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HUBBLE SPACE TELESCOPE AND THE SPACE SHUTTLE PROBLEMS

HEARING

BEFORE THE

SUBCOMMITTEE ON SCIENCE, TECHNOLOGY, AND SPACE

OF THE

COMMITTEE ON COMMERCE, SCIENCE, AND TRANSPORTATION

UNITED STATES SENATE

ONE HUNDRED FIRST CONGRESS

SECOND SESSION

ON

OVERSIGHT ON RECENT PROBLEMS WITH THE HUBBLE SPACE TELESCOPE AND THE SPACE SHUTTLE

JULY 10, 1990

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HUBBLE SPACE TELESCOPE AND THE SPACE SHUTTLE PROBLEMS

TUESDAY, JULY 10, 1990

U.S. SENATE,
COMMITTEE ON COMMERCE, SCIENCE, AND TRANSPORTATION,
SUBCOMMITTEE ON SCIENCE, TECHNOLOGY, AND SPACE,
Washington, D.C.

The subcommittee met, pursuant to notice, at 12:15 p.m. in room SR-253, Russell Senate Office Building, Hon. Albert Gore, Jr., presiding

Staff members assigned to this hearing: Steve Palmer, senior professional staff member, and Louis Whitset, minority staff counsel.

OPENING STATEMENT BY SENATOR GORE

Senator GORE. The subcommittee will come to order.

I would like to apologize to our witnesses and our guests for the delay in starting this afternoon. As I am sure has been explained to you, we have been in a lengthier than we expected classified session on aspects of this issue which cannot for good and valid reasons be discussed fully in an open session. Other members of this subcommittee who are not with us right now did participate actively during this classified session, as did my colleagues who are here now.

We have undertaken a responsibility to protect the classified material which made up the bulk of the session which began this morning and extended into the starting time for this hearing. Although some of our questions will be based on the understandings we bring with us from that session, we take very seriously, of course, the obligation to protect the national security information that we heard earlier.

Today we embark upon the second hearing of our Subcommittee on Science, Technology and Space to examine problems with the Hubble Space Telescope. We will also focus on the hydrogen fuel leaks in the Space Shuttles Columbia and Atlantis which have grounded the entire U.S. Space Shuttle fleet.

The difficulties with the Hubble and the space shuttle program are very disturbing and, without judging the cause of these two incidents, they have served to reaffirm my strong belief in the need for established quality assurance procedures and strong effective program management by NASA. Both are essential to successful development of the long-term, technically complex programs NASA has under way to explore our solar system, reveal the secrets of distant planets, and uncover the origins of the universe.

In the wake of the Challenger disaster, it quickly became apparent that NASA had neglected its mandate for quality control. NASA figures substantiate this, as the number of quality assurance personnel was slashed by 70 percent between

1970 and 1985. The Marshall Space Flight Center, one of the lead centers on the Hubble Space Telescope, suffered the biggest setback, as their budget for quality control was slashed and 87 percent of its quality control employees were eliminated during that time frame.

I am concerned that with cuts like these, NASA may not have had the manpower necessary to question the contractors on their actions and the testing procedures used with respect to the Hubble. As such, I intend to pursue, among other things, whether NASA was in a position to independently insure the quality of the Space Telescope prior to launch. It is my very sincere belief that reductions to NASA's quality assurance and program management cannot be taken without sacrificing the quality of the space program.

History tells us that the Hubble program was beset with a multitude of technical difficulties. It has also been alleged that NASA had committed itself to an overly ambitious schedule. NASA itself has acknowledged that the management structure developed for the Hubble Space Telescope may not have been optimal, to say the least.

NASA's problems in managing the Hubble become clear when one realizes that during its 12 years of development there were a total of 15 program managers between the Marshall and Goddard Space Flight Centers and NASA headquarters. It seems to me that NASA would be wise to use the Hubble Space Telescope as a case study for new managers on how to avoid calamity with future projects.

We will also direct a significant portion of our attention today to the space shuttle program and the ongoing investigation to determine the cause of the hydrogen fuel leak. The grounding of this Nation's principal space transportation system has potentially far greater implications than the blurring of the Space Telescope. It is, therefore, essential that we understand how two leaks could have occurred after so many successful shuttle launches as well as how they can be stopped. This is a safety issue of the highest priority, as I think all understand.

We have waited many years for the Hubble Space Telescope, and none can question the importance of the space shuttle system to our national space program. The purpose of this hearing is to help us to determine if fundamental errors have been made and, if so, they must be quickly identified and corrected and, more importantly, avoided in the future. A commitment to quality assurance and strong program management may well be the key to the future success of the U.S. space program.

As NASA continues to focus on the larger and larger and more expensive new start-ups, there must be a high level of assurance that sufficient quality control exists to merit the taxpayer investment.

Before concluding this statement, let me recognize our witnesses today. Our first panel consists of:

J. R. Thompson, Deputy Administrator at NASA;

Len Fisk, Associate Administrator for Space Science and Applications who was with us a week ago;

Bill Lenoir, the Associate Administrator for Space Flight; and

George Rodney, Associate Administrator for Safety, Reliability, Maintainability and Quality Assurance.

Our second panel will include representatives from the two prime contractors on the Hubble: John Rich, President of Hughes Danbury Optical Systems Corporation, formerly Perkin-Elmer Corp.; and Bert Bulkin, the former program manager of the Hubble at Lockheed Missiles and Space Company and now that company's Director of Scientific Space Programs.

Let me see if either of my colleagues has a statement.

Senator Pressler.

OPENING STATEMENT BY SENATOR PRESSLER

Senator PRESSLER. Mr. Chairman, I shall just summarize my statement because I want to hear the witnesses, and we have already spent a fair amount of time in the closed session.

Let me, first of all, say that all of us in Congress who care about space science have had high hopes for the Hubble Space Telescope. Through its development we were told that Hubble represented a landmark breakthrough in astronomy, a telescope with more than ten times the power of any ground-based observatory. With its sharp lens, Hubble was to unlock the secrets of the universe. It would be capable of viewing the remnants of the "big bang" that created the universe 20 billion years ago. It promised not only to support good research but to excite our young people about science as a career.

The latest troubles with Hubble, therefore, are so disappointing because our expectations were so great. It is my understanding that defects in the Hubble mirrors will eliminate the use of the main camera in the telescope and make it impossible to perform about half the experiments planned for the telescope.

I am hopeful, however, that NASA will devote maximum time and resources to restore Hubble's vision. I also hope that NASA will give serious consideration to an early shuttle mission to repair the Hubble defects. As it is, the shuttle will not visit Hubble until 1993, which would mean three years of space science lost. This tragedy must be avoided if possible.

I am eager to hear from our witnesses today about how the defects in the Hubble mirrors came about. How did distorted mirrors slip past NASA's review and testing process? I have read that the telescope's various elements were never tested as an integrated system prior to launch. If this is true, the Space Subcommittee must ask why.

Again, I have great confidence in NASA's formidable scientific and engineering talent which throughout its history has managed to achieve the impossible. I am hopeful that NASA can correct the defects in the Hubble Space Telescope so it can realize our great expectations.

I would also like to commend NASA on their quick and systematic response to the fuel leak problems in the space shuttle program. NASA's normal procedures caught the fuel leak in the Columbia space shuttle on the launch pad. The Columbia problems prompted NASA to test the Atlantis orbiter, which was scheduled for a July 15 mission. Those tests turned up a similar leak. Both space shuttles are undergoing detailed NASA tests to locate and repair the hydrogen leaks. Further, NASA has kept Congress and the public fully informed throughout this process.

One additional area in which I have a fair amount of interest is how much our method of budgeting causes something like this—for example, if you have to contract out for special engineers to do a short-term project and then leave the technicians behind, so to speak—and if, indeed, a part of this problem arose from the way funds are allocated by Congress. If we had more long-range planning, programming and budgeting, indeed, could high-quality engineers stay on a project for a long time?

If any of the witnesses could address issues of that sort, I would be very appreciative.

With its talent and experience in space transportation, I am confident that NASA will soon move past these setbacks and return the space shuttle to its position as the world's premier manned space flight vehicle.

Mr. Chairman, I look forward to hearing from our witnesses on the status of the Hobble Space Telescope and Space Shuttle programs. Thank you very much.

Senator GORE. Thank you very much.

Senator BRYAN. Mr. Chairman, thank you.

In the interest of time and the fact that all of us were engaged longer than we had anticipated in the classified briefing, I will forebear making a statement at this time.

Senator GORE. Thank you very much, Senator Bryan.

Welcome, gentlemen, your prepared statements will be included in the record in full. I want to encourage you to summarize them and speak to the high points of what you have to tell us this morning. In reviewing the prepared statements, not in any way to be critical of them, I found that they were general in nature, as ours have been. But if you can summarize the high points and get to the heart of what we are here to discuss, we would appreciate it.

Senator Hollings has a statement that he would like to have included in the record.

[The statement follows:]

OPENING STATEMENT BY THE CHAIRMAN

It is a tragedy that after 12 years and $1.6 billion for the development, integration, and testing of the Hubble Space Telescope, a flaw that has so completely blurred its vision could have gone undetected. Of course, we do not yet know the precise cause of the problem, but indications are that a spherical aberration will render much of the Telescope's science potential useless for the next several years.

At the same time, but perhaps of far greater importance because of its potential impact on the lives of future shuttle astronauts, NASA has continuing difficulties in identifying the cause of the hydrogen fuel leak in the Space Shuttles Columbia and Atlantis. While these may be isolated problems unique to the two orbiter assemblies, the fact remains that we must find the source of leak and resolve it before we again risk the lives of any astronaut.

This hearing, which is a follow-up to our session on June 29, is an important part of our oversight process. Today's session will enable the Members of this Committee to question those responsible for managing the Hubble Space Telescope program, the Space Shuttle program, and the Safety and Quality Assurance program within NASA. The first panel represents much of NASA's brain trust, and we are fortunate to have them with us. I am also pleased that representatives from both Lockheed Missiles and Space Company and Hughes Danbury Optical Systems will testify today. Together, these witnesses will help us better understand the current situation, as well as any actions the Congress must take to improve NASA and the U.S. space program.

It is our responsibility to work together to solve the problems encountered with the space shuttle and the space telescope. As Chairman of this Committee, I intend to work toward that objective.

Senator GORE. We are honored to have as our lead-off witness James R. Thompson, Jr., Deputy Administrator of NASA, who was also, of course, the Center Director at Marshall for some of the time involved here and so, perhaps, can supplement some of the answers of those who have line authority now but did not years ago.

If you could give us an overview to lead off, Mr. Thompson. I want to call you J.R.; I am so used to doing

STATEMENT OF JAMES R. THOMPSON, JR., DEPUTY ADMINISTRATOR, NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Mr. THOMPSON. Thank you very much, Mr. Chairman and other members of the Committee.

I certainly appreciate the opportunity to appear here today with my colleagues. I have no written testimony but would like to summarize some of my opening comments.

As you know, I have asked to join this hearing, since I am probably the senior NASA manager that is in the agency today who has had the most direct oversight responsibility on the Hubble Space Telescope program. And my personal involvement in the development of the space shuttle propulsion system now dates back almost two decades.

My management oversight of Hubble began when I returned to Marshall as director in late 1986, when we were at that time in the early phases of preparation for returning the space shuttle to flight; and certainly more recently, during the past year here in headquarters, as NASA's deputy administrator, where I was actively involved in the final flight readiness reviews prior to the flight, and personally feel directly responsible for the success of this mission.

I, with many others, applauded the launch of the Hubble; and since then I have been equally proud of our NASA and contractors' teams methodical and systematic checkout of the Hubble system. As we worked through the solar array, a deployment suspense, solved the interference issue with the high gain antenna, the guide star acquisition work that has already been accomplished, and came up with the fix of the bit reversal of the fine guidance electronics when crossing the South Atlantic anomaly, the space craft jitter issue caused by the thermally induced gradiance and the solar array booms now we believe is behind us, as are all of the above.

And now we are dealing with the problem of fixing the optics on the optical telescope assembly itself. Certainly I think from what I have read, others may be running away from Hubble. I am not, and NASA is not. I think it is far too early, and it is not justified. I am convinced in a very quick order we will land on our feet on Hubble. I have been with this agency far too long to revert to just a sideline Monday morning quarterback every time something does not work.

But do not get me wrong, Senators; I get as irritated as anyone, and perhaps more so than most, at mistakes. And I think we will learn from whatever mistakes we have made. I am convinced, though, that rigorous analysis and solid engineering are going to return Hubble to specification performance. And I believe that we have got the right team in NASA today to do the job.

Before closing, let me just give you a word on the hydrogen leak we have now found on two successive space shuttles. NASA today is doing exactly what we told this Committee, what I told this Committee, as well as NASA's Administrator Dick Truly on several occasions, as we testified here in this room during the shuttle recovery period after the accident. And that very simply stated was, we would not launch until we are ready. Today we are not ready. But I believe with the work that is in process, that we will be back in the air and will do it within a fairly short period of time.

At this point, Senators, I would like to pause and stop and ask my colleagues—and I would suggest we start with Len Fisk on my right—if they would like to add any remarks to my opening statement. And then we would be more than happy to try to answer your questions.

Senator GORE. Whichever order you care to go in is perfectly fine with us. We had a lengthy and informative session with Dr. Fisk a little over a week ago, and we will be glad to hear from you again now, Dr. Fisk. And we appreciated you joining us in the classified session as well.

STATEMENT OF LENNARD A. FISK, Ph.D., ASSOCIATE ADMINISTRATOR, OFFICE OF SPACE SCIENCE AND APPLICATIONS, NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Dr. FISK. Thank you, Mr. Chairman. I will be brief. Let me just bring you up to date on what has happened since the last time we talked at our hearing last week.

We have put together, on Hubble, essentially two panels, two optical panels. The first was to look at the data that we had from Hubble just to confirm that we did, in fact—that the best explanation to date is that we have this spherical aberration.

That panel met last week. And its report did, in fact, confirm as we expected that the most straightforward explanation of our problem is spherical aberration in the mirrors. But I think perhaps most important here, they also confirmed our conclusion that it is a very straightforward correction that can be made to return Hubble to its full capability, that the aberration is in fact such a simple aberration that it is a straightforward matter to incorporate in the second generation of instruments a full correction to this problem.

The second panel that has met is chaired by Dr. Lew Allen, the Director of the Jet Propulsion Laboratory, and is chartered in reviewing what in fact happened to the mirrors to cause the aberration when they were made back in the early 1980s. That panel also met on Thursday and Friday of last week, and it was a very productive meeting in that they put into two categories the processes that were used in constructing the mirror—those that are likely to cause an error of this size, and those that are not likely. They have focused now on examining the processes that could have caused an error of this size to try and determine what in fact did occur.

Over this week and next, there will be an extensive review of documentation going on and of the physical systems that were used to produce the mirrors. These physical systems still exist in their original configuration. Examination of those looking for evidence that would allow us to determine where the error was in fact made.

This panel will meet two weeks from yesterday—and the Lew Allen panel will meet two weeks from yesterday in Danbury, CT to review the outcome of that review. They will also examine proposals for subsequent tests if we are unable to find the error by physical examination of the equipment or by examination of the documentation.

We will at some point have to begin to think about tests of the existing backup secondary mirror and of the metrology unit itself which was used to make the primary mirror. We will examine those test procedures two weeks from now and decide where to go from there.

[The statement follows:]

STATEMENT OF DR. LENNARD A. FISK, ASSOCIATE ADMINISTRATOR FOR SPACE SCIENCE AND APPLICATIONS, NASA

Mr. Chairman and Members of the Subcommittee I am pleased to have this opportunity to report to the Subcommittee on the status of the Hubble Space Telescope (HST).

When I appeared before this Subcommittee on June 29th, I reported on NASA's preliminary assessment of tests conducted on HST over the weekend of June 23-24. These tests suggest that HST is experiencing what we believe is spherical aberration, or an inability to focus light into a single, precise point. I want to stress that our understanding of this anomaly is incomplete and it remains under study; however, NASA feels it is important to maintain our policy of openness with the public and the Congress. As I stated at the last hearing, I am prepared to provide whatever briefings and testimony you deem appropriate to keep you and the other members of Congress fully informed of this situation as it unfolds.

First, this spherical aberration is significant because it prevents Hubble from fulfilling one of its primary requirements, namely, that "70 percent of the total energy of a stellar image must be contained within a radius of 0.10 seconds of arc." Hubble is currently able to focus only 15 percent of an image's energy into that same area. However, and let me stress this again, this aberration will not prevent Hubble from answering the fundamental questions about the universe it was built to investigate. New,

exciting, and unique science will be conducted using Hubble in the near-term and over its entire 15-year lifespan, beginning almost immediately. Hubble will not be able to conduct certain scientific activities in the near-term, but it will be able to substitute significant science in a number of equally important areas. And over the next few years, Hubble's capabilities will be fully restored, allowing us to recapture the science that will be deferred in the interim.

It is important to remember that NASA was established to do challenging missions; missions that require men and machines that push the envelope of technology to its limits. The true test of NASA's abilities should be, and must be, how we react when confronted with adversity; how quickly and efficiently we overcome this problem. I am confident that we can, and will, overcome this.

Clearly, the first step has to be finding out the cause of this aberration. As I reported at the last hearing, I have established the Hubble Space Telescope Investigation Board to investigate the cause of this anomaly. This Board will be a working group charged to review, analyze, and evaluate the facts and circumstances regarding the manufacture, development and testing of Hubble's Optical Telescope Assembly.

This Board is chaired by Dr. Lew Allen, the Director of the Jet Propulsion Laboratory, and is composed of world-renowned experts in optical systems and spacecraft quality control. During this past week, the other members of the Board were formally announced. They are:

Charles P. Spoelhof (Retired) Vice President, Eastman Kodak Co.

George A. Rodney NASA's Associate Administrator for Safety and Mission Quality

John D. Mangus Head, Optics Branch, Space Technology Division NASA's Goddard Space Flight Center

Prof. R. (Bob) Shannon Director, Optical Sciences Center University of Arizona, Tucson

Dr. Roger Angel Professor of Astronomy, Steward Observatory University of Arizona, Tucson

The Board held its first preliminary meeting in Washington, D.C. on July 5 and 6. A copy of the Board's public statement following its first session is enclosed.

The second step is to continue the process of characterizing this problem and to understand its impacts on the scientific goals of Hubble. Our goal will be to maximize the scientific return of Hubble in the near term, as well as over its 15- year lifespan. Last week, the Hubble Science Working Group authored a white paper which summarizes their preliminary assessment of the impact on the science program. With your permission, I request that the Science Working Group's white paper be entered into the record.

In the next few months, NASA will be working with the Space Telescope Science Institute (STScI) and the Science Working Group to replan the scientific program for Hubble. As Dr. Peter Stockman reported at the last hearing, our initial assessment is that approximately 50 percent of the observations originally scheduled for HST are still viable. Again, as Dr. Stockman reported previously, part of the peer review panel that selected HST's first-year observations will be reconvened to reevaluate the proposals in light of Hubble's current strengths. It is important to remember that since there were ten times as many observations approved originally as could be scheduled during the first year, there is little doubt that HST will continue to be oversubscribed.

The third step of this process will be to develop and implement a long-term solution to the aberration. Our preliminary assessment is that the inclusion of a relatively small corrective mirror or lens in the front of the second generation instruments should eliminate the scientific impact of this aberration. We believe that this solution should be very straightforward and should not result in a significant cost or schedule impact in the development of the new instruments. NASA will also explore accelerating the delivery of the new instruments, especially the second Wide Field Planetary Camera, to further minimize the scientific impact.

Remember, what we are talking about here is not "losing science" as has been reported in the press; but rather, altering the mix across areas of science for the next few years. During this interim period, we will be deferring some significant science, primarily in visible light imaging, while substituting equally significant science. The bottom line is that visible light imaging will occupy a smaller portion of on-target observation time while ultraviolet observations, spectroscopy and astrometry will occupy a larger portion during the first few years. We fully expect that' after the second generation instruments have been delivered on orbit, that all the science that is deferred will be successfully completed. And when examined over its full 15-year operational lifetime, the relative distribution of observation time across the science program will even out.

I should also note that there appears to be the potential for acquiring additional visible and ultraviolet imaging science. We have formed a "tiger team" to review the potential benefits of various image processing or reconstruction techniques. It is thought that such techniques could provide up to three times more resolution than the current performance and thereby make some of the imaging science viable. We should have some more definitive answers on this by mid-August.

In conclusion, I would like to emphasize three points. First, we are committed to determine how and when the problems in the Optical Telescope Assembly occurred which led to the observed spherical aberration, and how this aberration could go undetected prior to launch. Second, we are committed to strive forward in understanding this problem relative to its impact on the scientific goals of the program and subsequently maximize the scientific return of this facility both in the short term and the long term. Finally, we are committed to develop and implement a long-term solution to the aberration to assure that the full potential of the Hubble Space Telescope is realized. I believe that

we will witness discoveries by the scientific community that will be characterized as world class. As Dr. Bahcall so aptly stated. "When we read the history books of this decade, we will not notice the prescription for the Hubble mirror was slightly askew. But we will notice that we opened major new chapters in the understanding of the universe. It will be an intellectual revolution."
Thank you very much.

Senator GORE. We are going to hold our questions until all four witnesses have finished.

STATEMENT OF WILLIAM B. LENOIR, Ph.D., ASSOCIATE ADMINISTRATOR, OFFICE OF SPACE FLIGHT, NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Dr. LENOIR. Thank you. I will submit for the record my testimony. Rather than highlight that, what I will do is to bring it up to date, since it was written yesterday, and our efforts continue.

As you know on the STS-35 or the orbiter Columbia, we have the hardware from that vehicle on both the orbiter's side and the external tank's side in the laboratory in California, undergoing tests. Those tests are continuing, and we have verified that it does leak.

Because of different thermodynamic conditions between what we saw on the pad and what we see in the laboratory, we cannot say that it is of exactly the same magnitude, but it is roughly equivalent. Our work continues in an attempt to isolate exactly where in the complex umbilical system it is coming from.

As of yesterday it would appear that the seals around the shafts into the 17-inch pipe, if you like, are suspect at this point and may be providing up to half of our total leak.

Until yesterday we felt that the main interface on that 17-inch pipe at the disconnect plane was highly suspicious. Yesterday we measured not very much leakage at that point, so we have to revisit that conclusion as well as to look at the data again.

STS-38, or the Atlantis vehicle, remains on pad A at the Cape where we experienced the first leak. We are in the process of reinstrumenting and adding significant instrumentation to that configuration in order to locate exactly where the leak comes from and to quantify it.

The testimony that we submitted yesterday indicates that we will be doing that on Saturday. We are running somewhat ahead of schedule and today our schedule indicates that we will be into that test on Friday morning. If our luck holds with us, Friday should hold. Again we will be isolating and trying to quantify the leak.

There are some similarities and some differences between the two vehicles. We must keep our minds open that we may be dealing with totally different and independent leaks.

We have reviewed our paperwork, our people, our quality assurance and everything that we have done to date in getting ready for each of those flights and we have detected no anomalies.

I should emphasize that at no time was our safety compromised. As J.R. indicated, our process was put in place in order to recognize potential safety concerns and to not fly. That is exactly what we have done.

With that, I will stand by for questions.

[The statement follows:]

STATEMENT OF DR. WILLIAM B. LENOIR, ASSOCIATE ADMINISTRATOR, OFFICE OF SPACE FLIGHT, NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Mr. Chairman and Members of the Subcommittee:

During the launch attempt for the STS-35 mission on May 29,1990, a hydrogen leak in excess of limits established to maintain safe operating conditions was detected by onboard hazardous gas detection systems. Leakage was detected both in the aft compartment and external to the liquid hydrogen external tank/orbiter umbilical assembly.

A subsequent tanking test that incorporated special ground instrumentation further isolated the leak to the free space between the two halves of the umbilical assembly. The umbilical provides capability to load propellant into the external tank and transfer propellant from the external tank to the Space Shuttle main engines during launch. The umbilical disconnect assembly is the separation point between the orbiter and the external tank after main engine cutoff.

The design of the umbilical disconnect has remained essentially the same throughout the Shuttle flight program except that a safety modification to incorporate a valve latch, which precludes inadvertent closure, was authorized after the Challenger accident. Data from the tanking test determined that the design changes incorporated by this modification did not contribute to the leakage.

Following rollback and orbiter demate, the LH2 External Tank (ET) side of the umbilical was removed and tested at Rockwell International, Downey, Calif. The testing was performed under precisely controlled liquid hydrogen test conductions. No leaks were detected. On June 29,1990, NASA conducted a modified propellant loading test of the STS-38 Space Shuttle vehicle to ensure the safety and integrity of the orbiter/ET umbilical. The test revealed a hydrogen leak. The results indicate the leak is in the vicinity of the umbilical mating plates. It appears to be primarily from the 17-inch line but possibly with a contribution from the 4-inch line. The leak is flow rate and temperature dependent. It is not as high as STS-35 but it exhibits many of the same characteristics.

Leonard Nicholson, Deputy Director, Space Shuttle Program, leads the NASA/industry team charged with analyzing the cause of the leak and determining corrective actions. Under Nicholson, four work teams have been formed:

Design and Analysis Team—to assess the flight hardware and ground support equipment hardware designs, fabrication and test programs, and assess ground processing procedures to ensure compliance with design intent.

Hardware Processing Team—to review all Kennedy Space Center procedures associated with ET and orbiter processing, including "as run" data, problem reports, processes, procedures and personnel certification.

Data Analysis Team—to analyze data from the tanking tests and applicable launches to identify trends, define additional tests and instrumentation needed to understand and isolate the source of the leak and review all tests currently planned for completeness and appropriateness

Fault Tree/Test Requirements Team—to develop and provide to the other teams a fault tree identifying failure scenarios and identify additional tests and data requirements.

An independent team, headed by Wayne Littles, Deputy Director, Marshall Space Flight Center, Huntsville, Ala., also has been formed with senior NASA and contractor representatives who are experts in liquid hydrogen technology. While they will work independently of the investigation teams, they will report to Nicholson and support the team as appropriate.

An extensive investigation is being performed to isolate the source of the leakage observed on both the STS-35 and STS-38 vehicles. In the interest of safety, all potential leak sources, including the very low probability of a parent metal flaw, are being investigated. A detailed investigation of all aspects of the STS-35 and STS-38 component history, including acceptance test procedure requirements and data, and design changes, is being performed.

STS-35 Umbilical Testing Columbia is in the Orbiter Processing Facility (OPF). The orbiter side of the LH2 umbilical from Columbia was shipped to Rockwell International on June 30 and was mated to its external tank umbilical in a special test fixture. On July 7, engineers completed the first in a series of tests in which the mated umbilical was exposed to super cold liquid hydrogen in a manner similar to conditions on the launch pad. The umbilicals were heavily instrumented to pinpoint the source or sources of the leak. Sensors detected hydrogen leakage in the umbilical at levels which exceeded design specification. Instrumentation measured a total leakage of about 2,700 standard cubic inches per minute (scim). Continuing tests on July 8 resulted in leak rates up to 8700 scim with an apparent complex dependence on temperature.

Following calibration checks to verify the accuracy of the leak detectors, and some modifications to the test equipment to ensure a good quality of liquid hydrogen was flowing through the umbilicals, the tests were repeated on July 8 to verify what was observed during the first series of tests. The results were similar. Analysis of the data continues in an effort to precisely determine the leak source.

STS-35 Tanking Test Meanwhile, engineers are preparing for a second on-pad tanking test of the STS-38 vehicle to isolate and identify potential leak sources. The test is currently planned for July 14.

To date, leak detectors at the launch pad have been reverified to be calibrated correctly and additional instrumentation is being installed around the umbilicals. Technicians are putting bags around all critical joints which are suspect, and detectors are being placed inside the bags to obtain a precise measurement of any hydrogen that may leak out of those joints.

Other Accomplishments—The investigation team has eliminated one of the early suspects for the leak, a minor misalignment between the external tank and the orbiter 3 centerlines observed and measured on both the STS-35 and STS-38 vehicles. Analysis has shown that the orbiter has sufficient

compliance to accommodate misalignments much larger than that measured on these two vehicles and still meet design specifications. This analysis has effectively ruled out the misalignment as a cause of the leak.

In addition to the work already described, the investigation team has calibrated leak detectors at the launch pad at KSC and conducted a mapping test with gaseous helium to ensure the detectors were performing properly.

— conducted visual inspection of STS-35 orbiter and ET seals and shipped to Downey to be used in liquid hydrogen test. @PARA8 = — developed a comprehensive test plan for both the Downey and KSC tests.

— compiled and baselined a comprehensive data package for members of the investigation team to use as a common starting point for the investigation.

— started a detailed review of the development history of all the external tank umbilicals built to date, with a special focus on 32 tanks (series 2000) which exhibited a higher mean leakage rate during qualification testing than any other series of tanks, and a comprehensive review of all the test data which qualified those umbilicals for flight.

— begun an exhaustive investigation into the history of the umbilical seals used in the Shuttle program.

— started a detailed review of the "as run" procedures used to mate the external tank to the orbiter.

— begun a painstaking analysis of the data from the STS-35 launch scrvb and the STS-38 tanking test to calculate as accurately as possible the leak rates based on the concentrations of hydrogen measured during those two events.

— conducted a review to identify other potential test facilities which could be used to better simulate the launch configuration of the external tank and orbiter umbilicals.

The ET/Orbiter umbilical is fully developed and qualified flight hardware that has met all of the functional requirements stipulated by specification. An acceptance test procedure, which is a screen to verify the manufacturing process for each component delivered, has been developed from performance requirements. The ATP stipulates the use of liquid tutrogen as an acceptable substitute for liquid hydrogen, which is extremely dangerous and volatile to handle.

The disconnect component specification allows a maximum hydrogen leakage of 200 standard cubic inches per minute (scim) for the mated disconnect assembly at cryogenic temperature (150 scims for the ET and 50 scims for the orbiter). The ATP has a more stringent limit on the ET disconnect, which is 50 scims. This allowable leakage rate was established to compensate for the temperature and media differences between liquid nitrogen and liquid hydrogen. The orbiter disconnect underwent ATP testing with liquid hydrogen because there are a limited number of production units.

Until the leak investigation is complete, Shuttle flights have been suspended. Returning the Shuttle fleet to flight status is the highest priority in the Space Flight Office, and every available resource within the Shuttle program is being brought to bear on solving this problem. An outstanding team is in place conducting the investigation and making significant progress on a daily basis. We believe the source of the leak can be isolated quickly and the problem fixed with minimum disruption to the Shuttle flight program.

Independent of these events, a component redesign to replace the current umbilical disconnect with a new design, has been underway and is well into the preliminary design phase. The new disconnect incorporates significant safety improvements, including redundant seals at all locations.

Senator GORE. Thank you very much.

Mr. Rodney.

STATEMENT OF GEORGE A. RODNEY, ASSOCIATE ADMINISTRATOR, OFFICE OF SAFETY, RELIABILITY, MAINTAINABILITY, AND QUALITY ASSURANCE, NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Mr. RODNEY. Mr. Chairman and distinguished members of the Subcommittee, I appreciate this opportunity to discuss the functions and activities of my office, the Office of Safety and Mission Quality. I might add that is a slightly different title than you are used to hearing; we have been going by the name of Safety, Reliability, Maintainability and Quality Assurance. We have shortened it. I assure you that it has had no impact on my roles and responsibilities.

Senator GORE. That sounds like a good decision.

Mr. RODNEY. Just a few words about what constitutes our safety and quality program. First, we are not talking just a single department—we are talking a commitment by NASA, really; and the responsibility for safety and quality rests

in the program management and in the line management. In my vernacular, the line management is our center directors, who implement the program objectives.

Our safety and quality organization works in conjunction with those organizations. We share the responsibility for the safety and quality. We provide the specific safety and quality policies and requirements. We verify the as-built hardware meets the engineering and program requirements. We insure through reviews, analysis, and independent assessment that the system is both safe and has the highest probability of mission success.

Now, when a program is successful, you will very rarely hear us mentioned. When we have a problem like we are having right now, we must share responsibility for the fact that we did not discover that problem and prevent it.

Since Challenger, we have developed a system and provided the resources that meet the findings of the Rogers Commission and the various Congressional inputs of the time. In fact, after Challenger, Mr. Chairman, as you mentioned in your opening remarks, you had some very pointed observations about the significant reductions that had occurred in the quality world. We have corrected that situation.

I will give you a few statistics. Between 1986 and 1990, in the civil service area, we have increased our civil service roles by 58 percent, from 845 to 1333. Now, included in there, one of the areas that you were worried about was the NASA Marshall Space Flight Center. We have increased that area by 128 percent, from 107 people approximately at that time to 245. My headquarters office has increased from 33 to 78. The support contractors that are in direct support of the civil service group—these are not the contractors that build our hardware, these are the ones that support us—has just about, well, has slightly more than doubled, from 711 to 1453. So we have made significant improvements in the resources available.

We have developed an aggressive, pro-active operation which involves every step of the program design, the development, the test, the build, the operation. We are active members in the design reviews, the test-readiness reviews, the launch-readiness reviews. Unlike the Rogers Commission, we are not a silent member in those reviews, and I sit beside Bill Lenoir at the launch-readiness reviews.

We do independent assessments throughout the operation to provide a check and balance on program decisions, and we have a separate safety review process that concentrates on safety issues.

We have concentrated our early efforts on the space shuttle. Since the return to flight, we have espoused safety first and schedule second. As J.R. and Dr. Lenoir stated, our current standdown is not the first evidence that this philosophy is well ingrained in NASA operations. It was one of the cardinal lessons of Challenger and it is being well honored.

Another cardinal lesson of Challenger was a lack of communication and candor concerning technical issues within NASA. The openness that we have used in discussing our current problems and preceding ones is ample evidence, I believe, that we have corrected this deficiency.

My office also has many initiatives in process to better insure the reliability and mission success of our future programs. To just mention a few, batteries are an inherent part of almost any program, and we have an active program to attempt to improve the manufacturing, the design, and the testing of batteries.

One of the sources of some of our problems is deficiencies in electronic packaging design. We have a program working to improve our electronic packaging. We have an active, very active role in improvement of what we call EEE parts, piece parts, which are the source of many failures in our aerospace

programs. We have a very active program to improve those. When I can get the funding, I want to do that on some of the mechanical parts. We are working Kapton wire, which is the aerospace standard wiring, to see if we can improve that issue.

NASA has taken the lead among government agencies to try to expand the so-called GIDEP, the Government Industry Data Exchange Program, to cover things more than just EEE parts. There are a lot of—I can go on and on with this list.

Now, a few words concerning our immediate problems. You have heard Dr. Lenoir describe the status of the space shuttle hydrogen leak. We do not know whether we have a very subtle hardware quality issue, or a very subtle engineering issue. It is obviously not easy to trace down, since we have had literally hundreds of people working the issue.

We are all very concerned why we have this particular situation at this time. We are proceeding in an orderly fashion and will insure the safety of the space shuttle. We will enhance the safety of the space shuttle and its overall reliability at the same time.

Now, in respect to the Hubble telescope, you are probably aware that I am a member of Dr. Allen's review team that is chartered to isolate the cause of the present problem. I particularly wanted to be a member of this team, as the events in question all occurred before my tenure with NASA.I wanted to see firsthand what lessons learned we may need to apply to future programs of this type.

Now, I might add that this is not a cop-out. The fact that this occurred before me does not mitigate my responsibility as I sit here. As part of this review, we will examine in detail the roles and activities of the safety, reliability, maintainability, and quality assurance activities during the design and development period of the telescope.

It might interest you that we have been active since that period, since Challenger, and I might sketch a few of the things we have done in this area. We were active participants in the program recertification review after Challenger, in which we re-reviewed the critical failure modes and effects analysis, and the hazard analysis. One of the things that came out of this review was the fact that we did have a re-inspection to check the staking of the bolts on the mirror assembly.

We were very instrumental in the decision of changing from Nicad batteries to nickel hydrogen batteries. We were instrumental in the decision process to determine whether we should do a thermal vacuum test after the long standdown. We also conducted a variety of independent analyses of such things as the thermal model as it impacted the electrical profile, the electrical power supply. We looked at the solar array degradation over time, and we re-reviewed the approach to factors of safety on the composite structure.

Now, these latter analyses, by necessity, were done rather late in the program, but are indicative of the types of independent design analysis that our current approach to safety and quality is doing on new programs.

Another interesting thing: we have done everything possible to open our lines of communication so people feel free to air their concerns. It is interesting to note that prior to the program office revealing the telescope problem, I can find no evidence of anyone approaching our organization to question the quality or testing of the mirror assemblies.

That concludes my remarks, and I thank you for the opportunity.

[The statement follows:]

STATEMENT OF GEORGE A. RODNEY, ASSOCIATE ADMINISTRATOR FOR SAFETY AND MISSION QUALITY, NASA

Mr. Chairman and distuinguished members of the subcommittee. I appreciate this opportunity to discuss the functions and activities of the Office of Safety and Mission Quality (OSMQ). Since its inception as the Office of Safety, Reliability, Maintainability and Quality Assurance (SRM&QA) in July 1986, the OSMQ has refocused NASA's overall approach to safety and quality assurance. Although we have recently changed our Office designation to OSMQ, we have not changed our orientation. The Office of Safety and Mission Quality is still the primary advocate for NASA SRM&QA The current level of SRM&QA involvement within NASA was not in place 10 or more years ago when the early Hubble Space Telescope concept and design activities were underway. In the brief 4-year period, the OSMQ has established new NASA-wide policies and procedures on safety and quality in support of NASA programs.

As a multi-discipline organization, the OSMQ performs independent assessments and reviews of all NASA programs as related to SRM&QA requirements. OSMQ assurance engineers and managers at Headquarters and throughout the NASA community actively participate in each stage of development of NASA systems, projects, and products from initial concept and design through test and operation. The objective is to infuse SRM&QA requirements at the earliest possible stage during development. Our goal is to work in partnership with program and project management to ensure that safety and quality considerations are inherent to each initiative.

SRM&QA resources have increased each year, allowing NASA to successfully achieve an integrated technical and managerial approach to SRM&QA This has been accomplished primarily through the careful selection of highly qualified personnel for each task area. The skill level and demonstrated performance of SRM&QA personnel lends immediate credibility to the independent technical evaluations that we must perform. The total civil service workforce for NASA SRM&QA at Headquarters and the field centers has increased from 845 in 1986 to approximately 1,330 today. The personnel are distributed based on the needs of current activities. As one would expect, the highest concentrations of SRM&QA personnel are at the field centers which directly support space launch/mission activities (Kennedy Space Center, Johnson Space Center, Marshall Space Flight Center, and Goddard Space Flight Center). Our government SRM&QA work force is supplemented by a contractor SRM&QA workforce that exceeds 6,000 people providing us with a current staffing total of approximately 7,600 people. These dedicated individuals are working in many different facets of the SRM&QA environment from the Headquarters level down to the Centers and support contractors. Detailed information regarding NASA-wide SRM&QA staffing is shown in Attachment I. SRM&QA funding has increased every year since the OSMQ was initially established. As a result, our current funding level is approximately $578 million, an increase of 22.5 percent over the last 2 years. The details of our funding over the past 3 fiscal years are shown in Attachment II.

At NASA Headquarters, the overall SRM&QA program encompasses a variety of assurance professionals in the following areas: Safety; Reliability, Maintainability and Quality Assurance (RM&QA); Program Assurance; systems Assessment and Trend Analysis; Quality and Productivity Improvement; and the Space Station Freedom Program (SSFP) Safety and Product Assurance.

The Safety Division provides oversight of all NASA programs and activities to eliminate or reduce the probability of accidents and hazards by achieving an optimum level of safety at the onset of system and program development. This division assures that safety risks are eliminated or controlled to an acceptable level consistent with program objectives for cost, schedule, and performance.

The RM&QA Division formulates and implements policies, procedures, requirements, and research technology objectives/plans to assure that RM&QA practices within each program are consistent with NASA goals, prescribed law, and federal regulations. This division also establishes technology development programs that advance the state-of-the-art in assurance techniques Additionally, it plans and administers NASA product assurance activities.

The Program Assurance Division provides common SRM&QA policies for all NASA programs. As a member of the Space Shuttle Management Team, this division actively participates in the prelaunch and launch decision process, which includes signing the Certificate of Flight Readiness and voting on the launch go/no go decision.

The Systems Assessment and Trend Analysis Division is the result of a recent consolidation of the Data Systems/Trend Analysis Division and Systems Assessment Division. This division has been rigorously staffed with experienced civil service and contractor personnel. Since the first part of this year, this division has completed significant independent assessments that are influencing current Shuttle program activities and has directed a NASA-wide trend analysis program conducted at Headquarters and the NASA Centers.

Within NASA, the OSMQ Quality and Productivity Improvement Programs Office promotes and recognizes timely delivery of high quality, error- free, cost-effective products and services. This Office develops, promotes, and applies advanced technology and management practices that contribute to NASA quality and productivity improvement.

The SSFP Safety and Product Assurance Office plans, directs, implements, and evaluates SRM&QA activities pertaining to the technical execution and physical readiness of the Space Station. This Office performs overall technical oversight of the SSFP to ensure developmental efforts are

being conducted on a sound engineering basis with proper controls. In particular, the focus is on identifying and precluding risks/hazards that can cause loss of life, personal injury, or significant structural damage to the Space Station.

Our efforts at Headquarters are significantly amplified by the support provided by the SRM&QA organizations at NASA field installations, including the centers, laboratories and testing facilities, contractors, subcontractors, and suppliers. The on-site, day-to-day involvement of these SRM&QA organizations in the development and operations of NASA programs and projects is integral to ensuring mission safety and quality.

The OSMQ concentrated most of its early SRM&QA efforts on the Space Shuttle Program. As NASA was moving toward Shuttle return-to-flight in 1988, the SRM&QA community espoused a "safety first, schedule second" approach to launch operations. NASA has fully embraced and endorsed this approach. The recent stand-down of the Space Shuttle program due to hydrogen leaks in the External Tank/Orbiter hydrogen umbilical disconnect system testifies that SRM&QA considerations have become paramount within NASA. Since return-to-flight and as our resources increased, we have been able to apply our SRM&QA assets across a broader spectrum of activities.

As you are undoubtedly aware, the NASA Office of Space Flight (OSF) has embarked upon an extensive test and analysis program to identify and ultimately correct the leaks in the External Tank/Orbiter hydrogen umbilical disconnect system. The Associate Administrator for Space Flight and the Director of Space Shuttle are conducting open status briefings at least twice per week to keep the public advised of all analysis findings. The OSMQ is closely monitoring these analyses. In addition, the OSMQ is supporting these OSF activities with data extracted from our extensive problem reporting systems resident at the field centers and contractor locations. We also are conducting independent reviews/assessments of the collected data.

Also, we have begun to focus more intently on NASA payload programs. We are supporting and providing oversight of payload-related activities at the centers that primarily support payload development (Goddard Space Flight Center, Lewis Research Center, Langley Research Center, Ames Research Center, and the Jet Propulsion Laboratory). It is impossible to state with certainty that the Hubble problem would have been detected if our current OSMQ organization had been in place. However, we are now taking a more active role in the early phases of program design and development where we can better influence the requirements for test and evaluation. The degree of this involvement is less than for manned systems.

As the Associate Administrator for Safety and Mission Quality, I was recently appointed to serve as a member of the Hubble Space Telescope Optical Systems Board of Investigation. Established on July 2, 1990, the Board is tasked to review, analyze, and evaluate the facts and circumstances regarding the manufacture, development, and testing of the Hubble Space Telescope Optical Telescope Assembly. This distinguished Board, which is headed by Dr. Lew Allen, Director of the Jet Propulsion Laboratory, began its investigative activities on July 5, 1990. Engineering, manufacturing, inspection, and testing records will be reviewed in detail by the Board of Investigation. Until our investigation is complete, it would be premature to speculate on causes or solutions.

Our SRM&QA organization at the Marshall Space Flight Center has directed the Defense Contract Administration Services (DCAS) representative at the Hughes Danbury Optical Systems, Inc. facility (formerly the Perkin-Elmer Co.) in Danbury, Connecticut to impound all discrepancy records related to the Hubble Space Telescope at that facility. These records include those of the Material Review Board as well as the detailed manufacturing and inspection records. All of this information will be used by the Board of Investigation.

With regard to NASA's program hardware in general, the OSMQ has established a Technical Standards Division to develop and implement NASA-wide standards and practices that support state-of- the-art and next generation applied technologies. The emphasis is on advancing applied technology that directly contributes to hardware improvements and SRM&QA-related enhancements as a major means of reducing program risk. This includes improved batteries and electronic piece parts, and better packaging design and manufacturing standards.

Another aspect of our early involvement in applied technology ventures is our active participation in the SSFP to integrate SRM&QA requirements into the early stages of development. The SSFP Safety and Product Assurance Office plans, directs, implements, and evaluates SRM&QA activities pertaining to the technical execution and physical readiness of the Space Station. Early SRM&QA involvement has been cited by a number of technical panels as fundamental to ensuring that SRM&QA factors are "designed in" rather than added on at later stages. The efficacy of this approach-of doing it right the first time-is realized in long-term savings in cost and man-hours. The SSFPO actively considers our requirements and issues in their programmatic analyses and reviews. This type of cooperation (with program management and engineering at all levels) is paramount to decreasing risk and increasing the potential for mission safety and operational success.

In conclusion, the current SRM&QA organization is structured to execute our responsibility to support all NASA programs from their early design phases through testing and actual operations. We believe it is an effective organization to carry out NASA requirements.

Senator GORE. Thank you very much. I am going to ask the staff to use a 10-minute clock on our questions. I anticipate we will have more than one round.

First of all, I think it is quite appropriate, Mr. Thompson, that you remind us of the many successful NASA accomplishments, even within the Hubble program, which is the focus of so much scrutiny now, after the mistake that occurred. Indeed, there have been remarkable achievements in solving a variety of problems of the kind which are to be expected in a program of this magnitude.

The problem that was not expected is the one which is the focus of a lot of our discussion here today. I also think it is appropriate, Mr. Rodney, for you to remind us of the many changes and improvements which have already been made by NASA in beefing up the quality control ability within the agency in the wake of the Challenger tragedy. And indeed, as you indicated, I did have a particular interest in that. And I want to say I have been impressed by what you have done in beefing up NASA's quality control capability.

In spite of all those good things, I am sure that all four of you understand very clearly why the public is concerned, and why it is necessary, in the light of an ambitious agenda NASA now has on the drawing boards, to have a thorough on-going review of these matters that have not gone well, and that have been very troublesome to NASA and to the whole country.

Dr. Lenoir, first of all, with regard to the fuel leaks in the shuttle fleet, it is my understanding that the umbilical assemblies now believed to be responsible for the problem were tested, and that actually 23 of the 60 assemblies failed in their first test. I also understand that two of those that failed are the ones now leaking. Instead of using the test failure as a trigger for redesigning the umbilical assembly, what was redesigned was the test. The test was made easier to pass. The new test used a liquid nitrogen which is 100 degrees warmer than liquid hydrogen which is used in shuttle operations. The second redesign test gave them a bill of good health.

Even though they failed the first test, they were put on the shuttles, and now two of those that failed are the culprits in grounding the shuttle fleet.

Is that essentially correct?

Dr. LENOIR. No.

There has been a lot written on this subject recently, and most of it comes out with the wrong flavor. Let me go back and describe what happened. The essence of what you say, some of which is true, some is not. The test was not redesigned. We have three different ways that we have tested the external tank side of the umbilical. The orbiter side of the umbilical is a component that is used over and over, so it gets tested once, is connected to an orbiter, and it gets reused.

The tank side of the umbilical is connected to the tank, and we throw it away with the tank. So we keep buying new ones, and then mating them with tanks and using them. Those new ones that we buy have to be acceptance tested, as we call it. The early ones were tested mated to a flight orbiter umbilical.

Senator GORE. What they call a slave unit?

Dr. LENOIR. No, it was an actual orbiter umbilical that connected to the orbiter—the flight unit. And we could do that until we accepted the last orbiter flight unit and connected it to an orbiter. Then it was no longer available for that test.

At that point we began using what was called a slave unit.

Senator GORE. Okay.

Dr. LENOIR. And then because of some difficulties associated with that sequence, we then later had a third way of doing it.

Senator GORE. Now, wait a minute. The difficulties associated with that test included the failure of the two units that are causing the problem now, right?

Dr. LENOIR. No. But what drove us to going to another way of testing was some of the difficulties in going through and actually performing the test. We invented something very similar to the slave unit called the orbiter simulator.

Senator GORE. Okay. Just wait a minute. Let me interject at this point.

Is it true that the two umbilical assemblies that are the cause of the problem right now, grounding the shuttle fleet, failed the test with the slave unit?

Dr. LENOIR. No.

Senator GORE. Is it true that 23 out of 60 assemblies failed during that testing sequence?

Dr. LENOIR. To the best of my knowledge, none has failed. That sequence comes in two parts, Senator. And the procedure, as originally written, has us do a sequence of functional tests, where we cycle valves and flappers with the external tank umbilical connected to the orbiter slave unit. Then we proceed into a leak test, where we put liquid nitrogen into it and we measure leak.

If that assembled unit, the tank umbilical and the slave unit do not exhibit a leak rate below a certain level—I believe it is 50 standard cubic inches a minute—then we remove the slave unit and replace it with a blanking plate. And this is all part of the original test procedure, unchanged, and repeat the test.

The premise there being that the slave unit is not flight hardware, it is not maintained to the same rigorous specifications that the flight hardware is, therefore is it more likely to be the subject of the leak than the flight hardware.

Senator GORE. Now wait a minute. Let me just be clear on this point.

You are telling us that, contrary to widely spread reports, none of these assemblies failed the test when the slave unit was used, is that correct?

Dr. LENOIR. No, the test is the total test.

Senator GORE. But wait a minute. I am trying to understand what you are telling me. There have been wide reports that when the slave unit was used in the testing program, approximately a third of the connectors failed. And two of those which failed are the two involved in the shuttle grounding. You are telling us now that that is just made up out of whole cloth, that it is not true, there is nothing to that?

Dr. LENOIR. I am taking issue with the use of the word "failed." I am saying at that step in the procedure, the leak rate on those 20-plus was indeed bigger than we were looking for, so we followed the procedure to the letter. We removed the orbiter slave unit. We replaced it with a closing plate that we knew did not leak, and we repeated the test. We did nothing different to the tank umbilical that would introduce or fix a leak.

Senator GORE. Well, now 20-plus, do you mean 23?

Dr. LENOIR. I do not know the exact number.

Senator GORE. Twenty-three out of 60 is what I am advised is the case. It has been reported 33 out of 60, but I am advised that it is 23 out of 60 failed or did not have an acceptable leak rate during that part of the test. Is that correct or not?

Dr. LENOIR. Those numbers are not exactly correct because we did not test 60 units that way. I will find the sheet here eventually.

Senator GORE. Mr. Rodney?

Mr. RODNEY. I believe we tested 27 with that setup.

Senator GORE. You tested 27 that way and 20 plus failed or 20 plus did not have the leak rate that you considered acceptable?

Mr. RODNEY. I would have to count them.

Senator GORE. Yes, please count them up.

Dr. LENOIR. It looks like 23 total.

Senator GORE. 23 of 27?

Dr. LENOIR. 18.

Senator GORE. 18 of 27?

Dr. LENOIR. They did not fail the test at that step.

Senator GORE. They just had an unacceptably high leak rate?

Dr. LENOIR. For that configuration. We, therefore, removed half of the configuration, the nonflight half. We repeated the test with the flight half, and they all passed.

Senator GORE. Did it cause you concern that 18 of 27 did not have an acceptable leak rate during that part of the testing program?

Dr. LENOIR. At that time it did not, because what we thought the problem was, and for that matter today still think, was the slave unit that was doing the leaking.

Senator GORE. Is it true that of those 18 which did not have an acceptable leak rate during that phase of the testing, two of those are the ones now leaking in the shuttle fleet?

Dr. LENOIR. That is correct. It is also true that many of those have flown and exhibited no leak whatsoever.

Senator GORE. Many or two?

Dr. LENOIR. One, two, three, four, five, six, seven, eight, nine, ten, 11.

Senator GORE. Okay, now wait a minute. There were eight in a row that failed during that testing sequence at one point; is that correct?

Dr. LENOIR. That is close, and that figure of eight comes from us. The real number is seven.

Senator GORE. Now of those seven in a row that failed, the two that are now leaking were part of that seven in a row; correct?

Dr. LENOIR. That is correct.

Senator GORE. Now of that seven, one flew successfully. One of the others was on Mission 33 which flagged the problem for you. Am I stating that wrong?

Dr. LENOIR. 29.

Senator GORE. 29 flagged the problem for you; correct?

Dr. LENOIR. Which flagged a problem. It is not clear it is the same; but yes.

Senator GORE. Okay, so that is two of them. One flew successfully; one flagged a problem which may or may not be the same problem. Then two are leaking. Where are the other three?

Dr. LENOIR. They are connected to tanks waiting to fly.

Senator GORE. Now when you took these 18 that did not have an acceptable leak rate during that phase of the testing and continued the testing program, you used liquid nitrogen; correct?

Dr. LENOIR. That is correct.

Senator GORE. Which is 100 degrees warmer than liquid hydrogen, which is what is leaking; correct?

Dr. LENOIR. That is correct.

Senator GORE. The leaks have occurred at the very low temperatures and very high flow rates, but the testing used 100 degree warmer liquid and was at a different flow rate, also?

Dr. LENOIR. Yes. Basically, it is a static test with no flow rate.

Senator GORE. With no flow rate?

Dr. LENOIR. That is correct.

Senator GORE. Okay. I guess the question that begs is since they did not pass one part of the testing program and since they are failing now and since the intermediate test, the test in between was at conditions which did not approximate the ones they have to go through. Was there something fundamentally wrong with your testing program?

Dr. LENOIR. The issue that you bring up on using liquid nitrogen vice liquid hydrogen is under review at this time. We suspect that that may not be an adequate

and distressful enough test on these units, but we have not yet come to that conclusion definitively. That is suspect.

We do not believe, however, that changing that would necessarily have found the problem. It is not clear at this point it is on the tank side.

Senator GORE. Okay. I am going to yield in just a second. In my next round I want to focus in on the Hubble, but the common denominator is, in my view, inadequate testing. A decision within NASA to be satisfied with a testing protocol which did not approximate the conditions under which the umbilical assembly was going to be used in that case or the final assembly of the Hubble to simulate how it was going to be totally configured in space, to test it that way before it was put into orbit.

In both cases, the testing program, which is part of quality assurance, was not handled in a way that caught the mistakes which have now shaken the public's view of how this is being managed. That is what I want to home in on in my next questions.

Mr. THOMPSON. Senator, I think there is no question but that any problem we encounter you can trace it back to some fundamental issue associated with lack of testing or could have been flushed out with additional testing. As you recall the details of the Challenger accident, there was that thread there as well.

I think these are real time judgments that we have to make all the time, and it may well be that in these two valves that we are talking about on the current orbiters that are leaking there may be something in the lot to which you alluded, in the way we are testing or in some other subtle issue that we have not been clever enough to date to find.

I do not think that we take issue that once we have a problem we can always look back on it and if we had done this and this and this we would have caught it. That has been said to me too many times through my experience in testing.

I am as convinced as you that more testing has just got to be better. Each day we are faced with these decisions, and we make what we believe are the right judgments at that time.

Senator GORE. Well, when you had seven in a row that failed—and I am going to use that word. You do not have to accept it.

Mr. THOMPSON. As Bill indicated, at that time the suspicion was or the thought was that the problem was on the ground support side——

Senator GORE. In the testing.

Mr. THOMPSON. On the ground support side of the hardware as opposed to the flight article.

Senator GORE. You concluded that the most likely explanation was that the test itself was flawed.

Mr. RODNEY. That is correct.

Mr. THOMPSON. Yes, with the ground support hardware.

Senator GORE. But then you followed it up with a test that was itself flawed.

Mr. THOMPSON. In retrospect that may turn out to be. I am not sure that that is the case.

We are not about to go out to the pad, roll out with anything when we are really concerned we have a problem. Clearly on these last two, I am quite confident that once we trace this thing to ground that we will find some simple reason and certainly never do that again.

Senator GORE. Let me just say one other thing here. If I were sitting in your chairs and answering the questions instead of asking them, I am sure I would feel the way I sense that you do. You have done so many things well and you have performed such a tremendous service to this country that, when these things go wrong, you feel like you get no credit for what you have done well. There are a

lot of great people at NASA who do their best and give their all and are even more heartsick than the rest of the country about these problems that are now coming to light.

You know, if the American people are going to have the confidence in your ability to handle projects like these, we have to get to the bottom of these things. When there is a pattern of what looks like inadequate testing and inadequate quality assurance which ends up grounding the entire shuttle fleet, rendering the Hubble telescope crippled for at least three years and causing other problems, then the public has a right to set a very high standard before agreeing to go ahead with an ambitious new agenda which requires a very high standard in order to insure success.

Mr. THOMPSON. You bet. We do not take exception with hearings like this, probings like this. We are much harder on ourselves than we read about in the newspaper and go through here today.

Senator GORE. All right. Senator Pressler.

Senator PRESSLER. Thank you.

I would like to ask, and indeed I would join in the remarks of Senator Gore, that you have done so many things so well and this is not just a process to find fault here. But, on how we do these things better, perhaps it is our fault in Congress the way we appropriate money to these agencies where the salary structure for engineers is perhaps lower than it is in the private sector, and where, although this was contracted out, the highly challenging things for engineers to do are performed, and then those engineers leave either because their contracts have expired because they are more expensive, or some other reasons, and the technicians who remain to do the testing are not of the same quality or are not as familiar with the program.

Is there some change in the personnel structure of the way engineers are hired or contracted for that could yield a better result here?

Mr. THOMPSON. Well, let me just state that certainly I think the numbers that the Senate mentioned earlier relative to the turnover in the Hubble program, both at Marshall, at the center, and at headquarters, are right on target. You have seen the same thing over the last several years in the space station. And I think those people that have left NASA have indicated publicly one of the major reasons happens to be the competitive salary.

Today, because of the attractiveness of the work, we do not have any problem hiring young people out of college. They love the type of work we do. There are certain high cost of living areas, like in Washington and out in California, where it gets a little tougher. But at our other centers that is not the problem.

What you are alluding to, retaining the skilled management and senior engineering personnel, is a problem. And yes, Congress can certainly help us with that. And I believe that steps are underway, unless turned around by the end of this year, to I think make a major advance in that direction and help NASA.

Senator PRESSLER. Does anybody else want to comment on that question?

[No response.]

Senator PRESSLER. All right. Let me ask you this.

As I understand it, the Space Shuttle Columbia and the Space Shuttle Atlantis have had almost identical hydrogen fuel line leaks. Has the remaining Space Shuttle, Discovery, been checked for fuel line leaks?

Dr. LENOIR. No, the requirement—well, the setup that is required to check it is essentially to be flight ready, mated with a tank, and out on the pad. And Discovery is in the orbiter processing facility undergoing preparation for its mission in October.

And until we resolve what our current problem is, we are more or less holding on any modifications on Discovery.

Mr. THOMPSON. Even if we knew that the rest of these valves in the system did not leak—let me just assume we knew that—we cannot proceed until we really understand this thing. We have been bitten too many times by trying to finesse something, and we are just not going to do it here.

Senator PRESSLER. Let me ask this, switching back to the Hubble problems. I guess in layman's terms, it is my understanding that the Hubble Space Telescope was never tested as a system before its launch, as a total system. I guess as just a basic question, why was not this ground-based testing performed?

Mr. THOMPSON. Well, you are right, it was not tested. The optical system is an all-up system. At that time, we did not feel it was necessary.

Now let me ask Len if he would like to expound on that.

Dr. FISK. It is important to know that there were many, many end-to-end tests of the spacecraft system, including the working of the instruments with the optical system over the time. What was not done is a combined test of the two mirrors working together in the optical telescope assembly.

It was judged, and I think in retrospect it was judged correctly, that the risk of doing the test and the cost of building a test facility that would have tested Hubble to its accuracy—remember we were building the world's greatest mirrors here, and therefore we would have had to build essentially the world's greatest test facility to test the world's greatest mirrors—that was not a necessary test to make.

Now, as always, if you have a problem, you say, well, there should have been a test that found that problem. And my guess is that, as we look at this, we are going to find that there were other tests that we could have done and should have done that would have revealed this problem. But I do not think that the end-to-end test decision was a bad one.

Senator PRESSLER. But I think in terms of the public perception, and we cannot be guided just by what people perceive, but people SAY. My word, when the car comes off the assembly plant, even though it has all been tested, somebody gets in and turns the switch and sees if it will go vroom, or whatever.

It is hard for a layman such as myself to understand why the Space Telescope was never tested as a total system. Is that unusual?

Dr. FISK. No, I do not think so. Again, the amount of tests that were done on the telescope facility itself, seeing that every piece of electronics worked, that all of the instruments had a clear path to the telescope, that the solar arrays were going to deploy, and the fine guidance sensors were going to work, all of those things were adequately tested, and the fact that this works on orbit as well as it does is proof of that testing.

The one test that was not done was building a facility in which you could put the two mirrors and test them to show that the focal plane was within a twentieth of the wavelength of light. And in very simple terms, we would have had to have built a test facility which had its optical properties as perfect or more perfect than that, and build it in such a way that you introduce no contamination into the telescope.

For example, J.R. mentioned earlier about thermal vacuum tests. We had a decision that several of us here were responsible for at the end of the telescope, of whether or not we should do a second thermal vacuum test. The first one was done in the 1985-86 time frame. And there was a lot of people who said, gee, you ought to do another one. Maybe it is not accurate any more.

And we decided that the risk of doing that was too high for what we were going to learn. It proved to be a wise decision. There are not any thermal problems

with the telescope. If the telescope were on orbit at the moment with major thermal problems, some of us would be very embarrassed that that was an unwise decision to have made. But you make those calls in the program.

I do think we are going to find that there were tests that should have been run that would have revealed this problem that were simpler to do than the kind of end-to-end tests, and perhaps there will be criticism that they were not run. But the end-to-end test was a question of cost, risk and what you learn from it.

Senator PRESSLER. Okay, well, that is good to have that explained. Because out in the general public, if they read that the Hubble Space Telescope was never tested as a system before its launch, those of us who are in the business of defending the program have a hard time explaining that. And I consider myself such very much a layman.

Mr. THOMPSON. But it is true that in the optical area that we did not do an end-to-end test for the reasons that Len mentioned. The structural modal test at the assembly level were done, acoustic tests, as he mentioned, thermal vacuum tests. These are tradeoffs we made. And I am sure once we pinpoint this problem in the investigative board, we will all look back and say, gee, we could have done that test for a fraction of what the pain has been to go through it. And I will lead that parade.

Senator GORE. Would my colleague yield on this point. Because I disagree with the way the exchange was left on this last point.

I think it is not just a technological decision, I think it is a philosophical issue. Regardless of how confident you are in the testing of the components separately, there is something about a final assembly test that gives you a reality check, a fail-safe procedure, that can catch problems which get through the component testing.

I personally believe that it was a mistake not to build into the bids the requirement of a final assembly test on the complete telescope as it was to be configured once it was put into orbit.

Now what do you think in retrospect, Mr. Thompson?

Mr. THOMPSON. Well, in retrospect, if we find the problem in that mirror, or one of the mirrors, that our experts now seem to be quite confident, then i think in some type of test, and it may be an all-systems test, would have been the right thing to do.

I am just guessing, but I suspect we will be able to look back on this and figure out some kind of test.

Senator GORE. Well, without compromising any of the classified material which we delved into earlier, let me state my understanding of how this came about, carefully, and ask you to comment.

There were two bidders, Kodak and Perkin-Elmer. Perkin-Elmer is now Hughes Danbury. Both bidders had experience that was relevant to the expertise they would bring to the Hubble. One of the bidders did propose a final assembly test. The winning bidder did not. The winning bidder, Perkin-Elmer, now Hughes Danbury, had a different testing philosophy and expertise that was probably more oriented toward aspects of the Hubble which at that time were thought to be the most difficult challenges to solve.

What I think went wrong is that NASA chose Perkin-Elmer for reasons it felt were valid, and may have been valid, because, as we have seen, the most difficult challenges—what were thought to be the most difficult challenges—have in fact been met.

But what went wrong is, in my opinion, NASA did not require that both bidders include in their bid proposal a final assembly test to check out the full

telescope as it would be configured in orbit before it was put into orbit. That could have been done. It could have been done. But it was not done.

Now, you can argue with that conclusion by saying well, technologically we know how to test all of the components in such a sophisticated way that we thought we would catch any such defect. But separate and apart from the technological decision, there is a question of "how much confidence are we going to place in component testing?" And how much are we going to accept the fact that no matter how good these component tests are, there is something about a final assembly test that gives us a reality check and lets us see how the thing is finally going to operate.

When you build a ship, you test it in the water before it is accepted. When you build an automobile, you drive it before you buy it. When you build almost anything, the final test is the final product. When you are putting on a play, every performer goes through the part of the play that that person has to perform. But the director, or the person responsible for it, before opening night, they say let us have a dress rehearsal to see how everything fits together. That, in my opinion, should have been required before the Hubble was flown.

Now that is the way I read——

Mr. THOMPSON. Senator, I would state certainly that the facts that you mentioned relative to the sequence of events with the contractor is exactly right. And in retrospect, perhaps an all-up systems test could have been done, and should have been done, certainly on our large programs, on the space shuttle, going back to the Apollo, we had to do component testing there. The first time we flew was when the vehicle saw the all-up test. The same with Skylab. We have got a biggie facing us on the Space Station, the assembly of the Space Station. We are going to go through that in a very agonizing way and make sure that at the module level and what we can do at the module level at the Cape is the right thing to do.

But right now, as you know, we are not envisioning an all-up assembly facility for the Space Station because today we do not believe it is necessary. And nobody loves more testing more than a lot of us in NASA. And so, philosophically I do not think we are going to take exception to your position because we agree with it.

Dr. FISK. The only other thing, if I may just make one comment. Normally when you decide you have got to test components together, you are unsure as to how they are going to interact. There is some complicated interaction between the components and you want to know whether all the parts do exactly what you expect them to do.

I think we ought to remember here that the design of the Hubble Space Telescope is a very standard design for an optics system. There is nothing exotic about this thing. It is a type of Cassegrainian telescope you can look up in an optics book and see what the shape of each of the mirrors ought to be.

But please just let me finish my point here. I think that we have every reason to be unhappy, to be concerned, that we were unable to determine accurately the shape of each of the mirrors individually. I mean, there is a failure in the system some place that we did not determine the shape of each mirror individually. But had the test on each mirror individually been correct, then by definition they would have worked together because the formula for putting them together was such a standard formula.

Mr. THOMPSON. But even if we had done something wrong, certainly testing at the next higher level would have caught whatever error was made.

Senator GORE. I am encroaching on my colleagues' time. If you will permit, let me just finish this sequence with one other question.

Not everything that the United States does in space is public knowledge. But it is fair to say that we have experience as a nation in putting optical systems into orbit prior to the placement of the Hubble in orbit. Without characterizing them or describing them, we have put optical satellites into orbit of various kinds.

It is my understanding that as a matter of course, there is always, always a final assembly test. Even if the component testing is done to the nth degree, they realize you can get all the components and test them separately. But you have got to have one final element, and that it is common sense to put them all together and test them the way they are going to look and function in orbit. That is the way we have done it before. And that was not required by NASA in this program.

Now, Dr. Fisk, do you think that is an unfair characterization?

Dr. FISK. I would just as soon not comment on other programs, but you are absolutely correct that we did not require an end-to-end test of this program. It is certainly a decision that we will review.

The main thing you want from your test program is to find the errors. And a judgment was made as to whether that was a test that would have found the errors. And if we had run an end-to-end test, we would have known about the errors, absolutely. If we had run some other tests which were probably simpler to conduct than the end-to-end test, we probably also would have found the errors.

Senator GORE. Senator Pressler, I apologize.

Senator PRESSLER. No, I think that was a good follow-up. Let me say, Mr. Chairman, that I have to go make a presentation in our caucus, so I am going to have to depart. But I do have some questions for the record regarding NASA's - the argument that NASA could have employed certain DOD tests used for its military satellites. Some of those may fall into a classified area.

But I guess the final question that I have is will the Hubble problems have any effect on the way we view similar big science projects like Mission to Planet Earth? And what is your judgment of the results of this situation?

Dr. FISK. I think Hubble had a lot of interesting management lessons, many of which were learned and understood before the current problem. And in conducting science programs, I think we have learned them very well.

Hubble had a multi-center management. Whenever we can avoid it we do not do that. Mission to Planet Earth is managed by the Goddard Space Flight Center. The Advanced X-Ray Astrophysics Facility is managed by Marshall Space Flight Center alone. Hubble had associated contractors, which caused some confusion. If we can avoid it, we do not do that. AXAF has a single prime contractor, TRW.

In the case of end-to-end testing, in the case of the Advanced X-Ray Astrophysics Facility, because it is in fact substantially simpler to do it in X-rays than it is in visual light, there is an end-to-end test facility being constructed at Marshall today to test the AXAF mirrors as a single system.

Mr. THOMPSON. Let me not leave that answer just there, though, because I personally do not agree that projects spread across NASA centers is necessarily a bad thing. Hell, that is the way we did Apollo; very successfully. We had multiple contractors, multiple centers, a lot of end-to-end tests, a lot of money. And we conducted Skylab in the same way. And we did the Space Shuttle very effectively, successfully, at multiple centers, across a number of contractors.

And today our plan is to do the Space Station the same way. So I do not want to leave the impression that the way we are structured to conduct our programs is flawed, in a sense, because I personally do not believe it is.

I believe in retrospect on this, we have got to go back and perhaps some of the comments that were made relative to the way we tested, and some of the assumptions we made, are more where the lessons are, as opposed to how we

structure the way we do business. I think once this is behind us we will all sit back and reflect on it.

Again, I want to restate for this committee, I am highly confident that this program is going to go forward and be highly successful. But we are also going to look at the management lessons learned and not just the technical.

But I do not want to leave the impression that multi- center, multi-contractors is not the way to go if that is meant by big science, because we have had a very successful past and are planning a successful future along those lines.

Senator PRESSLER. Thank you very much. I regret that I have to depart, Mr. Chairman.

Senator GORE. Thank you. Dr. Lenoir, before focusing completely on the Hubble in the remainder of our questions here, let me go back one more time to the shuttle fuel leaks. I get the impression that when you concluded the test procedure was probably—in giving you an anomalous result. You did not settle your suspicions about the accuracy of the test procedure, but instead moved to a new phase of the testing program, without determining whether or not the test which produced what now looks like a bad batch, and which were identified what now looks like a bad batch, without settling your suspicions that it was the test in error and not the equipment itself. Why would you not settle that question before installing the umbilical assemblies on the shuttle?

Dr. LENOIR. Because the way we had put the test together, we anticipated before we did it that we would likely have leaks. If we did, they would most likely be from the simulation side, the unreal part, and we would isolate and test only the flight part, the external tank umbilical. We could have repeated the test with only the orbiter slave unit in there, and then had it leaked, we would have said, yes indeed, that is what is leaking.

We did not do that, because we did perform a test that we felt at the time tested and verified that our flight external tank umbilical did not leak, and that is fact, in liquid nitrogen, it did not leak.

The suspicious part of the test to me is not that we replaced the slave unit with a blanking plate, but that we did it with liquid nitrogen and not liquid hydrogen. I might add, and I do not want to appear defensive, I have directed a review of the batch, and the whole process, to make sure that we fully understand them and their roles. To date, we have not found any connection of that with these leaks, other than the suspicious correlation that says, "two of those seven are these two leakers".

On the other hand, if I look at the alignment of the tank to the orbiter, the two most out of line are these two. We studied that exhaustively and concluded it is not a factor, because we have the ability to accommodate more than 10 times the actual misalignment. So we are looking at everything we possibly can, including statistical events that may just be a numerical coincidence.

Senator GORE. I do not know quite how to phrase this, but it seems to me that that is an issue. It is not the only time where there have been studies and tests which seem to identify a serious problem, and NASA, instead of accepting the evidence yielded by the test or study, challenges the validity of the test or the study.

Right now, we in this subcommittee are being told that the number of shuttle flights necessary to assemble the space station will carry with them an extremely high probability of another shuttle tragedy, and we are only slightly comforted by NASA's protest that there is something wrong with the study, because NASA comes and says, "Do not believe that. Those figures are off." Well, that is what NASA did on the test procedure that identified the two umbilical units that have now grounded the shuttle fleet. You shot the messenger, in effect.

Now, when another messenger comes and says, this mission, as it is currently designed, an 88 percent chance of another shuttle tragedy. Again, NASA shoots the messenger and says, "That study is wrong, do not believe it". We are getting to a point where we have got to have more. When a test or a study shows there is a high likelihood of a serious problem, in this case an 88 percent probability alleged of a shuttle tragedy with the mission program that is now planned out, in this case 18 out of 27 umbilical units failing at least one part of this test, we are no longer going to be satisfied with NASA saying that test cannot be believed. That is too pessimistic. It seems to me the burden of proof has to be heavier on NASA.

I have confidence you can meet that. I understand and I want to reiterate the fact that this is a new management team in NASA, changes have been made, as Mr. Rodney pointed out, since the Challenger tragedy. But the mind set, the mind set is also an issue. The willingness to shoot the messenger. The proclivity to shoot the messenger and to not give credence to test results or studies that seem to raise questions that might cause Congress to slow down or reconsider one of these large missions.

We had it again on the study by the astronaut office about the number of EVAs required on the space station. They came in here and sat right at that table, and they said; we have studied this, and we feel like there is going to be a requirement for an extraordinary number of EVAs, and if we are going to have that many EVAs, we will have to redesign the space station or develop a new space suit. But NASA officials come right afterwards and say, "No, do not believe that. That study is preliminary, premature, cannot be relied upon, and in no case do we want to have to redesign the space station"

There is a pattern, it seems to me. Then we get into this business where—and this is part of the mind set in the Congress, and I have been a part of it too—I want to be supportive of NASA, and I am supportive of NASA, but we get into a position where anybody that accepts one of these pessimistic studies is seen as hostile to NASA. And you get a mind set in the relationship between NASA and the Congress where there are two camps; there are those who are for NASA, and there are those who want to just cut all the money. You are either a cheerleader and you accept everything that NASA says, and you shoot the messenger that brings bad news, and you reject all pessimistic studies; or, at the other extreme, you just want to cut the program to the bone and just not have any new dreams in space and ambitious missions.

Well, we cannot accept those two extremes anymore. We have got to have hard-nosed scrutiny of exactly how these missions are going to be carried out. In order to rebuild the public confidence and support for NASA, there has got to be a dialogue between NASA and those who are authorizing and appropriating the money in behalf of the American people which results in very close oversight.

And, not just candor; I am not saying there has been a lack of candor. I hope it does not come across that way. I am saying that there is a kind of an "us and them" mind set, whereby the automatic tendency is just to reject any pessimistic news. That, in spite of the new management team, in spite of the beefing up in quality assurance and control, in spite of the confidence that I and others on this subcommittee have, and others have, in the individuals who are part of this management team, I think there is still something in what in the private sector would be called the corporate culture. I do not know what you would call it in NASA. Mind set is the closest I can come to it. There is still something in the attitude and approach which has that "shoot the messenger" quality to it. Now, if you think that is unfair, Mr. Thompson, tell me so.

Mr. THOMPSON. I would like to do that, because I do believe it is unfair. And when you say somebody in NASA takes exception to some study, I know that the top of NASA does not take exception to that. As a matter of fact, on a number of occasions, on a number of podiums, and I suspect in this room at this table, I have stated that it will not be too long before we have another accident. We are going to have many more leaks. You have just got to re-look at the reliability of the shuttle at the time of the Challenger accident.

Senator GORE. Wait a minute. Are you saying that you accept the fact that there is an 88 percent chance of losing a shuttle and crew with the number of missions needed to build the space station?

Mr. THOMPSON. Senator, I am not going to get into the numbers game, but let me tell you this. Let me just say this, because I am going to come damn close. At the time of the Challenger accident, the reliability was 96 percent. If we halve the unreliability, it is 98. Halve it again, it is 99, the unreliability. And at the flight rate over the next decade of what, 100, 120 missions? Very clearly, at those unreliabilities or reliabilities, however you want to look at it, we are going to lose another one.

And so, we do not take any exception to that. We are trying to be just as careful as we can. We do not have, I believe, the wrong mind set in NASA. We are most cautious at the Cape. We are most cautious in our assembly, and in the check out of these valves. In the check out of these valves down there, in retrospect, we may well look back and say, "We should have had an earlier alert." And we will have to see what the problem is there, but do not let me come across at all as saying, the top of NASA does not ever believe we are going to fail another shuttle. Space flight is not easy.

Senator GORE. When you say "we are going to lose another one," if you get the space station half built and a shuttle, with its crew, are lost, are you going to continue launching? Do you believe this nation will then continue launching the shuttle to finish up the space station?

Mr. THOMPSON. Certainly, I believe that. I think we are going to have to stop and find out what went wrong. The contrary position is, unless you can guarantee me we are never going to lose another one, then let's don't launch the next one, and certainly, I do not believe that; and I cannot convince you that we are not going to lose another one in the next decade.

Senator GORE. Let me just say this. If you believe it is a near certainty, 88 percent or higher, that we will lose a shuttle with its crew during the building of the space station——

Mr. THOMPSON. I did not say during the building of the space station. If we fly the next 100 times, we are likely to lose one. Now we have abort capability, we have a lot of escape mechanisms now, we have abort options we did not have before, so there are ways to recover.

If the point that we started on was NASA has not stated that we are concerned about the unreliabilities to the tune of 1 or 2 percent, that is just not right. I have stated, I know, as has Dick Truly, on too many occasions that there is risk in space flight. We accept that. Because of that, we are taking the actions that we have to at the Cape today.

Senator GORE. If there is a high risk of losing a shuttle and its crew during the construction of the space station, we need to know that before we start building that space station. If we lose a shuttle and its crew when the space station is halfway completed, then that raises the very real likelihood that the Nation would not tolerate a continuation of the same kind of program and bringing with it the risk of losing a third shuttle and its crew.

If we know now that there is a high likelihood of that occurring during the program, then it is time to look hard at the way that program is designed.

Mr. THOMPSON. I have not used the words "high likelihood", and I am not going to get into that numbers game. I am going to say that there is risk in space flight. If I stand here and tell the Congress we are not going to lose another one and if we fly 100 times, that does not pass the sanity check.

Senator GORE. That is going to extremes.

Mr. THOMPSON. One in 100, one in the next decade if we are flying ten per year.

Senator GORE. The Office of Technology Assessment says that in the next 34 flights over the next three to four years there is a 50/50 chance of losing another orbiter, another shuttle, if you assume a reliability of 98 percent.

Mr. THOMPSON. I agree with that, if you assume a reliability of 98 percent. That is just mathematics. I agree with that. I do not accept the fact that over the next 30 flights there is a high risk of losing one. We have had ten in a row. Looking back on the hardware and the data after those flights, we have not even come close to losing a flight.

On the other hand, I am going to be very open with this Congress and with this committee in saying that if we fly enough there is still the risk in space flight.

Do I think that we have the right caution in the agency and have the people uptight enough to proceed with the shuttle and the space station program and our science programs beyond that? The answer is yes, I believe we have it, Senator. So this dialogue with the Congress is certainly, I believe—I will sure open it up, because this is not the first time that I have expressed my concern for additional testing. We have to do more. Finally, you come down to money.

Senator GORE. It is not just money.

Mr. THOMPSON. It is not just money. It is attitude.

Senator GORE. You testified a moment ago that you believed that if we lost a shuttle and its crew halfway through the construction of the space station you would assume that the country would——

Mr. THOMPSON. I do not think that is going to happen.

Senator GORE. I understand that. You do not believe that it is going to happen, and we all hope it does not happen.

Mr. THOMPSON. I have not seen America quit. I have not seen America quit, and I do not believe we will. Now they may well damn demand even more of NASA, and that is okay. I like this oversight because it will certainly motivate us to go back and dig deeper, but we have the people with the right mindset thinking right in NASA today. I believe that.

Senator GORE. All right, let me back up and ask the question again which I started to ask.

You testified a moment ago that in your opinion if we did lose a shuttle and its crew halfway through the construction of the space station, you assume that the country would pause to assess the nature of the problem but then continue with the construction of the space station using the same shuttle program.

I think that if we know at the beginning that there is a problem, that there is a high likelihood—you describe it however you want——

Mr. THOMPSON. There is not a high likelihood. We do not believe that at the beginning. I did not say that halfway through the program I expect that to happen and that we ought to just pause a little bit and then go on. I do not believe it is going to happen. There is still risk in space flight, but I am convinced that America will not quit.

Senator GORE. There is no demand for zero risk in space flight. Again, we get into the problem of extremes. I am trying to get at the assumption that the Nation

would look at the program that way if we lost another shuttle halfway through the construction.

It comes back to the quality assurance and the reliability and the testing program that gives us that reliability. I think that while you will never get zero risk, you have to deal with the likelihood that if halfway through a project like this you have another shuttle loss and lose the crew, the Nation at that point will reassess the project. That might or might not be the right decision at that time. It depends on what happened and why and all of that.

The degree of risk that is acceptable has to be calculated with that in mind.

Mr. THOMPSON. We certainly agree with that, and we go through that every day. We have instilled it in our people, and that is why we have some of the test programs in place.

Let me just kind of recap a minute, because we started this last dialogue with your concern that NASA was of a mindset to put aside any report that there was any more risk in space flight. In the last two minutes we have gone the other way.

Senator GORE. No, not any risk; not any more risk.

Mr. THOMPSON. There is risk in space.

Senator GORE. Are you familiar with the study that calculates an 88 percent risk?

Mr. THOMPSON. Yes, I am very familiar with it.

Senator GORE. Do you accept that?

Mr. THOMPSON. Well, the arithmetic is right. If you assume a reliability of 98 percent in the next three or four years, you have a 50 percent chance of failure. That does not relate to today's space shuttle.

Senator GORE. What do you think the chance of failure is in the next three or four years?

Mr. THOMPSON. I think the chance is very, very low with the team that we have in place now. I think over a decade or a decade and a half there is some real possibility we will have at least an inflight abort.

A concern I would have is that there has been too much turnover over a decade and we tend to forget some of the problems of the past. That is a management issue we have today to try to instill. Because of leaks, let us go back one more time and look at the way we are doing business so that we are not falling into a trap.

I think it is very low, just to get to the heart of your question. I would like to make sure that you understand that NASA today is very concerned about the consequences not just to our projects but certainly to the lives involved, the image of the country and that kind of thing. We have the people in place to do it.

Senator GORE. Well, we are now getting reports that more shuttle flights will have to be added for the Station. Has that decision been made yet?

Mr. THOMPSON. No. We have got a sequence we are working on. We are going through the preliminary design review now. And we will come to grips with that at the right time. I would not be surprised to see a swing of a couple, plus or minus, as we finalize that.

Senator GORE. You do not think that it is fair to tell us at this point that it is now likely more shuttle flights will be needed for the Space Station as currently designed?

Mr. THOMPSON. I suspect by the time we get there and we add up all the logistics, then I suspect there may be more involved than, yes, our early study said.

Senator GORE. But you said a minute ago, there may be fewer.

Mr. THOMPSON. Fewer what?

Senator GORE. Shuttle flights.

Mr. THOMPSON. No.

Senator GORE. You said maybe one or two, plus or minus.

Mr. THOMPSON. No. I would not be surprised on the assembly itself. I am talking now about the resupply, the logistics.

Senator GORE. I am talking about the number of shuttle flights required to take the components up, and to assemble them.

Mr. THOMPSON. To assemble it, I think the number we have got now is about right, plus or minus a couple.

Senator GORE. What about taking the components up?

Mr. THOMPSON. Taking the components. up.

Senator GORE. Pardon me?

Mr. THOMPSON. Taking the components up.

Senator GORE. Will there be plus or minus flights? Is there an equal chance there will be fewer flights?

Mr. THOMPSON. I think it is going to be about the number we baselined today, which is 18.

Senator GORE. Why all these persistent reports that there is a weight problem that is going to necessitate a greater use of the shuttle to get it up there?

Mr. THOMPSON. We have a weight problem, Senator, in every program we run early.

Senator GORE. But at the present time you do not think that it is fair to say to the Congress, we now can tell you, we are not ready to make the decision yet, but based on what we know now about where the weight problem is, we now think there is a likelihood that more shuttle flights are going to be required?

Mr. THOMPSON. No, weight is coming out.

Dr. LENOIR. That would be premature. That is correct.

Mr. THOMPSON. We are not going to end up putting all the bells and whistles on this space station that people may want.

Senator GORE. Well, let me just say that the Nation asks astronauts to risk their lives. That is why they are heroes and regarded as heroes. That is part of manned space flight. There cannot be a zero percent failure rate. And at some point you get a failure rate that is not reducible further.

But the effort to get it to the lowest possible level must be made, I repeat, it must be made, even at higher costs.

Mr. THOMPSON. We agree.

Senator GORE. The problem that I think comes into this is that the higher cost involved sometimes brings a risk of its own. A risk identified by the agency as a risk that Congress is going to cross a threshold beyond which it will no longer support the program in question. And the mind set that I was trying to describe earlier has to do with the balancing of those two questions.

I have been getting the feeling, too frequently to make me comfortable, that NASA at times identifies that risk that the cost is going to push Congress past the point where it will approve the program as a risk that it is going to avoid at too high a cost on the other side. That is what I think has been making me uncomfortable about what I have been watching in the agency.

Now back to the Hubble.

If you want to comment on that, please feel free to do so.

Mr. THOMPSON. No, I certainly sense your concern.

I can assure you that I just do not believe that we are over there trading off what number will Congress buy, and that is the way we run our programs.

No, we feel very strongly in the total President's budget that is on the Hill today for next year. And we are not making those kind of tradeoffs. And I think as prior administrators and deputies have stated, if the budget gets to a certain

point, we will cancel the program. We just canceled a program down at the Marshall Space Flight Center just within the last month because of a budget issue.

And the OMV is one of the last programs in NASA that I wanted to cancel.

Senator GORE. Well, it is really a little bit more sophisticated than the way I just stated it. Because before you get to the point where you have to either cancel it or go forward, you get to a point where you can keep the cost down by eliminating testing, and then problems occur.

Mr. THOMPSON. If you went through the sequence of things that have happened with the OMV, for example, over the last several years, it is not testing we have cut back on, it is capability. Until we finally got to the point where the signals relative to the budget reality we were dealing with, it was a project that we just had to look hard at. So I do not think we are working the problem that you are most concerned about.

Dr. LENOIR. Yes, Senator, if I could take our current hydrogen leak situation and look at it in the context of your recent statements, I believe that we have broken into the chain of a potential accident, and that we have prevented a future accident by finding this problem the way we found it. It is not easy. It is very painful to sit and look at the very high likelihood that we will lose one or potentially more shuttle flights, and that we will spend money analyzing this and getting back to our safe configuration.

But we have not shirked from that. We are moving forward. We will find what the leak is. We will fix the leak. And we will look back and ask ourselves what could we have done differently in the past that would have avoided ever encountering this problem.

Senator GORE. Well, I think that ought to be said. I said that publicly a week ago myself, and I want to reiterate it now. The fact that this leak has been discovered is, in part, a testament to the rigorous procedures used by NASA today to identify the problem. And you deserve credit for that.

While we look back at what I believe were flaws in the original testing of the umbilical assemblies, and it is easier to do that in hindsight, we need to give adequate credit for the fact that you have gone through these extra procedures to identify the problem before it produced a failure at the present time. You do deserve that credit, and I think that is appropriate.

Dr. LENOIR. Yes, sir.

And when we have even better hindsight because we know exactly what the flaws were, then we also intend to go back in rigorous restudy and ask what could we have done differently to have avoided this.

Senator GORE. Now you said, Mr. Thompson, that the Hubble problem will be fixed in quick order, if I remember your statement correctly. What does "quick order" mean? We have been told it is at least three years. You are not changing that, are you?

Mr. THOMPSON. No, no. I think you are aware of—number one, I do not want to prejudge what the board is going to come up with. On the outside, I think you can bound it in terms of an updated instrument——

Senator GORE. Three-year minimum?

Mr. THOMPSON.——and resupply that. Whether something will shake out between now and then, we have got teams off looking at that. Historically in NASA, we have given a charge to a group of people to go out and let us be innovative and see what we can do. There are—I will just have to see how it comes out. But, no, on the outside a couple, three years.

And if we can be clever, I think there is a lot of things that can be done in data enhancement. And I know you are quite familiar with some of the capabilities

there. A lot can be salvaged there. There are a lot of other PIs that can be brought in the program. But let me ask Len to give you a——

Senator GORE. It cannot be fixed any sooner than three years, can it, Dr. Fisk?

Dr. FISK. No, I am not sure that is accurate. We are currently studying whether we can accelerate the replacement instruments. Three years is the schedule they are on at the moment. We are asking the question, "Can it be done in two years? Could it be done in a year-and-a-half with a replacement instrument?" And then examine whether or not a repair mission can be mounted at that time.

Senator GORE. And that assumes that it will get in the priority line for the shuttle flights?

Dr. FISK. I am absolutely confident that if we had the instruments ready to fly, that we would get all the priority we need.

Mr. THOMPSON. Or some other thing short of a new instrument. It could be bootstrapped onto another mission.

Senator GORE. Do you think it might be sooner than three years?

Dr. FISK. Yes, sir, I do.

Senator GORE. How soon?

Dr. FISK. Well, until I know—we are just guessing. In the case of the replacement instrument in question, it is not only a question of resources to do it, it is a question of technical people. Do we have people that could work three shifts a day, rather than two shifts a day? I mean, there are those kinds of questions that are going to have to be asked.

But, please, do not anybody lose sight of the fact that Hubble is going to be a very busy telescope over the next two years, even if we do not make a fix to the spherical aberration problem. The ultraviolet capability, the photometry capability, the spectroscopy capability, all of those things are going to be producing exciting scientific results independent of the spherical aberration fix.

Senator GORE. I was watching the Tonight Show, and Jay Leno was—I know there is precious little humor in any of this—but Jay Leno said the other night that the Hubble is not really out of focus, it is just that the universe is blurry. This is one of the discoveries, he opined.

I do not know how to react to what you have just said about the likelihood or the possibility that it can be fixed in quick order or more quickly than we were told a week ago. Should we put much stock in this? Or should we sort of plan, as we are looking at the space program, should we plan on the likelihood that it will take at least three years?

Dr. FISK. Let me answer this as straightforward as I can. The development schedule of the WF/PC replacement instrument, which was under way long before we discovered this spherical aberration problem, called for that instrument to be installed on orbit in June of 1993. So if you do nothing else, then there should be an instrument available to fly on a flight in June of 1993 to solve the problem.

We have asked the project to report, I believe, on the 24th of July on how possible it would be to accelerate the development schedule. We will know at that point what it will cost, and whether it is even technically feasible.

Senator GORE. So in two weeks we will know whether or not that instrument can be completed quicker than in time for a flight three years from now?

Dr. FISK. That is the plan.

Mr. THOMPSON. As well as, I think, get a better feeling for what else could be done——

Senator GORE. All right.

Mr. THOMPSON.——to improve the capability.

Senator GORE. Now, Dr. Lenoir, what is your estimate of how long the shuttle fleet will be grounded?

Dr. LENOIR. Again, that requires some speculation. Frankly, I will be surprised if we do not get one mission off prior to Ulysses. I will be very surprised if two weeks from now, we do not feel we understand the problem and have our plans in place and are in processing for the next mission.

Senator GORE. Do you know with certainty, now, on the Hubble, Dr. Fisk, that the problem exists with the primary mirror?

Dr. FISK. I do not know with certainty. The optical experts that have looked at the data and understand the nature of this telescope think it is most likely in the primary mirror. There are additional tests that we will run on orbit that should confirm it in one way or the other.

Senator GORE. Now your HST independent optical review panel has concluded, and I quote, "Replacement instruments can be corrected for the spherical aberration error of the telescope assembly, so that the original performance targets can be met." That seems to assume that they are pretty sure what the problem is.

Dr. FISK. Well, that is right. You may also notice in the first statement of that review panel, that they confirm that they believe that there is spherical aberration in the mirrors. And it is actually not necessary to know whether it is in the primary or the secondary in order to make the correction, although that information is useful. It is particularly useful in helping us to begin to understand what happened back in 1980 and 1981.

Senator GORE. They also conclude the spherical aberration error cannot be corrected with any of the existing hst controls.

Dr. FISK. That is correct. and more than that, we would be unlikely to try, because the spherical aberration that we have in the mirror is so simple, so spherical, if you like, that we know we can correct it. and if we were to fool with the shape of the mirror by using the actuators, we might put a more complicated pattern in, which therefore would be harder to correct in the long term.

Senator GORE. That seems to imply, then, that the replacement instruments are the indicated fix and that nothing else is going to solve the problem.

dr. fisk. well, it is two things.

Mr. THOMPSON. Why do you not tell him what we are talking about?

Dr. FISK. No, I am not going to tell him.

Dr. FISK. The replacement instruments are things you know you can do. That is not in question. We have got a lot of ingenuous people out there thinking of other ways that you could do this thing, including on-orbit repair. Some of them are way out of sight, that you would not even try. But we have given absolute license to everybody in the project to think about more imaginative ways to do this than simply replacement instruments, and as we had said the other day, people in this project, the astronomers, the scientists, everybody, are clever and stubborn, and it would not surprise me to find out that they would come up with something even more imaginative.

Senator GORE. Now, before we go to the contractors, let me pin down just a few more things briefly. The other bidder did include a plan for final assembly testing, correct?

Dr. FISK. That is correct.

Senator GORE. NASA did not require in the bid specifications that both bidders agree to perform final assembly testing, correct?

Dr. FISK. I believe that is correct, yes. They did require a test plan in considerable detail, which was reviewed, and certified and agreed to.

Senator GORE. Now, the question of whether or not final assembly testing of the telescope should be required prior to launch was addressed at the time the bids were opened and the contract was awarded. Was that decision not to require final assembly testing reopened after the bid was awarded?

Dr. FISK. Let me answer in two ways. We have asked the Lew Allen panel to go through this in considerable detail, and so let me speak from my knowledge of the project, which will be subject to the review of the Lew Allen panel, that it was an issue which was revisited and reaffirmed at various points during the development of the mirror. There are various references to it in the discussion with the science teams and so forth, but that process was reviewed and the original decision was reaffirmed.

Senator GORE. When you say it was revisited and reaffirmed, that implies that somebody in NASA was not quite sure that that original decision was correct. Why was it revisited?

Dr. FISK. Senator, I think you are over-interpreting that. The testing policy of the Hubble Space Telescope was under constant discussion throughout the entire mission. I mean, the things like the recent thermal vacuum test.

Senator GORE. No. I want to concentrate on this one point, Dr. Fisk. Let's not cover the whole waterfront. The question of whether a final assembly test should be required before launch, that question, you have testified, was revisited after the contract was awarded to a bidder which did not include such a test in its bid, correct?

Dr. FISK. It is my understanding, and please bear in mind that we are talking about a history that I am learning about.

Senator GORE. You were not personally there at the time?

Dr. FISK. I am not looking for an excuse. I am telling you that I am going by what I have been told by the project.

Senator GORE. Do you happen to know Mr. Thompson?

Mr. THOMPSON. Well, I can just state from what I know, and that is I have never heard of an issue being brought up, and certainly since my tenure at Marshall that wanted to re-question, or reopen, or re-look back on the decision of this end-to-end optical test, certainly in other areas, as Len indicated earlier, like in the thermal vacuum test, we did that. We went to the mat. We had a lot of discussion, but I never heard word one, and I chaired a series of quarterly reviews every third month with the scientists, with the PI's, with the engineers from Perkin-Elmer, with Lockheed, and I never heard it brought up.

Senator GORE. What? After the bid? After the bids were open?

Mr. THOMPSON. No. I am talking about from '86 on as we went through the "are we okay", as others were off working on the shuttle and now we were going to readdress what we were going to do with the Hubble. Should we go back and retest that or something else, and I never heard it brought up.

Senator GORE. Okay. Now, you have this quarterly review throughout the program and you never heard this point revisited. When you use the word "revisited", Dr. Fisk, what are you thinking about? Are you thinking about some magazine, some journal article that somebody wrote?

Dr. FISK. No. All I am saying——

Senator GORE. I know there was one of those.

Dr. FISK. Well, there is two points that you raise. One is that the testing policy on Hubble, including the lack of this system test, was common knowledge. I mean, it was not a secret. It was published. It was discussed. There are records, for example, in the discussions of the science meeting, for example, in which occurred in the 1979-80 time frame. I am sorry, I do not keep the date in my head, in which the project informed the scientists that they were, in fact, not doing an

end-to-end test, which I view as a revisiting of the issue. They commented on it. It might be also commented that there was no ripple as a result of that. Despite, you know, a lot of other very controversial issues going on in the project at that time concerning fine guidance sensors, instrument development——

Senator GORE. Can you supply us the document where the project people informed the scientists they were not doing an end-to-end test?

Dr. FISK. I will be very happy to.

Senator GORE. Was the tone of it to flag it for them and say——

Dr. FISK. I would have to go back and reread it. It is a one liner delivered by the project manager at the time, Mr. Kiefley, who said, "we informed the science group that there was not an end-to-end test being done", and there is no subsequent comment by anyone.

Senator GORE. Presumably, the science group would already know that if that decision had been made, correct?

Dr. FISK. Well, that was the point of my comment reaffirmed. But let me give you the exact date and I will deliver the document to you.

Senator GORE. Thank you. I appreciate that. We have covered the questions on program management. Which office within NASA, Mr. Thompson, was responsible for defining the criteria by which to decide the Hubble was adequately tested?

Mr. THOMPSON. I think the chief engineering organization. Marshall, in consultation with the scientific people. The optical experts as well as program management would be involved, because there is always a cost rate, right or wrong—would have been the driver for the decisions. Also the information was disseminated throughout all areas of the Hubble Space Telescope, to the scientific people to make sure that we were all together in terms of the requirements. So, you know, it had to start with engineering.

Senator GORE. Okay. But was there one person or one office with the line responsibility for deciding what would constitute an adequate assurance that it was ready to fly?

Mr. THOMPSON. I will have to get you the history back in the time frame of the Source Evaluation Board. But the way I started this hearing, I feel I was very much personally responsible as we went through the flight readiness review. Even if a mirror was ground 10 or 12 years ago, that it is part of my job to be smart enough to ask, "were all the right tests run?" And so I was very much a part of that process, as all of us at NASA were, that said, "we are ready to go".

Senator GORE. Thank you.

[The following information was subsequently received for the record:]

The office with line responsibility for preparing and maintaining the detailed technical specifications for all elements of the HST project was the Hubble Space Telescope Project Office at the Marshall Space Flight Center. The primary positions within that organization were the Project Manager, Chief Engineer and Project Scientist. The names of the individuals who held those positions, along with their approximate tenures, are listed below:

Project Manager
William Keathley (1977-1980)
Fred Speer (1980-1983)
James B. Odom (1983-1986)
Jerry Richardson (1986-1987)
Fred S. Wojtalik (1988-present)
Project Scientist
C.R. O'Dell (1977-1984)
Robert Brown (1984-1987)
Albert Boggess III (1987-present)
Chief Engineer
Jean R. Oliver (1977-present)

Senator GORE. Now Mr. Rodney, I have not asked many questions of your effort to establish an effective quality control program. But I am very interested in your comments. Accordingly, I have a number of questions for the record designed to flesh out what you have told us about the additional personnel added for quality control, and would appreciate your response.

Because of the time constraints that we have we are going to move to the next panel. Before you depart, I want to acknowledge your willingness to brief the committee members and staff on what is being found on the leak and the Hubble. It is my experience that you have been up front with us and shared the information as it has come in and offered several times to brief us as the process continues. I do not want my comments about the mind set in reaction to bad news or pessimistic assessments to be interpreted as a lack of candor. As I said earlier, I do not see it that way. And specifically, I do want to thank you for your openness in sharing information fully with us.

In spite of the fact that, in my opinion, the American people are quite concerned about these problems and are justified in insisting that they be corrected and that NASA learn from them, it is also my sense, as I am sure you know and feel, that the American people continue to feel pride in what NASA has accomplished, what it is capable of accomplishing now and in the future. The worst mistake we could make is to let a series of problems like this cause us to turn away from space exploration. That is the worst single mistake that we could make. But by golly, we are going to insist that these problems not only be fixed, but that we be given adequate and complete assurance that the proper lessons have been learned and that the proper changes and procedures are being made.

I want to say again in conclusion on this panel that we should make a distinction between mistakes and problems that occurred 10 years ago and the current management of the program, which discovered this leak before it caused a tragedy; and which has added the quality assurance personnel which hopefully, with new procedures, will prevent a recurrence of problems like this. So I do want to express again my confidence in the individuals who are managing NASA, even as I restate the determination of this Subcommittee to conduct oversight in a whole new way, at a whole new level of detail, to insist upon continuing dialogue. And again, we appreciate you offering to do that, both here, and as I mentioned, outside the hearing room on an informal and continuing basis. With that, we are going to move on to our final two witnesses today.

Thank you very much for coming.

[The following information was subsequently received for the record:]

QUESTIONS OF SENATOR GORE AND THE ANSWERS OF MR. RODNEY

Question 1. In your view, does NASA now have an adequate number of NASA quality assurance and safety personnel? In that regard, have you been denied requests in recent years for additional staffing resources by NASA or Office of Management and Budget (OMB)?

Answer 1. We have given this issue a great deal of attention across the NASA organization. We have added safety and quality staff at Headquarters and at the field centers primarily in support of manned programs. We have, for some time, been reassessing our levels of effort on other types of NASA activities. Part of our assessment of Hubble Space Telescope will be recommendations for possible changes in the level and type of safety, reliability, maintainability and quality assurance (SRM&QA) coverage for this type of program. Through a series of audits, we have also been looking at individual field centers to assure that they are adequately covered. All requests for additional personnel resources for Code Q have been well supported by NASA senior management and by OMB.

Question 2. In the broad perspective, what constitutes a good versus a bad safety and quality assurance program? Looking back, how would you characterize NASA's quality assurance effort in the 1980's? What are the differences between today's quality assurance program and that of the early 1980's?

Answer 2. One effective measure of the goodness of a safety and quality assurance program is the actual performance record. We have to consider NASA's success record and look closely at the

level of undesirable incidents to determine if safety and quality are effective. In the early 1980's, the level of resources, both budget and personnel, were much less than today's level. In retrospect, NASA's safety and quality program should have been stronger in terms of budget, personnel and organizational role. Today, we have made considerable progress in correcting this condition. We now report directly to the NASA Administrator at Headquarters and to the Center Director at the Centers, which was not always the case in the past. We have also made significant progress eliminating a "kill the messenger" syndrome that was sporadically evident in the past. We have improved our Problem Reporting and Corrective Action (PRACA) systems and insured better management visibility of significant problems. We have much greater emphasis on quality through such activities as the NASA Excellence Award, our overall Quality and Productivity Improvement Program, and specific quality provisions in our award fee determinations.

Question 3. Are there different approaches that your people take with respect to quality assurance of manned and unmanned space programs?

Answer 3. Basic quality assurance actions such as audits, inspection points, corrective, remedial, and preventive actions are implemented in the same manner regardless of manned or unmanned category. The real differences lie in the requirements imposed both on the contractor and the government people for each program. Historically, today's unmanned launch vehicles were the first manned launch vehicles. When the Shuttle Program was initiated, the Atlas did not toss out all of their proven quality methods. The approach used by the Shuttle for quality assurance was learned from what we refer to as "unmanned" launch vehicles. One of the outputs of our current review of the HST incident will be an assessment of any improvements to our current approach on unmanned programs.

The recent changes in unmanned launch vehicle procurement, i.e., commercialization, have significantly reduced and changed the oversight exercised by government quality assurance. They have changes from "controllers" of the processes to the "limited observers" of the process. The mandatory inspection points for the government quality people have been deleted from work/process documents. The approval of operating procedures by the government has been deleted. Material review board membership for the government no longer exists which means decisions to repair, replace, fly "as is", or scrap hardware are made without government concurrence.

Question 4. How does NASA ensure that every employee and contractor focuses on quality, reliability, and safety? How do you avoid the natural tendency to assume that someone else will take care of that?

Answer 4. To keep NASA management informed, we have designed safety and quality reporting systems, servicing all centers, contractors, and Headquarters areas. The Significant Problem Reporting (SPR) System assures major problems originating at the contractor site or centers are quickly brought to management's attention and are active until resolved. The PRACA System tracks all problems and serves an active role in trend analysis where historical problems are analyzed to determine frequency of occurrence and response to recurrence control. The NASA Safety Reporting System (NSRS) is a confidential, voluntary, and responsive channel to notify NASA's upper management of your safety concerns about any NASA programs or projects. NASA is making every effort to keep its work force aware of and focused on safety, reliability and quality assurance. For the contractor work force, we have instituted the NASA Excellence Award for Quality and Productivity. This is a proactive program giving our contractors a set of "world class" criteria to meet and exceed. Joint NASA/Contractor Quality Circles and suggestion programs have been implemented to encourage involvement and improvement opportunities. The Manned Flight Awareness (MFA) Program recognizes both NASA and contractor employees for their outstanding contributions to the Space Transportation System (STS) Program. We are, and have been, leaders in quality and productivity (Total Quality Management (TQM)) and have been recognized by OMB for having two of our centers receive the Quality Improvement Prototype Award. We are continuing our efforts in TQM awareness for the entire work force. Additionally, we are continually reviewing and monitoring our safety and quality systems through regularly scheduled and special audits to ensure that the system does not become routine or complacent.

Question 5. In manufacturing, American companies have been faulted for problems with quality and reliability. Since 1970, U.S. auto makers have lost much of the American car market to Japanese auto makers because Japanese cars have had better repair record and fewer design problems. U.S. car companies have made a concerted effort to improve the quality of their products in recent years and now make much better cars. One thing they realized was that it is not enough to just make sure that every part is made and installed properly, you also need to make sure that the entire car is designed with reliability in mind. That might mean redesigning a particular component so that it contains twenty parts rather than forty and thus much less likely to fail. Has that lesson been applied at NASA?

Answer 5. Yes, to the extent that this principle applies to aerospace programs. We intend to continue to champion efforts to improve the reliability of currently operational hardware by proposing design changes to improve reliability. One of the thrusts of NASA's Assured Shuttle Availability (ASA) Program which is to carefully assess those components that are most troublesome to provide new designs that are more reliable with reduced maintenance. However, there are some fundamental differences when comparing automobile to aerospace reliability. Automobile reliability is based on designing for durability within relatively liberal weight and sizing constraints. It is also based on the

premise that few failures are considered catastrophic. About the only place where redundancy is used in automobiles is the brake system. If you experience an alternator failure on a country road late at night, you might not agree with this philosophy, but it significantly reduces the complexity and cost of the automobile.

In aerospace, generally speaking, we must assume that any failure can never be fixed and in many cases must be considered catastrophic. While there are different applications of this philosophy in manned and unmanned programs, the net result in both cases drives us to significant use of redundancy that increases the- complexity of our designs and the number of parts involved.

Question 6. When you look at the blueprints for the Shuttle, I'm impressed by the incredible complexity of the system. And since Challenger, many of the systems have been made even more complex as parts have been added. (For instance, another o-ring and a heating element was added to each joint of the Solid Rocket Boosters (SRB's)). Is all this complexity necessary? Are NASA engineers and contractors given incentives to simplify and streamline their designs, to minimize the number of parts that could go wrong?

Answer 6. Yes, Shuttle systems are very complex. This complexity is inherent with the mission. It is compounded by the occasionally conflicting design requirements To. minimize weight, simplify systems while increasing reliability and flexibility, provide redundancy and improve systems safety.

Specifically addressing your question on the SRB Joint as an EXAMPLE. numerous different candidates for the Solid Rocket Motor (SRM) Field Joint were investigated prior to the selection of the current Redesigned Solid Rocket Motor (RSRM) design. A series of tests were then conducted on candidate O-ring materials. It was determined that the Viton used in the original design has the best combination of material/physical properties for the SRM joint 0-rings. One problem with Viton (and similar materials) is that it becomes stiffer or less resilient as it gets colder. For the o-rings to meet the NASA requirement to track and follow the case on pressurization at ignition (at twice the calculated rate), they must be at least 70 degrees F. The joint heaters were the engineering answer to keeping the joints well into the desired range of physical properties, in spite of the ambient temperature at Kennedy Space Center (KSC). In this example, complexity increased, as did weight, but reliability, flexibility, redundancy, and system safety have improved.

NASA has a very rigorous design review system with Preliminary Design Reviews (PDR's) held at 10 percent of design, Critical Design Reviews (CDR's) at 70 percent of design and Design Certification Reviews (DCR's) held at completion or 100 percent of design. NASA engineers, scientists, and technicians carefully track the design through these reviews to assure that the designs have been optimized, meet NASA requirements, and are the best engineering compromises possible.

A Failure Modes Effects Analysis/Critical Items List (FMEA/CIL) is generated that delineates all possible failure modes. The design is reviewed against the FMEA/CIL to reduce the causes and effects associated with these failures.

NASA continuously encourages its contractors to suggest improvements to their hardware to improve its cost, reliability, weight, etc., through contract incentives and awards.

Even though we have identified the causes and effects of many potential failures and redesigned many of the Shuttle systems to eliminate these failure modes before returning to flight, NASA must continue to improve the design and reliability of the shuttle systems and components in order to continue to improve the overall reliability and safety of the system. The agency has identified these equipments and components for modification and identified them in a budget line item entitled ASA.

Question 7. How would you characterize the relationship between NASA personnel and the quality control people at contractor facilities? More specifically, how would you characterize that relationship with respect to Hughes-Danbury on the HST?

Answer 7. Our relationship with our quality associates at the NASA contractors is very good. I can also say this for our current association with the Hughes-Danbury quality staff. They have been very cordial and genuinely helpful. The conditions that existed at Hughes-Danbury on the HST will be assessed in the Allen Board Report.

Question 8. In your view, is it prudent to rely upon the same contractors that do the design and development work for quality assurance? Does such a heavy reliance on this relationship imply that the pendulum has swung too far and that NASA should take stronger control of quality assurance for the U.S. space program?

Answer 8. End item quality is clearly the responsibility of the contractor. A company that has a contract to design and manufacture an item is also held responsible to assure the quality of the delivered product. Having a different company perform inspection would only serve to increase costs and lengthen schedules and could lessen accountability, i.e., who is responsible for the goodness of the hardware—the company that made a nonconforming part or the company that let a nonconforming part through the system? Generally, it is not good for the quality people to report to the same executive that is directly responsible for manufacturing because that sometimes presents him with a conflict over schedule versus hardware goodness. In the vast majority of cases with NASA contractors, the quality people are equal in stature to the manufacturing management and both report to a higher executive for conflict resolution. In some cases, we do have additions to contractor inspection, i.e., government mandatory. These critical inspection areas are verified by government employees. The amount of government verification is frequently reviewed for adequacy. We are currently reviewing

both the quality requirements we lay on our contractors and the degree and methods of government review and surveillance.

Question 9. That seems to indicate that you acknowledge that there were problems with NASA's quality assurance program in the 1980's. Can you please tell the Subcommittee what you think those problems were and how they have been corrected?

Answer 9. The focus problem with the HST has been traced to an instrument (reflective null corrector) used during the manufacture and testing of the primary mirror. If there was a situation today requiring that quality assurance must use the same measuring instrument as manufacturing, special calibration verification would be required of the instrument prior to use for inspection. We are unable to explain why quality assurance was not more intimately involved in the calibration and certification of the reflective null corrector in the 1978 and 1979 time frame. The independence of quality assurance today would assure that the instrument was inspected and that the metrology was certified. We will address this issue in more detail as part of our final HST assessment.

Question 10. From the information that you have been able to obtain—both independently and as a part of the dr. allen's investigation board—would you have advised that the two mirrors on the hst be tested in combination?

Answer 10. The level of testing performed on the HST appeared appropriate at the time based on the assumption that the individual elements were thoroughly tested and met their individual specification requirements. As we now know, this assumption was incorrect.

Any test performed on the completed Orbital Telescope Assembly (OTA) would have been performed to demonstrate compliance to the overall system specification requirements. Anything less would have been performed to find a specific problem, which at the time, was thought not to exist. A complete system-level test would have been extremely expensive, complex, and time-consuming. It would probably have resulted in some fundamental changes in the flight hardware design to enable a meaningful test to be accomplished. Based on our current knowledge of the complexity of this type of system, we would probably have been a very strong advocate of some sort of additional testing above that which was employed.

Question 11. Based upon what you know, was there significant pressure on NASA or Hughes Danbury quality control people not to slow progress of HST? Have you encountered any evidence of that pressure manifesting itself in the materials you have been reviewing?

Answer 11. The NASA and Perkin-Elmer (PE) quality assurance personnel did not appear to have been under any more schedule pressure on the OTA program than has been experienced on most programs. There is always pressure on quality assurance to perform their inspections/reviews so that manufacturing and engineering can continue their tasks; however, this pressure should not affect the scope of their activities. Because PE quality assurance was under the control of engineering at the time the reflective null corrector was assembled and measured, it is possible that schedule pressures may have helped dictate the very limited involvement by quality assurance that did occur.

Question 12. Given NASA's current relationship on quality assurance with its contractors, do you think errors like this could occur again without detection?

Answer 12. The present NASA organization gives the safety reliability and quality assurance organization an independent voice on all projects. This independence is also insisted on at the contractors' facilities. The present requirements would not permit the quality assurance organization to be a part of either the engineering or manufacturing organizations.

It has always been a general philosophy that inspection will be performed using inspection metrology. There are cases where inspection may be required to use manufacturing tooling; however, there must be methods to verify the accuracy of such tooling.

The HST problem originated in the early program stages where the design build and test philosophies were developed. We are continually looking at ways to improve the quality assurance involvement in the front end of the process rather than find the problem through inspection or test at the end of the process. We believe we have strengthened our capability both at the front end and throughout the design and build process. Out of our review of the HST will come recommendations for further improvements.

Question 13. Can you please elaborate? What types of independent review and assessments are being conducted on the Shuttle fuel system?

Answer 13. Basically, we are involving real-time with every step of the ongoing review process. Our involvement includes, but is not limited to, reviews OF. manufacturing processes, acceptance test procedures, inspection procedures, contamination control, and design adequacy of the seals. Also, the safety community is deeply involved in reviewing the concerns and issues associated with the propellant leak limits for the launch environment. This is to ensure that whatever leak limits are finally accepted will preclude both fire hazards and leaks that might grow in flight.

Question 14. What was your office's role with respect to the testing of the Shuttle Umbilical Assemblies in 1984? When the 33 units failed the original receiving tests, but later passed subsequent static plate tests, did the quality assurance program raise any questions or concerns?

Answer 14. The prime contractors engineering organization has responsibility for development oversight and approval of vendor's acceptance test procedures. The contractor's quality organization and DCMC inspection are responsible for ensuring that the acceptance testing is conducted in accordance with approved procedures. The approved test procedures for the 17 inch disconnect allows

for use of a blanking plate to isolate the part being tested from its mating half test equipment should the part fail the first leak test. All of the disconnects that failed the first leak test were subsequently tested with the blanking plate as are required in the approved test procedure. The purpose of the blanking plate is to isolate the item being tested from leaking test equipment. Nothing in our current review of this problem has been found to indicate this approach was technically faulty. It was subsequently changed because it was an obvious awkward and costly process.

Question 15 In your view, could and should this leak have been detected prior to the point where STS-35 was in the final stages of its launch countdown and STS-38 had been rolled out to the pad? Why did it take so long before these two leaks were detected? Are you satisfied with the current testing regime, using liquid nitrogen, for detecting leaks in these umbilical assemblies?

Answer 15. It is not believed that this leak could have been found using the existing test procedures, beginning with ATP and continuing through assembly and pre-flight checkout. It is believed that an acceptance test procedure capable of finding such leaks is possible, and that the best opportunity for finding these leaks exists at the vendor. However, the sensitivity of hydrogen systems to even the smallest leaks suggests that even a perfectly manufactured and tested unit could still develop leaks as a result of damage during shipment and assembly. In the case of the Orbiter, the continued operation of the unit will develop wear but presently the signature tests are designed to identify such deterioration. The delay in discovering these leaks is a direct result of their sensitivity to the LH2 temperature and molecular size. Due to the hazards associated with the use of LH2, it is

NASA-WIDE SRM&QA STAFFING TOTALS

CIVIL SERVICE	1986	1987	1988	1989	1990
HQ	33	64	64	73	78
JSC	159	170	195	210	210
KSC	212	260	280	399	399
MSFC	107	180	235	235	245
SSC	7	8	8	8	10
ARC	33	35	37	39	39
LaRC	62	62	61	63	62
LeRC	72	90	84	91	103
GSFC	160	163	165	178	187
TOTAL CIVIL SERVICE	845	1,032	1,129	1,296	1,333
JPL WORKFORCE	228	258	264	279	279
SUPPORT CONTRACTOR	711	971	1,198	1,477	1,453
MAJOR CONTRACTOR	N/A	3,165	3,877	3,961	4,095
DoD	438	438	438	438	438*
TOTAL	2,222	5,864	6,909	7,451	7,598

* PRELIMINARY – UNDER DISCUSSION WITH DoD

ATTACHMENT II

APPROXIMATE NASA SRM&QA FUNDING

(MILLIONS)

	FY 88	FY 89	FY 90
CIVIL SERVICE	54	61	65
JPL WORKFORCE	14	16	16
SUPPORT CONTRACTOR	83	102	104
MAJOR CONTRACTOR	267	268	334
DoD	30	30	30*
R&D SPECIAL PROJECTS	6	6	6
CODE Q R&D	14	22	23
TOTAL (SRM&QA)	$468	$505	$578

Senator GORE. Our final two witnesses on this next panel are Mr. Bertram Bulkin, Director of Scientific Space Programs with Lockheed Missiles and Space Company and Mr. John C. Rich, President of Hughes Danbury Optical Systems.

Gentlemen, welcome. We are glad you are here today, and we look forward to your statements. Your complete prepared statements will be included in the record in full.

I wish to advise and reassure both of you before you speak that the subcommittee has familiarized itself with the activities which you have performed on behalf of the United States of America in classified programs. We will take caution, as I know you do regularly, to avoid compromising classified information with importance to our national security. Within those boundaries we look forward to exploring fully the problems which have been brought to light concerning the Hubble telescope.

Mr. Bulkin, we will begin with you. Welcome, and please

STATEMENT OF BERTRAM R. BULKIN, DIRECTOR, SCIENTIFIC SPACE PROGRAMS, LOCKHEED MISSILES AND SPACE COMPANY, INC.

Mr. BULKIN. Mr. Chairman, it is a pleasure for me to be here today to share with you and the committee the roles and responsibilities for the Hubble Space Telescope——

Senator GORE. Excuse me. If you could move that microphone a little bit closer to your voice, we could pick it up a little easier.

Mr. BULKIN. Is that better?

Senator GORE. Yes, sir.

Mr. BULKIN.—and to go over the Lockheed roles and responsibilities for the Hubble Space Telescope. My name is Bert Bulkin. I am the Director of Scientific Space Programs for Lockheed Missiles and Space Company, Space Systems Division.

The Lockheed HST effort reports directly to me, and I have been personally involved in the telescope program since 1973. I was the Hubble Space Telescope program manager through the year of 1985.

Lockheed has been responsible for the design and development of the Support Systems Module, which is the basic spacecraft, since contract go-ahead in October 1977. In addition, we supported Marshall Space Flight Center in the system engineering task related to the Hubble Space Telescope intra- and external interfaces. We also had the responsibility for the physical integration of all associate contractor hardware, including hardware provided by the European Space Agency. We are also under separate contract with NASA Goddard for mission operations.

Lockheed integrated the Optical Telescope Assembly provided by Hughes Danbury Optical Systems, the Widefield Planetary Camera provided by JPL, the High Resolution Spectrograph provided by Ball Brothers, High Speed Photometer provided by the University of Wisconsin, the Faint Object Camera provided by Martin Marietta, the Faint Object Camera and Solar Arrays provided by the European Space Agency, and the Scientific Instrument Command and Data Handling subsystem provided by Fairchild Industries.

We assisted Marshall Space Flight Center in establishing all interfaces within the spacecraft among all the elements I previously described and those external to the spacecraft such as the tracking data relay satellite system, the shuttle and the mission specialists who will do the mission on orbit servicing.

It was mentioned before that the Optical Telescope Assembly was received from at that time Perkin-Elmer, today Hughes Danbury, in 1984.

The Hubble Space Telescope assembly process started in March of 1985. We proceeded to install all the flight hardware and started into functional testing to verify that all systems were compatible with one another and physically and functionally met their respective interfaces with the spacecraft.

After showing the satisfactory functioning of all the hardware interfaces, we subjected the total system to environmental tests. These included an acoustic test

to assure that the spacecraft could withstand the launch environment that would be experienced in the shuttle payload bay and a 57-day thermal vacuum test which simulated orbital conditions of vacuum and temperature extremes.

End-to-end data was gathered in real time through a satellite link by the Science Institute and the Space Telescope Operations Control Center at Goddard Space Flight Center. These tests, conducted from January through July of 1986, were interactive for Lockheed in Sunnyvale, the Science Institute and the Space Telescope Operations Control Center.

With the shuttle fleet grounded after the Challenger accident, upgrades to the system were deemed prudent because of increased emphasis on reliability, maintainability and safety. With all these upgrades completed, we readied the HST for shipment to Kennedy Space Center.

At the Kennedy Space Center, verification testing was again conducted to insure no shipping damage had occurred. Tests similar to those run in Sunnyvale at Lockheed were conducted through a satellite link both from Lockheed in Sunnyvale and from Goddard Space Flight Center, including the Science Institute.

Once in the shuttle bay, the Space Telescope Operations Control Center configured the spacecraft for launch.

During the testing of the Hubble Space Telescope prior to its launch, we had probably the highest rate of testing hours on any other spacecraft. We had approximately 12,000 hours of power on testing. We initiated something more than 3 million commands monitored over 8,000 data points, and we provided over 1,000 test segments.

After the launch on April 24, 1990, it achieved a near perfect 330 nautical mile orbit. We have been supporting the operations from Goddard Space Flight Center and Marshall Space Flight Center as well as Sunnyvale, California.

We are very proud of the performance on the HST as far as the Lockheed hardware and software is concerned. We believe it is testimony to many years of effort by a lot of individuals involved.

In addition to the basic challenge of the functioning product in the harsh environment of space on a one-shot mission, the challenge of very accurate pointing has been met. In conjunction with the fine guidance sensors provided by Hughes, our pointing control system can track a star to within the advertised accuracy of .007 arc seconds. This capability was demonstrated the first time fine lock was attempted in late May.

Although there has been a temporary setback in achieving all the goals set forth for the Hubble Space Telescope, we are confident that with a rearrangement of priority in observing programs and image enhancement by unique ground processing techniques, important science can be realized today.

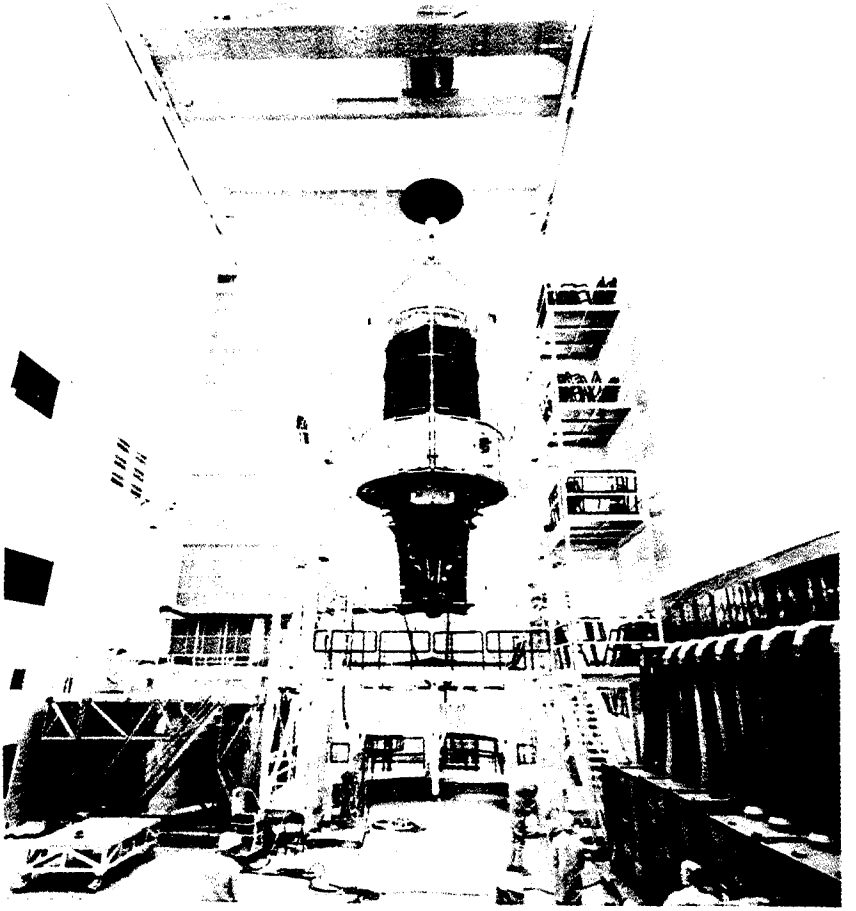
In addition, we have developed crew aids, special tools, and proven procedures that have been validated by neutral buoyancy simulations by the mission specialist astronauts that will enable the replacement of scientific instruments with corrective optics, as Dr. Fisk previously mentioned, on the first maintenance mission, bringing the HST to its full capability.

I have included as part of the statement the project roles and responsibilities and a chronological sequence of events that have transpired in the program since its inception and a couple of cutaway views of the telescope assembly showing the OTA mated to the SSM equipment section.

Mr. Chairman, we appreciate the opportunity to testify as part of the panel today, and I am prepared to answer any of your questions. Thank you.

[The charts follow:]

P12 3.85



SPACE TELESCOPE PROJECT RESPONSIBILITIES

MARSHALL SPACE FLIGHT CENTER
- PROJECT MANAGEMENT
- ORBITAL MAINTENANCE

LOCKHEED MISSILES AND SPACE CO.
- SPACE TELESCOPE SYSTEMS ENGINEERING AND INTEGRATION
- SUPPORT SYSTEMS MODULE DESIGN AND DEVELOPMENT
- SPACE TELESCOPE ASSEMBLY AND VERIFICATION
- SPACE TELESCOPE LAUNCH AND ORBIT VERIFICATION

GODDARD SPACE FLIGHT CENTER
- SCIENTIFIC INSTRUMENTS
- COMMAND AND DATA HANDLING SUBSYSTEM
- SPACE TELESCOPE MISSION CONTROL CENTER AND SCIENCE OPERATIONS
- SCIENCE INSTITUTE

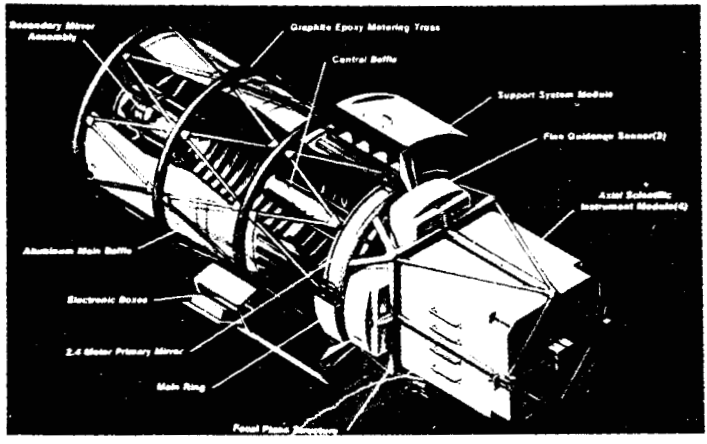
JOHNSON SPACE CENTER
- SPACE TELESCOPE-ORBITER-CREW INTERFACE AND OPERATIONS

PERKIN-ELMER
- OPTICAL TELESCOPE ASSEMBLY DESIGN AND DEVELOPMENT
- FOCAL PLANE ASSEMBLY SYSTEM ENGINEERING
- FINE GUIDANCE SENSOR

EUROPEAN SPACE AGENCY
- SOLAR ARRAY
- FAINT OBJECT CAMERA
- SCIENCE INSTITUTE PARTICIPATION

KENNEDY SPACE CENTER
- SPACE TELESCOPE-ORBITER LAUNCH OPERATIONS

CROSS SECTION OF THE HUBBLE SPACE TELESCOPE



Senator GORE. Thank you very much.
We will hold those questions, Mr. Bulkin, until we hear from Mr. Rich.

STATEMENT OF JOHN C. RICH, PRESIDENT, HUGHES DANBURY OPTICAL SYSTEMS, INC.

Mr. RICH. Thank you, Mr. Chairman.

I am John Rich, and I am President of Hughes Danbury Optical Systems, Incorporated. And for the record, I need to submit that my office is in Danbury, Connecticut, not in Virginia.

Senator GORE. I misstated that. I guess you have offices in Arlington.

Mr. RICH. We have offices in the area.

Senator GORE. But your main office is in Danbury, Connecticut, of course.

Mr. RICH. My office is in Danbury, Connecticut.

I appreciate your invitation to appear today before the Subcommittee.

Let me make a comment back to the June 29th day. Had I received your invitation earlier I would have been pleased to appear at the hearing you conducted on the 29th.

I would like to provide a little background on our company. Hughes Danbury Optical Systems, Incorporated, is, as has been mentioned, a former division of the Perkin-Elmer Corporation. The division was acquired in December of 1989, this last December, by Hughes Aircraft Company, and we are presently a wholly owned subsidiary of Hughes.

We are designers and manufacturers of complex optical and electro-optical systems. Our primary customers are the United States Government and its prime aerospace contractors. And we have worked closely with NASA and the Defense Department on a number of projects over the years. We have been a supplier to the government of precision optics since the late 1930s. We are regarded as one of the leading firms internationally in our field.

Let me state very clearly that no one is more troubled than my colleagues and I about the recent reports of a problem with the Hubble Space Telescope. And we will fully assist in analyzing, and we will do what we can to correct the problem. Dr. Malcolm R. Currie, Chairman of Hughes Aircraft Company, has publicly confirmed this, and has stated that the full range of Hughes technical capability is available for this effort.

I also need to say at the outset that we do not have the answers to the questions that are being asked as to exactly what is wrong with the Hubble, or what may have caused it, or how it all may have come about. It is simply too early to tell. I am, however, here in the spirit of cooperation, and want to cooperate in every way possible with the Subcommittee.

Also, like the Subcommittee, I am in the process of reconstructing the history of our work on Hubble, which goes back some 17 years. My review is not complete, so I am not able today to address thoroughly every question that needs to be answered. And I may have trouble—I may stumble on some of your questions, Senator.

I will, though, to the best of my ability, both in this statement and in answering any questions the Subcommittee may have, provide relevant information that is based on the state of my knowledge today.

Our involvement with the Hubble Space Telescope dates back to 1973, at which time we assisted NASA in early feasibility studies. At that time we also undertook some concept design on the parts of the optical system. NASA competitively awarded a contract to us in mid-1977 to design and fabricate the optical telescope assembly, which is sometimes referred to as the OTA, and the fine guidance sensors for the Hubble Space Telescope.

This work involved primarily the preparation of the two mirrors that have certainly been in the newspapers lately, a primary and a secondary. It involved the incorporation of the mirrors into a metering truss, which holds the mirrors in proper relationship with one another, and also provides for their adjustment. And the design and manufacture of the very precise fine guidance sensors that, in effect, aim and stabilize the telescope to permit it to perform its work.

Mr. Bulkin mentioned that in his opening statement.

The two mirrors which have received substantial attention in the media reports on this subject over the last few days are the 94 inches in diameter primary mirror and the 12 inch in diameter secondary mirror. And I have provided for the record, Mr. Chairman, a technical note published back in 1981 that gives a number of specifications and useful information regarding the telescope and our part in it.

Senator GORE. Without objection, we will include that in the record by reference.

Mr. RICH. Chronologically, we started our work on this contract in October 1977. An order for the large primary mirror blank was placed in November 1977 with Corning Glass Works. We received that blank a year later. The grinding and polishing of the primary mirror was completed in December 1980, and the entire mirror fabrication process, including the coating, was completed in February 1982. The secondary mirror, the smaller of the two, had been finished the prior year.

As has been mentioned, the entire optical telescope assembly was delivered to and accepted by NASA in October 1984. We recognize from the June 29th hearing that the Subcommittee is interested in quality control procedures, testing activity, and the interface between NASA and its contractors. Let me address very briefly each of those subjects in this prepared presentation.

The work which we do is, by its very nature, precision work. We work daily within tolerances that are measured in micrometers, that is, millionths of a meter. Accordingly, we have always emphasized quality control and have maintained a substantial independent department to conduct these activities.

NASA itself mandates that we and its other contractors have an approved quality control system. We have conscientiously and carefully adhered to that system. In addition to our quality control procedures, there were NASA representatives in our plant who were responsible for overseeing our contractual activities, including our quality control.

With respect to testing our work product, the design of precision optics today utilizes highly sophisticated computerized mathematical models that have themselves been verified through frequent use in the past and through cross-checks with other models. These models would generate specifications for an optical item that are analogous to an eye glass prescription. The correctness of this prescription is then confirmed through repetition of the underlying computer processes and through peer review by other scientists and engineers; and this was certainly done in the early days of the Hubble program.

There was extensive review of the mirror designs for the Hubble optical telescope assembly in the scientific community. During the manufacture, the optics are tested to determine their conformity with the prescription through the use of measurement devices. The final precision measurements can only, with today's technology, be made with optical devices as opposed to mechanical devices.

Testing the OTA mirrors employed lasers, precision instruments known as interferometers, and precision reference optics. Some press reports have questioned whether additional different tests should have been done on the mirrors, and we will have a chance to go through this in some detail in the weeks to come. The mirror configuration test we developed and relied heavily on and NASA approved was the only test that we judged to be sufficiently precise to meet the program's requirements.

As for our relationship with NASA, I can only describe it as one of cooperation, with continual communication throughout the OTA program. OTA, again, is optical telescope assembly. Both we and NASA have been careful to

Testing the OTA mirrors employed lasers, precision instruments known as interferometers, and precision reference optics. Some press reports have questioned whether additional different tests should have been done on the mirrors, and we will have a chance to go through this in some detail in the weeks to come. The mirror configuration test we developed and relied heavily on and NASA approved was the only test that we judged to be sufficiently precise to meet the program's requirements.

As for our relationship with NASA, I can only describe it as one of cooperation, with continual communication throughout the OTA program. OTA, again, is optical telescope assembly. Both we and NASA have been careful to document decisions that were made about the optical telescope assembly. There is a great deal of information in the file, and considerable records very well kept throughout the program.

We have high respect for the technical confidence and professional dedication of NASA's scientists and engineers, and we have valued their input, their oversight, and approval of our work throughout this program.

Before concluding, I would like to briefly review the activities we have undertaken to assist NASA and Dr. Lew Allen's optical telescope assembly review board in better understanding and resolving this problem. At the board's request—that is Dr. Allen's board—which we believe is wholly appropriate, we have provided the government with custody of all critical documents and hardware related to the OTA program. These will obviously be carefully reviewed as Dr. Allen's review proceeds; and we will assist him in every way we can to understand how documentation was generated, and how hardware was used.

To start this process several of us did, indeed, meet with Dr. Allen for the better part of two days last week. All of us who have worked on this program at Hughes Danbury are proud of our accomplishments. We are, as I say, deeply concerned about this problem. And we are therefore deeply committed to finding out what is wrong. This is a commitment that even our former employees feel. We have recently been contacted by a number of former employees who have volunteered to give their own time to help understand this, including an 82-year-old retiree, the most renowned senior optical designer from the Perkin-Elmer Corporation.

In summary, we appreciate the opportunity to meet with the Subcommittee. And again, I will try to candidly and directly answer any questions you or the subcommittee may have.

[The following information was subsequently received for the record:]

August 3,1990

The Honorable Albert Gore, Chairman,
Subcommittee on Science Technology and Space, Committee on Commerce, Science, and Transportation, U.S. Senate, Washington, DC

Dear Mr. CHAIRMAN.

I appreciated the opportunity to testify before your Subcommittee on July 10 regarding the recent problems with the Hubble Space Telescope.

As promised at that time, I am enclosing the following information for the record.

1. Amplification of Mr. Rehnberg's 1983 testimony. With respect to Senator Gore's question regarding J. D. Rehnberg 's statement. "This funding shortfall, in turn, resulted in elimination of development testing, cut backs on critical support hardware, interruption in certain development efforts, and in general, operational inefficiencies, "the following is submitted.

Mr. Rehnberg has reviewed the testimony presented to Congressman Volkmer on June 14 and 16,1983. He has also reviewed Congressman Volkmer's letter dated May 23,1983 inviting Perkin-Elmer to provide specific data pertaining to the status of the Hubble Space Telescope relating to our role on the program. We were asked to furnish information regarding future technical and schedule risks. The comment regarding the elimination of development testing was related to a section in the testimony entitled Factors Affecting Program Growth. At that point in time, all believed the

challenges of manufacturing and coating the primary and secondary mirrors were behind us. The testimony dealt with efforts then on-going, such as the Optical Telescope Assembly (OTA) integration and test flow, the development of the Fine Guidance Sensors (FGS) and the completion of these two main items. Previous funding limitations and extreme program schedule demands forced the elimination of development testing of subsystems as the OTA was built up. Many tests were deferred to later verification when the OTA was integrated with the Support System Module at Lockheed.

OTA vibration, acoustic and thermal vacuum tests at Perkin-Elmer were deleted and accomplished at the "all up" systems level at Lockheed. A Fine Guidance Engineering model was also deleted to save cost and schedule, but, at Perkin-Elmer insistence, the first FGS flight unit was subsequently designated a refurbished engineering model to be upgraded later as a flight article.

Mr. Rehnberg believes the statement in context, taken with the comments before it and after it, clearly describe the intent at that point in time to delineate difficulties with OTA system testing, and not with tests of mirror design and manufacture.

2. Additional details regarding quality assurance. With respect to Senator Gore's question regarding the details of how the Perkin-Elmer quality control personnel functioned with respect to the NASA quality control person on the scene, the following is submitted.

The quality control process of the HST program included the approval for formal procedures, the designation of mandatory inspection points, the review of polished mirror test data, the establishment of test readiness reviews, the establishment of operational readiness inspections, quality audits, and the system of engineering changes, configuration control, and material review boards. Each of these is described in detail as FOLLOWS.

A. Formal procedures were developed by the contractor's engineering and manufacturing organizations, and then sequentially and independently approved by the contractor's QA organization, the NASA on-site QA representative and, for certain types of procedures, the Marshall Space Flight Center QA organization in Huntsville.

B. Mandatory inspection points were identified by the contractor's QA organization and submitted to the local NASA QA for approval. The local NASA QA then designated which of those inspection points would require NASA inspection in addition to the contractor's QA inspection. Some inspection by NASA was assigned to the local Defense Contract Administration Service (DCAS).

C. The review of polished mirror test data, involving interferograms and complex measurements, was accomplished by contractor and NASA personnel qualified to interpret the results, and the NASA on-site QA function for the polished mirror tests was performed by a specially qualified NASA designee.

D. Test Readiness Reviews (TRR) were established and chaired by the contractor's QA organization to make sure that people, procedures and equipment were ready for tests and for operations that involved the moving of the primary mirror. The local NASA QA representative was always in attendance or was represented. Both the contractor's QA organization and the local NASA QA representative could dictate action items to be resolved before the test. Both QA organizations had to concur on the resolution of those items.

E. Operational Readiness Inspections (ORI) were established and chaired by the contractor's QA organization to make sure that people, procedures and equipment were ready for major tests. NASA augmented the local QA with additional representatives from Marshall Space Flight Center for such tests. The NASA QA team was led by a QA person from Marshall in the case of an ORI. Both the contractor's QA and NASA QA could dictate action times to be resolved before the test. Both QA organizations had to concur on the resolution-

F. Quality audits were conducted periodically from 1979 on. They included the NASA on-site QA representative as well as additional NASA personnel traveling in from Marshall Space Flight Center.

G. Engineering changes, configuration control and material review board actions all had independent approvals by the contractor's QA organization and the NASA QA representative.

In addition, I would like to clarify one matter. I have now spoken with a number of individuals who were actively involved in the Hubble program from 1977 to 1982 at Perkin-Elmer. Based upon these discussions, it appears that the tolerances of the Hubble mirrors were so small that the only reliable test was one using the type of optics I briefly described in my testimony, i. e., those tests with a laser an interferometer and a reference optic called a null lens. The company, NASA, and the consultants from the scientific community followed those tests and the data produced; it was not believed that other, less precise test were necessary.

While it now appears that other tests may have revealed the apparent spherical aberration in the Hubble mirror I am not aware of any evidence that judgments made in the 1977 to 1982 time frame were not sound. I am concerned in reading the-transcript of my testimony to the Subcommittee that it may have implied that I and others at the Company now believe that decisions made on the testing of the mirrors were unsound. As I said in my prepared statement, that is not my position. Of course, the final assessment on this issue must await tit ore detailed fact finding by Dr. Allen and his colleagues.

If I can provide the Subcommittee with any further information, I would be pleased to do so.
Sincerely,

JOHN C. RICH, *President.*

Senator GORE. Thank you both for your statements. And let me say that on behalf of the Subcommittee, we appreciate the fact that you are in the early stages of attempting to find out exactly what went wrong, and we do understand that your answers to our questions here today will necessarily be coming from a limited base of knowledge, in that you have not completed your review.

I think it is also worth saying that all Americans should be aware of the many outstanding and excellent contributions these two companies have made over the years to our national security and space programs,, to a wide variety of efforts that have benefitted all Americans.

I personally, Mr. Bulkin, put a statement in the record on the floor of the Senate recently about the SR-71 program, just to pick one example. Here you had—how many years did that operate—twenty?

Mr. BULKIN. 20-some-odd years.

Senator GORE. 27 years, I believe, flawlessly and came in below cost and above specs. Then, on its final retirement mission on the way to the museum, just in an offhand way, set the world speed record. I thought that was a class act.

And Perkin-Elmer, now Hughes Danbury, has similar accomplishments of extraordinary excellence under its belt. To the employees of both companies, let me say that this inquiry into what actually went wrong with the Hubble should not lessen their pride in what has been accomplished in both companies over the years.

But now let us get to the business at hand of how this could have gone so wrong. You were in the room when we questioned the witnesses from NASA earlier, I take it. Is that correct?

Mr. RICH. Yes, we were.

Senator GORE. In the exchanges concerning the Hubble, is there anything that you would like to challenge or correct based on what you heard? I said, for example, that it is my understanding there were two bidders for the optical—for the telescope itself; the Perkin-Elmer Company, now Hughes Danbury, and Kodak, out of Rochester; and that both companies brought different strengths to the contest; and that Kodak, because of its expertise in optics and mirrors, included in its bid an emphasis on some of the areas of strength that it had, whereas you included a little more emphasis on some of the areas of strength that Perkin-Elmer had. I guess the pointing precision is something that maybe you felt like you could do better than Kodak. And that was seen as the major challenge of the Hubble, and NASA decided that —that is fair to say, is it not?

Mr. RICH. That is fair to say.

Senator GORE. NASA probably looked at your strength in that area as a major reason for awarding you the contract. Is that fair to say?

Mr. RICH. I would say that was a heavy evaluation factor on the part of NASA.

Senator GORE. That is probably a better way to put it than the way I put it, but the meaning is the same.

And yet, because of Kodak's strength in the optics part of it, they had included in their bid, and were more able to include in their bid, a provision for a final assembly test of the completed telescope prior to launch. Is that correct?

Mr. RICH. Senator, unfortunately, I found out something here today, and that is that Kodak did put in their bid a final assembly test. So that is new information to me.

Senator GORE. Okay. Because of the bidding procedures a lot of that is kept from the other bidders.

Mr. RICH. Because of the bidding procedures.

Certainly, I do not have the visibility of the other bidders, and we do not always know.

Senator GORE. They did.

Let me ask you why you did not include in your bid a provision for final assembly testing?

Now, my overview of it leads me to believe that the reason they did and you did not has to do with the different experiences and strengths of the two companies. But focusing in on the decision by Perkin-Elmer, now Hughes Danbury, not to include in its bid a provision for final assembly testing, why did you feel it was not necessary to do a final assembly test?

Mr. RICH. Probably it would not do well to speculate. The exact answer to your question I do not have as part of my repertoire. I would again comment similar to the way that Dr. Fisk commented, that I would believe that a cost/benefit analysis on the cost of doing such a final test had to figure into those judgments and decisions made at that time.

But just to repeat, I do not know for a fact at this stage the philosophy in the decisions made in that bid.

Senator GORE. Let me state openly here that the cost of the final assembly test and facility for same included in the Kodak bid was $10 million, not $100 million, not $150 million, but $10 million on a project that turned out to be $1.5 billion. If you could have done a final assembly test for $10 million, obviously in retrospect you would do it now. But going into it, that did not seem like a reasonable investment?

Mr. RICH. I would say so.

Senator GORE. It is not clear to me that Hughes Danbury could have performed a final assembly test for as little as that. But the philosophy that guided your decision not to perform a final assembly test is what I really think is at issue. I am given to believe that you had a different approach to testing that was in some ways more sophisticated than what other companies could do. And that, because of your pride in that sophistication, you really felt that testing of each separate component could be done so well that it was not necessary to have a final assembly test.

Do you know enough at this point to respond to that as a question?

Mr. RICH. Senator, my review of the proposal we made at that time, which of course I can sit down and read, did in fact point out the strengths of the way in which we test individual mirrors and the test equipment and its certification that we use. And that was a strong point as we made that proposal to NASA.

Again, information about the detailed tradeoff of that with full-up testing, I do not have the benefit of those analyses.

Senator GORE. Now, assuming for a moment that the Subcommittee is correct in its investigation so far in determining that this decision was really addressed at the time the bids were opened, to your knowledge, during your construction of the telescope, did NASA ever raise with you the possibility of a final assembly test prior to their acceptance of the completed telescope?

Mr. RICH. To my knowledge, they never raised that formally with us.

Senator GORE. Well, that leaves hanging the next question. Was there an informal discussion of whether or not that might be a good idea?

Mr. RICH. The informal discussions, again, follows right in the path of Lennard Fisk earlier, that that subject was reviewed and discussed at various times. How far back in the program I do not know. But when I first became familiar with the program people spoke occasionally of final tests. Again, right

in the line of Lennard Fisk's comments, these were discussion items and not carried beyond that to my knowledge.

Senator GORE. Were there people within your company who felt like it would be a good idea to conduct a final assembly test?

Mr. RICH. A good idea? Yes, I would suspect there are several people who thought it would be.

Senator GORE. No, I am not talking about in retrospect. I mean during the times these informal discussions took place, were there people in your company who felt at that time that maybe this should be added?

Mr. RICH. Let me try to answer it in the following way. If I were to go back now and bring various people into the room who were in the program at the time and asked them, I would probably get several people who would say yes, they always thought it would be a good idea.

Senator GORE. Okay. That is a candid and fair answer. I appreciate that.

Mr. Bulkin, I am a little unclear about the relationship between Lockheed and Perkin-Elmer, now Hughes Danbury. Did your company have the final say on delivering the completed telescope to NASA for launch?

Mr. BULKIN. No, Senator. We were an associate contractor, as you know, and Perkin-Elmer at that time was responsible directly to Marshall Space Flight Center, as we were. And we had very little dealings with the internal design and testing of the optics themselves, just as the total optical telescope assembly was delivered to Lockheed.

Senator GORE. What was your responsibility under the contract? To integrate all of the parts of the full project?

Mr. BULKIN. That is correct. We had the support systems module, which was a primary development effort; and we had the requirements to establish all the interfaces with NASA. Since we were dealing with associate contractors, we had no direct authority to the other contractors; only through NASA. And so that was our primary role.

Senator GORE. Is that your understanding of it also, Mr. Rich?

Mr. RICH. Yes it is.

Senator GORE. So the primary responsibility for determining that the telescope was adequately tested and ready for launch rested with Hughes Danbury?

Mr. RICH. That is correct.

Senator GORE. Who created the criteria for deciding how much testing was adequate? Did your company do that, or did NASA do that?

Mr. RICH. Let me try it this way. NASA basically sent out a specification for the program in the '76-'77 time frame. We respond to that with a proposal, which in turn outlined our approaches to making things and to solving problems. In the process of accepting that proposal, and subsequent negotiations and developments from that, it was a process, generally, of the company proposing how we would do things and NASA approving those processes and procedures.

Senator GORE. So according to that model, you essentially proposed the criteria for adequate testing and NASA approved your proposal.

Mr. RICH. I believe that would have been the case.

Senator GORE. Those criteria were created, at least in preliminary form, when the bid was submitted, correct?

Mr. RICH. That is correct.

Senator GORE. Were those criteria formally reviewed after the contract was awarded?

Mr. RICH. Let me assume they were. I do not know for a fact. That can be easily checked. But in a program like this, it would be highly unusual if those

criteria were not reviewed regularly several times during the early two or three years of the program.

Senator GORE. I stated earlier that, as a matter of philosophy—that may be the wrong word, but it is the best I can come up with—as a matter of philosophy, it makes sense to have a final assembly test on a system like this. In retrospect, do you agree with that?

Mr. RICH. In retrospect, it is easy to agree with that.

Senator GORE. As I said when the NASA witnesses were here, and I will repeat it now, if there was one mistake that could be corrected to prevent this from occurring, it would be the decision by NASA not to require a final assembly test as an essential part of the criteria for what constituted adequate testing. Now I think I understand why Perkin-Elmer did not submit that. And I appreciate your candid statement that in retrospect, you wish you had. But I think the responsibility fairly lies with NASA in the construction of the criteria it approved.

Of course, as—and I do not want to put words in your mouth, but I think it is fair to say that Perkin-Elmer Hughes Danbury wishes it had included that in the criteria, and NASA wishes it had either approved it under those circumstances or required it itself.

Senator GORE. Let me ask both of you, are you fairly confident at this point that the problem does lie in one or both of the mirrors?

Mr. BULKIN. I believe so.

Mr. RICH. I think we have seen a very open and prompt reporting of the data and results by NASA, and I believe they are zeroing in on the problem, and I have no reason to argue with the assessments they are making, as painful as it may seem.

Senator GORE. Most people seem to be concluding it is the primary mirror. Is there reason for thinking that it is probably the primary mirror and not the secondary mirror and that it is probably the primary mirror alone and not both of them?

Mr. RICH. There is no particular reason to think that that I know of except the primary mirror is harder to make than the secondary. It is larger. There is some data that NASA is trying to get out of the spacecraft now from the faint object camera which might help pinpoint that a little better because of the nature of the images. So maybe we will see. I think that is what Dr. Fisk was referring to.

Senator GORE. Okay.

Mr. Bulkin, just because the primary mirror is larger and more difficult to make, is that the reason why most people seem to be assuming that it is likely that is where the problem is?

Mr. BULKIN. I believe so.

Senator GORE. All right. Mr. Rich, how did your company relate to NASA's quality control personnel? Did they come and visit your place often, interacting with your employees and asking questions? Did they submit written questions? Did they come and spend time with you? Can you give me a sense of exactly how that relationship unfolded?

Mr. RICH. Yes. To the degree that I am able to find out information and some from my personal memories, in the 1979, 1980, 1981 time frame there were basically three Marshall people in our plant full-time. At least one of those was a full-time quality person. In addition to that, Marshall used the DCAS, the Defense Contract Administration Service, who resides in our building to assist them during those times.

Further, whenever there were major events, major pieces of hardware being completed, major reviews, major certifications taking place, NASA augmented their staff in our plant in that time frame with people from Huntsville, Alabama.

Senator GORE. How many people did they have in that office on a regular basis, again?

Mr. RICH. In that time frame they had three, one of whom was a full-time quality person, one was basically the manager of the operation, and the third one was an engineer who served in quality assurance functions of the high tech operations. So they had a lot of attention on quality activities and a lot of attention on the floor activities and a lot of attention on the certification of the processes going on.

Senator GORE. Now when they ballooned the number of personnel during critical stages, that number of three would go up to what?

Mr. RICH. When they ballooned, which was not really until 1983, that number, if I wrote it down here, went from—let's see. If my memory serves me right, they ended up with about 25 people on site.

Senator GORE. Now there have been reports that some of the government scientists and outside experts asked by NASA to review this process by which the mirrors were being made had said they were often overworked and overwhelmed by the task and did not rigorously check crucial tests done by the mirror manufacturer. I am quoting from an article by William Booth in last Tuesday's Washington Post with that particular point.

Does it surprise you to hear that, or does that conform with your memory of their experience?

Mr. RICH. It does not particularly conform to my memory, but they are a better group to ask than I.

Senator GORE. Well, we will ask them.

According to William Fastie, an optical expert at Johns Hopkins University, one of the scientists appointed to monitor the polishing process—do you know him?

Mr. RICH. Yes, I do.

Senator GORE. He said Perkin-Elmer had "more autonomy than they should have" and went on to say that you had "a sweetheart deal".

Why would he say that?

Mr. RICH. Well, I saw that comment, and that comment disturbed me and disappointed me. I do not know why he would say that.

Just to pick up a little bit on the questions you asked previously about our relationship with the NASA people, that relationship was always very professional and very serious. They were a very demanding customer in our plant, on the floor and during the certification processes. So I am surprised by that comment.

Senator GORE. Now you know John Renberg?

MR. RICH. Yes, I do. He reports to me, by the way.

Senator GORE. He reports to you?

Mr. RICH. Yes, he does.

Senator GORE. He testified seven years ago that there was the elimination of development testing. What did he mean by that?

Mr. RICH. This issue was raised, of course, on June 29 in the hearing before the subcommittee, and so I took a minute to talk to Mr. Renberg. The testimony and his statements at that time really had to do with the development of the development problems associated with the fine guidance sensor and some of the structural work and some of the latches for the science instruments.

Mr. Renberg told me that those comments did not really go back to the 1979, 1980 and 1981 time frame, so that concern and that criticism was not a mirror issue.

Senator GORE. That was not a mirror issue?

Mr. RICH. That was not a mirror issue.

Senator GORE. What about the cutbacks on critical support hardware, interruption in certain developmental efforts and general operational inefficiencies? Did none of those refer to the mirror operation?

Mr. RICH. My understanding from my conversations just recently with Mr. Renberg is that the 1979, 1980 and 1981 time frame is not subject to those criticisms as was the 1982 and 1983 time frame.

Senator GORE. You said you have an independent department to oversee quality control?

Mr. RICH. That is correct.

Senator GORE. How many people in that department were assigned to the Hubble mirrors?

Mr. RICH. During the 1979, 1980 and 1981 time frame, there were approximately eight people associated with the program at that time that were in the quality control department.

Senator GORE. Did they coordinate their efforts with NASA's quality control person on the scene? Did they carry out their work independently? What was their relationship like with the NASA quality control specialist working in your plant?

Mr. RICH. I cannot testify from personal observation or personal memory, and probably should not speculate. I have no reason to think that it was anything but the most professional and the most proper. But I would prefer to supply that as a better answer, if I could, later.

Senator GORE. Well, I am not really getting at questions of professionalism or propriety. I have no reason to question that. But I am interested in the details of how the working relationship functioned, and if you could supply details on that matter for the record.

Mr. RICH. I would much prefer to do that rather than try to answer it now.

Senator GORE. That would be fine, if you could supply that for the record, we would be very interested in it.

Now at our first hearing on June 29, Dr. Fisk indicated that the management structure with which NASA oversaw the Hubble was not ideal; too many centers involved, poor communications between the different centers and the contractors. I do not want to put words in his mouth. That is my memory of what the essence of his testimony was.

And then you have the scientist I quoted earlier saying, "You had too much autonomy". You say you do not know why he said that. I am speculating here. Could it be that the loose and poorly coordinated management structure used by NASA could have resulted in more autonomy for Perkin-Elmer than was healthy?

Mr. RICH. I will give you my personal opinion based on, again, not personal knowledge, but understanding of people and reports I have had.

The relationship that was criticized earlier by NASA had to do with too many centers, and I think implied in some of the things Dr. Fisk said was his dislike for associate contractor relationships. He also got some argument about that from Mr. Thompson.

Senator GORE. Right.

Mr. RICH. The relationship we had with Marshall was very straightforward. We had a contract with them, and we understood who the customer was, and they understood who the contractor was. So I guess I am walking around trying to say,

I do not think that perception of loose management or loose management structure in any way implied loose management per se.

Senator GORE. Well, in conclusion, let me ask both of you one final question. First of all, no, one penultimate question for you, Mr. Rich. The Danbury Connecticut News Times reported a couple of days ago, I guess, that you had the know-how to catch optical aberrations because of past work, et cetera, but you did not use it for some reason. I take it you challenge that characterization? Or do you?

Mr. RICH. Well, let us find out what the problem is, first, before we really pin it down and state all the facts and the conclusions and so forth. There is no question we know what optical aberration is; we know what spherical aberration is—well, period.

Senator GORE. Let me ask the final question of both of you. You have sat through this proceeding. You are familiar with the hearing that we had June 29. And a certain understanding, a certain picture of what happened is coming out of this. Is there any part of that you would like to challenge? Do you think that the view we are getting of this is somehow off or unfair, biased against the true picture somehow? Is there some facet of this you would like to challenge based on what you have heard today?

Mr. RICH: No. I do not believe so. I think it is remarkable, the amount and quality of information you are getting from all sources.

Senator GORE. Mr. Bulkin.

Mr. BULKIN. At the risk of possibly minimizing a couple of the comments that were made, you know the initial idea not to test end-to-end probably was not a good idea. However, it was an inexpensive idea at the time. I am sure that played a major role. The $10 million, I cannot even discuss on how they would do that for $10 million. But, with the requirement on the telescope being a 20th of a wave, that test procedure and process would have been very expensive. At the time, it appeared that you could do it by analysis, it could be done.

There were many things that were done by analysis. We qualified many sub-systems by analysis without actually having to perform tests because of the cost involved. If it were done correctly, it probably would have found the error. A test naturally would have found the results, and the test did not have to be very exotic to find the problem that we have today, although the test at the initial part of it would have been a very expensive test set up, because it would not have been looking for a gross error. It would have been looking for a precise polishing job, and a figure in the mirror.

So, the testing of this instrument, including the fine guidance sensors and the telescope, not considering the optics portion of that, and the performance of the telescope other than the optics, is going extremely well, and it is not an incorrectable problem that we have, and I think it can be corrected as mentioned by the NASA witnesses earlier, and we are confident that it can be done.

You know, we are as disappointed as anybody as far as the results as you can imagine. Our experience has been, you know, that you always test when you can test, but when test processes get to be very expensive, you have to trade that off versus risks.

Senator GORE. So, there are really two impressions that have come out of our two days of hearings thus far, that you would like to challenge. One lies in painting the Hubble as deep a tragedy as it seems to be. You would qualify that by pointing out again, that the Space Telescope probably can be fixed. We may lose up to three years worth of science on a major part of it, but it probably can be fixed, assuming the shuttle fleet gets back up and all that, which it will. And so, you would challenge that part of the impression that comes out.

And secondly, you would say that in your opinion, $10 million is probably an unreasonably low figure for what it would have cost to do a final assembly test. I said earlier I do not think Perkin-Elmer could have done it for that. But that was the bid figure for the facility to do it by the other bidder. Now, the personnel cost of performing the test, maybe that is not in that figure. I do not know. I will have to go back and check that. But even if it was double that amount, that would be something that would certainly seem reasonable in retrospect, and it seems to me should have seemed advisable at the time.

I think, and I said earlier, that it is not as if the nation has never put up a complicated optical system in orbit. There are all kinds of differences, and I am not going to characterize what has been done in the classified systems, but I will say again, it is my understanding that we have always required a final assembly test, always, except with the Hubble. You do not challenge that, do you?

Mr. BULKIN. No.

Senator GORE. All right. With that, let me just say in conclusion that we will continue our investigation of this matter. I am asking the staff of the Subcommittee to interview a number of witnesses, including those who were quality control personnel within the company and within NASA during the manufacture of the mirrors. We do want to learn as much as we can about what went wrong and why, as an effort to rebuild confidence in these procedures. And with that, our hearing will stand adjourned. Thank you both very much for coming today.

[Whereupon, at 3:15 o'clock, p.m., the subcommittee adjourned.]

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