GENERAL OVERSIGHT

NATIONAL SCIENCE FOUNDATION

HEARING

BEFORE THE

SUBCOMMITTEE ON SCIENCE, RESEARCH AND TECHNOLOGY

OF THE

COMMITTEE ON SCIENCE AND TECHNOLOGY U.S. HOUSE OF REPRESENTATIVES

NINETY-FOURTH CONGRESS

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SEPTEMBER 30, 1976

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CONTENTS

WITNESSES

GENERAL OVERSIGHT

NATIONAL SCIENCE FOUNDATION

THURSDAY, SEPTEMBER 30, 1976

U.S. HOUSE OF REPRESENTATIVES,
COMMITTEE ON SCIENCE AND TECHNOLOGY,
SUBCOMMITTEE ON SCIENCE, RESEARCH AND TECHNOLOGY,
Washington, D.C.

The subcommittee met, pursuant to adjournment, at 9:40 a.m., in room 2318, Rayburn House Office Building, Hon. James W. Symington, chairman of the subcommittee, presiding.

Mr. MOSHER. I suspect this is the last committee session of my career, so I'm going to be very presumptuous. Until Jim Symington arrives, I'll assume the Chair. But the real necessity for that is we go into session in a few minutes, at 10 a.m. and it is difficult to get this important function accomplished.

Jim has prepared some remarks here, an opening statement, and OK, here he is.

Chairman SYMINGTON. Thank you, Mr. Mosher. The subcommittee will come to order. I wish you all good morning.

We are conducting this morning an oversight hearing on the National Science Foundation as a preview to the fiscal year 1978 authorization hearings.

Our subject today is the management of facilities that are supported by NSF funds, but you'll find that our concern also extends beyond facilities management to the management of equipment; and beyond the NSF to the entire federally funded research system.

In its fiscal year 1977 NSF authorization report, the Committee on Science and Technology expressed concern with the growing transfer of facilities and operational support from other Federal agencies to the NSF.

Our concern was threefold: That this trend toward the support of numerous big science projects by the NSF may erode the support available to individual researchers in the basic research areas; that such changes within the structure of the Government may result in the undesirable concentration of Federal basic research activities in NSF; and finally, that the NSF may not be properly staffed and organized to assume increased management responsibilities of large, complex facilities and operations.

This hearing is part of a major long-term inquiry which has been underway for much of the past year. However, our major focus today is on the Very Large Array and the Nevis synchrocyclotron project.

During the course of this hearing we hope to define further some of the issues and questions which underlie the management of these two very different types of research facilities. In doing so, we wish to begin to determine whether the past policies and procedures of NSF are sufficient in view of its role in the support of large facilities at present and in the future.

The Very Large Array and the Nevis machine are, in fact, two very different types of facilities. The Very Large Array is a radio telescope which will be used to probe the outermost reaches of the universe; and the Nevis synchrocyclotron is a medium-energy particle accelerator which will be used to probe the innermost recesses of nuclear structure.

The Very Large Array was funded from its original planning stages by NSF; the Nevis facility was constructed and operated with the Office of Naval Research support from 1946 to 1966, at which time its support was picked up by the NSF.

The Very Large Array will not be completed until 1981; from the beginning of its operation in 1950 until it was shut down for modernization in 1970, the Nevis machine was continually in the forefront of particle physics research.

By 1981, the Very Large Array project will have received several times more dollars from the NSF than the Nevis project; both, however, represent significant expenditures of Federal funds.

Both have encountered numerous problems in attempting to stay within original cost estimates. The problems encountered range from large increases in rates of inflation and costs of materials to underestimation of the cost and difficulty of various aspects of the project associated with the high-risk nature of basic research. Each has chosen to handle these problems in different ways.

In addition, both the Very Large Array and Nevis machine are coming into operation this year, and it is for this reason among others that the timing of this particular hearing seems appropriate.

We hope to come to a better understanding today of: Why certain decisions were made in the planning and construction of each of these facilities; what policies and procedures within the NSF affected the course of this decisionmaking; how well the NSF has been able to monitor the progress of such large, long-term projects; and what problems have been associated with managing and monitoring these facilities.

In reaching this understanding, both the subcommittee and the NSF should be better enabled to plan for the future of these and other facilities, and to determine whether new approaches to facility management within the NSF are called for.

We welcome as our witnesses this morning representatives of the National Science Foundation, the Nevis Laboratories, and the National Radio Astronomy Observatory, which operates the Very Large Array.

We plan to hear first about the Very Large Array from Dr. Robert Hughes, Assistant Director of the Astronomical, Atmospheric, Earth,

and Ocean Sciences at NSF, followed by Dr. David Heeschen, director of the NRAO. We would then like the opportunity to ask a few questions before moving on to the subject of the Nevis synchrocyclotron.

To talk about this project, we have with us today Dr. William Wright, Director of the Physics Division of NSF, and Dr. Leon Lederman, Director of the Nevis Laboratories, and professor of physics at Columbia University; and, again, we request the opportunity to ask questions after these presentations have been made.

We welcome the witnesses to the table, and ask them to proceed with their prepared statements.

I'm advised that the House goes into session at 10, in order to deal with actions of the executive branch, and therefore we would request the witnesses to keep their statements concise. We will keep coming back and forth to the hearing room, of course. But it looks as though we're going to have one of those mornings. So, if you could sort of summarize your testimony, the entire statement will be made a part of the record.

[A brief biography of Dr. Hughes follows:]

DR. ROBERT E. HUGHES

Dr. Robert E. Hughes was designated Assistant Director of the newly established Directorate for Astronomical, Atmospheric, Earth, and Ocean Sciences at the National Science Foundation on July 10, 1975. Dr. Hughes had previously been nominated by President Ford to serve as Assistant Director for National and International Programs and was confirmed by the Senate on December 18, 1974. Before coming to the Foundation in the fall of 1974 to serve in the Science and Technology Policy Office, Dr. Hughes had been professor of Chemistry and also, for the past six years, Director of the Cornell Materials Science Center at Cornell University. He is on leave of absence from Cornell University while at the National Science Foundation.

As Assistant Director for Astronomical, Atmospheric, Earth, and Ocean Sciences, Dr. Hughes is responsible for four Divisions—Earth Sciences, Ocean Sciences, Astronomical Sciences and Atmospheric Sciences—and also for the Office of Polar Programs. The Directorate funds and administers a number of major research programs such as the Global Atmospheric Research Program, the Ocean Sediment Coring Program, and the Arctic and U.S. Antarctic Research Programs. It also will administer a number of major national laboratories.

Dr. Hughes also served as Acting Assistant Director for the Scientific, Technological and International Affairs Directorate, when it was first established in 1975. In this capacity he supervised the activities of five Offices—Science and Technology Policy, Energy R&D Policy, National R&D Assessment, Science Information Service, and International Programs—and the Division of Science Resources Studies.

Dr. Hughes is a native of New York City. He received the bachelor of science degree from Lehigh University in 1949 and the Ph.D. in chemistry at Cornell University in 1952. The following year he served as an instructor at Cornell and was named as assistant professor of chemistry at the University of Pennsylvania in 1953. He became an associate professor at Pennsylvania in 1960 and a professor in 1964. He joined the faculty at Cornell in 1964 as a professor of chemistry. From 1967 to 1968 he was a National Science Foundation Senior Fellow at Cambridge, England.

Dr. Hughes served as a member of the Research and Development Study Group of the U.S. Commission on Government Procurement during 1971–72. He also was a member of the Solid State Science Committee of the National Research Council/National Academy of Sciences for many years and served as Chairman of the Committee from 1971 through 1973. He was a consultant on materials for the Department of Transportation and was also a consultant

with the Advanced Research Projects Agency of the Department of Defense, and with Rohm and Hass Company, Sun Oil Company, and Hercules Incorporated.

He is a member of the American Chemical Society, the American Crystallography Association, the American Association for the Advancement of Science, Cosmos Club, Cornell Club of New York, Sigma Xi, and Phi Beta Kappa.

Dr. Hughes is married to Lou J. Hughes, an assistant professor of chemistry at Ithaca College, and they have one son, Jeffrey.

STATEMENT OF DR. ROBERT E. HUGHES, ASSISTANT DIRECTOR FOR ASTRONOMICAL, ATMOSPHERIC, EARTH AND OCEAN SCIENCES, NATIONAL SCIENCE FOUNDATION

Dr. HUGHES. Thank you, Mr. Chairman.

Mr. Symington, before you arrived, Mr. Mosher indicated that this was the last meeting of the subcommittee in this session, and I want to take this opportunity to express my deep, personal pleasure at being able to appear before you at this time, and also my deep, personal respect for the contributions that you and Mr. Mosher and other members of this committee have made to the support of U.S. science.

Chairman SYMINGTON. Thank you, Dr. Hughes.

Dr. HUGHES. I am pleased to be able to respond to your interest in the Very Large Array, the new radiotelescope that is being created on the plains of San Augustin, west of Socorro, N. Mex.

The Very Large Array is a project of the National Radio Astronomy Observatory, one of five contractor-operated national astronomy observatories supported by the National Science Foundation. The Foundation's contractor for the management and operation of the NRAO is Associated Universities, Inc., AUI, a nonprofit corporation sponsored by nine universities.

When it is completed in early calendar year 1981, the Very Large Array will provide scientists in the United States with a radiotelescope capable of imaging celestial radio sources and measuring their radio spectra with unprecedented resolution, sensitivity, and imaging speed. Through waveguides and computers, the VLA will combine the signals from 27 synchronized antennas into a single image. A standard radiotelescope with a single reflector would have to be approximately 25 miles in diameter to match its performance in resolution.

The 82-foot-diameter antennas will be deployed along the arms of an equiangular wye of standard-gage double railroad tracks. Some of these elements are visible, Mr. Chairman, in the color photographs that were provided for you.

Chairman SYMINGTON. Thank you.

Dr. HUGHES. At intervals, spur tracks lead to observing stations on which antennas may be positioned. An antenna can be lifted off the pedestal at one station and moved to any other by means of a self-propelled transporter.

The antennas can thus be arranged in different networks on the 72 stations along the arms of the wye to meet differing scientific program needs.

This occasion is within a few months of the midpoint of the 8-year assembly schedule planned for the Very Large Array. I am happy to report that the project is both on schedule and within budget.

A major milestone was recently passed when the first three antennas completed for the array were connected to the central electronics and computer systems in the control building and successfully operated in an interferometer mode. At present, a total of six antennas have been completed and a seventh is under construction.

In its report on the NSF fiscal year 1977 authorization hearings, the committee expressed a concern that the NRAO advisory groups directly involved with the Very Large Array may be preoccupied with scientific and technical aspects of the project and suggested that a formal review of management and technical planning be undertaken.

We strongly agree that at this midpoint such an overview of the Very Large Array is appropriate and action has been taken to establish an ad hoc advisory panel in accordance with the committee's recommendation. The panel is expected to begin its study this November and report its findings and recommendations early in 1977.

I should point out that a comprehensive system of oversight and of management of the project has been in effect from the beginning. Corporate management responsibility rests with AUI. Planning and operational management is delegated to NRAO through its director, Dr. David S. Heeschen, and the Very Large Array project manager, Mr. John H. Lancaster. Mr. Lancaster is here with us today.

The Foundation's interface with its contractor, AUI, is through the director of the division of astronomical sciences in my directorate. Thus, the NRAO director and the NSF Division Director have the responsibility of assuring that the Very Large Array Project is being accomplished effectively, efficiently, and within estimated costs.

On the part of the Foundation, the day-to-day, sometimes hour-to-hour, interactions required by a project of this nature are performed by the Foundation's Very Large Array program manager, who works directly with AUI's Very Large Array project manager.

The NSF's responsibility and management functions are carried out as follows. Annually, before the start of the ensuing year's budget cycle, we request AUI to provide the Foundation with a detailed presentation of the proposed NRAO/VLA budget. That includes, of course, the budget and activities for Green Bank for the new year and also the long-range plans for the next 5 years.

Under the direction of the AUI president, Gerald Tape, the presentation is made by the NRAO director and his staff, including the Very Large Array project manager. In the process, the current status and future plans for the Very Large Array are reviewed.

This overall NRAO review is followed by two Very Large Array reviews each year, in July and December. The midyear review is held at the Very Large Array site in New Mexico, and is generally my opportunity to view the progress there. I might note that a number of the committee's staff attended this year's review. The other review is held at the NSF in December.

Additionally, there are regular site visits, about once each 6 weeks, made by the Very Large Array program manager and, as well, visits of other NSF cognizant personnel, including auditors.

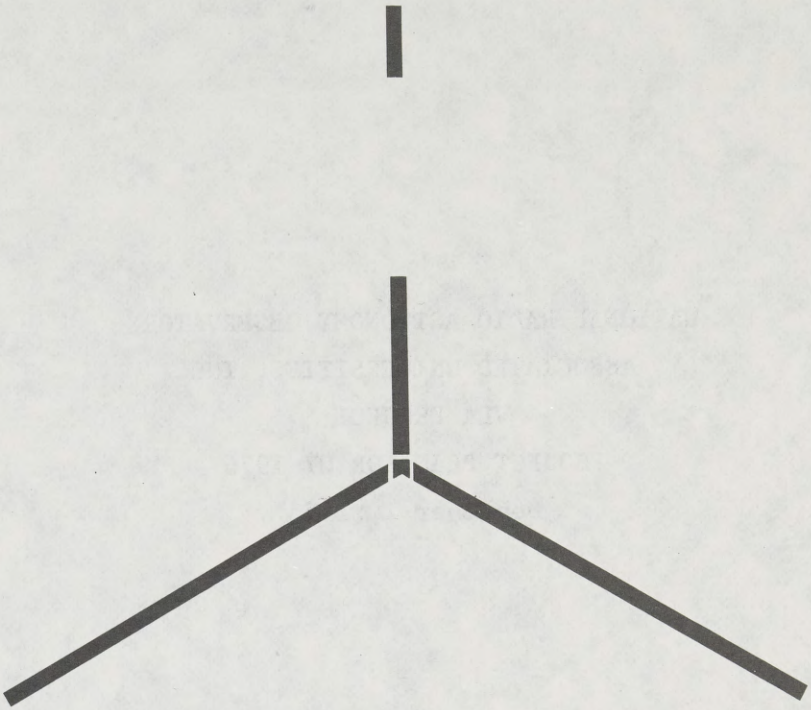
All of these review activities are supported by selected project documentation. Foremost is the Very Large Array project plan that AUI revises each year and submits to the NSF for approval, along with the NRAO program plan. Both plans are subject to revision during the course of the program year, which tracks with the calendar year, and each such revision must be approved by NSF.

Mr. Chairman, I would like to submit for the record a copy of the Very Large Array project plan for calendar year 1976. It is an extremely well prepared and detailed document.

Chairman SYMINGTON. Without objection, that will be incorporated in the record.

Dr. HUGHES. Thank you.

VERY LARGE ARRAY
PROJECT



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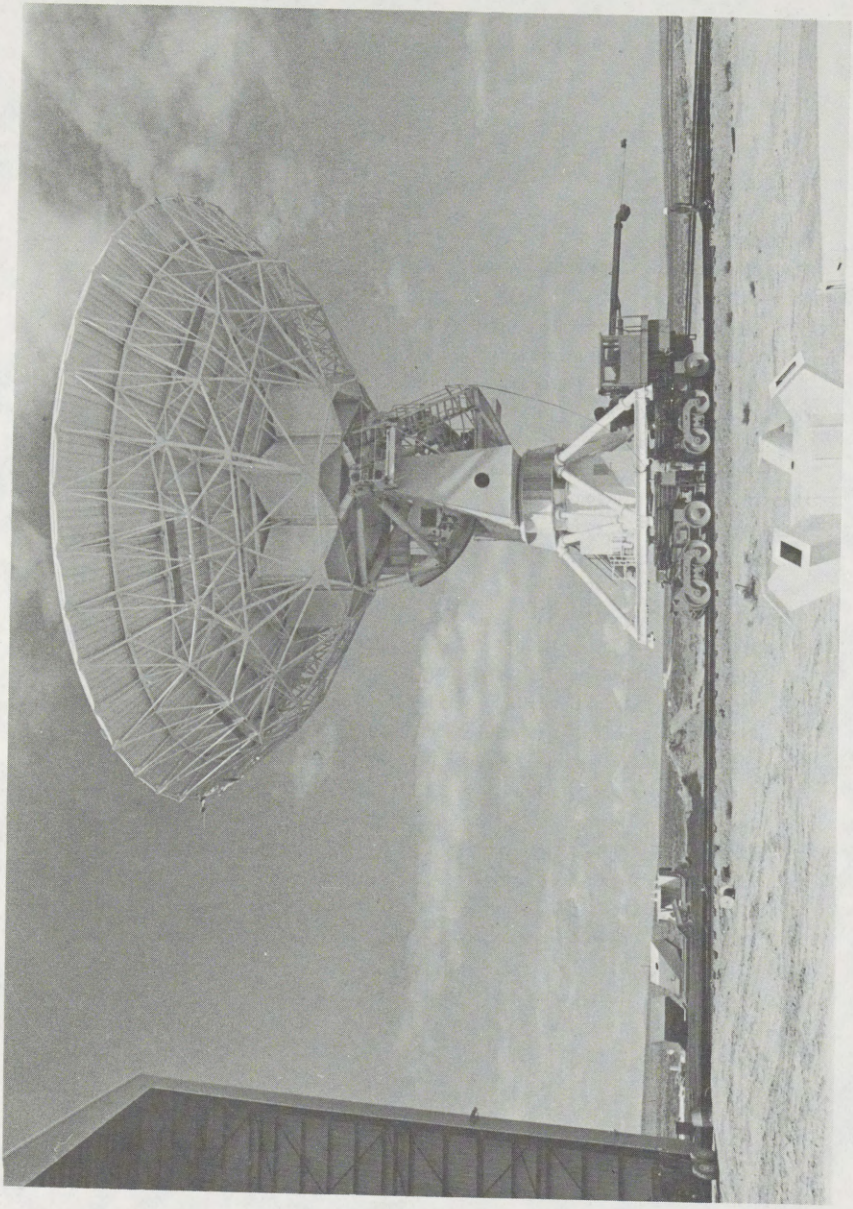
VLA PROJECT
PROJECT PLAN FOR CY 1976
December 1, 1975

NATIONAL RADIO ASTRONOMY OBSERVATORY
ASSOCIATED UNIVERSITIES, INC.
VLA PROJECT PLAN FOR CY 1976

INDEX



NATIONAL RADIO ASTRONOMY OBSERVATORY

VLA PROJECT

August 2, 1976

MODIFICATION OF PROJECT PLAN FOR CY-1976

The revisions to the VLA Project Plan for CY-1976 set forth below reflect changes resulting from additional funding provided by Amendments No. 18 and No. 20 to Contract NSF-C780.

Amendment No. 18 provided $90,000, which is to be used to help offset the increased take-up and delivery costs of rail from the Crab Orchard National Wildlife Refuge. Between eighteen and twenty track miles of rail became available from this source and had to be removed during 1976. This was considerably more trackage than had been contemplated when the CY-1976 Project Plan was prepared but, as it is the last large known source of excellent rail, there was no question but that it had to be obtained.

Amendment No. 20 provided $3,500,000 in transition quarter funds which, with $1,500,000 reprogrammed from the original CY-1976 Project Plan, will be provided to the antenna subcontractor, E-Systems, Inc., to permit the advance procurement of $5,000,000 of key equipment and material items for the eighteen antennas remaining under Subcontract VLA-6. This advance procurement and the resulting continuous production of antennas will advance the delivery dates for all remaining antennas.

The reprogramming of existing CY-1976 funding is set forth in the following table, given in thousands:

	12/01/75 Allocation	06/30/76 Allocation	Funds Reprogrammed	07/30/76 Allocation
Unused Contingency	$ 676	$ 948	$ 823	$ 105
Antenna Production	2,670	2,470	277	7,255
Antenna Travel	31	31	10	21
Construction Facilities	26	76	5	71
Site Work/Utilities	63	99	53	46
Building Complex	427	512	81	431
Wye Construction	3,946	4,193	165	4,028
Systems Integration	171	148	36	112
Project Management	635	662	10	672
1975 Carryover	-	-	40	-
TOTAL			$1,500	

The necessary revisions to the Financial Schedule are shown on the attached sheets:

Page		Revision
42	COMMITMENT SCHEDULE - CY-1973 THROUGH CY-1980	8/02/76
43	EXPENDITURE SCHEDULE - CY-1973 THROUGH CY-1981	8/02/76
44	FINANCIAL PLAN CY-1976	8/02/76
45	FINANCIAL PLAN CY-1976	8/02/76
46	FINANCIAL PLAN CY-1976	8/02/76
47	FINANCIAL PLAN CY-1976	8/02/76
58	EXPENDITURES AND COMMITMENTS, CY-1976, CUMULATIVE ACTIVITY	8/02/76

INTRODUCTION

This update of the Project Plan for the design and construction of the Very Large Array Project reports the progress which has been made during the last year, discusses changes which have been made in the previous plan, and forecasts activities to be undertaken in future years. In addition, revised cost estimates and commitment and expenditure schedules are included and discussed. Some sections, such as a description of the instrument and organizational details, are included to make the Project Plan understandable to one who is not intimately acquainted with the previous Plan.

Subsequent to submission of the CY 1975 Project Plan, which was based on a funding level of $13,000,000 in 1975, $16,000,000 in 1976, and $13,000,000 in subsequent years until completion, the National Science Foundation advised that $1,000,000 of 1975 funds would be deferred. This resulted in a decrease of funds available for Site and Wye work and effectively postponed any additional site and wye construction until the following year. In August this deferred $1,000,000 was made available and was utilized to stockpile additional waveguide. Later in the year, the Project staff was instructed to prepare its program plans based on $13,000,000 in CY 1976, in lieu of $16,000,000, and $13,000,000 in subsequent years. In November, the CY 1976 funding level was again cut to $12,400,000. The present plan is based on this level of financing and forecasts a total cost of $78,123,000, with final completion late in 1980. Variations in the yearly funding levels are assumed to affect the total Project costs through the application of a 6% per year escalation or de-escalation factor on selected budget items.

The present very rapid escalation is the item of greatest concern to the Project staff. The full impact of this escalation on Project costs cannot be forecast with any certainty, but present estimates allow only a dangerously low contingency within the budget.

78-882 O - 77 - 2

It is the intention of the National Radio Astronomy Observatory that activities during CY 1976 will follow the detailed Project Plan set forth. Should unforeseen conditions arise which require a major shift of emphasis or change the material or data presented in any substantial manner, the 1976 Plan will be revised.

DESCRIPTION OF THE INSTRUMENT

Higher resolution and sensitivity have always been major goals of radio astronomy instrumental development. The general concept of a very large antenna system that could obtain radio pictures with very high resolution, sensitivity, and speed was developed in the early sixties. The initial studies at NRAO in 1961 and 1962 led to the detailed design beginning in 1964. The design study was carried out by the NRAO staff, with the assistance of a number of radio astronomers from other institutions, and it resulted in the Proposal for the Very Large Array (VLA), published in 1967 (Vols. I and II), 1969 (Vol. III), and 1971 (Vol. IV).

In order to achieve the required angular resolutions, a radio telescope with dimensions of 35 km (23 miles) is needed. Since a conventional radio telescope having these dimensions is impossible to construct, other techniques which will simulate such a telescope must be used. By interconnecting several separated, smaller diameter antennas, the information leading to the desired resolution can be obtained. Many configurations of the antenna elements are possible, and careful studies of this problem, with the purpose of optimizing the use of a relatively small number of antennas, have resulted in the VLA system, consisting of 27 antennas, each 25 m (82 feet) in diameter, distributed along three 21 km (13 mile) arms of an equiangular wye. All the antennas will be movable over railroad tracks so that the picture area (field of view) and the resolution may be varied within wide limits. In this respect, the VLA is the equivalent of a zoom lens.

Each antenna element consists of a steel structure carrying a shaped reflector which is movable in azimuth and elevation in order to be able to point to any part of the sky. The reflector structure supports an aluminum reflector surface consisting of 172 aluminum panels. The surface accuracy and the precision of the drive system permit operation at wavelengths as short as 1.2 cm. During operation, the antennas are placed on observing stations. Seventy-two such stations will permit the four basic different configurations planned for the array. The antennas will be moved

between observing stations by a transport vehicle; one such transporter will be available in the early years of the Project, running on a double, standard gauge railroad track system. In later years, should funding permit, two additional transporters will be procured. A reconfiguration of the antenna system, using three transporters, is estimated to take twenty-four hours. When the railroad tracks are not used for moving antennas, they will be used for transportation of maintenance personnel and equipment.

The initial operating wavelengths for the system will be 21 cm, 6 cm, 2 cm, and 1.2 cm, with full polarization measurement capabilities. Spectral-line capabilities for the array are also being developed.

The central computer system will control the telescopes, monitor the system performance, and collect and analyze the data. The system output will consist of high resolution maps of the observed objects.

Power and telephone communications between the central site complex and the observing stations will be distributed through buried cables. Signal and local oscillator distribution, as well as control and monitor signals of all antenna functions, will be accomplished by a buried circular waveguide system.

The central building complex will consist of several buildings. A 22,060 square foot Control Building will house the control room, central electronic equipment, digital delay equipment, large central computers, specialized shops, laboratories, and office space. Three small, prefabricated metal buildings, which total 15,000 square feet, will house maintenance shops, the electronic and cryogenic shops, storage facilities, and office space. The subcontractor, who will fabricate and assemble the antennas, has constructed a 14,600 square foot Assembly Building, which he will use during his contract and which will be available for later use for antenna maintenance. In addition, a 5,320 square foot Cafeteria Building and a grouping of Visiting Scientists' Quarters will be constructed, as will necessary site work, water supply, sewage, electric utility, and similar facilities.

ORGANIZATION

Project Organization

The NRAO organization is shown on the accompanying organization chart (Figure 2). The VLA will be designed and procured as a project of the NRAO, with the Observatory being its own "prime contractor" for the job. Overall responsibility for the design and procurement of the VLA rests with the Director of NRAO, who, in turn, is responsible to the President of the Board of Trustees of AUI. AUI, in addition to its internal Trustees' committees, has the NRAO Visiting Committee to assist it in reviewing and evaluating the performance of NRAO. The Director has the NRAO Users' Committee, the VLA Advisory Committee, and the VLA Steering Committee to assist and advise him on VLA matters. A description and the membership of each of these committees is given in Appendix A.

Within the NRAO, primary responsibility for the VLA design has been assigned to H. Hvatum, Associate Director. Responsibility for implementation has been assigned to J. H. Lancaster, Assistant Director and VLA Project Manager.

Project Implementation

Implementation of the VLA, including the contracting and managing of all fabrication and construction is the responsibility of the Project Manager. This work will be carried out according to previously agreed upon drawings, specifications, budgets, and time schedules. The planned Project Management staff is shown on the accompanying organization chart (Figure 3).

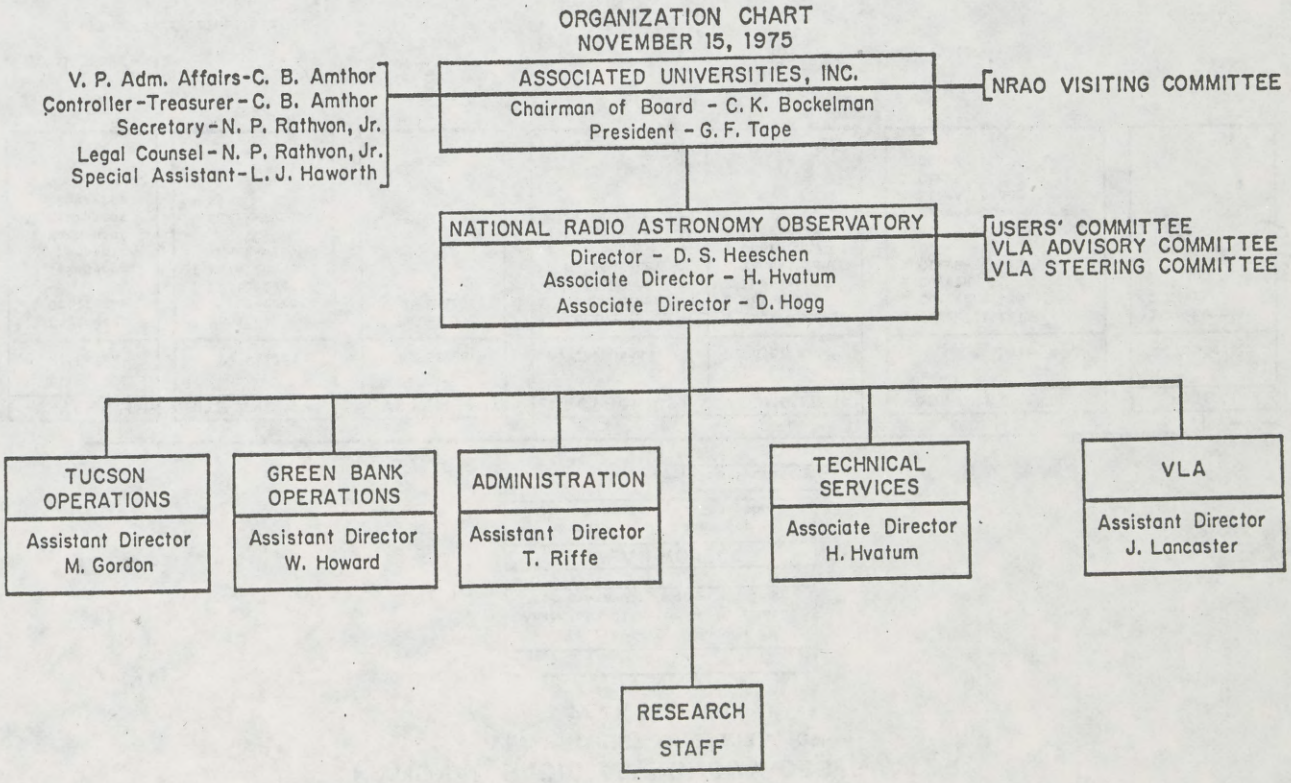
The only change made during the year in the Project Organization was the establishment of a Fiscal Group separate from the Administration Group.

On January 1, 1973, the Project was officially implemented with the transfer of fifteen existing NRAO staff members to the VLA. This staff has been increased since then to the present total of eighty-one members as shown below.

GROUP	1975 PROJECT PLAN FORECAST FOR 12/31/75	PRESENT LEVEL 11/15/75	LEVEL 12/31/76
Antenna	6	8	9
Electronics	36	32	36
Computer	15	13	16
Systems Integration	2	2	4
Site and Wye	7	6	7
Project Management	17	20	20
Totals	83	81*	92

*Includes three part-time people.

The projected peak construction staff shown by Figure 3 has increased from eighty-seven to ninety-two people scheduled for 12/31/76. This change results from the delay in the start of operational staffing from 1976 to 1977. This is depicted by Figure 4, which shows the construction and operational staffing through 1981.


ORGANIZATION CHART
NOVEMBER 15, 1975
V. P. Adm. Affairs-C. B. Amthor
Controller-Treasurer-C. B. Amthor
Secretary-N. P. Rathvon, Jr.
Legal Counsel-N. P. Rathvon, Jr.
Special Assistant-L. J. Haworth
ASSOCIATED UNIVERSITIES, INC.
Chairman of Board - C. K. Bockelman
President - G. F. Tape
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Associate Director - H. Hvatum
Associate Director - D. Hogg
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VLA ADVISORY COMMITTEE
VLA STEERING COMMITTEE
TUCSON OPERATIONS
Assistant Director
M. Gordon
GREEN BANK OPERATIONS
Assistant Director
W. Howard
ADMINISTRATION
Assistant Director
T. Riffe
TECHNICAL SERVICES
Associate Director
H. Hvatum
VLA
Assistant Director
J. Lancaster
RESEARCH STAFF

Figure 2

NATIONAL RADIO ASTRONOMY OBSERVATORY
VLA PROJECT ORGANIZATION
PEAK STAFFING

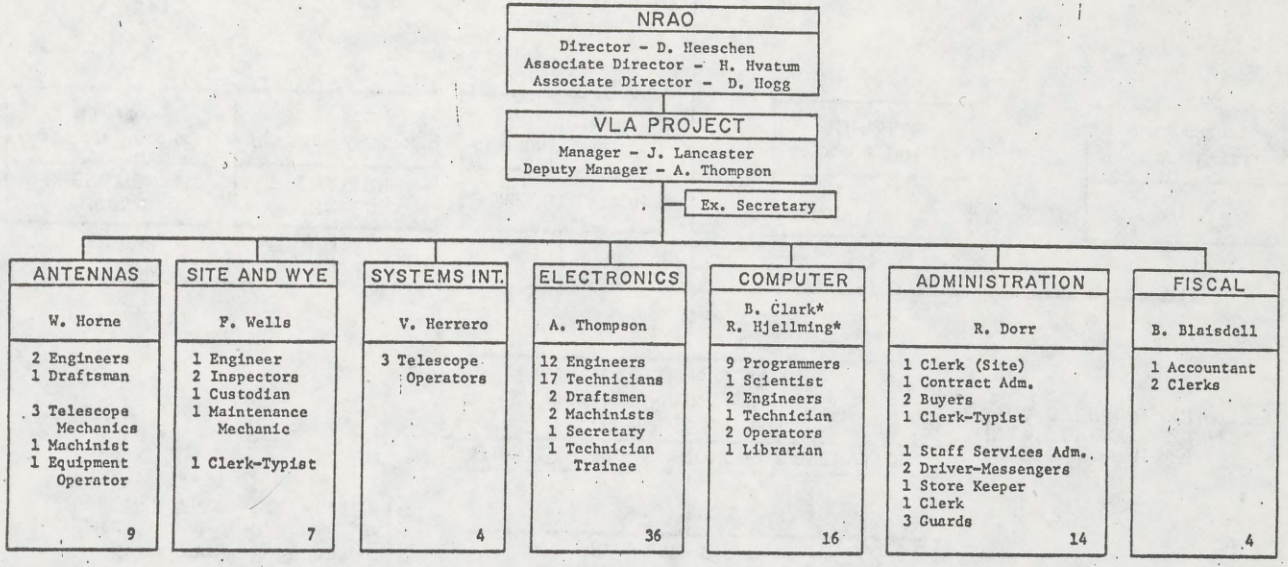
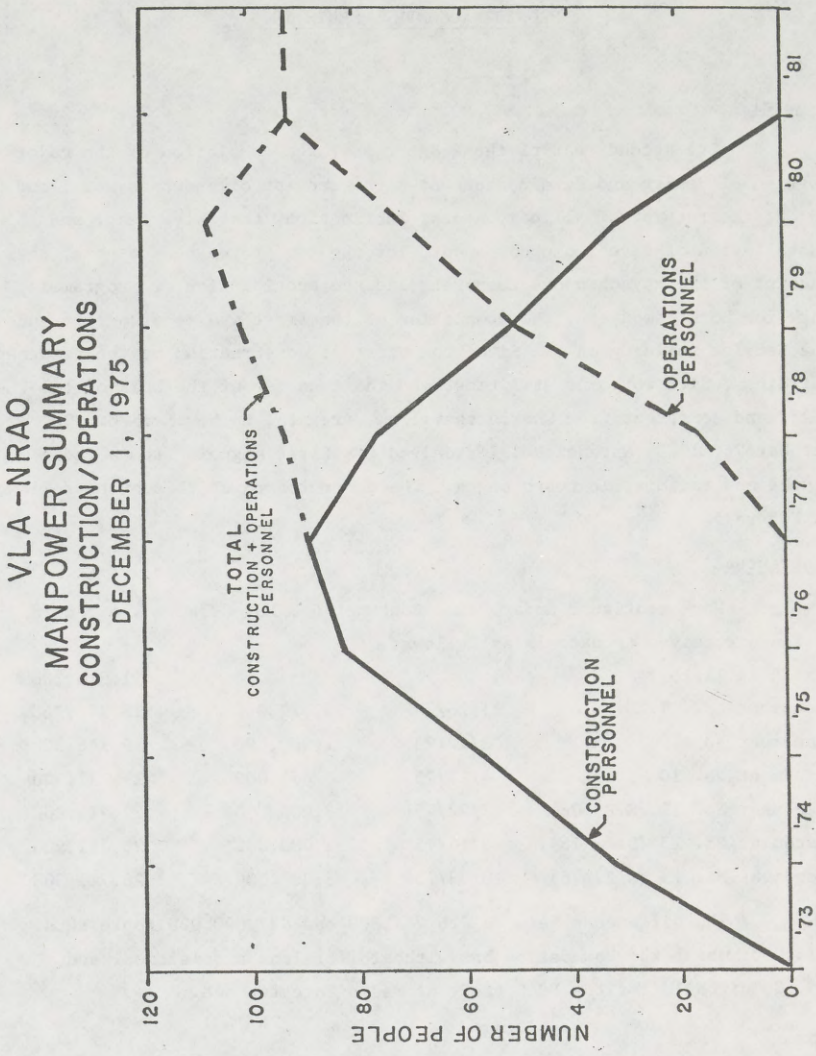


Figure 3

TOTAL SHOWN - 92

*NRAO Staff Scientists

12/1/75


V.L.A.-NRAO
MANPOWER SUMMARY
CONSTRUCTION/OPERATIONS
DECEMBER 1, 1975
TOTAL
CONSTRUCTION + OPERATIONS
PERSONNEL
CONSTRUCTION
PERSONNEL
OPERATIONS
PERSONNEL
NUMBER OF PEOPLE
YEAR
0
20
40
60
80
100
120
'73
'74
'75
'76
'77
'78
'79
'80
'81

-9-

Figure 4

PROJECT ACCOMPLISHMENTS 1975

General

The second year of the Project saw: the completion of the major portion of design and development work; the receipt of Antennas No. 1 and No. 2; the receipt of all components, fabrication, assembly, test, and installation of electronic components for the two prototype antennas; the receipt of the asynchronous computer, and the continuation of programming work for both computers; the completion of the first wye construction and the Service Building on the Site; the start of construction of the permanent buildings, Site work and utilities; and the transfer of the bulk of the VLA staff and equipment from Charlottesville, Virginia, to New Mexico. On October 24, 1975, Antenna No. 1 received its first signals from a radio source and radiometric tests began. The chart record of this event follows as Figure 5.

Contractual

Work continued under Prime Contract No. NSF-C-780. The record of funds received to date is as follows:

Available 11/15/74			$11,319,300
Amendment No. 7	11/26/74	$6,927,000	18,246,300
Amendment No. 9	3/12/75	1,000,000	19,246,300
Amendment No. 10	4/11/75	465,000	19,711,300
Amendment No. 12 (C.R.'76)	7/22/75	3,000,000	22,711,300
Amendment No. 13 (Def.'75)	8/14/75	1,000,000	23,711,300
Amendment No. 15 (C.R.'76)	10/03/75	3,000,000	26,711,300

The difference between $26,711,300 and $27,000,000 represents $273,000, which the Foundation has withheld for land acquisition, and $15,700 withheld for the ECAC study of radio interference.

Legal

The Santa Fe, New Mexico, legal firm of Montgomery, Federici, Andrews, Hannahs, and Buell continued to represent Associated Universities, Inc. in New Mexico. There were no legal problems of any nature in New Mexico.

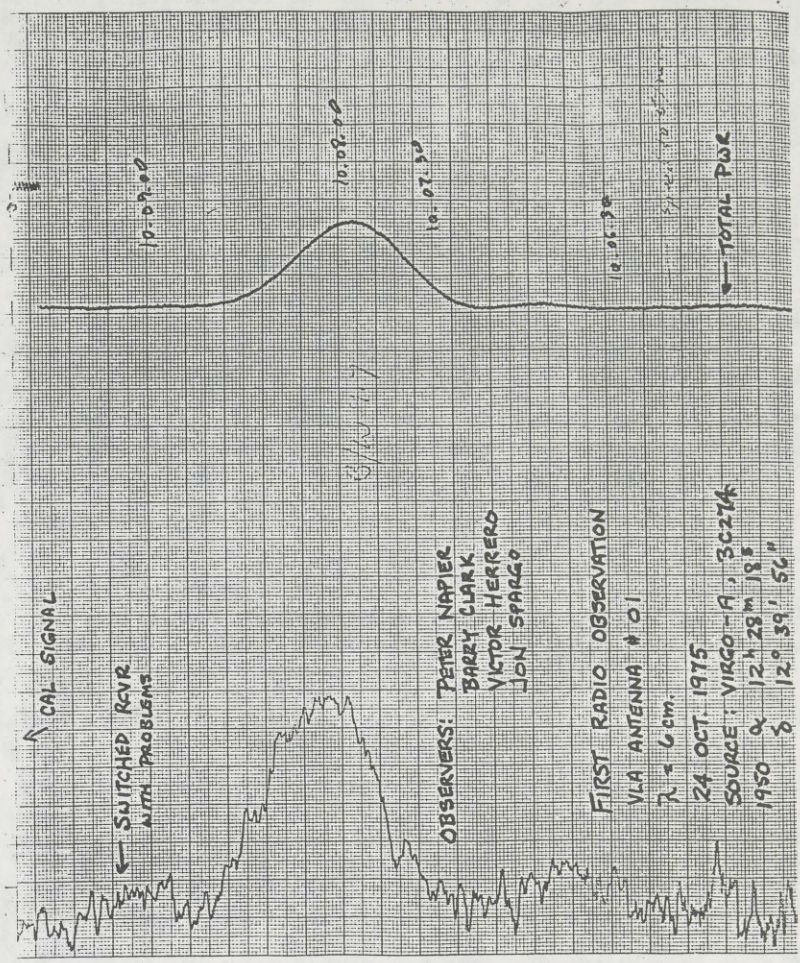

CAL SIGNAL
SWITCHED RCVR WITH PROBLEMS
OBSERVERS: PETER NAPIER
BARRY CLARK
VICTOR HERRERO
JON SPARGO
FIRST RADIO OBSERVATION
VLA ANTENNA # 01
λ = 6 cm.
24 OCT. 1975
SOURCE: VIRGO-A, 3C274
1950 α 12h 28m 18s
δ 12° 39' 56"
TOTAL POWER

Figure 5

New Mexico State Gross Receipts and Compensating Tax

In accordance with agreements among the AUI attorneys, the Foundation, and the AUI and NRAO staffs, no formal action was taken with the State of New Mexico. The Project continued paying this tax, through our construction contractors on construction services for conventional or "bricks and mortar" type construction.

A number of routine questions were raised by the tax authorities but there were no questions raised concerning our issuance of tax exemption certificates.

Land Acquisition

Early in the year, the landowner whose ranch surrounds the Central Site declined to accept payment under the terms of an executed land purchase agreement and requested that his land be condemned. As this might have halted the 1975-6 wye construction program, the Corps of Engineers pushed ahead and the final Declaration of Taking was filed with the District Court on August 13, 1975.

The three landowners who have possession of the outer portion of the legs of the wye would not accept a negotiated settlement and so their interest in the necessary land had to be condemned. This filing took place on April 10, 1975. These actions complete the land acquisition for the wye.

We do not as yet have all the necessary documentation on the land for the airstrip. However, as this is State land and construction is some years away, we do not anticipate any delay or difficulty.

Archaeological Approval

On September 24, 1974, NRAO requested the Foundation to look into the possibility of having the necessary archaeological work at the end of the southwest arm funded under a separate Foundation grant or by the Department of the Interior in accord with existing legislation. We did not wish to move at once on this matter as the Corps of Engineers had requested us to hold off until the main land acquisition program was complete. The Foundation has declined to issue a separate grant and the Department of the Interior has referred the matter back to the State of New Mexico. This matter is now

stalled, with perhaps the State Historic Preservation Officer, National Register of Historic Places, the Advisory Council on Historic Preservation, National Park Service, and others all having some input. This item will be a prime goal for 1976 as there seems to be some scientific pressure building up to complete the southwest arm as soon as possible.

Procurement - Antennas No. 1 and No. 2

As 1975 began, Antennas No. 1 and No. 2 were under fabrication at Hobbs, New Mexico, and E-Systems was having considerable difficulty with the delivery of gear reducers, gear segment forgings, motors, surface panels, and azimuth bearing forgings, which indicated a delay of six to eight weeks in the completion of Antenna No. 1. The most critical of these items, the azimuth bearing, was inspected and accepted at the manufacturer's plant on May 12, 1975. Trial assembly of Antenna No. 1 was completed at Hobbs in March; it was disassembled, painted, and shipped to the Site in April, where field assembly began April 29, 1975. On June 28th, the reflector, transition section, yoke and base were mated. On July 18th the antenna was moved on the transporter from the Assembly Building to the Master Foundation. This event proved that the antenna transport design concept was sound and that the fabrication techniques were well executed. The antenna was completed and, on September 22, 1975, it was accepted and moved by NRAO to the Maintenance Foundation at the Service Building where outfitting began.

Field assembly of Antenna No. 2 was accomplished more smoothly and with less manpower and was completed and accepted November 13, 1975. The next day it was then moved by NRAO back into the Antenna Assembly Building for outfitting by NRAO.

When tested prior to acceptance, both antennas exceeded the required design and manufacturing tolerances established during the design period. The following table sets out some of the design and actual tolerances. See Figure No. 6.

NATIONAL RADIO ASTRONOMY OBSERVATORY

VLA PROJECT

MECHANICAL PARAMETERS FOR ANTENNAS NO. 1 AND NO. 2

ITEM		SPECIFICATION	ANTENNA NO. 1	ANTENNA NO. 2
Panel Manufacture		.015 in rms	.011 in - .015 in rms	.011 in - .015 in rms
Panel Setting at 50°		.018 in rms	.0147 in rms	.0095 in rms
Azimuth Center to Foundation Center		0.500 in	0.080 in	0.060 in
Azimuth Lean		18 arcsec	12.5 arcsec	12.0 arcsec
Elevation Orthogonality		18 arcsec	11.0 arcsec	12.5 arcsec
Elevation Offset		0.100 in	0.060 in	0.030 in
Collimation Orthogonality		18 arcsec	3 arcsec	3 arcsec
Collimation Offset		0.250 in	0.030 in	0.050 in
Alignment Focal Mount to Collimation Axis		18 arcsec	5 arcsec	2 arcsec
Servo Error Signal		3.24 arcsec rms error 18 mph wind	3 arcsec Peak $\alpha = 45^\circ$ $\Psi = 120^\circ$ 25 mph wind	Not measured to date
Resonant Frequency	Rocking	2.07 Hz	2.2 Hz	2.2 Hz
	Torsional	2.15 Hz	2.14 Hz	2.1 Hz
Slew Rate	Elevation	20°/min	20°/min	20°/min
	Azimuth	40°/min	40°/min	40°/min

Figure

Procurement - Antennas No. 3 through No. 10

In accord with the terms of Subcontract VLA-6, NRAO, on December 9, 1974, authorized E-Systems to proceed with the manufacture, delivery, assembly on Site, alignment and test of Antennas No. 3 through No. 6. On January 6, 1975, E-Systems refused to complete Antennas No. 3 through No. 6, asserting that its obligation to continue performance had been excused due to unanticipated economic and inflationary factors which made continuation impracticable and that the balance of the options under VLA-6 had lapsed. E-Systems quoted the Uniform Commercial Code (Sections 2-615 and 2-616) as their authority for this action.

NRAO refused to accept this position and almost continuous negotiations followed during January, February, March, and April. Late in April an agreement was reached whereby E-Systems would complete Antennas No. 3 through No. 10 under the terms of the existing subcontract and that NRAO-AUI will treat future claims for relief equitably, based on considerations consistent with Government procurement practices.

E-Systems then moved ahead with the procurement of purchased items. The advantages of larger quantity procurement were apparent in both pricing and delivery promises from suppliers. At present, Antenna No. 3 is undergoing trial assembly at Hobbs, fabrication of No. 4 is complete, and the structural parts for Nos. 5 through 10 are in excess of 40% complete. Delivery dates for all critical equipment items are satisfactory except for the speed reducers and these are being worked on. It appears that the next eight antennas will be delivered on schedule.

Antenna Assembly - Maintenance Building

Construction of this building proceeded during the fall and winter of 1974-75 and was substantially completed in March. E-Systems occupied the building in April. One of the major contributors to the shorter assembly period for Antenna No. 2 was the more extensive use of this building and its equipment for the assembly of Antenna No. 2. At present, NRAO is using the structure for the outfitting of Antenna No. 2.

Antenna Transporters

Fabrication of the component parts of the transporter proceeded during the winter, followed by delivery of equipment and parts to the Site beginning in February. In March a five-man assembly crew arrived at the Site to begin assembly. This work went somewhat more slowly than scheduled. On June 28th the transporter was used to assemble Antenna No. 1 and on July 18th it carried the antenna to the Master Foundation. Acceptance tests were started in August and the transporter was finally accepted on September 22, 1975.

During the spring, when the effects of the extreme rate of inflation were being analyzed, it was decided that, in order to keep the Project cost estimate close to the original $76,000,000 budget, it would be necessary to indefinitely defer the construction of Transporters No. 2 and No. 3, as well as certain other desirable items. This would free funds which would be devoted to more vital scientific requirements of the instrument, such as feeds, receiving channels, computer software and hardware. This decision, while requiring careful scheduling of the existing transporter, has the advantage of not requiring the early addition of the operators and mechanics which might not be fully utilized for a period of time.

Electronic Systems

During 1975 the electronic equipment for the two prototype antennas was fabricated, tested, shipped to the Site, installed on the antennas and in the Electronics-Computer trailer and run-in tests and debugging began. Fabrication of electronic systems for Antennas No. 3 through No. 6 was begun and will be well toward completion by year's end.

In January, the mock-up Vertex Equipment Room was set up in Green Bank and a mechanical test was made of the waveguide interconnections between the feeds and the prototype front-end. On April 15, the first front-end was shipped to the Site where it and the feeds were assembled on the Feed Ring for Antenna No. 1. Tests and debugging continued until October 14th when the Feed Ring was mounted on the antenna.

Feeds for the 6, 2, and 1.3 cm bands have been mounted on the antenna and measurements of efficiency at all three wavelengths which have been made to date are close to the calculated values. Performance of the dichroic reflector has been tested and found to be satisfactory. As of November 17th, the 18-21 cm feed has not been received as the manufacturer has experienced difficulty in obtaining the required performance. One unit of the existing design is being obtained and should be tested by the end of the year.

Components of the local oscillator system were completed by midyear, with the exception of one module which is not essential for the initial operation. Subsequent work in this area has largely involved testing, checking of computer control functions through the monitor and control system, and documentation. Stability of the local oscillator system is critical to the array and detailed testing will move into the interferometer test phase next year. Local oscillator components for antennas 3 - 6 have been obtained or are in procurement, and assembly of modules by the Charlottesville group is progressing well.

Work on the waveguide continued at a rapid pace during the entire year. In January, the 100 meter section of 60 mm TE_{01} mode waveguide buried in 1973 was again tested and found to be well within specifications. In February, the waveguide coupler design was completed, tested, and found to be satisfactory for all close-in antenna stations. This full diameter design will permit couplers to be left in place during antenna moves and the use of much smaller and less expensive manholes. In April, trenching began for the placement of the 1.24 km of waveguide, which was laid during May and June. Tests were performed on this section during July and indicated the initial attenuation was within specifications over the 26-60 GHz range, with values of 2.35 and 1.31 dB per km at 26.5 and 50 GHz respectively. Further tests will be continued on this section to check on deterioration of the attenuation with time. Toward the end of the year the 20 mm waveguide runs to the antenna stations will be completed and the waveguide tied to the central electronic system in the testing trailer.

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In November, 1974, proposals were received from two concerns for the signal distribution equipment, which were substantially over budget allocations. Negotiations were held to reduce the complexity and price, and in February an order was placed with Hitachi Shibaden for $230,000, with delivery late this year.

In 1974, prototype modems were ordered from three companies for test purposes. These were all received and tested extensively during the spring. In May it was determined that none of the three were of sufficient quality to warrant procurement and an NRAO design was implemented. Components and subassemblies will be procured and assembled at the Site. The commercially designed units will, however, be satisfactory for initial systems testing with Antennas No. 1 and No. 2.

Cryogenics and the Dewar for the low temperature amplification equipment continue to cause problems. Although the first two compressor units are working satisfactorily, there is concern about vibration and the length of their operating time between breakdowns. Also, the vendor raised his price substantially when an order was placed for units No. 3 through No. 6. A development program is now under way, based on a Cryomech system compressor which seems much better designed and is considerably less expensive.

The Monitor and Control system was thoroughly tested and debugged during the year. After a careful review of the equipment received from the vendor and the extent of the revisions and changes found necessary, it was determined that subassemblies would be purchased and assembled in New Mexico. The necessary components for antennas 3-6 have been purchased, and some completed units have been received from an Albuquerque assembly house for checkout.

The Delay and Multiplier system for the first two antennas has been completed and its interface with the synchronous computer has been checked out. Plans to expand this to an interim 12-antenna continuum system are in progress.

Computer

The synchronous (on line) computer group continued development of software during the spring, conducted simulation mode tests and interface tests with the Monitor and Control system and other electronic equipment. On June 23rd the computer was shipped to the Site and reinstalled in a large computer-electronics trailer stationed at foundation CW-5. It was then connected to the central electronics and control and monitor equipment and simulation mode tests continued. By September, the software required for the single dish testing phase was completed and that required for the interferometer programs was in the debugging process. In early December, the synchronous system will be tied to Antenna No. 1, stationed at foundation CW-5, and, at the end of the month, also to Antenna No. 2, stationed at foundation CW-9.

In January, the asynchronous (off line) DEC-10 computer equipment was installed in Charlottesville and began to operate. Work continued on the development of the control language CANDID, which will be used as the top level of the asynchronous computer's data processing system. Extensive work has been accomplished on the VLA data base, functional operators, basic mathematical applications routines, coding routines, storage management, access routines and graphic routines. In June, a group of graphics-related programs call the "Omnigraph Package" was obtained from the National Institutes of Health, tested, and found to be invaluable for VLA graphics use. Also in June, a formal request for proposals was issued for procurement of the initial display and I/O equipment. The system will be based on a PDP 11/40 with 28K core memory and 2.4 million 16-bit words of cartridge disk storage. Output devices will be: a COMTAL Rasterscan CRT; refresh-type line graphics CRT based on a DEC GT40 system, a Versatec electrostatic printer-plotter; and a Textronix 4012 storage tube terminal. Purchase orders totaling $87,990 for this equipment were placed on August 29th, using advance 1976 funds. The balance of the year was spent in further development of details for the language, data base, specifications and programs.

Systems Integration

On January 1, 1975, a new Systems Integration Group was formed to coordinate the outfitting of the antennas, the various sighting and radiometer tests, and the start-up of interferometer operations. During most of the year the group consisted of two persons. First activity was the planning of the outfitting and ensuring that all necessary tools and equipment were on hand when the first antenna was received. In June the group moved to the Site and prepared cable harnesses, subreflector drive mechanism single dish test, and other equipment. Toward the middle of August, the single dish test trailer, with its control equipment and computer components, was moved to the Master Foundation and, on the nights of August 25th and 26th, the first optical star pointing tests were conducted with good preliminary results. On September 22nd the antenna was moved to the Maintenance Foundation and star pointing tests resumed. These tests, one conducted in wind gusts of 25 mph, indicated that the antenna has good tracking characteristics and meets all pointing specifications. On October 24, 1975, the front-end equipment was fully installed and the first radio source measurements were made. In October over twenty hours of radiometric testing was completed. At present, tests have been conducted using the 1.3, 2.0, and 6.0 cm feeds with satisfactory initial results.

Site and Wye Design and Construction

At the beginning of the year, Phase I construction, consisting of 1.24 km of wye trackage and services, was nearing completion, the contract for Phase II construction, consisting of the Control Building, Cafeteria Building, utilities and site work, had just been awarded on December 16, 1975, at a cost of $2,386,600, the detailed design of the balance of the array was nearing completion by the Engineer/Architect, and the 6,000 square foot prefabricated Service Building was well under construction.

The Phase I construction was substantially completed in February and in the same month the George A. Rutherford Construction Company began site work on Phase II, which is now approximately 65% complete, with occupancy scheduled 1 - 2 months prior to the contract completion date.

In March the Service Building was completed on schedule and was furnished and equipped for occupancy in April. The Title II detailed design for the wye was completed in April.

In May, the E/A was instructed to prepare the bid package for the Phase III construction to be built with 1976 funds. This was a difficult task as there was no knowledge as to the extent of the funds to be made available for this work. It was, therefore, decided that base bids would be requested on the C & D array work, estimated to cost about $2,443,000, with bid options taken which would extend the west arm to AW-6 at an estimated cost of $3,926,000. This work was completed and issued for bid on July 15th, with a due date of August 28, 1975. Twelve bids were received, which ranged from a low bid for the entire scope of work of $2,913,000 to a high bid of $5,474,812. These were extremely favorable prices, resulting from the large quantity of work included as well as the general depression in the construction industry in this area. The subcontract was placed on September 25, 1975, and the contractor has completed clearing and grubbing, sunk two water wells, erected his concrete plant and his crushing plant, and is beginning quarry operations.

In late September, a decision was made that the Project should proceed with a 5,000 square foot prefabricated steel warehouse structure and a 4 - 5,000 square foot similar structure for use as outfitting and maintenance shops for antenna outfitting and site maintenance. The warehouse structure will be used to store key components which have been ordered for antennas No. 3 through No. 10, spare parts, waveguide components, which now total nearly one million dollars, and other costly equipment and materials. The maintenance building will provide welding, electric, carpentry, plumbing and air conditioning shops and a general use area for the assembly of subcomponents and the repair of vehicles and equipment. This work was issued on November 12th, with proposals due December 8th.

During the year the stockpiling of railroad track, ties, and accessories proceeded very well. Additional details on these actions are covered below in the Project Management section.

Project Management

The principal activity of the Project Management Group during 1975 was in the procurement field. In the year ending October 31, 1975, a total of 2,080 subcontracts and purchase orders were placed, having a total value of $13,366,013. Many of these actions required extensive negotiations which resulted in appreciable savings and in keeping the effects of inflation to a minimum.

The group was instrumental in making advance arrangements and in conducting operations for the move of twenty-four employees and their families from Virginia and West Virginia to New Mexico during the period from April through July. In addition, thirty new employees required for the Project were located, interviewed, processed, and, where necessary, moved to New Mexico. A very active search was made for housing in the Site area and data collected on real estate agents, construction contractors, mortgage sources, and other items which would aid in the settlement of the VLA staff. At present, all employees, relocated and new, have found adequate housing without expenditure of Project funds for housing construction.

Late in 1974, arrangements were completed with the New Mexico Institute of Mining and Technology to provide office space on its campus for the VLA project management group. This space was completed in March, furnished, and occupied in April. The Service Building at the Site was also furnished in April in preparation for the arrival of the staff and the electronic equipment shipped from Charlottesville and Green Bank.

The discovery, inspection, contracting for take-up, shipping, and receipt of excess rail and fittings was a major task in 1975. To date, rail has been received or arrangements completed for rail from: the Crab Orchard Wildlife Refuge, Illinois; Mountain Home AFB, Idaho; Holloman AFB, New Mexico; Fort Hood, Texas; Lincoln Ordnance Depot, Illinois; Redstone Arsenal, Alabama; Sunflower Ordnance Depot, Kansas; Elgin AFB, Florida; and Myrtle AFB, South Carolina. Total tonnage is 5,300 tons, which is sufficient for 23 km of wye. Average cost to date, including take-up, transportation, and unloading costs, is $55.80 per ton, which compares with over $300 per ton at the peak of the supply shortage

and $230 per ton from a recent quotation. Used hardwood ties have continued to be procured at an average price of $5.42 each, which compares with a price for new softwood ties of $9.00 each and $16-18 each for fully treated hardwood ties. At present there are approximately 48,100 ties stored at the Site to support the 1976 wye construction program.

PLANNED ACTIVITIES - 1976

General

The main emphasis during the early months of the coming year will be to integrate the two prototype antennas, their electronics, waveguide system, and the synchronous computer into an effective interferometer. Following this, the move into the permanent Control Building must be made, and the asynchronous computer and its personnel moved to New Mexico and into the new building. In addition, the next four antenna elements and their electronics will be completed during the year so that in the beginning of 1977 the array will consist of six antennas operating on the C and D configurations plus the 8,527 meter portion of the southwest arm to antenna station AW-6. This section of the Project Plan will discuss the events of major import planned to take place during CY 1976.

Antennas

In January 1976 E-Systems will move the structural components of Antenna No. 3 to the VLA Site, with initial assembly scheduled to start on January 15. It is anticipated that Antenna No. 3 will be completed through acceptance testing by mid April of 1976. Antenna No. 4 assembly will start in late February and will continue in conjunction with Antenna No. 3, leading to a scheduled delivery date of May 24. Delivery of Antennas No. 4 through No. 10 will be made at about eight-week intervals, with completion of No. 10 presently scheduled for March 1, 1977. At the present time the only questionable delivery date for any component of the antennas is for the gear reducers for Antenna No. 3. Alternate plans have been made for retrofitting Antenna No. 3 so that succeeding antennas would not be affected by late delivery of Antenna No. 3.

Procurement of NRAO supplied and installed equipment for Antennas No. 3 - No. 10 is in progress and is anticipated to meet the schedules established by antenna delivery.

Beginning in January 1976 negotiations with E-Systems will be initiated to determine the delivery of the next increments of antenna procurement. It is anticipated that these negotiations will continue for several months.

During the course of 1976 the Antenna Group will be slightly expanded in order to accomplish both the monitoring of new construction, the outfitting of additional units, and the servicing and maintenance of completed antennas.

Electronics

During 1976 the major areas of activity in electronics will be continued testing of the prototype system, outfitting of Antennas No. 3 through No. 6 for array operation, setting up of the central electronics system within the Control Building, and procurement and assembly of systems for Antennas No. 7 through No. 10.

Two-element interferometer testing will just be commencing at the first of the year, with antennas at antenna stations CW-5 and CW-9, giving a 1.24 km baseline. The crucial stability of the electronics in both amplitude and phase, the reliability of the system, the effects of lightning-induced power dropouts, and almost all characteristics of the array operation can be determined from the two-element tests. These will, therefore, continue for the greater part of the year and merge into the preliminary array operations as more antennas become outfitted. Two additional staff members, with experience in bringing interferometer systems into operation, will join the group at the Site about January first to work on the testing. Hardware and systems modifications resulting from the tests will probably not require any major redesign in most areas, but preliminary tests showed, for example, that the temperature coefficient of phase in the local oscillator system can be significantly improved by some redesign of a frequency multiplier chain.

The electronics for Antennas No. 3 - No. 6 is being planned to keep pace with the delivery of the antennas by E-Systems, Inc. Performance of the antennas will be checked by single-antenna measurements as the feeds

and front-end racks are installed. The electronics installed will, at least initially, be identical to the prototype system for Antennas No. 1 and No. 2. Modifications resulting from the two-element testing will be applied as rapidly as possible. An improved model of the 18-21 cm feed should be ready for testing around July 1, following a choice of a contractor in late January and scale-model measurements about April first. The new design will then be retrofitted to existing antennas later in the year. Other development items in electronics will include: a cooled FET amplifier, which is being built by A.I.L. to replace the third stage in each parametric amplifier; a front-end with the Cryomech refrigerator and compressor; the new modem design; a phase detector module for the local oscillator system; and tighter waveguide couplers for the more distant stations on the array. This last item is expected to utilize the helix design but in 20 mm waveguide.

As the electronics for each antenna is brought into operation, the modules and other units involved must be checked for correct performance. This is a particularly important and time-consuming operation for the complicated monitor and control modules. Development of an automatic test system, which simulates the monitor and control interfaces and provides test signals, will be initiated and largely completed during 1976.

Design of the spectral processor with breadboard testing of new circuitry commenced at the end of 1975 and will continue during the following year. This effort will be divided between the Site and Charlottesville groups, with the former working largely on the delay and multiplier units and the latter on the control system and computer interface. The continuum delay and multiplier system developed during 1974-5 is to be extended to provide the capability of handling up to twelve antennas with one 50 MHz bandwidth and dual polarization.

Installation of equipment in the Central Control Building is expected to commence in July 1976. This will entail test and installation of the waveguide signal distributor, local oscillator and IF cabling systems. The initial control system for the array will consist of peripherals of the Modcomp synchronous computer arranged in the Control Room. Integration of these units with one or more consoles will be

deferred to a later year until some operating experience is gained. Interfacing the synchronous computer with the asynchronous computer that moves out to the Site in July is also a task that falls within the electronics domain.

Computer

During the early months of 1976, the synchronous computer group will be assisting in the testing and placing the prototype antennas into operation in the interferometer mode. During this time the debugging and development of the software programs will continue. Upon completion of the permanent Control Building by the construction contractor and the installation of necessary electrical services by NRAO, the computer will be moved from the trailer to the Computer Room and reconnected. As a considerable amount of the permanent central electronic equipment, such as the signal distributor, waveguide system, wireways and interconnecting cabling, must be completed before the computer can operate from the Control Building, it may be found advantageous to continue test operations from the trailer longer than presently contemplated. The balance of the year will be spent in operating the prototype antennas and in integrating Antennas No. 3 through No. 6 into the system as they are completed.

The asynchronous computer group will remain in Charlottesville until the Control Building is ready, now scheduled for the end of June, and then move with the DEC-10 computer and its auxiliaries to the Site where the computer will be installed in the Computer Room. Additional development of the software programs will continue throughout the year. Test programs using the two computers will be test-run and debugged during the later portion of the year in preparation for the start of partial operations.

During the major portion of the year a feasibility study will be conducted as to the most advantageous computer hardware to be used for the Spectral Line System.

Systems Integration

The tasks of the systems integration group are closely interwoven with the test and installation areas of the electronics program outlined above. Systems integration oversees the planning and coordination of the interferometer testing. The array operators who will run the equipment during the test observations are part of this group. During these stages of test operation, it will be necessary for them to learn the command language of the computer and the control functions of the electronics and to document this information in the form of an operator's manual.

Systems integration is also responsible for the day to day planning for the installation process, including the readiness of the electronics, the use of the transporter and its cherry picker, and the availability of cranes for mounting subreflectors and feeds. In a similar way, this group will be involved in planning the equipment installation in the Control Building.

No large items will fall solely within the domain of Systems Integration, but they will continue to work closely with the other groups throughout the year.

Site and Wye

The Site and Wye group will continue to supervise the construction of the Phase II contract for the Site buildings, utilities, and site work, the Phase III contract for construction of 13,100 meters (8.1 miles) of wye, and the Storage and Maintenance prefabricated buildings. In addition, the group will commence the installation of approximately 10,000 meters of 60 mm TE_{01} mode waveguide along the southwest arm of the wye. This waveguide must be installed to very stringent straightness tolerances as any curvature rapidly increases the attenuation. A supplemental agreement with the Engineer/Architect will be executed to assist in the supervision of construction.

It is expected that the Control Building will be completed in June 1976. At that time, NRAO must install a complex system of supports, hangers, electric trays and walkways in the high bay areas under the electronic and control room areas on which to mount the 60 mm waveguide, signal distributors, cables and other electronic equipment. In addition, electric power must be

distributed to the various computer and control components. The orderly activation of this very complex building will be one of the major work items for 1976. One area of considerable concern is the stability of the Site electric power supply. Studies are now under way looking into the effect that momentary power interruptions will have on computer and array operations. At present, it appears that it will be necessary to install constant power equipment to smooth over the one cycle to ten cycle dropouts.

In the late spring a decision will be made as to the level of funding which will be available for wye construction in 1977. When this is determined, the Engineer/Architect will be instructed to prepare bid documents for Phase IV construction, which will be issued in June or July for award as soon as funds are available. The recent Phase III bids have shown the large cost savings which can be achieved by constructing major portions of the wye under a single contract.

During the year the take-up of excess rail from various Government installations will continue as will the stockpiling of ties and railroad accessories. The increase of $90,000.00 in CY-1976 funding will be used to help offset the cost of rail take-up and delivery of 4,400 tons of rail and accessories at the Crab Orchard Wildlife Refuge, which was not specifically earmarked for action during CY-1976.

Project Management

During 1976, in addition to the main procurement functions, the Project Management group will furnish and equip the permanent Control, Cafeteria, Storage, and Maintenance buildings and coordinate the move of personnel and equipment into these buildings. It will also arrange for the transfer, housing, and move of some nine additional employees and their families from Charlottesville to New Mexico, along with the move and reinstallation of the asynchronous computer.

The stockpiling of rail, ties and accessories will continue. At present, materials at Mare Island Naval Shipyard, California; Torrance Naval Supply Center, California; McClellan AFB, California; Fort Sam Houston, Texas; Webb AFB, Texas, Aberdeen Proving Ground, Maryland; Crab Orchard Wildlife Refuge, Illinois; and Indian Head Naval Ordnance Station, Maryland, are being investigated. Should all of this rail be received, it

will amount to 5,400 tons, or enough for approximately 25.0 additional km of wye. It is expected that the per ton cost of rail will increase as the new sources are at a greater distance from the Site, and many are in high cost east and west coast locations.

PLANNED ACTIVITIES - 1977

Antennas

Procurement, fabrication, assembly, and test of antenna units 7 through 10 will be completed by late spring 1977 and the antennas will then be turned over for the installation of electronic sets 7 through 10. Antenna units 11 through 15 will be ordered as soon as 1977 funds become available, for delivery in 1977.

Electronics

Primary objectives during 1977 will be the installation and testing of electronics on antenna units 7 through 10. In addition, electronic components for antenna units 11 through 15 must be ordered, fabricated, and completed and made ready for installation and testing on the antennas beginning in late 1977. Fabrication of the Spectral Line Processor will continue.

Computer System

Major activities will include the planning of the programming necessary to support the Spectral Line Processor. Programming of the asynchronous computer will continue during 1977. During the year, the hardware for the Spectral Line computer will be specified and procurement begun.

Systems Integration

Primary activities will be to assist in the systems integration task of combining the antennas, electronics, and computer systems.

Site and Wye

The Site and Wye group will continue to supervise the construction of the railroad trackage and wye services. It is anticipated that a 12 kilometer package of track and wye services will be designed and bid during the summer of 1976, to be financed with 1977 funds. This work will be completed by one or more general contractors during 1977.

Project Management

Major emphasis in this area will be the general activities necessary to procure the next group of antennas, antenna components, and electronic systems. Additional responsibilities will include the activities necessary to procure any surplus rail and fittings still required for wye construction. Also, implementation of the initial operations budget will be accomplished.

PLANNED ACTIVITIES - 1978

Antennas

Procurement, fabrication, assembly, and test of antenna units 11 through 15 will be completed by early 1978 and the antennas will be turned over for the installation of electronic sets 11 through 15. Antenna units 16 through 20 will be ordered as soon as 1978 funds become available, for delivery in 1978.

Electronics

Primary focus during 1978 will be the installation and testing of electronics on antenna units 11 through 15. In addition, electronic components for antennas 16 through 20 must be ordered, fabricated, completed and made ready for installation and testing on the antennas beginning in late 1978. The preparation of specifications and design of the final Spectral Line processor will occur during 1978.

Computer

Primary objectives during 1978 will be the procurement, installation, and test of the Spectral Line computer.

Site and Wye

The Site and Wye group will continue to oversee the construction of wye trackage and services. It is anticipated that a 15 kilometer package of wye trackage and services will be designed and bid during the summer of 1977, to be financed with 1978 funds. This work will be completed during 1978 by one or more general contractors.

Project Management

Primary focus will be on the procurement activities required to obtain the next group of antennas, antenna components, and electronic systems, as well as implementation of the operations budget.

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PLANNED ACTIVITIES - 1979

Antennas

Procurement, fabrication, assembly and test of antenna units 16 through 20 will be completed early in 1979 and they will be turned over for installation of electronic sets 16 through 20. Antenna units 21 through 25 will be ordered as soon as 1979 funds become available, for delivery in 1979.

Electronics

The major emphasis during 1979 will be the installation and testing of electronics on antenna units 16 through 20. In addition, electronic components for antennas 21 through 25 must be ordered, fabricated, completed and made ready for installation and testing on the antennas early in 1980. Fabrication and receipt of the Spectral Line Processor will occur in 1979, at which time on-line testing will commence.

Computer

Receipt of the Spectral Line computer will occur during 1978, at which time extensive testing and integration into the existing computer complex will take place.

Site and Wye

The Site and Wye group will continue to oversee the construction of wye trackage and services. It is anticipated that a 14 kilometer package of wye trackage and services will be designed and bid during the summer of 1978 and awarded as soon as 1979 funding becomes available.

Project Management

Major objective will be the supervision of procurement activities necessary to obtain the next group of antennas, antenna components, and electronic systems. Implementation of the operating budget will continue.

PLANNED ACTIVITIES - 1980

Antennas

Procurement, fabrication, assembly and test of antenna units 21 through 25 will be completed early in 1980, and the antennas will then be turned over for installation of electronic sets 21 through 25. Antenna units 26 through 28 will be ordered as soon as 1980 funds become available, for delivery in 1980.

Electronics

The major focus during this year will be the installation and testing of electronics on antenna units 21 through 25. In addition, electronic components for antennas 26 through 28 must be ordered, fabricated, completed and made ready for installation and testing on the antennas in late 1980. Final testing of the Spectral Line Processor will be completed and integration with the computer will begin and continue through the year.

Computer

Development of programming and software will continue through the year.

Site and Wye

The Site and Wye group will continue to oversee the construction of wye trackage and services. It is anticipated that a 7.8 kilometer package of wye trackage and services will be designed and bid during the summer of 1979 and awarded as soon as 1980 funding becomes available.

Project Management

Emphasis will be on procuring the required antennas, antenna components, and electronics to complete the VLA construction. The operations budget will be fully implemented by the end of the year.

FINANCIAL PLANNING

This section of the CY 1976 Project Plan will present the various budget estimates and other schedules necessary for the proper financial planning of the Project. Presented are the following:

VLA FINANCIAL STATUS REPORT - Project summary report which details the financial condition of the Project from the standpoint of the authorized Project ceiling compared to total Project outlook.

VLA COST ESTIMATE - 12/1/75 - Shows the current cost estimate for the Project and compares the present estimate with that presented in the CY 1975 Project Plan. To show the magnitude of the sums assigned to escalation and contingency, these items have been set forth separately.

COMMITMENT SCHEDULE - CY 1973 THROUGH CY 1980 - A commitment schedule to show actual commitments through CY 1974 and how the estimated commitments will be divided between the various calendar years.

EXPENDITURE SCHEDULE - CY 1973 THROUGH CY 1981 - An expenditure schedule to show actual expenditures through CY 1974 and to forecast expenditures during the life of the Project.

FINANCIAL PLAN - CY 1976 - The financial plan for CY 1976 broken down into various categories. For comparison, the actual allocation of CY 1974 and 1975 funds has also been included.

COMMITMENT/EXPENDITURE SCHEDULE BY QUARTERS - CY 1976 - A commitment and expenditure schedule for CY 1976 broken down by quarters.

REVIEW OF FINANCIAL PLAN - CY 1975 - A detailed analysis of the revisions that have been made to the CY 1975 Financial Plan, giving the reasons for the changes.

EXPENDITURES AND COMMITMENTS - CY 1975 CUMULATIVE ACTIVITY - A report in graph form, showing scheduled and actual expenditures and commitments by months.

EXPENDITURES AND COMMITMENTS - CY 1976 CUMULATIVE ACTIVITY - A graphic presentation showing planned CY 1976 expenditures and commitments by months. This graph will be the basis of monthly reports.

CUMULATIVE - APPROPRIATIONS/EXPENDITURES/COMMITMENTS - A graphic presentation detailing total appropriations, expenditures, and commitments to date.

NATIONAL RADIO ASTRONOMY OBSERVATORY

VLA--FINANCIAL STATUS REPORT
(in thousands)

As of: 10/31/75

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
		Allocation to Date				Outlook			
Item	Project Ceiling	Allocated	Expended and Committed	Allocated Balance	Unallocated Balance	Est. to Complete	Est. Total	(Over) Under Ceiling	Notes
Site and Wye	27,860	7,241	6,682	559	20,619	21,129	27,811	49	
Antennas	20,400	5,608	5,346	262	14,792	16,050	21,396	(996)	
Electronics	17,000	4,833	4,410	423	12,167	12,816	17,226	(226)	
Computer	4,050	1,885	1,752	133	2,965	3,493	5,245	(395)	
Systems Integration	400	98	38	60	302	330	368	32	
Project Management	2,650	938	822	116	1,712	2,055	2,877	(227)	
Subtotal	73,160	20,603	19,050	1,553	52,557	55,873	74,923	(1,763)	
Contingency	2,840	216	---	216	2,624	3,200	3,200	(360)	
Total	76,000	20,819	19,050	1,769	55,181	59,073	78,123	(2,123)	(4)

Notes: (1) Basic estimate is that of August 1975.

(2) Escalation included for future years at 6% for site and wye work; National Radio Astronomy labor, and minor antenna equipment items. Antenna estimate is based on the existing contract costs for fabrication of the antennas. No future escalation has been included for electronics or computer purchased equipment.

(3) Estimate excludes the following deferred items: Transporters #2 and #3, $615K; Airstrip, $268K.

(4) Does not include $6,000,000 received for CY-1976 by Amendment #12 and #15 to Contract C-780.

Figure 7

Explanation to Accompanying Statement

Column (2) - Project Ceiling: Original estimates

Column (3) - Allocated: Funded by NSF and included in total funds provided in Contract C-780.

Column (4) - Expended and Committed: Actual cash paid out and orders written and accepted by vendors.

Column (5) - Allocated Balance: Column 3 less Column 4. (Current funds available for expenditure and commitment.)

Column (6) - Unallocated Balance: Column 2 less Column 3. (Funds due from NSF to fund the total project as originally estimated.)

Column (7) - Estimate to Complete: Original estimate updated to take into account current or known costs.

Column (8) - Estimated Total: Column 4 plus Column 7.

Column (9) - (Over) Under: Column 2 less Column 8.

Figure 7

COST ESTIMATE
(in thousands)
12/1/75

	3-5-13-16-13 → Funding 1975 Project Plan 11/15/74	3-5-13-12.4-13 → Funding PROJECT 1975 BASE	COST ESCALATION	ESTIMATE TOTAL
ANTENNA SYSTEM				
Antenna Element Design	225	225	-	225
Prototypes including Tooling	1,616	1,624	-	1,624
Production Models	16,724	17,324	203	17,527
Transporter Design	83	83	-	83
Transporter Prototype	311	365	-	365
Transporter Production Models	615	-	-	-
Assembly Structure	312	397	-	397
E.D.I.A.	1,097	1,073	102	1,175
TOTAL ANTENNA SYSTEMS	20,983	21,091	305	21,396
ELECTRONIC SYSTEMS DEVELOPMENT				
Feed System	155	161	-	161
Front End System	220	281	-	281
Local Oscillator System	96	97	-	97
Monitor/Control System	100	93	-	93
Waveguide System	225	278	-	278
IF Transmission System	245	243	-	243
Delay/Multiplier System	35	22	-	22
Spectral Processor	25	25	-	25
General Electronics	20	13	-	13
E.D.I.A.	722	405	42	447
SUBTOTAL DEVELOPMENT	1,843	1,618	42	1,660

Figure 8

COST ESTIMATE
(in thousands)
12/1/75

	3-5-13-16-13 → Funding 1975 Project Plan 11/15/74	3-5-13-12.4-13 → Funding PROJECT 1975 BASE	COST ESCALATION	ESTIMATE TOTAL
ELECTRONIC SYSTEMS PRODUCTION				
Feed System	1,641	1,858	-	1,858
Front-End System	2,786	2,989	-	2,989
Local Oscillator System	787	979	-	979
Monitor/Control System	738	654	-	654
Waveguide System	251	404	-	404
IF Transmission System	1,234	1,245	-	1,245
Delay/Multiplier System	437	799	-	799
Spectral Processor	1,310	1,310	-	1,310
General Electronics	963	1,498	-	1,498
E.D.I.A.	4,053	3,512	318	3,830
SUBTOTAL PRODUCTION	14,200	15,248	318	15,566
TOTAL ELECTRONIC SYSTEMS	16,043	16,866	360	17,226
COMPUTER SYSTEM				
Synchronous Subsystem	286	697	-	697
Continuum Asynchronous Subsystem	1,121	965	-	965
Display I/O Equipment	260	265	-	265
Spectral Line Computer	1,080	1,100	-	1,100
Computer Maintenance	-	315	-	315
E.D.I.A.	2,103	1,761	142	1,903
TOTAL COMPUTER SYSTEM	4,850	5,103	142	5,245

Figure 8

COST ESTIMATE
(in thousands)
12/1/75

	3-5-13-16-13 → Funding 1975 Project Plan 11/15/74	3-5-13-12.4-13 → Funding PROJECT 1975 BASE	COST ESCALATION	ESTIMATE TOTAL
SITE FACILITIES AND WYE				
Site Acquisition	238	293	-	293
Preliminary Design	225	225	-	225
Detailed Design	622	509	4	513
Construction Supervision	340	202	15	217
Survey/Soils	269	291	10	301
Construction Site Preparation		102	2	104
Construction Facilities	300	232	-	232
Computer/Site Trailers	50	40	-	40
Building Complex	2,263	2,358	-	2,358
Site Work/Utilities	861	1,152	-	1,152
Wye Construction	15,668	12,307	2,052	14,359
Waveguide Procurement	3,606	4,343	668	5,011
Waveguide Installation	2,416	1,375	212	1,587
Waveguide Antenna Stations	488	576	89	665
E.D.I.A.	558	695	59	754
TOTAL SITE FACILITIES/WYE	27,904	24,700	3,111	27,811

Figure 8

	COST ESTIMATE (in thousands) 12/1/75			
	3-5-13-16-13 → Funding 1975 Project Plan 11/15/74	3-5-13-12.4-13 → Funding PROJECT 1975 BASE	COST ESCALATION	ESTIMATE TOTAL
SYSTEMS INTEGRATION				
Personnel Costs	180	137	11	148
Materials and Supplies	150	150	-	150
Travel	70	70	-	70
TOTAL SYSTEMS INTEGRATION	400	357	11	368
PROJECT MANAGEMENT				
Personnel Costs	1,474	1,305	101	1,406
Materials and Services	788	1,178	143	1,321
Travel	392	141	9	150
TOTAL PROJECT MANAGEMENT	2,654	2,624	253	2,877
CONTINGENCY/RESERVE	1,475	3,200	-	3,200
TOTAL PROJECT	74,309	73,941	4,182	78,123

Figure 8

COMMITMENT SCHEDULE - CY-1973 THROUGH CY-1980
(in thousands)
12/1/75

	1973	1974	1975	1976	1977	1978	1979	1980	TOTAL
Site/Wye	964	875	4,924	4,807	3,277	5,252	7,624	-	27,723
Antenna Systems	315	2,453	2,740	7,794	3,794	3,605	461	52	21,214
Electronic Systems	816	1,460	2,292	2,876	4,001	2,400	2,171	1,142	17,158
Computer Systems	29	415	1,365	720	772	774	1,035	235	5,345
Systems Integration	-	-	46	112	86	40	-	-	284
Project Management	158	236	500	672	584	444	249	34	2,877
Contingency/Reserve	-	-	27	105	486	485	1,460	959	3,522
TOTAL VLA PROJECT	2,282(1)	5,439(1)	11,894(1)	17,086(2)	13,000	13,000	13,000	2,422	78,123
km of Wye/Services	-	1.24	-	13.0	12.0	15.0	21.76	-	63.0
Number of Antennas	-	2	4	4	5	6	7	-	28

Notes: (1) Actual.
(2) Actual through 6/30/76; estimated through 12/31/76.

Figure 9
Revised 4/20/76
Revised 8/02/76

EXPENDITURE SCHEDULE - CY-1973 THROUGH CY-1981
(in thousands)
12/1/75

	1973	1974	1975	1976	1977	1978	1979	1980	1981	TOTAL
Site/Wye	496	1,182	3,931	4,759	3,575	4,915	7,077	1,788	-	27,723
Antenna Systems	149	373	4,311	6,629	4,498	3,785	1,131	338	-	21,214
Electronic Systems	702	1,347	2,003	2,708	3,740	2,670	2,272	1,370	346	17,158
Computer Systems	29	367	1,171	768	771	774	982	483	-	5,345
Systems Integration	-	-	45	101	82	36	20	-	-	284
Project Management	158	235	499	665	578	366	330	46	-	2,877
Contingency/Reserve	-	-	27	105	486	485	1,460	959	-	3,522
TOTAL VLA PROJECT	1,534(1)	3,504(1)	11,987(1)	15,735(2)	13,730	13,031	13,272	4,984	346	78,123

Notes: (1) Actual.

(2) Actual through 6/30/76; estimated through 12/31/76.

Figure 10
Revised 4/20/76
Revised 8/02/76

FINANCIAL PLAN CY-1976
(in thousands)
12/1/75

	ESTIMATE	ACTUAL CY-1973	ACTUAL CY-1974	ACTUAL CY-1975	CY-1976 PLAN
TASK II ANTENNA SYSTEM					
Antenna Element Design	225	225	-	-	-
Prototypes including Tooling	1,624	-	1,623	-	-
Production Models	17,345	-	-	2,455	7,501
Transporter Design	83	-	83	-	-
Transporter Prototype	365	-	311	5	50
Transporter Production Models	-	-	-	-	-
Assembly Structure	397	-	312	86	6
E.D.I.A.	1,175	90	124	194	237
TOTAL - ANTENNA SYSTEM	21,214	315	2,453	2,740	7,794
TASK III ELECTRONIC SYSTEMS DEVELOPMENT					
Feed System	161	-	80	1	55
Front End System	281	96	64	81	30
Local Oscillator System	97	33	20	4	18
Monitor/Control System	93	74	9	2	-
Waveguide System	278	129	14	46	120
IF Transmission System	243	63	29	90	50
Delay/Multiplier System	22	7	14	1	-
Spectral Processor	25	-	-	4	10
General Electronics	13	-	13	-	-
E.D.I.A.	447	282	117	117	127
SUBTOTAL - DEVELOPMENT	1,660	684	360	346	410

Figure 11
Revised 8/02/76

FINANCIAL PLAN CY-1976
(in thousands)
12/1/75

	ESTIMATE	ACTUAL CY-1973	ACTUAL CY-1974	ACTUAL CY-1975	CY-1976 PLAN
TASK III ELECTRONIC SYSTEMS PRODUCTION					
Feed System	1,858	-	105	36	396
Front End System	2,921	-	214	384	422
Local Oscillator System	979	-	80	118	136
Monitor/Control System	654	-	15	85	118
Waveguide System	404	-	25	7	77
IF Transmission System	1,245	-	106	292	187
Delay/Multiplier System	799	24	62	122	38
Spectral Processor	1,310	-	-	-	70
General Electronics	1,498	108	135	254	259
E.D.I.A.	3,830	-	358	648	763
SUBTOTAL - PRODUCTION	15,498	132	1,100	1,946	2,466
TOTAL - ELECTRONIC SYSTEMS	17,158	816	1,460	2,292	2,876
TASK IV COMPUTER SYSTEM					
Synchronous Subsystem	697	-	248	-	21
Continuum Asynchronous Subsystem	965	-	-	923	140
Display I/O Equipment	265	-	-	34	80
Redundant Synchronous System	-	-	-	-	-
Spectral Line Computer	1,200	-	-	-	-
Computer Maintenance	315	-	-	71	83
E.D.I.A.	1,903	29	167	337	396
TOTAL - COMPUTER SYSTEM	5,345	29	415	1,365	720

Figure 11
Revised 8/02/76

FINANCIAL PLAN - CY-1976
(in thousands)
12/1/75

	ESTIMATE	ACTUAL CY-1973	ACTUAL CY-1974	ACTUAL CY-1975	CY-1976 PLAN
TASK I & V SITE FACILITIES/WYE					
Site Acquisition	293	-	-	-	-
Preliminary Design	225	225	-	-	-
Detailed Design	513	443	30	-	12
Construction Supervision	217	-	30	51	48
Survey/Soils	301	223	4	34	18
Construction Site Preparation	104	-	33	8	10
Construction Facilities	232	15	-	157	59
Computer/Site Trailers	40	-	-	36	2
Building Complex	2,358	-	-	1,814	431
Site Work/Utilities	1,152	-	-	615	46
Wye Construction	14,271	-	616	837	3,675
Waveguide Procurement	5,011	-	60	1,114	36
Waveguide Installation	1,587	-	-	116	170
Waveguide Antenna Stations	665	-	-	-	147
E.D.I.A.	754	58	102	142	153
TOTAL - SITE FACILITIES/WYE	27,723	964	875	4,924	4,807

Figure 11
Revised 4/20/76
Revised 8/02/76

FINANCIAL PLAN - CY-1976
(in thousands)
12/1/75

	ESTIMATE	ACTUAL CY-1973	ACTUAL CY-1974	ACTUAL CY-1975	CY-1976 PLAN
TASK IV SYSTEMS INTEGRATION					
Personnel Costs	148	-	-	33	62
Material, Services, Supplies	111	-	-	6	41
Travel	25	-	-	7	9
TOTAL - SYSTEMS INTEGRATION	284	-	-	46	112
TASK VIII PROJECT MANAGEMENT					
Personnel Costs	1,406	128	177	248	321
Materials, Services, Supplies	1,321	17	36	217	331
Travel	150	13	23	35	20
TOTAL - PROJECT MANAGEMENT	2,877	158	236	500	672
Contingency/Reserve	3,522	-	-	27	105
TOTAL PROJECT	78,123	2,282	5,439	11,894	17,086

Figure 11
Revised 4/20/76
Revised 8/02/76

COMMITMENT/EXPENDITURE SCHEDULE BY QUARTERS CY-1976
(in thousands)
12/1/75

	1st QUARTER		2nd QUARTER		3rd QUARTER		4th QUARTER		TOTAL CY-1976	
	COMMIT.	EXPEND.	COMMIT.	EXPEND.	COMMIT.	EXPEND.	COMMIT.	EXPEND.	COMMIT.	EXPEND.
Site & Wye	3,320	1,278	712	1,702	491	796	63	416	4,586	4,192
Antenna Systems	2,774	1,078	39	605	125	440	26	416	2,964	2,539
Electronic Systems	888	436	789	515	592	673	493	752	2,762	2,376
Computer	258	250	117	125	117	117	114	114	606	606
Systems Integration	79	45	32	43	30	42	30	41	171	171
Project Management	165	143	160	156	155	168	155	168	635	635
Contingency/Reserve	-	-	406	300	270	200	-	176	676	676
TOTAL PLANNED	7,484		2,255		1,780		881		12,400	
		3,230		3,446		2,436		2,083		11,195

Figure 12

CY-1975 REVIEW OF FINANCIAL PLAN
(in thousands)
12/1/75

		11/15/74	10/31/75	CHANGE
I & V	SITE FACILITIES & WYE	5,085	5,400[1]	+ 315
II	ANTENNA SYSTEMS	2,544	2,841	+ 297
III	ELECTRONIC SYSTEMS	2,805	2,557	- 248
IV	COMPUTER SYSTEMS	1,437	1,442	+ 5
VI	SYSTEMS INTEGRATION	98	98	-
VII	PROJECT MANAGEMENT	421	531	+ 110
	CONTINGENCY/RESERVE	610	216	- 394
	TOTAL PROJECT	13,000	13,085[1][2]	+ 85

Notes: (1) Includes $108K withheld by NSF for land acquisition by Army Corps of Engineers.

(2) Increase due to carry over of funds from previous years.

Figure 13

CY-1975 REVIEW OF FINANCIAL PLAN
(in thousands)
12/1/75

	11/15/74	10/31/75	CHANGE
TASK I & V - SITE FACILITIES/WYE			
Site Acquisition	-	108	+ 108(1)
Engineering - Preliminary	-	-	-
- Detailed	15	-	- 15(2)
Construction Supervision	70	81	+ 11(3)
Survey/Soils	15	30	+ 15(4)
Construction Facilities	195	190	- 5(5)
Computer/Site Trailers	50	50	-
Construction Equipment	-	50	+ 50(6)
Building Complex	2,163	1,860	- 303(7)
Site Work/Utilities	482	680	+ 198(8)
Wye Construction	1,325	922	- 403(9)
Waveguide Procurement	300	1,150	+ 850(10)
Waveguide Installation	158	80	- 78(11)
Waveguide Antenna Stations	158	30	- 128(12)
E.D.I.A.	154	169	+ 15(13)
TOTAL	5,085	5,400	+ 315

Notes: (1) Increased to cover cost of land acquisition by the Army Corps of Engineers.

(2) Required detailed design work accomplished within existing subcontract authorization without additional funding.

(3) Increase required to cover supervision by Joint Venture of Phase II construction of VLA building complex.

(4) Increase required to cover reimbursables in conjunction with BWH-CVA effort on supervision of Phase II construction.

Figure 13

(5) Allocation adjusted after receipt of bids for prefabricated Service Building.

(6) Not estimated in 11/15/74 Project Plan. Covers items such as cherry picker, fire engine, tank truck, platform truck, and forklift.

(7) Reflects receipt of contractual prices from George A. Rutherford Construction Company on VLA-65 for building construction for Control Building and Cafeteria. Construction of Visiting Scientists' quarters and permanent Maintenance Building deferred until later years.

(8) Reflects receipt of contractual prices from George A. Rutherford Construction Company on VLA-65 for site/utilities construction.

(9) Stockpiling effort on relayer rail, ties and track materials for future wye successful. Allocation reduced to cover other items.

(10) Increased to cover option to procure 10,000 meters of waveguide before price increase went into effect. CY-1975 procurements total 16,500 meters.

(11) Revised allocation based on installation of 1,250 meters of waveguide parallel to existing 1,250 meters of track and embankment.

(12) Revised allocation based on outfitting five existing antenna observing stations.

(13) Increased to cover additional manpower for site guards, cost of bus, and increased cost of miscellaneous material, services, supplies, i.e., power, telephone, vehicles.

Figure 13

CY-1975 REVIEW OF FINANCIAL PLAN
(in thousands)
12/1/75

	11/15/74	10/31/75	CHANGE	
TASK II - ANTENNA SYSTEMS				
Production Model Antennas	2,374	2,572	+ 198	(1)
Field Modifications	-	4	+ 4	(2)
Assembly Structure	-	81	+ 81	(3)
Transporter Assembly/Test/Spares	-	4	+ 4	(4)
E.D.I.A.	170	180	+ 10	(5)
TOTAL	2,544	2,841	+ 297	

Notes:

(1) Reflects the increase in costs of Antennas 3 - 10 at $26,926 each, totaling $215,408. E-Systems Amendment #12. An allowance for changes was already included in the $2,374K allocation, thus resulting in an increase of $198K.

(2) Not estimated in 11/15/74 Project Plan. Item required to cover field modifications of the antenna by NRAO personnel during integration of electronic systems and testing of element.

(3) Reflects increase due to strengthening of Antenna Assembly Building and furnishing and installing two doors in the Assembly Building and resulting New Mexico Gross Receipts and Compensating tax.

(4) Not estimated in 11/15/74 Project Plan. Item required to cover procurement of initial spare parts and miscellaneous hardware/fittings for transporter vehicle.

(5) Reflects increase due to need for specialized tools for NRAO outfitting and test of antennas and transporter, equipment and materials required by machine shop to fabricate or modify antenna hardware.

Figure 13

CY-1975 REVIEW OF FINANCIAL PLAN
(in thousands)
12/1/75

	11/15/74	10/31/75	CHANGE
TASK III - ELECTRONIC SYSTEM			
General Electronics	209	249	+ 40 (1)
Front-end System	440	461	+ 21 (2)
Local Oscillator System	174	117	- 57 (3)
Waveguide System	95	77	- 18 (4)
IF Transmission System	371	380	+ 9 (5)
Delay/Multiplier System	254	127	- 127 (6)
Feed System	322	248	- 74 (7)
Monitor and Control System	126	96	- 30 (8)
Spectral Processor	82	20	- 62 (9)
E.D.I.A.	732	782	+ 50 (10)
TOTAL ELECTRONICS	2,805	2,557	- 248

Notes: (1) Reflects an underestimate of test equipment requirements, DC power, outside fabrication of Module/Bin and procurement of hardware for systems 3-6, initial shop and laboratory furnishings, and weather instrumentation system for the monitoring of climatic conditions.

(2) Increases in the costs of the cryogenic system, RF components, general front-end development (Schottky Diode contract costs), cryogenic system development, and decreases in the cost of parametric amplifiers, up-converters and frequency converters for electronic systems 3 - 6.

(3) In-house fabrication of local oscillator modules is responsible for the reduction of CY-1975 costs. Also deferral of phase detector modules and some master-oscillator driver modules.

Figure 13

(4) Reflects the decrease in development of general waveguide system and installation and the increase of actual versus estimated cost of antenna coupling components and 20 mm TE_{01} mode waveguide.

(5) Reflects an increase in actual cost of development and fabrication of the signal distributor under contract with Hitachi Shibaden and a decrease in the cost of the IF/LO modems and the IF receiver.

(6) Change from two to one 50 MHz wide reception band (with full polarization) for interim system resulting from new plans for combined continuum and Spectral Line system.

(7) Reflects a decrease in feed development and dichroic mount/reflector costs due to using manual rotation system for units 3 - 6.

(8) Reflects a decrease in cost resulting from direct buying of components and using outside assembly versus complete outside procurement including components, assembly, and testing by company which also did development.

(9) Reflects a change in plan in which only an initial study was done in 1975. Design breadboard tests and procurement are reprogrammed for CY-1976.

(10) Underestimate of total requirements for bench stock components, stockroom materials, and initial supplies and materials for NRAO electronics/antenna machine shop.

Figure 13

CY-1975 REVIEW OF FINANCIAL PLAN
(in thousands)
12/1/75

TASK IV COMPUTER SYSTEMS	11/15/74	10/31/75	CHANGE	
Synchronous Subsystem	12	-	- 12	(1)
Asynchronous Subsystem	993	925	- 68	(2)
Display I/O Equipment	35	35	-	
E.D.I.A.	397	482	+ 85	(3)
TOTAL	1,437	1,442	+ 5	

Notes: (1) Reflects a decrease by transferring allocation for synchronous maintenance to an E.D.I.A. account.

(2) Reflects a decrease by transferring allocation for asynchronous maintenance currently under contract with DEC, VLA-43, from hardware account to computer maintenance account under E.D.I.A.

(3) Increase reflects transfer of allocation mentioned in Note (1) and Note (2) above in addition to $5K additional allocation to cover re-estimate of synchronous maintenance.

Figure 13

CY-1975 REVIEW OF FINANCIAL PLAN
(in thousands)
12/1/75

	11/15/74	10/31/75	CHANGE	
TASK VI - SYSTEMS INTEGRATION	98	98	0	
TASK VIII - PROJECT MANAGEMENT				
Personnel Costs	240	252	+ 12	(1)
Material, Services, Supplies	121	234	+ 113	(2)
Travel	60	45	- 15	(3)
TOTAL	421	531	+ 110	

Notes: (1) Reflects increase due to additional manpower staffing requirement for three guards for security at VLA Site during off-duty scheduling of regular NRAO personnel and decrease in number of positions by terminations and transfers.

(2) Reflects increase due to underestimated cost for GSA vehicle leases, telephone, and electric power, office equipment leases, and incoming/outgoing freight. The purchase of a bus for transportation of personnel and the bunk trailer and furnishings were not estimated in the 11/15/74 Project Plan.

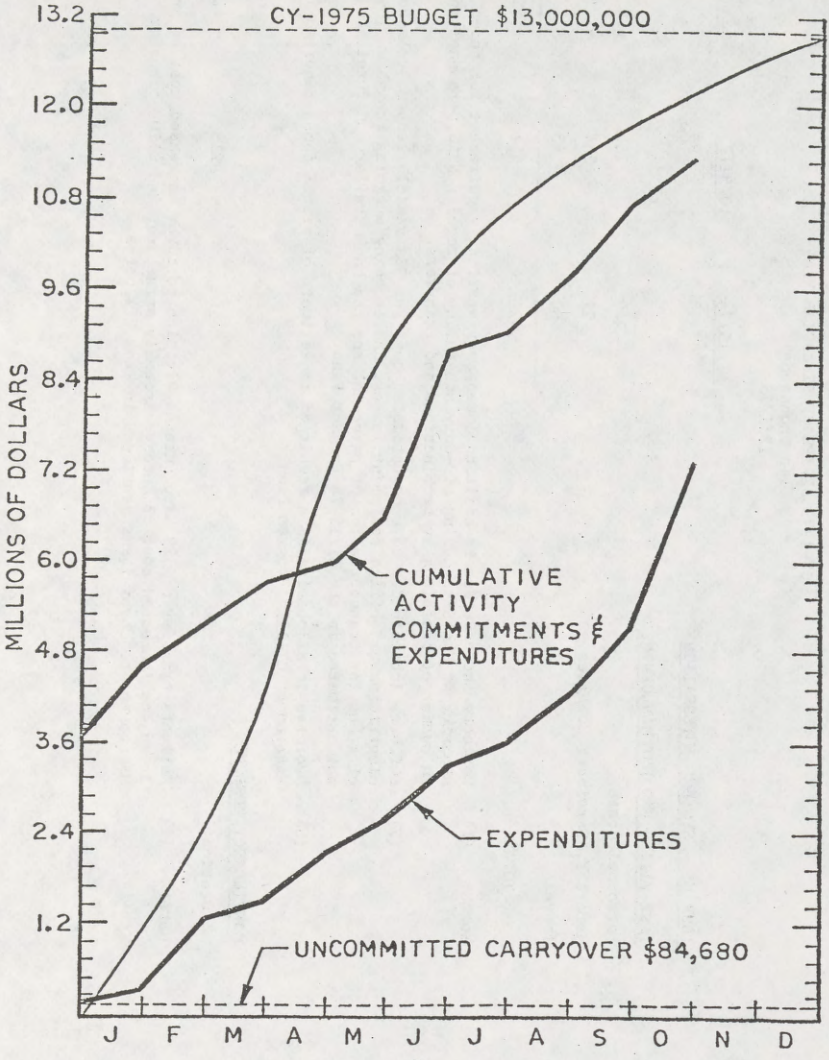
(3) Decrease in allocation is a result of re-estimate of travel funds required in Project Management CY-1975 Program Plan.

CONTINGENCY/RESERVE				
Allocation	610	216	- 394	(1)

Note: (1) Reflects transfer of $297K to Antenna Division to cover increased cost of Antennas 3 - 6 and increased cost of Antenna Assembly structure, and $110K transfer to Project Management to cover items mentioned in Task VII notes.

Figure 13

VLA-PROJECT REPORT
EXPENDITURES AND COMMITMENTS
CY-1975 CUMULATIVE ACTIVITY



-57-

Figure 14

VLA-NRAO
PROJECT REPORT
EXPENDITURES AND COMMITMENTS
CY-1976 CUMULATIVE ACTIVITY

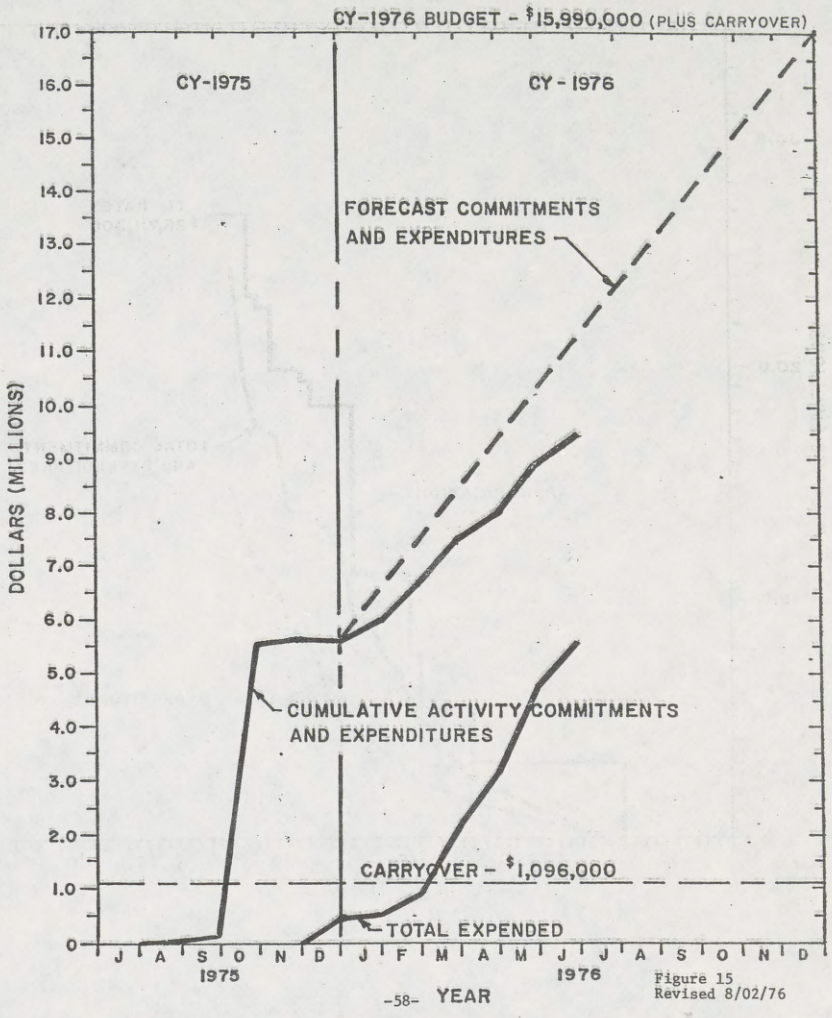
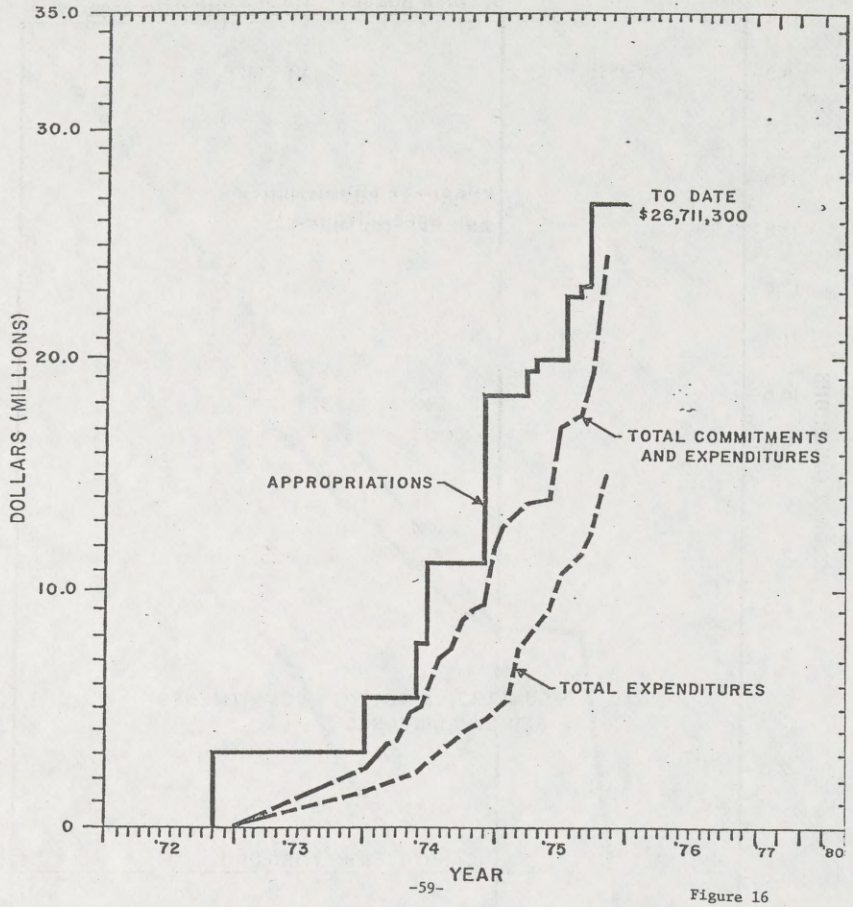


Figure 15
Revised 8/02/76

VLA PROJECT REPORT

APPROPRIATIONS, EXPENDITURES AND COMMITMENTS

CUMULATIVE ACTIVITY



-59-

Figure 16

PROJECT SCHEDULES

During 1973, 1974, and in 1975 until July, a detailed PERT network was used to plan, coordinate, and monitor the progress of the design, development, procurement, fabrication, and test of the various complex subsystems required for the VLA. This took about one and one-half man years per year to accomplish the mechanics of the system plus considerable additional time of the scientists and engineers who had to input into the system. With the completion of the prototype electronics, the delivery of both computers, the near delivery of the antennas, the move of the staff to New Mexico, and the start-up of the Systems Integration Group, it was decided to terminate the full PERT activity.

Work at the Site is being coordinated by the Systems Integration Group under the supervision of the Deputy Project Manager through the use of detailed bar schedules for the outfitting of each antenna. In Charlottesville, for the fabrication of the electronic components, PERT is still being used for scheduling and procurement purposes. There are attached as typical printout summary sheets for the 1975 and 1976 electronic modules, racks and bins. The computer is also being used to gather together data on the myriads of electronic components for each module, coordinate the requirements, and deliver to the procurement staff consolidated lists. This saves multiple requisitions and purchase orders and results in quantity discounts, which in many cases are substantial.

There follows as Figure 18 a VLA ACTIVITY SCHEDULE Bar Chart dated 11/15/75, which is time scaled to provide a concise, overall view of the entire Project. This chart is revised monthly to indicate the current status of the Project and revised annually or at other times when major schedule changes occur.

NATIONAL RADIO ASTRONOMY OBSERVATORY
CYCLE CODE BAR CHART

PROGRAM 06SEP75 REPORT DATE. ELECTRONICS - MODULES, RACKS ELC001
PROJECT VLA ELECTRONICS MODULES, RACKS, BINS FOR 1975(1) 15AUG75 ELO075 RUN DATE 15SEP75

CODE	CYCLE CODE DESCRIPTION	A ALL ACTIVITIES COMPLETE / * ALL ACTIVITIES NOT COMPLETE	FINAL DATE
AH	MECH PROCUREMENT		07MAY76
AM	ELEC PROCUREMENT		29AUG75
BB	MODULE L4		13OCT75
BE	MODULE L9		29JAN76
BH	MODULE L10		05FEB76
BK	MODULE L3		11FEB76
BN	MODULE L1		19FEB76
BR	MODULE L2		25FEB76
BU	MODULE L14		03MAR76
BW	MODULE L5		09MAR76
BY	MODULE L11		16MAR76
EB	MODULE T5		22MAR76
EE	MODULE L7		24SEP75
EH	MODULE L6		09OCT75
EK	MODULE T6		19NOV75
EN	MODULE T4A		31DEC75
ER	MODULE T4B		07JAN76
ET	TEST SET L7		13JAN76
EV	TEST SET L6		15JAN76
EX	REPAIR (SITE) L6		26DEC75
HB	MODULE F1		20OCT75
HE	MODULE F2		06OCT75
HH	MODULE F3		16DEC75
HK	MODULE F4		29JAN76
HN	MODULE F5		03NOV75
HR	MODULE F6		31DEC75
HU	FE POWER SUPPLIES		17NOV75
HX	VACUUM PANEL		08OCT75
HY	PARAMP PUMP PWR		29OCT75
HZ	TEST SET F5,3,2		18SEP75
KB	POWER SUPPLY P1		12NOV75
KE	POWER SUPPLY P2		17OCT75
KH	POWER SUPPLY P3		31OCT75
KK	POWER SUPPLY P4		14NOV75
KN	POWER SUPPLY P5		01DEC75
KR	PWR SUP,BIN PAN P1/2		15DEC75
KU			15DEC75
KX	PWR SUP,BIN PAN P4/5		09DEC75
NB	FE BIN WIRING		17DEC75
NE	CONT RM RACK WIRING		17OCT75
NH	VERT RM RACK WIRING		16MAR76
RB	FE RACK WIRING		12MAR76
RD	FE MODULE SHIP		04DEC75
RE	CONT RM RACK CKOUT		13FEB76
RH	VERT RM RACK CKOUT		07MAY76
			21APR76

01APR75 01JUL75 01OCT75 01JAN76 01APR76 01JUL76 01OCT76

Figure 17

NATIONAL RADIO ASTRONOMY OBSERVATORY
CYCLE CODE BAR CHART

PROGRAM 06SEP75 REPORT DATE. ELECTRONICS - MODULES, RACKS ELC002 RUN DATE 15SEP75
PROJECT VLA ELECTRONICS MODULES, RACKS, BINS FOR 1976(1) 06SEP75 ELC076

CODE	CYCLE CODE DESCRIPTION	A ALL ACTIVITIES COMPLETE	* ALL ACTIVITIES NOT COMPLETE	FINAL DATE
	:			31DEC76
AH	MECH PRCCUREMENT			13APR76
AM	ELEC PRCCUREMENT			27APR76
AP	FE ELEC PROCURE			26DEC75
BB	MODULE:L4			28SEP76
BE	MODULE:L9			05OCT76
BH	MODULE:L10			11OCT76
BK	MODULE:L3			18OCT76
BN	MODULE:L1			22OCT76
BR	MODULE:L2			29OCT76
BU	MODULE:L14			04NOV76
BW	MODULE:L5			11NOV76
BY	MODULE:L11			17NOV76
EB	MODULE:T5			04JUN76
EE	MODULE:L7			22JUN76
EH	MODULE:L6			03AUG76
EK	MODULE:T6			17AUG76
EN	MODULE:T4A			23AUG76
ER	MODULE:T4B			27AUG76
ET	TEST SET L7			08DEC76
EV	TEST SET L6			18NOV76
EX	REPAIR:(SITE) L6			12OCT76
HB	MODULE:F1			28JUN76
HE	MODULE:F2			07SEP76
HH	MODULE:F3			19OCT76
HK	MODULE:F4			26JUL76
HN	MODULE:F5			21SEP76
HR	MODULE:F6			09AUG76
HU	FE POWER SUPPLIES			04FEB76
HX	VACUUM:PANEL			28JAN76
HY	PARAMP:PUMP PWR			14JAN76
HZ	TEST SET F5,3,2			08JUL76
KB	POWER SUPPLY P1			14JUN76
KE	POWER SUPPLY P2			28JUN76
KH	POWER SUPPLY P3			12JUL76
KK	POWER SUPPLY P4			26JUL76
KN	POWER SUPPLY P5			09AUG76
KR	PWR SUP,BIN PAN P1/2			09AUG76
KU	:			03AUG76
KX	PWR SUP,BIN PAN P4/5			11AUG76
NB	FE BIN:WIRING			30MAR76
NE	CONT RM RACK WIRING			05NOV76
NH	VERT RM RACK WIRING			03NOV76
RB	FE RACK WIRING			04MAY76
RD	FE MODULE SHIP			02NOV76
RE	CONT RM RACK CKOUT			31DEC76
RH	VERT RM RACK CKOUT			17DEC76

01APR76 01JUL76 01OCT76 01JAN77 01APR77 01JUL77 01OCT77

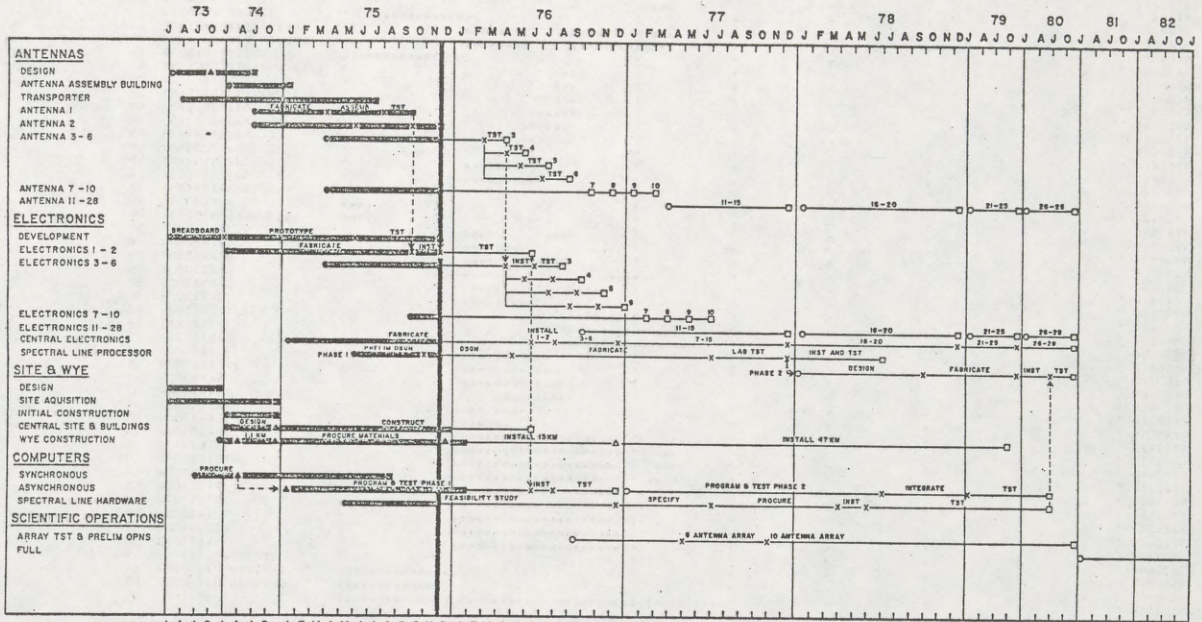
Figure 17

NATIONAL RADIO ASTRONOMY OBSERVATORY

VLA ACTIVITY SCHEDULE

11/15/75

UPDATE DATE: 01 DECEMBER 1975



ABBREVIATIONS

ASSEMBLE - ASSEMB	CH-VILLE - CV	INSTALL - INST	PRELIMINARY - PRELIM
COMPLETE - CMPL	DESIGN - DSGN	INTEGRATE - INTG	SELECT - SLCT
CONTRACT - CNTR	DETAIL - DTL	OPERATIONS - OPNS	TEST - TST

SYMBOLS

O START OF A PHASE
X END OF AN ACTIVITY
△ CONTRACT AWARD
□ END OF A PHASE

REV. NO	REV. DATE	REVISION

Figure 18

APPENDIX A

NRAO COMMITTEES

There are four major committees involved with the VLA - the NRAO Visiting Committee, the NRAO Users' Committee, the VLA Advisory Committee, and the VLA Steering Committee. The first of these provides the AUI Board of Trustees with an independent appraisal of NRAO performance, including the VLA. The Users' Committee and the Advisory Committee provide broad overall review and guidance. These two committees furnish scientific input and are the Project's liaison with the scientific community, thus assuring broad participation in the Project. The Steering Committee is responsible for more detailed reviews and advice on scientific and technical aspects of the Project.

The Visiting Committee and the Users' Committee have been in existence for many years and both have been involved with the VLA since its early design stages. The Steering Committee is an outgrowth of the design group, which was formed in the fall of 1972. Each of the committees is described below in more detail and the current membership of each is given.

In addition to the above standing committees, various ad hoc committees will be appointed as needed for specific tasks, such as the evaluation of proposals and selection of contractors.

NRAO VISITING COMMITTEE

This Committee is appointed by the AUI Board of Trustees and formally reports to the AUI Board on an annual basis. Its function is to review the performance of the Observatory, and advise the Trustees on how well it is carrying out its function as a national center, the quality of the scientific work, and the adequacy of its instrumentation and facilities. A thorough review of the VLA Project will be conducted by this Committee each year.

The current membership of the Committee is:

E. J. Blum	Meudon Observatory
R. D. Ekers	Kapteyn Laboratory
C. E. Heiles	University of California
F. J. Kerr	University of Maryland
V. C. Rubin	Carnegie Institution of Washington
E. E. Salpeter	Cornell University
P. Thaddeus	Institute for Space Studies
D. T. Wilkinson	Princeton University

NRAO USERS' COMMITTEE

This Committee consists of users, and potential users, of NRAO facilities from throughout the scientific community. It advises the Director and Observatory staff on all aspects of Observatory activities that affect the users of the telescopes - development of radiometers and auxiliary instrumentation, operation of the telescopes, the computer and other support facilities, and major new instruments. This Committee is appointed by the NRAO Director. It meets twice a year, and a broad review and discussion of the VLA will be a principal item for these meetings throughout the life of the Project.

The present membership of this Committee is:

B. Balick	University of California
A. H. Barrett	Massachusetts Institute of Technology
J. J. Broderick	Virginia Polytechnic Institute
B. F. Burke	Massachusetts Institute of Technology
T. A. Clark	NASA - Goddard Space Center
J. J. Condon	Virginia Polytechnic Institute
M. M. Davis	Arecibo Observatory
W. A. Dent	University of Massachusetts
J. R. Dickel	University of Illinois
J. N. Douglas	University of Texas
F. D. Drake	Cornell University
W. C. Erickson	University of Maryland
S. J. Goldstein	University of Virginia
C. E. Heiles	University of California
M. A. Kaftan-Kassim	State University of New York
F. J. Kerr	University of Maryland
H. C. Ko	Ohio State University
M. R. Kundu	University of Maryland
A. E. Lilley	Harvard University
H. Liszt	University of Pittsburgh
C. H. Mayer	U. S. Naval Research Laboratory
P. Palmer	University of Chicago
K. W. Riegel	University of California
A. G. Smith	University of Florida
L. E. Snyder	University of Illinois Observatory
P. Solomon	State University of New York (Stony Brook)

G. W. Swenson	University of Illinois
J. H. Taylor	University of Massachusetts
P. Thaddeus	Institute for Space Studies of New York
G. L. Verschuur	University of Colorado
J. F. C. Wardle	Brandeis University
J. W. Warwick	University of Colorado
G. Westerhout	University of Maryland
D. R. W. Williams	University of California
R. W. Wilson	Bell Telephone Laboratories
W. J. Wilson	Aerospace Corporation
B. Zuckerman	University of Maryland

VLA ADVISORY COMMITTEE

The Advisory Committee will periodically review the status and progress of the VLA. Its particular concern is with the broad elements of the Project, and especially those that directly influence the scientific capabilities and performance characteristics of the Array. It will advise on broad aspects of design, scientific emphasis, and priorities, as well as on general progress, to assist the Director and the Project staff in assuring that the scientific and technical specifications are met and that the VLA will be as responsive to the needs of radio astronomy as is possible.

When scientific observing commences, this group may also advise on the observing programs to be carried out.

The Committee is appointed by the NRAO Director. It is composed of scientists whose interests encompass all areas of radio astronomy and technology of concern to the VLA. An attempt is also made to maintain, in the membership, reasonable geographic distribution and representation of the major radio astronomy centers. The Committee generally meets twice a year, depending on the nature of current Project activities and their rate of progress.

The current membership of the Committee is:

B. F. Burke	Massachusetts Institute of Technology
J. N. Douglas	University of Texas
F. D. Drake	Cornell University
R. D. Ekers	Kapteyn Laboratories
C. E. Heiles	University of California

M. R. Kundu	University of Maryland
A. T. Moffet	California Institute of Technology
A. E. E. Rogers	Haystack Observatory
G. W. Swenson	University of Illinois

VLA STEERING COMMITTEE

The Steering Committee is the principal technical review committee for the Project. Its principal function is to continuously review technical designs, construction plans, etc., to assure that they are consistent with overall performance goals and that staff or contractor technical decisions do not unknowingly affect the system's performance. In addition, the Committee advises on technical matters, such as systems design, components design and selection, etc.

The Committee is appointed by the NRAO Director. It is composed principally of NRAO scientists and engineers who are thoroughly familiar both with the scientific requirements and uses of the VLA and with the techniques and instrumentation employed in the VLA. It meets approximately monthly, and more often if needed.

The current membership of the committee is:

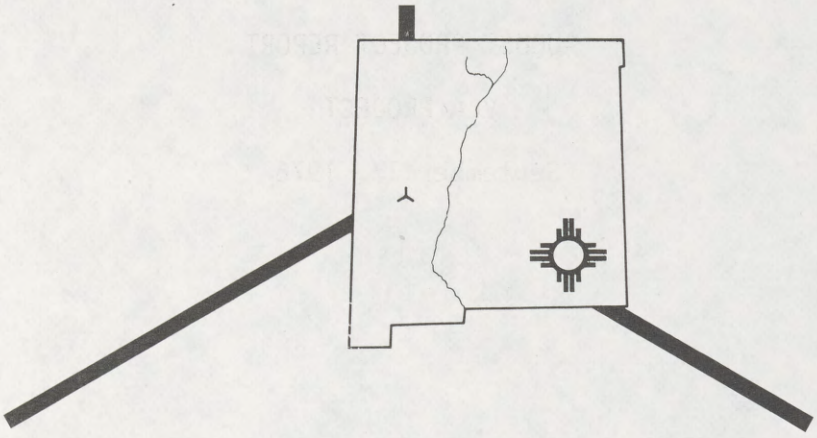
B. G. Clark
J. W. Findlay
E. Fomalont
E. Greisen
R. M. Hjellming
D. E. Hogg
K. I. Kellermann
F. N. Owen
C. M. Wade

Dr. HUGHES. The AUI also provides NSF a Very Large Array monthly project report that summarizes each of the Very Large Array activity categories by a separate status report. The report is particularly valuable for the detailed financial data it contains, including a forecast as well as a balance available for the expenditures of the Very Large Array.

A copy of this document is also being submitted for the record. It is the Very Large Array monthly project report for August, 1976, dated September 17, 1976.

[A copy of the August Report follows:]

VERY LARGE ARRAY PROJECT



NATIONAL RADIO ASTRONOMY OBSERVATORY
P.O. Box 0, Socorro, New Mexico 87801

OPERATED BY ASSOCIATED UNIVERSITIES, INC.
UNDER CONTRACT WITH THE NATIONAL SCIENCE FOUNDATION

NATIONAL RADIO ASTRONOMY OBSERVATORY

AUGUST PROJECT REPORT

VLA PROJECT

September 17, 1976

NATIONAL RADIO ASTRONOMY OBSERVATORY

MONTHLY PROGRESS REPORT

VLA PROJECT

AUGUST 1976

SITE AND WYE

Subcontract VLA-149; Wye Construction; Burn Construction Company, Inc.; $2,913,000

1. All main line trackage has been constructed on the ballast and all main line trackage on the west arm through BW-9 has been aligned and raised to final grade. Antenna station spur lines have been constructed, aligned and raised to final grade on the west arm through DW-9.

2. All antenna station foundation tie beams and pedestals have been poured except for the pedestals at station AW-8. Backfilling around all foundation tie beams is complete.

3. All electrical work is complete on the east arm except for ground rods and antenna ground connectors. Electrical work is progressing on the north arm and is estimated at 75% complete.

This contract is estimated at 93% complete.

Subcontract VLA-65; George A. Rutherford, Inc.; $2,395,400

1. Additional punch list work has been performed during the month on the control building mechanical systems and controls. Lacking for 100% completion is final test and balance work on the water systems.

This contract is estimated at 99.7% complete.

P.O. 02171; Don's Evergreen's and Landscaping; $16,282.95

1. All trees and shrubs have been planted. All gravel has been delivered and spread over plastic cover at all places, except the small areas north of the control building.

This order is estimated at 99% complete.

Waveguide is completely installed, including manholes from CW-9 to the control building.

Twelve hundred feet of trench from BW-5 has been trenched and eleven hundred feet of waveguide has been coupled, set to line and grade, and partially backfilled.

On August 10, 1976, approximately four inches of rain fell on the VLA Site in about ninety minutes, flooding the central portion of White Lake. Over 200,000 gallons of water topped the dikes surrounding the waveguide trench and flooded it to depths up to seven feet. Fortunately no water entered this section of waveguide.

ANTENNA DIVISION

Antenna No. 5

Outfitting continued on maintenance pad and is complete except for touch-up painting.

Antenna No. 6

Panel setting completed on August 12 with final RMS measured as 0.0106 inches. On August 16 the antenna was moved to the master pad for final alignment and servo tests. Antenna azimuth lean was adjusted on August 19, 1976 to 15 arcsec. On August 27 the servo tests were completed and resonant frequency was measured as 2.4 cycles/second in elevation and 2.35 cycles/second in rotation. Acceptance of the antenna will be September 2 on completion of painting and minor mechanical adjustments.

Antenna No. 7

Pedestal is finished through installation of elevation wheel and counterweight. The reflector structure is complete and ready for installation on the pedestal, except for painting. Anticipated mating date is September 7.

Antenna No. 8

Trial assembly of the reflector base triangle is complete in Hobbs. Trial assembly of the yoke arms and elevation wheel is completed and ready for painting. Reflector structure is on hand at the Site.

Antenna No. 9

Trial assembly of reflector started in Hobbs.

SYSTEMS INTEGRATION DIVISION

Two observing sessions were conducted this month using Antennas 1 and 2.

Run No. 1

2.5h	down - F3 module both antennas
1h	pointing adjustments
1h	phase correction system tests
2.5h	pointing A2
30h	6 cm observations on calibrators
3h	2 cm observations on calibrators

Run No. 2

2h	down - front end A1
3h	delay adjustments
35h	pointing observations A2

The first session was our last operating from the trailer. The second was our first operating from the control building.

Single dish testing started on Antenna No. 4. The subreflector was found out of alignment. After corrective work, efficiency measurements appear normal.

ELECTRONICS DIVISION

The major event in the electronics division this month was the move of equipment and personnel to the newly completed control building. Office equipment and materials were moved in on August 2, and electronics lab equipment on the following day. The last observing run from the electronics trailer was made on August 2-3 and the prototype electronics and computer were moved out of it on August 4. Of the electronics division, only the front end and cryogenics groups remain in the service building, because of its proximity to the antenna maintenance foundation. Cabling in the control building was largely completed in advance of the move. The twelve-antenna delay and multiplier system was in the screened room before the move, but could not be fully tested until the special control rack which interfaces it with the computer became available from the two element system.

Testing of the reassembled equipment occupied most of the month, and at the same time the waveguide group completed the connection from the control building down the west arm as far as CW9. Control of Antenna No. 2 at this foundation was achieved on August 26 and at approximately 1615 MDT on that day the first astronomical record was obtained at the control building, a single-dish scan of 3C273. On August 30 the 40-hour weekly observing runs recommenced and the first fringes were obtained at approximately 1915 MDT on 3C345 at 6 cm wavelength. This was one week ahead of the scheduled first run from the control building.

The prototype of the new 18-21 cm feed was delivered and assembled at the Site by J. J. Gustincic. Pattern tests made on it in California indicate slightly better performance than was obtained with the 3 cm wavelength model. Preparations were made for testing the feed on Antenna No. 2. Single-dish tests on Antenna No. 4 were partially completed after a readjustment of the mounting of the subreflector.

Cooldown tests of front end No. 5 continued and failure of an up-converter required its replacement with the spare unit. Replacement of the copper tubing in the cryogenics compressors with more reliable stainless steel was commenced and almost completed on one unit.

Preparation of the electronics for Antenna No. 3 was almost complete as the month ended. Installation of waveguide on Antenna No. 5 was completed. The delay and multiplier system presently contains cards for up to six antennas and these have been tested for satisfactory operation. Breadboard tests of new versions of modules L2 and L3 of the local oscillator system were commenced. These are the only two modules for which extensive redesign appears desirable.

Design of the spectral processor is continuing with investigation of the possibility of using one or more custom-designed integrated circuits. Design and specification of the IF filters for spectral line observing is also in progress.

COMPUTER DIVISION

Asynchronous Subsystem

During August the data line scanner necessary to expand the number of terminal access lines to the DEC-10 was added to the system, bringing the number of available lines to 16. The RFP for the addition of 128K of core to relieve serious performance problems was prepared and negotiation with DEC for the associated upgrading of the two data channels was begun.

Judy Myers joined the group as program librarian replacing June Thomas who remained in Charlottesville at the time of the move to the Site.

A faster SAIL version of FILRDB to put run data in a data base was completed except for further debugging dependent upon extensive use. Most of the planned experimental system of defined operators to do pre-synthesis processing was completed. This gives interim capabilities to extract data from the run data base, do flagging and editing, solve for baseline errors and correct data for these errrors, solve and correct for time errors, analysis data for point source fluxes and position offsets, shift reference positions, do empirical amplitude and phase calibration, and plot or list data on terminals or line printer. This temporary system will be put into effect the week of September 6.

Significant process was made on the problem of segmenting CANDID to reduce the size of the program that need be resident in core at any one time. Various time conversion operators were completed together with a number of generalized array operators: SUM, AVG, MIN, MAX, AND MINMAX. In collaboration with electronics and operations staff a monitor data base was designed and portions of the program to put data into this data base written. The system was designed so that asynchronous system programs, synchronous system programs, and array operators will use a single master file of information concerning the monitor data points to generate programs or documentation that they need.

Synchronous Subsystem

During August the modcomp computer system was moved to the control building, and operation was restored. The software was revised to handle the 12 element correlator, and a third antenna was logically connected to the system. An initial version of a program which assists observers to prepare his observation list has been added to the program system.

PROJECT MANAGEMENT

In August, 1976 there were a total of $225,000 procurements written. Of this total, there were 190 purchase orders totaling approximately $132,000 and Subcontracts totaling $93,000 written.

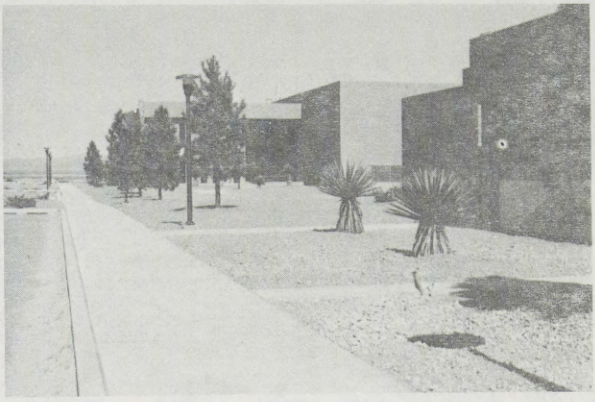
The take up of rail at Crab Orchard has been completed and all usable material received for storage at the Site.

Personnel

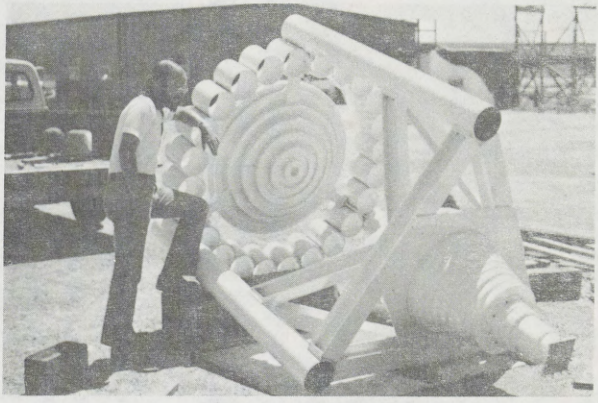
The personnel changes as of August 31, 1976 are as follows:

Division	Previous Level	Additions	Reductions	Current Level
Site and Wye	7	0	0	7
Antenna	9	1	0	10
Electronics	38	1	1	38
Computer	13	1	1	13
Systems Integration	3	0	0	3
Project Management	23	1	0	24*
Total	93	4	2	95

*Includes one part-time person



p8-76-1 Landscaping at Cafeteria and Control Building



p8-76-2 "L" Band Feed Manufactured by J. J. Gustincic

VLA PROJECT
MAJOR SUBCONTRACTS AND PURCHASE ORDERS PLACED

NUMBER P.O. SUBCONTRACT	VENDOR	ITEM DESCRIPTION	DATE PLACED	DOLLAR AMOUNT	DELIVERY DATE	CURRENT STATUS - ALL FIRM FIXED PRICE CONTRACTS EXCEPT WHERE NOTED
VLA-5	BWH/CVR Joint Venture	E/A Title I and II	6/11/73	$ 1,028,269		Title I - Completed Title II - Completed Title III - Work in progress in conjunction with VLA-149. Fixed price plus cost reimbursables.
VLA-6	E-Systems, Inc.	28 Radio Telescopes	10/18/73	$17,549,422	3/1/77	NRAO has taken possession of Antenna Nos. 1, 2, 3, 4, and 5. Antenna 6 will be accepted 9/1/76.
VLA-53	R. F. System	K and Ku Band Feed Horns	1/26/76	$ 109,168	6/7/76 7/19/76 11/15/76	K Band Feeds for Antennas 3 through 5 have been received. Ku Band Feeds for Antennas 3 through 5 have been received. Final Ku Band Feed due for shipment 9/9/76. K and Ku Band Horns for Antennas 7 through 10 due for delivery 11/15/76.
VLA-70 P.O. 52322	Sumitomo Electric USA, Inc.	4373 pieces of waveguide 4480 each coupling sleeves	1/27/75	$ 1,446,634	1/15/77	2313 pieces of waveguide and 2350 coupling sleeves have been received. 1000 pieces of waveguide and 1030 each coupling sleeves have cleared customs and will be coated approx. 9/30/76
VLA-134 P.O. 53578	Air Products and Chemicals, Inc.	Helium Compressors and Cryogenic Refrigerators	8/15/75	$ 139,545	11/1/76	Delivery of units for Antennas 7 through 10 will be completed by 10/30/76. Units retrofitted with ss tubing after fabrication.
VLA-149	Burn Construction Co., Inc.	Site Construction Phase III	9/25/76	$ 2,979,600	10/25/76	Work is Approx. 93% complete.
P.O. 53880	N. M. Tech.	Labor Hour Contract	9/1/75	$ 15,000	8/31/76	Approx. $8,139 spent effective 8/31/76.
VLA-160 P.O. S-00120	Wutzke RR Tie Co.	20,000 Used Cross Ties	10/17/75	$ 109,000	12/31/75	18,435 ties have been delivered for stockpiling.
P.O. S-00271	Timber Mtn. Forrest Products	20,000 Used Cross Ties	10/17/75	$ 115,000	12/31/75	13,530 ties have been delivered for stockpiling.

VLA PROJECT
MAJOR SUBCONTRACTS AND PURCHASE ORDERS PLACED

NUMBER P.O. SUBCONTRACT	VENDOR	ITEM DESCRIPTION	DATE PLACED	DOLLAR AMOUNT	DELIVERY DATE	CURRENT STATUS - ALL FIRM FIXED PRICE CONTRACTS EXCEPT WHERE NOTED
VLA-174	Lawrence Hefner	Provide Labor and Equipment	1/26/76	$ 62,400	2/28/77	Approx. $29,594 spent effective 8/31/76.
P.O. S-00815	Deluna Bluebird Bus Sales of N.M.	Coach	3/25/76	$ 53,626	8/1/76	Coach was delivered 8/10/76.
VLA-177 P.O. S-00985	Fujikura Cable Works Ltd.	Waveguide Coupling Components	3/5/76	$ 134,985	6/11/76 10/1/76	Partial shipments are on schedule.
P.O. S-00986	Hitachi Shibaden Corp. of America	Waveguide Adaptors	3/25/76	$ 47,800	6/30/76 10/1/76	Four have been received. Balance of 36 were shipped from L. A., Calif. on 8/31/76.
P.O. S-01147	Fujikura Cable Works Ltd.	Rotary Joints	3/30/76	$ 7,660	10/30/76	Two received July 12, 1976. Request NSF approval to purchase 8 additional units under option on July 15, 1976.
VLA-179 P.O. S-01046	AIL Div. of Cutler Hammer	Parametric Amplifiers	4/29/76	$ 62,320	10/12/76	Two due 9/2/76 and 6 due 10/12/76.
P.O. S-01134	Digital Equip. Corp.	Eight Line Comm. Group	4/5/76	$ 5,060	8/30/76	Delivered 8/10/76.
VLA-191 P.O. S-01162	Longwill-Scott Inc.	Rail Take Up Crab Orchard, Ill.	4/7/76	$ 118,385	7/31/76	Work was completed 8/27/76.
P.O. S-01749	Computer Products Unlimited Inc.	CRT Terminal	6/25/76	$ 2,965	7/30/76	Terminal was delivered 8/13/76.
P.O. S-01753	Modular Computer Systems, Inc.	CRT Terminals and Interface	6/25/76	$ 4,000	7/30/76	Terminals and interface will be shipped 9/3/76.
P.O. S-01946	Industrial Design Engineering Assoc.	Labor Hour Contract for Temporary Draftsman	7/21/76	$ 9,100	1/26/77	Draftsman is working in drafting section at 2015 Ivy Rd., Charlottesville, Va. $1,047 spent effective 8/31/76.
P.O. S-1984	J.J. Gustincic Consulting Eng.	Consultant Agreement	8/2/76	$ 4,000	12/31/76	Consultant on K. Ku and C Band Horn. $600 spent effective 8/31/76

VLA PROJECT
PROCUREMENT ACTIVITIES INITIATED

RFP NUMBER	ITEM DESCRIPTION	ESTIMATED COST	ISSUE DATE	BID DUE DATE	SUBMISSION TO NSF DATE	AWARD DATE	CURRENT STATUS
VLA-211	VLA Wye Communication System	$260,000	5/6/76	6/22/76	8/30/76	9/1/76	Specifications have been revised. Awaiting final proposal from Mountain Bell.
VLA-220	C Band Feed Horn for Antennas 2 through 10	$ 54,000	7/20/76	8/11/76	8/16/76	8/30/76	Purchase Order S-02245 awarded to J. J. Gustincic for $47,925.00.
VLA-223	Rail Take-up Hill AFB Utah	$ 58,203	8/9/76	9/9/76	9/15/76	9/30/76	Proposals solicited from 10 companies.
VLA-226	Prefabricated Mobil Motel Unit	$ 30,000	8/13/76	8/30/76	9/15/76	9/30/76	Proposals solicited from 19 companies.
VLA-227	Motor Vehicle for operation on RR Track and Ground	$ 12,000	8/25/76	9/28/76	8/26/76	10/15/76	Proposals solicited from 13 companies.

CY - 1976

VERY LARGE ARRAY

Status as of August 31, 1976

Project Number	Description	Allocation	Monthly	Expended	Committed	Total	Balance	Outstanding Obligations Pending	Net Balance
11000	Site and Wye	4,807,000	368,586	3,499,023	1,070,731	4,569,754	237,246	40,994	196,252
12000	Antenna System	7,794,000	37,864	1,907,369	5,702,328	7,609,697	184,303	48,252	136,051
13000	Electronic System	2,876,000	194,984	1,396,373	521,186	1,917,559	958,441	230,402	728,039
14000	Computer System	720,000	45,640	378,480	154,546	533,026	186,974	67,791	119,183
16000	Systems Integration	112,000	11,718	47,201	6,329	53,530	58,470	17,262	41,208
17000	Project Management	672,000	114,676	416,938	22,903	439,841	232,159	86,965	145,194
	Contingency	105,000	---	---	---	---	105,000	---	105,000
	Total VLA	17,086,000	773,468	7,645,384	7,478,023	15,123,407	1,962,593	491,666	1,470,927

TOTAL PROJECT

VERY LARGE ARRAY

Status as of August 31, 1976

Project Number	Description	Allocation	Monthly	Expended	Committed	Total	Balance	Outstanding Obligations Pending	Net Balance
11000	Site and Wye	11,572,406	706,902	10,179,982	1,159,268	11,339,250	233,156	40,994	192,162
12000	Antenna System	13,303,344	37,864	7,414,990	5,702,965	13,117,955	185,389	48,252	137,137
13000	Electronic System	7,464,934	208,684	5,976,440	522,621	6,499,061	965,873	230,402	735,471
14000	Computer System	2,528,589	45,640	2,108,538	179,940	2,288,478	240,111	67,791	172,320
16000	Systems Integration	158,000	11,718	93,752	6,337	100,089	57,911	17,262	40,649
17000	Project Management	1,568,961	114,676	1,309,970	23,404	1,333,374	235,587	86,965	148,622
	Contingency	105,066	---	---	---	---	105,066	---	105,066
	Total VLA	36,701,300(1)	1,125,484	27,083,672	7,594,535	34,678,207	2,023,093	491,666	1,531,427

(1) Total Project Allocation does not include $283,000 withheld by NSF for Army Corp. of Engrs. and $15,700 for ECAC study.

NATIONAL RADIO ASTRONOMY OBSERVATORY

VLA--FINANCIAL STATUS REPORT
(in thousands)

As of: August 31, 1976

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
		Allocation to Date				Outlook			
Item	Project Ceiling	Allocated	Expended and Committed	Allocated Balance	Unallocated Balance	Est. to Complete	Est. Total	(Over) Under Ceiling	Notes
Site and Wye	27,860	11,572	11,339	233	16,288	16,384	27,723	137	
Antennas	20,400	13,303	13,118	185	7,097	8,096	21,214	(814)	
Electronics	17,000	7,465	6,500	965	9,535	10,658	17,158	(158)	
Computer	4,850	2,529	2,289	240	2,321	3,056	5,345	(495)	
Systems Integration	400	158	100	58	242	184	284	116	
Project Management	2,650	1,569	1,333	236	1,081	1,544	2,877	(227)	
Subtotal	73,160	36,596	34,679	1,917	36,564	39,922	74,601	(1,441)	
Contingency	2,840	105	---	105	2,735	3,522	3,522	(682)	
Total	76,000	36,701	34,679	2,022	39,299	43,444	78,123	(2,123)	

Notes: (1) Basic estimate is that of August, 1975.

(2) Escalation included for future years at 6% for site and wye work; National Radio Astronomy Observatory labor, and minor antenna equipment items. Antenna estimate is based on the existing contract costs for fabrication of the antennas. No future escalation has been included for electronics or computer purchased equipment.

(3) Estimate excludes the following deferred items: Transporters #2 and #3, $615 K; Air Strip, $268 K.

Explanation to Accompanying Statement

Column (2) - Project Ceiling: Original estimates

Column (3) - Allocated: Funded by NSF and included in total funds provided in Contract C-780.

Column (4) - Expended and Committed: Actual cash paid out and orders written and accepted by vendors.

Column (5) - Allocated Balance: Column 3 less Column 4. (Current funds available for expenditure and commitment.)

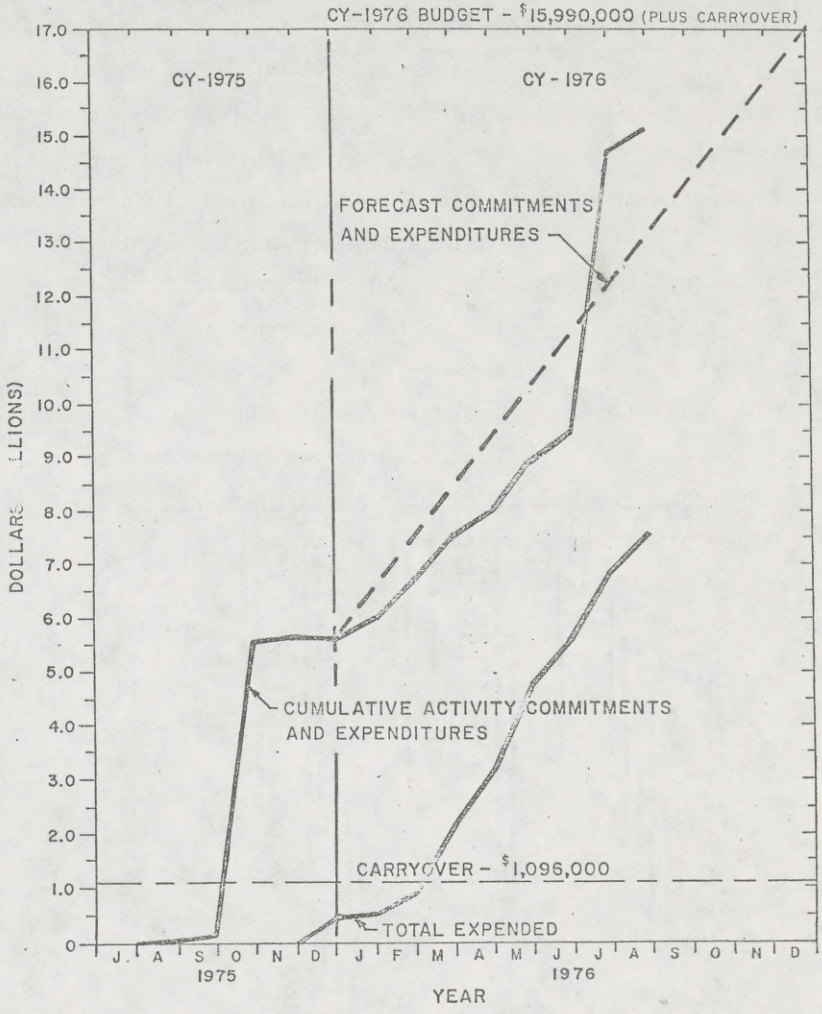
Column (6) - Unallocated Balance: Column 2 less Column 3. (Funds due from NSF to fund the total project as originally estimated.)

Column (7) - Estimate to Complete: Original estimate updated to take into account current or known costs.

Column (8) - Estimated Total: Column 4 plus Column 7.

Column (9) - (Over) Under: Column 2 less Column 8.

VLA-NRAO
PROJECT REPORT
EXPENDITURES AND COMMITMENTS
CY-1976 CUMULATIVE ACTIVITY

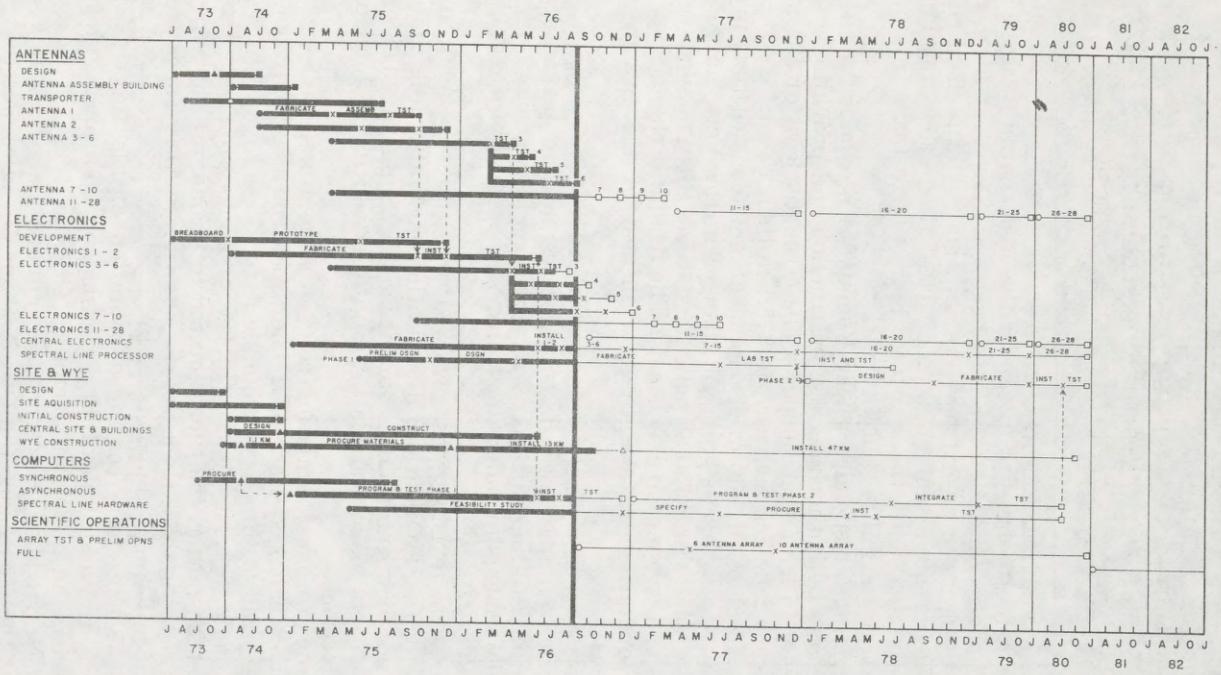


NATIONAL RADIO ASTRONOMY OBSERVATORY

VLA ACTIVITY SCHEDULE

11/15/75

UPDATE DATE: 9/1/76



ABBREVIATIONS

ASSEMBLE - ASSEMB	CH-VILLE - CV	INSTALL - INST	PRELIMINARY - PRELIM
COMPLETE - CMPL	DESIGN - DSGN	INTEGRATE - INTG	SELECT - SLCT
CONTRACT - CNTR	DETAIL - DTL	OPERATIONS - OPNS	TEST - TST

SYMBOLS

O START OF A PHASE
X END OF AN ACTIVITY
△ CONTRACT AWARD
□ END OF A PHASE

REV. NO	REV. DATE	REVISION
1	12/4/75	WYE CMPL 10/80

Dr. HUGHES. At this point, I would like to review briefly some of the history of the project. The need for an instrument such as the Very Large Array for astronomy research emerged from extensive discussion and study by the research community in the 1960's. From documents presented in earlier hearings, the committee is aware that the Very Large Array concept began developing at the NRAO in 1961.

In the years that followed, NRAO developed and submitted to the NSF a four-volume proposal for the Very Large Array totaling some 837 pages of highly technical description. The Very Large Array proposal was given an extensive review, both within the NSF and within the research community. As part of this review, the Foundation contracted with the Sanford Research Institute for a Very Large Array feasibility study.

The Congress responded to the Foundation's request for the Very Large Array by authorizing its construction and providing funds in fiscal year 1973 for that purpose. The estimated cost of $76 million at that time now has increased to $78.1 million.

As is true in all major development and construction projects, there have been some significant changes in the Very Large Array from the early proposal. There have been three major technical changes and two major deferments. The technical changes are:

Four operating wavelengths now instead of the two originally proposed;

Seventy-two observing stations instead of 100;

A buried circular waveguide system connecting the antennas to the control building instead of a coaxial cable system.

The deferments include: One transporter instead of three; elimination of the airstrip.

Each such revision was reviewed in detail by AUI and approved by the Foundation. Justification generally falls into three categories: new engineering and design developments, performance improvements made feasible by rapidly advancing technology, and cost reductions.

In order to offset escalating costs in some areas, AUI has had to make some balanced trade-offs. The procurement of only one transporter instead of three is an example.

Although there is no risk to the antennas from the lack of a backup transporter, the time required to reconfigure the array is increased. During the early use of the Very Large Array, operations will not be significantly hindered by this.

For the long term continued operation of the full array of 27 antennas, the added flexibility afforded by additional transporters may become an important factor.

Another trade-off concerned the elimination of a proposed airstrip at the site. Since the site is about 50 miles west of Socorro, N. Mex., and about 90 miles southwest of Albuquerque, an airstrip would be desirable for efficient transportation and for emergencies.

Before discussing future plans for the Very Large Array, it might be well to look at the present situation for such telescopes over the world. As far as we know, nothing to equal the completed Very Large Array is planned anywhere.

At the present time, the most powerful aperture synthesis radio telescope, which is the proper name of the telescope family to which the Very Large Array belongs, is at Westerbork in the northeastern Netherlands. The Westerbork array consists of 12 antennas, each 82 feet in diameter, arranged in a line 1 mile long. This telescope has carried out important studies of compact radio nuclei of galaxies and discovered radio galaxies that rank as the largest known objects in the universe.

The Very Large Array is expected to become the superior instrument early in calendar year 1978.

Because of the exciting research potential of the Very Large Array, it is desirable to bring the completed components into operation as soon as possible. For this reason, each antenna and segment of wye is being integrated into the system as soon as it is completed.

This requires an operations budget that will grow from an estimated $700,000 in fiscal year 1977 to an estimated $5 million in fiscal year 1981, the year of completion. This latter figure will provide the scientific research support required to operate the Very Large Array 24 hours a day.

A staff of 100 scientists, engineers, technicians, and other personnel will eventually be required.

The Very Large Array is a large and costly facility. We believe that our national facilities stimulate new scientific lines of thought and provide unique capabilities to extend the frontiers of science. Moreover, they are fully integrated into the scientific community. More than 60 percent of the observing time on all the instruments at the National Astronomy Observatories is utilized by visiting scientists who compete for the opportunity solely on the merits of their proposed research.

Scientists from institutions of every kind, large and small, affiliated, are equally accommodated. Most come from universities, often with departments of astronomy too small to afford the sophisticated observing facilities required for advanced research.

The Very Large Array is a major resource for the world astronomical research community. The scientific and technical advances that it will surely stimulate will raise new questions and new challenges for the 1980's and even beyond.

In order to insure that the Very Large Array will be able to contribute and respond to new research opportunities in the future, part of the design philosophy has been to provide for incorporation of anticipated technical developments.

For example, new optical transform analog computer systems are being developed for use in large-scale data transfer and processing, and I suspect that they will be ideal for the Very Large Array.

Many such improvements to the Very Large Array will undoubtedly be required in the future in order to fully exploit its capabilities.

In conclusion, Mr. Chairman, I believe the Very Large Array will be a magnificent achievement, magnificent not only because of the new discoveries that it will yield, but also as a symbol, a dramatic symbol of man's determination to reach out to see this awesome universe in which we live in all its many colors.

Thank you.

Chairman SYMINGTON. Thank you, Dr. Hughes, very much for your statement.

Before we proceed to questions, I think we'll ask Dr. Heeschen to supplement your testimony with his own, and then we'll have something to address ourselves to.

Dr. Heeschen?

[A brief biography of Dr. Heeschen follows:]

DR. DAVID E. HEESCHEN

Born: March 17, 1926; Davenport, Iowa.

Education: B.S., University of Illinois, 1949; Ph.D. (astronomy), Harvard University, 1937; and Sc.D. (hon) West Virginia Institute of Technology, 1974.

Position: G. R. Agassiz Fellow, Harvard University, 1953–54; Instructor, Wesleyan University, 1954–55; Lecturer and Research Associate, Harvard University, 1955–56; Astronomer, National Radio Astronomy Observatory, 1956; Director, 1962.

Membership: Fellow, American Academy of Arts & Sciences; Member, American Philosophical Society; National Academy of Sciences; American Astronomical Society (vice president, 1969–71); American Association for the Advancement of Science; International Astronomical Union (vice president, 1976–82); International Scientific Radio Union; Sigma XI.

Family: Wife, Eloise; children, Lisa, David and Richard.

STATEMENT OF DR. DAVID S. HEESCHEN, DIRECTOR, NATIONAL RADIO ASTRONOMY OBSERVATORY

Dr. HEESCHEN. Mr. Chairman, members of the committee: I am happy to be here today and to have this opportunity to discuss the Very Large Array with you.

I believe you are generally familiar with the instrument and its status, and Dr. Hughes has given a good description of it, as well.

Included with the supplementary material submitted for the record of this hearing are a number of photographs of the site and the most recent project plan. This latter document contains, in its first few pages, a summary description of the instrument.

[A complete description of the Very Large Array follows:]

DESCRIPTION OF THE INSTRUMENT

Higher resolution and sensitivity have always been major goals of radio astronomy instrumental development. The general concept of a very large antenna system that could obtain radio pictures with very high resolution, sensitivity, and speed was developed in the early sixties. The initial studies at NRAO in 1961 and 1962 led to the detailed design beginning in 1964. The

design study was carried out by the NRAO staff, with the assistance of a number of radio astronomers from other institutions, and it resulted in the *Proposal for the Very Large Array (VLA)*, published in 1967 (Vols. I and II), 1969 (Vol. III), and 1971 (Vol. IV).

In order to achieve the required angular resolutions, a radio telescope with dimensions of 35 km (23 miles) is needed. Since a conventional radio telescope having these dimensions is impossible to construct, other techniques which will simulate such a telescope must be used. By interconnecting several separated, smaller diameter antennas, the information leading to the desired resolution can be obtained. Many configurations of the antenna elements are possible, and careful studies of this problem, with the purpose of optimizing the use of a relatively small number of antennas, have resulted in the VLA system, consisting of 27 antennas, each 25 m (82 feet) in diameter, distributed along three 21 km (13 mile) arms of an equiangular wye. All the antennas will be movable over railroad tracks so that the picture area (field of view) and the resolution may be varied within wide limits. In this respect, the VLA is the equivalent of a zoom lens.

Each antenna element consists of a steel structure carrying a shaped reflector which is movable in azimuth and elevation in order to be able to point to any part of the sky. The reflector structure supports an aluminum reflector surface consisting of 172 aluminum panels. The surface accuracy and the precision of the drive system permit operation at wavelengths as short as 1.2 cm. During operation, the antennas are placed on observing stations. Seventy-two such stations will permit the four basic different configurations planned for the array. The antennas will be moved between observing stations by a transport vehicle; one such transporter will be available in the early years of the Project, running on a double, standard gauge railroad track system. In later years, should funding permit, two additional transporters will be procured. A reconfiguration of the antenna system, using three transporters, is estimated to take twenty-four hours. When the railroad tracks are not used for moving antennas, they will be used for transportation of maintenance personnel and equipment.

The initial operating wavelengths for the system will be 21 cm, 6 cm, 2 cm, and 1.2 cm, with full polarization measurement capabilities. Spectral-line capabilities for the array are also being developed.

The central computer system will control the telescopes, monitor the system performance, and collect and analyze the data. The system output will consist of high resolution maps of the observed objects.

Power and telephone communications between the central site complex and the observing stations will be distributed through buried cables. Signal and local oscillator distribution, as well as control and monitor signals of all antenna functions, will be accomplished by a buried circular waveguide system.

The central building complex will consist of several buildings. A 22,060 square foot Control Building will house the control room, central electronic equipment, digital delay equipment, large central computers, specialized shops, laboratories, and office space. Three small, prefabricated metal buildings, which total 15,000 square feet, will house maintenance shops, the electronic and cryogenic shops, storage facilities, and office space. The subcontractor, who will fabricate and assemble the antennas, has constructed a 14,600 square foot Assembly Building, which he will use during his contract and which will be available for later use for antenna maintenance. In addition, a 5,320 square foot Cafeteria Building and a grouping of Visiting Scientists' Quarters will be constructed, as will necessary site work, water supply, sewage, electric utility, and similar facilities.

[Five photographs with captions follow:]

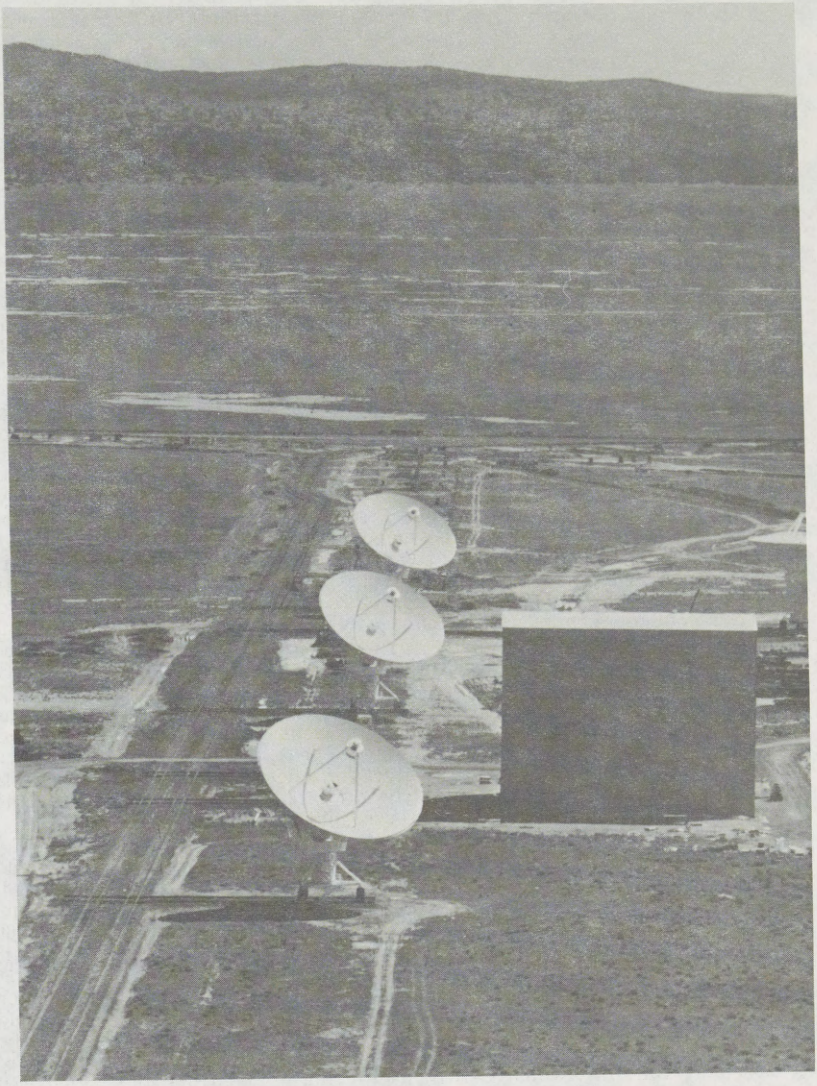


FIGURE 1.—The VLA site, looking along the southwest arm towards the array center. The antenna assembly building is in the foreground. The construction of the track near the center and along the north and southeast arms is in progress.

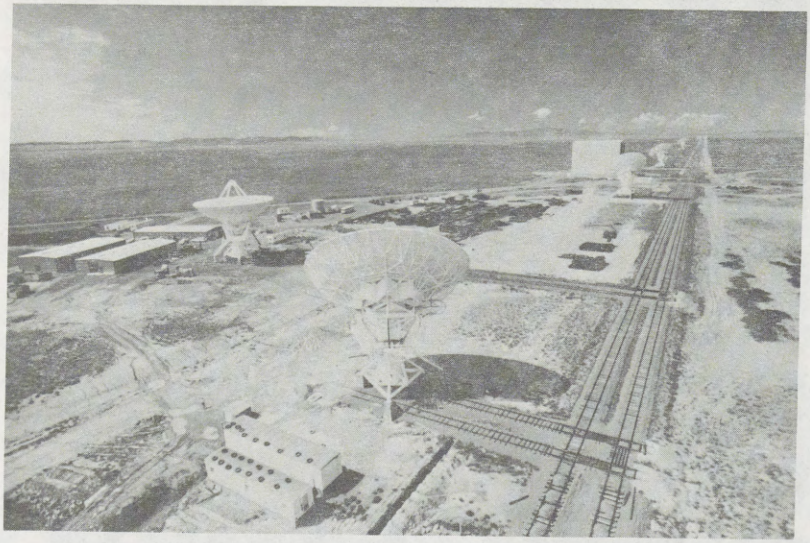


FIGURE 2.—The southwest arms of the VLA, looking from the array center. The temporary electronics and control building is in the foreground, and the stockpile of rails and ties is at the center of the picture. The track extends a distance of 10 kilometers along the southwest arm.

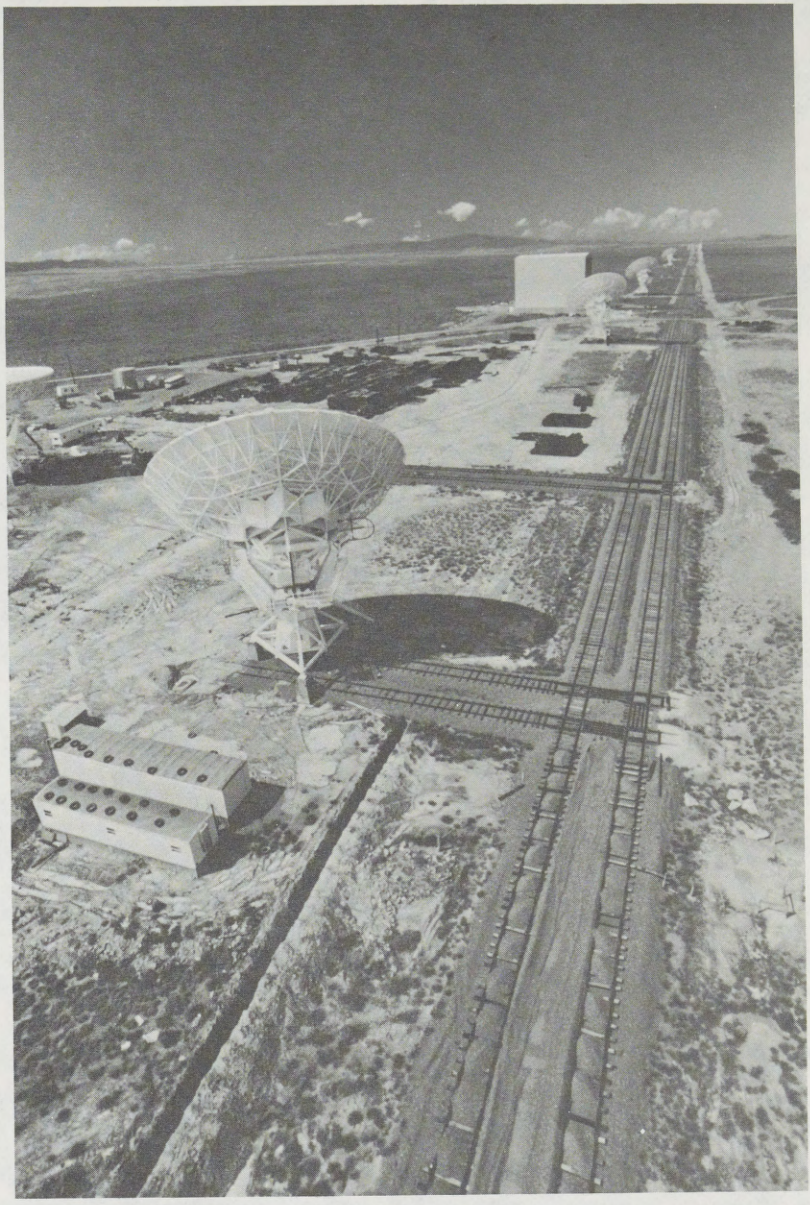


FIGURE 3.—The VLA site, looking from the array center along the southwest arm. The open trench in the foreground is for the waveguide. The electronics array control computer have now been moved from the temporary buildings (foreground, left) to the central control building.

FIGURE 4.—The VLA site, looking along the southwest arm. The antenna assembly building and the rail stockpile are at the center of the picture. The three buildings at the lower left provide space for electronics, the machine shop, and warehouse.

FIGURE 5.—The VLA site, looking towards the array center. The sixth antenna is under construction in the antenna assembly building.

This morning I want to address five specific topics. Most of these are under more or less continuous review, and I think all of them are particularly interesting right now, when we are about halfway through the construction project, in terms of both time and money.

The first topic or question is: Has the need for the Very Large Array been diminished by scientific development or by the construction of other new telescopes? This, of course, can be a real possibility in the case of a long-term project. But in the case of the Very Large Array the answer is definitely no.

The Very Large Array was conceived in response to the need of radio astronomers for an instrument that could produce radio pictures of detail similar to that of a high-quality optical photograph; pictures covering a small area of sky with a resolution of about one-half second of arc. That need is at least as great today as it was 10 or 15 years ago. Although the Very Large Array will be so flexible and powerful that it will be the dominant instrument for research in many areas of radio astronomy, its design parameters were chosen with particular attention to three general areas—extragalactic radio sources, cosmology, and the evolution of stars. I'd like to say a few more words about each of these areas.

The radio emission which we observe from distant objects—galaxies and quasars—apparently arises from explosions in the nuclei of these objects. The energy released in these events is much greater than we see anywhere else in the universe—much greater than that of a star such as our Sun, for example. Understanding these tremendously energetic phenomena remains one of the major challenges in the physical sciences.

Another consequence of the great energy of these extragalactic sources is that they can be observed, with radiotelescopes, at very large distances and are therefore potentially useful for studying the overall nature of the universe. Because the Very Large Array will be able to detect sources more than 10 times fainter than can any other radiotelescope, it should be uniquely important for such cosmological studies.

The third area is the study of the evolution of stars. Since gaseous material is an efficient emitter of radio waves, radio astronomy has been particularly valuable in studying those stages in the life of a star when it is interacting with gas. With the increased sensitivity and the resolution of the Very Large Array, much progress should be made in studies of the formation of stars from gas clouds and of the loss of material from stars in the final stages of their evolution.

Some progress is of course being made now in all of these areas, but they are very difficult and fundamental problems and all are badly in need of the high resolution, high sensitivity observations that only the Very Large Array will be able to produce. No other existing or presently-planned instrument anywhere in the world comes within a factor of 10 or the power of the Very Large Array. I think it is worth emphasizing that the Very Large Array is truly unique; that it should have tremendous impact on fundamental scientific problems; and that it is not likely to be preempted in the readily foreseeable future.

The second topic, or question, is: Will the telescope work as expected? Six antennas have now been completed, along with one transporter. Electronics have been installed on four antennas. Some electronics and two computers are also operating in the central control building. About 9 miles of track are complete or nearing completion. All of these units have now been thoroughly tested, singly and in some cases working together as a system.

Two antennas and their electronics and the control computer have been operating as an interferometer since last February, and a third antenna has just been added. Earlier this week I participated in a 40-hour-long observing session using these three antennas during which the performance of the electronics, the control computer, and the data analysis computer were further tested. As a result of all this testing, we believe that the array will certainly work at least as well as expected—it will meet the design goals.

We have, of course, found many problems. Most of these have been or are being corrected, and solutions for the others are in hand. There are no known problems that can endanger the fundamental performance of the array.

There are still a few uncertainties. For example, the performance of the array at its shortest wavelengths depends critically on the nature of the atmosphere. We know from earlier measurements and studies that the atmosphere will allow good operation a large fraction of the time—at least two-thirds of the time—but we don't know yet the details beyond that. Nor do we yet fully understand the best way to handle certain computer-related problems, such as the analysis of spectroscopic data, and data archiving and retrieval. These kinds of problems relate more to the way in which the array will be used than to its basic performance.

Construction and testing are now sufficiently far along that it is extremely unlikely that any major technical problem will develop that could adversely affect the basic performance of the array.

Several items of the original plan were, as you know, deleted or modified in response to large price increases that occurred early in the project. None of these directly affect the basic performance of the array. They may, however, affect the efficiency with which it is used, as Dr. Hughes has described.

A third topic is, how good is the cost estimate?

The original most estimate was $76 million; our present estimate, with about $37 million now allocated, is that the total cost will be about $78 million.

Tracing the history of our cost projections is somewhat complex, because some plans have been changed and some items have been deferred or deleted, but it seems clear that the $2 million increase is due to the fact that inflation has been considerably greater than was anticipated in the original $76 million estimate.

The present estimate of $78 million is based on our actual, most recent procurement experience in each area; and since we have now procured some of everything, we think that these are pretty hard estimates. Inflation is still the biggest uncertainty. Other, smaller uncertainties are in the interface areas between construction and operation—final tests and debugging, development of maintenance pro-

cedures, and the like. In these areas we haven't yet had much experience, and we may not have correctly estimated the manpower required. Finally, we would, of course, like to restore some of the deleted items if that becomes financially feasible.

Now the fourth topic, the program for the remaining 4 years of the construction project.

Construction of the Very Large Array is proceeding on schedule. Major procurements of antennas, electronics, and track will continue through fiscal year 1979, and construction of the array will be completed in late 1980 or early 1981. All of this construction, since it is repeating what has already been done, is expected to be straightforward and routine. In fact, we anticipate that one of our bigger problems may be boredom on the part of some of our technical people by the time they are building or installing the 27th identical unit.

But we are also about to enter into a new and exciting phase of the project. Late this year or early next, we will start a limited schedule of scientific observations; first with 3 antennas, then with 6 in the spring, and hopefully with 10 by the end of 1977.

This is important for several reasons:

First: Scientific observing by our staff and by visiting scientists is by far the most severe test the system can be given and is therefore the best way to accomplish the final shakedown and debugging.

Second: We need to start learning to use the array—how to calibrate it, what the maintenance and reliability problems may be, how does the atmosphere affect operation, and so on.

Finally: Of course, the scientific contribution that can be made with even three or six antennas is important. By the time 10 antennas are available for observing, the system will be at least the equal of any other instrument in the world. We are already getting many inquiries from scientists who want to use a subsystem of the final array just as soon as it can be made available to them.

Trying to operate one set of antennas and associated equipment while another set is still under construction may cause some complications, and the needs of the construction job must have first priority. However, I do think it is important to get some limited scientific observing started as early as is feasible, for the reasons just mentioned.

The final topic I want to take up is that of longer range requirements for the Very Large Array after construction is over and it has been in operation for a time.

The Very Large Array is certainly going to produce exciting new observational results in many areas of astronomy, which can be expected to generate a great deal of interest and activity, and attract more scientists to these areas. This will, I will think, create further need for more support of astronomy in the universities.

There are also several areas in which I foresee a more or less continuous demand by radio astronomers for expansion of the Very Large Array. One is in the area of computer hardware and software. Some of our colleagues have already found ways to make the Very Large Array even more powerful and useful than it is presently de-

signed to be. These require more computing and more software capacity than we are now able to provide. In addition, the need for more powerful analysis capability is never ending, and in the case of the Very Large Array we are able to provide really only minimal capability now.

Another rather obvious way to later improve the very large array is to add additional wavelength bands. Four wavelength bands will be available with the Very Large Array as it is now being built. Observations over a wider range of wavelengths would be important to many areas of research. Scientists are already proposing that at least one longer wavelength be added.

We do not recommend making these additions now. The Very Large Array as presently designed should be completed, and prove its worth, before additions are proposed. However, I do think it is normal and healthy that these possibilities exist, especially for an instrument with as much potential as the Very Large Array.

I hope that the Very Large Array operating budget will always contain reasonable sums for upgrading the Very Large Array equipment and making small improvements or additions.

Larger modifications or additions will undoubtedly be requested, as the scientific needs and technological opportunities develop. These will have to be considered on their own merits and in the light of the then-existing scientific and general priorities, and the budget situation.

However, I would like to reiterate that the Very Large Array as it is now being built is a superb scientific instrument. It is going to have tremendous impact on our science. It is unique in the world and will remain so for a long time.

Thank you.

Mr. MOSHER. Tom?

Mr. DOWNING. No questions.

Mr. MOSHER. You're the chairman.

Mr. DOWNING. All right.

Thank you very much. I'm sorry I was a little late. I have some specific questions for later witnesses.

Mr. Mosher?

Mr. MOSHER. Well, I hesitate to ask questions because I know so little about radio astronomy. But, in general terms, I judge from what you said, particularly toward the conclusion of your most recent remarks, where you were talking about the inevitability of the demand for expansion of the capabilities of this instrument, I judge that it has been wisely designed to allow flexibility for such expansion. There must be tremendous possibilities for future expansion of the facility after you begin to use it, and have tested it, and so forth. That's implied in the design: is that true?

Dr. HEESCHEN. Yes, sir, that is true. We have tried to not close the door on any more future possibilities than we absolutely have to, and on the whole there are many opportunities for increasing its potential in future years.

Mr. MOSHER. But, of course, no one can foresee what the costs will be for that, and they're not part of any present proposed budget, or anything like that. It's just assumed that that will be up for future decision by NSF and by the Congress.

Dr. HEESCHEN. Yes.

Mr. MOSHER. Now, both of the witnesses have referred to the fact that expenditures are keeping fairly well within cost estimates.

But do I judge correctly that you have been able to do that only by cutting back on the original plans? You are within cost estimates only because you've deleted some of what you expected to do at the start?

Dr. HUGHES. Mr. Mosher, I don't believe that any essential features of the original design have been impaired by any of the changes that have been made. And, indeed, in some areas improvements have been made.

The trade-offs in some cases were made on the basis of cost reduction. For example, the decision to have only one transporter rather than three.

In other cases, they were made because of new technological developments, as for example the development of new helical-wound cylindrical waveguides that replaced the originally-designed coaxial cable system.

And in other cases, in response to what might be termed value engineering. The original design contemplated 100 stations on which the 27 antennae would be deployed. Subsequent analysis, in fact rather detailed computer analysis, demonstrated that the number could be reduced to 72 without seriously interfering with the quality of the array. That represented a saving of about 30 stations.

Another area, for example, involved the acquisition of railroad track. It turned out happily that, by working very, very hard at it, the Very Large Array management was able to acquire used railroad track for 72 miles of the double railroad system from Government excess sources.

Now, it is true that in the original proposal and the original funding, new track was contemplated. And, of course, the savings there were immense, I think on the order of magnitude of well over $1 million.

Mr. DOWNING. Excuse me for interrupting, but there is a quorum call on the Floor of the House, and the committee will have to recess for approximately 10 minutes.

Mr. MOSHER. Jim will be back, and he can continue as soon as he gets back.

Mr. DOWNING. I appreciate the patience on the part of the witnesses during these closing days of Congress. Things get hectic around here, but we're trying to do so many jobs at the same time. I'm sure the witnesses understand.

The committee will recess for 10 minutes.

[Recess.]

Chairman SYMINGTON. We will resume our hearing at this time. I wanted to get into some questions of cost estimates, and how they're proceeding.

When was the last cost estimate prepared for the project? In other words, the last detailed one?

Dr. HUGHES. As I indicated, Mr. Chairman, each year the VLA management produces a Project Operating Plan and also a 5 year plan that develops detailed cost estimates for the completion of the project.

In addition, last year, with stimulation from this committee, the Very Large Array management and NSF undertook to develop several alternate cost estimates for completion that included completion in one year shorter time, and also in 2 years shorter time.

I believe the Very Large Array management is now in the process of developing another cost estimate for the completion of the project.

Dr. Heeschen?

Dr. HEESCHEN. Yes. We do a detailed item-by-item cost estimate each year at about this time, beginning in August, in preparation for our submittal to the NSF.

In addition, throughout the course of the year, we update that estimate based on our procurement experience during the year. So that last year about this time was when we produced our most recent detailed cost estimate, and we're in the process of updating that now.

Chairman SYMINGTON. Your costs appear to rise about 9½ percent a year. What portion of that would you assign to inflation?

Dr. HUGHES. Some elements of the program have suffered heavily because of inflation. During the first 2 years of construction, the price of steel went up approximately 50 percent.

As I indicated earlier, it has been necessary for the program management to establish a number of trade-offs and system design changes in order to accommodate the increasing costs.

I think it's difficult to assess precisely the fraction that's due to inflation because of the continuously-changing character of the program.

But I would emphasize again, as I indicated earlier, that none of the operating characteristics of the system have been adversely affected by these trade-offs.

I would say, Mr. Chairman, that on the average the percent of increase due to inflation would be essentially the same as for any major construction project.

Chairman SYMINGTON. You made the eliminations which you've detailed to cut costs.

Had you not made them, what increment of cost would you have encountered?

Dr. HUGHES. Mr. Chairman, I think that we could provide for the record a detailed analysis of the savings associated with each of the decisions which were made, if that would be helpful.

Chairman SYMINGTON. Would you do that? Yes, I'd appreciate that.

Dr. HUGHES. Yes.

[The material referred to follows:]

VERY LARGE ARRAY (VLA)

DETAILED ANALYSIS OF THE SAVINGS ASSOCIATED WITH EACH OF THE MAJOR TECHNICAL CHANGES AND DEFERMENTS MADE TO REDUCE THE COSTS OF THE VLA

Major technical changes

1. *Reduction in Antenna Stations from 100 to 72.*—During detailed design it was determined that, by using a geometric spacing of antenna stations, various stations in each of the four configurations became common and resulted in decreasing the total number of antenna stations from 100 to 72 at no loss in the efficiency of the instrument. This resulted in a cost reduction of $1,204,000.

2. *Reduction in Maintenance Building.*—Original plan was for a permanent maintenance building constructed of masonry block, precast concrete wall panels and precast concrete roof. Size was 15,510 SF, including some laboratory and office space. This building was bid-in during 1974 at $593,000, less $85,000 for emergency electricity generators, or $508,000 building cost. To save funds, two 6,000 SF prefabricated metal buildings were constructed at a cost of $149,500. The existing 6,000 SF Service Building will continue to be used for laboratory, machine shop, and office space. The cost reduction was $358,500.

3. *Reduction in Visiting Scientist Quarters.*—Original plan was for two permanent masonry structures, each containing five motel-type rooms; bid cost in 1974 was $207,000. Present plan is to obtain two four-room motel type, prefabricated, wood stud units at a total estimated cost of $70,000. One of these units is now under contract, and the second will be procured later in the program. The cost reduction was $137,000.

The total savings associated with the changes is $1,699,500, arrived at as follows:

Reduction in antenna stations	$1,204,000
Reduction in maintenance building	358,500
Reduction in visiting scientist quarters	137,000
Total	1,699,500

Deferments

The VLA Project Plan for Calendar Year 1976 includes the following deferred items:

	Estimated cost
Transporters 2 and 3	$615,000
Construction of airstrip	268,000
Total	883,000

The second transporter and airstrip deferrals are not viewed as savings at this time because both of these items are desired for the VLA. If possible, they will be funded from contingency elements in the project budget. This will require a final determination in about a year that the funds are not required for higher priority usage.

The third transporter will remain in the deferred category until it is determined to be essential to the efficient operation of the array.

Chairman SYMINGTON. There's an astronomy book by—or perhaps it's a paper—by Anthony Lawton, "Red Giant Opens Its Eyes," published in *Space Flight* this summer. It describes details of the construction commission performance program of a very large Soviet radiotelescope, RATAN–600.

Are you familiar with that?

Dr. HEESCHEN. I know about it, sir, yes.

Chairman SYMINGTON. Do you also speculate that the capability that the Soviet Union claims, a new phase of deep space work, et cetera, et cetera—does this have any implications for our program one way or the other?

Dr. HEESCHEN. We don't think it does, sir. That telescope is very different, and it just doesn't approach the Very Large Array in any way.

Chairman SYMINGTON. All right. I didn't think so, but the note was handed me by a scientist on the staff.

Now, this airstrip, this was eliminated, right?

Dr. HUGHES. Yes, sir.

Chairman SYMINGTON. But you want one eventually? Is that the idea or not?

Dr. HEESCHEN. It would be extremely useful to have one, yes.

Chairman SYMINGTON. Would it be useful to have one now, or when?

Dr. HEESCHEN. It would be useful to have one now. It would be most—or more—useful to have one when the array is operating. At least my idea about the airstrip, that its greatest usefulness, is to bring visitors in, visiting scientists in, from universities who are on tight schedules, and it's a convenience for them more than anything else.

Chairman SYMINGTON. Of course it's 90 miles from Albuquerque, so a helicopter is a convenience there, isn't it?

Dr. HEESCHEN. Yes.

Chairman SYMINGTON. Were you thinking of having them fly from the east coast and land?

Dr. HEESCHEN. No. Oh, no. This would be to get them from Albuquerque to the site. And I think the reason for an airstrip as opposed to a helicopter is that helicopters are so much more expensive to charter than are airplanes.

Chairman SYMINGTON. Wait 'til the wind is right and get a balloon.

Counsel advises that we should maintain a distinction between emergency situations and conveniences, and that helicopter services could be available, perhaps for emergencies at least, and the people could drive or bus or whatever to the site from other States or wherever.

Dr. HEESCHEN. There is helicopter ambulance service available in Albuquerque that we could use in the event of an emergency that would require it. It isn't clear what is the quickest way to ge somebody out—that is calling Albuquerque for a plane or helicopter, or driving him to Soccoro, where there are hospital services. Soccoro is 40 miles away.

Chairman SYMINGTON. What was the airstrip's estimated cost?

Dr. HUGHES. I believe it was $268,000.

Chairman SYMINGTON. OK.

There are some detailed questions here, which we may want to submit for the record, I think.

There seems to be a question of taxes to New Mexico. Is that a problem for the administration?

Mr. HUGHES. It is a matter, Mr. Chairman, that the NSF General Counsel and the AUI Counsel are discussing with the New Mexico State Government, and with the Department of Justice. I think it would be inappropriate for me to comment on it in detail.

Chairman SYMINGTON. When will the project be fully operational with all its antennas, as far as you know?

Dr. HEESCHEN. In late 1980 or early 1981.

CHAIRMAN SYMINGTON. Yes. But you expect it to be at maximum operational capacity by 19——

Dr. HEESCHEN. By the end of 1980, approximately, it will be in full operation; partial operation very soon.

Mr. MOSHER. Could I interject there?

Chairman SYMINGTON. Yes.

Mr. MOSHER. I don't like that word "maximum" or "full." I got the impression that with the flexibility built into this design its use

could hopefully increase and it could grow over the years. Is that right?

Dr. HEESCHEN. Yes, sir. I wouldn't use the word "maximum" either. By "full operation" I simply mean that the 27 antennas and all of their equipment will be there operating, the originally proposed instrument.

Mr. MOSHER. While we were gone, perhaps the chairman asked about the transporters. It was originally intended that there be three transporters, I believe; and there is now only one.

When will you be purchasing a second, and how soon would you really need it, in terms of the demands of the job?

Dr. HEESCHEN. Getting a second transporter will halve the time required to reconfigure the array, to move antennas around to some new sets of locations. And I think the first time that this would really be very important to us is about 2 years from now.

We can of course reconfigure it with just the one transporter. That was the basis for our decision to cut two out, that the money could better be spent elsewhere, if we had a limited sum of money.

But if we could get it back, I'd say 2 years from now is when we'd first really need it.

Mr. MOSHER. But you would have to come back to the Congress for an appropriation?

Dr. HUGHES. In the present form of the program plans, there are no funds that are allocated for the acquisition of a second or a third transporter.

Two possibilities exist: Real economies might be realized by new developments as yet unforeseen, in which case there is a priority list of elements that we would then turn to, and the transporters would be fairly high on that list, later in the use of the system.

The second alternative, of course, is the one you've mentioned, in which case it would be necessary to return to the Congress for authorization to extend the capabilities of the system, either with transporters or with new computer systems, or whatever else might be needed.

I think we're trying to be open and frank about this, indicating that this system will be such a national resource that ultimately I think we will feel obliged to upgrade it and make it more and more effective and useful.

Mr. MOSHER. Could I ask just a couple of more questions?

Chairman SYMINGTON. Go ahead.

Mr. MOSHER. Several years ago I was privileged to visit the Big Dish down at Arecibo in Puerto Rico, and had the thrill of climbing around those catwalks and so forth up there.

But will you distinguish for the record the type of work that is done in Puerto Rico and what the Very Large Array will be doing? Are they both under the same management and under the same consortium of universities? Or is it different?

Dr. HUGHES. They're under different management. Cornell University manages the Big Dish down at Arecibo.

Mr. MOSHER. Wasn't it at one time under some sort of a university consortium though, centered in Cornell?

Dr. HUGHES. Originally it was built by the Department of Defense, the Advanced Research Projects Agency, and then transferred to the National Science Foundation.

Mr. MOSHER. But this is different management?

Dr. HUGHES. Yes.

Mr. MOSHER. Now could you distinguish briefly how the jobs differ?

Dr. HEESCHEN. I'll try to do so. The Arecibo Dish is a very large collecting area. Its collecting area is about four times the collecting area of the Very Large Array. So that for observing single point sources in the sky, wthout any detail of the structure of the source, at long wavelengths—because the Arecibo Dish does not work to as short wavelengths as the Very Large Array—then the Arecibo Dish is excellent for looking at single, individual point sources, very faint ones, at long wavelengths.

The Very Large Array, on the other hand, will ultimately look at fainter objects, and always with much higher resolution, with greater attention to the detailed structure of the object and its shorter wavelengths.

So, for point source work, they complement each other very well. For structure work, the Very Large Array is quite a different instrument.

Mr. MOSHER. That was the next question I was going to ask. They do complement each other, though, and there's a lot of work that's done——

Dr. HEESCHEN. Yes; a great deal.

Mr. MOSHER. As I remember it, we authorized and appropriated several million dollars to refurbish the Big Dish at Arecibo several years ago.

Has that produced the increased productivity that was then anticipated and hoped for?

Dr. HUGHES. Mr. Mosher, may I turn to Mr. Daniel Hunt, the Deputy Assistant Director for Opeartions of AAEO, who is the former head of the Office of National Centers and Facilities? He has followed these developments for many, many years. He can speak directly to the Cornell University effort to upgrade the Arecibo Dish.

Mr. MOSHER. Mr. Hunt?

Well, just briefly. It's sort of an analogous situation.

Dr. HUGHES. Yes.

Mr. HUNT. The answer is affirmative to your question. The funds appropriated by Congress were about $5.6 million for the upgrading. This has been accomplished and, yes, the scientific goals have been reached.

I would like to give you a good example of this: Of course, one of the objectives was to operate at shorter wavelengths, or at higher frequencies, and—I have to turn to our cooperation with NASA—we worked with NASA to install an "S" band radar. The new surface allowed operation down to 12.6 centimeters.

One of the significant recent accomplishments was pinpointing the landing spot on Mars through the use of this radar, and the surface of the upgraded antenna.

Now, it is expected that there will be significant advances also in radio astronomy in the future, as well as has been done in radar development.

Dr. HUGHES. Mr. Mosher, I might add that that was a rather dramatic enterprise. You may recall, only weeks ago, Viking was circling Mars after it was ascertained that its original landing site was too precipitous. NASA of course was using photographic means to survey the surface to find an alternate site.

It turned out that the system resolution of the orbiting Viking orbiter was not sufficient to pick out such a site. But the Arecibo Dish in Puerto Rico was able to pinpoint precisely the site at which the landing was made successfully. And, indeed, I'd like to say that NSF was happy to be able to stop everything else at Arecibo and cooperate with NASA in that moment of peril.

Mr. MOSHER. Well, that is a fascinating example.

Just one more question, Mr. Chairman: There have been several references in the testimony to the influence of the atmosphere, that is, its effect on the use of the instrument.

And what of the future—in terms of this location, what is the future? How many problems can we anticipate in the years ahead from encroachment of civilization, population, industry, and so forth, out there? You say Albuquerque is what, 50-some miles away? Is some other city closer? Is there sufficient isolation to guarantee that the atmospheric conditions will still be useful 30 or 50 years from now?

Dr. HEESCHEN. The principal atmospheric characteristic that we're concerned with is the total amount of water vapor in the atmosphere between us and outer space.

I don't believe that is seriously affected by human activity, so it's unlikely that any sort of manmade things are going to affect that situation.

Mr. MOSHER. In other words, increasing smog is not a problem?

Dr. HEESCHEN. No.

Mr. MOSHER. And I assume you selected the site with that fact in mind?

Dr. HEESCHEN. Yes. There are human activities that could cause us difficulties in the long run, but this is a very isolated place, in fact, and we think it's as unlikely to be encroached upon as any place we could find.

Mr. MOSHER. I have no further questions.

Chairman SYMINGTON. You mentioned, I think, Dr. Hughes, that you were—or perhaps it was Dr. Heeschen, who said in 1981 you'd be operational.

Now, you're not sure whether you have the computer capacity, or are you, to deal with the 27 antennas?

Dr. HEESCHEN. We are sure that we have the computer capacity to deal with 27 antennas in the ways that we originally proposed to use those 27 antennas. But people are clever, and they have found new ways—or are proposing new ways—to use the antennas that we're not able yet to keep up with in the computer.

Chairman SYMINGTON. What is the cost of the computer component now in the array?

Dr. HEESCHEN. The total cost of computer hardware and software is about $5.5 million.

Chairman SYMINGTON. So it's a big, substantial portion?

Dr. HEESCHEN. Yes.

Chairman SYMINGTON. That could be increased. You might have to increase that by some measure, if you encountered new——

Dr. HEESCHEN. We hope that——

Chairman SYMINGTON [continuing]. Excuse me—new uses and new ways to use the information?

Dr. HEESCHEN. Yes, sir; that's correct.

Chairman SYMINGTON. All right.

Dr. HEESCHEN. We also—if I could add—really need some new developments in these areas—technical development in these areas—to accomplish all of the things the Very Large Array could ultimately do.

Chairman SYMINGTON. For example, when the project was in the design stage, you anticipated certain uses. I imagine as the years have gone by new ones have been suggested, and maybe even confirmed, as are likely.

Can you give an idea of—say you started out with a factor of 100—how many percentage points you've gone up to the next 100 in uses? That is, what percent increase has there been in the speculative areas, at least, of uses since you first designed it?

Dr. HEESCHEN. I'm a little hesitant to try to guess that one. The nature of the science, of course, has changed greatly since the early sixties, and that has affected it.

The total ways in which the Very Large Array would be used, or the total number, the total kinds of radio astronomy it could be used on, has at least doubled or tripled.

Chairman SYMINGTON. I just wondered if there was some kind of predictable curve that you get on because of the amassing of knowledge that comes in on a fairly steady basis, or whether you sort of level off and then maybe shoot upward when somebody thinks of a real great use that could require——

Dr. HEESCHEN. It happens both ways. If you look on a short time scale, there are those continuities you just described, where somebody makes a discovery. But averaged out over the years, it's sort of an exponential growth in all areas of science.

Chairman SYMINGTON. Do you have any——

Dr. HUGHES. I believe it is correct to say, Mr. Symington, that astronomy is in a period of great discovery, great excitement, and great fulfillment. In recent years the discoveries of quasars and pulsars and giant radio sources have increased the demands on these major instruments enormously.

Chairman SYMINGTON. You mentioned in that connection the Netherlands has an installation comparable.

To what extent would you expect to divide responsibilities with that installation, as distinct from paralleling their work or duplicating it?

Dr. HEESCHEN. Both we and they would keep in very close touch with what the other institution is doing. This is done by the individual scientists, and also on a more organized basis.

There will, of course, be some overlap, because a certain amount of overlap is desirable, checking each other's results, and so on. But, on the whole, they will be used for complementary types of things.

Chairman SYMINGTON. Do they also open up their facility to visiting scientists, this kind of thing?

Dr. HEESCHEN. They do, yes, but not quite to the same extent that we will.

Mr. MOSHER. Mr. Chairman, could I just add a comment? Couldn't this be cited as what you and I would—and I think other members of this committee would—agree is a very commendable example of a most dramatic, certainly convincing example, of Government's commitment in support of basic research, that is going to produce results in basic research for many, many years to come, probably for generations? It's an exciting example of Government cooperation—partnership between Government and the scientific community.

Dr. HUGHES. As I indicated, Mr. Mosher, I think it will stand as a very dramatic symbol of that.

Chairman SYMINGTON. It's also an opportunity for international coperation, too. The subcommittee could look at that.

Do you have any other questions?

Mr. MOSHER. No.

Chairman SYMINGTON. We have a series of somewhat technical questions we'd like to submit in writing, Dr. Hughes, Dr. Heeschen, if we may.

Dr. HUGHES. Yes.

[A list of additional questions follows:]

VERY LARGE ARRAY (VLA)

ANSWERS TO QUESTIONS POSED BY THE SUBCOMMITTEE ON SCIENCE, RESEARCH AND TECHNOLOGY OF THE COMMITTEE ON SCIENCE AND TECHNOLOGY

Question No. 1. What sums do they include for future inflation?

Answer. The November 7, 1975, VLA Project cost estimate on which the calendar year 1976 program was based contained the sum of $4,182,000 for future inflation. The amount is made up of a 6 percent year allowance for future inflation in the budgets for site and wye work, National Radio Astronomy Observatory labor, and antenna equipment items.

General improvement in the performance and specifications of marketed items of electronics and computer equipment have offset price increases. As a result, no allowances for future inflation are considered necessary in these categories.

The antennas are being procured on a fixed-price subcontract, which removes this category from such consideration.

The sum for futher inflation to be included in the November 1976 VLA Project cost estimate is $3,042,000.

Question No. 2. What would the total estimated program cost be for the items that were deferred or deleted if they were still included?

Answer.

1975 VLA project cost estimate	$78, 123, 000
Deferred items:	
Transporters 2 and 3	615, 000
Airstrip	268, 000
Subtotal	883, 000
Total estimated cost if deferred items are included	79, 006, 000

These items have been deferred until all high priority scientific design and construction problems are solved. It is expected that the deferred items will be financed from the $3,200,000 contingency budget during the later years of the project. Note that the amount for contingents has been included in accordance with good engineering practice and is not intended to provide for future inflation.

Question No. 3. Are there any plans for installing onsite mobile voice communications equipment in the antennas and the transporters?

Answer. Yes. At present there are four mobile voice communication sets and a central station in the Control Building. These are used when antennas are moved and for control and safety procedures when an antenna is being worked on or activated. A permanent wye communications system is planned, and the first portion was placed under contract on October 5, 1976.

Question No. 4. Has NSF arranged for emergency personnel evacuation services via helicopter?

Answer. No. This possibility has been investigated in the past from time to time, but no formal arrangement has been made. Two companies in Albuquerque have helicopters for rent, neither equipped for litters. If the helicopter happens to be ready on the ramp with a crew immediately available, flying time to and from the site to an Albuquerque hospital is 1½ hours. These helicopters are in general use, and the chance of having one immediately available is considered small.

The VLA contractor, Associated Universities, Inc. (AUI), maintains a fully equipped ambulance at the site at all times, and four AUI employees have been trained in emergency medical treatment. Emergency running time to Socorro General Hospital is about 45 minutes. The Socorro hospital has full operating facilities and a doctor is on call at all times.

Depending on the emergency, consideration would be given to commercial helicopter service or to the Air Force Air Rescue helicopter service based at Kirkland Air Force Base, Albuquerque, New Mexico, about 90 miles from the VLA site. This latter service responds on a "life or death" basis.

Question No. 5. Would increasing the FY 78 authorization for accelerated railroad construction result in improved continuity of the work force and construction economies?

Answer. Yes. Should the FY 1978 authorization be increased to, for example, $20,400,000, all the remaining wye construction would be placed under one contract instead of three. Also, all remaining waveguide would be procured. This would save an estimated $295,000 in escalation plus an estimated 5 percent in construction efficiencies for the single contract, which amounts to an additional $397,000, or a total of $692,000. Due to higher priority funding requirements elsewhere in the NSF, there are no plans for such an increase at this time.

Question No. 6. Are additional track mounted vehicles needed? What type of vehicles? How much will they cost?

Answer. Yes. A total of five vehicles suitable for running on railroad tracks will be needed. Two of these have been obtained from Federal excess at no cost to the project. A third, actually a modified 3/4-ton pickup for rail or ground travel, is in the process of being purchased. Two additional new vehicles, probably another pickup and a panel truck, are also planned. The November 1975 cost estimate included $30,000 for the three new vehicels.

Vehicles of this type are required to service antennas outside of the central site area. This is due to an agreement with local ranchers to have no permanent roads within the rights-of-way for the wye arms.

Question No. 7. Has buried waveguide settlement decreased since July 76? What risk is there of needing to remove and reinstall waveguide in the future or of downgrading performance?

Answer. No. The attenuation of 50 GHz in the 1.24 km prototype waveguide section increased from 1.36 dB/km in April 1976 to 1.43 dB/km in September 1976.

Mechanical measurements show increases in the curvature of the guide which account for this increase in loss, but only in the vertical plane. This indicates that the settlement is taking place in the fill and not in the undisturbed soil. While it is difficult to state in physical terms what the allowable limits of this settlement are, the loss budget is 1.6 dB/km over most of the operating frequency range. There are indications that the increase will level off before this figure is reached.

New burial techniques have been developed, and recently installed waveguide sections show improved stability as well as performance. Some test sections (along the north arm) utilizing various other techniques, such as pretensioning and a concrete strip, will be installed.

The possibility exists that in the future small sections that have been subjected to abnormal soil conditions may have to be repaired. However, no such conditions have developed so far. In the unlikely event that the loss would increase to the point that the loss budget was exceeded for the outer stations, a repeater station will be installed.

Question No. 8. Are the current array signal receipt and processing performance objectives still the same as originally proposed at initial authorization?

Answer. Yes. In brief, these are the resolution, sensitivity, and speed capabilities of the array as an astronomical instrument for imaging (and mapping) the radio sky.

As originally proposed, the VLA would have a resolving power (radio) approaching that of groundbased optical telescopes—approximately one second of arc. Because resolution scales linearly with wavelengths, the VLA will have the following performance in this regard:

Wavelength band, cm:	*Resolving power sec of arc*
18 to 21	2.1
6	.6
2	.2
1.3	.13

Sensitivity is a function of collecting area. Since the number of antennas and the diameter of their reflectors remains unchanged, the VLA will have its originally planned high sensitivity.

The original goal for speed of information flow also remains unchanged. The VLA will provide up to three high-quality radio pictures per day. Many other capabilities remain to be discussed, such as the spectroscopy features of the instrument, pointing and tracking accuracy, and sky coverage. None of these performance objectives have been revised downward and each remains essentially as proposed.

Chairman SYMINGTON. In the interests of time, I think we need to get on to the synchrocyclotron at this time. We'll excuse you and Dr. Heeschen.

Thank you very much for your very helpful testimony.

Dr. HUGHES. Thank you, Mr. Chairman.

Chairman SYMINGTON. I believe we will call to the table at this time Dr. William Wright, Division Director of the Physics Division of the National Science Foundation; and Dr. Leon Lederman, director of the Nevis Laboratories. Dr. Fregeau is accompanying Dr. Wright as well, I believe.

I understand that just as in my State there's a difference of opinion between the two pronunciations of "Missouri," there are two pronunciations of "Nevis." I will defer to the witnesses on that.

Dr. WRIGHT. Nevis (nĕv'-is) is the preferred pronunciation.

Chairman SYMINGTON. Nevis is preferred? OK. Let the record so show, if there's a way of doing that.

Dr. Wright?

[A brief biographical sketch of Dr. William E. Wright follows:]

DR. WILLIAM E(RSKINE) WRIGHT

Position: Division Director for Physics.

Office: Directorate for Mathematical and Physical Sciences, and Engineering (MPE).

Education: DePauw University B.A. 1942 Major in Mathematics; Mass Institute of Technology Teaching Fellow 1942–44; Military Service: USNR, 1944–46; Massachusetts Institute of Technology, PhD, Physics, 1950 (1946–50).

Professional history: National Science Foundation, Deputy Division Director for MPS, July 18, 1976 to November 12, 1966; Division Director for MPS, 1966–75; Division Director for Physics/MPE, 1975 to present; and Office of Naval Research, 1950–66.

Professional memberships: Sigma Xi, American Association of Physics Teachers, Fellow of the American Physical Society, Phi Beta Kappa, and American Nuclear Society.

Home address: 5818 Greenlawn Drive, Bethesda, Maryland 20014.

Family: Wife: Margaret; Children: Michael, Margaret, Sara, and Leslie.

STATEMENT OF DR. WILLIAM E. WRIGHT, DIRECTOR, DIVISION OF PHYSICS, NATIONAL SCIENCE FOUNDATION

Dr. WRIGHT. Thank you, Mr. Chairman, members of the subcommittee, for the opportunity to meet with you here today to discuss the proton synchrocyclotron at the Nevis Laboratory of the Physics Department of Columbia University.

The Nevis synchrocyclotron is an example of a major facility whose principal support comes from the Physics Division of the National Science Foundation.

This facility was initially constructed with support from the Office of Naval Research beginning in 1946. It began operation in 1950, permitting an excellent and extremely productive research group to develop. Many discoveries of fundamental importance were made, which were recognized by many major honors and awards.

In discussions held in 1966 involving the U.S. Navy, the Atomic Energy Commission, the NSF, and the Office of Science and Technology, it was concluded that the program at this facility was of great importance and that the capabilities of the laboratory should be expanded.

The U.S. Navy was unable to provide for this expanded capability and it was recommended that the NSF undertake support of the Nevis facility.

A proposal from Columbia University to upgrade the cyclotron was submitted to NSF and funded in 1967. The improvement project to raise the energy, intensity, and quality of the proton beam called for a reconstruction of the whole cyclotron using new design concepts and a substantial modification of almost every part of the machine.

In considering the proposal, the National Science Foundation not only obtained reviews to assess the scientific desirability of the improvement, but also obtained an analysis of the cost estimates from an industrial firm specializing in cyclotron construction. Independent assessments were also made by two accelerator experts who visited the site to study the project in detail.

Planning and other preparations for the improvement project were carried out until the end of 1970, when the cyclotron was shut down for installation of the new components.

According to the planned schedule, the accelerator was to be out of operation for only 1 year and was expected to provide the higher energy and intensity beam by 1972. The assembly and retrofitting took longer than initially anticipated.

In 1973, NSF formed a Technical Review Committee whose membership included three outstanding accelerator experts. This com-

mittee analyzed the status, manpower, schedules, and budget of the project and made both technical and managerial recommendations. The Technical Review Committee has continued to oversee this project and has served an important managerial function.

Substantial management improvements were made in 1973, and Professor Derek Storm was appointed director of the cyclotron project. In 1975, the Technical Review Committee noted that "the appointment of Derek Storm as project director"—then 2 years ago —"has brought about a major improvement in the cyclotron management picture. This improvement in management capability is recognized in each area of the machine."

Important developments in the project after that time include the following: In September of 1974, all components necessary for acceleration of protons were in place and functioning—protons were accelerated to about 100 million volts; in January 1975, protons were accelerated to full energy, inside the cyclotron; and in September 1975, protons at full energy were extracted from the cyclotron, at low intensity.

At the time of the Technical Review Committee visit in November of 1975, a fault in the radio frequency system which seemed impossible to locate constituted a serious problem. However, a consultant from a similar accelerator in Switzerland was brought in and helped to solve the problem in approximately 3 months.

In February of 1976, a high intensity full energy beam of protons was delivered into the experimental area. This demonstrated that all the major technical problems of the improvement projects had been solved, except that of reliable operation over long time periods.

Prior to the decision by NSF in March of 1976 to provide continued funding for the project, a meeting was held between the NSF staff, the chairman of the Physics Department of Columbia University, and senior Nevis staff. That discussion led to the development of a tight schedule for the remaining 9 months of 1976, with the specific objective of demonstrating reliable high intensity performance over a test period from September 15, 1976, through December 15, 1976.

The proposal received from Columbia University following that meeting recommended that certain minimum criteria concerning the operation and reliability of the synchrocyclotron be achieved by December 15, 1976. The Nevis staff felt that, unless these criteria were met, the prospects for success of the synhrocyclotron program would be so diminished that they would consider the project unworthy of further investment of funding and effort.

The schedule for use of the cyclotron was considerably disrupted in April 1976 as a result of a power supply short circuit which damaged the beam extraction system. However, much of the lost time has been recovered and there is presently a good chance that the performance criteria will be met in the specified time.

The instrument is now operating with the extracted beam, but at a reduced repetition rate.

I would like to turn to a discussion of some more general aspects which seem to emerge from the Nevis experience and from our experience with other facilities.

As you know, Nevis is not the only facility supported by the NSF physics division, nor is it the largest. Both the Cornell University electron synchrotron and the Indiana University cyclotron facility, which has just come into highly successful operation, are supported by NSF at a higher level than is the Nevis synchrocyclotron.

The Cornell facility is generally recognized as a celebrated success. Its design was excellent; furthermore, it was completed within schedule and below estimated cost. Its director at that time, Dr. Robert Wilson, went on to even greater achievements as director of the Fermi National Accelerator Laboratory at Batavia, Ill.

The histories of the other two facilities I have mentioned—Nevis and Indiana University cyclotron facility—have some aspects in common.

In each case, the technical design was extremely innovative. The Indiana cyclotron, designed by Professor Hartin Rickey and funded by NSF in 1968, contains several entirely new concepts and is a major advance in the state of the art. As I previously remarked, the Nevis upgrading project required major changes in many areas—magnetic field, radiofrequency, and beam extraction.

In both cases it became clear that the kind of innovative thinking that led to the design was not necessarily the most appropriate for the coordination and execution of the actual construction effort.

At Indiana, Professor Robert Pollock has brought the machine into successful operation for a large number of outside user groups.

Constructing, or modifying, a major facility at a university may require stronger local management than that to which some universities are accustomed. Further, it seems that even stronger local management may be required if the facility is to be nationally available to users rather than a departmental facility.

By the same token, if a facility is intended to be nationally available to users, the sponsoring agency must be prepared to provide strong financial support for such aspects as space, technical support staff, and instrumentation.

It is our experience that the use of technical review committees has been extremely valuable at Nevis and other projects. We have been particularly fortunate in the caliber of the consultants whom we have been able to recruit to perform these duties.

Furthermore, in addition to performing the functions of assessment and reporting, the committees bring to the project a particular combination of expertise and experience, rarely found at a single institution.

We have learned, too, that the value of such a committee seems enhanced when it maintains long-term contact with the project through frequent site visits and through the receipt of regular progress reports.

As major facilities become larger and more expensive, they tend to serve as regional or national facilities rather than facilities for the benefit of a single university group. Thus, the success or failure

of a project involves potential users across the Nation, and many institutions are affected, in addition to the host institution.

Any agency which becomes a sponsor for such facilities should be prepared to study very carefully the institutional environment, to require agreements with the host institution that will guarantee adequate staffing, to conduct cost and schedule analyses, and to maintain close monitoring of projects on a month-to-month or sometimes a day-to-day basis.

We believe that many of these needs have only become imperative in the last decade, but that a great variety of practicable and proven management tools now exist.

A partial list of management techniques employed at NSF-supported facilities includes the following, most but not all of which are used at any one facility:

A university advisory committee, appointed by the university in consultation with NSF and reporting on the conduct of the facility to the university.

A program advisory committee, appointed by the project director in consultation with NSF and advising him on scientific priorities within the research program.

The users committee, selected by and representing the users, monitoring the services provided to satisfy user needs.

NSF-appointed technical review panels, reporting to NSF on such topics as technical status, staffing, management, and budget.

In most cases, the university, the project director, and the foundation find it beneficial to communicate the reports of these various committees to the other participants in the project management. The National Science Foundation staff attend many committee meetings as observers.

Direct monitoring techniques employed by NSF include:

Site visits by NSF staff, perhaps with outside consultants, several times a year;

Monthly or bi-monthly status or progress reports;

Comprehensive annual reports and proposals for renewal of support;

In the case of Nevis, submission of the weekly work schedule for key parts of the program;

Visits of project staff to NSF;

And, of course, direct telephone communications.

With the committee's permission, I would like to provide for the record the following documents illustrating some of these management activities:

The most recent Nevis bimonthly report.

An example of a Nevis weekly work schedule.

Revised plan and budget resulting from visits of Nevis staff to NSF.

Chairman SYMINGTON. Without objection, that will be incorporated in the record.

Dr. WRIGHT. Thank you very much.

Nevis Synchrocyclotron Bi-Monthly Report, June–July, 1976

I. INTRODUCTION

During the past two months, we have been preparing the new channel for operation and simultaneously completing work in a number of other areas. The completion of the channel was delayed by about a month, so that the accelerator operation originally scheduled for early July has been delayed until mid-August. The particular problems with the channel and its present status are discussed in Section III. The completed work includes the high power rf filter, the TVB installation, the preparations for the shielding improvement, and the channel remote handling apparatus. The details of this work are presented below.

A new feature is being added to the experimental area. Professor Wu and collaborators are developing a system for using a bent crystal spectrometer to analyze pionic x-rays made in a target that is combined with the pion production target. This scheme involves putting the pion and x-ray target in the primary proton beam between the present production targets. Most of the shielding modifications for this system have been finished.

In order to adhere as nearly as possible to the accelerator operation schedule, the NVS installation has been revised. Whereas previously we had intended to install the entire NVS system during the month of August, we now have deferred the actual system installation. We intend to concentrate on installing the tracks for the remote operation of the NVS some time in late September The tracks will be completed as much as possible outside of the vacuum chamber, so the installation will take about a week. The modifications of the NVS deflector and target for the remote installation have been deferred because of pressure on the engineering and shop staff to finish more pressing items. This NVS work will be completed later, after the tracks are in place. Thus we still expect to begin steady experimental operation in September.

II. RF SYSTEM

All of the work planned for the rf system during the June and July period was finished. The "donut" seals and rf contracts were modified. The new capacitor rotors have been installed and tested. The high power filter has been installed in the plate line and tuned to the proper band. The rf system, with these modifications, has been tested briefly. At present we are concentrating on building diagnostic devices for the modulator, which will enable us to monitor the pulse current in each of the three parallel output tubes. The design of the SCR power turn-off device for the rectifier has been completed, and we are awaiting delivery of the components.

III. EXTRACTION SYSTEM

The main extraction system work has been on the new current channel. However, the work on the TVB has been just as important. The new TVB has been installed in the chamber, using the final mounts necessary for the remote installation. Tests on the coil will begin in the first week of August.

The channel installation which was anticipated for the end of June was delayed for about three weeks by mechanical problems in the positioning mechanism. Once installed, a leak was found in a weld. While this leak was being repaired, some other damage was done to the septum, which caused more leaks. Consequently about 10 days were lost making repairs. The channel was installed and we began tests on July 30. Previous to these tests, the channel power supply was installed and tested, and the bus bars, with the remote removal devices, were installed.

During the first tests, at the full main magnetic field and nearly the normal operating channel current, the tungsten septum support collapsed. The cause of the collapse is unclear, since a similar tungsten support, with the same load, worked on the old channel. The most likely explanation is that a crack was started and propagated in the tungsten from a notch cut in it. Although we

have a spare piece of tungsten, we are rebuilding the septum with a titanium support plate of twice the thickness. The effect of the added thickness will be to reduce the extraction efficiency by about 7%. The titanium plate should be almost twice as strong as the tungsten one, and should be less subject to crack propagation. Furthermore, the strength of the titanium is more precisely known than that of the tungsten. By a well coordinated repair effort, we expect to have the channel fixed by August 8. The simplicity of the construction of this channel makes the repair possible in this time period. It would have taken months to repair the old channel, if a similar problem had occurred.

IV. SHIELDING

The shielding modifications discussed in the last bi-monthly, report have been designed, and all the material is on hand except the concrete, which will be delivered during the construction period. In addition, there have been some modifications to the beam line shielding to accommodate the neutral beam line. These have been designed and some of them have been implemented.

V. REMOTE HANDLING

The channel remote handling system can be considered in three subsections: the tracks in the chamber, the tools and remote lifters for the bus bars, and the shielding. The tracks are installed and were used for the channel installation. The tools have been completed, and some mockup tests have been completed. The shielding supports have been installed, but the iron shielding is not finished. However, complete tests of the remote scheme can be done with mockup shielding. We expect to do such tests in September.

The TVB remote handling system can be considered in four sections: the tracks in the chamber, the insertion device, the remotely operable door (the channel and its door are an integral assembly), and the shielding cart. The tracks are being installed in the chamber in early August. The insertion device is finished, and the remotely operable door is mounted. The shielding cart (without iron shielding) is about half-finished, and the tracks that it runs on are being installed. Again, complete mockup tests are planned for September, using all the apparatus except the iron shielding.

The remaining remotely handled parts of the extraction system are first, the regenerator, iron channel, and current iron channel group, and second, the peeler. The devices in the first group are complete and the mounting plate is under construction. The peeler itself is nearly complete, and the insertion plates are under construction. These devices will also be tested in September.

The remaining elements that require remote handling include the center insulators, the beam line joints, and the NVS apparatus. The first two of these were completed and tested some time ago. The NVS system is to be installed on tracks using the same cart that is used for the TVB. The tracks are being designed for installation in September or October. The modifications to the NVS system that must be made before installation will be done and tested in mockup situations after October. Then the system will be installed remotely after that time.

VI. BEAM LINES

1. B.L. I: The tuning with alpha particles in the pion beam configuration is nearly finished.

2. B.L. II: The slit and degrader has been extensively modified for operation as an "Arizona beam" muon channel, as outlined in the last report. The assembly will be replaced in the first week of August.

3. B.L. III: The alpha particle measurements planned in the last report have not yet been carried out. However, the beam line is operational, and will be tuned using pions as soon as the accelerator runs.

4. Neutral Beam: The neutral beam is designed for viewing pionic x-rays produced in conjunction with the pion production target. The design of this beam has been completed. Most of the shielding and magnet cabling modifications necessary to use the beam have also been completed.

VII. EXPERIMENTAL ACTIVITIES

Presently four different experimental setups are being worked on. Professor Wu's group, in collaboration with Prof. Y. K. Lee of Johns Hopkins, is setting up and testing apparatus for a pionic x-ray experiment. The pionic x-ray experiment on the neutral beam is being designed by professor Wu's group in collaboration with Dr. Lu of Yale. Professor Sach's experiment (#3) on $\pi \rightarrow e\nu\gamma$ and $\mu \rightarrow e\gamma$ has some of its apparatus on the floor. Experiment #1 (Price et al) is being set up in B.L. III. At present, one of the two sets of multi-wire proportional chambers has been set up and tested and the other is being set up. The bending magnet for the beam spectrometer has also been put approximately in place. This apparatus will be used initially for tuning that beam line.

VIII. SCHEDULE

The channel will be repaired and installed by August 9. Measurements will be completed by August 13. Accelerator operation will begin August 15. We intend to run the accelerator 50% for testing and 50% for experimental operation until mid-September. The repetition rate will be brought to 150/sec, and the ion source tip improvements will be carried out. In the meantime, the remaining construction details and mockup tests on the remote handling will be completed. In the second half of September, we will test the remote handling of the channel, TVB, and the rest of the extraction system, so that we will be ready for operation at several microamps by October first.

Physical Review, Analytic Subject Index Number 25.80

(Abstract Submitted by Richard Madey for the Fall Meeting of The Division of Nuclear Physics, American Physical Society, October 28–30, 1976)

*Neutron Spectra from Nuclear Capture of Negative Pions.** T. WITTEN, B. ANDERSON, A. BALDWIN, T. VILAITHONG, R. MADEY, *Kent State U.;* and F. WATERMAN, *U. Chicago*—The energy spectra of neutrons emitted following nuclear capture of negative pions stopped in C, O, Al, Cu, Pb, and a tissue-equivalent liquid[1] were measured at the Columbia University Nevis Laboratory. Energies in the region from 8 to 120 MeV were measured by the neutron's time-of-flight over a distance of 2 m from the target to a 5'' diam x 4'' thick NE–102 plastic scintillation counter, which has a time resolution of 1.1 ns (fwhm) for a 4 to 1 dynamic range of pulse heights from a ^{60}Co source. Timing was obtained from a pion telescope, which contained a Cerenkov counter to reject electrons. These results will be compared with previous measurements and with the predictions of intranuclear cascade calculations.[2]

Cyclotron Activities for Period September 7–14

REVIEW OF PAST WEEK

Most of the work planned was completed.

Some of the scheduling of shop work for the spare channel was completed, but time estimates for some of the subassemblies have not been finished.

The calculations of the extraction efficiency of the new channel show that its acceptance is better and its effective septum thickness is lower than the previous channel. Thus the efficiency should be up to 10% higher.

The north shielding wall and south roof were placed. Some iron pieces were cut to fill cracks in the north wall.

The extra shielding building plans are complete.

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* Supported in part by NIH grant CA–14375 and ERDA Contract E(11–1)–2231.

[1] Distilled water (58.2 w/o), glycerol (34.4 w/o), and urea (7.5 w/o). Atomic composition is 71.6 w/o O, 14.9 w/o C, 10 w/o H, and 3.5 w/o N. Density is 1.10 g/cc.

[2] M. Guthrie el a, Nucl. Instrum. Methods *66*, 29 (1968).

The beam stop was not washed out, since Fleisher decided the electrical leakage was probably due to some shifting iron pieces.
The shielding for the neutral beam line was built.
The trailer was not installed, because some shielding is in the way and must be placed first.
The 12 kA supply cooling was not completed.
The problems with air-vacuum feed on the TVB have been rectified.
Some parts have been built to start the final mockup tests on the channel remote handling.
The slit drives were connected.
The run plan was followed completely—with internal beam accelerated on September 7.

ACTIVITIES FOR PRESENT WEEK

Finish shielding, including iron pieces—Dowds.
Place trailer for BL III—Dowds.
Set up crew and schedule for building extra shielding—Shill.
Open beam stop, to fix electrical leakage—Fleisher.
Finish 12 kA power supply cooling—Dowds.
Build new reel for TVB air-vacuum line—Shill.

RUN PLAN

September 7—Run internal beam.
September 8—Extract beam (shielding must be up).
September 9–14—Test and tune new extraction channel.
September 13–14—Deliver beam on target (at low repetition rate) for BL III survey.

A REVISION OF THE PROPOSAL SUBMITTED TO THE NATIONAL SCIENCE FOUNDATION FOR CONTINUATION OF RESEARCH PROGRAM AND SYNCHROCYCLOTRON OPERATION AT THE COLUMBIA UNIVERSITY NEVIS LABORATORIES, 1976

Principal investigators: Leon M. Lederman, Director, James Rainwater, Professor of Physics; Allan Sachs, Professor of Physics; Chien Shiung Wu, Professor of Physics; For the Physics Department, Robert Serber, Chairman; and for Columbia University, Lorrie L. Millman, Projects Officer.

I. Introduction and Summary

This is a revision and updating of the proposal, submitted in November 1975 for continuation of the research program and synchrocyclotron operation at the Columbia University Nevis Laboratories. Since that time, the rf system has been cured of a sparking problem and substantially increased in amplitude to eliminate most of the beam loss during acceleration. Extraction and external beam elements have been installed and operated reliably. We have transmitted *more than 55%* of the small radius beam (15 in.) through the extraction system and a slow extracted beam has been delivered to the pion production target. We have demonstrated the capability for delivering $>6\mu A$ on target and the schedule for achieving such operation is included here. Tuning of the secondary beams is in progress with initial pion experiments scheduled to start March 15. Three in-house research groups have apparatus ready to start their experimental programs, and arrangements are being made for detailed scheduling of outside users. Through May, during the beam tuning and initial experiments, the average beam intensity will be kept below the 1 μA level in order to limit the activation of the chamber. During June, it is planned to install improved "second generation" extraction elements (current channel, bump coil, and iron channels) with remote handling facilities. Starting in July, the average beam current will be increased to produce higher intensity pion and muon beams for experimenters.

NSF MPS 75-17396 RENEWAL—REVISED FOR 9 MONTHS, FEBRUARY 1976 FOR APR. 1, 1976–DEC. 31, 1976

	NSF funded man-months					
	Cal	Aca	Smr	Operations	Research	NSF request
A. Salaries and wages:						
1. Senior personnel:						
a. Coprincipal investigators		3.7	5.0	$13,000	$19,000	$32,000
b. Faculty associates		5.7	6.0	10,000	10,000	20,000
2. Other personnel:						
a. 4 Research associates	36			30,000	16,000	46,000
b. Nonfaculty professionals:						
2 Staff associates	8.1			12,000	5,000	17,000
3 Programers	7.7			5,000	5,000	10,000
1 Operating engineer	9			15,000		15,000
6 Mechanical engineers	45.5			60,000	10,000	70,000
4 Electrical engineers	15.3			21,000	4,000	25,000
c. 4 GRA's		12	12	5,000	4,000	9,000
d. 8 Pre-baccalaureate students			24	8,000	2,000	10,000
e. Administration	46			32,000	8,000	40,000
f. Technical:						
6 Cyclotron operators	54			51,000		51,000
6 Cyclotron maintenance	54			53,000		53,000
10 Technicians [1]	87.8			74,000	12,000	86,000
3 Electricians	20.7			20,000	5,000	25,000
6 Machinists	55.8			55,000	7,000	62,000
2 Draftsmen	22.5			23,000	3,000	26,000
2 Electrical technicians	16.2			16,000	3,000	19,000
g. Overtime				8,000	1,000	9,000
Total salaries and wages				511,000	114,000	625,000
B. Fringe benefits				87,000	19,000	106,000
Total salaries and fringe				598,000	133,000	731,000
C. Permanent equipment:*[2]						
1. Remote manipulators				3,000		6,000
2. Spare vacuum capacitor				2,200		
3 Spare Freon pump				800		
D. 1. Equipment built at Nevis *[2]				40,000	15,000	55,000
2. Expendable supplies				59,000	23,000	82,000
E. Travel				4,000	1,000	5,000
F. Publications				1,000	1,000	2,000
G. Other costs:						
1. Computer				14,000	8,000	318,000
2. Power				253,000	24,000	
3. Communications				7,000	4,000	
4. Transportation				7,000	1,000	
Total nonsalary (C–G)				391,000	77,000	468,000
Total direct costs (A–G)				989,000	210,000	1,199,000
Indirect costs (31 pct.)				248,000	53,000	301,000
Total costs				1,237,000	263,000	1,500,000

[1] Includes: 5½ general technicians, ½ welder, 1½ rf technicians, 1 physician aide, ½ comp. operator, ⅔ safety technician, ½ photographer.

[2] Indirect costs are 31% of the entire budget excluding equipment with *'s and salaries of staff on construction. Computation on following page.

The university will cost share in accordance with current NSF policy.

ICA calculation:

	In thousands
Total direct costs	$1,199
Less non-ICA (C, D.1)	61
Total	1,138
31 pct. of above	352.8
Minus ICA of staff on construction	51.8
Total	301.0

NSF MPS 75-17396 RENEWAL, REVISED FEBRUARY 1976 FOR 9 MONTHS, COMPARED TO ORIGINAL BUDGET

[In thousands of dollars. Man-months in parentheses]

	12-mo original budget	Original budget scaled to 9 mos	Revised 9-mo budget
A. Salaries and wages:			
1. a. Coprincipal investigators	$43 (12.3)	$33.8 (10.3)	$32 (8.7)
b. Faculty associates	27 (16)	21.3 (12.7)	20 (11.7)
2. Other personnel:			
a. Research associates	93 (75)	69.8 (56.3)	46 (35.3)
b. Nonfaculty professionals:			
Staff associates	23 (10.4)	17.3 (7.8)	17 (7.8)
Programmers	17 (12.6)	12.8 (9.5)	10 (7.6)
Operating engineer	20 (12)	15 (9)	15 (9)
Mechanical engineers	93 (51)	69.7 (38.3)	70 (38.3)
Electrical engineers	41 (24)	30.7 (18)	25 (15.2)
c. GRA's	22 (60)	16.5 (45)	9 (24)
d. Prebaccalaureate	10 (24)	10 (24)	10 (24)
e. Administration	62 (67.3)	46.5 (50.5)	40 (46)
f. Technicians:			
Cycl. Operators	68 (72)	51 (54)	51 (54)
Cycl. Maintenance	70 (72)	52.5 (54)	53 (54)
Technicians	114 (117)	85.5 (87.8)	86 (87.8)
Electricians	40 (36)	30 (27)	25 (18)
Machinists	83 (74.4)	62.3 (55.8)	62 (55.8)
Draftsmen	34 (30)	25.5 (22.5)	26 (22.5)
Electrical Technicians	37 (33.6)	27.8 (25.2)	19 (17.2)
g. Overtime	12	9	9
Total salaries and wages	909	687	625
B. Fringe benefits	154	116	106
Salaries and fringe	1,063	803	731
C. Permanent equipment[1]	128	128	6
D. 1. Equipment built at Nevis[1]	134	134	55
2. Expendable supplies	124	93	82
E. Travel	7	5	5
F. Publications	6	4	2
G. Other costs	655	491	318
1. Computer	(35)	(26)	(22)
2. Power	(595)	(446)	(277)
3. Communications	(15)	(11)	(11)
4. Transportation	(10)	(8)	(8)
Total nonsalary (C–G)	1,054	855	468
Total direct costs (A–G)	2,117	1,658	1,199
ICA (31 pct)	497	373	301
Total costs	2,614	2,031	1,500

[1] No ICA Charges.

II. Status of Synchrocyclotron

A. EXTRACTION

The Nevis Synchrocyclotron has a slowly extracted beam of 20 nanocoulombs/pulse. The extraction system has been tuned to an efficiency of between 55 and 70%. The uncertainty is due to the uncertainty in the response of the secondary emission monitors. The slowly extracted beam pulse has a duration of 2 ms, and the beam is uniform during a period of about 1 ms. These times are to be compared with the 3.3 ms period of the machine. The entire extraction system has been installed, and the beam shape determined at various points up to the edge of the chamber. The beam spot outside of the vacuum chamber has been measured photographically, and its size, 0.6 in. diameter, is consistent with prior calculations.

B. EXTERNAL BEAM

The external proton beam components were attached to the chamber at the beam exit point. All the magnets were placed for the proton beam and the beam was brought to the pion production target on March 9th.

C. RF SYSTEM

The rf system, which is now operating reliably, had a sparking problem which caused a considerable amount of trouble during the last months of 1975. This trouble appears to have been a reasonance in a coil in the dee cooling water feed. The coil was designed as a trap for a 36 MHz parasitic. Installation of filters in the oscillator anode coupling line produced a more effective parasitic suppression, and enabled us to (electrically) decouple the water coil-trap from the resonator. Otherwise, the rf system operated without significant component failure since February 1975.

Although the system had no serious breakdowns from February 1975 to the onset of the sparking problem, the low frequency voltage was inadequate for 100% transmission of the captured protons to full energy. There were actually two problems: First, a resonance in the oscillator tube filament introduced an rf voltage dip that caused severe beam loss at about 450 MeV proton energy. Second, the rf voltage decreased smoothly with decreasing frequency, so that a large fraction of the beam was lost gradually during the acceleration cycle. The first problem was corrected in September, 1975 and the second was solved during January and February, 1976 by increasing the oscillator plate supply voltage and also changing the cathode coupling line termination. At present, the transmission from 15 in. radius ($\sim$20 MeV) through the extraction system is $\leq$55%. Since the extraction efficiency is between 55% and 70% (as measured with secondary emission monitors), the transmission from 15 in. to parking radius is between $\leq$79 and 100%.

D. BEAM INTENSITY

The pulse charge of 20 nC would yield 6 μA extracted beam at the nominal repetition rate of 300 pulses/sec. We have operated the rf system at that rate, at full power, for a few hours. More regularly, we have operated the rf system at 75 or 150 pulses/sec. When operating beam studies, we restrict the pulse rate to 1 to 3 pulses per second, to minimize activation in the chamber. We have operated beam briefly at a rate of 75 pulses/sec, and measured 0.8 μA on a meter connected directly to the beam stop outside the chamber. (Although one would expect 1.5 μA with 20 nC per pulse at this repetition rate, the beam was only tuned to about 10 nC per pulse at the time of this measurement.)

III. Summary of Goals (To be Achieved by 15 December, 1976)

A. OPERATIONS

1. The accelerator should demonstrate a capability of operating at $\geq$10 μA over a sustained period of time.
2. Losses inside the machine will be limited to $\leq$5 μA.[1] The overall transmission efficiency from 20 MeV to target should be better than 65%.
3. The overall reliability[2] in the period September 15–December 15 should be such that $\geq$2000 μA hours of beam will be delivered on target.

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[1] Limitation of intensity left in accelerator. We estimate that 5 to 6 μA is a reasonable limit to the intensity which may be left in the accelerator. We base this on the availability of remote handling equipment to service insulators, bump coil, and current channel. In the old accelerator and in the SREL machine, we note that nearly 2 μA were left inside, with no remote handling capabilities.

[2] Reliability Details

a. In order to measure reliability, we are continuing to record the following data:
1. Basic operating time of rotating capacitors, magnets, rf system.
2. rf repetition rate.
3. beam charge per pulse.
4. fraction of pulses aborted or skipped due to sparks,
5. beam profiles in extraction system,
6. all component failures are logged.
7. shape (intensity vs time) of slowly extracted pulse.
8. when the secondary beams go into operation, similar data will be recorded. This data will be relevant both to machine performance and secondary beam performance.

b. We expect to exhibit between September 30 and December 15 that we can operate the machine for 50% of the 300 hours/month of work scheduled. Furthermore, we expect to run successfully 70% of the time scheduled on a weekly basis.

4. By the end of this period, we should be operating steadily with an overall duty factor $\geqq 50\%$ as determined by standard accidental rate measurements.

5. In this period, all beam lines will be fully tuned and activated with measured performance and good reliability.

6. Remote handling equipment will be capable of replacing components which have suffered long term irradiation corresponding to $\leqq 5$ μA left inside the accelerator.

7. The laboratory should demonstrate a viable plan for improvement of performance such that operation at $\geqq 10$ μA can be expected with an overall reliability of $\geqq 70\%$ of scheduled accelerator time.

8. Obviously, we have as an overriding goal, the ability to operate three simultaneously running physics experiments.

B. RESEARCH PROGRAM

Details of the research program have appeared in the proposal of November and in previous documents. The in-house program is recalled as follows:

1. Search for Direct Leptons, Nevis 22.
2. Backward Proton-Nuclear Scattering, Nevis 13.
3. Muon-Proton Scattering (Proton Charge Halo), Nevis 1a.
4. Inelastic $\pi\pm$ Nuclear Scattering, Nevis 1b.
5. Rare Decay Modes of the Pion, Nevis 3.
6. Muonic Atoms, Nevis 2a.
7. Muon Capture in H_2, D_2, Nevis 2b.
8. Resonance Neutron Time of Flight Spectroscopy, Nevis 7.

The time scale for phasing in these experiments is moderated by (i) the desire to maintain low intensity in the short term period, (ii) the status of similar research efforts in other laboratories, and (iii) the availability of scientific manpower in view of the continuing needs of the accelerator development program.

In this connection we note that several new graduate students are on hand and the Physics Department has forwarded the nomination of two new assistant professors who have expressed great interest in research with the synchrocyclotron: Dr. John Yoh (Ph.D. Cal Tech 1970) and Dr. Jeffrey Weiss (Ph.D. Harvard, 1972).

We now list those programs which we hope will constitute our *initial* program:

Nevis 22—Search for direct electrons (Berliner, Holland, Lederman, Price, Sachs, Storm, Beam III)

This experiment was proposed publicly by L. M. Lederman at the Los Alamos/Sante Fe meeting on High Energy Physics and Nuclear Structure in June, 1975. The objective is to look for the possible existence of a new, short-lived particle of mass $<5M\pi$ and which has a decay mode into electrons. Various high energy experiments have suggested such a possibility. It is an ideal first experiment and we expect to mount it in Beam III during March. We have been developing a Cerenkov counter based on the foam principle to obtain a large rejection against hadrons in a short path length. We can also use a $\sim$2 m gas Cerenkov counter which would give a >1 GeV threshold for muon counting. The residual apparatus requirements are beam counters and PWC's which are available from the scattering group. We are aware of one attempt at Los Alamos to search for these particles and believe our approach should have better sensitivity—note that this is a background, not an intensity problem.

Nevis 13—Backward p-nuclear scattering (Berliner, Lederman, Price, Storm)

This experiment should follow closely on Nevis 22. This experiment, designed to study the short range correlations of large numbers of nucleons, has been planned for many years. It requires a scattered proton beam of $\sim 10^9$ p/sec and is therefore suited to low intensity operation. Here again, the experiment has been attempted at Los Alamos but, in our opinion, far from the desired sensitivity. All the major components of apparatus have been constructed.

Nevis 3—Search for rare decay modes of the pion (Holland, Sachs and Prof. R. Newman, U. Cal., Irvine, Beam II)

The rate of stopped pions from a 1 μA proton beam will be sufficient to make a search for the neutrino-less decay $\mu^+ \rightarrow e^+ + \gamma$ to a sensitivity considerably greater than the present upper limit of 2×10^{-8} of normal muon decay. The apparatus is essentially that which has been constructed primarily to measure the "structure dependent" contribution to $\pi \rightarrow e\nu\gamma$, and the low intensity beam will also permit careful tests of the background for that experiment.

New Program—Investigation of Nuclear Quadrupole Moments from Muonic and Pionic Atoms—The Effect of Strong Interaction on the h.f.s. Splitting and Broadening (Dugan, Chen, Cheng, Lidofsky, Wu, Beam I)

In several very recent experiments in pionic and muonic atoms, there is interesting evidence indicating that certain atoms formed from highly deformed nuclei can be used to make precision determinations of the electro-quadrupole moments. Furthermore, by a comparative study of the quadrupole moments determined from muonic and pionic atoms of the same nucleus, one can evaluate the strong interaction shift and width of the 4f level in the pionic atom.

The reason for strong h.f.s. splitting and broadening is fundamentally very simple but intriguing. The different hyperfine states reflect simply different orientations of the nucleus and the plane of the atomic orbit. Clearly, for a deformed nuclear "cigar" the ends are much closer to the circular orbit if the "cigar" lies in the plane than if it is perpendicular to it. The strong interaction shifts and widths are therefore bigger in the first case. This type of investigation will not only yield precision determination of the quadrupole moment of certain nuclei, it will also offer a novel means to study the strong interaction in h.f.s. splitting.

Excitation of Nuclear Rotational Spectra in Pion Capture in Nuclei (Dugan, Chen, Cheng, Lidofsky, Wu)

In several cases of the absorption of stopped pions in heavy nuclei, highly excited rotational levels of spin I ~37/2 have been observed from the target nuclei after the removal of several neutrons. These observations are not only extremely intriguing but could be of considerable potential use. Although the mechanism of this process is not known, a likely hypothesis is that one of the two fast nucleons produced in the π absorption in the nuclear surface escapes with a large amount of angular momentum while the other one sticks in the nucleus. A selective study of this new phenomena may lead to understanding a new mechanism of nuclear excitation.

Precision Measurement of $m\mu$— (Dugan, Chen, Cheng, Lidofsky, Wu)

Precision measurements of the profile of the Pb K absorption edge make possible precision measurements of muonic x-ray energies in P. The 3d→2p transition of the muonic phosphorous atom falls precisely on the K-edge of Pb, the exact shape of which has been accurately measured by Bearden. By using the same calibrated foils used in the absorption edge measurement, the muonic 3d→2p transition energy may be accurately measured, from which a precision determination of the muonic mass may be made. We hope to do this experiment with a low intensity Nevis μ^- beam using a Ge(Li) crystal with an energy resolution of better than 1%. Previous measurements of the muon mass by this technique used γ-ray detectors with energy resolutions from 10–20% (NaI and Proportional counters); use of the high resolution Ge(Li) crystal will allow the separation of the muonic line from nearby background peaks (e.g., from muonic carbon x-rays and electronic Pb x-rays) which was not possible in previous experiments. An accuracy of ~50 ppm in the muon mass should be achievable with ~10^8 μ^- stops, which can be accumulated in a few days even with a low intensity muon beam of ~20,000 μ^-/sec.

IV. Time Table and Plans for Achievement of Operation Goals

A. Low Intensity Beam.
Some Beam on Target *March 10.*
½ μA Beam on Target for Experiment: *March 15–30.*
Some Beam on Target for line tuning and measuring.
Set up and Test of Experiments *March through May.*
B. Remote Handling and New Channel—Necessary for Raising Beam Intensity.
1. Finish Construction of Channel: *April 30.*
2. Power Supply.
a. Delivery *April 1.*
b. Install and Test *April 30.*
3. Channel Installation, Remote Apparatus.
a. Complete and Test Mockup: *April 30.*
b. Correct Any Problems: *May 30.*
c. Install Tracks in Chamber and Test: *June 30.*
C. Bump Coil and Remote Handling.
1. Finish Radiation Hardened Bump Coil: *April 15.*
2. Finish Remote Insertion Device: *April 1.*

3. Install Tracks and Test Remote Handling: *June 30.*

D. New Iron Channel, Current Iron Channel.

1. Finish Construction: *April 30.*

2. Install Remote Mechanism: *June 30.*

E. Replace Present rf Filters with High Power Components: *April* (necessary to run 300 pulses/sec).

F. Miscellaneous. Completion of Spare Rotors: *April 1.* Completion of New Stators: *May 15.*

Thus this plan will enable us to use the present beam at the full rep rate and thus put up to 6 μA on target. The main limitation to doing so at present is the difficulty in maintenance or repair on the current channel. Once the remote handling is available (after June), we will be able to safely leave several μA of beam in the machine. Also, the extraction efficiency will be increased to 70% with the new channel.

G. Operation at 1 to 5 μA: *July.*

During initial operation of the new channel and bump coil, we will limit the beam to 1 μA. By the end of July we expect to have 5 μA on target. During July we expect to devote 100 hours to experiments.

H. Installation of NVS Pulser and Target: *August.*

I. Raise extracted bean intensity from 5 to $\geqq$10 μA.

1. Remote Handling Equipment Tested: *June 30.*

2. New Channel and Bump Coil proven in operation for two months: *September 30.*

3. Ion Source Developments.

a. Develop new tip with better ion extraction: *July 31.*

b. Develop new pulser to produce longer pulses: i. design: *June 30*; ii. build: *August 30.*

(At present, the phase acceptance time is only half-filled).

J. Run primarily for experiments *after September 15.* For the 3 months between Sept. 15 and Dec. 15, we expect to devote at least 150 hours/months to experiments.

V. Minimum Criteria to be Met by December 15, 1976 for Continuation of Funding for the Nevis Synchrocyclotron (S.C.)

The Nevis Staff believes that, if the following *minimum* criteria are not achieved by 15 December 1976, the prospects for success of the S.C. Program will have been so diminished that we would consider the project unworthy of further investment of funding and effort.

Criteria: By 15 December, the accelerator should have been operated at an average intensity of $\geq$3 μA for a substantial fraction of scheduled time such that an integrated intensity on target of $\geq$750 μA hours will have been achieved over the time period $\sim$ Sept. 15–Dec. 15. (We have 900 hours scheduled for this period.) During this operation, all beam lines would be activated; the transmission, defined from 20 MeV to target, should be greater than 50%; the duty factor should be $\geqq$50% multiplied by f, the fraction of the maximum number of plses per sec (300). In turn, f should be $\geqq \frac{1}{2}$.

In addition, the accelerator should have a demonstrated reliability of $\geqq$50% of the time scheduled in advance for machine operation. Finally, there should be a clear understanding of any factors which limit the performance and a demonstrated capability of achieving all of the goals listed in Sec. III in the next year. A time table for reaching the goals should exist and be convincing to the NSF Staff and to any Review Group.

VI. Budget Justification

A.B. SALARIES, WAGES AND FRINGE BENEFITS, $731,000

We plan to add 1 Research Associate to the Staff, in addition to the Accelerator Physicist to be selected from several candidates in early 1976. The Accelerator Physicist will be a permanent member of the Nevis Staff. He may eventually devote up to half his time to experiments, but for the coming year, he will work entirely on the cyclotron. He, Dr. Cohen and Dr. Holland will form a group of permanent staff physicists working more than half-time on the cyclotron. This group is augmented by Professors Dugan, Sachs and Storm. The Research Associate will work with Professor Rainwater on the NVS Project, and will aid in the installation and running of NVS. There will also be three graduate research

assistants added to the scientific staff after the first three months of the budget. Both the Research Associates and the four graduate students will be working extensively on either the accelerator or the secondary beams during the coming budget year.

The engineering staff includes 1 operating engineer in charge of the cyclotron, 1 rf engineer, 3+ F.T.E. senior mechanical engineers, 1 jr. mechanical engineer, 1 F.T.E. electronic engineer. This last category includes 1 man who spends part of his time upgrading and maintaining the EMR 6130 computer.

The planned level of our supporting staff is adequate for the operation of the S.C. Of the 6 cyclotron operators and 6 maintenance men, 2 in each group will be on shifts, leaving the other 4 to maintain and repair the vast amount of equipment necessary to run the cyclotron, do rigging, assist the experimenters and help build and install new equipment for the cyclotron. Of the 5½ general technicians, a crew of 2, partly supervised by the junior engineer, will be on permanent second shift both to expedite the construction of new experimental or cyclotron equipment and to help the experimental groups on the floor if more manpower is needed than the second-shift maintenance men can provide. In addition, these second-shift technicians will continue to provide extra help in repairing and servicing components of the cyclotron in order to minimize downtime.

C. Permanent equipment	$6,000
Remote manipulator fixtures	3,000
Spare vacuum capacitors	2,200
Spare freon pump	800
D.1. Equipment built at Nevis	55,000
Operations	40,000
New ion source pulser	3,500
Control and monitoring equipment for rf	1,000
Modifications to remote handling system	3,000
Add beam defining slits to secondary beam lines	7,000
Spare beam stop	12,500
Power distribution for experiments	3,000
Partially equip four experimental counting rooms	10,000
Research	$15,000
μP nuclear pp backward:	
Steel plate	1,000
Material for stands	500
Small parts	1,500
	3,000
Rare decay of pion:	
Complete magnet	2,000
Cables, lightpipes, PM's, etc	2,000
	4,000
Neutron velocity spectrometer:	
Complete all internal parts of cyclotron for NVS work	8,000
D.2. Expendable supplies	82,000
Operations	59,000
Vacuum system (including Liquid N_2)	5,300
Ion source	1,100
rf	2,200
Extraction	1,500
Remote handling	1,100
Console	1,500
Beam transport	1,500

Beam stop	700
Electrical motors and controls	700
Cooling system (including freon and H_2O treatment)	8,300
Electronic replacements	1,500
General replacements	6,000
	31,500

In addition, there is the general operation of this laboratory as noted in the following table.

Stockroom	$16,000
Vehicles maintenance operator	1,500
Xerox, post office	6,000
Computer, office supplement	3,500
Health and safety	3,500
Machine shop supplement	5,500
Electronic shop, drafting, and test area supplies	3,000
	39,000

This will be split as follows: 70% for operations: $27,500; 30% for research.

Research	$23,000

Mesic X-rays:	
Liquid N_2	1,000
Computer tapes, Miscellaneous small parts	500
	1,500
Neutron velocity spectrometer:	
Rental of separated isotopes	3,000
μP, π nuclear, pp backward:	
Gas for spark chambers	3,000
Computer tapes	1,000
PM, miscellaneous small parts	1,000
	8,000
Rare decays:	
Gas for chambers	1,000
Miscellaneous parts	1,000
	2,000
30 percent. of general lab operations	11,500

POWER CALCULATION

	Peak	Scheduled hours	On factor	MWH energy	Cost
April	2.4	250	0.7	420	35
May[1]	2.5	300	.7	525	41
June[1]	0.7	0	----------	216	15
July[1]	2.5	300	.7	525	41
August[1]	.7	0	----------	216	15
September[1 2]	1.9	300	.7	399	31
October	2.5	300	.7	525	40
November	2.5	300	.7	525	40
December	2.5	300	.7	525	40
Subtotal					298
					[3] —21
Total					277

[1] Summer rate.
[2] NVS.
[3] 21 K is the amount paid by CU and the High Energy Grant.

Note.—It is assumed we will be shut down in June to install the new current channel and ot er devices in the chamber; also to install the NVS equipment in August.

VII. Impact of Reduced Budget on the Nevis Program

The originally submitted budget of $2.6 million for 12 months reflected our best estimate of what was needed to complete the accelerator, strengthen its reliability, develop facilities for users, and support an active in-house research program.

In order to reduce the budget to $1.5 million for 9 months, the major deletions which have been made are (see Sec. III, table I) :

1. Research Staff. The number of Research Associates devoted exclusively to in-house research has been reduced from 4 to 2 and the number of Graduate Research Assistants has been reduced from 5 for 9 months to 4 for 6 months.

2. Equipment and Supplies for Research. Permanent Equipment (C) for research has been deleted. More than half of the equipment to be built at Nevis for Research (D.1) has been deleted. Expendable supplies (D.2) allocated to research for the 9-month period, have been reduced by 35%.

3. Equipment and Supplies for the cyclotron and user facilities. The computer for logging and monitoring cyclotron operation has been deleted. Funds for increasing and updating the user equipment pool have been deleted. Funds for fitting out counting rooms for users have been reduced by 70%. The hydrogen exhaust system and upgrading of the pump house have been deleted, along with a number of improvements planned for the rf and extraction systems of the cyclotron.

4. Power costs. The funds for power for cyclotron operation have been reduced.

In submitting the reduced budget, we have made every effort not to impede the completion of the accelerator itself; however, the ability to support users of the accelerator during this period will be hampered and the in-house research experiments will be stretched out where necessary.

The major impact of deletion (3) will be to postpone the time when Nevis will be able to provide many of the facilities and equipment which outside users and in-house research groups have come to expect at most accelerators.

The reduction in power costs (deletion 4) is accounted for by: (a) the revised plan for two (instead of one) months of no operation, during one of which the new extraction elements and remote handling apparatus will be installed and during the second of which the NVS system will be installed; (b) a reduction from 15 to 10 shifts per week during October, November and December when full-scale operation is expected; and (c) postponement of the ability to use the three secondary beam lines simultaneously at full magnet power—e.g., operation of beam line III may be only for pions and muons and not for (higher momentum) protons.

We reemphasize that completion of the cyclotron will not be seriously affected by the reduced budget, since most components will have been acquired and most of the cyclotron staff will be retained. This will be achieved, however, at the cost of delay in the full exploitation of the Nevis beams, and the postponement of improvements in future cyclotron operation.

VIII. Scheduling, Reporting and Records

We will issue bi-monthly progress reports stating in detail the progress toward the goals listed in Sec. V. In addition, the reports will detail the current status of the project in such a way that they will present a complete history to any outside consultants called in to review the progress of the accelerator.

We will make a weekly schedule of cyclotron activities which will be prepared together with a summary of the previous weeks achievements. These schedules and summaries will be circulated among the staff and will be kept on file.

Along with the schedule, we will make a detailed cyclotron run plan. This plan will state the purpose of operation, and the anticipated machine performance. Then the hourly record of component failures will be appended to the run plan, indicating whether the failure defeated the primary purpose of operation. If a secondary purpose of operation can be substituted without interfering with the long range development, this will be done and noted in the run log. In addition, the integrated beam on target will be recorded and compared to that of the run plan.

We have scheduled 300 hours/month, which is based on a 5 day week with 2 shifts per day, with 1 day/week devoted principally to scheduled maintenance.

Dr. WRIGHT. Actions of the National Science Foundation must always be taken within the total national perspective, as best that can be determined.

It is quite common that special study groups, committees, or panels are convened to help in such a determination. Among the more ambitious efforts of this nature have been the Bromley panel, in the area of physics, and the Greenstein panel in astronomy.

Frequently, smaller efforts are undertaken with the more limited objective of commenting upon a particular subdisicipline. In 1974, the Atomic Energy Commission, now the Energy Research and Development Administration, and NSF jointly convened a committee to review U.S. Medium Energy Science, the Hildebrand committee, for that purpose.

That committee sent subcommittees to visit each of the major, relevant facilities: the Bates Electron Linear Accelerator at MIT, Nevis, Space Radiation Effects Laboratory in Langley, Berkeley, Indiana, Los Alamos Meson Physics Facility, and Stanford. Their comments and recommendations are contained in a report issued in September, 1974, with which the members of this committee and its staff are familiar.

A valuable internal management tool at NSF is the NSF Physics Advisory Panel, consisting of 14 physicists from throughout the country, who meet twice a year. This panel keeps constant watch over the Foundation's physics programs in the country in the context of the overall national picture.

This panel has discussed with us the problems associated with funding major facilities while at the same time maintaining a national research program on a broad front.

The ultimate funding decisions on large projects the size of Nevis reside with the National Science Board. The National Science Board is required by law to decide on proposed funding for all such large projects.

Of course, the board can and does review smaller projects, particularly those in new programs or other areas of particular interest. This review is a heavy responsibility for both the Board and NSF staff.

Again, with the committee's permission, I would like to provide for the record a copy of the material presented to the National Science Board last March, material which preceded NSB's decision to approve support for Nevis for a further year.

Chairman SYMINGTON. It will be made a part of the record.

Dr. WRIGHT. Thank you.

PHYSICS RESEARCH PROGRAM AND SYNCHROCYCLOTRON OPERATION

Columbia University, New York, New York; Leon Lederman, James Rainwater, Allan Sachs, Chien-Shiung-Wu, Department of Physics, Nevis Laboratories; Twelve months; $2,100,000.

DESCRIPTION OF THE PROJECT

Columbia University's Nevis Synchrocyclotron Facility was constructed with ONR support, beginning in 1946. The Synchrocyclotron first operated in 1950 permitting an excellent and extremely productive research group to de-

velop. NSF support, beginning in 1966, has been provided by grants GP–2606, GP–8943, GP–22786 and now MPS75–17396.

In 1966 a design study for modification of the Synchrocyclotron was performed under grant GP–6205 and a major modification was funded in 1967 under grant GP–7177. This modification was to raise the energy, intensity and quality of the proton beam. This would extend and improve the capability of the machine to produce secondary beams of neutrons, pions and muons with which to study elementary particle properties, nuclear properties and fundamental symmetry laws. The Synchrocyclotron was shut down in 1970 for installation of the major new equipment. The modified Synchrocyclotron is not yet in full operation, though both internal and external beams have been produced for developmental purposes. It is hoped that 1976 will see the commencement of the research program.

The modification of the Synchrocyclotron is expected to make the machine strongly competitive with other "meson factories" initiated at about the same time and presently just coming into full operation. The Nevis Synchrocyclotron will not have such high beam intensities as will be available at the Los Alamos Meson Physics Facility (LAMPF) but will have the advantage of a good duty factor (50%) which is very important for coincidence experiments such as identification of rare decay modes and observation of reactions leading to multiparticle final states. The program is strengthened by the mutual stimulation of the intermediate and high-energy physics programs at Nevis and by the interaction with the strong Columbia University theory group. The relative smallness and flexibility of the Nevis operation are expected to encourage speculative experiments that might be more difficult to stage in a more formalized atmosphere surrounding a machine representing an investment ten times larger, as at LAMPF. Consequently, the Nevis group and the Nevis facility will play an important role in this area of research.

RESEARCH ACTIVITIES

There is a long history of important achievements at the Nevis synchrocyclotron in the fields of muon and pion physics and in neutron resonance spectroscopy. These research activities continue to probe the frontiers of knowledge in several fundamental fields of physics; strong and electromagnetic interactions, weak interaction processes, and atomic and nuclear structure problems. Although the Synchrocyclotron is low in particle energy compared to a number of other accelerators, much of the work using it will be among the most fundamental being carried out in elementary particle physics, as well as in nuclear structure and atomic physics.

The Nevis Laboratory is also the base of operations for a number of "user groups" supported for work at various higher energy accelerators located elsewhere. Thus, the research staff involved with the NSF-supported synchrocyclotron research has valuable opportunities for interaction with researchers and ideas which have contributed substantially to the entire field of particle and nuclear physics.

The research program in preparation includes about twenty different experiments. Some of the major ones are described in Appendix I.

OUTSIDE USERS

With the completion of the major modifications and the building expansion carried out in the past few years, the laboratory is changing its original character of serving mainly the Columbia staff's research needs. There is a strong Program Advisory Committee including members of national eminence, and users from many universities expect to participate in the program. These include New York University, College of William and Mary, Yale, Northwestern, Pennsylvania State, University of Chicago, Wisconsin, and the University of Virginia. The attached budget follows the customary practice of including funds for all operation of the accelerator without regard to the institutional affiliation of the users; but includes research support funds only for the scientists from Columbia University. Experiments of non-Columbia users are

funded through the research programs of various government agencies including NSF.

PERSONNEL

The programs described in Appendix I are the work of the highly experienced staff of the Nevis Laboratory under the direction of Dr. Leon Lederman, as well as a number of users from the other parts of Columbia and from outside institutions. In addition to the four principal investigators, Dr. Min-Yi Chen, Dr. G. Dugan, Dr. Lawrence Price and Dr. Derek Storm are faculty members associated with this project. Dr. Storm is the Accelerator Director. The personnel also include seven research associates and fifteen non-faculty professionals, five graduate students and eight undergraduate. (A biographical sketch of the principal Nevis scientists involved with this NSF grant is given in Appendix II.) There is in addition, close and fruitful interaction with other members of the Nevis staff carrying out the high energy physics program under separate support.

REVIEW AND PROGRAM MANAGEMENT

When the improvement program was initiated in 1966, and in subsequent years, mail reviewers consistently recognized the brilliance of the Principal Investigators and the high probability that results of fundamental importance would be obtained with the improved Synchrocyclotron. The important part to be played by the Nevis Synchrocyclotron in the national program was recognized by a joint National Science Foundation-Atomic Energy Commission (now ERDA) Committee to Review U.S. Medium Energy Science, which reported on September 16, 1974. Programs and facilities relevant to this area of physics are supported by both agencies and it was desirable to see a single national perspective or critique. The committee was asked to provide recommendations for program priorities among medium energy research activities based on three different assumptions for budgetary levels through FY 1979. The Committee felt that for many reasons it would be valuable to maintain the Nevis Synchrocyclotron throughout this period, in addition to the LAMPF linear accelerator at Los Alamos. Concerning synchrocyclotrons they recommended that "if they (Nevis) reach their design performance levels, as we expect, the two older cyclotrons (LBL 184-inch and SREL) will no longer be competitive and should, we believe, be shut down by the end of the period even at high budget levels". On the other hand, they stated that "construction at Nevis is essentially complete but the committee does feel concerned about the progress in achieving an accelerated beam. The committee feels that the schedule for achieving a high level of performance at the Nevis cyclotron, or even for achieving an internal full energy beam, is not predictable now with certainty. It would be imprudent, however, to wait indefinitely for the machine to become operational. As a minimum we expect a full energy internal beam to be produced by Fall 1975." "The committee also recommended that "In the unlikely event that the Nevis machine fails to live up to expectations . . . serious consideration should be given to major upgrading and modernization of the SREL facility . . . coupled with a compensating decrease in support for Nevis".

In the 17 months since the above committee report, Nevis has made progress towards, but has not yet achieved, full operation. The minimum goal recommended by the committee of full energy internal beam by Fall 1975 was in fact reached in January 1975; a small external beam sufficient for test purposes was obtained in September 1975. It is now accepted that the modification is successful in principle. However, several serious problems remain to be solved, particularly in the radiofrequency system.

On November 5, 1975, a Technical Review Committee of two accelerator physicists and one engineer visited Nevis accompanied by NSF staff members to conduct a detailed technical review of the Synchrocyclotron modification program. This committee, originally formed in 1973, had periodically reviewed progress. The committee reported that "over the past two years slow but significant progress has been made in the areas of understanding and proving out the basic elements of the re-built Nevis Cyclotron; no fundamental accelerator physics problems appear to exist . . ." They found progress in the major areas which had previously been of concern. However, they expressed new concerns, in particular about the radiofrequency system, and the absence of user evalua-

tion of the external beam. The committee noted that "tune-up, shake-down and modification, and start-up are likely to take at least six months and can take longer than a year if problems persist in the RF and extraction system". Nevertheless, "the committee notes that the appointment of Derek Storm as Project Director (two years ago) has brought about a major improvement in the cyclotron management picture. This improvement in management capability is recognized in each area of the machine and the new method of reporting progress against milestones is indicative of the interest now being paid to management problems". However, they said that "the committee is concerned by the apparent temporary status of Storm, which seems inconsistent with statements describing strong backing of the project by the Physics Department at the University".

An extensive mail review has been conducted over the last two months and ten reviews have been received. The reviews reflect the concerns expressed above, particularly the contrast between the brilliance of the principal investigators and the very poor progress that they have made over the years in bringing the improvement program to completion. A serious worry is that the principal investigators may be overcommitted to experiments done elsewhere, and are not devoting enough of their attention to this project. The reviews recognize correctly that the situation at Nevis is disturbing the scientific community and, that it is time for Nevis to fish or cut bait. The ratings by the reviewers range fairly uniformly from "excellent" to "fair" while the predominant recommendation is that a short final opportunity should be given, under stern control, for the team to demonstrate their ability to operate the Synchrocyclotron. The large majority consider the funding level requested by the Principal Investigators excessive under the present circumstances.

In view of the progress made in the last year towards operation of the facility, it seems that the Nevis Synchrocyclotron can eventually become a productive facility. However, because of the serious difficulties still to be faced, only one year's approval by the Board is requested in order that the Board shall have an opportunity to review the project at an early date, particularly since the initiation or non-initiation of the Nevis experimental program is expected to have a major impact on other needs such as at SREL. Furthermore, while the Principal Investigators request a grant of $2,614,000, a review and analysis of the situation indicate that a constructive grant will be possible at a significantly lower level of support. The authorization requested from the National Science Board is therefore reduced to $2,100,000 (including support for Rainwater's neutron velocity spectrometer research, which is no longer supported by ERDA). Within this authorization a grant will be negotiated which concentrates the effort towards bringing the facility into productive operation. An improved management plan incorporating agreed-upon performance goals and deadlines will be devised. Further funding of the Synchrocyclotron would be contingent upon performance measured in terms of these goals and deadlines.

GRADUATE STUDENTS

The training of graduate students has always been a major contribution of the Nevis Laboratory. According to the proposal, 83 graduate students have obtained their Ph.D. degree for work performed with the synchrocyclotron, or for theoretical work based on experiments using it. Many of these graduates can be found successfully associated with nuclear or particle physics laboratories throughout the world. The Synchrocyclotron has also been an important training ground for post-doctoral physicists and many well-known physicists have emerged from the program.

APPENDIX I

MAJOR RESEARCH EFFORTS PROPOSED

1. MUON-PROTON SCATTERING

This experiment will search for long-range charge structure in the proton by scattering muons off protons. An electron scattering experiment has found an oscillation about the dipole form factor which may be attributable to an extended charged halo around the proton. Muon scattering will provide a detailed examination of parts of this form factor. The use of muons has several virtues since absolute cross sections must be measured and radiative correc-

tions for muons are very small. The demands of the experiment place major emphasis on the instrumentation, the good duty cycle and (to a lesser extent) on the anticipated intensity.

2. PION-NUCLEUS SCATTERING

Since the pion is the principal carrier of the nuclear force which binds nucleons in the nucleus, it is important to understand the interaction of pions with nuclei. This experiment will test theories which are developed from the fundamental pion-nucleon interaction to describe pion-nuclear scattering.

3. RADIATIVE DECAY OF THE PION

A small part of this radiative process involves photons emitted from the "core" of the weak interaction. This emission depends on the structure of the weak interactions, and nuclear current algebra calculations lead to predictions for the vector and axial vector parts of the weak interaction current. The precision of the proposed measurement provides a critical test of current algebra, the PCAC (Partially Conserved Axial Current Hypothesis), coupled with assumed contributions of the pion, the rho and A_1 vector mesons. A further interest lies in the comparison of the vector part (as determined here) to the lifetime of the neutral pion, to which it is related by CVC (Conserved Vector Current).

4. BACKWARD PROTON SCATTERING

Correlation effects, or small distance clustering, have not been clearly established. Backward proton scattering will establish the limits of existence of many-nucleon short-range clustering even if this constitutes a very small part of the total nucleon wave function. The experiment opens an entirely new domain of physics far outside the scope of classical nuclear physics. For example, the probability that 200 nucleons in lead all coalesce into a volume of radius 10^{-4} cm can be measured. It is possible that such an extreme state of matter is not rare and could provide a laboratory in which one can study totally new properties of matter in a condition which is speculated to occur in the cosmos when a neutron star is formed. This experiment is related also to the proposal by T. D. Lee and G. C. Wick that an abnormal state of nuclear matter could possibly be produced in sufficiently dense nuclear matter.

5. EXPERIMENTS WITH STOPPED MUONS

An extensive program is planned for the stopped muon beam. This includes an attempt to measure separately the rate of muon capture in hydrogen in both the singlet and triplet bound states, to give information on the weak axial-vector form factors; a search for metastable 2s states of muonic atoms, which if found will provide an opportunity to study the weak currents; precision measurements of the mass of the negative muon will be made in a variety of ways.

6. NEUTRON VELOCITY SPECTROMETER MEASUREMENTS

Professor Rainwater will continue his program of studying with extremely high resolution the level densities of nuclei near the neutron capture threshold. The measurements have led to significant new developments in the characterization of statistical equilibrium and the formation of the concept of randomness at the level of individual quantum states of a many-body system.

7. SPECULATIVE EXPERIMENTS

The group, following its tradition of speculative experimentation is considering the possibility of looking for violation of baryon conservation in proton-proton collision; observation of weak interactions between strongly-interacting parties by means of strangeness-changing transitions; search for new particles in the mass region between one and three pion masses.

8. USER PROGRAM

In addition to the above experiments there is an extensive list of outside users who expect to use the facility and who have had their experiments approved by the Program Advisory Committee.

APPENDIX II

Leon Lederman—Ph.D. Columbia, 1951; Columbia University, 1951 to present; Higgins Chair of Physics, 1972; Member NAS, 1965; Recipient, National Medal of Science, 1965.

James Rainwater—Ph.D. Columbia University, 1946, to present; E.O. Lawrence Award in Physics 1963; Member NAS, 1968, Nobel Prize for Physics, 1975.

Allen Sachs—Ph.D. Harvard University, 1950; Columbia University, 1949 to present.

Chien Shiung Wu—Ph.D. University of California, Berkeley, 1940; Columbia University, 1944 to present; Pupin Chair of Physics 1972; Member NAS, 1958; President American Physical Society, 1975. Numerous honors and awards.

Min-Yi Chen—Ph.D. Princeton University, 1968; Columbia University, 1968 to present.

G. Dugan—Ph.D. Harvard University, 1970; Columbia University, 1970 to present.

Lawrence Price—Ph.D. Harvard University, 1970; Columbia University, 1970 to present.

Derek Storm—Ph.D. University of Washington, 1970; Columbia University, 1970 to present.

APPENDIX III

12-MONTH BUDGET

	Operation	Research
A. Salaries:		
Senior personnel:		
(1) 4 Coprincipal investigators (6 academic months; 5 summer months)	$17,000	$26,000
(2) 4 faculty associates (10 academic months; 6 summer months)	14,000	13,000
Other personnel:		
(3) 7 research associates (75 calendar months)	55,000	38,000
(4) 15 Nonfaculty professionals (110 calendar months)	133,000	61,000
(5) 5 graduate students (45 academic months; 15 summer months)	5,000	17,000
(6) 8 prebaccalaureate students (24 summer months)	6,000	4,000
(7) 13 secretarial (67 calendar months)	37,000	25,000
(8) 37 technical (435 calendar months)	359,000	87,000
(9) Overtime	10,000	2,000
B. Total salaries and wages	636,000	273,000
C. Fringe benefits	107,000	47,000
D. Total salaries, wages and fringe benefits	743,000	320,000
E. Permanent equipment	86,000	42,000
F. Expendable equipment and supplies	174,000	84,000
G. Travel	4,000	3,000
H. Publications	3,000	3,000
I. Other costs (mainly electrical power)	600,000	55,000
J. Total direct costs	1,610,000	507,000
K. Indirect costs	386,000	111,000
L. Total costs	1,996,000	618,000

Dr. WRIGHT. At that time, the Board had in hand the file relating to the Nevis project and specifically discussed the details of the revised plan and budget under which Nevis is now operating.

Mr. Chairman and members of the committee, I hope this account has given you some picture of how we have proceeded in handling NSF support for the Nevis facility, and some of the generalizations that can be drawn from this experience. No two facilities of this size are ever entirely alike.

There is a very real challenge for those who seek to improve the tools by which research is carried out. It places an equally great challenge on the management oversight of such efforts. We have learned from our past experience, but we must also be prepared to meet further changes that new situations may require.

I should be happy to try to answer any questions you may have.

Chairman SYMINGTON. Thank you very much, Dr. Wright, for that informative testimony.

Before we get to the questions, I think we'll proceed directly to hear from Dr. Lederman, of the Nevis Laboratories.

[A brief biographical sketch of Dr. Leon M. Lederman follows:]

Leon M. Lederman, Professor of Physics, Director, Nevis Labs; 1943, B.S. City College of New York, 1948, A.M. Columbia University, 1951, Ph.D., 1943–46, U.S. Army 1951–present, Columbia University. 1965, Elected to National Academy of Sciences, 1965, National Medal of Science Recipient.

STATEMENT OF DR. LEON M. LEDERMAN, DIRECTOR, NEVIS LABORATORIES, DEPARTMENT OF PHYSICS, COLUMBIA UNIVERSITY

Dr. LEDERMAN. Mr. Chairman, it's a real pleasure to meet with Members of Congress who are concerned with science, and whose perceptions in the past 30 years have made possible the great eminence of science in this country.

I would like to ask your permission, in the interest of brevity, to submit the list of attachments to which I might refer from time to time.

Chairman SYMINGTON. Fine.

[The material referred to follows:]

(Attachment I)

NEVIS PROGRAM ADVISORY COMMITTEE, 1971–76

Prof. G.T. Garvey, Princeton University
Dr. M. Goldhaber, Brookhaven National Laboratory, Director
Prof. V. Hughes, Yale University
Prof. J.M. Miller, Columbia University, Chemistry Dept.
Prof. R. Serber, Columbia University, Physics Chairman
Prof. V.L. Telegdi, University of Chicago
Prof. J.D. Walecka, Stanford University
Prof. L. Wolfenstein, Carnegie-Mellon University
Prof. C.S. Wu, Columbia University

NEVIS PROGRAM ADVISORY COMMITTEE 1976

Prof. P. Barnes, Carnegie-Mellon University
Prof. K. Crowe, Director of Lawrence-Berkeley Cyclotron Lab
Prof A. Goldhaber, SUNY at Stony Brook
Dr. M. Goldhaber, Brookhaven National Laboratory
Prof. V. Hughes, Yale University
Prof. J.M. Miller, Columbia University, Chemistry Dept.
Dr. F. Scheck, Institut fur Physik, Mainz, Germany
Prof. R. Serber, Columbia University Physics Chairman
Prof. R. Siegel, William and Mary College, Director, SREL
Prof. J.D. Walecka, Stanford University
Prof. C.S. Wu, Columbia University

78–882—77——11

(Attachment II)

NEVIS PROPOSAL LIST

Proposal No. 1a—To Measure Muon-Proton Elastic Scattering at Very Low Momentum Transfer. E. Aslanides, L. Lederman, L. E. Price, D. W. Storm, E. Picoult, S. White, *Columbia University.*

Proposal No. 1b—Proposal for a Survey of $\pi^{\pm}$ Scattering by a Range of Nuclei. E. Aslanides, L. M. Lederman, L. E. Price, E. Picoult, D. W. Storm, S. White, *Columbia University.*

Proposal No. 2a—The Measurement of the 2s→2p Transitions in Muonic Atoms I. and II. C. S. Wu, M. Y. Chen, S. C. Cheng, Y. Asano, E. Hu, *Columbia University;* V. W. Hughes, R. D. Ehrlich, D. C. Lu, P. Egan, *Yale University.*

Proposal No. 2b—Muon Capture in Gaseous Hydrogen and Deuterium; Measurement of Singlet and Triplet Rates in Hydrogen. V. W. Hughes, R. D. Ehrlich, D. Lu, P. Egan, *Yale University;* H. M. Foley, C. S. Wu, M. Y. Chen, S. C. Cheng, Y. Asano, E. Hu, *Columbia University.*

Proposal No. 3—To measure the Rare Decay, $\pi^{+} \rightarrow e^{+} + \nu + \gamma$. M. Holland, R. Newman, W. Orance, A. Sachs, L. Teig, *Columbia University.*

Proposal No. 4—Precision Measurement of Soft x-rays from Muonic and Pionic Atoms. B. Budick, S. Derman, *New York University.*

Proposal No. 5b—Search for the 2s Metastable State of Muonic Hydrogen. P. Egan, D. Casperson, V. W. Hughes, M. Camani, *Yale University;* C. S. Wu, *Columbia University.*

Proposal No. 5c—Ultrahigh Precision Measurements of Muonium Ground State Energy Levels: Hyperfine Structure Interval and Muon Magnetic Moment. V. W. Hughes, D. Casperson, T. Crane, P. Egan, P. Souder, R. Stambaugh, J. Wesley, *Yale University;* G. zu Putlitz, *Heidelberg, Germany;* P. A. Thompson, *LAMPF.*

Proposal No. 7—Resonance Neutron Time of Flight Spectroscopy Using the Modified Nevis Synchrocyclotron. J. Rainwater, M. Slagowitz, H. I. Liou, G. Hacken, W. Makofske, F. Rahn, *Columbia University.*

Proposal No. 8—I. Neutrino Interactions of Astrophysical Interest at the Los Alamos Meson Physics Facility (LAMPF);

II. Measurement of the Mass of the Muon Neutrino. S. Meyer, J. Keren, *Northwestern University.*

Proposal No. 10—Gamma-Neutrino Correlation after Muon Capture. M. Eckhause, J. R. Kane, G. H. Miller, R. E. Wesch, *College of William and Mary.*

Proposal No. 11—Pre-Therapeutic Studies with Negative Pions. P. W. Todd, *Pennsylvania State University.*

Proposal No. 13—Search for Short Range Nuclear Correlations. L. M. Lederman, *Columbia University.*

Proposal No. 14—Precision Measurements of the Muon Magnetic Moment and the Hyperfine Interval of Muonium by "Ramsey Resonance" in High Field. V.L. Telegdi. W. Kells, P.M. McIntyre, *Univ. Chicago;* H. Kobrak, R.A. Swanson, *UCSD. La Jolla;* A. Magnon, *Harvard Univ.*

Proposal No. 17—Measure the Absolute Yield of Gamma-Rays from Radiative Muon Capture in Calcium. R. Siegel, C. Cox, M. Eckhause, R. Hart, J. Kane, R. Welsh *William and Mary.*

Proposal No. 19—Neutrons in Negative Pion Radiotherapy. R. Madey, F.M. Waterman, A. Baldwin, *Kent State Univ.*

PENDING PROPOSALS

"Test of Muon Number Conservation", C.Y. Chang et al, *University of Maryland—Nevis 15.*

"Prompt Gamma Rays from Pion Reactions on Nuclei", W.J. Kossler et al, *William and Mary—Nevis 16.*

"Proposal for Experiments with Polarized Muons Part I. Polarized Muonic ^{209}Bi Atom". T. Yamazaki et al, *University of Tokyo—Nevis 18.*

"Elastic Scattering of $\pi\pm$ —p at 10–100 MeV", M. Blecher et al, *VPI—Nevis 20—Withdraw.*

"Studies of Spallation Reactions of Medium Mass Nuclei Induced by Pions at the Pion Nucleon Resonance Energy", P. Haustein et al, *Yale University—Nevis 21.*

"Search for New Low Mass Structures and Particles", L.M. Lederman et al, *Columbia University—Nevis 22.*

"Investigate the Pionic X-Rays by a Curved Crystal Spectrometer on the Nevis Cyclotron", C.S. Wu et al, *Columbia University—Nevis 23.*

(Attachment III)

Chronological History of Major Nevis Laboratory Research

Synchrocyclotron Research

Date	Work	Authors
1950	First External Pion Beams	Bernardini, Booth, Lederman, Tinlot.
1950–54	Strong Interaction of Pions	Bernardini, Booth, Chedester, Isaacs, Lederman, Sachs, Steinberger, Tinlot.
	Spin and Parity of Pion	Chinowsky, Durbin, Loar, Sachs, Steinberger.
	Lifetime of Pions	Bernardini, Booth, Byfield, Durbin, Havens, Kessler, Lederman, Loar, Tinlot.
	Weak Interactions of Muons Pion-Proton Interactions.	Bramson, Havens, Seifert, Bodansky, Goldhaber, Lederman, Sachs, Steinberger.
1953	First Measurement of Mesic X-Rays, Correct Nuclear Radius.	Fitch, Koslov, Rainwater, Frati.
1952–56	Optical Model for Pion-Nucleus Scattering	Baker, Byfield, Kessler, Edelstein, Lederman, Lindenbaum, Pevsner, Rainwater, Williams.
1955	Rho Value of Muon	Lederman, Rinehart, Rogers, Sargent.
1957	Parity Violation in Pion and Muon Decay	Berley, Coffin, Garwin, Larsen, Lederman, Lubkin, Tausner, Weinrich.
1958	Magnetic Moment of Muon by Resonance Technique	Coffin, Garwin, Lederman, Penman, Sachs.
1959	Parity of the Neutral Pion	Plano, Prodell, Samios, Schwartz, Steinberger.
1960	Discovery of Muonium	Hughes, McColm, Prepost, Ziock.
1956	Slow Neutron Resonance Research: High Resolution Neutron Time of Flight Spectroscopy.	Desjardins, Havens, Rainwater, Rosen, Garg, Ceulemans, Petersen, Wynchank.
1960	Rho Value	Plano.
	First Synchrocyclotron Long Beam by Vibrating Target.	Rosen.
1961	Study of Muon Depolarization Semi-Conductors	Eisenstein, Feher, Prepost, Sachs.
	Measurement of Muonium Hyperfine Splitting	Hughes, Prepost, Ziock.
	200-Meter Flight Path Neutron Resonance	Havens, LeCroy, Rainwater, Rosen.
1962–63	Muon Capture in Hydrogen	Anderson, Bleser, Lederman, Meyer, Rosen, Rothberg Wang, Zavattini.
	Precise Comparison of $\mu^+\mu^-$ Lifetimes	Ibid.
	Resonance Measurement of Muon Moment to 10 ppm.	Hutchinson, Menes, Patlach, Shapiro.
1963	Precise Determination of Rate of $\pi \rightarrow e + \nu$	DiCapua, Garland, Pondrom, Strelzoff.
1964	Rho value of Muon	Bardon, Lee, Norton, Peoples, Sachs.
	Beta Decay of the Pion	Bartlett, Devons, Meyer, Rosen.
	New Value of α from Muonium Hyperfine Structure	Cleland, Bailey, Eckhause, Hughes, Mobley, Prepost, Rothberg.
1965	Search for H^4 and n^4 via π^- Absorption in Lithium	Cohen, Kanaris, Margulies, Rosen.
	High Resolution Measurements of Isotope Shifts in Mesic X-rays.	Cohen, Devons, Nissim-Sabat.
1966–71	Precise Measurements in Muonic Atoms: 1) Magnetic Dipole Hyperfine Structure; Intensity Anomaly; Isotone Shifts; Nuclear Excitation.	C. S. Wu, Lee, Chen, Cheng, Macagno, Hitlin, Kast, Rushton.
1968–71	Refined Measurements on Muonium: Hyperfine Structure, Pressure Shifts.	Hughes, Rothberg, Amato, Crane, Thompson, Zuputlitz, Egan, Stambaugh.
1970–71	Further Refinements in Slow Neutron Resonances	Rainwater, Slagowitz, Hahn, Havens, Camarda, Liou, Hacken, Rahn.

(Attachment IV)

CHART II.—NEVIS AS A PRE- AND POST-DOCTORAL TRAINING LAB

Since 1951, we have graduated *96* students whose work was based on the Synchrocyclotron. These included experimental physicists, some nuclear chemists and several theorists who worked very closely with the experiments. One of these (Leon Cooper: Interpretation of Mu-Mesic X-Rays with James Rainwater) went on to a Nobel Prize in Physics, 1971. Of the remainder, 20 hold senior professorships in major universities, 7 are teaching in colleges, 16 are in industrial laboratories or administration, 18 in government labs or agencies, 12 in university laboratories, 3 have returned to their country of origin, 2 are deceased and rest unknown. About ⅓ are working in other fields: ranging from the bio-medical to college administration. Some of the more notorious of our students have been: D. Bartlett, M. Block, W. Chinowsky, V. Fitch, D. Hitlin, S. Lindenbaum, S. Penman, J. Peoples, A. Pevsner, R. Prepost, J. Rosen, J. Rothberg, N. Samios, M. Schwartz, G. Shapiro. Twenty-Six young post-doctoral physicists have spent at least two years at Nevis continuing their training on the synchrocyclotron and contributing their varied background to the Nevis mix. Some of the more notable were: D. Bodansky, L. DiLella, G. and S. Goldhaber, J. Orear, R. Plano, L. Pondrom, C. Rubbia, J. Tinlot, E. Zayattini.

(Attachment V)

Chart III

Synchrocyclotron facilities:	MeV	Year
Berkeley	300	1946
Rochester	250	1948
Columbia	385	1950
Chicago	460	1951
Carnegie	440	1952
Liverpool	385	1952
Berkeley	740	1957
CERN	600	1958
SREL	600	1965
New medium energy facilities:		
LAMPF	800	1975
Nevis	560	1976
SIN (Zurich)	600	1975
TRIUMF (British Columbia)	525	1975

Note.—All but Columbia, SREL and Berkeley have been terminated.

(Attachment VI)

CHART IV.—MEDIUM ENERGY PHYSICS STAFF

SENIOR STAFF

Leon M. Lederman, Professor of Physics, Director, Nevis Labs—1943, B.S., City College of New York, 1948, A.M., Columbia University, 1951, Ph.D., Columbia University, 1943–46, U.S. Army, 1951–present, Columbia University; 1965, Elected to National Academy of Sciences, 1965, National Medal of Sciences Recipient.

James Rainwater, Professor of Physics—1939, B.S., California Institute of Technology, 1941, M.A., Columbia University, 1946, Ph.D., Columbia University, 1941–46, Manhattan Project; 1963, Ernest O. Lawrence Award in Physics, 1968, Elected to National Academy of Sciences, 1975, Nobel Prize for Physics.

Chien-Shiung Wu, Professor of Physics—1936, B.S., National Central University, Nanking, China, 1940, Ph.D., University of California, Berkeley, 1940–44, University of California, Smith College and Princeton University, 1944–present, Columbia University; 1958, Elected to the National Academy of Sciences, 1975, President of the American Physical Society, 1976, National Medal of Science Recipient.

Allan M. Sachs, Professor of Physics—1942, B.A., Harvard University, 1947, M.A., Harvard University, 1950, Ph.D., Columbia University, 1942–45, Army Air Force, 1967, Chairman, Physics Department, Columbia U.

(Attachment VII)

CHART V

SCIENTIFIC STAFF

Dr. S. Cheng—1966, B.A., M.I.T., 1971, Ph.D. Columbia University, 1971–present, Columbia University.

Dr. R. C. Cohen—1950, B.A., University of Pennsylvania, 1964, Ph.D., Columbia University, 1964–present, Columbia University.

Dr. W. Diamond—1969, B.S., University Waterloo, Canada, 1974, Ph.D., University of Toronto, Canada, 1976, Columbia University.

Prof. G. Dugan—1967, B.S., Iona College, 1972, Ph.D., Columbia University, 1972–present, Columbia University.

Dr. M. Holland—1964, B.S., Clemson University, 1969, Ph.D., University of Virginia, 1969–present, Columbia University.

Prof. L. Price—1965, B.S., Pomona College, 1970, Ph.D., Harvard University, 1970–present, Columbia University.

Prof. D. Storm—1963, A.B., Princeton University, 1970, Ph.D., University of Washington, 1970–present, Columbia University.

Dr. R. Werbin—1963, B.S., R.P.I., 1972, Ph.D., Columbia University, 1972–present, Columbia University.

(Attachment VIII)

TABLE I.—FINANCIAL SUMMARY OF NEVIS OPERATIONS

[15 shifts per week. All figures in thousands (1975 dollars)]

	Fiscal year appropriations [1]					
	1973	1974	1975	1976	1977	1978
Cyclotron experimental areas and operation [2]	1,000	1,270	[3] 1,148	[3] 1,300	[3] 1,500	1,450
Research:						
Columbia experimenters	700	420	600	650	700	750
Research facility support		110	200	250	300	350
Total Nevis budget	1,700	1,800	1,948	2,200	2,500	2,550
Outside users support		200	600	650	700	750
Total support of machine and research at Nevis	1,700	2,000	2,548	2,850	3,200	3,300

[1] The NSF appropriations for Nevis are actually spent primarily in the next fiscal year. That is the May 1, 1974 appropriation covers activities primarily during May 1, 1974 to Apr. 30, 1975. The table gives for 1973 and 1974, the actual appropriations, and for later years the projected needs.
[2] Based on power costs as of spring 1974.
[3] Includes 50, 100, 200 in fiscal years 1975–77 for accelerator improvements.

TABLE II.—FINANCIAL SUMMARY OF NEVIS OPERATIONS AT EXPANDED LEVEL

[21 shifts per week starting in 1976. All figures in thousands (1975 dollars)]

	Fiscal year appropriations [1]				
	1974	1975	1976	1977	1978
Cyclotron experimental areas and operation [3]	1,270	[2] 1,148	[2] 1,492	[2] 1,708	1,682†
Research:					
Columbia experimenters	420	600	650	700	750
Research facility support	110	200	350	420	490
Total Nevis budget	1,800	1,948	2,490	2,830	2,920
Outside users support	200	600	1,150	1,260	1,350
Total support of machine and research at Nevis	2,000	2,548	3,640	4,090	4,270

[1] The NSF appropriations for Nevis are actually spent primarily in the next fiscal year. i.e. the May 1, 1974 appropriation covers activities primarily during May 1, 1974 to April 30, 1975. The Table gives for 1974 the actual appropriations, and for later years the projected needs.
[2] Includes 50, 100, 200 in FY 75–77 for accelerator improvements.
[3] Based on power costs as of spring 1974.

TABLE III.—FINANCIAL SUMMARY OF NEVIS OPERATIONS AT REDUCED LEVEL

[~7.5 shifts per week starting in 1976. All figures in thousands (1975 dollars)]

	Fiscal year appropriations [1]				
	1974	1975	1976	1977	1978
Cyclotron Experimental Areas and Operation [3]	1,270	[2] 1,100	[2] 1,200	[2] 1,000	1,120
Research:					
Columbia experimenters	420	†300	†325	†350	†375
Research facility support	110	150	180	225	250
Total Nevis budget	1,800	1,550	1,705	1,575	1,745
Outside users support	200	300	325	350	375
Total support of machine and research at Nevis	2,000	1,850	2,030	1,925	2,120

[1] The NSF appropriations for Nevis are actually spent primarily in the next fiscal year, i.e. the Mar. 1, 1974, appropriation covers activities primarily during May 1, 1974 to April 30, 1975. The Table gives for 1974 the actual appropriations, and for later years the projected needs.
[2] Does not include any accelerator development funds. However, funding for operations, etc. kept up in 1975–76 to ensure completion of machine.
[3] Based on power costs as of spring 1974.

† The funds indicated here as supporting Columbia experimenters at the Nevis cyclotron operating at such a reduced level are not to be interpreted as adequate to support the research program at Columbia University at all areas of nuclear science.

(Attachment IX)

Appendix I

Medium Energy Physics at Nevis: Details

Medium energy physics at Nevis divides naturally into two categories: I. Fundamental Particles, and II. Structure of Nuclear Matter. The first category is generally dominated by the high energy accelerator, however, Nevis has made many contributions in this field and it continues to be an area of interest. Secondary beams at Nevis consist of pions and muons. Although these particles are in general now very well understood and in fact used as probes in nuclear collisions, there are subtle properties not yet measured. Furthermore, although the pion fits into a broad family of strongly interacting particles, the muon has no strong interaction and its role in the grand organization of particles is still not understood. An anecdote illustrates the principle—

> The muon was discovered in cosmic rays in 1935. Since 1950, it has been made and studied extensively in all of the world's accelerator laboratories. It is known to be born in the radioactive decay of a pi-meson. It was known to have a spin and to decay in turn into an electron and to neutrinos. Interest in muon measurements waned. Then, in 1957, we discovered, at Nevis, that all the muons emerging in a given direction from their pion parents were spinning in the same direction! This was observed in the experiment which established parity violation,[1] in pion and muon decay and gave rise to polarized muon beams. The fundamental law (more properly, lawlessness) that was established was the violation of left-right symmetry in nature. The application is that polarized muons are now routinely used to study magnetic effects in atomic nuclei and to detect and measure interstitial fields in solid state materials. Many further applications are expected.

Several of the experiments now proposed at Nevis intend to further refine the properties of this mysterious particle; one proposes to make an ultra precise measurement of its intrinsic magnetism, one to test the law that the total number of muons and muon-type neutrinos in the universe is constant. (The muon type neutrino was discovered by Nevis physicists at Brookhaven in 1962—a natural continuation of their study of muon properties at Nevis.) We emphasize that the proposed muon experiments require the intensity and good duty cycle characterized by the parameters of the improved accelerator.

Other research deals with the very familiar proton—it is well known that the proton's electric charge is smeared out over a radius of 10^{-13} cm. Most of the charge is heaped up at the center and its shape is well studied by high energy electron scattering e.g., at Stanford. However, it was noted back in 1970 that the change *could* extend out in a wispy tail to quite far distances and none of the experiments so far done would have detected this "halo". Since the proton is the nucleus of hydrogen—a charge halo would also have some effect on notions of atomic structure. In 1976, this issue is still burning and a Nevis experiment is designed to probe the proton charge far from the core, using the new intense muon beams. We emphasize the fact that although the issue was known since $\sim$1970, the resolution still awaits the particular irradiation of the Nevis accelerator.

Picking other examples from our long list, we now discuss the structure of matter using intermediate energy projectiles. Here, we select a unique and (to us) fascinating example: The backward deflection of protons hitting heavy nuclei such as lead, uranium, etc. To find why this is interesting, we must follow the logical process chronologically.

> In 1965, a Nevis group engaged in what has since become a popular pastime—hunting the quark. To study the possibilities of producing quarks in high energy collisions with heavy nuclei, we decided to do an analogue study to answer the question: How much assistance is given to the collision by the "natural motion of the hundreds of protons and neutrons bound in the nu-

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[1] T. D. Lee, C. N. Yang, The Nobel Prize in 1958 for suggesting that the law of conservation of parity could be violated. The suggestive data came from high energy accelerators at BNL and Berkeley. Th first verification was made by C. S. Wu et al in low energy nuclear physics.

cleus? We studied production of antiprotons with bombarding energies too low to make them in simple proton-free proton collisions. Much to our surprise, we found that we could produce antiprotons off uranium targets with protons of 3 billion electron volts *less* than that required of proton-proton collisions. We concluded: Something inside the heavy nucleus encouraged a cooperation between large numbers of protons and neutrons in order to pool their common energy to produce the antiproton. Quantitative data were deduced and the question was then made more incisive: How probable is the close collaboration of the 200 particles in uranium? By close we mean 10^{-14} cm, i.e., the density of matter at that instant exceeds by far the density in a neutron star!

We determined that the backward deflection of protons from the Nevis accelerator would signal a momentary accumulation of nuclear matter.

We expect to run the experiment in the next months, but already the ideas have had intriguing consequences, which are a dramatic illustration of the way physics works—by accident and the close proximity of high energy, medium energy, nuclear and theoretical science.

Professor T. D. Lee of Columbia has spent the past 20 years trying to understand the apparent breakdown of left-right symmetry and of other symmetries in the laws of nature. He speculated that the universe may have a hidden complexity in which the "missing" symmetry could hide. To explore this hidden space, he needed a very strong nuclear force field. In discussion it was determined that the high nucleon density resulting from complex collisions could do it. Further analyses (with Professor G. C. Wick of Columbia) uncovered an amazing result: if conditions were correct, the collision of two uranium nuclei, each with a transient accumulation of density, could result in a new form of stable matter with the release of energy 100 times that of nuclear fusion. The nuclear community received this report with healthy skepticism but a conference, referred to above, held at Bear Mountain, in November 1974, and attended by representatives of all of the great schools of nuclear theory agreed that the Lee-Wick process could indeed take place if certain parameters, not yet established experimentally, were favorable.

At present, the situation awaits results from a uranium accelerator—(Bevalac, soon!).[2] If the Lee-Wick process can be induced (the experiments are very difficult, the probability remote), we could be faced with unusual sources of energy and a periodic table of stable elements which would number 10,000 or more, instead of the present $\sim$ 100. The implications for technology are vast. But the main point of the story is not uncharacteristic—and its exploitation depended on the unique features: medium energy nuclear physics, concern with fundamental issues, strong theoretical backup. It is clear that our interest in Nevis proposal No. 13 is still lively: the backward scattering of protons from uranium.

We select a final example: The study of "exotic" atoms. These are atoms in which the planetary electrons are replaced by a pion or a muon. Because these particles are much heavier than electrons, their orbits are very much closer to the nucleus and important nuclear properties influence the orbits slightly. By precise measurements on the energies of x-rays emitted by pions and muons when they "jump" from orbit to orbit, one can detect these nuclear influences. This has been one of the most active fields pursued by medium energy accelerator labs.

This research was started by Professor J. Rainwater and Professor V. Fitch (now, Chairman, Princeton Physics Department) at Nevis in 1953. They detected the first mesic x-rays and deduced the fact that nuclear radii were 30% smaller than had been thought—thus correcting a major parameter in our understanding of the atomic nucleus.

Professor C. S. Wu has a long and ambitious program of mesic atoms planned and is at this time set up on the floor of the accelerator studying novel techniques for advancing this subject. Incidentally, she recently took her apparatus to Brookhaven and obtained some of the most precise data on exotic atoms with circulating antiprotons and K-mesons. Practical applications of these techniques in biology, medicine and engineering are rapidly expanding.

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[2] The Nevis experiment would provide indicative but not definitive data.

(Attachment X)

Appendix II

Practical Applications

A. General

The primary objective of the Nevis Laboratory is to advance fundamental knowledge in particle and nuclear physics. In other places we, and many others, have argued the case for society to invest a very modest fraction of its resources in this enterprise. The argument rests on the one hand upon a philosophical pillar: that the very origins of modern civilization were concerned with the deepest questions of what we were made of, where did we come from, where are we going, how do we work. From Ptolemy to Einstein these quests served to elucidate the laws by which the physical universe operates. The sequence of ever more profound syntheses leads us to magnifiers of our perceptive powers: microscopes and telescopes and particle accelerators. A technological culture without these perceptions and without this quest would be as sterile and anachronistic as one that denied art and music, poetry and philosophy. The second pillar is the clear reading of the history of modern civilization—that rests solidly on the advances made in fundamental knowledge *unmotivated* by technological mission. Thus the transistor was not invented by the communication industry, and nuclear fission did not arise from an R-and-D program of Utilities.

Few pure scientists are so pure as to not be aware of the responsibilities they share for the problems of modern society—which are almost all technology driven: pollution, energy crises, famine, armaments. We understand that there is no turning back—that solutions require even more technology albeit more rationally and compassionately deployed. The question of whether we understand enough about the universe, about matter and energy to resolve these 20th century crises is difficult to answer because so many other considerations are involved. However there are also the crises of the 21st century: some anticipated such as the shortages of basic materials and many still unknown. There is a real fear that perhaps we just don't have enough basic knowledge to cope with these dimly perceived terrors.

B. Nevis Contributions

1. Muons

At Nevis, as at most other frontier research laboratories, we are aware of and sensitive to these problems. We have contributed in several ways. As noted above, the fields of mesic X-rays and polarized muon beams were both started at the Nevis cyclotron. In a symposium on Practical Applications of Accelerators (Los Alamos: LA–5535–C, 1974) ten papers (out of 18) were devoted to the application of these two discoveries to the following subjects: (1) Fissionable Material Assay, (2) Medical Diagnostics, (3) Hot Atom Chemistry, (4) Solution Chemistry, (5) Solid State Physics.

2. Fast electronics

In a less direct way, our work on fast pulsed electronics has advanced this art which continually finds its way into communications and computer technology. In particular the read-out system of the new drift chamber particle detectors has direct utility in recent application of these instruments in molecular biology.

3. Production of radioisotopes

More directly, we have been studying the problems involved in producing short-lived radioisotopes which have clinical value in nuclear medicine. Our proximity to the densely populated metropolitan area makes this especially attractive for short half-life isotopes. We are in communication with HEW Division of Nuclear Medicine, the Radioisotope Division of Union Carbide and the Brookhaven Linac Isotope Production group. One of the most exciting prospects is Iodine-123 for thyroid diagnostic procedures. This isotope is far superior to those currently being used. It is estimated that there could be a national demand for 1,000,000 mCi/yr. The 13 hour half-life presents a distri-

bution problem, but the Metropolitan area could be entirely supplied by the Nevis facility. The presence of a back-up source at Brookhaven alleviates the problem of absolute dependability of source.

Other isotopes we could supply are: Xenon-127, which if available, can be used for early detection of pulmonary disease and for lung perfusion and ventilation studies.

Thallium-201: this has considerable potential as a tracer in coronary artery disease, also as a scanning agent for the renal medulla and as a tumor localizing agent. Nevis could supply about 30% of the anticipated demand as estimated by Union Carbide.

In summary, the Nevis facility has the high energy (570 MeV) and will soon have the intensity to become a major supplier of new and improved radioisotopes in the important Eastern Seaboard area. A prime consideration is *reliability* of source. This consideration may dictate and perhaps even finance a complete set of spare parts and overdesign of critical components. More likely, one would require teamwork between two sources, i.e., Nevis and Brookhaven, to provide reliable service to the Metropolitan area.

Dr. LEDERMAN. The Nevis Synchrocyclotron Lab proposed to the Office of Naval Research by I. I. Rabi and John Dunning in 1946, as Columbia's transition from Manhattan District work into the field of large particle accelerators, was dedicated by then Columbia president, Dwight Eisenhower, in 1950 as the world's most powerful accelerator operating at an energy of 385 megaelectronvolts.

In 1970, it was shut down for a major modernization program after 20 years of operation for research.

In those 20 years, some 600 research reports had been written and 96 students received Ph. D.'s as a result of research involving this facility. And some 40 post-doctoral physicists continued their training in this laboratory.

Out of Nevis has come a large number of very important discoveries. In my attachments I list some of these. I also include an account of some of the output of scientists. I don't list all 600 research reports, only the most important ones.

It is relevant to note that these achievements were made in the context of a rapidly developing field which saw similar, often more powerful facilities, operating in Rochester, Pittsburgh, Chicago, and Berkeley; as well as Liverpool, Geneva and Moscow. I've included a tabular description of these for your information in the attachments.

These cyclotrons, for a while, represented the energy frontier. However, higher energy facilities were soon developed at such laboratories as Brookhaven and CERN.

While continuing research at the cyclotron, now referred to as "intermediate energy physics," the Nevis staff branched out into this high energy field in 1956 under a separate contract. Thus, the research program at Nevis became an intimate blend of cyclotron-based research and investigations carried out at the larger accelerators located at national laboratories.

The resultant mix, spiced by close communication with the powerful theoretical physics group in the Department of Physics at Columbia, has produced a significant fraction of the major breakthroughs in basic physics over the last 25 years.

Mr. Chairman, as an aside, I'd like to make a comment stimulated by your introductory remarks about "big science." There is certainly

an area of relevant concern, insofar as big science is related to individual investigators. However, we believe that in a proper environment, big science is nothing more than a collection of individual investigators doing their own work and coming to grips with their own problems in their own way.

The decision to propose a modernization of the Nevis accelerator was taken in 1966, that is by the Columbia group, after a careful study of alternatives and was based on the following considerations:

One: We were convinced that an imaginative pursuit of intermediate energy physics would generate very important scientific results and could even lead to totally new phenomena; that is, discoveries more characteristically expected of frontier energy research.

This conviction developed as a result of our experience both with the Nevis accelerator and at Brookhaven and elsewhere. However, these ideas could not be pursued because of the inadequacy of the accelerator, especially as related to its intensity.

Two: Columbia University's low energy nuclear physics research under Professors Havens, Rainwater, and Wu was based upon a 6 MeV van de Graaff. If this lower energy accelerator were retired, we reasoned, the joining of forces would bring powerful additional talent to the exploitation of the improved accelerator.

Three: A strong group of physicists at Yale University, which had carried out a brilliant series of experiments at Nevis, was available to assist in the design of the modifications and committed to assist in exploiting the new beams. Enthusiasm was informally expressed by other nearby institutions, such as New York University and City University.

Four: The educational mission of the university, i.e., the training of physicists, seemed somewhat better fulfilled with cyclotron research where teams of three to five people could manage the experiment, as contrasted with high energy research where groups of students, junior faculty, and professors often exceeded 10.

In our original 1966 proposal, we provided a long and detailed list of important research that required the much higher intensity facility. By 1970, when data for the last old cyclotron experiment had been obtained, we had focused on a first generation of research experiments that the Nevis staff had in mind. I will touch upon these a little later in my statement.

By this time, the role of Nevis as a national facility had become clear. The combination of U.S. policy and budget constraints had resulted in thinning out of the program: Accelerator laboratories at Rochester, Chicago, Carnegie, Cosmotron at Brookhaven, Princeton Penn Accelerator, and Cambridge Electron Accelerator were closed or closing. The funding of Berkeley and the Space Radiation Effects Laboratory in Virginia was severely restricted.

Intermediate energy facilities in the United States were to be invested in Los Alamos meson physics facility, LAMPF, a $60 million proton linear accelerator and in the modernized Nevis.

I will discuss further the research objectives as of this date. The major thrusts are described in detail in the attachments, which I would like to provide for the record.

However, it remains to discuss the physics potential of Nevis in the cold light of 1976. Let me review now the current rationale for Nevis:

One: Nevis will only have one-tenth of the primary beam intensity of the LAMPF accelerator in the next several years, but its beam duration will be more than 10 times longer—it is called duty cycle. For many types of experiments, the slow drooling out of particles is crucial so as not to jam the detectors and electronic logic.

Two: Nevis will serve as a good location for users in the eastern U.S. Easy access, especially for small, university-based teams with teaching commitments, is an important consideration.

Three: Nevis, as a laboratory, has a strong tradition of innovative research which has led to the opening of new fields. Its electronics instrumentation group is widely recognized as outstanding—probably I might add the best in the world. The production of new physicists, who are leading contributors to the applications of physics in education, government, industry, and research, is truly outstanding.

Four: The close mix of high energy, medium energy, and nuclear physics has traditionally been more than just in name only. Technique and physics ideas have surged back and forth across these artificial boundaries. The very close coupling to the Columbia theorists, led by Prof. T. D. Lee and his colleagues, brings this brew to a boil.

We recently held a conference at Bear Mountain called "BeV/Nucleon: How and Why?" This was sponsored by Nevis and the National Science Foundation and involved just such an interdisciplinary blend to address fundamental questions in the meeting ground of particle and nuclear physics. Consequences for research at Nevis, Fermi National Acceleration Laboratory, Bevalac—the high energy heavy iron accelerator at Berkeley—was stressed at this conference.

Incidentally, more details on this are included in my attachments. And then——

Five: Nevis is a university-based facility. The concentration of facilities in national laboratories has led to a serious depletion of technological capability in universities—where, traditionally, special talents are found.

It is perhaps no accident that in spite of LAMPF, Brookhaven, Fermilab, SLAC, and CERN, large national or international laboratories, most of the innovative electronic instrumentation has come from much smaller university based groups, for example Chicago and Nevis.

Six: In the interest of brevity, I have listed a series of specific experiments but with your permission, I'd like to skip over these and just make some general remarks. We can burden the record with the details.

The program at Nevis which we present represents what we think is a judicious balance, what we think and what our advisory com-

mittee agrees, is a judicious balance between attacks on outstanding problems at the frontier and bold, new salients in areas so new that one doesn't even recognize there are problems. We have tried to balance our research program between those two.

I might just select one item, which is most dramatic perhaps, as an illustration, and this is the item called Experiment Number 13, the Search for Bizarre States of Nuclear Matter, and this I discuss at length in the attachment.

But here, basically, we are looking for spontaneous fluctuation, presumably rare—in fact very rare—in which a large fraction of the protons and neutrons inside a heavy nucleus, for example inside uranium, find themselves in practically the same place. If this would happen, this implies a transient density which is experienced in macroscopic nature only in the collapse of a neutron star towards a black hole.

How do we see this? The signature is the backwards deflection of a 570-MeV proton. The experiment is very sensitive. When we run it, we believe we can detect one such happening for every 100 billion ordinary nuclear collisions.

I would also like to refer you to the attachment labeled Appendix II of the material submitted, which elaborates on some of the practical applications which we are also concerned with at the Nevis facility, and go on to the status of the improvement program.

The Nevis machine was shut down in 1970. Acceleration first took place in 1975, and extraction did not take place until mid-1975. The modification program proved to be more complex than anticipated.

The initial stages were plagued by engineering difficulties and a psychology of poverty brought about by the dramatic change in U.S. funding patterns for research that began roughly in 1968. That this attitude was pervasive may be indicated by the fact that all of the other medium energy programs funded at about this time —LAMPF, Indiana, and the Bates Lab at MIT—ran into long delays from their projected time scales.

In 1973, partly through the institution by the NSF of a rigorous set of site visits by outside experts, the management of the cyclotron project was modified. Assistance from nearby technical reservoirs such as Brookhaven was elicited and progress became much more encouraging.

Last spring, we carried out our first experiment, "Neutrons in Negative Pion Therapy"—a biomedical experiment carried out by a visiting group from Kent State and Chicago.

As of this date, we are delivering a beam of 570-MeV protons—the original energy of the old machine was 385 MeV—at an intensity which is being deliberately held low to avoid premature irradiation of machine components. The present beam intensity is equivalent to about three microamperes for normal operation and we expect that this will be gradually improved to within the design intensity range of 10–20 microamperes. This results in improvement of at least a factor of 100 in the research capabilities of this machine.

Three experimental teams are carrying out the first phase of the research program. These include physicists from Columbia, Yale, and Johns Hopkins.

We expect the research program to grow over the next year such

that by the end of 1977, we will be doing about six to eight experiments a year. This assumes funding for 15 shifts a week, that's 8-hour shifts.

The funding level envisaged is about $2.6 million, for which we include cyclotron operation, in-house research, and outside users' support. We can predict with fair confidence that this should grow to about $2.9 million in fiscal year 1978 to accommodate inflation and modest improvements in the design of components.

Tables of Nevis funding requirements through 1979 were presented to the Hildebrand Committee to Review U.S. Medium Energy Science, and these are also in the appendix. We find no reason to change these significantly, and these are 1974 estimates. They are still a good estimate of our needs.

In the longer range, we anticipate a lifetime of the modernized accelerator, based on much experience, of about 10 years. We can see no situation in which further modifications of major impact would be made. We assume that over this period the array of modern medium energy facilities in this country and elsewhere will have exhausted present possibilities.

Should intermediate energy physics still pose interesting problems at the end of this time, it is likely that entirely new technology systems will be required to advance the subject to yet another stage of incisiveness.

The users community in intermediate energy physics is clearly identified and has been informed of the availability and status of the Nevis beams. We have in fact received some 23 proposals for experiments of which 15 are from outside users or are collaborations with outside users. These are listed in the attachments.

In order to evaluate proposals, we have appointed a group of distinguished physicists to serve as a program advisory committee. The list of past and present members is also attached.

The group is charged with the responsibility of reviewing and recommending action on all proposals for use of Nevis facilities. NSF participates in the monitoring of these procedures. The committee contains physicists who are familiar with programs at other laboratories to assure a broad and diversified program.

Groups approved to run on the accelerator usually require additional help from the host laboratory, such as in the form of electronics and computer assistance. Since the Nevis staff are very strongly involved as users of other facilities—Brookhaven, Fermilab, and CERN—the need for host services is fully appreciated. Clearly the amount of assistance we can offer depends on the funding level, and we are keenly aware that this level depends on how successful we are in meeting the instrumentation and beam requirements that are needed for advanced research in many institutions.

Thank you.

[The complete prepared testimony of Dr. Lederman follows:]

STATEMENT ON THE NEVIS LABORATORY BY PROFESSOR LEON M. LEDERMAN, DIRECTOR, NEVIS LABORATORIES, DEPARTMENT OF PHYSICS, COLUMBIA UNIVERSITY, NEW YORK, N.Y.

I. Brief History of Nevis Laboratories

The Nevis Synchrocyclotron Laboratory was proposed to the Office of Naval Research by I.I. Rabi and John Dunning in 1946 as Columbia's entry into the field of large particle accelerators. It was dedicated by then Columbia Presi-

dent, Dwight Eisenhower in 1950 as the world's most powerful accelerator operating at an energy of 385 MeV. In 1970, it was shut down for a major modernization program after 20 years of operation for research.

In those twenty years, some 600 research reports had been written and 96 students received Ph.D.'s as a result of research involving this facility. In addition, about 40 post-doctoral physicists had continued their training in this laboratory. Out of Nevis has come a large number of very important discoveries. I have a list of these and also an account of the output of scientists which I would like to provide for the Record. It is relevant to note that these achievements were made in the context of a rapidly developing field which saw similar, often more powerful facilities, operating in Rochester, Pittsburgh, Chicago, and Berkeley, as well as Liverpool, Geneva and Moscow. A tabular description of these is provided for the Record. These cyclotrons, for a while, represented the energy frontier. Higher energy facilities were soon developed at such laboratories as Brookhaven and CERN. While continuing research at the cyclotron, now referred to as "intermediate-energy physics," the Nevis staff branched out into this high energy field in 1956 under a separate contract. Thus, the research program at Nevis became an intimate blend of cyclotron-based research and investigations carried out at the larger accelerators located at national laboratories. The resultant mix, spiced by close communication with the powerful theoretical physics group in the Department of Physics, has produced a significant fraction of the major breakthroughs in basic physics over the past 25 years.

II. The Synchrocyclotron Modification Program

A. MOTIVATION: CIRCA 1966

The decision to propose a modernization of the Nevis accelerator was taken in 1966 after a careful study of alternatives and was based on the following considerations.

1. We were convinced that an imaginative pursuit of intermediate energy physics would generate very important scientific results and could even lead to totally new phenomena, i.e. discoveries more characteristically expected of frontier energy research. This conviction developed as a result of our experience *both* with the Nevis accelerator and at Brookhaven and elsewhere. However, these ideas could not be pursued because of the inadequacy of the accelerator, especially as related to the intensity, that is, the beam current available.

2. Columbia University's low energy nuclear physics research under Professors W.W. Havens, James Rainwater and C.S. Wu was based upon a 6 MeV van de Graaff. If this lower energy accelerator were retired, the joining of forces would bring powerful additional talent to the exploitation of the improved accelerator.

3. A strong group of physicists at Yale University which had carried out a brilliant series of experiments at Nevis was available to assist in the design of the modifications and committed to assist in exploiting the new beams. Enthusiasm was informally expressed by other nearby institutions: NYU, City University, etc.

4. The educational mission of the University, i.e. the training of physicists, seemed somewhat better fulfilled with cyclotron research where teams of 3 to 5 people could manage the experiment as contrasted with high energy research where groups of students, junior faculty and professors often exceeded 10 people.

B. MOTIVATION: 1976

In our original 1966 proposal we provided a long and detailed list of important research that required the much higher intensity facility. By 1970, when data for the last "old cyclotron" experiment had been obtained, we had focused upon a first generation of research experiments that the Nevis staff had in mind. I will touch upon some of these a little later in my statement. By this time, the role of Nevis as a national facility had become clear. The combination of U.S. policy and budget constraints had resulted in the thinning out of the program: Rochester, Chicago, Carnegie, Cosmotron, PPA, CEA were closed or closing. The funding of Berkeley and SREL was severely restricted. Intermediate energy facilities in the U.S. were to be invested in Los Alamos Meson Physics Facility (LAMPF), a $60 million proton linear accelerator and in the modernized Nevis.

I will discuss further-on the research objectives as of this date. The major thrusts are described in more detail in a separate document which I would like to provide for the Record. However, it remains, to discuss the physics potential of Nevis in the cold light of 1976. Let me review then the rationale for Nevis:

1. Nevis will have 1/10th the primary beam intensity of LAMPF in the next several years but its beam duration will be more than 10 times longer (duty cycle). For many types of experiments, the slow drooling out of particles is crucial so as not to jam the detectors and electronic logic.

2. Nevis will serve as a good location for users in the eastern U.S. Easy access, especially for small, university-based teams with teaching commitments, is an important consideration.

3. Nevis, as a laboratory, has a strong tradition of innovative research which has led to the opening of new fields. Its electronics instrumentation group is widely recognized as outstanding. The production of new physicists, who are leading contributors to the applications of physics in education, government, industry and research, is truly outstanding.

4. The close mix of high energy, medium energy, and nuclear physics has traditionally been much more than "in name only". Technique and physics ideas have surged back and forth across these artificial boundaries. The very close coupling to the Columbia theorists—notably T. D. Lee, N. Christ, A. Mueller, R. Serber, G. C. Wick and G. Feinberg, brings the brew to a boil. The Bear Mountain Conference: "BeV/Nucleon: How and Why?" was sponsored by Nevis (and NSF) and involved just such an interdisciplinary blend to address fundamental questions in the meeting ground of particle and nuclear physics. Consequences for research at Nevis, Fermi National Acceleration Laboratory, Bevalac—the heavy ion acceleration facility at Berkeley, etc. were stressed at this conference.

5. Nevis is a university based facility. The concentration of facilities in national laboratories has led to a serious depletion of technological capability in universities—where, traditionally, special talents are found. It is perhaps no accident that in spite of LAMPF, BNL, FNAL, SLAC, CERN, etc., most of the innovative electronic instrumentation has come from much smaller university based groups, e.g. Chicago and Nevis.

6. And what about the senior staff that created this laboratory and participated in modeling its traditions? I have a list of their names for the record. These seniors are energetic and enthusiastic about the rich possibilities for physics with the new accelerator and fortified by an unusually talented group of young scientists.

C. RESEARCH PROGRAM AT NEVIS

Here we outline briefly some of the proposed experiments designed by the in-house staff.

No. 1a. Muon-Proton Elastic Scattering at Small Angles (Lederman)

The objective here is to study the shape of the electric charge distribution in the proton, especially at the "edges" where the charge falls to zero. Essentially nothing is known here—the charge could extend out beyond the orbit of the band electron insofar as previous measurements are concerned. Although this has been a known problem for many years, the resolution awaits the special properties of the Nevis muon beam.

Nos. 2a, 5b. 23. Study of Pion and Muon Induced X-Rays (C. S. Wu)

The atom which is formed when a meson (pion or muon) replaces an electron in orbit around a nucleus was discovered at Nevis in 1953 by James Rainwater. The x-rays generated by meson "jumps" between orbits have been measured and constitute a rich source of information about the nucleus. The increased intensity of muon and pion beams will permit much more incisive measurements. When applied to the simplest system: a muon in orbit around a proton, the issue involves details of atomic physics. The basic data are relevant to applications of muons to chemistry, solid state physics and as a bio-medical tool.

No. 3. Rare Decay Modes of Pions and Muons

This is a "fundamental particle" experiment. Pions usually decay into muons and neutrinos but, very rarely, they have been observed to give rise to elec-

trons, neutrinos and gamma rays. High intensity will permit a quantitative study which involves the weak force that generated the pion's instability.

No. 1b, 16, 17, 21. Nuclear Structure Research Using Meson Probes (Many)

Here unique nuclear processes can be induced by poking mesons at the nucleus. The nuclear response, by gamma emission, neutrons or breakup teaches us details of the nuclear structure which cannot be reached by other means.

No. 13. Search for Bizaare States of Nuclear Matter (Lederman)

This is discussed at length in Appendix I. Basically we are looking for the spontaneous fluctuation (presumably rare) in which a large fraction of the protons and neutrons inside a heavy nucleus (e.g. uranium) find themselves in the "same place". This implies a transient density which is experienced in macroscopic nature only in the collapse of a neutron star towards a black hole. The signature is the backwards deflection of a 570 MeV proton. The experiment is very sensitive—we can detect one such happening for 100 billion ordinary nuclear collisions.

No. 7. Neutron Velocity Spectroscopy (Rainwater)

This is a continuation of a program of precise measurements of nuclear energy levels begun by Rainwater in 1956 at Nevis. The Nevis accelerator will make "tons" of slow neutrons whose velocity is precisely clocked over a flight path of 600 feet. The nuclear excitation generated by these neutrons is recorded. Theoretical efforts to accommodate the vast number of highly resolved lines has led to a "new statistical mechanics" of energy levels.

No. 11 and unnumbered: Bio-medical Applications

It is widely known that pions may provide a unique tool for cancer therapy. Many backup experiments are required and one was already run this spring. We are also deeply engaged in studying the problem of isotope production. Nevis could help to supply an expanded demand for iodine-123 (123) for the entire nation but the New York area constitutes a major fraction of the demand.

III. Status of the Improvement Program

The Nevis machine was shut down in September 1970. Acceleration first took place in January 1975 and extraction did not take place until mid-1975. The modification program proved to be more complex than anticipated. The initial stages were plagued by engineering difficulties and a psychology of poverty brought about by the dramatic change in U.S. funding patterns for research that began roughly in 1968. That this attitude was pervasive may be indicated by the fact that all of the other medium energy programs funded at about this time, LAMPF, Indiana, Bates (MIT), ran into long delays from their projected time scales.

In 1973, partly due to the institution by the NSF, of a rigorous set of site visits by outside experts, the management of the cyclotron project was modified. Assistance from nearby technical reservoirs such as Brookhaven was elicited and progress became much more encouraging. Last spring we carried out our first experiment: "Neutrons in Negative Pion Therapy"—a biomedical experiment carried out by a visiting group from Kent State and Chicago.

As of this date, we are delivering a beam of 570 MeV protons (the original energy was 385 MeV) at an intensity which is being deliberately held low to avoid premature irradiation of machine components. The present beam intensity is equivalent to about three microamps for normal operation and we expect that this will be gradually improved to within the design intensity range of 10-20 microamps. This results in an improvement of at least a factor of 100 in the research capabilities of this machine.

Three experimental teams are carrying out the first phase of the research program. These include physicists from Columbia, Yale, and Johns Hopkins.

IV. Funding and Future Plans

We expect the research program to grow over the next year such that by the end of 1977, we will be doing about 6-8 experiments per year. This assumes

funding for 15 shifts per week. The funding level envisaged is about $2.6M for which we include cyclotron operation, in-house research and outside users' support. We can predict with fair confidence that this should grow to $2.9M in FY 1978 to accommodate inflation and modest improvements in the design of various components.

Tables of Nevis funding requirements through FY 1978 were presented to the "Hildebrand" Committee to Review U.S. Medium Energy Science, in 1974. I would like to submit these tables for the Record. We find no reason to change these significantly. They are still a good estimate of needs.

In the longer range, we anticipate a lifetime of the modernized accelerator, based on much experience, of about 10 years. We can see no situation in which further modifications of major impact would be made. We assume that over this period, the array of modern medium energy facilities in this country and elsewere will have exhausted present possibilities.

Should intermediate energy physics still pose interesting problems, it is likely that entirely new technology systems will be required to advance the subject to yet another stage of incisiveness.

V. The Users' Program: Nevis Program Advisory Committee

The users community in intermediate energy physics is clearly identified and has been informed of the availability and status of Nevis beams. We have in fact received some 23 proposals for experiments of which 15 are from outside users or are collaborations with outside users.

In order to evaluate proposals, we have appointed a group of distinguished physicists to serve as a Program Advisory Committee. This group is charged with the responsibility of reviewing and recommending action on all proposals for use of Nevis facilities. NSF participates in the monitoring of these procedures. The Committee contains physicists who are familiar with the programs at other laboratories to assure a broad and diversified program.

Groups approved to use the accelerator usually require additional help from the host laboratory—usually in the form of electronics and computer assistance. Since Nevis staff are very strongly involved as "users" of other facilities (BNL, Fermilab, CERN), the need for host services is fully appreciated. Clearly the amount of assistance we can offer depends on the funding level. We are keenly aware that this level depends on how succssful we are in meeting the instrumentation and beam requirements that are needed for advanced research in many institutions.

Chairman SYMINGTON. Thank you, Dr. Lederman, very much.

Just to simplify one aspect of the problem, the modernization project began in 1970, or was it 1971?

Dr. LEDERMAN. The modernization actually began in 1967 in the way of designing of components. The machine was shutdown—the machine ran until the end of 1970.

Chairman SYMINGTON. And was that supposed to be a 1-year shutdown?

Dr. LEDERMAN. We thought the shutdown—the estimate then was a 1-year shutdown.

Chairman SYMINGTON. Right.

Now, of course, there was no technical review committee at that point assigned yet, was there?

Dr. LEDERMAN. No, there was not.

Chairman SYMINGTON. And it wound up to be about a 4-year shutdown?

Dr. LEDERMAN. That's right.

Chairman SYMINGTON. Do you think we should have established a technical review committee right away? Would that have knocked a year or two off the delay?

Dr. LEDERMAN. I'll have to agree that, judging from the impact of the technical review committee when it did appear, that this would have been a very helpful thing.

Chairman SYMINGTON. Who makes the decision as to whether the technical review committee is established, or who initiates the idea? Did that come from the project or from——

Dr. LEDERMAN. In this case it came from the National Science Foundation. When we need extra help we call in consultants. We do call in consultants.

Dr. WRIGHT. But these people were consultants to the NSF in that capacity.

Dr. LEDERMAN. Yes.

Chairman, SYMINGTON. I see.

Dr. WRIGHT. But we agree with what Leon has said, and if one were to do it all over again, one would probably have initiated that particular kind of a review earlier in the proceedings.

Chairman SYMINGTON. This would be because, apparently, that review has sorted out, or helped to sort out, many problems and has expedited the return to schedule, right?

Dr. LEDERMAN. I would say it had a very large influence. It was very helpful, in fact. Some of these very people who came were people we had tried to consult before, but they were very busy people. The NSF seems to have much more clout than we had.

Chairman SYMINGTON. Well, Dr. Wright, with the advantage of hindsight, I suspect that you would have liked to have assigned a technical review committee sooner.

Is there anything else you would have done differently that you know of?

Dr. WRIGHT. There's one other thing, perhaps, which might have been done, or should have been done. While there was no technical review committee in the very earliest stages, we did ask three different consultants to go look over the project and give us their opinion. Analyses such as that, I think, might have been done in more detail than they actually were. Now, of course, in that case they would cost more. We do know when you're starting out on new projects you ought to do a lot of design work to be sure you're on the right track, and you have to invest your money that way.

In retrospect, it would appear that we perhaps should have conducted analyses of the cost and schedule estimates in more detail than they actually were.

Chairman SYMINGTON. When you have an advisory committee set up to assist in getting a project moving again, is it normally made up of physicists and innovative scientists, or people with experience in management, construction, and——

Dr. WRIGHT. I would say the group of people from which we selected usually had experience of their own in building a major accelerator, if that's what you're talking about, or a major telescope, if that's what you happen to be talking about.

Chairman SYMINGTON. I was referring to your own facility, I think.

Dr. WRIGHT. Right.

Chairman SYMINGTON. You were talking on page 5 about the problems of Nevis, and saying that the innovative thinking that leads to design isn't necessarily the most appropriate for coordination and execution.

Dr. WRIGHT. Two of the members of that technical review committee were engineers who had been very successful in bringing about major cyclotron construction projects at other places, and in that sense they would bring some operational or managerial expertise with them.

Chairman SYMINGTON. All right.

On page 7 of your statement, you list the direct monitoring techniques employed by NSF, which are used in the management of various facilities.

I would just ask if you could rank them in the order of importance.

Dr. WRIGHT. I think that's roughly in the order that they are given, actually, which brings in consultants as being very important.

One exception to that would be the fourth one, "in the case of Nevis, submission of the weekly work schedule for key parts of the program." That might be a bit extreme for routine operation. It is possible to overmanage something, as well as it is possible to undermanage it. So I wouldn't include that in general. It was specific to the particular situation at Nevis.

Chairman SYMINGTON. These contacts you have with the project in the monitoring process, do they occur with the regularity that's predictable to the people working on the project itself, or do you have sort of an ad hoc intervention, where you ask them what they're doing at the moment?

Dr. WRIGHT. I think ad hoc is probably more descriptive. But to schedule something, you know you have to be in touch with the other party anyway.

Chairman SYMINGTON. Yes, right.

Sometimes it's effective management technique to be somewhat unpredictable in the scheduling or your visits and your phone calls, and this kind of thing.

There are a good many questions, here again, which we will wish to submit in writing. The time is somewhat limited, and I know that my colleague on the committee, Mr. Downing of Virginia, has some questions of particular relevance to his State and district. I'd like to give him an opportunity to ask them.

Mr. DOWNING. Thank you, Mr. Chairman. I appreciate your generosity.

Dr. Wright, I read your very fine statement, but I fail to find any mention of the Space Radiation Effects Laboratory in Newport News, Va.

Can you account for that?

Dr. WRIGHT. We were asked to talk about Nevis——

Mr. DOWNING. Oh, I beg your pardon.

Dr. WRIGHT. As an example of a major facility within the NSF program.

Mr. DOWNING. You do fund SREL, as it's called?

Dr. WRIGHT. Yes, sir.

Mr. DOWNING. Do you know what funding they've requested for the next fiscal year?

Dr. WRIGHT. SREL requested $982,009 for calendar year 1977. We are negotiating a support level of $750,000 for that period.

Mr. DOWNING. All right.

Are you going to fund them?

Dr. FREGEAU. Mr. Downing, I believe the transfer to NASA, which is the contract holder with the group at Langley, will be completed today; the amount is $750,000. It is being funded out of the transition quarter.

Mr. DOWNING. Right. Well, that's spendid news.

Dr. Wright, it's my understanding that proposal review is accomplished by means of a "referee reports" and these are requested by NSF from independent members of the scientific community on all proposals that you fund.

What referee reports do you have on Nevis, and have they been critical reports?

Dr. WRIGHT. There's a long history, since 1966—so the file pertaining to Nevis is roughly a full file drawer. At the time the modification program at Nevis had been started, there had been both what we call ad hoc mail reviews from the scientific community and there had been discussions of the whole national effort in this general area of physics with the Office of Science and Technology, involving not only NSF but AEC and ONR at that time.

So there is that kind of documentation initially.

Renewal proposals are not always sent out for review. However, between 1966 and 1975 there were five additional full scale reviews which probably involved about 30 reviewers.

Mr. DOWNING. Have these been critical reports?

Dr. WRIGHT. That's partly the reason we had the meeting in the Foundation to which I alluded in my testimony, where we worked out a schedule for bringing the instrument into operation in a way so it could actually be used for a research program as it now is.

By that time we were indeed getting some critical comments.

Mr. DOWNING. Well, we've——

Dr. WRIGHT. Not all critical, but some.

Mr. DOWNING. We've been funding this thing since 1966, and it is not fully operational yet, is it?

Dr. WRIGHT. No. It's still operating at a lower intensity than one would like it to. That's at least partly due to the fact that if you moved to the higher intensities you'd build up induced radioactivity which is then very difficult to deal with, and they don't have all the remote handling equipment that they need.

Mr. DOWNING. How has NSF handled these critical reports?

Dr. WRIGHT. How have they handled them?

Mr. DOWNING. Yes. When you get critical reports sent in on Nevis, what do you do?

Dr. WRIGHT. For a project this size, any action on the part of the Foundation requires National Science Board review. So the whole

chain of command within the Foundation, right on up through the National Science Board, sees these reviews.

Mr. DOWNING. Dr. Wright, it looks like I'm chairman again. There's a roll call on the Floor.

Dr. FREGEAU. Could I add one word, Mr. Downing?

Mr. DOWNING. Yes.

Dr. FREGEAU. In some of the material submitted for the record we have included the written documentation presented to the National Science Board last spring on its last decision on this project. Included is a summary of the review comments, both positive and negative.

Mr. DOWNING. Thank you.

The committee will recess for approximately 10 minutes, and if the witnesses will bear with us, we would certainly appreciate it. Thank you.

[Recess.]

Chairman SYMINGTON. The subcommittee will come back to order. I hope Mr. Downing will shortly return, and he will continue with his questions. I have a few more, too.

Back in the time when Nevis—I guess this is for Dr. Lederman—was supported by the Office of Naval Research, ONR had reasons for that, and then had reasons why they dropped this support.

Just to enhance the understanding of the committee, I wonder if you could give us a picture of those reasons?

Dr. LEDERMAN. I think if I understand it, the reason they dropped the support was because the decision we made was either to modernize or go out of business, and they agreed with this, as I understand it. They felt we should modernize.

But they themselves did not see their own funding picture in such a way as to do this, and I understand it was at their initiative that the NSF and Office of Science and Technology were called in, to see how they could help us with this modernization.

The decision that was made was that we would go to the NSF.

Chairman SYMINGTON. Perhaps what I'd like to know is, what matters were of interest to the Office of Naval Research which were being studied at Nevis?

Dr. LEDERMAN. Well, that's something I really don't know much about. I know of the connection between Columbia and the Office of Naval Research, and it's really gone both ways. The former director and builder of the original cyclotron, Dr. Eugene Booth, took over as manager of a very large underwater laboratory, which was—it was called Hudson Laboratory at Columbia University.

I have the impression that over those years the ONR became more and more mission-oriented, and the decision that basic research might drift gradually more to the NSF from the Department of Defense was sort of generally——

Chairman SYMINGTON. Yes. Was that the Mansfield amendment——

Dr. FREGEAU. This was before the Mansfield amendment, Mr. Chairman. In the Department of Defense that was an ongoing transition over, I would say, most of the 1960's.

Both Dr. Wright and myself have been on the staff of the Office of Naval Research, and being interested more in the long-range and fundamental science of the country, we accepted positions in the National Science Foundation in the sixties, because that was the direction in which things were going.

Chairman SYMINGTON. I see.

Dr. FREGEAU. And, quite understandably, from the Navy's viewpoint.

Chairman SYMINGTON. Now, the GAO, in its "Answers to Questions on Government-Supported Medium Energy Particle Accelerators," which Congressman Downing requested be prepared, remarked that it found the cost records maintained at Nevis to be inadequate for the purposes of its audit in 1975. That's quite technical.

But would you have agreed with its assessment, and would the procedures established now for making the records intelligible have helped that, Dr. Lederman?

Dr. LEDERMAN. That's right. It's curious, although we were pioneering in the use of computers for scientific research, we hadn't yet got on to the usefulness of the computer as in accounting.

Part of the difficulty was really the question of organization of the data. And when they came to us—we just were not prepared—we had to dig it out. We eventually did dig it out, and in that process we did establish a much more methodical and systematic way of identifying expenses.

Dr. FREGEAU. I think it's fair to say, Mr. Chairman, that we looked into this matter also from the NSF management viewpoint. The basic data, accounting data and so forth, were all there.

The compilations in the form that GAO requested were not available, and the Nevis group appears not to have understood quite what the GAO was asking for, and so gave the GAO the impression that no information was available.

However, since then, compilations of this form have been made.

Chairman SYMINGTON. All right.

Well, I now would like to defer again to Congressman Downing for his further questions.

Mr. DOWNING. Thank you, Mr. Chairman.

Dr. Fregeau, repeat for me again the funding arrangements for SREL, which you said were accomplished today?

Dr. FREGEAU. In August of this year, the National Science Board approved the funding for the next 1-year period, which incidentally is calendar year 1977, in the amount of—I've forgotten the exact approval.

Mr. DOWNING. $750,000.

Dr. FREGEAU. In any case, the funding transfer paperwork then starts, after we have approval from the National Science Board. This is being funded out of the transition quarter funds for the entire calendar year 1977 in the amount of $750,000.

Our paperwork is in the form of a fund transfer to the National Aeronautics and Space Administration, since they are the owners

of the property and handle that aspect. Of course, the laboratory is fully aware of the funding level.

Mr. DOWNING. So it's being funded through NASA?

Dr. FREGEAU. Yes, sir.

Mr. DOWNING. I see.

Dr. FREGEAU. NSF transfers the funds to NASA.

Mr. DOWNING. Thank you.

Dr. Wright, it appears that the Nevis modernization program began shortly after NSF assumed the funding in 1966.

What was the justification for that modification of the program, and does that justification remain valid now?

Dr. WRIGHT. We certainly think it does, to answer the last question first.

The justification for doing it was that the proposal had been submitted, it had been reviewed, and engineering and physicist consultants had assessed the plan. It had been assessed in the Office of Science and Technology to the point that it was something that just couldn't be not done by the country, and the Navy was not going to be able to do it.

So, the whole project was transferred from the Office of Naval Research to the National Science Foundation, including the improvements.

Dr. FREGEAU. I believe Mr. Downing is asking for the scientific justification.

Mr. DOWNING. That's correct.

Dr. WRIGHT. Well, of course, OST endorsement is a scientific justification.

There were three things to be done, major things to be done, to the accelerator: (1) One was to change the magnetic field, its design; (2) to change the RF frequency; and (3) to end up with an extracted beam which one could then beam on a target and create by that interaction mesons which themselves would form another beam, which could be used in experiments further downstream.

And the whole possibility of using mesons in a way such as that was extremely interesting scientifically, and in fact still is—it's the motivating force behind the existence now of the Los Alamos meson physics facility. People want to do the physics that they can do only with the mesons.

Mr. DOWNING. When does NSF expect the full design capability of Nevis to be achieved, and how will that capability when it's achieved compare with other U.S. accelerators?

Dr. WRIGHT. In terms of duty cycle, it will be unique in that general energy range.

In terms of intensity—what would it be?—the highest intensity of any U.S. accelerator, other than LAMPF. Is that correct?

Dr. LEDERMAN. Yes.

Dr. FREGEAU. LAMPF has an intensity factor of 10 higher, but in very short pulses, which for some types of experiments are not——

Mr. DOWNING. Well, it wouldn't surpass the Anderson Laboratory in New Mexico [LAMPF], would it?

Dr. WRIGHT. It will have a better duty cycle, which is an advantage for doing certain kinds of experiments.

Mr. DOWNING. What would the intensities be of Los Alamos as compared to Nevis?

Dr. LEDERMAN. The expected intensity at Nevis we think, to answer the first part of your question, should be achieved by, I hope, the middle of next year. By the middle of next year we should receive somewhere between 10 and 20 microamperes, which is about one-tenth of what the expected LAMPF intensity would be at that time.

The willingness we have to expand our own efforts in doing research with the machine is because there is another condition, other than intensity, which plays an important role. For certain types of experiments, an important class of experiments, you can't use the very high intensity of LAMPF because it comes out too abruptly, and therefore you need a kind of machine, the Nevis kind, in which the particles are doled out continuously and smoothly, a little bit like the advertisements for the Wankel engine.

That kind of facility, the approaching 100 percent duty cycle, is the kind which makes Nevis unique as another facility.

Now, these are the only two medium energy facilities that would be left in the country, except for the older machines: The Berkeley accelerator, which I think is now diverted almost totally to medical physics; and the SREL accelerator. The Nevis beams should be quite substantially more intense than the SREL accelerator.

Mr. DOWNING. NSF has funded Nevis about $8 million since this modernization campaign began.

How much of that went to the modification?

Dr. WRIGHT. Modification? About $8 million.

Mr. DOWNING. About $8 million.

Dr. WRIGHT. That is the total for modification.

Mr. DOWNING. All right.

This is a delicate question, and I don't mean it wrong, but you had a very fine, able scientist from Columbia University that joined NSF in 1968. Is it possible that in his enthusiasm you may have funded this project when it really maybe should not have been funded?

Dr. WRIGHT. No. I don't really think so at all. The documentation of the desirability of going ahead with the Nevis modernization program, or modification program, was all done, and the initial funding had been made available by the Foundation long before then.

In fact, Dr. Fregeau was the first program officer for the Nevis modernization. Actually, the individual in question did not join the Foundation until 1970.

Mr. DOWNING. But to continue pouring substantial sums of money into a project that has taken so long to be operational—how do you account for that underestimation of the cost and results?

Dr. WRIGHT. Earlier I alluded to the fact that some of the earlier reviewers did suggest that the time schedule had been underestimated. The costs, of course, have also turned out to have been underestimated. A part of that is due to inflation.

Had the project been finished faster the inflationary period would not have been so long.

Mr. DOWNING. Are there any further questions of the witnesses?

[No response.]

Mr. DOWNING. Gentlemen, on behalf of the committee I thank you for coming today and making a significant contribution. I do wish you luck on Nevis. I hope it becomes fully operational as soon as possible.

Even though I am retiring at the end of this year, I want you gentlement not to forget that the Space Radiation Effects Laboratory is still very dear to my heart, and it does a great job 5½ days a week, three shifts a day.

Thank you very much, ladies and gentlemen.

Dr. WRIGHT. I have an appointment with the director of SREL next month sometime. He wants to come up and talk about some other new ideas.

Mr. DOWNING. Thank you, Doctor.

Chairman SYMINGTON. If the Congressman has concluded his line of questioning, we do have other questions in writing which we will submit to Dr. Wright and Dr. Lederman.

[Additional questions for Dr. Wright and Dr. Lederman follow:]

ADDITIONAL QUESTIONS FOR DR. WILLIAM E. WRIGHT

Question 1. On page 7 of your statement, you list a number of "direct monitoring techniques employed by NSF" which are used in the management of various facilities. (*a*) Would you recommend that all of these techniques be adopted as standard practices in the management of all facilities supported by the NSF? (*b*) How many of these techniques are required under the current policies of the NSF?

Answer 1. (*a*) All of these direct monitoring techniques should be considered in connection with the management of each major facility supported by the National Science Foundation (NSF). However, not each of them need be adopted in every case. The requirement for direct monitoring is probably stronger if the project is in a construction, or moficiation, phase, than if it is in an operating phase. The required frequency of site visits by NSF staff, work schedules, or visits of project staff to NSF might be much diminished in the latter case.

(*b*) Annual reports and proposals for renewal of support are required for all National Science Foundation (NSF) projects. No other procedures are required of all projects since small projects require less management attention than do large ones. The specific set of management techniques is adjusted to the specific case. For projects of the scope of the Nevis Laboratory, most or all of the techniques listed would be used.

Question 2. (*a*) Are there industry representatives on the Nevis Technical Review Committee?

(*b*) Are there any general NSF guidelines for selecting the members of such Committees?

Answer 2. (*a*) The number of people with successful experience in designing or supervising the construction of major research facilities is never very large because the number of such projects is itself rather small. Within that, and other constraints, we try to achieve adequate depth in all our review procedures. At the time the Nevis modification was first proposed we did make use of the expertise which Brobeck Associates could bring to bear. At this time there are no industry representatives on the Nevis Technical Review Committee. The membership of that committee now comprises:

Dr. Paul Reardon, an engineer and formerly director of Accelerator Operations at Fermilab. He is currently Director of the large Energy Research and Development Administration (ERDA) fusion program at Princeton.

Mr. John Martin, also an engineer and formerly in charge of cyclotron construction at Oak Ridge. He is currently in charge of construction of a heavy ion facility at that same Laboratory.

Dr. Henry Blosser, a physicist who has been in charge of the very successful program of design and construction of the cyclotron at Michigan State University.

It should also be pointed out that even though there is no industry representative on this particular committee at this time, there are usually industry representatives on the Physics Division Advisory Panel which reviews all programs of the Division.

We feel the Nevis Technical Review Committee achieves adequate breadth and depth by drawing upon successful experience at two ERDA National Laboratories and one major university project.

(*b*) Since the number of such projects is actually rather few in number and the expertise required for each project must be drawn from wherever it can be found; university, Federally Funded Research and Development Center (FFRDC), government laboratory, or industry, I do not believe that general guidelines other than those governing considerations of conflict of interest are possible. Each action must be appropriate to the particular project and its problems.

Question 3. On page 6 you list a number of needed procedures which in your view help to assure the effective management of regional or national facilities. You further state that "We believe that many of these needs have only become imperative in the last decade." Why is this true?

Answer 3. During the last decade three trends stand out as one considers major research facilities: (*a*) The costs are frequently large. (*b*) The technical complexity is frequently great (this is not divorced from Item a. of course). (*c*) It is frequently required that the facility serve a large number of users visiting from other institutions.

Each of these increases the burden of managerial responsibility on both the operating, or host, institution, and the sponsoring agency. I alluded to this matter in my direct testimony. In addition to what is said there, one might say that many of the visiting users will also be supported by the sponsoring agency. This adds another dimension to the coordinating and supervising responsibilities of the sponsoring agency.

Question 4. In the planning stages, the NSF "obtained an analysis of the cost estimates from an industrial firm specializing in cyclotron construction. Independent assessments were also made by two accelerator experts."

(*a*) Was the analysis of cost estimates done by the industrial firm in agreement with the actual amount awarded subsequently by the NSF for this project?

(*b*) Were any of these analyses and assessments critical of the design or the proposed plan?

(*c*) What *is* an "accelerator expert?" Where did these two accelerator experts come from?

Answer 4. (*a*) The analysis of cost estimates provided by the firm said that the two year duration planned for the conversion project seemed optimistic and that 10-15% should be added to the total estimated cost. It stated that the major uncertainty seemed to be associated with the radio frequency system and that plans for fabrication "should realistically recognize the possibility of major changes being required before satisfactory performance is obtained." The initial NSF grant was for less than the amount requested.

(*b*) The industrial firm did not make any major criticism of the design or plan. It confirmed the cost estimates for many of the subsystems and made suggestions for improvements of others at revised cost estimates. In general, their most negative criticisms are summarized in the answer to Q. 4-a.

The two accelerator experts made comments on different aspects. One said that the design was basically sound and that the project should be supported. He suggested a larger contingency cost allowance than that requested and also suggested that the possibility should be studied that a somewhat lower design energy should be adopted than the originally proposed 600 MeV. The other concentrated his remarks on the beam extraction system. He said that the Nevis staff had not done enough studies of this aspect but that Nevis had the staff capable of achieving a successful extraction scheme.

(c) We would define an accelerator expert as one who has successfully designed, constructed or managed a major accelerator closely related in nature to the accelerator under consideration. The two accelerator experts who consulted in the initial stages of the Nevis project were, respectively, a senior engineer from the accelerator group at a national laboratory where a successful cyclotron had just been completed, and the director of a major university consortium devoted to the design, modeling and planning of high energy accelerators.

Question 5. Can you predict what your most likely response will be if the minimum criteria, recommended by the Nevis investigators as those defining the worth of further investment of funding and effort, are *not* achieved by December 15, 1976? What factors will you take into consideration in making this decision if you are faced with it?

Answer 5. We expect to appoint a technical review panel to study the status of the machine and its performance relative to the goals and minimum criteria set by Columbia University. Our reponse to any failure to meet the minimum criteria will depend on what areas of performance are deficient, since some deficiencies are easier to correct than others. Our assessment of these problems will be strongly guided by the panel.

Question 6. What is the current NSF policy on the maintenance of financial records by any grantee? Do these policies, in your opinion, need to be strengthened?

Answer 6. The National Science Foundation (NSF) policies on the maintenance of financial records by grantees are governed by Department of the Treasury regulations and Office of Management and Budget circulars. A summary of these is given in Sections 500 and 510 of the *NSF Grants Administration Manual* (attached). These policies are adequate to protect the interest of Government. Reports giving special compilations of the basic financial data are requested when appropriate.

Attachment:

STEWARDSHIP OF FEDERAL FUNDS

500 GENERAL

While no particular type of financial management system or classification of accounts is required, NSF expects that the responsible officials of the grantee will exercise careful stewardship of the Federal funds made available for the support of projects undertaken with NSF financial assistance. This chapter summarizes NSF requirements relating to the management of, accountability for, and reporting on such Federal funds. Included are long-standing NSF guidelines plus summaries both of Department of the Treasury regulations and of new standards of Office of Management and Budget Circular No. A-102 (Attachments A, B, C, G, H, J, and L) which are appropriate to the types of projects which NSF supports.

510 STANDARDS FOR FINANCIAL MANAGEMENT SYSTEMS

The financial management systems of NSF grantees and of their subrecipients should provide for the following:

a. Effective control over and accountability for all Federal funds, property and other assests. Relative to an accounting system to handle NSF grants, NSF suggests the establishment of accounting entries and control accounts for monitoring and reporting grant amounts due from NSF. (Accounts receivable equal awards less Final Fiscal Report unexpended balances less advances, and NSF cash on hand equal advances less expenditures). Accounting controls of this type can be developed under any existing accounting system and in many cases with only minor modifications.

b. Procedures to minimize the time elapsing between the transfer of funds from the U.S. Treasury and their disbursement by the recipient. (See 520, "Withdrawals of Cash from the Treasury.")

c. Accounting records which are supported by appropriate documentation.

d. Procedures for determining the allowability of costs in accordance with applicable Federal cost principles. (See "Expenditures Under NSF Grants," Chapter III.)

e. Records which identify adequately the source and application of funds for NSF-supported activities.

f. Comparison of actual expenditures with amounts budgeted for each grant. (See 573, "Grant Fiscal Report.")

g. Accurate, current and complete disclosure of the financial status of each NSF-supported project in accordance with Federal reporting requirements. (See 570, "Financial Reporting.")

h. Independent audits to be made of the recipient's records and activities to determine, at a minimum, the fiscal integrity of financial transactions and reports.

i. A systematic method to assure timely and appropriate resolution of audit findings and recommendations.

ADDITIONAL QUESTIONS FOR DR. LEON M. LEDERMAN

Question 1. With the luxury afforded by hindsight, if you could begin the modernization project all over again, what would you do differently?

Answer. There are two principal points we would have changed: (i) we should have have made a much stronger case for adequate funding. As it turned out, our original request for $4.9M was too low and the grant of $4.0M disastrous. Our best estimate now is that $6M could have done the job with resultant savings. (ii) We should have put a greater emphasis on engineering in the direct management. As it turned out, our theoretical design proved to be correct and even elegant, the interface to engineering failed. The above hindsight corrections should have enabled us to handle the high risk technologies we encountered in the course of the project.

Question 2. On page 8 of your statement you state that "the initial stages were plagued by engineering difficulties and a psychology of poverty." (*a*) Could the engineering difficulties have been avoided, in your view? If not, why not? If so, how?

Answer. There were, in this project, unavoidable difficulties, a good example being the rf insulators that were also called upon to support the floating iron shims. A stronger appreciation of the engineering problems as stated above, could have led to a solution in a shorter time. We needed a larger engineering staff but also more of an engineering "sense" in the management.

Question 2. (*b*) Would you elaborate on what you refer to as the "psychology of poverty brought about by the dramatic change in U.S. funding patterns for research that began roughly in 1968?" Specifically, what were your experiences in obtaining funding at that time that lead you to make this statement?

Answer. With accelerator laboratories closing everywhere (as detailed in my testimony) and the annual basic research budgets of the NSF and ERDA level or contracting, we considered ourselves lucky to be funded at all. Thus, we accepted the NSF funding level. Subsequent budgets proposals for preoperating, retrofitting and other items associated with the project were generally reduced by the NSF. We were also painfully aware that colleagues everywhere were in even worse shape with possibilities for new detectors, for utilization of existing facilities, severely restricted. As a consequence, we were trying to do too much with too few people. Note that between 1968 and 1975, basic research made do with an essentially fixed number of dollars and an inflation that, for scientific work, averaged 8% per year. This established the "psychology of poverty"—i.e. a willingness to work yourself harder and make do with what you have.

Question 3. The following is a list of the "questions driving research in physics" which were listed in the NSF budget book for Fiscal Year 1977:

What are the ultimate fundamental particles? In what sense do elementary particles have structure? Can the constituent elements of that structure have a separate existence?

Can the various interactions between particles (the strong, electromagnetic, weak forces) be reduced to a common principle?

How can we further our understanding of gravity and of the role it plays in determining the evolution, structure, and fate of the universe? How can we understand the interaction of plasmas and magnetic fields, and their cosmological implications?

What laws of symmetry and conservation are basic to all matter?

What principles at the particle or atomic level determine the bulk properties of matter?

Why does matter have the properties that we detect? Could these properties be otherwise?

How would you relate the research going on at the Nevis laboratories, including the high-energy physics research, to these questions? Would you agree that these are an appropriate list of questions driving research in physics today?

Answer. The list of questions is indeed appropriate and we have addressed several of them, e.g. "what are the ultimate fundamental particles, etc.?" In a recent paper which was also the subject of news stories in the Washington Post and the New York Times, etc., the discovery of a "charmed baryon" was announced. This work was carried out at Fermilab by a group from Nevis, Illinois, Hawaii, and Fermilab under the direction of Professor Wonyong Lee of Nevis. This work clearly addressing the problem of the "quark" structure of matter.

Similarly, work at Fermilab and at CERN under my direction, attempts to probe the structure of the proton via the "massive lepton pairs" emitted in high energy proton-proton collisions.

Work at Brookhaven by Professors Baltay and Lee deal with neutrino reactions which are most relevant to the second question: Can the various forces . . . be reduced to a common principle. The detailed properties of "neutral currents" being studied are directly related to recent progress on the unification of weak and electromagnetic forces.

Past and future work on the Nevis accelerator is relevant to the questions on symmetry and also, the question on the bulk properties of matter. We have already alluded to the Nevis experiments on parity violation which in fact initiated extensive work on symmetry and conservation laws in this field. A deep question of the symmetry of muons and electrons will receive attention via Nevis Proposal No. 22. A program of study of rare decay modes of pions and muons is also relevant since details of the symmetry violating forces are studied. Finally, we note that polarized muons explore details of bulk properties of matter via the magnetic fields while muonic x-rays continue to illuminate the problems of atomic physics; both topics will, in fact, dominate the Nevis cyclotron program as a glance at the list of proposed experiments would show.

Question 4. You state that you anticipate a lifetime of the modernized accelerator of about 10 years. Why *10* years? Will we know everything there is to know about intermediate-energy physics by then? Realistically, how likely do you think it is that there will be a renewed or continuing interest in intermediate-energy physics beyond that time?

Answer. We chose 10 years as a round number which seemed to be valid in many examples. The original Nevis accelerator program was interesting and viable for about 15 years before the need for improvement became pressing. Here a discovery coming after 7 years of work (polarized muons) had extended the field of research considerably. The BNL Cosmotron had a good 10 year activity. In the present case, we note that there are four machines (see my list) that will specialize in this field. We can be sure that some of these will fruitfully continue to collect data well beyond 10 years but the Nevis standard of quality in physics coupled with the relatively modest capital investment will make it unlikely that we would want to continue in the field without some new feature that would extend precision or some other parameter significantly. It is highly unlikely that this new feature could be achieved by "improvement". More likely, it will come from some creative new technology in accelerator design.

Question 5. Are the experiments you describe on pages 5-7 ready to perform? How far along are you in actually setting up the physics program associated with this machine?

Answer. At this time (October 1976), we have three teams now in the process of beginning research on the floor. One of these is already collecting data. A visiting team (Kent State) will return in December for their second Nevis run. The long delay in our schedule has resulted in a problem insofar as some of the Users' Program—commitments have been made elsewhere. We believe that in about 6 months, the relevant Users' Program will be in full swing. New ideas, stimulated by the actual presence of an operating machine, are beginning to be heard. On October 16, the Nevis Program Advisory Com-

mittee (NPAC) will meet to review the entire program for its relevance in view of the work in other laboratories.

Question 6. What procedures have you established for scheduling time on the machine? Who handles these details?

Answer. Experiments are approved by the NPAC. The Laboratory Director (myself) in conjunction with the Cyclotron Project Director (Dr. D. Storm) and the User Liaison Physicist (Dr. R. Cohen) discuss the schedule for the following month—fitting in experiments with accelerator work. The day-to-day administering is carried out by Drs. Cohen and Storm.

Question 7. Earlier this year you proposed a timetable for the achievement of operation goals which included the following:

a. Remote Handling and New Channel: Channel Installation, Remote Apparatus—By June 30, to install tracks in chamber and test.

b. Bump Coil and Remote Handing—By June 30, to install tracks and test remote handing.

c. New Iron Channel, Current Iron Channel—By June 30, to install remote mechanism.

d. Operation at 1 to 5 μA—By the end of July, to have 5 μA on target. During July, to devote 100 hours to experiments.

e. Installation of NVS Pulser and Target—During August.

f. Raise Extracted Beam Intensity from 5 to 10 μA—By June 30, to test remote handling equipment. By September 30, to prove new channel and bump coil in operation for two months.

g. Ion Source Developments—By July 31, to develop new tip with better ion extraction. By June 30 to design, and by August 30 to build a new pulser to produce longer pulses.

Which of these goals have been achieved, and when were they achieved? If any have not yet been achieved, when do you now expect them to be achieved?

Answers. Remarks on timetable for goals and schedules:

The first time mentioned was June 30. By that time, we wanted to have the remote handling equipment installed in the chamber for the bump coil, the current channel, and the new iron channel and current iron channel assembly. Included in these goals was the prior completion of the current channel and the other devices.

This work was not finished by June 30, primarily because of slippage of a few months in the completion of the current channel. That channel, with its tracks, was installed and tested during July and early August. The bump coil remote handling is finished and most of it was installed in September and the early part of October. About two days work remains to be done in the chamber, and this is scheduled for the latter part of October. The remote handling mechanism for the iron channel and current iron channel is nearly finished and will also be installed in October. The final demonstration of the entire remote handling system will also be done in October.

The NVS pulser and target installation is not related to the general machine operation, but rather is a separate piece of equipment for operating the cyclotron as a neutron burst generator. The installation was deferred from the August goal to free manpower for more essential work. The design was modified so the apparatus can be put in remotely anytime during the next year.

The schedule for beam intensity developments, with a 5 μA goal for July 31 and a 10 μA goal for September 30 has been shifted by 10 weeks along with the other items. The ion source improvements, which are to be concurrent with the beam intensity improvements, have also been shifted 10 weeks. Thus, we expect to reach the 5 μA goal in mid-November, and the 10 μA goal in mid-January 1977.

Presently, operation hours on the channel and bump coil are being accumulated. By October 31, enough time should be accumulated to prove their reliability.

Additional Comments, Nevis Laboratories, Leon M. Lederman, Columbia University

Here are some "I-should-have saids" after the hearing of 30 September on the Nevis Laboratories. These were stimulated by some of the general questions but especially by the remarks of Mr. Downing. I clearly understand his

interest in SREL and only wish he were representing my district. Nevertheless, some of the implications of his questions are disturbing and I would like to address these briefly.

As detailed in my statement, the Nevis Lab has had a distinguished record of accomplishments in physics and has a staff which has won three National Academy memberships, one E.O. Lawrence Award, two Presidential Medals of Science, and one Nobel Prize (1975). In any contest as to what the judgment of the scientific community would be, the record and the potential for accomplishment in science is vastly greater at Nevis than the record and potential of the SREL staff. The Nevis problem lay in a series of engineering difficulties in part due to the high risk technology pursued, in part due to undersupport but basically also due to an insufficient appreciation of the nuts and bolts practical engineering as opposed to the theoretical designs of the improvement program, however brilliant these in fact turned out to be. There are two main points that follow. One is that the NSF demonstrated very deep understanding of the Nevis problem, once it was perceived in 1972. They reacted with severity in imposing technical reviews and insistence on a reorganization of the direction of the program to stress the engineering. But they also recognized the underlying quality and accepted great risks in continuing to encourage the program towards a successful conclusion. Thus, I look at the NSF program management in this case as representing the very highest example of government science administration. The program officers worked hard at understanding the problem, they took risks to back their judgment and their purpose was the ultimate advance of the science they administer.

The second point has to do with Mr. Downing's constituency. It is indeed a tragic situation in which competent scientists are prevented from carrying out worthwhile research because of lack of funding. In my testimony, I summarized the large number of facilities that had been closed in the past ten years. Clearly, obsolete facilities should be retired but equally clearly, the process went much too far. The SREL operation ought to continue to be funded as long as they are doing good physics but Mr. Downing's efforts, in my view, ought to be focused on the real culprit: the overall funding level of the basic research budget of the NSF and on the policy which has led to so severe a contraction of science support in the U.S. The intervention of regional congressional "clout" and its substitution for the peer review system and judgment of dedicated civil servants would clearly introduce chaos into the administration of U.S. science support. I have every confidence that Congress would work to moderate this approach. Finally, I would like to thank you once again for the opportunity of appearing before you and enjoying a morning of rare interest.

Chairman SYMINGTON. Thank you very much for your courtesy in being with us today. I appreciate it very much.

Dr. WRIGHT. Thank you.

Dr. LEDERMAN. Thank you.

Chairman SYMINGTON. The meeting is now adjourned.

[The hearing in the above-entitled matter was adjourned at 11:55 a.m.]

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