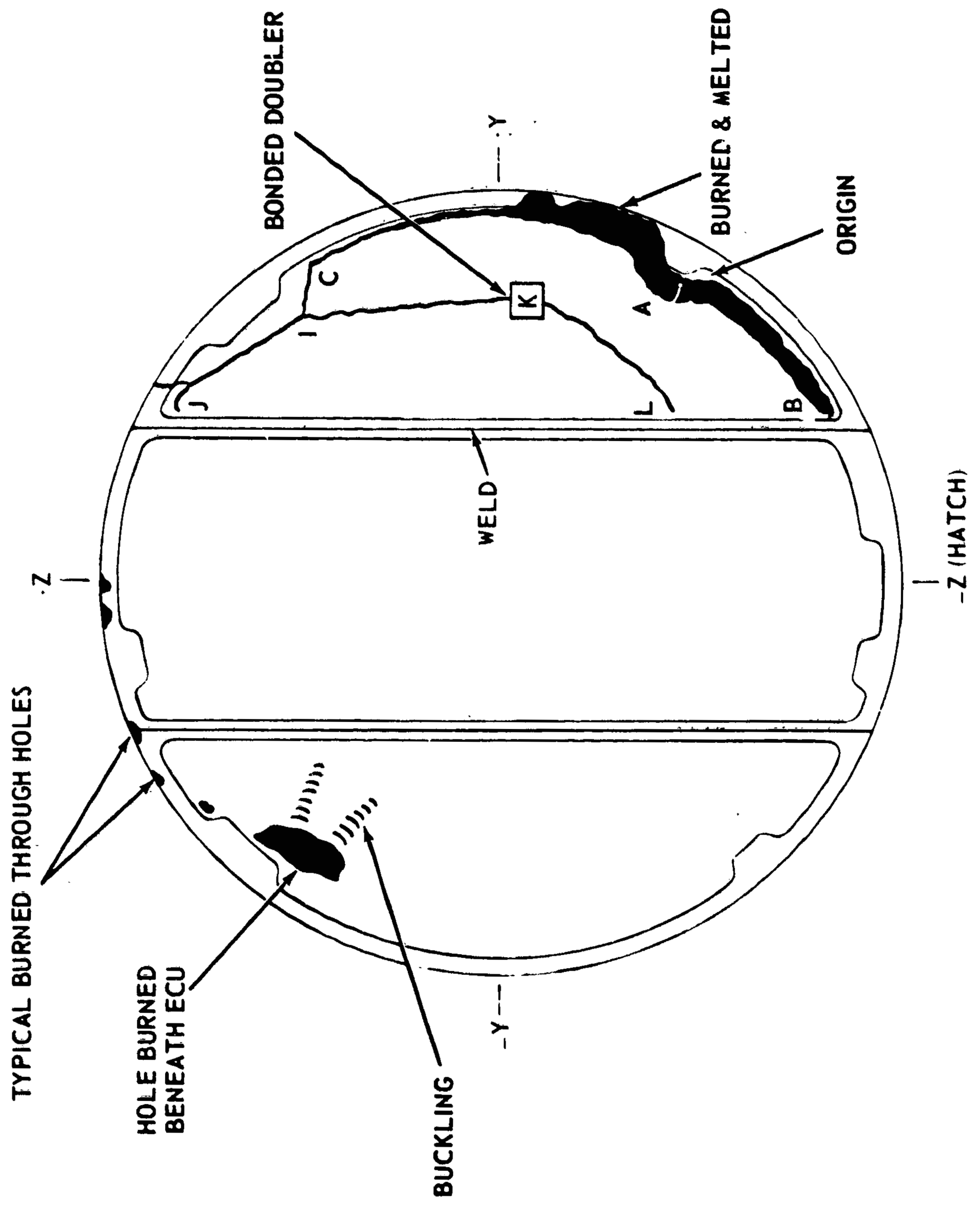
VIEW A

ORIGIN OF CABIN PRESSURE

ENCLOSURE 10-9



INNER FACE OF AFT BULKHEAD



OUTER FACE SHEET OF AFT BULKHEAD

CODE	GAS OR FLUID CONTAINED	PRESSURE
A	OXYGEN	SAME AS CABIN
B	OXYGEN	SAME AS CABIN
C	AIR	AMBIENT
D	AIR	AMBIENT
E	NITROGEN	AMBIENT
F	OXYGEN	700 PSI
G	OXYGEN	700 PSI
H	OXYGEN	100 PSI
I	NITROGEN	AMBIENT
J	WATER GLYCOL	50 PSIG
K	OXYGEN	20 PSIG

NOTE: RED ARROWS ON ENCLOSURES 10-13b, 10-13c, AND 10-13d INDICATE DIRECTION OF FLOW IN TUBE

TUBING CODES FOR USE WITH ENCLOSURES 10-13B, 10-13C, & 10-13D

LIST OF REFERENCES

10-1 "Apollo Mockup SMD-2B Plots, 0-60 Sec. .12 Window" Manned Spacecraft Center, NASA, March 6, 1967.

10-2 Panel Number 18, Integration Analysis (Appendix D-18) For Final Report to AS-204 Review Board

10-3 STN 43 - Delta P vs CDU Gimbal Angles

10-4 STN 42 - Cabin Pressure Relief Valve and Vent Line Flow Characteristics

10-5 STN 37 - Soot Comparative Analysis (Test results will be contained in Appendix G of the Apollo 204 Review Board Final Report)

END

DATE

FILMED