APOLLO ACCIDENT

HEARINGS

BEFORE THE

COMMITTEE ON AERONAUTICAL AND SPACE SCIENCES UNITED STATES SENATE

NINETIETH CONGRESS

FIRST SESSION

TO

HEAR MEMBERS OF THE APOLLO 204 REVIEW BOARD ON THEIR FINAL REPORT OF INVESTIGATION AND TO DISCUSS THE BOARD'S FINDINGS, DETERMINATIONS, AND RECOMMENDATIONS

APRIL 11, 1967

PART 3

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Likely areas in which this harness could have ignited the fire, of course, are near the door and up in the area behind the door.

Now, the reason we believe the fire started in this place is, first, from the physical evidence in the spacecraft—that is the firing patterns, the fact that all combustibles were completely burned away here, whereas in all other locations there is evidence of some of the combustibles melting rather than being burned away, indicating that the fire got to these other combustibles at a time period where oxygen was either completely depleted or partly depleted within the spacecraft.

Furthermore, we have investigated the arrangement of the combustibles in the spacecraft. There was a Raschel net, the debris trap net that ran horizontally along the floor in this area. We have carried out a special test in 16 and a half psi oxygen atmosphere, and ignited the net at the location of the harness and measured the time for the fire to travel to the corner, where it could communicate with a vertical Raschel net. And the total time from ignition to the time when that fire would come within the view of the astronauts was approximately 8 seconds.

This period of time fits very closely with the time difference of 9.7 seconds from the time that there are indications of an arc in the spacecraft from the data and the time that the spacecraft crew reported a fire.

Thank you.

The CHAIRMAN. Doctor, we are going to have to keep fighting quorum calls. There is a live quorum call now which we are trying to avoid so we can continue the discussion. If you can finish by about 12 o'clock so we can start with the questions, we would appreciate it.

SUMMARY OF BOARD'S FINDINGS

Dr. THOMPSON. I have Colonel Borman to sum up the findings; that would finish our presentation.

The CHAIRMAN. Thank you.

Colonel BORMAN. Mr. Chairman, Senator Smith, members of the committee, sir, I will present to you the findings and recommendations of the Board. You have them in part 6 of the Board's final report if you care to follow them at your desk.

May I have the first slide. (Fig. 46.) The first finding that the Board arrived at was that there was a momentary power failure at the 23:30:55 Greenwich mean time; evidence of several arcs was found in the post fire investigation; and that no single source of ignition was conclusively identified.

Next slide. (Fig. 47.) From this the Board determined that the most probable initiator was an electrical arc in the section between minus Y and plus Z spacecraft axes. The exact location best fitting the total available information is near the floor in the lower forward section of the left-hand equipment bay where the Environmental Control System instrumentation power wiring leads into the area between the Environmental Control Unit and the oxygen panel. No evidence was discovered that suggested sabotage.

The next (fig. 48) finding, (*a*) the command module contained many types and classes of combustible material in areas contiguous to possible ignition sources; (*b*) the test was conducted with 16.7 pounds per square inch absolute, 100 percent oxygen atmosphere.

1. FINDING:

A. THERE WAS A MOMENTARY POWER FAILURE AT 23:30:55 GMT.

B. EVIDENCE OF SEVERAL ARCS WAS FOUND IN THE POST FIRE INVESTIGATION.

C. NO SINGLE IGNITION SOURCE OF THE FIRE WAS CONCLUSIVELY IDENTIFIED.

FIGURE 46

DETERMINATION:

THE MOST PROBABLE INITIATOR WAS AN ELECTRICAL ARC IN THE SECTOR BETWEEN THE -Y AND -Z SPACECRAFT AXES. THE EXACT LOCATION BEST FITTING THE TOTAL AVAILABLE INFORMATION IS NEAR THE FLOOR IN THE LOWER FORWARD SECTION OF THE LEFT-HAND EQUIPMENT BAY WHERE ENVIRONMENTAL CONTROL SYSTEM (ECS) INSTRUMENTATION POWER WIRING LEADS INTO THE AREA BETWEEN THE ENVIRONMENTAL CONTROL UNIT (ECU) AND THE OXYGEN PANEL. NO EVIDENCE WAS DISCOVERED THAT SUGGESTED SABOTAGE.

FIGURE 47

Next slide (fig. 49) determination, the test conditions were extremely hazardous.

Next slide (fig. 50) recommendation, the amount and location of the combustible materials in the command module be severely restricted and controlled. Restrict the amount and control their location.

Next slide. (Fig. 51.) Third finding. The rapid spread of the fire caused an increase in the pressure and temperature which resulted in a rupture of the command module and creation of a toxic atmosphere. Death of the crew was from axphyxia due to inhalation of toxic gases due to fire. A contributory cause of death was thermal burns.

Nonuniform distribution of carboxyhemoglobin was found by autopsy.

2. FINDING:

A. THE COMMAND MODULE CONTAINED MANY TYPES AND CLASSES OF COMBUSTIBLE MATERIAL IN AREAS CONTIGUOUS TO POSSIBLE IGNITION SOURCES.

B. THE TEST WAS CONDUCTED WITH A 16.7 POUNDS PER SQUARE INCH ABSOLUTE, 100 PERCENT OXYGEN ATMOSPHERE.

FIGURE 48

DETERMINATION:

THE TEST CONDITIONS WERE EXTREMELY HAZARDOUS.

FIGURE 49

RECOMMENDATION:

THE AMOUNT AND LOCATION OF COMBUSTIBLE MATERIALS IN THE COMMAND MODULE BE SEVERELY RESTRICTED AND CONTROLLED.

FIGURE 50

3. FINDING:

A. THE RAPID SPREAD OF FIRE CAUSED AN INCREASE IN PRESSURE AND TEMPERATURE WHICH RESULTED IN RUPTURE OF THE COMMAND MODULE AND CREATION OF A TOXIC ATMOSPHERE. DEATH OF THE CREW WAS FROM ASPHYXIA DUE TO INHALATION OF TOXIC GASES DUE TO FIRE. A CONTRIBUTORY CAUSE OF DEATH WAS THERMAL BURNS.

B. NON-UNIFORM DISTRIBUTION OF CARBOXYHEMOGLOBIN WAS FOUND BY AUTOPSY.

FIGURE 51

Next slide. (Fig. 52.) Medical opinion determined that unconsciousness occurred rapidly and death followed soon thereafter.

Next slide. (Fig. 53.) Finding: Due to internal pressure the command module inner hatch could not be opened prior to rupture of the command module. This is, of course, because of the fact that we had a sealed hatch that was designed to operate in orbit.

Next slide. (Fig. 54.) Determination: The crew was never capable of effecting emergency egress because of the pressurization before rupture and their loss of consciousness soon after rupture.

DETERMINATION:

AUTOPSY DATA LEADS TO THE MEDICAL OPINION THAT UNCONSCIOUSNESS OCCURRED RAPIDLY AND THAT DEATH FOLLOWED SOON THEREAFTER.

FIGURE 52

4. FINDING:

DUE TO INTERNAL PRESSURE, THE COMMAND MODULE INNER HATCH COULD NOT BE OPENED PRIOR TO RUPTURE OF THE COMMAND MODULE.

FIGURE 53

DETERMINATION:

THE CREW WAS NEVER CAPABLE OF EFFECTING EMERGENCY EGRESS BECAUSE OF THE PRESSURIZATION BEFORE RUPTURE AND THEIR LOSS OF CONSCIOUSNESS SOON AFTER RUPTURE.

FIGURE 54

Next slide. (Fig. 55.) Recommendation: The Board recommends that the time required for egress of the crew be reduced and the operations necessary for egress be simplified.

Next slide. (Fig. 56.) Finding number five: Those organizations responsible for the planning, conduct and safety of this test failed to identify it as being hazardous. Contingency preparations to permit escape or rescue of the crew from an internal command module fire were not made. (*a*) No procedures for this type of emergency have been established either for the crew or for the spacecraft pad work team, (*b*) the emergency equipment located in the white room and on

RECOMMENDATION:

THE TIME REQUIRED FOR EGRESS OF THE CREW BE REDUCED AND THE OPERATIONS NECESSARY FOR EGRESS BE SIMPLIFIED.

FIGURE 55

5. FINDING:

THOSE ORGANIZATIONS RESPONSIBLE FOR THE PLANNING, CONDUCT AND SAFETY OF THIS TEST FAILED TO IDENTIFY IT AS BEING HAZARDOUS. CONTINGENCY PREPARATIONS TO PERMIT ESCAPE OR RESCUE OF THE CREW FROM AN INTERNAL COMMAND MODULE FIRE WERE NOT MADE.

A. NO PROCEDURES FOR THIS TYPE OF EMERGENCY HAD BEEN ESTABLISHED EITHER FOR THE CREW OR FOR THE SPACECRAFT PAD WORK TEAM.

B. THE EMERGENCY EQUIPMENT LOCATED IN THE WHITE ROOM AND ON THE SPACECRAFT WORK LEVELS WAS NOT DESIGNED FOR THE SMOKE CONDITION RESULTING FROM A FIRE OF THIS NATURE.

C. EMERGENCY FIRE, RESCUE AND MEDICAL TEAMS WERE NOT IN ATTENDANCE.

D. BOTH THE SPACECRAFT WORK LEVELS AND THE UMBILICAL TOWER ACCESS ARM CONTAIN FEATURES SUCH AS STEPS, SLIDING DOORS AND SHARP TURNS IN THE EGRESS PATHS WHICH HINDER EMERGENCY OPERATIONS.

FIGURE 56

the spacecraft work levels was not designed for smoke conditions resulting from a fire of this nature, (*c*) emergency fire, rescue and medical teams were not in attendance, (*d*) both the spacecraft work levels and the umbilical tower access arm contain features such as steps, sliding doors, and sharp turns in the egress paths which hinder emergency operation.

Before leaving that I would like to point out that the key phrase here is that the test was not identified as being hazardous. Consequently, the deficiencies that we listed here in (*a*), (*b*), (*c*), and (*d*) resulted from the fact that the test was not identified as being hazardous.

Dr. THOMPSON. Colonel, this is—I do not believe you are really adding any comments.

Colonel BORMAN. Do you want me to go right on through?

Dr. THOMPSON. It is not necessary since the chairman and members of the committee have read the report. I think that you just stand on what is presented here.

Colonel BORMAN. Yes.

The CHAIRMAN. I agree with you. This is word for word.

Dr. THOMPSON. Yes. I do not think he plans to add much of anything to that, so we can let that stand as a sum up as written.

The CHAIRMAN. We will really put it in the report but—I hate to sort of cut you off.

Colonel BORMAN. No, sir, that is fine.

The CHAIRMAN. Do you have anything you want to say about this situation?

Colonel BORMAN. Well, sir, perhaps if we have discussion later on I will have an opportunity to comment.

(The remaining slides (figs. 57 to 76) in Colonel Borman's illustrated talk referred to above are as follows:)*

DETERMINATION:

ADEQUATE SAFETY PRECAUTIONS WERE NEITHER ESTABLISHED NOR OBSERVED FOR THIS TEST.

FIGURE 57

*For convenience, part VI of the Board's report entitled "Board Findings, Determinations, and Recommendations" is printed in an appendix, see p. 267.

RECOMMENDATIONS:

A. MANAGEMENT CONTINUALLY MONITOR THE SAFETY OF ALL TEST OPERATIONS AND ASSURE THE ADEQUACY OF EMERGENCY PROCEDURES.

B. ALL EMERGENCY EQUIPMENT (BREATHING APPARATUS, PROTECTIVE CLOTHING, DELUGE SYSTEMS, ACCESS ARM, ETC.) BE REVIEWED FOR ADEQUACY

C. PERSONNEL TRAINING AND PRACTICE FOR EMERGENCY PROCEDURES BE GIVEN ON A REGULAR BASIS AND REVIEWED PRIOR TO THE CONDUCT OF A HAZARDOUS OPERATION.

D. SERVICE STRUCTURES AND UMBILICAL TOWERS BE MODIFIED TO FACILITATE EMERGENCY OPERATIONS.

FIGURE 58

6. FINDING:

FREQUENT INTERRUPTIONS AND FAILURES HAD BEEN EXPERIENCED IN THE OVERALL COMMUNICATION SYSTEM DURING THE OPERATIONS PRECEDING THE ACCIDENT.

FIGURE 59

DETERMINATION:

THE OVERALL COMMUNICATION SYSTEM WAS UNSATISFACTORY.

FIGURE 60

RECOMMENDATIONS:

A. THE GROUND COMMUNICATION SYSTEM BE IMPROVED TO ASSURE RELIABLE COMMUNICATIONS BETWEEN ALL TEST ELEMENTS AS SOON AS POSSIBLE AND BEFORE THE NEXT MANNED FLIGHT

B. A DETAILED DESIGN REVIEW BE CONDUCTED ON THE ENTIRE SPACECRAFT COMMUNICATION SYSTEM.

FIGURE 61

7. FINDING:

A. REVISIONS TO THE OPERATIONAL CHECKOUT PROCEDURE FOR THE TEST WERE ISSUED AT 5:30 PM EST JANUARY 26, 1967 (209 PAGES) AND 10:00 AM EST JANUARY 27, 1967 (4 PAGES).

B. DIFFERENCES EXISTED BETWEEN THE GROUND TEST PROCEDURES AND THE IN-FLIGHT CHECK LISTS.

FIGURE 62

DETERMINATION:

NEITHER THE REVISION NOR THE DIFFERENCES CONTRIBUTED TO THE ACCIDENT. THE LATE ISSUANCE OF THE REVISION, HOWEVER, PREVENTED TEST PERSONNEL FROM BECOMING ADEQUATELY FAMILIAR WITH THE TEST PROCEDURE PRIOR TO ITS USE.

FIGURE 63

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RECOMMENDATIONS:

A. TEST PROCEDURES AND PILOT'S CHECKLISTS THAT REPRESENT THE ACTUAL COMMAND MODULE CONFIGURATION BE PUBLISHED IN FINAL FORM AND REVIEWED EARLY ENOUGH TO PERMIT ADEQUATE PREPARATION AND PARTICIPATION OF ALL TEST ORGANIZATIONS.

B. TIMELY DISTRIBUTION OF TEST PROCEDURES AND MAJOR CHANGES BE MADE A CONSTRAINT TO THE BEGINNING OF ANY TEST.

FIGURE 64

8. FINDING:

THE FIRE IN COMMAND MODULE 012 WAS SUBSEQUENTLY SIMULATED CLOSELY BY A TEST FIRE IN A FULL-SCALE MOCK-UP.

FIGURE 65

DETERMINATION:

FULL-SCALE MOCK-UP FIRE TESTS CAN BE USED TO GIVE A REALISTIC APPRAISAL OF FIRE RISKS IN FLIGHT-CONFIGURED SPACECRAFT.

FIGURE 66

RECOMMENDATION:

FULL-SCALE MOCK-UPS IN FLIGHT CONFIGURATION BE TESTED TO DETERMINE THE RISK OF FIRE.

FIGURE 67

9. FINDING:

THE COMMAND MODULE ENVIRONMENTAL CONTROL SYSTEM DESIGN PROVIDES A PURE OXYGEN ATMOSPHERE.

FIGURE 68

DETERMINATION:

THIS ATMOSPHERE PRESENTS SEVERE FIRE HAZARDS IF THE AMOUNT AND LOCATION OF COMBUSTIBLES IN THE COMMAND MODULE ARE NOT RESTRICTED AND CONTROLLED.

FIGURE 69

RECOMMENDATIONS:

A. THE FIRE SAFETY OF THE RECONFIGURED COMMAND MODULE BE ESTABLISHED BY FULL-SCALE MOCK-UP TESTS.

B. STUDIES OF THE USE OF A DILUENT GAS BE CONTINUED WITH PARTICULAR REFERENCE TO ASSESSING THE PROBLEMS OF GAS DETECTION AND CONTROL AND THE RISK OF ADDITIONAL OPERATIONS THAT WOULD BE REQUIRED IN THE USE OF A TWO GAS ATMOSPHERE.

FIGURE 70

10. FINDING:

DEFICIENCIES EXISTED IN COMMAND MODULE DESIGN, WORKMANSHIP AND QUALITY CONTROL, SUCH AS:

A. COMPONENTS OF THE ENVIRONMENTAL CONTROL SYSTEM INSTALLED IN COMMAND MODULE 012 HAD A HISTORY OF MANY REMOVALS AND OF TECHNICAL DIFFICULTIES INCLUDING REGULATOR FAILURES, LINE FAILURES AND ENVIRONMENTAL CONTROL UNIT FAILURES. THE DESIGN AND INSTALLATION FEATURES OF THE ENVIRONMENTAL CONTROL UNIT MAKES REMOVAL OR REPAIR DIFFICULT.

B. COOLANT LEAKAGE AT SOLDER JOINTS HAS BEEN A CHRONIC PROBLEM.

C. THE COOLANT IS BOTH CORROSIVE AND COMBUSTIBLE.

D. DEFICIENCIES IN DESIGN, MANUFACTURE, INSTALLATION, REWORK AND QUALITY CONTROL EXISTED IN THE ELECTRICAL WIRING.

E. NO VIBRATION TEST WAS MADE OF A FLIGHT-CONFIGURED SPACECRAFT.

F. SPACECRAFT DESIGN AND OPERATING PROCEDURES CURRENTLY REQUIRE THE DISCONNECTING OF ELECTRICAL CONNECTIONS WHILE POWERED.

G. NO DESIGN FEATURES FOR FIRE PROTECTION WERE INCORPORATED.

FIGURE 71

DETERMINATION:

THESE DEFICIENCIES CREATED AN UNNECESSARILY HAZARDOUS CONDITION AND THEIR CONTINUATION WOULD IMPERIL ANY FUTURE APOLLO OPERATIONS.

FIGURE 72

RECOMMENDATIONS:

A. AN IN-DEPTH REVIEW OF ALL ELEMENTS, COMPONENTS AND ASSEMBLIES OF THE ENVIRONMENTAL CONTROL SYSTEM BE CONDUCTED TO ASSURE ITS FUNCTIONAL AND STRUCTURAL INTEGRITY AND TO MINIMIZE ITS CONTRIBUTION TO FIRE RISK.

B. PRESENT DESIGN OF SOLDERED JOINTS IN PLUMBING BE MODIFIED TO INCREASE INTEGRITY OR THE JOINTS BE REPLACED WITH A MORE STRUCTURALLY RELIABLE CONFIGURATION.

C. DELETERIOUS EFFECTS OF COOLANT LEAKAGE AND SPILLAGE BE ELIMINATED.

D. REVIEW OF SPECIFICATIONS BE CONDUCTED, 3-DIMENSIONAL JIGS BE USED IN MANUFACTURE OF WIRE BUNDLES AND RIGID INSPECTION AT ALL STAGES OF WIRING DESIGN, MANUFACTURE AND INSTALLATION BE ENFORCED.

E. VIBRATION TESTS BE CONDUCTED OF A FLIGHT-CONFIGURED SPACECRAFT.

F. THE NECESSITY FOR ELECTRICAL CONNECTIONS OR DISCONNECTIONS WITH POWER ON WITHIN THE CREW COMPARTMENT BE ELIMINATED.

G. INVESTIGATION BE MADE OF THE MOST EFFECTIVE MEANS OF CONTROLLING AND EXTINGUISHING A SPACECRAFT FIRE. AUXILIARY BREATHING OXYGEN AND CREW PROTECTION FROM SMOKE AND TOXIC FUMES BE PROVIDED.

FIGURE 73

11. FINDING:

AN EXAMINATION OF OPERATING PRACTICES SHOWED THE FOLLOWING EXAMPLES OF PROBLEM AREAS:

A. THE NUMBER OF THE OPEN ITEMS AT THE TIME OF SHIPMENT OF THE COMMAND MODULE 012 WAS NOT KNOWN. THERE WERE 113 SIGNIFICANT ENGINEERING ORDERS NOT ACCOMPLISHED AT THE TIME COMMAND MODULE 012 WAS DELIVERED TO NASA; 623 ENGINEERING ORDERS WERE RELEASED SUBSEQUENT TO DELIVERY. OF THESE, 22 WERE RECENT RELEASES WHICH WERE NOT RECORDED IN CONFIGURATION RECORDS AT THE TIME OF THE ACCIDENT.

B. ESTABLISHED REQUIREMENTS WERE NOT FOLLOWED WITH REGARD TO THE PRE-TEST CONSTRAINTS LIST. THE LIST WAS NOT COMPLETED AND SIGNED BY DESIGNATED CONTRACTOR AND NASA PERSONNEL PRIOR TO THE TEST, EVEN THOUGH ORAL AGREEMENT TO PROCEED WAS REACHED.

C. FORMULATION OF AND CHANGES TO PRE-LAUNCH TEST REQUIREMENTS FOR THE APOLLO SPACECRAFT PROGRAM WERE UNRESPONSIVE TO CHANGING CONDITIONS.

D. NON-CERTIFIED EQUIPMENT ITEMS WERE INSTALLED IN THE COMMAND MODULE AT TIME OF TEST.

E. DISCREPANCIES EXISTED BETWEEN NAA AND NASA MSC SPECIFICATIONS REGARDING INCLUSION AND POSITIONING OF FLAMMABLE MATERIALS.

F. THE TEST SPECIFICATION WAS RELEASED IN AUGUST 1966 AND WAS NOT UPDATED TO INCLUDE ACCUMULATED CHANGES FROM RELEASE DATE TO DATE OF THE TEST.

FIGURE 74

DETERMINATION:

PROBLEMS OF PROGRAM MANAGEMENT AND RELATIONSHIPS BETWEEN CENTERS AND WITH THE CONTRACTOR HAVE LED IN SOME CASES TO INSUFFICIENT RESPONSE TO CHANGING PROGRAM REQUIREMENTS.

FIGURE 75

RECOMMENDATION:

EVERY EFFORT MUST BE MADE TO INSURE THE MAXIMUM CLARIFICATION AND UNDERSTANDING OF THE RESPONSIBILITIES OF ALL THE ORGANIZATIONS INVOLVED, THE OBJECTIVE BEING A FULLY COORDINATED AND EFFICIENT PROGRAM.

FIGURE 76

The CHAIRMAN. Are you ready to start the questioning now?
Dr. THOMPSON. Yes, sir.

BOARD HAD COMPLETE FREEDOM

The CHAIRMAN. I think in order to get around completely, we will give each person 10 minutes.

Dr. Thompson, did you feel as Chairman of the Board, that the Board has had complete freedom to carry out its responsibilities in the investigation of Apollo 204 fire?

Dr. THOMPSON. Yes, sir. I have been very much impressed with the cooperation and the candid, wholehearted support we have had from all people that we have had to ask for help from and who assisted us in this investigation.

The CHAIRMAN. Some people have been worried because this is an inside investigation, that you have not brought in a lot of outside experts. I think it has been done very well, but I just want to be sure that you, as the Chairman, were not hampered in your investigation.

Dr. THOMPSON. We certainly were not hampered in any way. We called upon the people who are most expert, most knowledgeable about this entire affair and they all cooperated in a very wholehearted manner.

The CHAIRMAN. Thank you. Do you know of any attempt by NASA or the spacecraft manufacturer to suppress any information which the Board regarded as pertinent?

Dr. THOMPSON. No, sir. Everyone, the contractor and all elements of NASA, contributed in a wholehearted manner to the requirements of this review.

The CHAIRMAN. Did the Board have adequate personnel, financing, and facilities to undertake the investigation in the depth deemed necessary?

Dr. THOMPSON. Yes, sir. There was very adequate support with a high priority. Wherever we put a demand, we got immediate and wholehearted support.

The CHAIRMAN. What is the status of the Apollo 204 Review Board? Has it completed its work? Have you disbanded or are going on for a while?

Dr. THOMPSON. Upon delivery of the report to the Administrator we are in recess subject to recall by me, the Chairman, until we are actually discharged by the Administrator. There is some unfinished business that has been referred to in investigations that I have said will not influence our findings, our opinions, as expressed here, but we do feel it necessary to wind up the affairs that will be incorporated in appendix G of the report.

The CHAIRMAN. It has been NASA's objective to design spacecraft and other hardware, and conduct operations with safety as the paramount concern. To what do you attribute the design and other deficiencies set forth in your report, which clearly indicate that the objective has not been obtained?

Dr. THOMPSON. Somehow or other in the process of the manufacture and quality control inspection, the results in certain areas that we have identified just have not come out as well as we think is actually required.

The CHAIRMAN. I think I am going to let the other members question. Senator Smith?

QUESTIONS IF DEFICIENCIES EXIST IN OTHER AREAS OF MANNED SPACECRAFT PROGRAM

Senator SMITH. Thank you, Mr. Chairman.

Dr. Thompson, the preface of the Review Board's report indicates that the report is not intended as representing a total picture of the manned spacecraft program. This is understandable since your investigation was directed toward uncovering specifics concerned with the accident. However, the Board did review NASA's management structure and the written procedures and operating practices for the Apollo program.

In light of this information, could we get your opinion as to whether the types of deficiencies disclosed for this one spacecraft may well exist in other areas of the manned spacecraft program?

Dr. THOMPSON. I think, Madam Senator, that the findings that we have may reflect certain areas that can well be improved, will require

improvement, in matters that we have remarked on, particularly in the last two findings of our report. We think that in this very complex program, not all the objectives of management or desired by management have been achieved and I think we have identified those at least in a general way, and I fully expect that the Apollo Program Office, the directors, those responsible for the direction of the Apollo program will make use of this identification that we have provided to effect certain improvements. I do think they are quite important, relative to the future program, but I do think they are perhaps things you would find in or the general kind of things that you would find in any tremendously large undertaking. Any management has problems. We have identified some and, I think, it may be quite helpful to the Program Office in their efforts to correct the problems.

Senator SMITH. But, you would say there were some deficiencies in other areas of the program similar to some you found in this one?

Dr. THOMPSON. I think any program has deficiencies. We thought that there were certain ones that we should identify here that certainly the management should direct attention to.

ASKED IF PROBLEM RELATED TO TIGHT SCHEDULES

Senator SMITH. Dr. Thompson, the Board's report points out some serious deficiencies relating to design, workmanship, quality control, and failure to complete required engineering changes. In your opinion, are these deficiencies attributable in some measure to the tight schedules used for the program in order to assure a manned lunar landing in this decade?

Dr. THOMPSON. I cannot identify anything of that sort. A program of this kind has to have a very hard drive. It has to have built-in urgency in order to keep all the people properly motivated.

The thing that we directed our attention to was the other side of this tremendous project, that is, the orderliness that is required to see that this hard drive does not disregard some of the paperwork and those things that may be overlooked if there just is not sufficient attention paid to them.

I cannot conceive of a program of this nature that would offer a tradeoff between haste and the other orderly side of it. They have to be matched. You could not tell people to slow down because we are just going too fast here. I say you have just got to put the hard drive in both sides of this picture from where I sit.

Senator SMITH. Doctor, if the hard drive that you refer to is not responsible for these irregularities and deficiencies, then what would in your opinion, be the primary or underlying reason for such errors of omission and commission discussed in the Board's report?

Dr. THOMPSON. Well, I just think somehow or other they have not quite found out how to put all that order in. It is a very demanding task. This is a tremendously big program involving hundreds of thousands of people. Even the test itself, just the head count for the test itself showed 959 people on duty doing various tasks at that time. The organization of all that effort is a difficult management task but I do not see why it cannot be accomplished.

I think that an overview of it, as we have done, will identify areas that will provide a useful guide to improvements that ought to be made.

Senator SMITH. Well, of course, Dr. Thompson, we have to know in order to be able to correct the deficiencies and this is where I hope you and your associates may be helpful to us. I think it is very necessary for us to know just exactly what brought about these deficiencies—whether it was the tight schedules, the rush or negligence or some other reason—before we can go on to make the corrections. I am sure you understand what I have in mind.

Dr. THOMPSON. I do.

REQUESTS OPINION ON MANAGEMENT DEFICIENCIES

Senator SMITH. In several sections of the report the Board addresses itself to program management deficiencies and problems in the relationship between centers and with the contractor. I think it would be helpful to the committee if you would give us your opinion as to where in NASA's management structure the major deficiency lies with respect to the failure to recognize and correct the more serious deficiencies noted in the Board's report.

Dr. THOMPSON. The problem, as I see it, is in an evolving situation where so many people are involved and the necessity for employing so many people under, say, different centers.

There are three major groups involved in this program. There is the contractor. The contractor himself has groups at his plant and at the Cape. NASA has major groups at MSC and KSC. The difficult management problem of dealing with all those working relationships and laying out the areas of responsibility so that everyone is really fully coordinated is a tremendous task, and this has been subject to change over the recent years.

I feel that is the major factor in that.

Senator SMITH. Dr. Thompson, it may not be your responsibility to identify the areas of responsibility in the agency, however, you have been so close to this accident, you and your associates have gone into so many facets of it, and you have made numerous findings that it seems to me you could come up with the basic deficiencies or the area which is basically at fault in the management of the program. I presume that is what we have to find before we can go on with any corrections.

Dr. THOMPSON. Well, we have gone to a point, I think, of identifying areas. I think that we would get a little far afield if we try to tell how to recognize it. I think that perhaps we have done about as much as is appropriate, to our knowledge, at the moment in identifying the areas that we thought required attention and I believe it is more in the area of the program office to respond to just how the problems that we have identified can be effectively dealt with in the management.

Senator SMITH. We are all in this together, Dr. Thompson, and I have supported this program since its beginning, and I am sure we all want to see our space exploration plans and programs continue, and we want to see it successful.

I would like to get on the record your own feelings about whether there is a deficiency or inefficiency in the management of the space agency. It seems to me you could not help but come through with such a complete and wonderful report as you have provided without having some personal feelings about it.

Dr. THOMPSON. Well, I am afraid that my feelings, as far as I feel qualified to comment at this time, are pretty well expressed in the report. I think that it would be better to try to reach an understanding with the program office to see whether or not these things that we have identified as problems are being solved.

Now, we did not consider ourselves a board of management experts nor did we employ management experts to try to analyze the problem in detail, so I would be a little hesitant to pull off the top of my head at this point, statements beyond what we have already stated.

The CHAIRMAN. If you will yield to me, Senator Smith. Senator Smith asked a question asking you if you will give us your opinion as to where in NASA's management structure the major deficiency lies. In Dr. Seamans' letter of instructions to you he said:

> Consider all of the factors relating to the accident, including the design, procedures, organization, and management.

We really want to know if you have thought about this management question. You have been exposed to two and a half months of it. You have done a great job. Have you not had some feeling as to what this management problem has been?

Dr. THOMPSON. I think we identified certain problems. We said there was cumbersomeness in the operations relative to the conflicting management requirements of orderliness in dealing with a dynamic program, particularly, in the operations at the Cape where the MSC, the Manned Spacecraft Center, has the major responsibility, and when the spacecraft arrives at the Cape, the execution of that responsibility falls pretty much in the hands of another group.

Now, the working out of these areas of responsibility without impairing the necessary restraints as to cost and identification—clear delineation of the effect of any changes poses some rather difficult problems and I think that there is an area in this working relationship that can be improved to meet two conflicting requirements, flexibility, and yet not license to make changes.

Now, this is a difficult thing and, I think, quite a lot of what we directed our attention to and identified, was in that area. MSC at this stage is responsible for the spacecraft and yet it is another group, through delegation of responsibility, that is working on it. I think the lines are pretty well worked out. I do not think we saw any obvious flaws in the line of authority but there seems to be a lack of flexibility.

The CHAIRMAN. Doctor, you used charts showing the wiring as not very satisfactory. I helped with the long examination of the Navy Dapartment on the *Thresher*. At one point we found what we thought was a rather improper setup.

Have you not determined as yet anything about the propriety of these management problems and the product of them?

Dr. THOMPSON. Well, we have identified, I think, certainly certain items of workmanship that we were quite dissatisfied with and this is, say, a joint responsibility of NASA—I say a joint responsibility—of course, it is NASA's responsibility to get contractors responding, but workmanship certainly impresses us as being somewhat deficient and somehow or other it got through. I do not know that we are able to identify in detail. I think the Apollo program management will have a hard look at that.

Senator SMITH. Well, Dr. Thompson, in your finding 10, you recommend that—

Every effort must be made to insure the maximum clarification and understanding of the responsibilities of all the organizations involved, the objective being a fully coordinated and efficient program.

NASA and the industry are pretty big organizations. It would seem to me after all the efforts you have made that there would be some way for you and your people, with their variety of experience and background, could pinpoint the responsibility of either the positions or the levels where the problems exist.

Dr. THOMPSON. Well, I think we have identified, in our report, that there were certain processes that went ahead with more or less informal understandings rather than documented understandings. In a program as demanding as this, a certain amount of that is necessary. The remarks that we addressed ourselves to in that case were related to the fact that there seem to be rather too much informal understanding between the people involved at the time of the test rather than giving us the assurance that the written instructions required for all these people who are involved had been distributed to them long enough in advance, so that we are certain that everyone understood fully what the test group was doing. And, it is in this area where we felt that more attention to the, what I would call the orderliness of the project would be appropriate.

Senator SMITH. Well, Dr. Thompson, continuing with your finding 10, part D states:

Deficiencies in design, manufacture, installation, rework and quality control, existed in the electrical wiring.

Now, someone has to be responsible for that. I do not mean the individual involved, but some organizational unit must be specifically responsible for this work and do you mean to tell us that you cannot identify that area where the responsibility lies?

Dr. THOMPSON. Well——

REQUESTS STATEMENT OUTLINING PROBLEMS

Senator SMITH. Or if you could give us a statement on what has to be done to define those areas.

Dr. THOMPSON. The Apollo program office is organized in such a way as to attempt to deal with this. One of the members of the board is from the quality assurance area of responsibility, Mr. George White. I do not know whether he wants to comment on that.

Mr. WHITE. Yes, I would like to address myself to that question. The wiring problems that we have found in our investigation——

Senator SMITH. Will you identify yourself.

Mr. WHITE. I am George White, director of reliability and quality in the Apollo program office in Washington. These wiring deficiencies stem originally from a lack of adequate engineering information being passed on to the manufacturing people which in turn, means that in the inspection operation, rather than having the hardware compared with the engineering drawings and engineering requirements, it is compared with the inspector's knowledge of accepted practice.

Now, this sometimes leaves sort of a qualitative approach to things and there is not a firm set of criteria against which the inspector can judge.

The original responsibility here, of course, lies with the contractor, but NASA has inspectors on the spot who double check the contractor's inspection operation and, therefore, NASA must accept responsibility here, along with the contractor. In fact, the ultimate responsibility obviously is NASA's.

Does that answer your question on that, Senator?

Senator SMITH. Well, not wholly, no. Dr. Thompson said a few moments ago that he did not think he could come out from the top of his head with an opinion. I wonder, Doctor, if you would be willing to give this some specific thought. You know what I am after, and then give this committee the benefit of your thinking on it. I think we are relying a great deal on you and your associates and I personally will appreciate it if you can give me the benefit of your own personal thinking.

Dr. THOMPSON. Let me add one more thought to this. In my statement I pointed out that we had looked at the Block I design. Now, some of these deficiencies, particularly the wiring which has been the cause of great concern, we understand has been greatly improved in the Block II design. It has been recognized in the manufacturing process by the program office and the contractor and we have not examined—we have not looked over the Block II design, but our understanding is that this important question has been dealt with in an effective manner in the Block II design. So, in other words, it is a recognized problem that is being dealt with.

Senator SMITH. But, Block I spacecraft was to be flown by man, was it not?

Dr. THOMPSON. Sure, 012.

Senator SMITH. Should it not have been just as important before this happened as it is now?

Dr. THOMPSON. You are correct. Number 012 was a Block I spacecraft and that was the one that was to be flown.

Senator SMITH. What I am trying to get is, where the error was, where we slipped up in not having or taking every precaution before we had that test. I do not see why we would not have precautions in testing before flight.

Dr. THOMPSON. Well, I guess it is a matter of judgment that was made relative to that flight. Maybe I had better ask Colonel Borman. He was going to fly in a Block I spacecraft and he was prepared to go although knowing right much about this. I think we had better let him comment on that.

Colonel BORMAN. Yes. I think, Senator, we were very aware of the problem of fire in flight and we had adopted procedures primarily of venting the command module to a vacuum to eliminate the fire. We had done an extensive study on this before our Gemini 7 flight. However, I think that none of us were fully aware of the hazard that existed when you combine a pure oxygen atmosphere with the extensive distribution of combustibles and the likely source of ignition, and so this test, as I mentioned briefly during the findings and determinations, was not classified as hazardous.

I did not consider it as hazardous. I do not believe that anyone within the test organization or the program office considered it hazardous. And, this is the unfortunate trap through which we fell.

Senator SMITH. Well, Colonel, were you aware of the electrical deficiencies before you were appointed to the board?

Colonel BORMAN. Yes, Ma'am.

Senator SMITH. Mr. Chairman, I have other questions that I am quite anxious to ask, but if you would like to go around and then come back to me.

(The material referred to above follows:)

In my opinion, the overall organization structure of the Apollo program, both Government and Contractor, is sound. What I, personally, and the other Board members were concerned about were the procurement/inspection/checkout/acceptance processes of Apollo spacecraft at lower levels of management. I felt that this was a weakness within the structure that should be looked into by the top management of NASA. The accomplishment of this objective must face the difficulties of dealing with the dynamic requirements of a fast moving program. When you consider that two NASA Centers, Manned Spacecraft Center and Kennedy Spacecraft Center, and two Contractor facilities, North American Aviation, Downey and North American Aviation, Florida facility must, of necessity, coordinate the total effort, it is not difficult to discover areas where the administrative, engineering and operational procedures may show defects.

The Board described the management and organization of the Apollo program in Appendix E of its report to the Administrator, NASA. In its report, the Board set out in considerable detail the management and responsibility levels. However, no attempt was made to ascertain the actual working relationships as they currently exist between the various management levels. The Board did not consider itself to be charged with the responsibility of management analysis. Furthermore, if it had, the investigation would have taken several more months.

If any management level is to be charged with the failure to recognize and correct the deficiencies noted in the Board's report, it would be the design and layout engineering level. I pointed out in my testimony and it is a matter of record that the Board and I were seriously concerned with the electrical wiring and soldered joints. I specified the material to you in my testimony and referred you to page 6 of Appendix D-9 of the Report. I believe that when the wiring and plumbing joint problem is solved by the Apollo Program Office, coupled with the recommended reduction of flammable material, the reliability of the Apollo spacecraft will be increased to an acceptable level not only for safety, but for mission success.

The CHAIRMAN. Thank you.

Senator Cannon?

Senator CANNON. Thank you, Mr. Chairman.

RELATIONSHIP OF BOARD MEMBERS TO NASA

Doctor, I would like to review for a few moments with you the relationship of the various members of the Board to NASA—and I am not doing this from a critical standpoint—but I think it is well to know exactly what the relationship is.

Would you start with yourself and tell us what your relationship is to NASA and what it has been for the past several years.

Dr. THOMPSON. I am Director of the Langley Research Center of NASA. Our area of effort is in the research field. We report into headquarters through what is called the Office of Advanced Research and Technology. We do not have any direct connection with the Apollo program except in a supporting role as providing technology relative to this. This is technology developed by our research programs.

Now ——

Senator CANNON. And you have been with NASA yourself ever since NASA was first formed, have you not?

Dr. THOMPSON. Yes, sir. I have been ——

Senator CANNON. Now, as I understand it, if you consider the counsel not to be a member of the Board, six of the eight members are assigned to NASA and are employed by them, perhaps with the tech-

nical exception of Colonel Borman, who is assigned to them but is actually employed by the Air Force, I presume. Is that correct?

Dr. THOMPSON. Yes, sir.

Senator CANNON. And, what is Dr. Faget's relationship to NASA?

Dr. THOMPSON. Dr. Faget, will you describe your position at MSC, Manned Spacecraft Center.

Dr. FAGET. Yes. I am the Director of Engineering and Development.

The CHAIRMAN. I cannot hear you.

Dr. FAGET. I am the Director of Engineering and Development at Manned Spacecraft Center.

Senator CANNON. Does that mean that you had the responsibility for the general program of engineering and development for NASA?

Dr. FAGET. I have the general responsibility for providing engineering and development work as related to manned spacecraft; yes, sir.

Senator CANNON. And that included the capsule in this particular instance?

Dr. FAGET. That includes——

Senator CANNON. In the Apollo program?

Dr. FAGET. That includes all of the manned spacecraft program and Apollo as well, certainly.

Senator CANNON. And have you been with NASA since its inception?

Dr. FAGET. Yes, sir. I, like Dr. Thompson, was with NACA and have been with NASA since its inception.

Senator CANNON. Now, what about Mr. Geer?

Mr. GEER. I am E. Barton Geer. I am at the Langley Research Center and I am in engineering and design of flight vehicles and systems at Langley.

Senator CANNON. Now, is that completely disassociated with the space systems?

Mr. GEER. Yes. Manned space system; yes.

Senator CANNON. But, you are employed by NASA and have been for some period of time in your present assignment.

Mr. GEER. Yes, sir.

Senator CANNON. Dr. Thompson, were you ——

Dr. THOMPSON. I was trying to say he is one of my employees in one of the divisions at Langley.

Senator CANNON. And, Dr. Van Dolah, of course, is not connected with NASA, as I understand it, except as a member of this Board, and perhaps has assisted in advice on previous occasions.

Dr. VAN DOLAH. That is correct.

Senator CANNON. Colonel Strang, of course, is an Air Force officer and assigned to the IG Division out at Norton, is that correct?

Colonel STRANG. Yes, sir. Located at Norton, but under the Inspector General, Air, Washington.

Senator CANNON. And, you have no relationship to NASA as such, except as a member of the Board?

Colonel STRANG. Absolutely not.

Senator CANNON. What about Mr. White?

Mr. WHITE. I am director of reliability and quality in the Apollo program office here in Washington and in that position I am on the

staff of General Phillips. He has five divisions in his organization which are "Operations, Test, Program Control, Systems Engineering, and Reliability and Quality." I am director of the reliability and quality division.

Senator CANNON. Would you say the matters involved here relate directly to reliability and quality in this particular instance?

Mr. WHITE. Yes, sir.

Senator CANNON. So, any finding of the Board, any adverse finding would reflect adversely on your office, would it not?

Mr. WHITE. I believe that is right.

Senator CANNON. And, what about Mr. John Williams?

Mr. WILLIAMS. I am director of the manned spacecraft operations at Kennedy Space Center.

Senator CANNON. How long have you been in that position, Mr. Williams?

Mr. WILLIAMS. I joined NASA in 1959.

Senator CANNON. You have been with NASA since its inception up to the present time?

Mr. WILLIAMS. Essentially since its inception.

Senator CANNON. And, you were directly related to the particular program here, is that correct?

Mr. WILLIAMS. Yes, sir.

Senator CANNON. And, Mr. Malley, while I presume he was not a member of the Board, he also is an employee of NASA and——

Dr. THOMPSON. At Langley. Chief counsel at Langley.

Senator CANNON. Getting back to Mr. Williams, you are directly involved in the spacecraft program and the operational program of the Apollo program, is that correct?

Mr. WILLIAMS. Yes.

Senator CANNON. Dr. Thompson, do you think the fact that six of the eight members of the Board are directly employed by or related to NASA would in any way tend to have the Board less critical of the actions that have been reviewed here than if it were an objective board from some other source? And, I am not saying that in a critical vein because I realize that to get people from the outside that are familiar with what is going on would be extremely difficult.

Dr. THOMPSON. Well, I feel that the people that I have had working on this Board have been very effective even to the point that Mr. George White perhaps criticized himself. Now, just what some other people would have done, I do not know. They could have been critical, I say—without knowing how to respond I do not believe I can tell that, but these people certainly have responded in a very effective manner and as you point out, they are knowledgeable which was a basic element of consideration, because we had to tie onto an existing system, a very complex system to pursue our review. So that I do not think our task suffered from the fact they were associated with it but I know it benefited very greatly because they were.

Senator CANNON. Now, you pointed out correctly, that they were critical but I am wondering if they might tend to be—the point I am concerned about is might they tend to be less critical than if they were from some other source?

Dr. THOMPSON. Well, I cannot tell, because I do not know who the other people would be.

DEFICIENCIES NOTED IN DESIGN REVIEW

Senator CANNON. Doctor, the report of the Apollo Review Board, Design Review Panel 9, states that independent design reviews were made by NASA and North American personnel during which numerous design deficiencies were noted. Now, I would like to ask you if that was the first design review that was ever made of the block I spacecraft by NASA personnel.

Mr. WHITE. The answer to that is "No," that there have been many design reviews conducted in the normal course of the program. Preliminary design reviews early in the design stage, and a critical design review when design is completed. There is a design certification review which had been completed on this spacecraft which is performed prior to every major change in the design of any particular element of the program.

For example, in this case, it was the first manned spacecraft, so we had a design certification review that was conducted by Dr. George Mueller and his Management Council, composed of the directors of the three centers involved. So, there had been numerous design reviews in the normal course of the program. This is our standard policy.

Senator CANNON. Why would you say that these design deficiencies were not noted previously, then, in these many design reviews?

Mr. WHITE. I believe probably the most significant thing here is that the deficiencies that we have found, particularly in the wiring installation, are detailed types of deficiencies concerned with routing and inadequate clearances and inadequate protection of wiring, which may not have actually been gone into. Design reviews have been devoted primarily to the more broad questions of design of subsystems, and capability of subsystems to do their jobs. And, in this sense perhaps the design review did miss some of these fine details which turned out to be very important.

Senator CANNON. Are you in effect, saying that nobody envisioned that you might have a fire and, therefore, you were looking at other things? Is that an oversimplification of it?

Mr. WHITE. Not exactly that, although the end result turned out to be that, yes.

PRESSURE DUMPING SYSTEM

Senator CANNON. Getting back to the technical part of this process—I would like to ask Colonel Borman—it has been stated here that the module could not be opened because of the pressures that built up. There is a pressure dumping system as was explained and I would like to ask you from your standpoint as a pilot, and as an operator, is that a quick release-type system that would be adequate for rapid dumping?

Colonel BORMAN. The system was not sufficient to dump the rapid build up of pressure that we experienced in this fire, sir. There was one dump valve, primarily designed for use again on orbit to expose the spacecraft interior to a vacuum. It was not adequate in the accident.

Senator CANNON. And, will that be one of the items that will have to be redesigned for a rapid dumping system?

Colonel BORMAN. In my opinion, yes, sir.

Senator CANNON. Now, Dr. Thompson, on page 8 of your statement, you say the majority of tests and analyses have been completed. The tests remaining to be completed will not affect the conclusions arrived at in the report.

If they will not affect the conclusions, why are you conducting other tests?

Dr. THOMPSON. We started a series of tests. The Board sponsored certain tests to pursue its review and those tests were not all completed at the time we considered that we had enough information to draw our conclusions from them.

However, the information being developed by those tests seems to be of sufficient interest so that we would like to have those tests completed and put into our final report in appendix G. So, they will have benefit to the future, although we do not depend on them for our determination at this time. They are technical matters that we thought ought to be completed.

Senator CANNON. And, may eventually affect redesign of the capsule in some other particulars.

Dr. THOMPSON. They will be useful in the future for those who are going to carry out the program and perhaps relative to redesign.

DISCUSSES WIRING CONDITIONS

Senator CANNON. Now, in your statement, you identified the conditions that led to the disaster and I would like you to explain, if you will, the third one where you say vulnerable wiring carrying spacecraft power. Do you relate there to wiring that is vulnerable under fire conditions or otherwise vulnerable wire?

Dr. THOMPSON. The vulnerable wire I think, was pretty well explained by the discussion here. I will interpret it this way: That there were certain wire bundles that were subject apparently to pressures that can ultimately result in failure of the insulation. Now, this insulation is very good from the fire standpoint. But, I believe it was noted that it has a characteristic for cold flow.

The cold flow that we referred to can be important if a wire bundle carrying power, presses on a sharp edge so that there is a fairly high amount of pressure on a point and it can be that under continual pressure it will break through, cut through insulation and make a short or fire. When wires with this type of insulation are installed, it is very important to see that their good characteristics are not offset by some disregard for this characteristic; and this is one of the principal things that we had in mind.

Senator CANNON. That is a well-known feature. That was known to you long before NASA was ever organized when you were related with its predecessor. Why is this matter found to be of particular importance at this point, when it is well known in the trade and has been for many years?

Dr. THOMPSON. The characteristics of this particular insulation, which is a new one, relatively new in the field, because of its fire resistance, is important. This particular type of insulation is very good from a flammability standpoint, but it does have this other characteristic that requires additional care in utilization of it.

RUSSIANS USE NITROGEN AND OXYGEN

Senator CANNON. Now, in your reference to the use of a, you call it a diluent gas——

Dr. THOMPSON. Yes, sir.

Senator CANNON. I would like to ask what is the Russian system? What do the Russians use?

Dr. THOMPSON. Col. Borman knows perhaps as much about that as anybody.

Colonel BORMAN. The Russians, to the best of my knowledge, sir, use a 14.7-pounds-per-square-inch atmosphere with essentially air. Nitrogen and oxygen.

Senator CANNON. Did they use that throughout the flight or just for ground?

Colonel BORMAN. No, sir. I believe they use it throughout the flight. This is based on discussions that I have had with Russian engineers when you and I met in Las Vegas the last time I saw you.

QUESTIONS NEED FOR TWO-GAS SYSTEM

Senator CANNON. And is the consideration now that we may go to diluent gas system on the ground and then to a pure oxygen system airborne? Is that what is now being considered?

Colonel BORMAN. Sir, I have, if I may, at least two hats when I testify. One as a Board member and one as a crewmember. I would like to answer that in my capacity as a crewmember, if you will.

Senator CANNON. Fine.

Colonel BORMAN. It would be my hope that the approach we take would be to remove the flammables from the spacecraft interior. Oxygen per se is not dangerous. It requires an ignition source, combustible materials and, of course, in an oxygen atmosphere you have a severely hazardous situation.

I would hope that we are able to remove enough of the combustibles, and to strategically locate those that remain, so that we can continue to use a hundred percent oxygen atmosphere.

The use of a two-gas system on the pad and then the resultant requirement to purge upon reaching operational altitude in my mind is very undesirable. This means that you would have to expose a command module to a vacuum almost immediately after insertion into orbit unless you were willing to stay in your suits for 4 to 5 days while the normal leakage bleeds off the nitrogen.

So I would hope that the management can find ways to remove—to replace many of the combustible materials, to strategically locate the others, and then to test the reconfigured spacecraft with a full-scale mockup such as we have recommended; and to prove that in this 16.7-pounds-per-square-inch oxygen with the new materials, regardless of where we might have an ignition source, we will not have the disaster that we had at Cape Kennedy.

CREW IS FINAL REVIEW BOARD ON MAKING FLIGHT

Senator CANNON. Now, is your judgment in that regard affected in any way by the time schedule in the Apollo program, the fact that if we went to a two-gas system it might delay the objective of the program?

Colonel BORMAN. Sir, I would be remiss if I did not admit that I am extremely anxious to meet the goals of this program. I am extremely—quite frankly, personally I am very anxious to make sure that, to see that we have an American lunar landing first. That is a personal desire.

However, never since I have been associated with NASA have I ever experienced any decision where a known detriment to crew safety was sacrificed to any operational requirement. And although I am willing to accept risk as I pointed out yesterday to the House committee, I am not willing personally to accept undue risk and I would not participate in any decision which I thought was expediting a program in an unsafe manner; and in the final analysis the crew is the real review board because if we do not like the way the spacecraft is configured, we don't have to get in.

Senator CANNON. And you would have no hesitancy if your recommendations were followed; you would have no hesitancy as a pilot yourself to proceed on that basis?

Colonel BORMAN. That is correct, sir.

Dr. THOMPSON. Could I add something on that point, Senator?

Senator CANNON. Yes, sir; you may.

COMPARES ONE-GAS AND TWO-GAS SYSTEMS

Dr. THOMPSON. I referred in my statement to the necessity for working out all the operations that would be associated with the two-gas system. Those problems have not been solved and whereas we have a very extensive record of reliable operation with oxygen, pure oxygen, in flight, we have no record that shows that we really know how to work with all these problems of diluent gas, identification of all the constituents in there, all the machinery or all the mechanisms that would be required to get out of the spacecraft and go into space; get out of the spacecraft and get on the moon, get back in.

Now, those problems are very considerable and as long as we are able to go along with this system that has proven to be so reliable until this last event; I think there is a pretty strong compulsion to stay with it.

Now, there are times I think if a craft is going to stay in space for long periods of time, it will probably be necessary to use a two-gas diluent system. But those problems, say, are not solved and I think we have to be very careful in trading off the unknowns of an unproven system for one identifiable item of risk in a well-proven system.

So that our feeling is that one of the most important things is to deal with matters as Colonel Borman has talked about, we have talked about getting rid of the sources of ignition, reducing the combustibles, making a greater use of materials that will not easily ignite, and otherwise reengineering the interior relative to this whole question of ignition and flammability rather than say we want to undertake a risk that we have not even properly assessed.

BOARD PERSONNEL DISCUSSED

Senator CANNON. Thank you, Doctor.

My time is about up. I would like to ask you just one final question relating back to my initial point.

There has been some criticism as you know that there are, or were too many NASA personnel and not enough outside experts on the Review Board.

What would have been the effect of bringing in more non-NASA experts in your judgment?

Dr. THOMPSON. In my opinion it would have been rather difficult. If Dr. Van Dolah does not mind my referring to his indoctrination into the system required to pursue a review of this magnitude without familiarity with it, I am sure he will agree that at times he became very impatient with the system because it seemed to get in the way of progress, but the system is the one thing, paperwork, the direction to people, is one of the major elements that makes a program like this possible, that makes it possible to organize efforts on a large scale with people on a 24-hour basis and a 7-day week basis and that system at times gets in the way of quick steps, but if we did not have people who were conversant with that, I am afraid we would have been very—would have felt frustrated and probably would have had a lot of trouble with them.

Senator CANNON. When you say "had a lot of trouble with them," do you mean just delaying your decisions or——

Dr. THOMPSON. I think it would——

Senator CANNON. Or impeding progress?

Dr. THOMPSON. I think they would have felt frustrated and felt dissatisfied with the lack of progress.

Senator CANNON. We are not concerned here with what the members might have felt. We are concerned with what the Board might find and might have found and what they can report to this committee and to the public.

Dr. THOMPSON. We acquired a great many experts to work with the Board. We canvassed the whole country and we got an extremely responsive effort from experts in all areas wherever we looked for help, and some volunteered their help and were very helpful, and I don't think, in any way, we suffered from lack of expertise in the areas that we pursued because the country as a whole seemed to be very, very interested in contributing anything that they could.

The heads of—well, the president of MIT, and the other colleges, offered to help and did contribute. We got help, expertness from the FAA, the CAB. We employed the expert assistance of the Naval Research, one of the Naval Research's most active people on fire. I don't see how we could have gotten much better help than we had.

Colonel BORMAN. Sir, don't you think really it is safe to say that regardless of who composed the Board, the findings and determinations and recommendations would probably not have been materially changed. Is that what you are getting at?

Senator CANNON. That is what I am trying to get at.

If that is your conclusion, I am very happy to have it, Colonel.

Do you agree with that, Doctor?

Dr. THOMPSON. I think that we were able to do an adequate job with the people that we had and with all the help that we got and I don't see how we could have much improved our capability.

Senator CANNON. And you had all the expert help you needed according to your testimony.

Dr. THOMPSON. Expert help from any source we asked for help, we got it.

Senator CANNON. Thank you, Mr. Chairman.

The CHAIRMAN. Before Senator Curtis starts, will you please review the statements by panel No. 9—Design Review Panel—on page D-9-6 and give us some statement this afternoon because in that report the panel speaks of design deficiencies. It says: "Some areas of wiring exhibited what would be referred to as rat nests." I think those are pretty strong words and you might have something to say.

Senator Curtis?

BELIEVES FIRE DUE TO ERROR IN JUDGMENT

Senator CURTIS. Thank you, Mr. Chairman.

Did this fire occur because of a wrong decision or decisions made by our space scientists?

Dr. THOMPSON. I don't think it was a particular decision that caused it. I think it was a situation as has been pretty clearly described that resulted in it but I don't see any particular decision that caused it.

I don't see how we could identify it beyond what we have already described in that connection.

Senator CURTIS. What I want to know is this. Was the error or shortcoming, if there were such, in the field of scientific decision, of our space scientists, or was it in the area of executing what our space scientists said should be done?

Dr. THOMPSON. I think it was an error in judgment in identifying how great the risk was with what we saw there and as Colonel Borman has said, he knew about those things and the risk that apparently lay there had not revealed itself to the point that people thought it was too great to undertake the flight.

Senator CURTIS. Well, maybe I have not stated my question very well but what I am trying to get at is this. Was the plan scientifically wrong or was the shortcoming in executing the plan?

Dr. THOMPSON. There was nothing wrong with the plan that I know of.

As far as being scientifically wrong, I don't think there was anything wrong in that sense. It was simply the execution, detailed execution that resulted in this event.

Senator CURTIS. Do you concur in that, Colonel Borman?

Colonel BORMAN. Yes, sir.

Senator CURTIS. I believe you stated that you were aware of defects or problems in wiring prior to going on this board.

Colonel BORMAN. Yes, sir. I was on the backup crew for the sister ship to Spacecraft 012 and there were problems in wiring.

I must point out there are problems in the development of every vehicle.

Senator CURTIS. I understand.

Colonel BORMAN. And these were normal problems.

ASTRONAUT WOULD NOT HESITATE TO ENTER SPACECRAFT

Senator CURTIS. Now, would you have entered that spacecraft on this morning of the accident if your turn had been called?

Colonel BORMAN. Yes, sir. As a matter of fact,——

Senator CURTIS. Would you have had any hesitancy?

Colonel BORMAN. No, sir.

Senator CURTIS. And would you have been mindful of what you have just stated about criticism of some of the wiring?

Colonel BORMAN. No, sir; because in my opinion the people that were responsible for that spacecraft, including the crew, and the crew assumes a major interest in the reliability of the hardware, felt that the defects that had been noted throughout the development had been corrected and the spacecraft as it existed prior to this test was believed to be in good shape.

Senator CURTIS. Were there defects of workmanship?

Colonel BORMAN. There were, sir.

Senator CURTIS. Did they go beyond workmanship?

Colonel BORMAN. Defects in the design of the wire bundles, their routing, their construction, and in my opinion, a basic deficiency in the wiring, in the harnesses, that distribute electrical energy.

Senator CURTIS. Well, if you would have entered that spaceship that morning, would you have been motivated by a willingness for a risk taking?

Colonel BORMAN. No, sir. As I pointed out earlier, I am afraid that sometimes the newspapers and the magazines attest a great deal more of the silk scarf attitude to the astronauts than actually exists. I am willing to accept reasonable risks in pursuit of worthwhile goals but I am not willing to accept any undue risk.

Senator CURTIS. I understand.

Colonel BORMAN. So I would not have entered that spacecraft if I would have thought there was any danger of the disaster that occurred.

Senator CURTIS. In other words, while you were critical of some of the wiring, workmanship, and design, you were never critical to the point that you would say, "Well, I would not get in one of those"?

Colonel BORMAN. That is correct, sir.

FIRE LASTED 25 SECONDS

Senator CURTIS. How long did that fire last?

Colonel BORMAN. Dr. Van Dolah—excuse me, may I ask him?

Senator CURTIS. Yes, sir.

Dr. VAN DOLAH. It probably lasted only about 25 seconds, sir.

Senator CURTIS. Did the fire extend beyond the time that the astronauts died, do you think?

Dr. VAN DOLAH. Well, I might say that the fire presumably went out at about 30 seconds after the minute, some 25 seconds after we had the first report that there was a fire in the spacecraft.

The levels of carbon monoxide were very high at that time because of the deficiency of oxygen for the combustion.

I think that the medical testimony, medical evidence, medical opinion states that unconsciousness probably came in a matter of perhaps 30 seconds after the lethal quantities of carbon monoxide developed, 15 to 30 seconds, I believe, and that death followed a few minutes later.

Senator CURTIS. The fire was out, then, when they died?

Dr. VAN DOLAH. Yes, sir.

FAST OPENING HATCH MAY HAVE SAVED CREW

Senator CURTIS. Well, would it have made any difference what kind of an escape hatch there would have been?

Dr. VAN DOLAH. Yes, sir.

As I pointed out in the pressure record that we have of the fire, there was a period of many seconds, many in terms of the total event, perhaps 8 seconds or so before the fire began to be very vigorous. If there had been means for rapid dumping of the pressure and a hatch that could open in 2 or 3 seconds, I believe the crew could have escaped with only minor injuries at most.

Senator CURTIS. Are you prepared to say what kind of a hatch it should be, taking into account that the vehicle be in orbit?

Dr. VAN DOLAH. No, sir. I believe this gets beyond my expertise.

I think that it needs to be quick opening for certain emergencies but needs to have ample protection against accidential opening at times when you don't want it to open, but I believe this is something that others would be better prepared to discuss.

Dr. THOMPSON. Could I say something at this point, Senator?

A hatch design, redesign, was underway prior to this and I think that perhaps Colonel Borman can describe the situation a little bit better than I can relative to that.

Colonel BORMAN. Sir, the hatch that we had on the Apollo 012, Command Module 012, was an inward opening hatch that used the pressure of the spacecraft atmosphere to seal it, help seal it on orbit. It was a hatch that was not desirable for extra-vehicular activities. As a consequence of this, a redesigned hatch for Block II spacecraft was on the way at the time of the fire.

This hatch is being pursued actively now and all Block II spacecraft will have this new hatch. It is an outward opening hatch that will open in a matter of seconds.

Senator CURTIS. Now, if that hatch had been on the vehicle at the time of the accident, would they have escaped?

Colonel BORMAN. In my opinion, yes, sir.

Senator CURTIS. That is all, Mr. Chairman.

The CHAIRMAN. Senator Young?

Senator YOUNG. Thank you, Mr. Chairman.

At this time I have no questions.

The CHAIRMAN. Senator Jordan?

BOARD MEMBERSHIP WELL QUALIFIED

Senator JORDAN. Thank you, Mr. Chairman.

Going back to the line of questioning pursued by Senator Cannon, I am not altogether satisfied, Dr. Thompson, with some of the answers.

I want to go into this a little deeper.

You say in your statement the Apollo 204 Review Board was established by the Administrator of the National Aeronautics and Space Administration on January 27 and was confirmed by memorandums.

Now, we get appointments by the executive branch and confirmations by the Senate in some instances but I don't understand what confirmation by memorandums is.

Will you explain the memorandums and who issued the memorandums?

Dr. THOMPSON. Well, sir, I think this is a case where the paperwork had not quite caught up with the program, some of the same things we talk about in pursuit of this whole endeavor. The events move fast and I accepted the responsibility as Chairman and did not wait

for the paperwork to catch up. I talked to Dr. Seamans as we went along, we formulated the course of action. The paperwork caught up with us as indicated by those two memorandums, although we had oral understanding, verbal directions as to what course we would follow.

Senator JORDAN. You have already testified that you believe the members of the Board, members of the panel, and certainly I am not doubting their competence, but you testified that perhaps they were the best qualified to make this in-house investigation.

Is that true?

Dr. THOMPSON. Well, I would say they were qualified to make it. I don't know whether they are best qualified. I think they did a very good job as far as I am concerned. They supported me.

Senator JORDAN. Do you believe that it was necessary to have on this team, making an investigation of itself, the director for reliability and quality of the Apollo program?

Dr. THOMPSON. It was very useful to have someone who was thoroughly conversant with that area on the Board as far as I was concerned and I did not detect in any way that he was withholding because he thought that he was criticizing himself in any way.

Senator JORDAN. Do you believe it would be absolutely essential to have a director of the whole spacecraft operation at Kennedy Space Center on the Board?

Dr. THOMPSON. I thought it was very essential because he was the most knowledgeable one. He certainly has contributed information no one else could have contributed to this Board as far as I can determine.

Senator JORDAN. But your research and the investigations have pointed up very clearly that there was sloppy work in many respects, has it not?

Dr. THOMPSON. I don't understand the question. Stoppage of work?

Senator JORDAN. Sloppy work. Sloppy is the adjective that has been used in describing it.

Dr. THOMPSON. I don't think we used that. I read that perhaps in the newspaper. There was work that we did not think was as good as it should be.

Senator JORDAN. But you think that the men who have those responsibilities in the program are thoroughly competent to make a judgment as to exactly what happened here and how best to remedy it, in the future?

Dr. THOMPSON. I think that we have identified the problems. I think that the action that has to be taken here ought to fall in the area of the program office with the things identified as we have seen them. They may find out things, too. My experience in managing projects is that a manager always has problems. They normally don't have to air them so much in public as these are. However, a manager has to manage and he always has problems and I think we have helped identify some of the problems that management has.

Senator JORDAN. Well, criticism has been leveled, Dr. Thompson, and I think will continue to be leveled, at the fact that the Board was predominantly staffed by members of NASA. As a matter of fact,

staffed by the very people who had the responsibility for the execution of this part of the program. That is true, is it not?

Dr. THOMPSON. Yes. I think that that criticism will probably persist.

Senator JORDAN. And you think even so this particular Board could do a more objective job than could a board of independent status and background?

Dr. THOMPSON. My position is that we needed people who are very knowledgeable about the program to run this review.

Now, if we had had to get too many people who did not know how to do that, were not familiar with all the system, I think we would have had a very difficult job in moving as fast and effectively as we did.

CERTIFICATE OF FLIGHT WORTHINESS ISSUED

Senator JORDAN. The Board's report, states that in August 1966 a review of the spacecraft was conducted by NASA at the contractor's plant. Where was the contractor's plant?

Dr. THOMPSON. Downey, Calif.

Senator JORDAN. Afterward, NASA issued a certificate of flight worthiness and authorized the spacecraft to be shipped to Cape Kennedy.

The report further states that the certificate included a listing of open items and work to be accomplished at Kennedy, and one of the findings in the report states that there were 113 significant engineering orders not accomplished at the time the Command Module was delivered to NASA and yet it was given a certificate of flight worthiness at the point where it was manufactured in California.

Who would give it that certificate of flight worthiness at that point?

Dr. THOMPSON. The program manager for the Apollo Spacecraft program.

Senator JORDAN. Even though it had 113 significant orders not accomplished at that time?

Dr. THOMPSON. I think that this is a situation a program manager always has to face when it was not an off-the-shelf item. He made some judgments and he identified the number of open items and he made the judgment that it was time to ship in order to keep things moving properly.

Senator JORDAN. Is it usual to issue a certificate of acceptance when there are so many significant changes still to be made?

Dr. THOMPSON. There are a series of signoffs and I am not sure just—I am not at all certain that there is not always this element.

As a matter of fact, I am almost positive there is this element of lack of completion involved in this act. There has to be a judgment as to whether or not it is proper in view of that, whether the work properly should be accomplished during the next phase of the program.

Senator JORDAN. Were all these significant engineering changes eventually accomplished before initiation of manned testing of the spacecraft in the pure oxygen environment?

Dr. THOMPSON. John, do you not have the answer to that?

Mr. WILLIAMS. We had to do research. Anything that would affect the pure oxygen environment was accomplished prior to the first manned——

Senator JORDAN. A little louder, please.

Mr. WILLIAMS. Anything that would affect the spacecraft, 113 items, in a pure oxygen atmosphere had been accomplished prior to the altitude chamber run last October or November.

Dr. THOMPSON. Let me add one point.

Senator JORDAN. Yes, go ahead.

Dr. THOMPSON. The completion—the requirement for completion of all those items is judged in relation to what is being done at that particular time, too, though that does not mean that it is actually necessarily flight ready. Certain things could be left undone, at least conceivably they could be left undone and still not involve risk.

Senator JORDAN. Then it would follow that on the next page of your report you state that in December of that year the program director conducted a recertification review which closed out the majority of those open items, but would you define what is meant by "closed out"?

What do you mean when you say "closed out"?

Mr. WILLIAMS. Mr. White?

Mr. WHITE. An item is considered to be closed out when the deficiency has been corrected or it has been determined that it is not significant to the safety of the spacecraft. This involves an engineering review and signoff of a piece of paper that has this deficiency recorded on it.

While I have the microphone, here, if I may, I would like to make another statement with regard to this certificate of flight worthiness.

When the certificate is signed, it does include a list of exceptions, and it is considered normal practice that not every single one of these deficiencies must be corrected before shipment. They are listed and this list is transferred then to Cape Kennedy so that they are corrected at that point.

Senator JORDAN. Were any deficiencies listed with respect to the wiring?

Mr. WHITE. I believe there were. I can't specifically list them.

Senator JORDAN. And in your judgment they were corrected at Kennedy Space Center prior to this test?

Mr. WHITE. The deficiencies that were known to be dangerous, I would say, had been corrected.

We depend quite a bit on the tests that are conducted at the Cape which essentially operate all systems and do put power in all systems. Thereby we find whether or not there is a short or an open circuit or something of this sort.

The deficiencies of the nature of the wire routing, inadequate clearances, and lack of protection may not in all cases have been corrected.

Senator JORDAN. Had those safety precautions been taken with respect to this particular spacecraft prior to the test?

Mr. WHITE. What steps did you mean, Senator?

Senator JORDAN. The safety precautions of checking out the wiring and checking out the whole program for——

Mr. WHITE. Yes.

Senator JORDAN. For safety?

Mr. WHITE. Yes, sir.

There had been other tests run. There had been tests run in the space chamber at Cape Kennedy, two manned tests and two unmanned tests, which did operate all systems satisfactorily.

We did not encounter any problems of the sort that occurred on the pad.

QUESTIONS CONDITION OF GAS MASKS

Senator JORDAN. Going to another matter, I had very little time to get through this voluminous report but I did note that certain individuals testified that the gas masks were either faulty or did not fit well enough to prevent leaks.

Is such equipment kept in a constant state of readiness and repair and have the personnel been trained in their use?

Dr. THOMPSON. Dr. Van Dolah?

Dr. VAN DOLAH. The majority of the gas masks that were available on the pad were masks that were designed to handle toxic fumes from the hypergolic propellants in that area.

They were not designed, with only four exceptions, to handle smoke and there is some question about whether the ones designed for smoke could actually handle the rather bad smoke conditions that existed at the time of the fire at the spacecraft level.

Senator JORDAN. The point is no one expected this kind of problem.

Dr. VAN DOLAH. That is correct.

Senator JORDAN (continuing). With this spacecraft at that time, is this right?

Dr. VAN DOLAH. That is correct, and I might go on to say that all of the personnel on the pad as far as I know were trained in the use of these masks. It was primarily the design of the mask itself.

Senator JORDAN. Thank you.

The CHAIRMAN. Does any other Senator have questions?

Senator Percy?

We will meet back here this afternoon at 2:30 instead of 2 o'clock, in this room rather than the room previously announced.

Senator Mondale?

WRENCH SOCKET FOUND IN SPACECRAFT

Senator MONDALE. Mr. Thompson, pictures of the probable source of the fire show a wrench socket.

Dr. THOMPSON. Yes, sir.

Colonel BORMAN. That is not the problem.

Senator MONDALE. The stories say it has nothing to do with the cause of the fire.

Was that wrench socket supposed to be there?

Dr. THOMPSON. No. I don't think it was.

Senator MONDALE. Isn't that rather illuminating evidence of lack of adequate attention to detail?

Dr. THOMPSON. It got left there. I am not too familiar with all the procedures that are followed to see that workmen don't lose tools and not recover them. I have heard of processes of shaking the spacecraft, and so forth, but having seen that there, it seems to be quite noteworthy that it had not been recovered.

QUESTIONS FLEXIBILITY OF MANAGEMENT WITHOUT LICENSE

Senator MONDALE. You indicated that you thought one of the management objectives of the program ought to be flexibility without

license. To me that carried with it an implication that you had observed some evidence of license in the operation of the program.

Could you give us examples of what you had in mind when you made that statement?

Dr. THOMPSON. We did not observe the license.

We observed what we call the cumbersomeness of process.

Senator MONDALE. Could you give us an example?

Dr. THOMPSON. The problem in dealing with the changes in test programs at the Cape, I think that perhaps Mr. John Williams can describe some of the incidents to illustrate the point.

Mr. WILLIAMS. I think that the test program was outlined from the MSC to the Cape in the form of a GORP, a ground operations document. This is then answered by test outline and the change in GORP. A change in the GORP document requires a contract change. This goes back to the contractor and they put out the test specifications back down to the Cape, the OCP is implemented, and it is quite a long road, a long way to go to make changes in a particularly flexible program.

Senator MONDALE. Did you have any specifics in mind when you said the objective of the program from a management standpoint ought to be flexibility without license or were you speaking without a specific example?

Dr. THOMPSON. I addressed myself to the problem that is pretty well identified here I think in appendix D, page 7 of the report, which went into this in considerable detail and this is a difficult problem that I think has not quite been solved.

I think this is a problem that the management has got to try to figure out a procedure for introducing as well as they can. They cannot give up the controls but at the same time they have got a dynamic program going on and somehow or other it seems as though it would be possible to introduce a quicker response system to those dynamic requirements.

We are addressing ourselves to that problem. We have not arrived at specific recommendations to management, just how to do that.

I think that would require considerable study.

WIRING DEFICIENCIES

Senator MONDALE. Colonel Borman indicated the existence of what I think he described as a basic deficiency in wiring or basic deficiencies in wiring.

Did you identify whose responsibility or whose fault that was?

Colonel BORMAN. Yes, sir.

I believe that the responsibility for the—at least the initial design, was with the contractor.

Of course, the ultimate responsibility is NASA's because NASA has the requirement to approve the design, monitor the design and check on the workmanship involved.

So I think it is a shared responsibility.

COMBUSTIBLE MATERIALS

Senator MONDALE. What about the apparently excessive quantity of combustible materials present at the time of this fire? I think some-

one indicated nearly 70 pounds of combustible material of one kind or another was in that spacecraft.

As I understand it, there is a procedure by which before any materials can be introduced in the spacecraft, they have to be approved, for several reasons, and I assume one of the tests would be combustibility.

Were some of these materials of a combustible nature introduced into the spacecraft without complying with that procedure?

Colonel BORMAN. Yes, sir; some of them were. For instance, the pads that the hatch was to be rested on, you saw those black pads, they were not flight items. The configuration of the spacecraft is an evolving thing. When we finally get to the flight day, launch day, we have a spacecraft that would not have many of the combustibles in it that were in this particular spacecraft.

However, some of the specifications that NASA used for putting combustibles within the spacecraft were sufficiently or too permissive. Some of the equipment that we did not, or that we thought was relatively harmless if kept away from wires turned out to burn very readily.

Senator MONDALE. Did the Commission seek to establish responsibility for that failure to comply with regulations?

Colonel BORMAN. Well, sir, by the failure, you mean the putting in the——

Senator MONDALE. In other words, the fact that substantial quantities of combustible materials were in fact in the spacecraft contrary to procedures that were to be followed in such tests.

Did anybody seek to establish who was responsible for this oversight?

Colonel BORMAN. Yes, sir.

I believe that the responsibility—there were two different problems. One was the fact that for flight we had too many combustibles in the spacecraft.

Now, in some cases these combustibles were installed in violation of NASA specifications.

Senator MONDALE. By whom?

Colonel BORMAN. By the contractor, they are installed by the contractor but the——

Senator MONDALE. With the approval of the Program Office?

Colonel BORMAN. Yes, sir. In other cases the specifications were not rigid enough we know now, and it involved—involves the items that were in for this test only, the mats and the protective liners over the umbilical cords, they were all in and their presence was noted but the fact that they were in was not believed to present a hazard and so although they were properly noted and their presence was documented, they still were there.

VIBRATION TEST

Senator MONDALE. Mr. Thompson, according to reports, spacecraft 012 was delivered to the Cape without being vibration tested, is that correct?

Dr. THOMPSON. Yes, sir.

Senator MONDALE. How did that happen?

Why didn't that test take place?

Dr. THOMPSON. Well, as I understand it, a management decision was made to depend on the very rigid component testing—components had been subjected to a very rigid vibration test.

The thing that we commented on was that the entire spacecraft had not been subjected to an overall vibration test.

The management decision apparently was, as shown by the record, that they would go along with the flight test, unmanned flight test, and which would in their opinion constitute a measure of the capability for this spacecraft to withstand this vibration, and that was done.

Senator MONDALE. Weren't you critical of the fact that this had not been vibration tested?

Dr. THOMPSON. We were critical because the view that we have is that the best way to really find out whether a spacecraft of this type, now, not the one that will be man flown but a spacecraft of this type with all installations abroad, will stand the vibration that is experienced, particularly through the boost period, is to vibrate it and vibrate it at a certain level that gives a vibration level that is equal to the level that will be experienced during the launch period if it could be identified, and certainly it is shaped identified now, plus a factor of about 50 percent in time. That is a procedure that is used in most spacecraft.

Senator MONDALE. Did you seek to identify responsibility for this failure? In your——

Dr. THOMPSON. Failure to ——

Senator MONDALE. Failure to perform the vibration test of the spacecraft? Was any attempt made to assess——

Dr. THOMPSON. The program office. I don't know exactly who in the program manager's office but the decision was made to proceed that way.

Senator MONDALE. Would you say that—would it be fair to characterize your report as concluding that this spacecraft was not ready for flight? That it should have been vibration tested?

Dr. THOMPSON. Well, I would hesitate to say that it was not really ready for flight. It certainly is shown now by hindsight to have had risk in it that indicates it was not ready for flight.

The judgment there includes—all these things that have been done and relative to the particular vibration test, I think reliance was put on the flights that had been made. If I had been responsible at that point, whether I would have declared my own, as directing the program, that it was ready or not I don't know. I am not sure whether I would or would not.

I did think that this vibration test was a better assurance of the reliability of the spacecraft.

Colonel BORMAN. Sir, may I add something?

Dr. THOMPSON. Colonel Borman wants to add something.

Colonel BORMAN. I think if you would phrase the question, did the people that were concerned at the time feel that the spacecraft was ready for that test, to the best of their knowledge, the answer would be an unqualified "Yes".

I talked to Ed White shortly before. The crew thought they were over a lot of the problems and they were on the way. The night of the accident I talked to Wally Schirra who had just returned from running the test on a spacecraft and he was really dumfounded that the tragedy could have occurred because he had felt the spacecraft had evolved into a workable machine.

So I think if you put it in the time frame when the accident occurred, you have to say the people were satisfied.

CITES POLICY QUESTION

Senator MONDALE. Thank you, Colonel.

Mr. Chairman, if I may, I would like to make one observation here that I think is brought out by these questions.

It seems to me that this report is very sound in the technical and engineering field.

We get precise clearances as far as could humanly be determined after this tragedy and the destruction that followed the fire.

But it seems to me that our committee's responsibility is in the policy question, the management field. We should not try to compete with you in building a better spacecraft or being better pilots. Our basic question is whether it is being managed well, whether the policy approaches underlying the program are sound, and it seems to me in this particular field as distinguished from the engineering side that we are not getting the kind of hard answers that we need to do our job.

The CHAIRMAN. Well, I would think that Mr. Webb might be here on Thursday and we might ask him some questions at that time.

Senator Percy?

Senator PERCY. Colonel Borman, you mentioned before that you would not have hesitated on this fateful day to enter the spacecraft yourself knowing what you did at that time.

I now ask the obvious question.

Knowing what you know now, would you have refused to enter the spacecraft on that day?

Colonel BORMAN. Yes, sir.

CITES AREAS OF DEFICIENCY

Senator PERCY. Could you describe in lay terms the outstanding characteristics of the spacecraft that you feel now in retrospect were deficient?

Colonel BORMAN. Yes, sir. I think that the deficiencies that we have noted here, if I were to single them out, I think the first basic deficiency was in the fact that the test was not identified and classified as a hazardous test.

Now, this was a failure in the procedures and in management, if you will.

The second deficiency was we had combustibles, too many combustibles within the spacecraft contiguous to ignition sources and in a 16.7 pure oxygen atmosphere.

This was a deficiency.

The third basic deficiency was the fact that we had vulnerable wiring that provided the ignition source.

Senator PERCY. Do you feel that responsible management could have detected these with adequate testing, ahead of time?

Colonel BORMAN. Sir, the answer is "No," but if I may expound, this spacecraft had undergone 6½ hours of testing under the exact same conditions at the Cape without any problems involving arcs, sparks, or any sort of short circuits.

It had undergone 62.2 hours of testing in an oxygen environment without any of these difficulties. I think that in pointing out the deficiencies as we have done in a very frank manner we often overlook

the fact that there is a great deal of effort to overcome and to pinpoint these.

Now, unfortunately we were not successful in this case.

Senator PERCY. Mr. Chairman, there is some doubt as to whether I can get back this afternoon.

Could I ask a question or two of Mr. Webb?

The CHAIRMAN. Excuse me.

Senator PERCY. Will Mr. Webb be speaking or testifying this afternoon?

The CHAIRMAN. He will not be testifying this afternoon.

I would prefer to wait for questions for Mr. Webb until he appears.

Senator PERCY. Would you prefer to hold those over until then?

The CHAIRMAN. If it is agreeable to you.

Senator PERCY. I will try to return if I can.

There is some doubt whether I can get back.

The CHAIRMAN. Thursday afternoon will be the time Mr. Webb testifies.

Senator PERCY. All right. Fine. I will hold off until then, Mr. Webb.

Thank you, sir. I have no further questions.

The CHAIRMAN. Any more questions?

Dr. THOMPSON. Mr. Chairman——

Senator PERCY. I will wait until Thursday.

The CHAIRMAN. Yes. Doctor?

COMPARING OF RATIO OF COMBUSTIBLES IN APOLLO AND GEMINI

Dr. THOMPSON. One point that has constantly come up here in a large amount of combustibles within the spacecraft, but in comparison with the previous spacecraft I think the ratio per man is about the same. That is, in other words, somewhere around 20 pounds, a little over 20 pounds per man, and I believe that in the Gemini—someone made the calculation for me the other day and showed that the Gemini —I think the spacecraft had about 20 pounds per man, too. This one has 70 which is a little over 20 pounds per man.

I thought it was a matter of interest to clarify the impression that it was a very large amount of combustible material, perhaps out of line with previous experience.

The CHAIRMAN. We will meet, then, at 2:30 again this afternoon in this room.

(Whereupon, at 1 p.m., the committee was recessed, to reconvene at 2:30 p.m., of the same day.)

AFTERNOON SESSION

(The hearing resumed in the afternoon at 2:30 o'clock with the same witnesses.)

The CHAIRMAN. Dr. Thompson, this morning in answer to one of my questions, to what would you attribute design and other deficiencies set forth in your report, you said somehow it—meaning quality—was not attained.

QUALITY RESPONSIBILITIES DISCUSSED

It seems to me that that is a function of management. If you set out to do something and you get a bad job, you do not blame the work-

men. Do you blame these difficulties on management or the workers, these conditions?

Dr. THOMPSON. Well, it seems to me management to the extent that they did not manage to get the workmanship into it. Just where that falls is a little bit difficult to say. The process somehow or other did not arrive at good workmanship, and the element—that goes back to management—they failed to get it and in that sense I guess is where it lies.

The CHAIRMAN. In conducting your review did you have any difficulty in determining who was responsible for a particular activity?

Dr. THOMPSON. I do not think we did. We have a very good delineation of the organization and responsibilities. I think all those can be pretty well traced down through the information we have.

The CHAIRMAN. This responsibility——

Dr. THOMPSON. Appendix E deals in the matter of organization, line responsibility.

The CHAIRMAN. Well, was this matter of responsibility clearly defined, do you think?

Dr. THOMPSON. I think it is; yes, sir.

The CHAIRMAN. Were there any voids or duplications?

Dr. THOMPSON. We thought that the delineation of responsibilities was very well defined there. I would not say there were any voids that were apparent to us or unnecessary duplications.

The CHAIRMAN. Do you feel that there has been a division of responsibility which contributed to the fact that the desired quality levels were not achieved, for example, divisions of responsibility between the Manned Spacecraft Center and North American Aviation? Were they properly defined?

Dr. THOMPSON. I think that the relationship between MSC, yes, Manned Spacecraft Center, and North American were very well defined, yes, sir.

The CHAIRMAN. Do you feel that about—the same definition exists on Apollo as on Mercury?

Dr. THOMPSON. I am not too familiar with the exact definition that was used of responsibilities in Mercury. As far as I know—well, I really do not have anything to base an opinion on, I guess.

The CHAIRMAN. That is the best answer you can give me, Doctor, if that is the situation.

Dr. THOMPSON. Yes, sir.

The CHAIRMAN. In its finding No. 5, the Board referred to "Those organizations responsible for the planning, conduct and safety of this test failed to identify it as being hazardous." Was there one specific organization responsible for establishing the practices for this test?

Dr. THOMPSON. Well, as to that it is a fairly complex matter that involves not only the line organization but the criteria that are used for defining hazardous operations, and they are different levels involved in those decisions.

Without a proper definition of criteria to clearly define what is hazardous and what is not, you cannot exactly blame a line organization for not imposing—for not having a good program when all they are doing is dealing with criteria that are not quite adequate to the situation so it is sort of a mixture of levels.

I think the reason we couch it in those terms is that there is a mixture of responsibilities required to really assess the criteria and then impose and direct the line organization and set up the proper organization to see that those criteria are properly applied.

It is a little bit more than just one aspect to it. So there is some combination of organizational elements involved, it is NASA and the contractor. The contractor is the main arm that implements the program. NASA has the responsibility to see that they do it, and hold them to it. It is not too easy to just say that this one element is responsible for any particular deficiency when there is a mixture of that kind. I think it needs a pretty general review to correct the situations that have been identified.

PRAISES SELECTION OF PANEL

The CHAIRMAN. This morning, Doctor, I had the impression that there were some questions which would indicate that the panel was not very well selected because of the employees and associates. I want to say I know how hard it is to do, having had a few years experience with atomic energy when they had an examination. I think it is a very good panel that got real good results, and I do not know where you could have gone to find that type of individual outside the organization.

I may be the only one, but I, for one, feel that the panel is well picked.

Dr. THOMPSON. Thank you, sir.

The CHAIRMAN. Thank you.

Was there any one specific organization responsible for establishing procedures for this test?

Dr. THOMPSON. The contractor is responsible for that. Whatever the contractor does had to be approved by NASA so that what the contractor does is subject to that approval, but then again going back to the criteria again, they also have probably somewhat a mixture of responsibility, although NASA always is in a position of ultimate responsibility for it.

What really need review are the criteria and a complete study of those things that are pertinent to an adequate safety program.

QUESTION OF OXYGEN

The CHAIRMAN. I was wondering, if a decision is to be reached about oxygen as the sole atmospheric gas, where would a nonscientific member of the committee such as I am, find out what the judgments might be? I would like to help get a clear decision on that question of oxygen.

It seems to me in looking at it that it is pretty complicated for a lay person to decide that.

Dr. THOMPSON. Well, I do not believe there is any subject that has been studied more than that particular thing.

The one we talked about is the one common in this room, that is nitrogen that is a common diluent for the oxygen, and there are advantages from a favorability standpoint of having air as is in this room.

However, another one that is discussed and considered, has been studied at great length, is helium, and helium has the possibilities of being a suitable diluent. Neither one of them escaped the danger of bends. If a person has this gas in his system and is subject to sudden depressurization, he gets the bends, and that is one of the hazards that goes along with a two-gas system.

Now, beyond that, as soon as you have a two-gas system, you have a mixture of gases in your spacecraft and then you must have, first of all, a means for identifying what you have there, the problem of identifying the mixture so that you know in fact that what the astronaut is getting is oxygen and in proper proportion, and not all nitrogen or all helium or all carbon monoxide or a disproportionate amount of those gases, is one of the problems.

A great deal of work has been done in developing the mechanisms, devices by which you can make the proper measurement. What you can do is—there are versions now that according to our recent studies are—I am talking about the Office of Advanced Research and Technology which has research programs in this area—show that there is great promise for means of, we think, for a flight-qualified instrument that will identify the amount of oxygen, the CO_2 and the water vapor. The amount of nitrogen can be identified as to just what is left, and a device of this kind, however, has to be worked out so it really is flight-qualified before you would want to trust or rely on it for a voyage to the moon or any other voyage far away from the earth.

The CHAIRMAN. Do you not have to do this same determination for the MOL?

Dr. THOMPSON. It certainly will have to be developed for the MOL if we are going to use it. I think they are using a two-gas system.

The CHAIRMAN. Some of the people who have to speculate have speculated that you had already decided—I am sorry—that the NASA organization has already decided on a one-gas system, and it makes it kind of hard.

I remember I asked a scientist how I could learn something about this. He said, "Well, you have to respect oxygen, you have to respect pure oxygen."

He said, Some people ignite a match by scratching it on a fingernail. You try that in pure oxygen and it will burn your arm off. I have not tried it.

Dr. THOMPSON. Oxygen has to combine with something else in order to make a complete combustion process. Oxygen by itself is a very useful gas. We all use it and we depend on it, but when it gets in close proximity with certain fuels or what we call fuels or combustible materials, they will then get in trouble, and it is the removal of those things that combine so readily with oxygen that is one of the basic elements of the improvement program that we are talking about.

This whole matter, however, as I say, has been—as a matter of fact, it is a subject of continuous study not only just because of the advantages of having a diluent gas from a flame standpoint but I think there is a pretty substantial body of thought that a man should remain for an indefinite period in an oxygen, pure oxygen, atmosphere. So that in longer duration flights, we would presumably have to have another two-gas system. However, the experience up until now, I believe,

leads to a considerable confidence in up to perhaps 30 days of pure oxygen environment is suitable for the man, is not harmful to him. And the simplicity of it and the reliability of it from an operational standpoint is a very important factor in the continued use of it.

The thing to guard against is letting that pure oxygen get too close to things that will burn and then igniting them.

ELECTRICAL SYSTEM DEFICIENCIES

The CHAIRMAN. I asked this morning, and this afternoon you might want to finish your answer of the Board's finding No. 10, that deficiencies existed in the command module design, workmanship and quality control.

To what basic factor do you attribute these deficiencies in almost every aspect of the electrical system?

Dr. THOMPSON. I think we are going back pretty much to the things we have commented on earlier, that we just have not, some how or other, have not borne down enough on all the quality control machinery and have not borne down on the engineering that is necessary to the point that we have gotten what we want or should have out of this.

I can give you an example in the wiring; for example, the wiring that we see in this, particularly in this block I design, is not a very good exhibit of what we consider good wiring practice. What we think it shows is that there has not been a really adequate use of engineering before the wires were installed.

The wires—in order to avoid these problems of having wires go over sharp edges or get in front of doors that have to be opened and then have to go around elements of the vehicle in such a way as to avoid any abrasion or sharp bends—have to be engineered in a very careful way and should use three-dimensional forming to do that.

It is a pretty good engineering exercise to just lay out those wires as an engineering exercise. And this is the thing, I think, that is basically back of the faults that we see in this wiring.

The more wires were added, the conflicts were added, and then the wires were wedded up without just an engineering analysis of just where they should go and how they should be channeled around to avoid trouble of abrasion, how they should be channeled to avoid the danger of people stepping on them or misusing them after installing.

Fundamentally, I think this is what is back of what we have seen there, too much building without the real intensive use of engineering to formulate the design before allowing people to put wiring in.

30 MILES OF WIRE IN SPACECRAFT

I could add just a point perhaps about the wiring: There are according to the figures—I have, 30 miles of wire in a spacecraft, and there are 13,000 segments of wire. That 30 miles is cut up into 13,000 segments, and it does offer a fairly demanding exercise to engineer these wire bundles, 30 miles of wire in pieces so it does not get into some of these problems we see.

NO ESTIMATE ON DELAY OF GOAL

The CHAIRMAN. This question is purely related to your experience on the Board in this matter. You do not have to guess if you do not want to guess at it. What do you believe will be the impact of the accident on the national commitment to land men on the lunar surface and return them safely to earth by 1970? The goal President Kennedy set up where he said we will land a man on the moon and bring him back safely in this decade. Would you care to speculate what the results of that accident might be?

Dr. THOMPSON. Well, I have not tried to do the management exercise and to figure out how they are going to—what work is really necessary to deal with many of these questions we have brought up. We think it is necessary to deal with them, and I think they can all be solved. I do not think we have identified things that are of such fundamental nature that shows anything really wrong in the concept of this vehicle.

I think there are just a number of details that really require correction. Just how long it is going to take to do that is beyond the area of our effort. I think it will undoubtedly take a little longer than was originally anticipated but just how much that is I do not know.

The CHAIRMAN. We all seem to be guessing it might be 6 months or 12 months or 14 months and so forth. I think those have to be guesses, and I just wanted to know if you would guess.

Dr. THOMPSON. I would like to refrain from guessing. I would rather be able to estimate it, and I have not done that because that is a little beyond the area of our effort here, and I think it is more in the field of the program office. I think they are the ones who should make those estimates.

The CHAIRMAN. I have advanced it as a guess.

Senator Smith?

COMPARISON OF SPACECRAFT AND AIRPLANE DEVELOPMENT

Senator SMITH. Yes, Mr. Chairman.

Dr. Thompson, do any of the Board members have specific familiarity and experience with the development and manufacture of commercial and military aircraft?

Dr. THOMPSON. George, do you qualify for that?

Mr. WHITE. I have some experience, yes.

Dr. THOMPSON. Would you like Mr. George White to speak on this? He is familiar with this area.

Senator SMITH. I will address myself to Colonel Strang if you would rather I would.

Dr. THOMPSON. Colonel Strang is in the Office of Safety of the Air Force.

Senator SMITH. Why do I not address my questions to both of them.

Dr. THOMPSON. And see where you get the best response, maybe that is the best technique.

Senator SMITH. Although I recognize that the development and production of aircraft is not as complex as that for the Apollo spacecraft—it was my understanding that we were conducting the Apollo

program in such a way as to assure the integrity of production. Could you tell us whether the types and number of deficiencies reported in the Board's report in the area of design, workmanship, and quality control is the type of engineering practice found in the production of commercial or military aircraft?

Mr. WHITE. It has been my experience, Senator Smith, that the type of deficiencies we have found are typical of the deficiencies that are normally found in an airplane development program.

I think one of the significant differences here is that in the case of an airplane development program there is usually one aircraft set aside as an experimental aircraft, at least one, many times three or even more, and these deficiencies are found and corrected in this first experimental aircraft. When the aircraft gets into production, things are usually on a routine basis so that the deficiencies are considerably less.

In our case it was almost tantamount to having the experimental aircraft, in this case the spacecraft, being our first manned spacecraft, so not all of the bugs had been worked out of the system.

Senator SMITH. Well, should they not have been worked out in the unmanned spacecraft?

Mr. WHITE. They were to quite a degree, but not completely.

Senator SMITH. Well, whose responsibility was that?

Mr. WHITE. Well, as I said, this morning—I do not know whether you were here at the time—the original responsibility for manufacturing and for these deficiencies lies with the contractor. However, NASA does have inspectors on the spot in the contractor's facility, and NASA does control the basic policies, so that the ultimate responsibility does lie with NASA.

Senator SMITH. Well, in the aircraft industry would a plane be flown with—and I read from your finding 10—"Deficiencies in design, manufacturing, installation, rework, and quality control existed in the electrical wiring." Would you have gone ahead with aircraft as you did with the space vehicle?

Mr. WHITE. I think for comparable types of deficiencies, yes, this has been done. There have been wiring problems in aircraft that are comparable to what we have had here.

Senator SMITH. Colonel Strang, would you have anything to add?

Colonel STRANG. The only thing I could add, Senator Smith, is that in the Air Force in the missile program we accepted exceptions to the missile system in the line of what Mr. White has just spoken of. They are well-documented so that both the Air Force and the contractor are well aware of what we accept with exceptions.

Senator SMITH. Would an airplane with 113 engineering changes to be made be certified for use for example?

Colonel STRANG. Senator Smith, my remarks were primarily for missiles. In the aircraft side of the house it would be a little different as far as I am concerned in that my experience has been around aircraft maintenance engineering. As you probably know, the Air Force has a team in the contractor's facility that accepts the airplane. The airplane is then delivered to the operational units. That is the area that I would come into; and usually the items of exception—from the experience I have had in the past—would be of a minor nature. Nothing ever to affect the safety of flight.

Senator SMITH. I am using the airplane industry because it is the closest type of program to spacecraft that I can think of.

Colonel STRANG. Yes, ma'am.

Senator SMITH. You may have—Dr. Thompson.

Dr. THOMPSON. Senator Smith, we do have on the Board an ex-test pilot. Maybe you would like to hear from him. Colonel Borman is an ex-test pilot, and maybe he has experience applicable to that situation.

Senator SMITH. Thank you for that Colonel Borman?

Colonel BORMAN. Yes, ma'am, I think just as a general comment it would be safe to say that the level of workmanship or the quality control and care of detail that we find in the spacecraft business is a whole order of magnitude higher than what we ordinarily experience in the aviation business, and this is with due reason, of course, because airplanes have an extended flight test program. You do not have the final dependence upon the system that you do in a spacecraft.

So I think based on my experience in both aviation and the space business that we find a much higher level of redundancy, of detailed engineering and of documentation of effort in the space business than we do in the airplane business.

Senator SMITH. As a layman, would there not be less chance of deficiencies in the case of the spacecraft?

Colonel BORMAN. Yes, ma'am. I think that, by and large, our experience with spacecraft has been phenomenal and the success we have had and in the fine engineering that we have experienced, including the disaster, I would say, by and large, we have gotten probably the best engineering effort and the best workmanship on any machine that has ever been built by man in our space program.

Senator SMITH. I agree with you, and in this tragedy I hope we do not lose sight of that very great accomplishment.

Colonel BORMAN. I hope we get better as a result of it. As a matter of fact, it would be a shame if we did not improve based upon what we have learned from this tragedy.

DISCUSSION OF DEFICIENCIES

Senator SMITH. The main body of the report represents a summary of the Board's findings and conclusions relating to the various areas of the investigation. I believe it would be helpful to the committee if the Board discussed examples of its findings which formed the basis for its conclusions in the following areas: One, the report states that the deficiencies existed in command module design, workmanship and quality control.

Would you please discuss some of the more serious deficiencies found in each of these areas and how they relate to the Board's statement that, and I quote, "These deficiencies created an unnecessarily hazardous condition and their continuation would imperil any future Apollo operation"?

Two, the Board reports that differences existed between ground test procedures and the in-flight checklist. Would you also describe some of the more important differences and explain their significance?

That may be all too much in one question.

Dr. THOMPSON. In appendix D, 9–6, we discuss wiring. We also discuss the so-called ECS, environmental control system plumbing joints.

The wiring specifics, one, wiring of lower equipment bay was routed through narrow channels having 90-degree bends. This could cause mechanical stress on a Teflon installation. Somewhere in these areas was found damage to the sleeve which covered shielded wire. This is in line with what I was saying earlier, and it is particularly important to the use of Teflon insulated wire. Teflon insulation has a very good merit in that it is resistant to flame which is very important for wiring. It is a relatively soft material and has to be handled carefully as regards such things as an abrasion, bearing on sharp edges and so forth.

It goes on, there are several items there, there are items 1 to 6 there, that I think are rather specific and provide a specific basis for our findings.

Senator SMITH. Mr. Chairman, I would ask that the section of the report from which Dr. Thompson is reading be included as a part of his answer if that is agreeable to him.

Dr. THOMPSON. Yes.

The CHAIRMAN. Without objection, that will be done.

(The material referred to follows:)

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.

Dr. THOMPSON. The ECS, the environmental control system plumbing joints—now I make a distinction between ECU, the environmental control unit, and ECS, the environmental control system. The unit has to be connected in as a unit and then by plumbing, as I call it, tubes distribute the coolant and perform its functions of controlling the oxygen through connections to many lines within the spacecraft, so that the whole system is called ECS, and it is the plumbing, the joints, of that ECS that we have particular reference to, and their items 1 to 4, I believe the first one, the ECS design criteria, emphasizing minimum weight, resulted in the selection of aluminum piping with solder joints.

Design approach utilized the kind for the normal operating stresses but failed to account for the loads and stress had by handling it in installation.

Most of our criticism, I think, is summed up in an interpretation of that comment. Very well fabricated solder joints, not subject to

anything but the loads which they were really designed to withstand, or the pressures in the line in the protected area, could very well stand up.

The facts of life are that in putting these things in and having them exposed to the problems or installation, other activities around the area, the movement of people, and subject to the vibration of the spacecraft, that the loads on those joints, the stresses on those joints, even though they might be very well made, would fail, because they just do not have the tolerance for abuse that is almost—some of them almost certainly get.

Now, the other thing that we worry about is that the integrity of the joints, its ability to withstand the environment, also depends on its being a very good one, and in our opinion it is hard to determine the quality of a solder joint on aluminum. I have seen some very good ones, and I have seen some that are not so good.

Opinion is that the joints should be improved in such a way as to provide, I would say, a great overstrength, assurance that even though abused, it is subject to the various things that are not really planned for, it will still retain its integrity, and that in essence is the feeling about the use of solder joints.

Senator SMITH. Would this be a design deficiency?

Dr. THOMPSON. I think this is a design deficiency. The collars that are used there provide such a short connection that it has certainly impressed us as being unable to withstand the abuse they would almost certainly get.

Senator SMITH. Now, shall I repeat the second part of the question?

Dr. THOMPSON. Yes, please.

DIFFERENCES IN GROUND TEST AND IN-FLIGHT PROCEDURES

Senator SMITH. Describe and explain the significance of some of the more important differences the Board found between ground test procedures and the in-flight checklist.

Dr. THOMPSON. Will you handle that?

Colonel BORMAN. Yes, ma'am; if I may. This was my area, I believe.

The differences that existed between the in-flight checklist and the operational procedure for this test were minimal. However, we put this in because we felt that any difference was significant. In fact the in-flight checklist is designed for a flight, for launch, and the test that was being run of course was not a launch or not a proposed flight, so there were some differences existing in switch positions between the checklist for flight which was used and the operational check procedure for this test.

We feel it is important that both the crew and the test personnel on the ground operate from the same piece of paper, and that is why the recommendation is in here.

INQUIRY ON BARON REPORT

Senator SMITH. I have just one more question in a couple of parts, Mr. Chairman.

There have been several newspaper reports that a Mr. Thomas Baron, a former employee of the Apollo spacecraft contractor, had

rendered a report to both the spacecraft contractor and NASA pointing out several serious allegations concerned with poor quality assurance procedures and practices at Cape Kennedy. Did the Board read and evaluate Mr. Baron's report, Dr. Thompson?

Dr. THOMPSON. They did, at least some members of the Board, and the counsel read the report of Mr. Baron. There are two reports that he has written.

Senator SMITH. Then would you give us, give the committee, the Board's opinion of the validity of his allegations and whether or not there were any similarities between his allegations and the Board's findings?

Dr. THOMPSON. There was certain validity to some of the things that he stated. They were similar to some of the things which we have said. He was in the quality control office and saw some of the things going on in his view that he had—I think put him in a position to see some of the problems that are involved in the program.

He viewed the type of things that a quality control inspector would see in the position he had. I am not sure that he always knew what the final outcome was, how the matters that passed under his purview were actually handled.

In our opinion, after reading the report, we did not see that he was adding greatly to the knowledge we were getting from other sources, and it was generally somewhat vague as to just whether there was fault or whether he just saw things that were in process of being corrected.

Senator SMITH. Did any of the panels make a summary of Baron's report? I have not read the report thoroughly, but I am told that the Board does not include——

Dr. THOMPSON. I think—you read it, George. Did you read the full report?

Mr. WHITE. I did read it, but I have not prepared a summary of it.

Senator SMITH. There is no summary of it.

Mr. WHITE. No.

REQUESTS SUMMARY OF BARON REPORT

Senator SMITH. Dr. Thompson, would you be able to get a summary of Baron's report and give it to the committee?

Dr. THOMPSON. I will do that, yes, ma'am.

Senator SMITH. If you will, please.

Dr. THOMPSON. Yes.

(The summary submitted is as follows:)

During the course of the Apollo 204 Review Board investigation, a 58 page document called "An Apollo Report" was furnished to the Board by a Mr. Thomas R. Baron, a former North American Aviation, Inc. Quality Control Inspector and Receiving Inspection Clerk. This document was severely critical of North American Aviation's conduct of the Apollo project. Mr. Baron was requested to testify to the Board about his allegations which he did on February 7, 1967. In addition, he furnished a 275 page document entitled "The Baron Report." The testimony before the Board and the 275 page document reiterated and set out in more detail the allegations originally made against North American Aviation, Inc., in the 58 page document.

The criticisms levied by Mr. Baron at his former employer, North American Aviation, Inc., can be grouped into five (5) categories: (1) quality control.

(2) safety, (3) records and documentation, (4) personnel, and (5) operations. These allegations are summarized in the following:

1. *Quality control:*

Throughout the report, allegations are made of generally poor workmanship observed by Baron. Because of faulty quality control procedures, unacceptable workmanship was often missed by inspectors. When he himself observed defects which he was unwilling to pass, Baron would report these to his supervisors. The report details various instances where nothing was done to correct the deficiencies he noted. Specific samples of poor quality workmanship discussed in the report are faulty installation of spacecraft 012 heat shield; faulty installation of spacecraft 009 rendezvous window; poor workmanship in splicing on the quads; and unsatisfactory water glycol operations in ground support.

The report is also critical of test and inspection procedures, alleging that tests were frequently conducted by unqualified personnel using equipment not suited for the particular test being conducted. The failure of NASA personnel to participate in many of these tests and to maintain a general cognizance of the daily workings on the project has, in Baron's opinion, made such lax procedures possible.

2. *Safety:*

Baron alleges that the general level of safety on the project site was low. Lack of sufficient standards was a factor, which together with supervisory and employee carelessness contributed to the hazards he observed in the operations. Among the particular hazards he details are permitting smoking during and immediately after hazardous operations; conducting fuel operations to diesel power unit when oxidizer transfer unit operation was being conducted; leaving open drains at various levels of pad 34; absence of nets and chain rails to safeguard men working at different levels of the gantry; nonoperating elevators for emergency egress; falling objects endangering personnel on the ground; and operating of high pressure valves without proper protection.

3. *Records and documentation:*

In several areas, there are no procedures established for uniform record keeping. Where records are maintained, they vary from technicians notes to standard printed forms. Because of this lack of uniformity, it is possible to initiate relatively major alterations on the systems without these alterations ever being documented for future reference. An example of this situation is seen in the removal and replacement of parts in the coolant system without proper documentation. Where record keeping procedures are fairly well established, the procedures are often grossly inefficient. Parts distribution is an example of this inefficiency. Forms used for this are printed in two copies. One copy is torn off and thrown away without ever being used.

4. *Personnel:*

Personnel working on the project are shifted from one job to another before acquiring extensive familiarization with the particular project on which they are working. This prevents technicians from becoming "professional" and hinders their opportunities for advancement in the company.

Personnel control is generally poor; technicians at times standing around with nothing to do, while at other times, there was a lack of technicians for a given task. Work that should have been done by experienced mechanics was done by NASA Quality Control personnel and engineers would from time to time perform functions that the technicians should have been performing. Some phases of the work were improperly supervised, there being no qualified engineer on the project site.

These and several other personnel problems contributed to the lowering of morale among North American Aviation employees and a resultant reduction of efficiency.

5. *Operations:*

The Baron Report alleges a "lack of coordination between people in responsible positions" and a "lack of communication between almost everyone." More specifically he alleges a failure to provide official tie in periods for work; scheduling of work in areas so nearby as to cause almost certain contamination; and difficulty in determining whether meter calibrations are up-to-date.

CONSIDERED APOLLO SHIP SAFE AT TIME OF TEST

Senator SMITH. Mr. Chairman, I think Colonel Borman answered a question this morning, and I would like to ask it over and get it again on the record.

Colonel Borman, did you consider the Apollo spacecraft safe, safe enough for yourself to have gotten into it and why?

Colonel BORMAN. And what was the last part?

Senator SMITH. And why?

Colonel BORMAN. Yes, ma'am, I considered the command module 12 to be a safe vehicle at the time of the test. I was assigned as a backup crew commander for a sister ship to spacecraft 12, and although we had development problems and wiring problems and so on, you expect these things in the normal R. & D. program, and I can state that the crew from spacecraft 12 felt that the spacecraft was rounding into shape and both the prime crew and the backup crew were of the opinion that spacecraft 12 was a safe ship at the time they entered it for this test.

Senator SMITH. Thank you very much, Colonel. I thought I understood you correctly this morning, but I wanted to get it on the record again.

Colonel BORMAN. Yes, ma'am.

Senator SMITH. Thank you very much.

Thank you, Mr. Chairman.

The CHAIRMAN. Senator Young.

QUESTIONS ON HATCH DESIGNS

Senator YOUNG. Just a few questions, I believe.

According to the finding of the Board, the inner hatch could not be opened properly, and that the crew was never able to effect emergency egress because of pressurization and so forth, and then the Board made a recommendation that the time required for egress of the crew be reduced, and the operations necessary for egress be simplified.

Now, had thought been given to that before this tragedy occurred?

Dr. THOMPSON. I think Colonel Borman could better summarize that complete situation for you, sir.

Senator YOUNG. Yes.

Colonel BORMAN. Yes, sir; if I may.

At the time of the accident there was on the drawing boards a new hatch designed to open outward and to be hinged to the spacecraft. But the prime reason for the new design was to facilitate extravehicular activities on orbit. It was considered that for every conceivable hazard on the ground the present hatch or the hatch that was on board the spacecraft would suffice.

Now we know that it did not. But as we—as I have attempted to point out, the problem here was that we overlooked the possibility of an internal spacecraft fire.

Senator YOUNG. Yes, but, Colonel, before this tragedy occurred, it was not possible to open that from the outside, was it?

Colonel BORMAN. No, sir. You could open it from the outside. The problem is that the hatch is forced on to its latch by pressure within the spacecraft, and the pressure inside the spacecraft was 2 pounds per square inch higher than the atmospheric pressure. That does not

seem like much, but over the area of the spacecraft that puts a force of about 2,400 pounds holding that hatch shut. So until you can get rid of the pressure within the spacecraft, you cannot open the hatch. And that was the problem.

Senator YOUNG. But the Board did make a finding that before the tragedy occurred there was failure to consider that the egress hatch was a hazardous situation.

Colonel BORMAN. That is correct, sir.

Senator YOUNG. Was that not negligence that the people failed to consider that hazardous before?

Colonel BORMAN. Sir, you could describe it as negligence. I would prefer to describe it, perhaps, as an oversight, since I feel that I share my full share of the blame for overlooking this problem.

I probably have had more experience or as much experience in similar test conditions as any man alive, and I certainly was not concerned about the particular situation that we had. So I agree with you, we were negligent, if you wish, but at least we had an oversight.

Senator YOUNG. Well, there was no intent, as a matter of fact, to use this new hatch design in the Apollo program, was there?

Colonel BORMAN. There was, yes, sir. It was being designed at the time for incorporation on the Apollo.

Senator YOUNG. For the Apollo application program.

Colonel BORMAN. No, sir; for the Apollo lunar program. But, you see, we had no plan for doing extravehicular activity on the Block I spacecraft. So we felt there was no requirement to incorporate this new hatch design on command module 12 because it would not be actuated on orbit.

QUESTIONS ON FUTURE EVALUATION OF FINDINGS

Senator YOUNG. Well, I think my next question should be directed to Dr. Thompson.

The Board having made findings, determinations, and recommendations, will the Board at some future time look at this matter again? Will the whole matter be evaluated to see whether all necessary actions have been taken on the Board's recommendations?

Dr. THOMPSON. Well, sir, I was hoping the Board would be able to go out of business here pretty soon. But we were charged with the responsibility by the Administrator for making this study and reporting to him, and we are currently in recess, holding ourselves together to finish up some of the reporting of tests in progress, and I have noted it will not influence our findings but they do need to be incorporated in the record, and I was hoping that having identified to the Administrator the things we found, that the discussion of whatever is done from here on would be—would fall to the lot of the program office, and I thought maybe the Board could then be dismissed and go back to our normal duties.

Senator YOUNG. Well now, important recommendations have been made to try to insure more safety for the crew. Will there not be some check made within a reasonable time as to whether all of those recommendations have been complied with? If so, when?

Dr. THOMPSON. I think it could be assured that the program office, the Administrator and the program office will report, will take this

matter into consideration and take appropriate action, but it is not in the area of the responsibilities of this Board to see that the action is taken, as I understand our responsibilities.

Senator YOUNG. Well, maybe, Colonel Borman, maybe I should ask you this question: Since there are recommendations that the amount and the location of combustible materials be restricted in the future, that is in itself an admission, is it not, that there was laxity in permitting so much combustible material in the spacecraft?

Colonel BORMAN. Yes, sir; there were too many combustibles on board.

Senator YOUNG. Do you know personally whether thought had been given to the danger of that before?

Colonel BORMAN. Sir, we considered the danger of combustibles on board the spacecraft before our flight of Gemini 7, and we had done an extensive study of in-flight first. We were the first American crews to remove the spacesuits in flight, and when you fly without a spacesuit on, you lose the prime protection against fire when you are in orbit, which is to depressurize the cabin, so we were very particular in looking into means of controlling fires during flight.

We did not consider this problem sufficiently for test on the ground.

Senator YOUNG. But now hindsight shows that there really was negligence in connection with that.

Colonel BORMAN. Well, as I said before, sir, I guess you could call it negligence. We had over 3,000 hours of experience testing in a hundred percent oxygen. I believe it is in the record. I am sure it is over 3,000 hours. As you may or may not know, sir, when I fly, when I flew up here from Houston, I was using 100 percent oxygen all the way on my airplane, the T–38 that we fly. I am afraid that we overlooked the potential hazard of combustibles, pure oxygen and an ignition source.

COMMUNICATIONS SYSTEM

Senator YOUNG. Did you yourself at times prior to this tragedy consider that the overall communications system was unsatisfactory, was not adequate?

Colonel BORMAN. Sir, I was not involved in testing an Apollo spacecraft at the Cape. We had a different communications system for Gemini and it was adequate. But according to all the testimony that we had and the records of the tests, the present ground communications system at Cape Kennedy was inadequate.

Senator YOUNG. Do you know whether Dr. Thompson and others knew of that fact beforehand? Was it considered by you before this tragedy occurred that the overall communications system was not adequate or was somewhat unsatisfactory?

Dr. THOMPSON. No, sir. I learned about all this when I was assigned the responsibility as Chairman of this Board. I am stationed normally at Langley Research Center, and I was not—I am not familiar with all the operations at KSC. I am much more familiar than I was at the end of January.

Senator YOUNG. Well, are you able to expand on this determination for the committee, particularly with respect to why there was not provided a satisfactory communications system before this tragedy occurred? Can anyone answer that question fully?

Colonel BORMAN. Sir, if I may, I can tell the reason for it anyway. The spacecraft uses a four-wire system; the ground communications system at Cape Kennedy is a two-wire system. This results in the requirements for what we call voice-operated relays to transmit messages from the spacecraft to the various organizations.

Now, if these relays are all set to actuate at the proper level, the system works fine. The problem is in getting them all set to the proper level, and this communications system, although I must point, sir, that we found that it did not contribute to the accident, it nevertheless made the test difficult. They were holding at the time of the accident for a communications problem, as you may have read. So the Board said that one of our recommendations was that before the next manned flight we fix it.

Senator YOUNG. Yes.

Now, thank you Colonel, for your opinion on that. But do you know what organizations were responsible for the design, the building, and the operation of the communications system which you now know was not adequate?

Colonel BORMAN. I believe it would be the Kennedy Spacecraft Center, sir.

Senator YOUNG. Is that——

Colonel BORMAN. I am not sure, but I would say that is who it was.

Senator YOUNG. And you surely believe that should be corrected?

Colonel BORMAN. I certainly do, sir.

Senator YOUNG. As quickly as possible?

Colonel BORMAN. Yes, sir.

Senator YOUNG. Thank you. No further questions.

The CHAIRMAN. Senator Brooke.

SPACECRAFT SAFETY

Senator BROOKE. Colonel Borman, if I understood you correctly, in answer to Senator Smith's question, you said that in your opinion this spacecraft was safe at the time, and yet after reading the Board's findings it is inconceivable to me that you could make such a statement that the spacecraft was safe at the time. Is this statement based upon your beliefs prior to this accident or do you still believe the spacecraft was safe?

Colonel BORMAN. Sir, I am certain that I can say now the spacecraft was extremely unsafe. I believe what the message I meant to imply was that at the time all the people associated and responsible for testing, flying, building, and piloting the spacecraft truly believed it was safe to undergo the test itself which was being conducted at the time, and my opinion is based on many hours in a sister ship that I spent in checking, in testing of a sister ship.

Senator BROOKE. But one of the things that is included in the report was that the coolant leakage was a chronic problem.

Colonel BORMAN. That is correct, sir.

Senator BROOKE. And apparently this was known by you and by members of the spacecraft prior to this unfortunate accident.

Colonel BORMAN. That is correct, sir, and the last coolant leak that was discovered at Cape Kennedy was a leak of about five drops of coolant that was unexplained, and as a result of this leak of just five

drops the entire environmental control unit was sent back to the contractor, the launch date was slipped, and every effort was made to make sure that the leaks had been understood and corrected.

So these things that were problems along the way, we thought, had been corrected.

Senator BROOKE. But you knew that the coolant was combustible.

Colonel BORMAN. Sir, it is combustible, but it is extremely difficult to ignite.

Senator BROOKE. And you felt that it was—the fact that it was combustible did not necessitate the changing of the coolant.

Colonel BORMAN. That is correct, because, you see, the coolant is contained of course in plumbing, and hopefully if you do not have leaks, and if you have no ignition source, you will not have a fire.

Senator BROOKE. But you did not know about the joints and that you did have leakage.

Colonel BORMAN. Yes, sir.

Senator BROOKE. You recommended correction of that.

Colonel BORMAN. Yes, sir.

MANAGEMENT ASPECT OF PROGRAM

Senator BROOKE. Now, prior to this Board's report you had hearings, the committee had hearings, and if we were to believe what was said by those who appeared before us, the accident could not have occurred because everything was right, a hundred percent pure oxygen was right and everything else was right.

Now, of course, the Board, having made in-depth study, has obviously found some mistakes and some errors and some conditions that need rectifying.

Did the Board go in depth into the management aspect of the program?

Colonel BORMAN. No, sir, I do not believe so. I believe Dr. Thompson should answer that.

Dr. THOMPSON. We went into management to the extent that it impacted the things that were involved in our review; that is, as I was trying to visualize it one day, I said we started from inside and worked out. We did not look at management and then concentrate on an area of deficiency. We looked at an accident, something that had gone wrong, and then looked outward from that to see if there were management aspects of the operation that seemed to have impact on it. And to that extent we did look into certain management problems.

Senator BROOKE. If management had been proper, could not these findings that were relative to mistakes and errors in this spacecraft have been found prior to this accident and corrected?

Dr. THOMPSON. Well, we did not find any direct connection between the accident—the management and this accident. We saw things that we thought needed to be improved in the management as we looked into this problem. But I do not think any management is perfect on the point that there might not be something wrong somewhere.

The assurance of quality, I think, left something to be desired, but we have gone into that in considerable detail here, I think, in identifying those areas; to the extent that those areas reflect management, I suppose we are criticizing management.

I do not know exactly how to be more definitive about it though than we have in the statements we have made on it.

The assurance of quality is certainly a NASA responsibility, and we tried to impose on the contractor the direction and control, whatever it is, that will insure that the quality is, in fact, built into the spacecraft, and somehow or other that result did not come out exactly right.

DISCUSS EVENTS PRIOR TO FIRE

Senator BROOKE. Now, Dr. Thompson, your Board has not been able to actually pinpoint the cause of this accident, is that correct?

Dr. THOMPSON. We have established a most probable cause, and we have established conditions that support that kind of thing as being almost certainly the cause, but we are not certain that we have put our finger on the exact thing that ignited that fire.

Senator BROOKE. In your opinion, if the recommendations that are contained in this report were carried out, is it true that this accident would not have occurred?

Dr. THOMPSON. Yes, sir; that is the intent of our recommendations which is to remove the probability of fire, and we think that by following the recommendations that we have made and certainly a great deal of progress is already being made that we know of in that direction, that the probability of fire will be reduced to a very low level.

Senator BROOKE. Of course, hindsight is always easier than foresight. But assuming that these matters could have been found out previously, then is it not the responsibility of someone or some organization to have done what this Board did prior to this accident, and corrected these things which would have avoided this accident?

Dr. THOMPSON. Well, the stimulation has been very great here to go into a depth that, perhaps, has not been followed before. I think we probably have gone into greater depth than some of the reviews that have been made up until now and, of course, we have usurped a lot of manpower. We have had an overriding priority on all manpower to try to support this thing. So I do not think that the Agency would like to support this kind of review very often.

Senator BROOKE. This manpower could have been mustered previously, could it not, for an important operation such as this?

Dr. THOMPSON. It could have if the need had been identified in the way it was here.

Senator BROOKE. There was no question about shortage of manpower, shortage of equipment, in preparation for this operation?

Dr. THOMPSON. Well, in managing a program I think there is a shortage of manpower to do all the things. We have interfered with the ordinary use of manpower in a rather drastic way. So we have diverted manpower from their normal duties in a pretty extensive fashion.

Senator BROOKE. That is all, Mr. Chairman.

Dr. THOMPSON. Could I add one more point about this?

The CHAIRMAN. Yes.

Dr. THOMPSON. In dealing with the fire, the assessment of fire, I think we, perhaps, made some mention of this earlier or it is implied in the record, that we have stimulated here a very important advance in the understanding of the risk of fire by this review.

Prior to this review the understanding of flammability of materials was dependent to a large extent on tests in laboratories of small specimens arranged in different ways, some horizontal, burning horizontal, some vertical, some upward and some vertically downward, even 45 degrees, samples of materials with various kinds of nap on them, and on a variety of results which were obtained, and there was no real standardized method for deciding on flammability of materials.

What has been achieved here is a utilization of a mockup over at the Command Spacecraft Center to get, I think probably for the first time, a reliable index of the flammability of materials for real useful application to this problem.

At MSC, the Manned Spacecraft Center, they immediately constructed a boilerplate model mockup of this vehicle arranged in such a way that it could simulate the vehicle rather carefully as regards the arrangements of combustible materials in it.

The first exercise was the attempt at duplication of the actual accident, and I think in two attempts, the first one was not arranged quite right—well, the simulation was not quite what it should have been—and the next one, the arrangement of the vehicle was very similar as regards combustibility of materials, the arrangement of combustible materials, and a very adequate simulation of the combustibility problem was achieved.

Now, this goes way beyond the use of just samples of materials. An overriding factor is: How are they arranged? How is nylon knit? Is it coarsely knit or is it finely knit? Does it have a fuzzy edge? How is it arranged as far as continuity is concerned? And all those factors, factors of the geometric arrangement, and the nature of the weaving are very important factors.

The important result has been achieved that a system or a method of testing and evaluation has been developed that will be extremely useful in qualifying the vehicles for future flight use.

This simulator will be used to evaluate the improved arrangement and selection of materials so that there can be a very good evaluation of what the flammability risk is and the extent to which it has been reduced, and I think it is a very important achievement that, as I say, has been stimulated here by the start of this review.

The CHAIRMAN. I think that is true, Doctor. We had a hearing about these materials, and the Senator from Illinois examined the material, as we all did, and I think a very important contribution has been made by it.

I did not mean to interrupt you, Senator.

Senator BROOKE. Dr. Thompson, aside from the flammability of materials, take, for instance, the training of the launch pad crews for emergency training. This particular operation was not classified as hazardous, I understand.

Now, presumably, you will go through this stage again or this phase again.

Would it be classified hazardous the next time and, if so, why would it be classified hazardous?

Dr. THOMPSON. Well, I feel pretty sure it will be classified as hazardous. But the criteria that were used, that were in existence at the time of the test, did not automatically classify it as hazardous because those criteria apply to the use of hypergolic fuels in the space-

craft, and the application of the criteria simply that were in use did not identify this as its operation. I am sure those rules will be changed.

The same spacecraft, in the vacuum chamber, was classified as a hazardous operation because it was in a vacuum chamber at KSC.

Senator BROOKE. That is all.

The CHAIRMAN. Senator Cannon.

MATERIALS PANEL BOARD

Senator CANNON. Thank you, Mr. Chairman.

Doctor, the Materials Work Panel stated that several inadequacies were found in materials control, control of flammable materials installation was exercised by several organizations which tended to act independently.

Now, from a systems management standpoint, what organization should have been responsible for establishing and monitoring such controls?

Dr. THOMPSON. Well, the Apollo program office had the responsibility for that, and then the execution of the installation is in the hands of the contractor, and then the inspection, I think, is in the hands of MSC.

I think this is the basis for the several organizations, and the way this works out is that there are certain criteria, guidelines, used for installation for these materials dependent on their sensitivity to ignition, as to how close they should be placed particularly relative to possible ignition points.

Our understanding is this: that the contractor's guidelines that he developed and used in the installation were checked by MSC walk-through inspections at various stages, and I think this is the basis for this evaluation.

The MSC criteria that were used in that walk-through inspection had been identified as being more rigorous than the criteria used by the contractor, and when a walk-through inspection was made at the plant, the application of that more rigorous guideline resulted in the removal of a substantial amount of material because of its proximity to what were thought to be possibly ignition points or wire models, I believe, are the main criteria.

Later on during the course of the progress of the completion of this vehicle and in getting it ready for flight, other materials, flammable materials, might have been added, and a walk-through inspection, another walk-through inspection, which according to our understanding would have used the same criteria that the Manned Spacecraft Center used, would have been employed at that time.

That walk-through inspection was to have taken place within a few days, I think only a day or so after this accident. It had not taken place. It had not been accomplished prior to the accident, and I believe this application of different criteria arrived at in this way is the basis for that statement.

Senator CANNON. From a systems management standpoint shouldn't there have been one organization responsible, directly responsible, to tie these loose ends together?

Dr. THOMPSON. I think there is room for improvement in that respect; yes, sir.

Senator CANNON. In view of the leakage problems experienced in the environmental control system in Spacecraft 012 prior to the accident, did the Board find any evidence that joint redesign or other corrective action was underway to correct the deficiency?

Dr. THOMPSON. In the joints we did not.

QUESTIONS ON REDESIGN

Senator CANNON. Wasn't that a failure from a management standpoint, with the history of leakage that had been indicated?

Dr. THOMPSON. As far as we know that design had been accepted, and it was not subject to redesign. There was apparently a different idea of what is appropriate. We differ with the program office on that score.

Senator CANNON. And you recommend now that there be a redesign, this is part of your recommendation?

Dr. THOMPSON. We recommend that there be a redesign to the extent at least of applying much greater strength at those joints to give it redundancy necessary to stand abuse.

Senator CANNON. Now, in finding No. 11 reference is made to "open items," and "engineering orders not accomplished."

What is the significance of these findings to good engineering, manufacturing, and quality control practices?

Dr. THOMPSON. Well, I think this is a matter of judgment.

As to how many open items are appropriate, there are always open items, there are bound to be some. But our view of the situation was that there were probably more than would represent what we considered a proper situation. We thought there were more of those than were consistent with what there should be.

Senator CANNON. In your judgment, what accounts for this number of discrepancies in operating practice in the spacecraft program?

Dr. THOMPSON. I think that Mr. Williams should answer.

Mr. WILLIAMS. I think you will find a lot of significant engineering orders were open at the time of delivery down at the Kennedy Space Center and 623 engineering orders were released subsequent to the delivery.

Senator CANNON. How many was that?

Mr. WILLIAMS. 623 engineering orders. I think the only thing here is that the spacecraft was continuing to be designed, or the engineering orders, at least, were putting improvements and changes into the spacecraft as it was going through the test at the Cape.

I think that is the significance of the 22 orders not on the books yet. There was a timelag between the release of engineering orders at Downey, and incorporation into orders down at the Cape.

Senator CANNON. Would you anticipate as the program goes along that you would continue to have discrepancies develop; that is, as your experimentation progresses?

Mr. WILLIAMS. No, sir. This is the first manned spacecraft, and you would assume that you would get several engineering changes, and so forth, along the way during the testing program. I think the number should decrease.

Senator CANNON. The number should decrease, but you would be constantly getting new ones, would you not?

Mr. WILLIAMS. Getting new ones?

Senator CANNON. Yes, having new items developed that you would find required them to be changed.

Mr. WILLIAMS. I do not follow.

Senator CANNON. Perhaps I would prefer to ask Colonel Borman that as a test pilot. Isn't it usual to find discrepancies develop as you go along in a testing program?

Mr. WILLIAMS. Oh, sure.

Senator CANNON. And you find new items occurring that were not initially on the list as old items are corrected?

Mr. WILLIAMS. Yes, sir.

Colonel BORMAN. Yes, sir. I think Mr. Williams just misunderstood your question.

Senator CANNON. I see.

In finding No. 8 you recommend tests with full-scale mockups and flight configuration to determine the risk of fire.

Did the Board consider that good engineering practice would have specified such tests prior to the accident?

Dr. THOMPSON. The fire hazard has been completely reassessed as a result of this, and I do not think that we would have acquired a new value in the scheme of things and, as I think I indicated, the important development of a very good scheme for properly evaluating the fire risk or the flammability, has been a development that we think should be really applied to any future programs, and that mockup scheme should be utilized, and I am sure that they plan to utilize it to qualify what new engineering approaches to this problem are employed. So that we would not have said this before the fire.

Senator CANNON. But you feel that it would be good practice to follow?

Dr. THOMPSON. We feel it is an extremely valuable addition to the whole technology of conducting proper qualification tests.

ASTRONAUT EAGER TO MAKE FLIGHTS

Senator CANNON. I would like to direct a series of questions here to Colonel Borman, and I presume that you will be in command of the next flight, is that certain now, in view of the reorganization? [Laughter.]

Colonel BORMAN. As a matter of fact, I may be back in the Air Force. [Laughter.]

Colonel BORMAN. No, sir. I was assigned to the third manned flight, sir, and since I have been at Cape Kennedy since the 28th of January, I understand that some of the crews have been realined, but I hope that I will be flying one of the earlier flights.

Senator CANNON. Let me ask you these questions in the context of either your membership on the Board or as a pilot and a potential commander of one of the Apollo flights.

Colonel BORMAN. Yes, sir.

Senator CANNON. Referring to page 9 of the doctor's statement, assuming that item 2, an extensive distribution of combustible materials in the cabin is corrected, as has been described here today; assuming that the wiring deficiencies from a vulnerability standpoint have been corrected; assuming that the vulnerability of the plumbing items have been corrected, as they were described here; assuming that the hatch is redesigned to provide for a rapid-crew escape, and

that provisions are made on a standby basis for rescue or medical assistance, would you then be willing to assume position of command in that capsule with the sealed cabin pressurized with the oxygen atmosphere?

Colonel BORMAN. I would be willing and eager to, sir.

Senator CANNON. Now, relating specifically to the other findings of the Board, of course, finding No. 1 presumably relates to the cause of the arcing.

In No. 2, do you feel if the recommendation of the Board is followed with respect to finding No. 2, that that would provide adequate safeguards from the standpoint of combustible material there?

Colonel BORMAN. Yes, sir; if we go the additional step that Dr. Thompson has just recommended, and that we check out the reconfigured spacecraft with the full mockup test.

ESCAPE POSSIBLE WITH NEW HATCH

Senator CANNON. I take it that, of course, finding No. 3 just related to the causes, and would you consider that finding No. 3 would be adequately taken care of if you have the redesign of the hatch and the rapid egress available?

Colonel BORMAN. Sir, it is my opinion, and I believe it is shared by the other members of the Board, that had we had the new hatch installed on this command module the crew would have escaped, so I would say, "Yes."

Senator CANNON. In that connection, will there be a provision, a redesign provision, for a rapid dumping of pressure other than just the removal of the hatch?

Colonel BORMAN. Yes. It is my understanding—of course, I believe you should address this to the Program Office, sir. I do, from the knowledge that I have, believe that this is being incorporated also. It is certainly important.

Senator CANNON. Of course, if that were true that would take care of finding No. 4; would it not?

Colonel BORMAN. Yes, sir.

Of course, if we get the new hatch the rapid dumping of the pressure will lose its significance on the ground, but we would still like to have it in the air.

Senator CANNON. You would like to be able to dump the pressure in the air?

Colonel BORMAN. I should not say in the air, I should say in orbit, sir.

Senator CANNON. In space.

Colonel BORMAN. Yes, sir.

Senator CANNON. Now, finding No. 5, of course, I think it has been well identified as being a hazardous condition, so there would be no need for any further identification in that area.

On finding No. 6, I take it that it does not actually relate to the cause, as to this type of occurrence again, but simply better procedure; is that correct?

Colonel BORMAN. That is correct, sir.

Senator CANNON. And finding No. 7 likewise did not contribute to the cause of the accident in this instance, and you would assume that that would not contribute to a future accident.

Colonel BORMAN. Yes, sir. I would also hope that it does not happen again. I do not like to get changes in the test procedure the night before we are supposed to run the test.

Senator CANNON. Finding No. 8, I think, requires no comment there in view of your comments already on the full-scale mockup.

I believe also you have commented on No. 9 there accordingly.

Do you have any further comments with respect to finding No. 10, Colonel Borman, insofar as you are concerned as a pilot?

Colonel BORMAN. Sir, the only finding part of No. 10 we have not touched on is 10g, "No design features for fire protection were incorporated." By this we mean there were no auxiliary, or one of the implications is, there were no auxiliary oxygen masks to protect the crew in the event of a toxic atmosphere on orbit, and I would hope that this recommendation will be heeded by the Program Office also.

Senator CANNON. The recommendation being that investigation be made of the most effective means of controlling and extinguishing a spacecraft fire and also to consider that auxiliary breathing oxygen be provided to protect from smoke and toxic fumes.

Colonel BORMAN. Yes, sir.

Senator CANNON. Are there any matters that, in connection with finding No. 11, that you think should be commented on from your standpoint?

Colonel BORMAN. No, sir.

Senator CANNON. Thank you very much, Mr. Chairman. That concludes the questions I have.

The CHAIRMAN. Do you have anything else, Senator Young?

Senator YOUNG. Yes.

UNIFIED HATCH PREFERRED

Colonel Borman, you deserve our gratitude for your frank answers to questions, and I compliment you on being very, very knowledgeable in this subject, and, therefore, I am directing a question to you. From testimony at our previous hearings, it is unclear to me and there seems to be some confusion about the status of this redesigned hatch, and I believe you can clear up this uncertainty.

Now, I know that Dr. Mueller on February 27 stated that consideration was being given to three different hatch concepts: One—you will find it on pages 98 and 99 of that hearing, you are familiar with it—one, the present two-hatch system; a second was the three-man sized hatch to provide an opening large enough for simultaneous three-man egress, and then there was this third concept that he told about.

Now, he said that NASA is evaluating these three concepts, but you indicated in your testimony, Colonel, that a decision had been made prior to the time this tragedy occurred.

Now, will you please clarify that for me?

Colonel BORMAN. Sir, it was my understanding that the decision—at least perhaps a decision had not been made by Dr. Mueller, but I believe that I am safe in saying that the decision among the flight crew, at least indicating the desirability of the unified hatch, had been agreed upon prior to this accident, and I believe, sir, that this is the type of hatch that is now being designed, the one that is shown on page 99 of your Apollo accident hearings, part 2.

Senator YOUNG. Well, here again Dr. Mueller stated that "We are evaluating this design against the present design," and so has a decision already been made to put the new hatch on block II spacecraft?

Colonel BORMAN. It is my information, sir, that, yes, it has been made, and it will be the unified hatch.

The CHAIRMAN. What is the basis of your information?

Senator YOUNG. Yes.

Colonel BORMAN. The basis of my information is informants that——

The CHAIRMAN. The information we have is it was not.

Colonel BORMAN. Sir, the basis of my information is by contact that I maintain with my fellow flight crew people and people in the Apollo office that are dealing with this problem daily. We have members of our organization that are interested in this, and that have been following the developments of it, sir.

The CHAIRMAN. Would not Dr. Mueller have to be brought into this somewhere?

Colonel BORMAN. I am sure he will have to approve it, but I think he has already done so. I believe it would be better for you to ask him, though all I can tell you, it is my understanding.

The CHAIRMAN. We did ask him.

Colonel BORMAN. Yes, sir; but you asked him on February 27. I think perhaps he will tell you, if you ask him tomorrow, that it is being—I hope he will confirm what I have just mentioned here. [Laughter.]

The CHAIRMAN. I realize you have hopes.

Colonel BORMAN. I have my hopes, but I also have my sources of information, sir.

Senator YOUNG. But it appears there is a discrepancy at the present time, is that not right?

Colonel BORMAN. I think, sir, that perhaps when Dr. Mueller testified before you, that he was still considering them, and perhaps I was premature in saying that I was—the other two hatches, in my opinion, were so out of the question that I immediately settled on the one that we have here.

Senator YOUNG. Well, we may be impressed by your view and agree with you, but apparently if a decision has already been made to put that new hatch on this spacecraft, if that has been made, when is it going to be done?

Colonel BORMAN. Sir, it is my understanding that it will be available the latter part of this year. And may I just suggest, I would like to be able to tell you exactly, but this is really in the area of the program office, sir, and everything I am telling you is just information I picked up through communication with Houston.

Senator YOUNG. Yes; but we really cannot rely definitely on this except that it is your understanding, based on your information, is that not right?

Colonel BORMAN. Yes, sir.

Senator YOUNG. Because there is a discrepancy as the record now stands, is that not correct?

Colonel BORMAN. I think there is a discrepancy in that I testified that it was my belief that at the time of this accident, a unified hatch was on the design board, and Dr. Mueller said at the time of the accident there were three different approaches being considered.

Senator YOUNG. That are presently being considered?

Colonel BORMAN. Yes, sir; and I guess I had considered them rapidly and settled on one that I felt was proper.

Senator YOUNG. But you have been too optimistic.

Colonel BORMAN. I may have been mistaken, but I would be willing to wager if I could.

The CHAIRMAN. No bet.

Senator BROOKE. Mr. Chairman.

The CHAIRMAN. Senator Brooke.

FLIGHT CREW SATISFIED SPACECRAFT SAFE FOR TEST

Senator BROOKE. Colonel Borman, I would think that the flight crews, having worked with the spacecraft, make recommendations that programing would listen to and utilize.

Now, you knew the flight crew intimately. Had at any time any member of the flight crew ever brought to your attention anything concerning that spacecraft which they felt could have been rectified or should have been rectified which was not done prior to this accident?

Colonel BORMAN. No, sir. I might add that never in my experience with NASA—I have been almost 5 years now at Houston, never in this time period, in my experience, have I ever seen in any instance any item that was identified as affecting crew safety overlooked, turned down, or relegated to a lower priority for any reason whatsoever, and in this case unfortunately we did not identify the hazards.

But the hazards that have been identified have never been diluted for any reason that I know of, sir.

Senator BROOKE. To the best of your knowledge none of the mistakes which have been found by this Board were ever mentioned by members of the space crew.

Colonel BORMAN. Well, yes, sir. There is—we knew about the coolant leaks, we knew about the trouble with the ECU, we knew about the wire problems, but, as I pointed out, there was a continuing vigorous effort to correct these items, and we had hoped and believed that the action was sufficient and adequate.

Senator BROOKE. This crew believed that everything that could have been done at that time had been done.

Colonel BORMAN. Sir, I think I can say that at the time they entered the spacecraft, they were satisfied that they had a spacecraft that was not only adequate but safe for the test that they were performing.

ALARM SYSTEM NOT WORTHWHILE

Senator BROOKE. Will the new spacecraft have an alarm system?

Colonel BORMAN. Sir, the old one had an alarm. We had an extensive caution and warning system. We do not have a reliable means of picking up fire detection. Fire detection is in its infancy, and we do not have that, and I would not propose that we install one.

Senator BROOKE. You do not propose to install one.

Colonel BORMAN. No, sir.

Senator BROOKE. Why?

Colonel BORMAN. Because of my experience in the aviation business where they have sometimes caused more troubles than they are worth.

I just do not believe that if we do the other things that we have recommended that they will be required for this item.

Senator BROOKE. Would you agree with that, Dr. Thompson?

Dr. THOMPSON. I agree with that. I am afraid if you put in a system, it might not see the fire, we might not know where it is going to occur, and I doubt that we know enough about where it is going to occur to properly sound an alarm that would be effective. If we did, we would fix that place so that the fire did not occur, and my understanding of fire alarm systems is that—like Colonel Borman's is—they might be much more hazardous than they are safe.

Senator BROOKE. The second reason would obviously be sound, but the first reason of course we did not know in this instance what could have happened so that would not necessarily be a justifiable and valid reason for not having a fire alarm; is it, Dr. Thompson?

Dr. THOMPSON. Well——

Senator BROOKE. If you feel it is going to be hazardous.

Dr. THOMPSON. I think it would be a very difficult problem to have an alarm that would provide a useful purpose arranged in such a manner that would give any reasonable additional assurance to reliability of the vehicle, and I would be willing to be convinced if I saw one, but I would be very skeptical. It would be very hard to prove to me that the system was not just another gadget that perhaps was more risky than it was safe.

Senator BROOKE. No further questions.

The CHAIRMAN. Mr. Gehrig has some questions.

Mr. GEHRIG. Dr. Van Dolah, the fire occurred in three phases, is that correct?

Dr. VAN DOLAH. Yes, sir; we have described it.

THREE PHASES OF FIRE

Mr. GEHRIG. Would you put into the record a chronology of the fire giving each of the three phases, the duration of the phase, and what characterized that phase?

Dr. VAN DOLAH. Yes, sir.

Mr. GEHRIG. If you can just furnish that for the record, it would be fine.

Dr. VAN DOLAH. All right, fine.

(The information referred to follows:)

First phase approximately 21:30:55 to approximately 21:31:19—relatively slow burning—intensely hot flames.

Second phase approximately 21:31:19 to approximately 21:31:25—turbulent burning—violent conflagration.

Third phase approximately 21:31:25 to approximately 21:31:30—rapid decrease in oxygen, rapid increase in soot and carbon monoxide.

Mr. GEHRIG. At what time did the third phase of the fire start?

Dr. VAN DOLAH. The third phase started at the time that the cabin atmosphere returned to atmospheric pressure, which we estimate to be about 25 seconds after the minute, that is 23:31:25.

Mr. GEHRIG. At what time did the third stage end?

Dr. VAN DOLAH. Well, again, as it can only be estimated; but we again estimate it to have lasted about 5 seconds so that it would end at 30 seconds after the minute.

Mr. GEHRIG. Dr. Thompson, panel 11, the Medical Analysis Panel, determined that the suit of the command pilot failed prior to the rupture of the pressure vessel which occurred at 23:31:19 G.m.t., as I understand it. In other words, at 19 seconds after the minute. Do you agree with that?

Dr. THOMPSON. I agree with the findings that have been determined by them; yes, sir.

Mr. GEHRIG. And the origin and the propagation of the fire estimates are that significant levels of carbon monoxide were present in the spacecraft atmosphere by 23:31:30, 30 seconds after the minute. Or 11 seconds later after the rupture.

Dr. THOMPSON. Yes, sir.

Mr. GEHRIG. Since one suit had failed, these gases are introduced into all of the suit loops, as I understand it; is that correct?

Dr. THOMPSON. Yes, sir.

Mr. GEHRIG. And therefore the crew was exposed to a lethal atmosphere right after the first suit failed. What is the best determination as to when the crewmembers lost consciousness?

Dr. THOMPSON. I think it is written in the record. I cannot recall the figures.

Mr. GEHRIG. As I read the report, the medical panel estimates that consciousness was lost between 15 and 30 seconds after the first suit failed.

Dr. VAN DOLAH. That is correct.

Mr. GEHRIG. And since the first suit failed prior to the cabin rupture at 23:31:19, that means that the medical panel estimated that unconsciousness did not occur until 23:31:34, which would be after the fire occurred. Is that correct? And perhaps not as late as 23:31:49.

Dr. VAN DOLAH. I do not think that is quite correct; no, sir. There is no precise knowledge as to when the first suit failed. We only know it failed prior to the burst of the cabin which occurred about 19 seconds after 23:31. But that suit could have failed many seconds before that, sir.

Mr. GEHRIG. What time did the fire start? As I understand, it started at about 23:31:04.7—no, I am sorry.

Dr. VAN DOLAH. That was the beginning.

Mr. GEHRIG. 04.7.

Dr. VAN DOLAH. That was the beginning the first verbal report of fire, sir.

Mr. GEHRIG. But it could not have started you think before 23:30:50.

Dr. VAN DOLAH. We do not know when it started.

Mr. GEHRIG. You have no estimate at all of when the fire started.

Colonel BORMAN. Yes, we estimated it started——

Mr. GEHRIG. You estimate it started at that time.

Dr. VAN DOLAH. Yes, sir.

TIME OF DEATHS DISCUSSED

Mr. GEHRIG. Did the medical analysis make any determination as to the time that death occurred?

Dr. THOMPSON. Medical opinion?

Mr. GEHRIG. Yes.

Dr. VAN DOLAH. The estimate is that chances——

Dr. THOMPSON. I think at this point it would be very well to have Dr. Berry, who is—who just walked in the room here, testify.

Mr. GEHRIG. Was Dr. Berry a member of the medical panel?

Dr. THOMPSON. He is head of the medical group. He heads up the medical group that we had on our panel and is very conversant with this whole matter; and we have relied very heavily and, as a matter of fact, our position has been established by the people who worked for Dr. Berry, who are on our panel with the assistance of Dr. Berry.

Mr. GEHRIG. I think the committee would prefer to hear Dr. Berry another time, Dr. Thompson. We would prefer to have the Board's views now.

What I am trying to establish is the sequence of events. As I understand it, the medical assistance panel did not make a determination as to the time death occurred. They only made a determination—an estimated—as to when unconsciousness occurred.

Colonel BORMAN. We have it right here, sir. I think on D 11–8, the determination, right above No. 15, gives you the best estimate of that. It is estimated that the time consciousness was lost was between 15 and 30 seconds after the first suit failed. "Chances of, resuscitation decreased rapidly thereafter and were irrevocably lost within 4 minutes."

Mr. GEHRIG. Dr. Thompson, does the Board feel, that is, is it the judgment of the Board, that death occurred before the fire was extinguished or before the fire ended?

Dr. THOMPSON. I think about the same time. This comes about the same time the fire ended but while they were in a very lethal atmosphere of carbon monoxide, the termination of the fire ended up with a chamberful of a high concentration of carbon monoxide.

Mr. GEHRIG. It would cause unconsciousness.

Colonel BORMAN. The hatch was not removed until about 4 minutes, 36 seconds. Your survival would be minimal.

Mr. GEHRIG. Is it reasonable that the——

Colonel BORMAN. Thirty-six, excuse me.

Mr. GEHRIG. I am sorry, 36 what?

Colonel BORMAN. Thirty-six seconds.

The CHAIRMAN. Would you start back your sentence and repeat it?

Colonel BORMAN. Yes, sir. The hatch was removed 4 minutes and 36 seconds after the crew report of fire, and it was the opinion of the best medical advice that we can have, that we have had, that the crew was beyond revival at that time.

Mr. GEHRIG. But then one can reason if there had been proper emergency procedures established for the ground support people outside they would have been able to remove the hatch within 90 seconds that perhaps some crew members could have been saved.

Colonel BORMAN. I think this is conjecture. You certainly would have to have some feeling, I think, for the intensity of the fire and the toxicity of the atmosphere.

From talking to the witnesses who were on the pad at that time, it was a very violent reaction. There was an intensely toxic atmosphere around the outside of the spacecraft, heavy smoke, and the efforts at rescue were severely impeded not only by the lack of equipment but by just the sheer lack of visibility.

Mr. GEHRIG. So if the proper equipment had been available, they could have worked on the hatch door.

Colonel BORMAN. That is correct.

DISCUSS TESTS PRIOR TO FLIGHT

Mr. GEHRIG. How many manned tests are run on the pad before there is a manned Apollo spacecraft flight?

Mr. WILLIAMS. If you will take a look at the test program, you run a detailed systems test first and then an electrical mate test between the launch vehicle and the spacecraft and then an integrated test with the launch vehicle and the plugs-out test followed by FRT test, flight readiness test, which is followed by servicing of the spacecraft on the launch pad.

Mr. GEHRIG. So how many manned tests are there? I do not know if I caught it, five or six.

Mr. WILLIAMS. About five or six.

Mr. GEHRIG. What test number was being run on January 27 when the accident occurred?

Mr. WILLIAMS. 0021, the plugs-out test.

Mr. GEHRIG. And had manned tests been run on the pad with the spacecraft prior to this test?

Mr. WILLIAMS. Yes, sir. The detailed systems test, the electrical mate test, and the integrated test with the launch vehicle.

Mr. GEHRIG. With men in the spacecraft.

Mr. WILLIAMS. With men in the spacecraft.

Mr. GEHRIG. During any of these prior tests, was the spacecraft—was the spacecraft pressurized with 100 percent pure oxygen at 16.7 psi?

Mr. WILLIAMS. No, sir; not on the pad. It was pressurized with roughly 16 pounds in the altitude chamber four different times.

Mr. GEHRIG. So January 27 was the first time that the Apollo spacecraft was pressurized on the pad with 100 percent pure oxygen.

Mr. WILLIAMS. On the pad, that is right.

Mr. GEHRIG. Mr. Chairman, may I suggest that we put into the record some organization charts that we have used here of the Office of Manned Space Flight, the Manned Spacecraft Center, the Marshall Space Flight Center, and the Kennedy Space Center, and I would also recommend that the Board put in the record at this point an organizational chart of the North American Aviation Co.

The CHAIRMAN. Without objection.

(The charts (see figs. 77–86) referred to follow:)

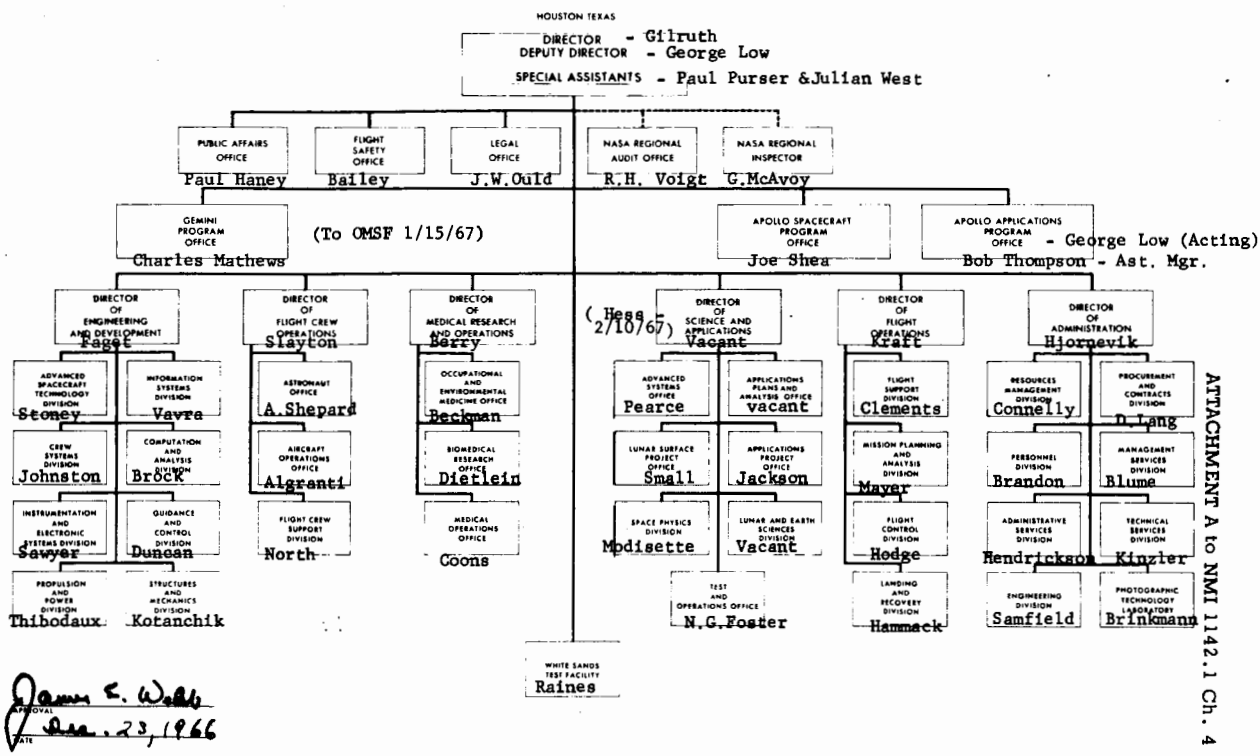
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
MANNED SPACECRAFT CENTER
HOUSTON TEXAS
DIRECTOR - Gilruth
DEPUTY DIRECTOR - George Low
SPECIAL ASSISTANTS - Paul Purser &Julian West
PUBLIC AFFAIRS OFFICE
Paul Haney
FLIGHT SAFETY OFFICE
Bailey
LEGAL OFFICE
J.W.Ould
NASA REGIONAL AUDIT OFFICE
R.H. Voigt
NASA REGIONAL INSPECTOR
G.McAvoy
GEMINI PROGRAM OFFICE
Charles Mathews
(To OMSF 1/15/67)
APOLLO SPACECRAFT PROGRAM OFFICE
Joe Shea
APOLLO APPLICATIONS PROGRAM OFFICE - George Low (Acting)
Bob Thompson - Ast. Mgr.
DIRECTOR OF ENGINEERING AND DEVELOPMENT
Paget
ADVANCED SPACECRAFT TECHNOLOGY DIVISION
Stoney
INFORMATION SYSTEMS DIVISION
Vavra
CREW SYSTEMS DIVISION
Johnston
COMPUTATION AND ANALYSIS DIVISION
Brock
INSTRUMENTATION AND ELECTRONIC SYSTEMS DIVISION
Sawyer
GUIDANCE AND CONTROL DIVISION
Duncan
PROPULSION AND POWER DIVISION
Thibodaux
STRUCTURES AND MECHANICS DIVISION
Kotanchik
DIRECTOR OF FLIGHT CREW OPERATIONS
Slayton
ASTRONAUT OFFICE
A.Shepard
AIRCRAFT OPERATIONS OFFICE
Algranti
FLIGHT CREW SUPPORT DIVISION
North
DIRECTOR OF MEDICAL RESEARCH AND OPERATIONS
Berry
OCCUPATIONAL AND ENVIRONMENTAL MEDICINE OFFICE
Beckman
BIOMEDICAL RESEARCH OFFICE
Dietlein
MEDICAL OPERATIONS OFFICE
Coons
(Hess - 2/10/67)
DIRECTOR OF SCIENCE AND APPLICATIONS
Vacant
ADVANCED SYSTEMS OFFICE
Pearce
APPLICATIONS PLANS AND ANALYSIS OFFICE
vacant
LUNAR SURFACE PROJECT OFFICE
Small
APPLICATIONS PROJECT OFFICE
Jackson
SPACE PHYSICS DIVISION
Modisette
LUNAR AND EARTH SCIENCES DIVISION
Vacant
TEST AND OPERATIONS OFFICE
N.G.Foster
DIRECTOR OF FLIGHT OPERATIONS
Kraft
FLIGHT SUPPORT DIVISION
Clements
MISSION PLANNING AND ANALYSIS DIVISION
Mayer
FLIGHT CONTROL DIVISION
Hodge
LANDING AND RECOVERY DIVISION
Hammack
DIRECTOR OF ADMINISTRATION
Hjornevik
RESOURCES MANAGEMENT DIVISION
Connelly
PROCUREMENT AND CONTRACTS DIVISION
D.Lang
PERSONNEL DIVISION
Brandon
MANAGEMENT SERVICES DIVISION
Blume
ADMINISTRATIVE SERVICES DIVISION
Hendrickson
TECHNICAL SERVICES DIVISION
Kinzler
ENGINEERING DIVISION
Samfield
PHOTOGRAPHIC TECHNOLOGY LABORATORY
Brinkmann
WHITE SANDS TEST FACILITY
Raines
APPROVAL
DATE
Dec. 23, 1966

FIGURE 78

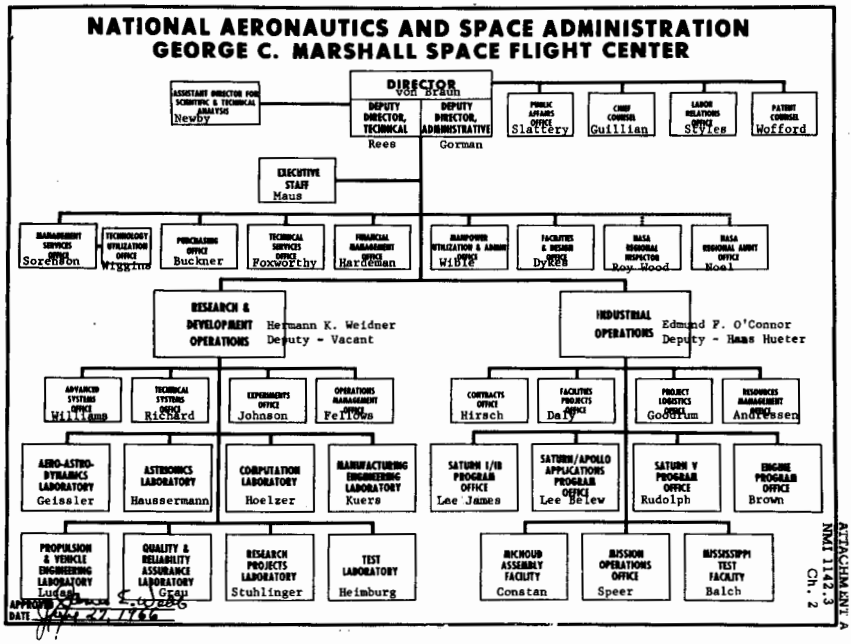

FIGURE 79

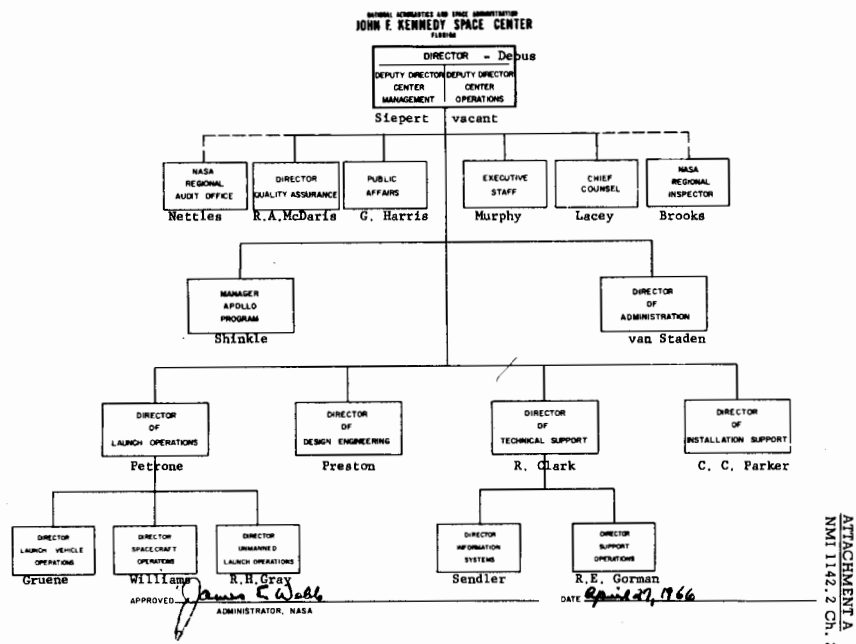

FIGURE 80

(The material on North American Aviation referred to was submitted as follows:)

Transmitted herewith is the North American Aviation, Inc. organizational structure together with a brief narrative of the organization and management of the Apollo Command and Service Module Program.

DIRECTION AND CONTROL OF APOLLO COMMAND-SERVICE MODULE (CSM) PROGRAM

I. ORGANIZATION AND MANAGEMENT OF APOLLO CSM PROGRAM

North American Aviation (NAA), by the nature of its organization and the policy of its management, makes available to the customer the full resources of the company in support of the Apollo CSM Program. Program management has been assigned to direct and control the Program to satisfy customer technical, schedule, and cost requirements.

A. Corporation

The Space and Information Systems Division (S&ID), which is responsible for the Apollo CSM and Saturn II Programs is one of seven NAA operating divisions supported by corporation administrative organizations. Each division is headed by a division president who is also a vice president of the corporation responsible to NAA President, J. L. Atwood. Mr. Atwood is also Chairman of NAA's Board of Directors. The corporation establishes and administers the broad policies which constitute the framework within which each operating division functions. Chart "X" shows the NAA corporate organization.

B. S&ID

S&ID is headed by Division President, H. A. Storms. This division is responsible for the Apollo CSM and Saturn II Programs which are being carried out under separate program managers. The Apollo CSM Program is directed by Apollo CSM Program Manager and S&ID Vice President, D. D. Myers, who is responsible to both NASA and Division President, H. A. Storms. Advanced Programs Development, and Research, Engineering and Test furnish special technical support as needed. Other S&ID functions provide administrative support—Chart "Z" shows the S&ID organization.

C. Apollo CSM

As shown in Chart "L," the Apollo CSM Program Manager, D. D. Myers, is assisted by Deputy Program Manager, C. H. Feltz, and four Assistant Program Managers. Directors of four functional areas report directly to the Program Manager. The Director of Quality and Reliability Assurance is responsible to the Program Manager in technical matters although reporting administratively to the S&ID Director of Quality and Reliability Assurance. The Director of Apollo CSM Operations, Florida, J. L. Pearce, is responsible to the Apollo CSM Program Manager although he reports administratively to the NAA General Manager of the Florida Facility, W. S. Ford. This organizational plan gives the Apollo CSM Program Manager direct control and responsibility over all phases of the Program including all subcontracting, which is administered by Apollo Material.

D. Florida facility

The overall Florida Facility organization is shown in Chart "Q." and the Apollo CSM Florida organization, in Chart "E." The Apollo CSM Florida Director, J. L. Pearce is supported by three managers, the Chief Project Engineer, R. W. Pyle, and the Technical Support Chief, R. E. Franzen. The three managers have separate areas of responsibility: Test Operations, J. M. Moore; Test Sites, R. E. Barton; and Quality and Reliability Assurance, J. L. Hansel. Very close liaison and control between Downey and Florida Apollo CSM operations is maintained.

II. PROGRAM HARDWARE RESPONSIBILITY

S&ID is responsible, with NASA concurrence, for the overall development, design, manufacture, and test of Apollo CSM hardware.

A. Spacecraft configuration

The Apollo CSM configuration is shown in Chart ZZ. S&ID is responsible for the command and service modules, the launch escape system, the spacecraft/lunar module adapter, and most subsystems pertaining to these modules. S&ID is responsible for coordinating the physical and operating interfaces of these modules and systems with the Associated Contractors (shown in Chart LC), and NASA.

B. Ground support equipment (GSE)

NAA supplies GSE as directed by NASA to support Apollo CSM test and checkout operations at all test sites. This GSE consists of checkout equipment, auxiliary equipment, servicing, and handling equipment. NAA is responsible for the design, manufacture, and checkout of this GSE.

C. Subsystems

The following Apollo CSM subsystems and modules are being produced inhouse at NAA:

Subsystem or Module and Division.—
Command and Service Modules (Complete): S&ID;
SLA (Complete): S&ID;
Launch Escape System Structure: Los Angeles Division;
Sequencer System: Autonetics; and
Command Module Reaction Control System: Rocketdyne.

Units that are made at other NAA divisions are designed, manufactured, and tested under S&ID supervision and control.

D. Subcontractors

Major and minor subcontractors are selected with NASA concurrence by S&ID, and are under S&ID surveillance. The subsystems they fabricate are designed, manufactured, and tested under S&ID supervision and control. Chart R shows the Apollo CSM major subcontractors and the systems for which each is responsible.

E. Suppliers

S&ID buys hardware for the Apollo CSM Program directly from over 12,000 first tier suppliers of which 9,000 represent small business; and the remainder, large business. All such hardware must be bought from S&ID approved sources and the hardware must be certified and tested as required to meet applicable specifications. Suppliers of these first tier suppliers represent many thousands of additional firms.

III. PROGRAM CONTROL PROCEDURES

A. The baseline for NASA and NAA management of the program is contained in the contract. The particular control baselines are the technical, master end item and specific end item specifications, the contract plans, and contract change notices which become incorporated into the baselines by specification and supplemental agreements. The controlling plans are the Manufacturing Plan, the Quality Control Plan, the Configuration Management Plan, the Ground Operations Requirement Plan and the Reliability Plan.

B. Control Tools—Cost, Schedule and Quality. Program control procedures are implemented only after formal Joint NASA/NAA interface agreements. These interfaces consist of contractual, technical and schedule meetings and documentation. Contractual direction is given by NASA to NAA through (bilateral) Supplemental Agreements and Contract Specification Change Notices and through (unilateral, by NASA) Contract Change Authorizations. Technical direction is given by NASA through Program Management Meetings, letters and wires to the NAA contracting officer and in formal reviews and Interface Control Documents. Formal joint reviews are Preliminary and Critical Design Reviews (PDR's and CDR's), First Article Configuration Inspection (FACI), Customer Acceptance Readiness Reviews (CARR) and Flight Readiness Reviews (FRR).

Through the S&ID Apollo CSM Program Manager's Office, control is exercised over CSM program costs, schedule and quality. The control media include the following:

1. *Cost Control* is provided primarily through Joint NASA/NAA negotiated and approved "work packages" with individual work package managers assigned to control costs, schedule achievements and quality. The choice of work package breakdown structure has enabled individual cost control of functional elements within S&ID as well as major subcontractors which supply CSM subsystems. NASA, NAA division and corporate policies assure proper make or buy decisions, subcontractor bid selection and the like.

2. *Schedule Control,* is provided by use of a "Master Development Schedule," a formal schedule change system, a PERT reporting system of scheduled milestones and formal critical problem reports. Major schedule changes receive concurrence of the NASA Program Manager prior to NAA implementation. The selection of schedule milestones, monitored by PERT are also identified in the cost control work packages, yielding an integrated cost/schedule measuring device.

3. *Control of Quality* is provided by (a) jointly approved hardware qualification test-selection, criteria, test surveillance and test report approval, (b) Joint NASA/NAA mandatory inspection point assignments and surveillance, and (c) step-by-step inspections (NASA/NAA) through manufacture, checkout and prelaunch operations. A failure reporting system assures follow-up on potentially discrepant hardware. Control of subcontractor quality is provided in a similar fashion, with NAA and NASA approvals obtained as described in paragraph E.

C. *Management Control Documents*—Management control documents for Apollo CSM hardware exist at both the program level and at the first-line level of NAA S&ID management. The top documents serve to record design and product cer-

tification and flight readiness. These are the jointly approved minutes of PDR, CDR, FACI, CARR, Design Certification Review (DCR) and FRR.

The first-line level management control documents are:

1. *Design*—Master Change Records (MCR), drawings, process specifications, interface control documents and measurement lists.

2. *Manufacturing*—Fabrication and inspection record tickets, planning tickets, tool orders and parts replacement requests.

3. *Material (Purchasing)*—Purchase order, purchase order change notice and specification control documents.

4. *Test and Operations*—Operational test plan, operational checkout procedure, not satisfactory report, test preparation sheet, development test procedure.

5. *Quality and Reliability Assurance*—Inspection test instructions, material review disposition and quality control specifications.

D. *Configuration Management*—Configuration Management is practiced through compliance with the NASA Apollo Configuration Management Manual and NAA Division Policies as implemented by the Apollo CSM Change Control Board, chaired by the Assistant Program Manager. Configuration changes with major program impact are resolved at Joint Change Control Board meetings between the NASA and S&ID Program Managers.

Changes imposed on program baselines originate from both NASA and NAA. NASA directed changes are processed by Contracts through the Change Control Board for preparation of proposals. In-house changes are processed by the Apollo CSM chief project engineer also through the Board for evaluation and direction. Change control documentation is in the form of a Master Change Record (MCR) which defines the change and is the basis of an order to the functional departments to provide cost and schedule information for necessary evaluation, prior to final implementation. The MCR can be used, as above, to determine details of a change prior to implementation; however for urgent changes the purpose of the MCR is to initiate action, which is accomplished upon MCR approval by Program Management for "Release to Production".

Configuration records are maintained in mechanized records of released engineering drawings and specifications. These records provide indentured drawing lists, parts lists and alpha-numeric parts or drawing lists. The manufacturing planning system assures drawings and engineering order (E.O.) compliance utilizing Fabrication and Inspection Records (FAIR) and a Change Verification Record (CVR) for each end item. The FAIR provides both fabrication instructions and inspection verification; the CVR provides E.O. records and verification of compliance.

During Downey, Houston and Florida testing, a Test and Inspection Record (TAIR) system provides identical configuration and inspection information.

E. Subcontractor control baselines consist of (a) approved design specifications, drawings, components, qualification test plans and reports, acceptance test plans, critical process specifications, and component failure histories. A FACI is conducted for complex (major) procurements by S&ID with a NASA audit. Other procurements are subjected to FACI at NAA, utilizing subcontractor data. All baselines are re-verified to NASA at the SC 101 (Block II lunar capable vehicle) FACI.

Conformance of the subcontractors is controlled by "freezing" component changes at FACI, strict part number control, identification and reidentification, source or receiving inspection to formally approved drawings and baselines and component repair or overhaul, controlled to the configuration specified in the approved baseline.

Changes are justifiable only for NASA or NAA requirements modifications; failure in qualification, during production or in operational tests; or for significant cost reduction. Change controls parallel the NASA–S&ID change control procedures. This method of subcontractor control is in effect at such major subcontractors as Honeywell, AiResearch, Beech and Pratt & Whitney.

F. Field Site Control—Apollo CSM Program Field Site efforts with activities at Florida, MSC–Houston, White Sands, New Mexico and El Centro, California, are managed as are similar efforts in Downey. The management differences are caused by the fact that hardware at field sites has usually been transferred to NASA-owned, and also is governed by NASA field site management procedures, rather than NAA or NASA–MSC.

Hardware flow through the field site is controlled by the Ground Operations Requirement Plan (GORP) contractual document, as modified by operational changes and deviations approved by the NASA–KSC or other field site change board.

Hardware changes evolving from NASA and NAA sources, identified previously are processed through the Downey system for incorporation in a similar manner to other changes.

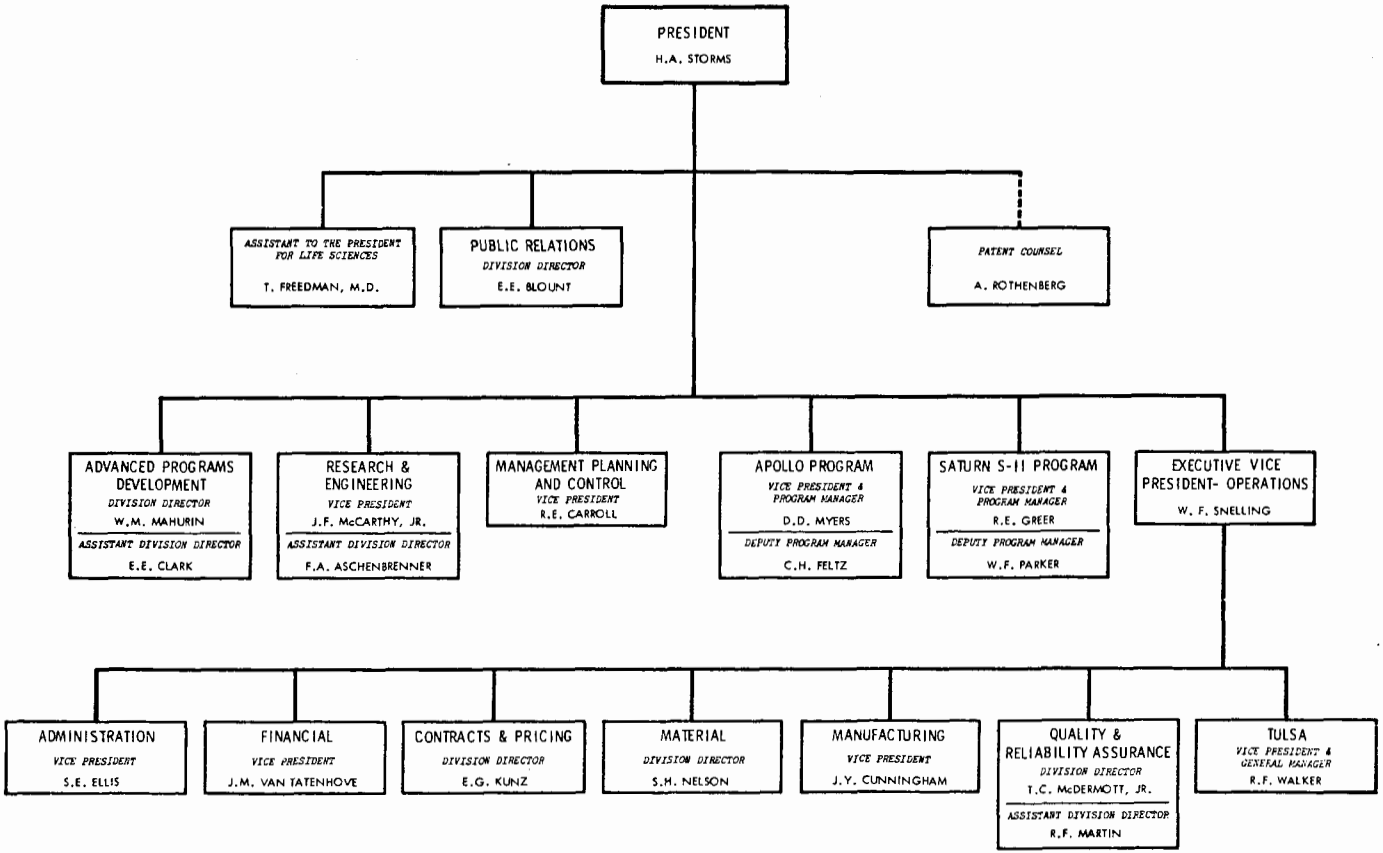
PRESIDENT
H.A. STORMS
ASSISTANT TO THE PRESIDENT FOR LIFE SCIENCES
T. FREEDMAN, M.D.
PUBLIC RELATIONS
DIVISION DIRECTOR
E.E. BLOUNT
PATENT COUNSEL
A. ROTHENBERG
ADVANCED PROGRAMS DEVELOPMENT
DIVISION DIRECTOR
W.M. MAHURIN
ASSISTANT DIVISION DIRECTOR
E.E. CLARK
RESEARCH & ENGINEERING
VICE PRESIDENT
J.F. McCARTHY, JR.
ASSISTANT DIVISION DIRECTOR
F.A. ASCHENBRENNER
MANAGEMENT PLANNING AND CONTROL
VICE PRESIDENT
R.E. CARROLL
APOLLO PROGRAM
VICE PRESIDENT & PROGRAM MANAGER
D.D. MYERS
DEPUTY PROGRAM MANAGER
C.H. FELTZ
SATURN S-II PROGRAM
VICE PRESIDENT & PROGRAM MANAGER
R.E. GREER
DEPUTY PROGRAM MANAGER
W.F. PARKER
EXECUTIVE VICE PRESIDENT- OPERATIONS
W. F. SNELLING
ADMINISTRATION
VICE PRESIDENT
S.E. ELLIS
FINANCIAL
VICE PRESIDENT
J.M. VAN TATENHOVE
CONTRACTS & PRICING
DIVISION DIRECTOR
E.G. KUNZ
MATERIAL
DIVISION DIRECTOR
S.H. NELSON
MANUFACTURING
VICE PRESIDENT
J.Y. CUNNINGHAM
QUALITY & RELIABILITY ASSURANCE
DIVISION DIRECTOR
T.C. McDERMOTT, JR.
ASSISTANT DIVISION DIRECTOR
R.F. MARTIN
TULSA
VICE PRESIDENT & GENERAL MANAGER
R.F. WALKER

FIGURE 81

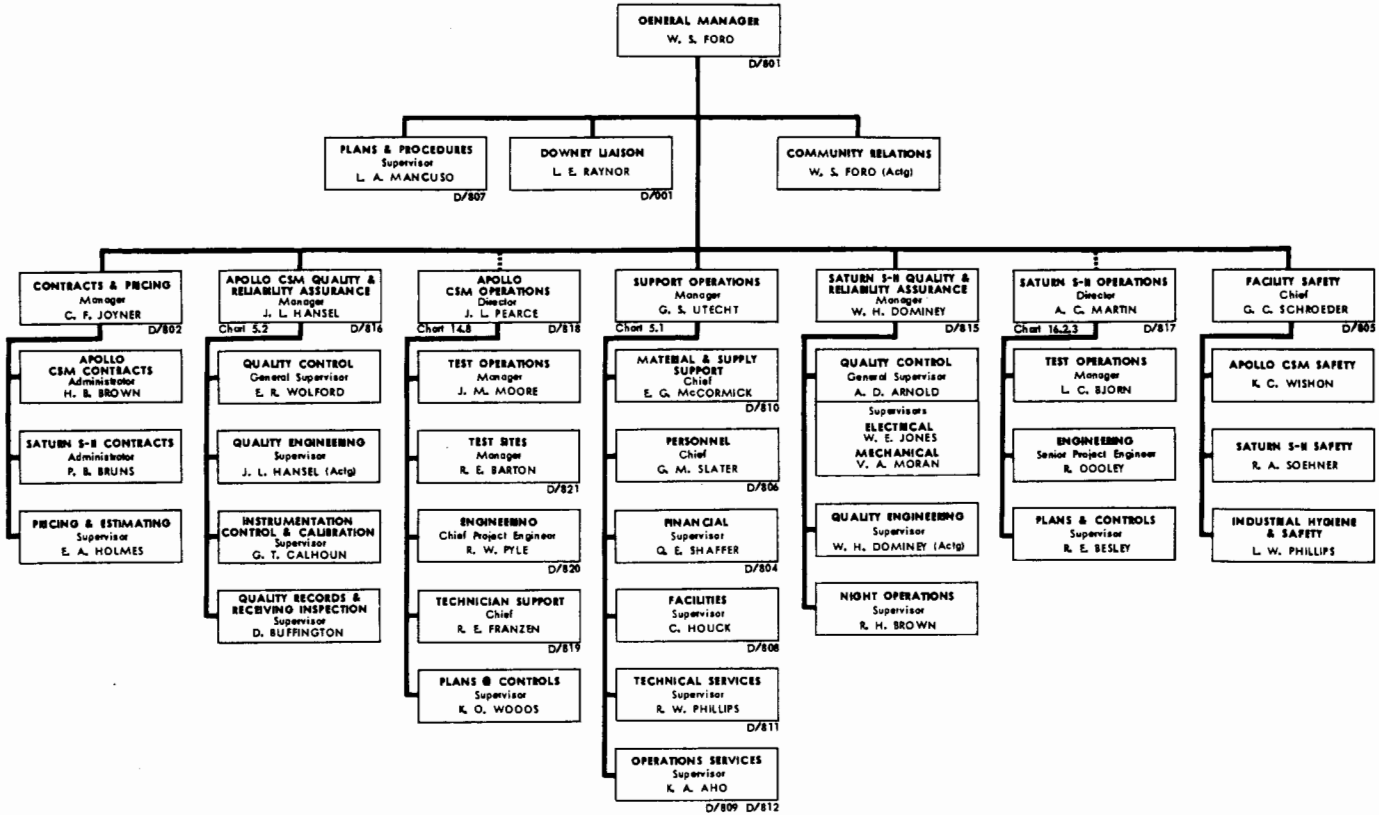
GENERAL MANAGER
W. S. FORD
D/801
PLANS & PROCEDURES
Supervisor
L. A. MANCUSO
D/807
DOWNEY LIAISON
L. E. RAYNOR
D/901
COMMUNITY RELATIONS
W. S. FORD (Actg)
CONTRACTS & PRICING
Manager
C. F. JOYNER
D/802
APOLLO CSM CONTRACTS
Administrator
H. B. BROWN
SATURN S-II CONTRACTS
Administrator
P. B. BRUNS
PRICING & ESTIMATING
Supervisor
E. A. HOLMES
APOLLO CSM QUALITY & RELIABILITY ASSURANCE
Manager
J. L. HANSEL
Chart 5.2
D/816
QUALITY CONTROL
General Supervisor
E. R. WOLFORD
QUALITY ENGINEERING
Supervisor
J. L. HANSEL (Actg)
INSTRUMENTATION CONTROL & CALIBRATION
Supervisor
G. T. CALHOUN
QUALITY RECORDS & RECEIVING INSPECTION
Supervisor
D. BUFFINGTON
APOLLO CSM OPERATIONS
Director
J. L. PEARCE
Chart 14.8
D/818
TEST OPERATIONS
Manager
J. M. MOORE
TEST SITES
Manager
R. E. BARTON
D/821
ENGINEERING
Chief Project Engineer
R. W. PYLE
D/820
TECHNICIAN SUPPORT
Chief
R. E. FRANZEN
D/819
PLANS & CONTROLS
Supervisor
K. O. WOODS
SUPPORT OPERATIONS
Manager
G. S. UTECHT
Chart 5.1
MATERIAL & SUPPLY SUPPORT
Chief
E. G. McCORMICK
D/810
PERSONNEL
Chief
G. M. SLATER
D/806
FINANCIAL
Supervisor
Q. E. SHAFFER
D/804
FACILITIES
Supervisor
C. HOUCK
D/808
TECHNICAL SERVICES
Supervisor
R. W. PHILLIPS
D/811
OPERATIONS SERVICES
Supervisor
K. A. AHO
D/809 D/812
SATURN S-II QUALITY & RELIABILITY ASSURANCE
Manager
W. H. DOMINEY
D/815
QUALITY CONTROL
General Supervisor
A. D. ARNOLD
Supervisors
ELECTRICAL
W. E. JONES
MECHANICAL
V. A. MORAN
QUALITY ENGINEERING
Supervisor
W. H. DOMINEY (Actg)
NIGHT OPERATIONS
Supervisor
R. H. BROWN
SATURN S-II OPERATIONS
Director
A. C. MARTIN
Chart 16.2.3
D/817
TEST OPERATIONS
Manager
L. C. BJORN
ENGINEERING
Senior Project Engineer
R. DOOLEY
PLANS & CONTROLS
Supervisor
R. E. BESLEY
FACILITY SAFETY
Chief
G. C. SCHROEDER
D/805
APOLLO CSM SAFETY
K. C. WISHON
SATURN S-II SAFETY
R. A. SOEHNER
INDUSTRIAL HYGIENE & SAFETY
L. W. PHILLIPS

FIGURE 82

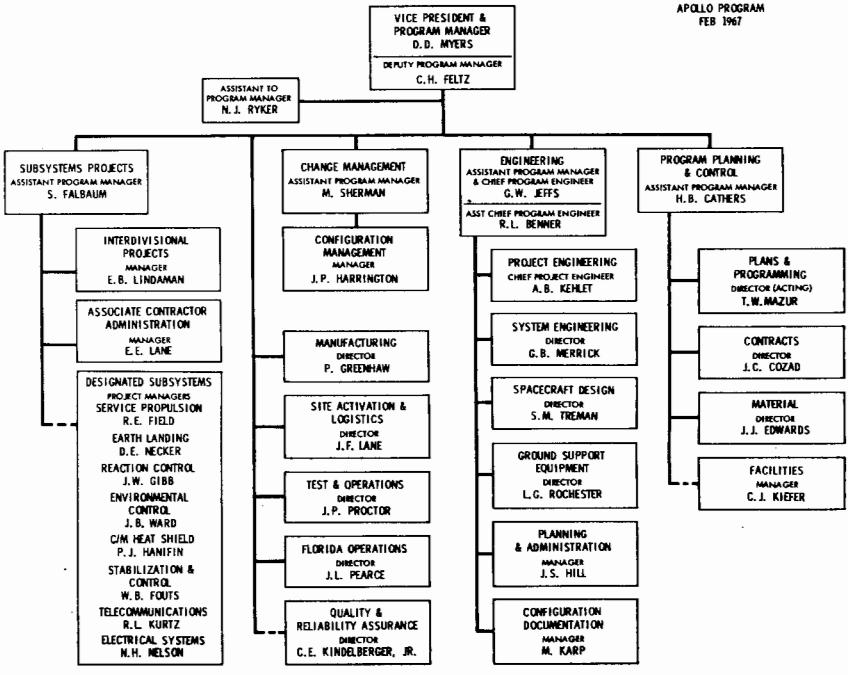
APOLLO PROGRAM
FEB 1967
VICE PRESIDENT & PROGRAM MANAGER
D.D. MYERS
DEPUTY PROGRAM MANAGER
C.H. FELTZ
ASSISTANT TO PROGRAM MANAGER
N.J. RYKER
SUBSYSTEMS PROJECTS
ASSISTANT PROGRAM MANAGER
S. FALBAUM
INTERDIVISIONAL PROJECTS
MANAGER
E.B. LINDAMAN
ASSOCIATE CONTRACTOR ADMINISTRATION
MANAGER
E.E. LANE
DESIGNATED SUBSYSTEMS
PROJECT MANAGERS
SERVICE PROPULSION
R.E. FIELD
EARTH LANDING
D.E. NECKER
REACTION CONTROL
J.W. GIBB
ENVIRONMENTAL CONTROL
J.B. WARD
C/M HEAT SHIELD
P.J. HANIFIN
STABILIZATION & CONTROL
W.B. FOUTS
TELECOMMUNICATIONS
R.L. KURTZ
ELECTRICAL SYSTEMS
N.H. NELSON
CHANGE MANAGEMENT
ASSISTANT PROGRAM MANAGER
M. SHERMAN
CONFIGURATION MANAGEMENT
MANAGER
J.P. HARRINGTON
MANUFACTURING
DIRECTOR
P. GREENHAW
SITE ACTIVATION & LOGISTICS
DIRECTOR
J.F. LANE
TEST & OPERATIONS
DIRECTOR
J.P. PROCTOR
FLORIDA OPERATIONS
DIRECTOR
J.L. PEARCE
QUALITY & RELIABILITY ASSURANCE
DIRECTOR
C.E. KINDELBERGER, JR.
ENGINEERING
ASSISTANT PROGRAM MANAGER & CHIEF PROGRAM ENGINEER
G.W. JEFFS
ASST CHIEF PROGRAM ENGINEER
R.L. BENNER
PROJECT ENGINEERING
CHIEF PROJECT ENGINEER
A.B. KEHLET
SYSTEM ENGINEERING
DIRECTOR
G.B. MERRICK
SPACECRAFT DESIGN
DIRECTOR
S.M. TREMAN
GROUND SUPPORT EQUIPMENT
DIRECTOR
L.G. ROCHESTER
PLANNING & ADMINISTRATION
MANAGER
J.S. HILL
CONFIGURATION DOCUMENTATION
MANAGER
M. KARP
PROGRAM PLANNING & CONTROL
ASSISTANT PROGRAM MANAGER
H.B. CATHERS
PLANS & PROGRAMMING
DIRECTOR (ACTING)
T.W. MAZUR
CONTRACTS
DIRECTOR
J.C. COZAD
MATERIAL
DIRECTOR
J.J. EDWARDS
FACILITIES
MANAGER
C.J. KIEFER

FIGURE 83

17AP86788

APOLLO ASSOCIATE CONTRACTORS

MIT	GUID & NAV EQUIP. - TECH MGMT
AC ELECTRONICS	GUID & NAV EQUIP. - MFG
CHRYSLER	S-I
BOEING	S-IC
NAA S&ID	S-II
DOUGLAS	S-IV & S-IVB
GENERAL ELECTRIC	ACCEPTANCE CHECKOUT EQUIP.
GRUMMAN	LUNAR MODULE
HAMILTON STANDARD	SPACESUIT & PORTABLE EQUIP.

FIGURE 84

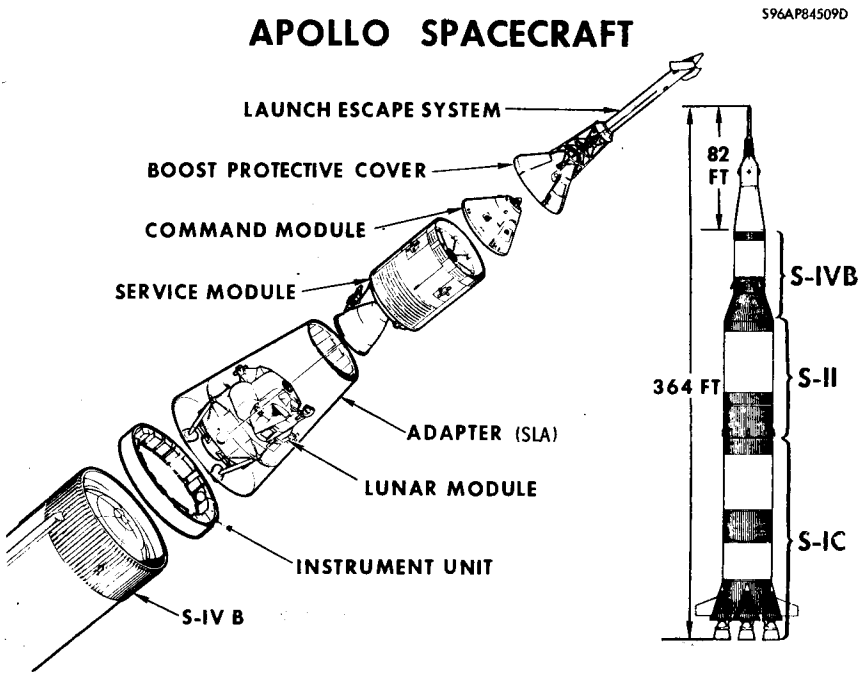
S96AP84509D
APOLLO SPACECRAFT
LAUNCH ESCAPE SYSTEM
BOOST PROTECTIVE COVER
COMMAND MODULE
SERVICE MODULE
ADAPTER (SLA)
LUNAR MODULE
INSTRUMENT UNIT
S-IV B
82 FT
364 FT
S-IVB
S-II
S-IC

FIGURE 85

APOLLO MAJOR SUBCONTRACTORS

SUBSYSTEM	SUBCONTRACTOR
SERVICE MODULE PROPULSION MOTOR	AEROJET-GENERAL CORPORATION
CM HEATSHIELD BRAZED STRUCTURE PANELS	AERONCA MFG CORPORATION
ABLATIVE HEATSHIELD	AVCO CORPORATION, RESEARCH & ADVANCED DEVELOPMENT DIVISION
SUPER CRITICAL GAS STORAGE	BEECH AIRCRAFT CORPORATION
COMMUNICATIONS AND DATA	COLLINS RADIO COMPANY
ENVIRONMENTAL CONTROL	GARRETT CORPORATION, AIRESEARCH MFG. DIVISION
MISSION SIMULATOR TRAINER	GENERAL PRECISION, INC. LINK DIVISION
STABILIZATION AND CONTROL	HONEYWELL
LAUNCH ESCAPE AND PITCH CONTROL MOTORS	LOCKHEED PROPULSION COMPANY
REACTION CONTROL MOTORS (SERVICE MODULE)	THE MARQUARDT CORPORATION
EARTH LANDING	NORTHROP CORPORATION, VENTURA DIVISION
ESCAPE TOWER JETTISON MOTOR	THIOKOL CHEMICAL CORPORATION, ELKTON DIVISION
FUEL CELL	PRATT & WHITNEY AIRCRAFT, DIVISION OF UNITED AIRCRAFT CORPORATION

FIGURE 86

NASA-CONTRACTOR AND STRUCTURE QUESTIONED

Mr. GEHRIG. Dr. Thompson, the chairman asked a question early this afternoon as to whether or not the Board felt that there was a division of responsibility which contributed to the fact that desired quality levels were not achieved. For example, divisions of responsibility between the Manned Spacecraft Center and North American Aviation, et cetera, that were not properly defined. As I understood your answer, you said that the Board had found these—the gist of your answer was that there were not divisions of responsibility, but that does not seem to be the same as your determination under finding No. 11, and I wonder if you can speak to that determination and amplify this for the committee.

Dr. THOMPSON. The problem, I think, that we have identified is more the interface between MSC and KSC. As the spacecraft is moved from the custody of Downey, the contractor, under MSC control, cognizance, to Kennedy, KSC, where in effect another group of NASA employees take over but still under the control of MSC, and I think that in the development of working interfaces there of MSC retaining the control over the spacecraft as far as design changes in things that affect the cost are concerned, or changes to the spacecraft, that there is some—a problem of cumbersomeness or what was defined to us as cumbersomeness, that relates to working out in an effective way those relationships. This is, I think, as close as I can come to, or is about as well as I really understand the problem.

We heard quite a lot of talk about this in our considerations here, and I believe that it is the development in this evolving area that is not yet perhaps resolved. All the interface of the NASA organization working with another set of contractors, another contractor group, too.

Now, North American has 8,000 employees at Downey and something like a thousand at KSC, so the spacecraft moves from one group of people to another but—two different groups, in effect, with the necessity for actual control remaining always at MSC, and I think that the problems are the interface problems that have not been sufficiently smoothed out to deal with the flexibilities required, or the quick response that is required with the necessity for actual restraint, and I do not believe that I can go much farther than that.

Mr. GEHRIG. So that there are some management problems. There are some management problems, in this area.

Dr. THOMPSON. There are management problems in every program I have ever seen and this is one that probably is not fully resolved yet. The lines of organization seem to define these things to a point that it does not appear in the line organizations.

Mr. GEHRIG. Mr. Chairman, those are all the questions that I have.

The CHAIRMAN. We will go back again. We want to see if there are additional questions.

Senator Curtis?

SAFETY GIVEN TOP CONSIDERATION

Senator CURTIS. Just one question, and I am sorry I had to be out. If this has been covered, why, I will not go over it again.

Colonel Borman, this morning I asked you about the fact that you had objections to the wiring before you went on this Board. Did you express those objections to anyone?

Colonel BORMAN. Sir, I believe you asked me if I knew of deficiencies in the wiring, and I said yes, I did. The deficiencies were continually being corrected, and they were known, and they were modified, and as far as I know at the time of this test the wiring was accepted.

Senator CURTIS. In other words, you are referring to some deficiencies that were known and——

Colonel BORMAN. And had been fixed.

Senator CURTIS. And when it was mentioned they were taken care of.

Colonel BORMAN. Yes, sir.

Senator CURTIS. So you were not referring to some deficiencies that, after they became known, were neglected.

Colonel BORMAN. No, sir.

Senator CURTIS. Do you know of anything in the space program where such a thing prevailed?

Colonel BORMAN. Sir, while you were out I mentioned to Senator Brooke that I know of no instance in my 5 years with NASA when there has been ever any compromise when a question of crew safety was involved in any respect—time, schedule, money, and everything—everything was sacrified to provide a safe vehicle.

Senator CURTIS. Did you ever receive any rejection of questions or inquiries about something? Was there freedom to express a concern about something that ought to be improved?

Colonel BORMAN. Yes, sir; I think speaking again as a flight crewmember, this is, in my opinion is, one of the very great assets of NASA as an organization. The opinions, the considerations, and sometimes even the desires of the flight crew are always listened to and very often heeded. We have a very willing and able access to every level of management.

Senator CURTIS. Well, I will not pursue it any further, and I am pleased that Senator Brooke did follow through, because I was afraid this morning we may have left a record that to some would indicate that you were aware of some deficiencies that somebody failed to take care of.

Colonel BORMAN. I am sorry I left you with that impression.

Senator CURTIS. No; I think it was the questioning that would have left that.

BOARD UNANIMOUS IN FINDINGS

The CHAIRMAN. Dr. Thompson, we know that each member of the Apollo 204 Review Board has formally signed the Board's report indicating concurrence in the findings included therein. However, I think it would be well that the record show that this committee has been assured that no Board member has any reservation concerning any aspect of the report or any of the findings and recommendations.

Therefore, if any member has any such reservation, would he please stand up, identify himself, and state what part of the report he wishes to have qualified insofar as he is concerned?

You have to speak now or forever hold your peace.