NATIONAL RADIO ASTRONOMY OBSERVATORY

VERY LARGE ARRAY COMPLETION REPORT

JULY 1982

VERY LARGE ARRAY COMPLETION REPORT

July 1982

NATIONAL RADIO ASTRONOMY OBSERVATORY
VLA PROGRAM COMPLETION REPORT

TABLE OF CONTENTS

I. INTRODUCTION

With the completion of the Very Large Array Project (VLA), the astronomers of the United States and the world now have a radio telescope with the resolution and sensitivity of the finest optical telescopes. This Completion Report will not delve into the details of the design or capabilities of the instrument but restrain itself to a discussion of the construction.

Should the reader desire additional information on the technical aspects of the VLA, he is referred to D. S. Heeschen's articles The Very Large Array published in Sky & Telescope magazine, June 1975, (Reference No. 1), and The Very Large Array to be published in the Astronomical Review Monograph - Telescopes for the 1980's, (Reference No. 2), and to A. R. Thompson, B. G. Clark, C. M. Wade and P. J. Napier article The Very Large Array published in The Astrophysical Journal Supplement Series 44-151-167, 1980 October, (Reference No. 3).

II. SUMMARY

The construction scope of the VLA was resolved by March 1971 for submission to the Congress, and its cost was estimated at that time to be $76,000,000. Congress authorized the VLA in 1972 and appropriated $3,000,000 for the start of detailed design work. Funding was to be limited to approximately $10,000,000 per year so that other research supported by the National Science Foundation would not be severely impacted. Completion was scheduled for late 1981.

The project formally began on 1 January 1973 when 15 existing NRAO employees were transferred to the VLA organization. By April, five proposals for the design, fabrication and assembly of the 28 25-meter antennas were in hand and negotiations started. In June a subcontract was awarded to an Albuquerque engineering firm, covering the design of all site facilities. Award of the antenna subcontract, in the amount of $16,894,000, could not be made until October as the FY 1973 appropriations legislation was delayed. During the year development of the electronics and computer planning proceeded at an active pace.

1974 saw the award of subcontracts covering the design and fabrication of the antenna transporter, the first 60 mm TE_{01} waveguide, the on-line synchronous computer, the scientific asynchronous computer, the first 1.25 km section of wye trackage and the permanent site buildings and utilities.

The first antenna was received 22 September 1975, electronics installed and the first radio signals received on October 24th. Antenna No. 2 was received November 13th. Both exceeded the required technical specifications. By December both antennas were placed under computer control.

On 18 February 1976 first fringes were obtained at a 6 cm wavelength, using Antenna No. 1 and No. 2 on a 1.24 km baseline, followed later in the year by fringes at 18-21, 2.0 and 1.3 cm, thus proving the system. In August the Control Building was completed and occupied, and in October the first non-NRAO astronomer utilized the VLA for test operations.

By January 1977 five antenna elements were in use on a 5.2 km baseline. This number increased to ten elements by January 1978, fifteen elements by January 1979, and 21 elements by January 1980. Baselines grew steadily throughout the years with an E-W baseline of 27.7 km and a N-S baseline of 5.4 km, in use in January 1980.

In January 1981 all 28 antennas were completed with 27 in use in the A configuration. The instrument was finished nearly a year ahead of the schedule made in 1973, and at a cost of $78,578,000.

III. THE EARLY HISTORY THROUGH 1972

A. Development of the Design

The need for a radio telescope of great resolution and sensitivity had been evident to United States astronomers since the late 1950's. Other nations, particularly England, Australia and Holland, were surpassing the United States in their instrumentation and the time was right for the United States to make a quantum jump ahead. Starting in the 1961-62 period, the National Radio Astronomy Observatory established a study group to determine the type and size of the required instrument. By 1963 it was decided that the radio telescope should be of the interferometer type using the technique of earth rotation aperture synthesis developed by M. Ryle. Serious development work along these lines began early in 1963 and a prototype interferometer was begun at the Green Bank Observatory. By 1967 the initial design was sufficiently firmed up so that it was possible to submit a proposal for a Very Large Array Radio Telescope to the National Science Foundation. See A Proposal for a Very Large Array Radio Telescope, Volume 1, The VLA Concept, (Reference No. 6), Volume II, System Design, (Reference No. 7), and Volume III, An Update of Work Accomplished since January 1967, (Reference No. 8). While this proposal was working its way through various review committees, work continued at NRAO in developing the design. These efforts culminated in March 1971 when the proposal was submitted to Congress by the National Science Foundation. Congress authorized the program in 1972.

B. The Scope of the Original Instrument

The proposal for the Very Large Array was based on the following performance goals:

Resolution	1 arc second at 11 cm wavelength
Sensitivity	10^{-3} to 10^{-4} Jansky units

Sidelobes	Not to exceed -20 dB
Field of View	1 to 10 arc minutes
Wavelengths	5 and 11 cm
Polarization	Linear and Circular
Sky Coverage	-20° to +90° declination
Speed	8 to 10 hours per observation
Spectral Line	Design should not design it out
Map Size	About 100 x 100 points per side

C. Site Selection

By 1965 sufficient data concerning the technical requirements of the VLA were determined so that it was possible to begin the search for an acceptable site. The site selected would have to rate very high when the following criteria were considered:

1. The site must be large, nearly level, and permit three equangle arms to be placed with one between 4° and 10° of a true north-south line.

2. The site must be south of latitude 42° N and preferably south of latitude 40° N to maximize sky coverage.

3. The site should be at a high elevation to maximize antenna sensitivity. Atmospheric water vapor should be at a minimum.

4. The site must be in a rural, low population density area with little chance of future development to minimize cost and future interference with the instrument.

5. The site should be in an area of low natural hazards to the instrument.

6. The area should not contain conflicting activities such as nuclear testing.

7. The site should be near a town or city where the staff would live and enjoy reasonable amenities. Transportation for visiting scientists should not be too difficult.

8. The site should lend itself to economical construction of the VLA including land purchase.

9. The climate at the site should not give extreme temperature differentials.

These criteria dictated that the site must be in the southwestern portion of the United States, south of latitude 42° N and west of longitude 100° W. During the fall of 1965 the Site Selection Group reviewed United States Geological Survey topographical maps of this area and selected 34 possible sites. Of these, 14 were ruled out because of poor orientation, conflicting activities or poor topographical characteristics. The remaining 20 sites were inspected by air between 17 November 1965 and 29 October 1969. Aerial inspection ruled out 11 sites and ground inspection ruled out two more. This left seven good sites. These were studied by the Group and three selected as being potentially the best.

In May 1966 the Albuquerque firm of Limbaugh Engineers, Inc. was given a subcontract to make a preliminary engineering study of these three sites. The Limbaugh report, dated November 1966, Site Development and Facilities Requirements for the Very Large Array, (Reference No. 4), did not make any conclusions.

Work on the technical development of the instrument continued, and by 1969 it was determined that the arms could be reduced from 24 km (15 miles) to 21 km (13 miles) and that sites as far north as 42° N latitude could be considered. This added four additional sites. In October 1969 Limbaugh Engineers, Inc. was requested to study the four additional sites and update their report on the previous three. This was done and a report submitted, dated December 1969, Site Development and Facilities Requirements for the Very Large Array, (Reference No. 5).

The NRAO Group confirmed the Limbaugh study and completed Volume IV, The Site of the VLA Proposal in December 1971 and Volume IVA, The San Augustin Site in April 1972 (Reference No. 9 and No. 10). From all the data it was obvious that the San Augustin site, 52 miles west of Socorro, New Mexico, and between the Villages of Magdalena and Datil, was far superior to the other sites.

The National Science Foundation requested the National Academy of Science to review the site selection. This was done early in 1972. The Academy concurred in the site selection criteria and the actual selection. The site was then approved by the Foundation.

D. The Environmental Impact Statement

Once the site was selected and approved in 1972, it was necessary to prepare in accord with United States Government Council on Environmental Quality regulations, an Environmental Impact Statement for the Very Large Array. The responsibility for preparation of the draft statement was assumed by the National Science Foundation with NRAO assisting with the details.

The first step was a public meeting held in Magdalena 15 May 1972 to discuss the VLA with local residents, ranchers and public officials. The statement was then drafted and issued for public and private comment. The strongest comment came from David W. King, New Mexico State Planning Officer, speaking for the land owners. He asked that the following points be included:

1. Restoration of all grasslands destroyed by construction
2. No tourists to be allowed on the arms of the array
3. No permanent roads to be constructed along the arms
4. No additional land is to be taken at a later date

The Statement was then put in final form, dated 6 October 1972, accepted by the President's Council on Environmental Quality and

published in the Federal Register on 6 August 1973, "Final Environmental Statement - Very Large Array". (Reference No. 11). It was thought at the time that this ended work on the Impact Statement.

At the request of the U. S. Bureau of Land Management, the Project Manager met with BLM officials on 11 October and 30 November 1972. On 6 December 1972 the Acting State Director of BLM sent NRAO a letter stating the Final Environmental Impact Statement was not acceptable to the State Office of the BLM and that they were taking this matter up with their national headquarters. The next meeting was on 6 April 1973, followed by a NRAO letter on 12 April, which stated that NRAO believed the Impact Statement was final but NRAO would cooperate with BLM in any reasonable way. On 1 May 1973, Arlen P. Kennedy, Socorro District Manager of BLM, wrote stating they still did not believe the Impact Statement was adequate. This was followed by a NRAO letter of 8 May restating the NRAO position. No further correspondence has occurred.

At the request of the Foundation the Environmental Impact Statement was updated and sent to the National Science Foundation on 22 March 1978.

IV. THE VLA ORGANIZATION

A. Management Concepts

Discussions concerning the management of the design and construction of the VLA began in the late 1960's and continued until the instrument was authorized in 1972. One basic concept was paramount, that was that the NRAO scientists who conceived and developed the various systems should play a strong part throughout the detailed design and construction, and even into initial operation.

A second basic concept was that the construction staff should be kept as small as possible and the design and construction of components and systems should be subcontracted out to the maximum extent possible. This would minimize the "hire-fire" ratio and help to ensure that the really key scientists and engineers would stay throughout the entire construction period and into operations. It later proved that although this concept was sound, in actual practice it could not be followed completely as it was not always possible to find qualified commercial concerns who could complete some of the state-of-the-art components at anything near a reasonable cost.

A third basic concept was that the Project Manager would be a professional manager and not necessarily a scientist assigned to the management task.

A fourth basic concept was that the instrument must meet or exceed the minimum design criteria and be constructed within the established cost ceiling of $76,000,000.

B. Development of the Management Plan

The first management plan was set down in The VLA Concept, Volume I of A Proposal for A Very Large Array Radio Telescope, dated

January 1967, (Reference No. 6). It provided for a management staff of 30 man-years per year in keeping with the subcontracting concept.

From 1967 until 1971 the management plan underwent further development. At this time the proposed VLA organization consisted of five divisions; Antenna, Electronics, Computer, Site and Administration, reporting to a Project Manager who reported to the NRAO Director. The direct project staff varied from 17 to a maximum of 28, plus from 10 to 21 people assigned from other NRAO divisions. Coincidental peak was 45 persons. In administering the VLA development and design, the NRAO Director would be assisted by a VLA Advisory Committee selected from eminent radio astronomers and engineers outside of NRAO.

In late 1971 the National Science Foundation engaged the Stanford Research Institute under Contract NSF-C706 to make a feasibility study of the VLA. Their report entitled VLA Feasibility Study, (Reference No. 12), was issued in February and March 1972. It confirmed the feasibility of the VLA concept and the proposed management organization. It did, however, question the total manpower proposed as being low, was concerned about the "borrowed" NRAO personnel and suggested that the VLA, in reporting directly to the NRAO Director, might overburden him. This later suggestion was accepted and the VLA Project Manager reported to the Associate Director for Technical Services.

In June of 1972, NRAO prepared a draft of a document entitled "Construction Management Plan" which although never issued in final form served as the basis for future planning.

C. The Management Plan

The VLA Project was formally authorized by the National Science Foundation on 8 November 1972 when Amendment No. 24 to prime

contract NSF-C450 was executed. On 30 October 1972 the first VLA Project Plan - CY 1973, was issued by NRAO (Reference No. 13). It contains a full description of the proposed organization including the first VLA Project Organization - 1/1/73, Exhibit 1. Also included are descriptions and membership of the four advisory and review committees which assist the management of Associated Universities, Inc. and NRAO in supervising the VLA Project. These are the NRAO Visiting Committee, the NRAO Users Committee, the VLA Advisory Committee and the VLA Steering Committee.

As the design progressed and procurements began, it became quickly apparent that many of the components necessary for the VLA could not be farmed out to industry for development, design and construction. It was found that specific items of equipment, such as parametric amplifiers, or helium refrigerators, could be developed and produced by industry, but frontend receivers could not unless very long lead time was allowed and the Project was willing to pay a very large cost premium. As time went on many items which were thought to be developed and purchased by outside vendors had to be developed and constructed in-house. The effect of this is shown by the increase in personnel in the various groups as shown on Figure 1, entitled Tabulation of Manpower Estimates. Thus the manpower required for electronics construction increased from 23 to 42 persons largely because of the need to establish assembly groups in both Charlottesville and in New Mexico. In the antenna area E-Systems would not make relatively simple additions to the antennas at a reasonable cost, so this group was increased from 6 to 11 to accomplish the necessary work.

Late in 1974 it became apparent that there was a time between the completion of an antenna, including its electronics and its scientific operation, which was neither construction or operation. During this time the telescope and its various systems would be tested, pointing corrections and baselines established, communications

NATIONAL RADIO ASTRONOMY OBSERVATORY
VLA PROGRAM COMPLETION REPORT

TABULATION OF MANPOWER ESTIMATES

Group	Program Plan Years							
	1973	1974	1975	1976	1977	1978	1979	1980
CONSTRUCTION								
Antenna	6	5	6	9	11	9	5	2
Electronics	23	40	40	36	42	38	29	20
Computer	2	6	16	16	14	5	5	2
Systems Integration	–	–	3	4	4	1	–	–
Site & Wye	6	6	8	7	3	2	2	2
Program Management	15	13	14	20	3	3	3	2
Sub-Total	52	70	87	92	77	58	44	28
OPERATIONS								
Antenna	–	–	–	–	2	6	12	15
Electronics	–	–	–	–	5	11	24	28
Computer	–	–	–	–	4	10	13	12
Array Operations	–	–	–	–	4	7	11	13
Site Management	–	–	–	–	–	–	–	6
Sub-Total	–	–	–	–	15	34	60	74
COMMON COST	–	–	–	–	30	30	32	31
TOTAL	52	70	87	92	122	122	136	133

Figure 1

and signals calibrated, and similar work done. This would also be a training and shakedown period for operators and equipment. In addition, the prime contract with the NSF required AUI to complete Task VI entitled VLA System Integration and Test.

To separate out these costs a Systems Integration Group was established on 1 January 1975 under Dr. Victor Herrero. This group was phased out in 1978 and the remaining people transferred into the Array Operations Group.

The NRAO Long Range Plans originally planned for VLA operating budgets to begin in CY 1976 and gradually increase until full operations were underway in CY 1981. However, the Foundation did not provide operating funds for CY 1976, and so no division of personnel was effected until CY 1977. The method used was a very careful analysis of those people whose time would be principally devoted to operations. In most cases, such as array operators, certain electronic and antenna technicians, the selection was obvious. In other cases the selection had to be judgmental. The total personnel, and hence cost, assigned to operations also had to bear a sound relationship to the number of antennas which were operating. From Figure 1 it can be seen that between 1977 and 1981 the percentage of total project personnel assigned to direct operations increased as follows: 12%, 28%, 44%, 56%, 100%.

In 1977 when operations formally began it was advantageous to establish a Common Cost category of expenditures so that these costs could properly be distributed between construction and operations. The common cost group consisted of administrative, business, personnel, purchasing, food service, maid service, janitorial, guards, drivers, fiscal and site maintenance personnel. Expenses for utilities, communications, transportation, stationary and similar expenses used by both construction and operating groups were included.

The final project organization was identical to that established in 1973 as shown by the VLA Program Organization - 1-1-80 included in the VLA Program Plan for CY 1980, Exhibit 2. Through the years the management organization has worked very well principally because of the high caliber of the Division Heads. With only six or seven individuals reporting directly to the Project Manager and each of these fully capable of handling his area with a minimum of supervision, it left the Manager adequate time to work with the NRAO, AUI and NSF management.

D. THE ADVISORY AND REVIEW COMMITTEES

As set forth above the VLA Program was advised and reviewed by five advisory committees. These were as follows:

The NRAO Visiting Committee

Appointed by and formally reports to the AUI Board of Trustees. Its function is to review the performance of the Observatory including the quality of the scientific work and adequacy of its instrumentation and facilities. It meets once each year and during the VLA construction carefully reviewed and reported on the Project.

The NRAO Users Committee

Appointed by the NRAO Director. Its function is a broad review of the NRAO program as it effects users of the telescopes. It meets twice each year and considers both the overall design and progress of the VLA. It reports on an informal basis to the Director.

The VLA Advisory Committee

Appointed by and reports to the NRAO Director. It is concerned with the broad elements of the design, scientific emphasis, priorities and general progress. Members are appointed who have broad

experience in the various aspects of radio astronomy so that the combined expertise of an international group can be utilized in assisting the direction of the Project. It met twice each year for at least two days and was of invaluable assistance throughout the years.

The VLA Steering Committee

Appointed by the NRAO Director as a working group of senior NRAO scientists and engineers. The committee was used extensively in the early days of the Project as a technical review group to analyze technical designs, construction plans, etc. to ensure that they were consistant with overall performance goals. This group met weekly in the early days of the program and ceased to operate as a working group in about 1978.

The VLA Post-Processing Committee

Toward the end of the Project the NRAO Director appointed a VLA Post-Processing Committee to oversee the post-processing development work for VLA scientific data. Its membership consisted of NRAO scientists who were thoroughly familiar with the scientific requirements of the VLA and its post-processing requirements.

In general, the committee form of review worked very well throughout the life of the Project. This was undoubtedly due to the caliber of the personnel appointed and to their great interest in the program of the Observatory and the development and construction of the VLA. One possible deficiency was their review of the computer capacity planned for the instrument, particularly as the power of the VLA continued to increase through the years. Perhaps more forceful statements and criticism on this point might have resulted in a more balanced design.

The membership of the various committees and their terms of office are included in the Appendix as Exhibit 3, 4 and 5.

E. Personnel

The VLA has been very fortunate in being able to attract and maintain a very capable work force in spite of a substantial turnover through the years. Total employment and forecast employment is plotted on Figure 2, entitled Program Manpower 1973-1980. It will be noted that the curve is very irregular showing periods when resignations dropped total employment by up to 8 persons. In this case it required over six months to regain the eight people lost.

It is always difficult to recruit and keep competent scientists, engineers and technicians in a remote area. In the case of the VLA the challenge of constructing a very unique instrument and the existence of the New Mexico Institute of Mining and Technology helped a great deal. On the other hand academic pay scales, the long bus ride to the site, the semi-desert nature of New Mexico, the small city and an average school system were reasons given for leaving. In all a total of 317 persons were hired during the eight years of the Project. In addition, about 18 persons were transferred from the existing NRAO staff.

It is always difficult to determine the exact reasons for terminations but a study of the records indicate the approximate percentages given below:

Professional Advancement	33%
Better Salary or Wage	13%
Dislike of Socorro Area	9%
Requested Resignation	11%
Transferred	12%
Personal (no clear reason)	20%

NOTE: Personal (no clear reason) generally associated with pay, location, husband transferred.

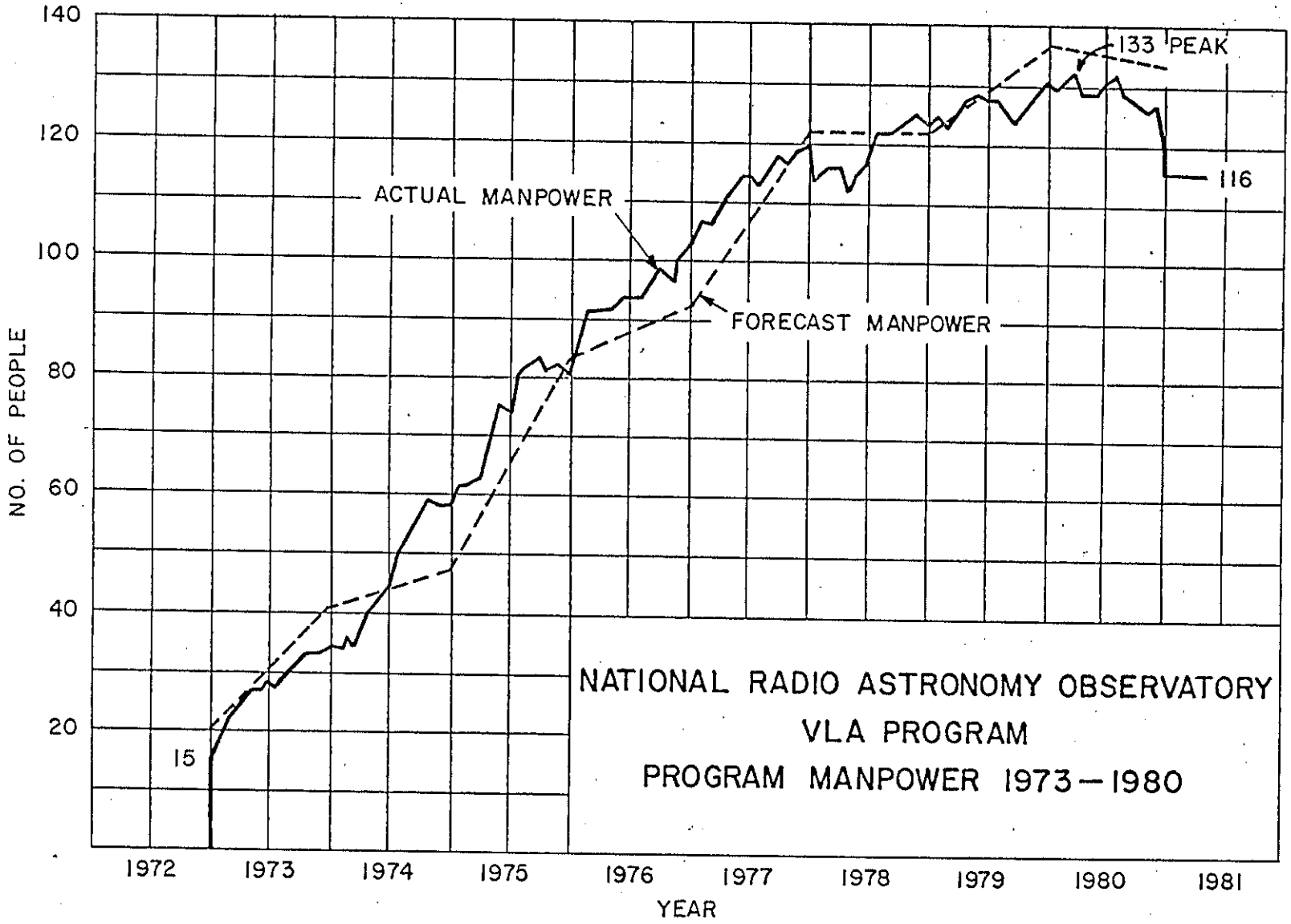

140
120
100
80
60
40
20
NO. OF PEOPLE
133 PEAK
116
ACTUAL MANPOWER
FORECAST MANPOWER
15
NATIONAL RADIO ASTRONOMY OBSERVATORY
VLA PROGRAM
PROGRAM MANPOWER 1973—1980
1972
1973
1974
1975
1976
1977
1978
1979
1980
1981
YEAR

Figure 2

The curves on Figure 2 illustrate several other key decisions which were made during the Project. In late 1973 and early 1974 it was obvious that the purchase of complete electronic subsystems was not feasible. This resulted in a jump in electronic people from 23 to 40. Somewhat later in 1974 it was decided to increase the computer manpower from 6 to 16 persons. The next jump came in 1976 when the impact of operations began to be felt and it was realized that the construction could not be completed and the array operated without increasing manpower. At this time antenna personnel increased from 9 to 13, electronics personnel increased from 36 to 47 and business and site maintenance personnel increased from 20 to 30. This later increase included drivers, cooks, guards, housekeepers, fiscal clerical and purchasing people as the site became operational. The last increase occurred in 1979 as the operations program increased in scope requiring a Site Management Group of 6 persons, an increase in electronics personnel to 53, antenna people to 17, computer people to 18, and common cost people to 32.

Turnover of personnel is a very costly item to a program like the VLA. When a highly trained engineer leaves the program, costs for a replacement approximate the following:

Increased salary differential for new hire	$2,000-3,000
Advertising for position	$ 800-1,000
Cost of bringing candidate for interview	$ 300- 600
Travel cost for man and family	$ 600-1,200
Per diem cost for family of 4 (20 days)	$1,500
Moving costs (3-bedroom household)	$2,000-4,000

A complete listing of VLA personnel who were directly employed on the Project for excess of one year is contained in the Appendix as Exhibit 6, entitled VLA Personnel Employed on Project. In addition to these people, many other NRAO employees stationed in Charlottesville, Green Bank and Tucson, and many visiting scientists, assisted in the work.

V. COST ESTIMATION AND FUNDING 1973-1980

A. Initial and Yearly Project Cost Estimates

The initial cost estimate for the VLA on which the Congressional Authorization was based, was made 10 March 1971 and was based on a one-year design plus a four-year construction program. It amounted to $63,047,000 as shown in Appendix as Exhibit 7, entitled The VLA Budget, dated 25 September 1974. This was revised on 15 February 1972 when the funding limitation of $10,000,000 per year was imposed to $76,000,000. The principal cause of this increase was that funding would now stretch over nine years instead of three years, resulting in much higher escalation and certain inefficiences of construction.

Each summer-fall thereafter until 1980 the entire VLA Project was re-estimated and adjustments made to the total estimated construction cost. These yearly cost estimates are shown on Exhibit 8 entitled Table of Cost Estimates and will be discussed in some detail in the following paragraphs. A beginning to end summary is as follows:

TABLE OF INITIAL & FINAL COST ESTIMATES
(In thousands)

Item	Initial 3/10/71	Final 2/1/81	Increase	% Increase
Site & Wye	$23,823	$27,143	+$3,320	+14%
Antenna Systems	22,012	22,812	+ 800	+ 4%
Electronic Systems	14,117	17,761	+ 3,644	+26%
Computer Systems	5,291	6,437	+ 1,146	+22%
System Integration	-	201	+ 201	-
Program Management & Common Cost	4,354	4,224	- 130	-3%
Contingency	6,403	-	- 6,403	-
TOTALS	$76,000	$78,578	+$2,578	+3%

The table shows that the largest increase in cost (26%) went into electronics to improve the sensitivity and reliability of the instrument. The next largest increase in cost (22%) went into the computer systems to increase their capacity and to provide for post-processing. The increase in Site & Wye cost of 14% is due to the addition of a number of items plus a much larger escalation rate (13%) than the 6% included within the inital estimate. Antenna systems and Program Management were well within the estimating order of accuracy.

B. Review of Yearly Changes in Estimated Construction Cost

Exhibit 8, Table of Cost Estimates, shows in summary form the yearly changes in the estimated cost of construction. Some of these yearly changes are quite dramatic and usually were caused by a change of scope of the Program, poor previous estimate or extra-ordinary bids. Explanations for the revisions can usually be found in the VLA Program Plans for each year set out as Reference No. 13 for CY 1973 to Reference No. 20 for CY 1980.

Detailed explanations are included in the yearly construction cost estimates. Detailed cost estimates for the CY 1976, CY 1977, CY 1978 and CY 1979 have been collated and bound into separate documents.

C. Funding By the National Science Foundation

The management of a major scientific construction project, like the VLA, without foreknowledge and a commitment as to the total funding and the yearly funding for each of eight years is a very difficult undertaking. A part of the FINDINGS AND RECOMMENDATIONS of the Ad Hoc Advisory Panel for the VLA stated:

> "The eight-year funding schedule based on federal budget limitations has imposed severe limitations on the ability of management to achieve even better results."

The following four items may be considered as typical:

1. E-Systems under their original contract would have had to go to their suppliers and vendors seven different times to order components. Each time the price would have escalated and costs would have been very high because of the small quantities involved. When the contract was changed to permit them to purchase for the last ten antennas at one time the average cost of steel dropped from $.38 to $.18 per pound.

2. Parametric amplifiers were purchased on three separate occasions. In between orders, the AIL Division of the Eaton Corp. disbanded their assembly crew and literally forgot how to make the amplifiers. As a sole U.S. source this was devastating and deliveries were a year behind schedule. If NRAO had not developed the cooled GaAs FET amplifiers as a subsitute, there would only have been 16-17 working antennas at Dedication instead of 27.

3. TE_{01} waveguide was ordered four times due to financial restraints. The first waveguide was purchased for $43.82 per meter and the last for $79.34 per meter.

4. It was necessary to build the wye trackage and electronic systems under four separate contracts spread out over five years even though it was all designed prior to the award of the first contract. Think of the savings in procurement, efficiency, mobilization, completion time, and escalation if this could have been awarded in one contract.

This does not mean that the Foundation did not do everything within its power to assist NRAO in getting the work completed. Attached as Exhibit 9, Funding Status, is a record of how the Foundation funded the Project. Of perhaps more interest is Exhibit 10, Funding and Expenses by Years, which shows the initial proposed funding, the actual funding, the total expenditures and commitments and the total expenditures. The Foundation was under no legal obliga-

tion to fund the Project until the beginning of each calendar year, but in each year advance funding was made enabling the project to jump ahead. It should be noted how closely the Total Expenditure & Commitment curve followed the available funding curve. The curves also show that actual Funding was behind the proposed funding for the first four years of the program, until the special Fiscal transition year funding became available in 1976.

D. Changes in Yearly Funding

As mentioned previously, the VLA was to be funded over nine years with three million dollars the first year and ten million dollars for the next seven years. The funding came through at $3M for the first year but in 1973 the Senate voted the $10M, while the House voted to postpone the Project for one year. Compromise was not reached until late fall when $5M was approved. This drastically revised the planned construction of the VLA. It was planned that all permanent buildings would be placed under contract in late 1973, so that construction could begin in the early spring of 1974 and be ready for occupancy in the summer-fall of 1975. Designs were ready and bidding was scheduled. This change in funding delayed the permanent buildings one year and caused the construction of a temporary building and trailers at the site. It also cost one year's escalation on the buildings and on the $5M until it could be restored. Another effect was that the main antenna design and fabrication subcontract was held up for four months from June 1973 until October 1973.

During the summer and fall four additional cost estimates were compiled and submitted to the Foundation to show alternate funding plans. It was estimated that the delay in funding of the $5M would increase the Projects cost by $2.2M if it was not returned until the ninth year, making the final cost $78.2M.

The CY 1974 Project Plan was based on $3-5-10-10M funding and resulted in an estimated construction cost of $78.2M. Following

submission and authorization, the Foundation requested cost estimates for a total of 17 different funding arrangements including what NRAO considered the optimum. Total estimated cost of construction varied from $80.4M down to $70.3M. The most efficient plan provided for all track and wye construction and the buildings to be constructed under one subcontract. This study was very valuable as it convinced all parties that construction cost varied severely with the period of construction. The Foundation then made a determined effort to increase yearly funding which resulted in receipt of $12.5M in CY 1974 instead of the planned $10M.

The CY 1975 Project Plan was prepared based on an optimistic $3-5-13-16-13-13-7-4.3M funding and resulted in an estimated cost of $74.3M. Unfortunately the Foundation could not maintain this proposed level of funding. Early in 1975 NRAO was again asked to make a series of cost estimates based on different levels of funding. Five different plans were presented which ranged from $73.8M to $78.5M in total cost.

For CY 1976 the Foundation advised that funding of $3-5-13.5-13-13-13-5.9M would be available which resulted in a construction cost of $78.1M. In this year the federal government changed its fiscal year from July 1st-June 30th to October 1st-September 30th and E-Systems attempted to back out of their antenna subcontract. Fortunately the fiscal year change resulted in $3.5M of transition funds becoming available and more fortunately the Foundation authorized its use for the antenna subcontract. This resulted in about $16M being made available in CY 1976 instead of $12.5M.

For CY 1977 the Foundation reduced the $13M to $12.5M which resulted in a construction cost estimate of $78.2M. For CY 1978 the expected $13M was again reduced to $12.5M by the Foundation. A reduction in the Contingency/Reserve estimate held the forecast of construction cost to $78M.

A number of revisions occurred in the CY 1979 construction cost estimate. First the expected funding of $13M for CY 1978 was reduced to $11.5M which was a severe cut as it mostly effected conventional construction which was escalating at about 12% per year. Secondly, the Foundation advised NRAO that it expected the VLA funding to provide all imaging processing equipment required for the VLA observers. Thirdly, as special or operating funds were not available for spare parts, the cost of the initial inventory, estimated at over $1,000,000, would have to come from construction funds. These plus high escalation in the mechanical areas resulted in a cost estimate of $79M. In February 1979 the Foundation instructed NRAO to limit the total cost of the Project to $78,570,000. To meet this lower ceiling it was necessary to make a very severe reduction in the mass data storage capability. For this budget presentation it was definitely decided that the air strip and Transporter No. 3 would be cancelled.

The cost estimate for CY 1980 was held at $78.6M to meet available funds. One other major revision was made to the construction cost estimate in October 1980 when $850,000 was gathered from other VLA construction accounts in order to upgrade the DEC-10 scientific computer and to add a DEC-VAX 11/780 processor & auxiliaries. The total cost of the VLA remained at $78.6 million.

VI. PROCUREMENT AND CONSTRUCTION SCHEDULING

A. The PERT Scheduling System

It was realized before the VLA Project was authorized that scheduling and control of the hundreds of thousands of components required for completion would be a major management task. For this reason a PERT (Program Evaluation and Reporting Technique) system was established in 1972 and various work breakdown structures and network diagrams studied. This work continued through 1973 and 1974 until July of 1975. At that time network diagrams were being maintained monthly and separate monthly computer print-outs were run on the following work packages:

Narrative Report
Project Management Activity-Time Status Report
Major Event Report
Contract Number Summary Table
Kilometer Stone Report
Antenna 01 Construction
Antenna 02 Construction
Antenna 03 Construction
Antenna 04 Construction
Antenna 05 Construction
Antenna 06 Construction
Asynchronous Computer Hardware
Asynchronous Computer Project Book
Asynchronous Computer Level 1 Programming
Asynchronous Computer Level 2 Programming
Asynchronous Computer Optical/Analogy Processing
Asynchronous (Proto) Computer
Spectral Line Computer System
Prototype Electronics Subnet
WG Distribution System Subnet
Delay System & Multiplier Subnet

IF/LOBE Rotator System Subnet
Front End System Subnet
Cassegrain Mod Subnet
Control & Monitor System
Control & Monitor 01, 02
Spectral Line Processor Subnet
Local Oscillator System
60 mm Mixed Waveguide
Antenna Couplers
Signal Distribution System
1 km WG Install & Test
Trailers for Electronics Installation
Control System Subnet
Antenna 01 Remove Equip. - Install in Con. Rm.
Antenna 02 Remove Equip. - Install in Con. Rm.
Delay & Multiplier System Subnet
Module Documentation Subnet
Front Ends for Antenna 01, 02
Electronics for Antenna 03
Electronics for Antenna 04
Preliminary Operating Evaluation
Electronics Procurement
Site Construction Subnet
Transporter 01
Single Dish Test for Antenna 01
Single Dish Test for Antenna 02
Single Dish Test - Electronic Systems
Antenna 01, 02 Preparation Interferometer Test
Antenna 01, 02 Interferometer Testing
Build 3 km of Wye
Build 1 km of Wye

During 1974 a study was made to see if implementation of a PERT-COST computer control system was feasible. It was decided that

the complexities and potential overlaps on a repetitious program made implementation impracticable.

In the spring of 1975, prior to the move to the site, a study was made of the effort required to maintain the PERT system. It was determined that the one and one-half man years per year plus many hours time of engineers and scientists were not cost effective. At the site the scheduling and coordination work was turned over to the newly formed Systems Integration Group. This was not satisfactory and an experienced man who had project management experience at Collins Radio and Motorola was hired as Assistant Project Manager to accomplish the scheduling task through the use of daily contact with key personnel and line-of-balance controls and bar charts. The most effective coordination and control technique throughout the last years of the program was the regular hourly meetings held every Monday morning at the site where problems and delays were aired and solutions immediately determined. This meeting was attended by 12-14 key people and no meeting was skipped during the 5 1/2 years it was run.

In Charlottesville PERT techniques were used until mid-1980 to control the fabrication of the electronic modules and other equipment manufactured and assembled in the NRAO electronic shop. It was also most effective in scheduling requisitions to achieve economics in procurement through mass buying of common components.

B. Scheduling of Construction

The PERT information and experience during the design and construction of Antennas No. 1 and No. 2 and their electronics was invaluable in establishing a detailed bar chart for the balance of construction. This chart was revised annually based on funding and the plan set forth in the yearly Project Plans. It was used each month to report progress. For reference purposes the chart used in the CY 1973 Project Plan and the chart used upon completion of the Program are included as Exhibit 11 and 12.

The importance of the weekly coordination meetings cannot be over emphasized. It was at these sessions that prime and secondary problems became apparent and all personnel that these problems would effect were there to comment and assist in proposing solutions or alternate actions. All persons necessary to make a prompt and effective decision and lay out the best course of action were in the room. In later years these meetings were also attended by key Charlottesville managers through telecommunication tie-ups.

C. Summary of Kilometer Stones

Various key events during the life of the Project are set down here. A more detailed schedule is included as Exhibit 13, entitled A Chronological History of the Very Large Array Radio Program.

1972	November 08	Received NSF authorization to proceed ($3,000,000 funding).
1972	December 08	Issued RFP for twenty-eight antennas to ten concerns.
1973	October 18	E-Systems, Inc. of Dallas, Texas awarded sub-contract to design and fabricate the VLA antennas.
1973	November 02	NRAO takes possession of central VLA Site.
1974	January 30	E-Systems, Inc. of Dallas, Texas, awarded sub-contract to design and fabricate Transporter No. 1.
1974	June 17	Digital Equipment Corporation awarded subcontract for the asynchronous (scientific) computer.
1974	June 17	Burns Construction Co. awarded subcontract for construction of first portion of wye trackage and power system.
1974	June 24	Modular Computer Systems awarded subcontract for synchronous (on-line operating) computer system.
1974	August 22	Fabrication of two prototype antennas authorized.

1974 December	29	George A. Rutherford, Inc. of Albuquerque awarded Phase II subcontract to construct permanent buildings, site work and utilities for VLA.
1975 May		The VLA organization moved from Charlottesville, VA to the site and offices in Socorro, N.M.
1975 July	18	Transporter moved Antenna No. 1 to Master Pad.
1975 September	25	Contract awarded for Phase III construction to provide C & D array plus southwest arm to AW-6.
1975 October	24	First radio observation by Antenna No. 1 - Virgo - A, 3C274 at 6cm.
1976 February	18	First fringes, Antennas 1 and 2, 6 cm, 1.24 km baseline.
1976 June		Asynchronous Computer and 13 employees moved from Virginia to New Mexico.
1976 September	14	First fringes, two element array, 18-21 cm.
1978 June	15	Formal announcement published in the Bulletin of the American Astronomical Society, Volume 10, Number 1, that the VLA was open for scientific proposals.
1978 June	23	Phase IV wye construction contract awarded, $2,916,080.
1979 April	26	Phase V wye construction contract issued in the amount of $2,820,000.
1979 November	09	Last Antenna, No. 28, accepted from E-Systems.
1980 February	01	Final increment of funds received by NSF to complete VLA construction.
1980 June	09	Phase IV Construction complete.
1980 September	26	Antenna No. 28 declared operational.
1980 October	10	VLA formally dedicated, attended by 600 guests and staff members.
1981 January	22	All 27 antennas working on the A Configuration.

VII. LAND ACQUISITION

A. Basis for Land Acquisition

The basis for the amount and layout of the land to be acquired was established in the 1971-1972 period. The design dictated 21.0 kilometer (13.05 miles) arms and a central area to be owned by the U. S. Government large enough for all buildings and the conjunction of the three wye arms. The center of the wye and the orientation of the arms were also determined and effectively frozen at that time. It was agreed that the central area should consist of one section of land (652 acres) and that the arms of the wye should be 600 foot wide permanent right-of-ways. After considerable objection on the part of rancher Jay Taylor to the VLA encroaching into his North Lake irrigation fields, the north arm of the wye was shortened to 18.9 km (11.77 miles).

B. The Land Acquisition

The National Science Foundation awarded Interagency Agreement No. NSF-CA90, dated 15 June 1972, to the office of the Chief of Engineers, Department of the Army, to obtain the necessary land for the VLA. The first task was to prepare a Real Estate Planning Report, (Reference No. 22), which was done and submitted under date of 5 December 1972.

From that point the Corps worked very closely with the NRAO and at no time was the progress of the VLA slowed or hampered by lack of entrance or the right to use either private, State or Federal land.

Access for land surveys and sub-soil exploration were obtained on all parcels by 15 January 1973 and possession of the central site was granted on 2 November 1973. On 12 January 1973

Limbaugh Engineers of Albuquerque began the detailed mapping of the entire site.

Land acquisition of private, State and County land proceeded during the years 1973 through 1978. In many cases it was necessary for the Corps of Engineers to resort to condemnation proceedings as the land owners were not satisfied with the maximum sum which the U. S. Government was authorized to pay. The State of New Mexico did accept the settlement offered and this cleared up access to approximately one-third of the wye arms.

C. The Lawsuit with Ranchers Ake, Dunlap and Taylor

The three ranchers who owned the land near the ends of the three arms would not settle with the U. S. Government and brought suit in Federal Court against the Governments condemnation action on 3 April 1975. Judge Bratton appointed a three-man Commission to hear the case and make recommendations of proper compensation. The Commission held a number of hearings during 1978 and 1979 and visited the site on 9 February 1979. Principle complaints of the ranchers was the loss of value of their ranches due to the construction of the VLA and the difficulty of working the ranch across the wye trackage. The loss was calculated on a before and after valuation of the ranch.

Final judgement was rendered by Judge Bratton on 14 November 1979. A table showing the awards follows:

	Ake	Dunlap	Taylor
Award	$85,000	$92,000	$42,000
Deposit	- 25,636	- 30,975	- 1,570
Deficiency	59,364	61,025	40,430
Interest	16,491	16,952	11,186
	$75,855	$77,977	$51,616

Total extra payment of $205,448 was made by NRAO upon the direction of the Foundation.

D. The Status of the Bureau of Land Management Land

The VLA wye arms travel over 11.54 miles of land under the jurisdiction of the Bureau of Land Management of the U. S. Department of Interior. This amounts to 839.56 acres. On 1 May 1974 the Corps of Engineers, in accord with instructions of the BLM, prepared a Land Withdrawal Document for the land required for the VLA. This followed the issuance of a special land use permit, issued on 17 April 1974. On 23 July 1975 a MEMORANDUM OF UNDERSTANDING, authorizing the construction of the VLA, was executed by the National Science Foundation and the Bureau of Land Management.

Then on 25 January 1979, nearly five years later, BLM advised the Corps of Engineers that they could no longer approve a land withdrawal and that the National Science Foundation would have to apply for a Right-of-Way across the BLM lands involved. The necessary application papers were prepared by the Corps of Engineers and sent to the Foundation on 27 April 1979. After a series of negotiations the Foundation sent the formal request to the Corps of Engineers on 30 September 1980 with Amendment No. 8 to Interagency Agreement No. NSF-CA90. The Corps of Engineers is handling the obtaining of the necessary right-of-way from BLM. The District Corps of Engineers in Albuquerque sent the papers to BLM State Headquarters in Santa Fe on 7 January 1981 and BLM in Santa Fe has sent them to Socorro for action.

E. The Status of the Airstrip Land

The documents and illustrations utilized in 1972 when the Environmental Impact Statement was being prepared showed the proposed airstrip to the east of the center of the array with its airplane

parking area approximately four miles from the building complex. When it came time to design the airstrip, a far superior location to the west was found which was flatter, less expensive and would have the airplane parking area within about one-half mile from the buildings. An airport easement was obtained 20 January 1977 from the State at a cost of $8,550.

The airstrip was always a low priority VLA item and its construction was shifted back until all higher priority items were obtained. In the CY 1979 Program Plan the airstrip was dropped as a part of the VLA construction program. On 19 August 1980 Dr. Morton Roberts requested the NSF to terminate the airport easement with the State. As of 1 April 1981 the Foundation still has this request under consideration. Rancher John Benton, on whose ranch the airstrip is sited, does not believe the present location is in accord with the Environmental Impact Statement. He insists that he must be well compensated if this site is to be used.

F. The Ake Archaeological Site

New Mexico State law and the regulations of the Museum of New Mexico require that the land used for any new project be inspected by a State licensed archaeologist for evidence of historical land use. NRAO engaged Dr. Stanley D. Bussey of New Mexico State University as a consultant to accomplish the survey. Dr. Bussey found no evidence of archaic land use on the north or east arms but did find evidence of ancient habitation near the end of the west arm. His report recommended an extensive excavation and cataloging operation estimated to cost $60,000. On 20 September 1974 NRAO requested the Foundation to fund the necessary work through its archaeological grant program. The Foundation turned this request down as did the National Park Service of the Department of the Interior who have funds for this type of work. The State had no funds so the VLA contracted with New Mexico State University at an estimated cost of $96,800. Between September

1974 and the contract date of April 1977, two of the three potential sites were abandoned and the third and most important site was placed on the National Register of Historical Places on 2 April 1976.

New Mexico State University attempted to begin work in June 1977 but was refused access to the land by Rancher Marvin Ake. A court action then had to be started in Federal Court, after clearance by the Department of Justice in Washington, to force entrance. Suit was filed but it took until 13 December 1977 before access was gained. The field work started in the early spring and was completed in May 1978. It was not until November 1980 that the final report was issued. In the meantime, to keep wye construction on schedule, NRAO arranged with the State Historic Preservation Officer to issue a preliminary approval which he did on 18 June 1979.

The investigation found three specific areas of interest. The oldest is that of the Folsom culture which dates back about 10,000 years. The other two areas are of the later Cochise culture which dates back four to six thousand years. Over 3,000 artifacts were found. For full details see "The Ake Site", (Reference No. 21).

It is difficult to realize that this action which began in July of 1974 took until November of 1980 to resolve, a period of six and one-half years. Over six Federal agencies and two State agencies were involved. It caused a reorganization of the construction scheduling for the wye but in the end, because of fiscal restraints, did not delay the completion or increase the cost of the Project.

G. Low-Level Air Force Supersonic Flights

In 1975 and early 1976 work at the site was occasionally disturbed by low-level Air Force supersonic flights. This was resolved in March to October 1976 when at NRAO's request the Air Force

changed the location of their training route to miss the VLA by some twenty miles.

H. Supersonic Flight Operations - Morenci Area

In November 1977 advice was received that the Air Force was plannng a supersonic flight practice area west of Datil which would involve one hundred sonic booms per week, involving over pressures up to a factor of 5. A letter was directed to the Air Force on 30 December 1977 which resulted in the movement of the area so that it cleared the westernmost antenna by 20 nautical miles (23 statute miles).

I. Cost of the VLA Site

Of some historial interest is a review of the land cost for the VLA Site. The first estimate of the land cost was contained in the Limbaugh Engineers, Inc. Engineering Study of the VLA Site, (Reference No. 4 and 5) and was given as $83,000 in the 1966 report and $77,000 in the 1969 report.

The VLA Proposal, Volume No. I, (Reference No. 6), in 1967 and Volume III, (Reference No. 8), in 1969 both estimated site acquisition cost at $100,000. In the VLA Project Plan of 30 October 1972, (Reference No. 13, pg. 19), an estimate of $142,000 was used. In late February 1973 the Corps of Engineers Real Estate Planning Report, dated 5 December 1972, (Reference 22, pg. 31), became available, which estimated the total land acquisition cost at $220,700 including administrative costs.

To date the actual costs for VLA Site Acquisition, exclusive of aggregate borrow pits which were arranged for by NRAO and charged out to the various construction contractors, is as follows:

Interagency Agreement No. NSF-CA90 with the Corps of Engineers, Department of the Army, providing for Acquisition of the VLA Site, 15 June 1972	$ 20,000*
Amendment No. 1 of 22 March 1973	165,000
Amendment No. 2 of 13 November 1974	73,000
Amendment No. 3 of 15 April 1975	35,000
Amendment No. 4 of 30 April 1975	n/c
Amendment No. 5 of 11 May 1976	10,000
Amendment No. 6 of 7 April 1977	10,000
Sub-Total	$313,000

*Not charged to the VLA Cost as the Project had not been authorized at that time.

Subcontract No. VLA 51C with Dr. Stanley D. Bussey of New Mexico State University	2,500
Subcontract No. VLA 256 with New Mexico State University for Archaeological work, dated 15 April 1977	98,000
Direct payment by NRAO to ranchers subsequent to award by the U.S. District Court	205,000
Total VLA Site Acquisition Cost	$ 618,500

VIII. THE DESIGN AND CONSTRUCTION OF THE ANTENNA SYSTEMS

A. The Design

In early 1972 when the possiblity of VLA funding became more promising an in-house review of the antenna design was initiated. At the time of the start of this design effort, the short wavelength limit of operation of the proposed antenna as set forth in Volume III (Reference No. 8) of the VLA proposal was 3.5 cm. The objective of the in-house design effort was the up-grading of the antenna performance specifications while at the same time staying below the performance point at which a rapid climb in the cost curve of any component of the antennas would commence. This was essentially a maximizing of the performance of the individual components of the antenna within a cost budget, preparing the error budget and performance predictions and then checking with the system planners to adjust the mechanical performance of the antenna to the scientific objectives of the total instrument. This design study showed that panel manufacturing costs increased rapidly if reflector surface error less that 0.030 inches (0.75 mm) RMS is specified which agreed well with the desired shorter wavelength of 1.3 cm. The lowering of the short wavelength limit increased the resolution of the array by a factor of 2.7 but resulted also in an increase in the required pointing precision of individual antennas. This design pointing precision, determined by nonrepeatable pointing, is primarily controlled by wind or thermally induced deformations throughout the structure. The choice of shortest wavelength required two parallel choices which were:

1. Definition of a wind and temperature environment which would yield, on the chosen site, reasonable observing time at the shortest wavelength while not requiring a more expensive design which would provide reasonable antenna stiffness and temperature control.

2. Choice of an antenna structure, including servo and drive capabilities, which would meet the chosen environment and chosen short wavelength without going to the point where component and system costs would start rising rapidly.

This design study revealed that the upgraded objectives could be met and that costs of the antenna and transport hardware could be held within the previously established budget. This design study also simplified preparation of antenna specifications for the Request for Proposal to potential subcontractors and gave NRAO an in-house prepared proposal containing detailed error budgets, component performance analysis, weight estimates and cost estimates against which subsequent subcontractor proposals could be evaluated.

After placement of the subcontract with the successful bidder, E-Systems, Inc. of Dallas, Texas, the detailed analysis and final hardware design was accomplished. Design and purchase specifications were prepared for all the various mechanical, electrical and structural components of the antenna system as well as fabrication and assembly drawings for the antenna. All drawings and specifications were reviewed, corrected and approved by NRAO. These specifications contained the material specifications, performance requirements, manufacturing specifications and the inspection, test and acceptance provisions for the major components of the antennas. During this final design stage the subcontractor prepared the assembly specifications which contain the alignment, test and acceptance documents and procedures which are necessary to verify that the antenna will meet the performance specifications set forth in the contract. Attached as Exhibit 14, Antenna Parameter Comparisons, is a comparison of the antenna parameters of the NRAO feasibility design and the E-System design. Exhibit 15, Surface Error Budget and Precision Pointing Error Table, compares the surface error and pointing error budgets of the two designs. Exhibit 16, Antenna Mechanical Parameters, compares the

specified manufacturing and assembly tolerances with the field achieved results.

B. The Selection of the Antenna Subcontractor

The conceptual design of the antennas was completed by the fall of 1972 and work started on the Request for Proposals in close cooperation with the National Science Foundation. The formal solicitation ad was placed in the Commerce Business Daily on 15 November 1972 and on 08 December 1972 the RFP was issued to ten prequalified contractors. A Contract Selection Committee was appointed by the NRAO Director, charged with the overall responsibility for selection and recommendation of award to the Director. The committee was assisted by a Business Evaluation Subcommittee and a Technical Evaluation Subcommittee. During the proposal period criteria for selection were prepared by both subcommittees. On 23 and 24 January a pre-proposal meeting was held in Socorro, New Mexico to clear up any questions the contractors might have and to ensure prospective contractors became acquainted with the VLA Site.

Five detailed proposals were received 14 March 1973 as follows:

Collins Radio Company	$31,757,157
E. Systems, Inc.	16,881,671
Philco-Ford Corp.	21,635,254
Radio Corporation of America	29,468,122
Rohr Industries, Inc.	20,558,778
VLA Engineering Estimate	$19,289,000

After a period of evaluation, there followed technical and business conferences with each of the vendors and the issuance on 15 March 1973 of a call for a "Best and Final" price proposal from each contractor. The call consisted of two parts: one of a general

nature applying to all vendors; and the second a list of items applying to each specific vendor.

On 25 July 1973 five "Best and Final" proposals were received as follows:

Collins Radio Company	$ 18,404,277 (not firm)
E-Systems, Inc.	16,997,675
Philco-Ford Corp.	19,283,938
Radio Corporation of America	24,871,274
Rohr Industries, Inc.	20,434,828

The Technical and Business Evaluation Committee carefully reviewed the Best and Final Proposals and rated them as follows:

Firm	Technical Evaluation	Responsiveness	Business	Weighted Combination
Collins	64.1	75.1	76.6	69.1
E-Systems	86.2	88.4	89.7	87.5
Philco-Ford	92.8	78.3	80.9	87.6
RCA	77.2	83.8	79.8	78.7
Rohr	85.7	85.7	89.0	86.7

As E-Systems weighted evaluation was within 0.1% of Philco-Ford, as their price was over $2,000,000 lower, and as the RFP stated that "Price is a significant factor in the final selection...." it was the Selection Committee's unanimous recommendation on 30 July 1973 that the subcontract be awarded to E-Systems. The NRAO Director approved this selection as did the National Science Foundation. For further details see Reference No. 23, "RFP-VLA-01 Antenna Procurement Contract Selection Committee" - Final Report, 30 July 1973.

Due to a problem with 1974 funding from Congress, the actual contract was not awarded to E-Systems until 18 October 1973.

Only the design phase, at a cost of $225,000, was authorized. The balance of the work was covered by unilateral options to be executed as funds became available.

C. The Antenna Assembly Building

During the preparation of the Antenna Request for Proposals and the subsequent negotiations, it became evident that a large assembly building could speed the fabrication and testing of the antennas and would be of great use to NRAO during the life cycle of the VLA as a maintenance center. Hence, each Contractor was asked, as an alternate to his proposal, to quote the cost of such a structure. E-Systems quoted $311,579 for the proposed building. Other quotations were $177,215, deduct $468,800 and $348,859. The proposed buildings had valuations up to $862,800.

E-Systems alternate was accepted on 4 January 1974 and they were instructed to design and construct the building which was completed in April 1975. One very serious fault was discovered during the design of the building which challenged its safety. This was that the Uniform Building Code in use in most western states, and on which the NRAO specifications were based, had no provision for open, three-sided buildings. In this type of building wind forces on the building can be 35% higher than on closed buildings. Considerable research had been done on the Vertical Assembly Building at Cape Canaveral which had not been incorporated into the building codes. As the Assembly Building was about ten stories high, no chances could be taken, and the subcontractor was instructed to strengthen the steel building frame at a cost of $63,290.

D. Later Negotiations with E-Systems, Inc.

About three days after E-Systems executed the subcontract to fabricate the VLA antennas, on 18 October 1973 the oil embargo was

started by the OPEC nations. Within eight months the cost of steel had doubled and E-Systems claimed they were facing very large losses. Informal talks took place during the fall of 1974 with E-Systems requesting that the subcontract be changed to a cost-plus type for Antennas No. 3 through No. 18. On 9 December 1974 NRAO authorized E-Systems to proceed with the fabrication of Antennas No. 3 through No. 6 in accord with the existing fixed-price subcontract. On 6 January 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 proceeded rapidly with procurement, fabrication and assembly and found that procurement for eight antennas at once vastly improved their purchasing cost and vendor deliveries.

Discussions with E-Systems, Inc. concerning the completion of antennas beyond No. 10 began on 10 January 1976 and continued throughout the spring. In January E-Systems was forecasting a loss on Antennas No. 3 through No. 10 of $1,050,000, or $131,000 per antenna, and at least $150,000 per antenna beyond No. 10. On 16 June 1976, E-Systems requested forbearance on all remaining antennas unless NRAO made $9,000,000 immediately available for advance procurement and increased the lump sum price by $1,074,150.

On 1 July 1976 NRAO refused forbearance. Subsequent negotiations resulted in an agreement that E-Systems would complete all remaining antennas, that the sum of $5,000,000 would be made available for advance procurement, that the lump sum price would not be be increased, that the discount for advance ordering would be waived, and that antennas would be delivered on an advanced schedule, which cut approximately fifteen months off the previous schedule. This agreement was fully executed on 21 July 1976. A record of the E-Sytems subcontract is included as Exhibit 17, entitled Subcontract VLA-6 Antenna Fabrication - E-Systems, Inc. - Summary of Amendments.

The final contract price was $18,156,054 of which $17,755,258 was for the antennas and $400,796 for the Antenna Assembly Building. The increase in antenna cost from start to completion of the subcontract represents 5.1% of the initial subcontract price. This is considered to be very satisfactory for high technology fabrication in a period of rampant inflation.

E. The Fabrication, Assembly and Test of the Antennas

Detailed design started immediately after the 18 October 1973 date and was completed by 31 July 1974. During the design period it became apparent that delivery of key items of equipment, such as the bearings, were so long that completion of the two prototype antennas would be greatly delayed. To combat these delays, NRAO authorized $870,275 for advance procurement. Fabrication of the two prototype antennas was authorized on 22 August 1974. Eleven months later, on 18 July 1975, Antenna No. 1 was picked up by the transporter and moved to the Master Foundation for final alignment, testing and acceptance, which occurred on 22 September 1975. Antenna No. 2 was accepted 13 November 1975. Both prototypes exceeded performance specifications.

The balance of the fabrication, assembly and testing work went smoothly once contract problems were solved. The delivery

schedule and actual acceptance dates are set forth on Exhibit 18, entitled Status-Procurement of Antenna No. 3 through No. 28. The performance specifications and how well the antennas met them is included as Exhibit 16, entitled Antenna Mechanical Parameters.

F. NRAO Furnished Hardware and Major Antenna Modification

During preparation of the Antenna Specifications and during later contract negotiations with the bidders it became apparent that certain hardware items should be designed, furnished and installed by NRAO. Justification for NRAO performing these portions of the antenna work consisted of:

1. Uniqueness of the particular equipment, such that it was not normally supplied the antenna subcontractor.
2. Status of the AUI design, such that a firm contract with the antenna subcontractor could not be arrived at when the prime subcontractor was concluded.
3. Very high proposed prices by the antenna subcontractor for elements of the antenna and for auxiliary antenna systems.
4. Delivery dates of NRAO supplied equipment which were later than scheduled antenna delivery dates.

These items which were designed, fabricated by NRAO, either in-house or by subcontract, and installed by NRAO forces after acceptance of the antenna from E-Systems were waveguide, cable trays and cabling, addition of a cryogenic compressor platform, addition of pedestal room heating, provision of the feed mounting ring which is the cover for the vertex room, the focusing feed mount at the apex of the reflector, the subreflector support tube, the subreflector, focusing feed mount controls, alignment and indexing of the subreflector and touch-up painting of the antenna.

Modifications to the antenna by NRAO forces were made during the construction period either because of changed performance requirements, equipment improvement requirements, improvement of service and maintenance features or addition of control and safety features. The more significant modifications made to the antennas were:

1. Conversion of the vertex room air conditioning system from a standard compressor on-off, proportional heat control system with an accuracy of $\pm 2^{\circ}F$ to a gas modulated system with proportional heat control which achieves a vertex room temperature control with $\pm 0.5^{\circ}F$ accuracy.

2. Provision of walkway and stairway access to the elevation platform and thence to the vertex room to replace the ladder access on the antenna as supplied.

3. Addition of a heater/blower to provide heated air to the interior of the position inductosyns in order to pressurize the inductosyn preventing infiltration of dust and to prevent moisture condensation.

4. Change of the elevation limit switches from cam operated on-axis limit switches to knocker limit switches activated by the elevation gear rack to secure more precise control and to eliminate an overspeed fault which developed in the control system.

5. Modification of the servo controls to provide more extensive automatic safety features. These included telephone activated fault resets, telephone activated stow and brake features, and anemometer activated automatic stow controls, at each antenna.

6. Provision of single phase protection equipment at each antenna to protect antenna electrical equipment against loss of phase.

G. The Transporter Design and Construction

The original mobility system for the antenna systems was set forth in Volume II of the VLA Proposal (Reference No. 7) and was arrived at after evaluation of various transportation systems including rail support, pneumatic tire support as used in Green Bank, crawler systems and two more exotic possibilities; ground effect vehicles or a canal system with flotation provisions. The rail system was chosen as the most practical system for the weights to be moved, the terrain and soil conditions and consideration of the moving time and maintenance of the roadways. The rail transport concept as proposed in Volume II consisted of double main line track spaced at 15'-0" centers, with towing vehicles adapted from highway type vehicles, lifting and lowering mechanism built into each antenna and used standard railroad switches at each station intersection with curved track leading to the offset stations.

In late 1967 NRAO, by subcontract, performed a more complete design study of the antenna and mobility features of the VLA. The mobility system consultant, Systems Development Laboratories, after a cost study of the switch and curve system, recommended that a 90° spur system be used and that a special vehicle be provided to accomplish both the turn at the intersection and the lifting and lowering of the antennas on the foundations. The approach recommended by Systems Development Laboratories was to place complex mobility features in the small number of transport vehicles rather than in the larger number of antennas. The choice of a 90° spur system over the more conventional turnout system eventually turned out to be a most fortuitous choice as antenna station configurations were changed from a total of 100 stations to 72 stations and the smallest configuration resulted in antenna spacings which were too close together to permit access by curved turnouts. The railroad consultant for the site and wye design contract was able to suggest a job fabricated crossing method which, using the transport vehicles capability of raising its trucks, eliminated the need for commercially fabricated crossing fix-

tures at the spur intersections. This one change at the intersections reduced the cost of the railroad portion of the VLA Project by an estimated amount of $24,000 for each of the 76 intersections built. During this design study a dynamic analysis resulted in the change of track spacing from 15'-0" to 18'-0" centers to reduce both rail loading and sub-grade loading.

The detailed design and fabrication contract for the transport vehicle was placed in January 1974 and the first transporter vehicle was accepted by NRAO in September of 1975. This vehicle, as completed, was essentially unchanged from the design as developed in 1967 with the exception of the elimination of the second drive diesel in order to reduce costs. The elimination of the second drive diesel did not reduce carrying capacity, loaded or unloaded speed, but only resulted in the reduction of the loaded speed when traveling up a 2% grade against a 25 MPH wind from 5 MPH to approximatley 3 MPH.

After acceptance of Transporter No. 1, a small number of modifications have been made to the vehicle to increase its usefulness to the project. These are:

1. Provision of an air compressor and pumping equipment to handle both greases and oils plus platforms for lubricant drums to enable the vehicle to perform oil changes and lubrication of the antennas.

2. Addition of a small diesel generator to allow provision of power to the antenna during transport, avoid heating and cooling cycles which are damaging to the antenna receiving equipment.

The original mobility concept proposed three transport vehicles primarily based on time required for reconfiguration of the array. After two years experience with the transport vehicle and in view of the change in station amounts which did not require that all

antennas be moved when configuration was changed, the decision was reached to only acquire a second vehicle and eliminate the third one. Since these vehicles are the only means of servicing, repairing or maintaining the antennas, it was not considered prudent to have only one such vehicle but elimination of the third vehicle does reduce both capital cost and requirement for a third operating crew which would only be utilized at reconfiguration times.

The second transport vehicle was contracted for in January of 1979 and incorporated those design improvements which had been suggested by operating experience with Transporter No. 1. It was delivered to NRAO in late spring of 1980 and has been placed in service.

IX THE DESIGN AND CONSTRUCTION OF THE ELECTRONIC SYSTEM

A. Overall System Design

The overall block diagram for the VLA Electronics System was designed by the Head of the NRAO Electronics Division in late 1972 and early 1973. Having the complete system defined down to the module level by a single person proved to be a definite advantage in generating a self-consistent design with a minimum of interface problems between different parts of the system. The most important technical decisions that were made during this early design phase were the choice of the frequency ranges for the four observing bands, the choice of the feed system and low noise amplifier elements for these bands, and the choice of the 60 mm helix waveguide for the signal distribution system. Other major decisions that followed in 1973 included the choice of a digital delay system, rather than an analog one as had been used in previous interferometers and arrays. This choice hinged upon the successful demonstration at NRAO that a practical digital system could be made to handle the required 50 MHz bandwidth. The primary local oscillator frequencies to be distributed throughout the array were also decided at about the same time.

The original plan for the project called for Antenna No. 1 and No. 2 to be fully outfitted with their electronics systems and tested for six months before construction of future systems had to begin. Because of schedule slippage, however, the production of systems 7-10 had to be started before a 2-element interferometer was operational. As a result, significant retrofits to the electronics on Antenna No. 1 through No. 10 had to be made throughout the Project. This did not have a significant impact on the final completion date for the complete electronics system.

B. The Waveguide System

The choice of the 60 mm helix waveguide for the array communication system was probably the most innovative design decision made in the electronics system. The VLA waveguide system remains the only one of its kind in the world that is fully operational. Before finally committing to the waveguide, a 200 m length was tested in Green Bank during the summer of 1973. This 200 m and 100 m length was test buried at the site in December 1973. As described in Section XI-I, the problems with increasing attenuation due to waveguide settling that were encountered early in the program, were solved by altering the burying techniques. At completion of the waveguide installation, attenuation was well within the specification as shown in Exhibit 19, 60 mm Helix Waveguide - Average Attentuation. The specification on attenuation was 1.4 dB per km over the VLA operating band and this was clearly achieved. Exhibit 20, 60 mm Helix Waveguide Attenuation vs. Time at 50 GHz, shows the loss of various sections of waveguide measured at 50 GHz, plotted as a function of time. Note that the loss of the section CW-5 to CW-9 is abnormally high because of the original installation method, but that its loss has stabilized and is no longer increasing with time. Because this is a short length of waveguide, its impact on the loss of the West Arm as a whole is minimal.

One of the major technical problems encountered with the waveguide system was the design of a suitable directional coupler which would couple each of the antennas into the main waveguide run. In 1974 a helix coupler was designed which had narrow bandwidth and did not have sufficient coupling for the farthest out antennas. This coupler would have required a coupler change in the main waveguide whenever an antenna was moved. This was considered a severe operating constraint and development work continued until, in 1976, a visiting Japanese engineer invented the sector coupler which proved ideal for

the VLA application. A production run of 64 sector coulers, which required special machining capabilities, was successfully completed by Bogue Machining in 1978.

C. The Feed System

After the four primary receiving bands of the VLA (L,C, Ku and K band) were chosen, an investigation of possible feed systems to support these frequencies was carried out in late 1972 and early 1973. Finally, after studying various combinations of prime focus and cassegrain systems, an offset cassegrain feed system was chosen. The VLA design was modeled on the system developed by the Jet Propulsion Laboratory for their 210 foot antenna. It was also decided to use a non-parabolic main reflector to take advantage of the increased aperture efficiency available with a shaped reflector system. A contract for a prototype feed system was placed with Rantec, Inc. in 1973 at a cost of $144,000. The feed design was specified to be suitable for both the VLA and the 140 foot telescope in Green Bank, so that the prototype system could be used and tested on the 140 foot telescope which was converted to a cassegrain feed geometry in 1974. Rantec was given the design goal of designing a feed system that would cost $40,000 each in quantity production. The 140 foot telescope was successfully tested in 1974, but when Rantec's bid for a follow-on order of 28 feed systems was received, it was approximately $2,500,000 above the VLA budget. To reduce cost the feeds were put out for competitive bid and a complete redesign of the L Band feed was undertaken. Orders for the L and C Band feeds and the subreflectors were placed with Ancom, Inc. for the Ku and K Band feeds with RF Systems, Inc. and for all circular and linear polarizers with Atlantic Microwave, Inc. The cost was now within budget. Tests of the first systems showed that the L and C Band feeds were not sufficiently efficient and a contract for new designs was given to consultant J. J. Gustincec in 1976. This new

design met the efficiency specification and was actually less expensive than the original design. All subreflectors, after the first two, were built by Milliflec, Inc.

In May 1976 it was discovered that the two circularly polarized beams of the antenna were displaced by 0.06 beam widths in the sky. Theoretical analysis and extensive experimentation eventually showed that this was due to the cross polarization performance of the offset feed geometry. It was decided in late 1976 that the limited scientific impact of this instrumental effect did not warrant redesign of the feed system, especially since six feed systems had already been procured.

D. The Cryogenically Cooled Receivers

The cryogenically cooled low-noise receivers caused the most problems of any part of the total VLA electronics systems. This resulted primarily from the difficulty of constructing, on a tight schedule, 28 state-of-the-art cryogenically cooled front ends, each with eight receivers, and keeping them operating reliably. A prototype receiver was tested on the 140 foot telescope in 1974 and orders were placed for components for the first two VLA receivers. A significant decision at that time was the choice of the low bidder, Air Products, as the supplier for the cryogenics systems, even though all previous cryogenics experience at NRAO had been with Cryogenics Technology, Inc. (CTI). In retrospect, a wiser decision would have been to build prototype systems with cryogenics units from both suppliers. This concept of proving second sources for critical components would also have been worthwhile in other areas of the electronics system, such as the parametric amplifiers discussed below. The first complete receiver was tested on Antenna No. 1 in October 1975, and almost immediately reliability problems became evident. In April 1976, after components for six systems had been procured, the

decision was made to switch from Comtech C Band parametric amplifiers to AIL units. Although the AIL units proved to be more reliable, AIL continually had problems meeting delivery schedules throughout the program. One of the causes of this was that orders could be placed for only seven systems at a time, so that critical materials such as ferrite, dielectric and varactors had to be "rediscovered" each year.

An interesting benefit of the delivery problem associated with the AIL paramps was that it encouraged the design and development, at the NRAO Central Development Laboratory in Charlottesville, of a replacement cryogenically cooled C Band GaAs FET amplifier. This amplifier was only one quarter the cost of a paramp and was much more reliable. From front end 22 onwards, cryofets were used in place of the second stage paramp.

By 1977, after ten units had been purchased, it was decided that the reliability of Air Products cryogenics systems was inadequate and the decision was made to switch to CTI units. Fortunately, the pricing situation had now reversed and the CTI units cost almost one-half of the Air Products units. Later, in 1978, it was decided to replace all Air Products units with CTI units. Another significant step in improving cryogenics reliability was the construction, in 1978, of a specially designed cryogenics laboratory and clean room. By the end of 1980, cryogenics reliability was no longer a problem.

E. The Delay Multiplier System

The prototype, two antenna, delay-multiplier system for continuum use was built and tested in 1974. The system used state-of-the-art techniques such as high component density multilayer printed circuit boards and ECL logic to obtain the 100 MHz data rate needed for the VLA. It was decided in 1975 to construct a combined continuum and spectral line correlator system. This would give exten-

sive spectral-line capabiity at a low total cost. However, in order to keep up with the schedule of continuum testing of the array, an interim continuum system, handling first 6 and then 12 antennas, was constructed and based upon the prototype 2 antenna design.

The final continuum/spectral-line system utilized two custom integrated circuits especially designed for the VLA to reduce cost and power consumption and to increase reliability. The two special I.C.'s were a dual 2-bit multiplier and a 12-bit integrator. They were designed and constructed by Silicon Systems. Another innovative design feature of the spectral line system was its ability to test and heal itself. In November 1978 the old 12 antenna system was decommissioned and the new spectral line system, which supported all antennas with 2 IF's, was brought into operation. Significant problems with digital cross talk were intitially encountered, but these were solved in 1979 by replacing some logic types and rewiring the complex integrator back plane. The second half of the delay-multiplier system, to handle two more IF channels, was completed by the end of 1980 but was not put into operation because of inadequte data handling capabilities in the computer system.

F. The IF-LO System

One of the most difficult performance specifications to meet was the array phase stability specification of one degree of phase error per GHz of observing frequency. As late as June 1977 the phase stability of the local oscillator system was still approximately three times worse than specification. This problem was eventually solved by significant redesign of the LO system with particular care being paid to the temperature stability of components. Major portions of the LO systems of the first ten antennas were retrofitted; by 1980 the instrument was meeting its phase stability specification.

Another problem which made significant redesign of the LO and IF systems necessary as performance testing progressed was the problem of RFI and spurious signals. Improved shielding of the local oscillator modules of the antennas was necessary to prevent the LO signals from leaking into the low noise receiver and additional filters had to be added to various IF modules to reduce undesired spurious responses. By the end of 1980, spurious signals had been reduced to acceptable levels for wide-band continuum observations, but it is expected that increased spectral line observing will make further improvement necessary.

X. THE DESIGN AND CONSTRUCTION OF THE COMPUTER SYSTEM

A. Initial Procurement and Temporary Installation of Synchronous and Asynchronous Computer Systems

During late 1972 and early 1973 a number of major decisions were made concerning the future VLA computer systems. The label synchronous computer system was assigned to the portions of the system involved in real time array control, data acquisition, and data processing. The label asynchronous computer system was assigned to all non-real time or off-line VLA data processing. For practical reasons the asynchronous computer system was discussed in terms of an initial continuum data processing system and a subsequent spectral line system which would involve both the hardware of the continuum system and hardware purchased later to handle the more extensive spectral line data processing problem. Beginning in 1973 two members of the NRAO scientific staff took separate responsibility for these two groups and together with the head of the NRAO Computer Division and two hired programmers started the system design. At the beginning of serious system design the total VLA budget for computer software and hardware was $4.5 million. Based upon previous experience at NRAO and with other aperture synthesis arrays, it was decided that aside from the purchase of standard computer languages and operating systems, all synchronous and asynchronous software would be developed by NRAO and VLA staff. The most important decisions affecting the future of VLA computer development were:

1. A small network of mini-computers would be developed into the synchronous computer system.

2. NRAO would spend only about half of the VLA asynchronous computer budget intended for hardware on a medium-sized general purpose computer specified as capable of handling the data processing

for a 10 antenna continuum system, deferring the expenditure of the remaining hardware money until the future when it was expected that considerable more capable computer systems could be purchased with the available money.

3. Although the eventual replacement of the initial medium-sized general purpose computer with a single larger computer was not excluded, the option of using the initial computer as the control computer for a network of dedicated mini-computer system was considered to be of at least equal likelihood, and this option evolved into the selected option in subsequent years.

The above mentioned specifications led to an initial procurement for portions of the asynchronous continuum system beginning with a Request for Proposals on 23 August 1973. Nine companies responded and after one was rejected as not meeting minimum specifications, the proposal from Digital Equipment Corporation, centered around a DEC-10 CPU, was the successful low bidder. After evaluation of the proposals for the synchronous computer system the low bidder meeting specifications was Modular Computer Systems who proposed a network of four Modcomp II CPU's with necessary peripherals. At this time the eventual purchase of a redundant, back-up synchronous system was also planned.

The debates concerning the magnitude of the VLA computing problems resulted, in early 1976, in an increase of the planned computer budget to $5.5 million. This was mainly to expand the planned software effort from one involving a maximum of six programmers to one with a maximum of sixteen programmers. These programmers were divided between the synchronous and asynchronous groups. Because it was decided that software development must begin well in advance of the time when there would be buildings at the VLA Site capable of containing the VLA computer systems, the initial synchronous and asynchronous systems were installed in temporary quarters in Charlottesville. The

synchronous system was in the Ivy Road electronics building and the asynchronous system was in a building several blocks away. Programming of the synchronous system began shortly after installation in July 1974. The initial hardware of the asynchronous system was installed and made operational in January 1975.

B. Installation of Computer Systems at VLA Site

On 23 June 1975 the synchronous computer system was shipped to the VLA Site and reinstalled in a temporary trailer next to Station CW5. By the end of the year the system was mated to the necessary electronic systems and was capable of control and testing of Antenna No. 1 on Station CW5 and Antenna No. 2 on Station CW9. During 1975 the asynchronous system group proceeded with software development in Charlottesville. In June 1975 the procurement for the first mini-computer in the asynchronous computer network, an image display and analysis system began. This resulted in purchase of a DEC PDP 11/40 with a 256 x 256 COMTAL image display system. During 1975 the first complete block diagram of a proposal for the final asynchronous computer network was developed. In the proposal the DEC-10 was the control computer for four mini-computer systems connected by high speed data links. The four mini-computer systems were dedicated to sorting, map-making, mass storage access and image display and analysis. The assumption was made that the network approach was a more cost-effective way of handling 27 antenna continuum and spectral line processing at the VLA Site.

In March 1976 the synchronous system first controlled two antennas and their electronics to make the first visibility measurements of an astronomical radio source. Its role thereafter was a combination of testing antennas, carrying out astronomical observing programs and improvement of necessary software. In June 1976 the asynchronous computer system was installed in the VLA Control Building, as

was the synchronous computer system two months later. In December 1976 the synchronous and asynchronous computer groups were organized as a single VLA computer group under the direction of B. G. Clark.

C. Combined Operation and Development of VLA Computer Systems

During 1977 the first complete, though in many cases temporary, set of programs for editing, calibrating, mapping and displaying maps was available in the DEC-10 and used to support astronomical observing. Two mini-computer systems were added to the synchronous system in 1977. An additional Modcomp with an attached array processor was obtained to manage the new correlator system with capabilities to handle both continuum and spectral line situations and a back-up Modcomp was ordered with single duplicates of almost all of the peripherals in the synchronous system. The latter system was to be maintained such that any time a component fails in the synchronous system, only a substitution would be necessary to maintain full operation. In September 1977 a PDP 11/70 with an array processor was obtained that would be programmed as a system in the asynchrounous network devoted to making and cleaning maps. The software development to perform network communication between DEC-10, PDP 11/40, PDP 11/70, and future components of the asynchronous system began. By the end of 1977 it was decided not to implement any type of optical processing system as part of the VLA computer system. This ended a nearly three year investigation into such devices that had been carried on mainly in Charlottesville. A more specific design consisting of mini-computers and array processors was conceived to play the role of sorting and map making for the full VLA data rate - this system would become a special part of the asynchronous system and was called the "pipeline". The design of the pipeline was improved in 1978 with planned implementation over the period 1979-1981. The PDP 11/40 system evolved to a fairly complete image display system during 1978 and a Dicomed film writer was added as an output device. At the end

of 1978 NRAO staff evolved the concept of defining a portion of VLA data processing as post-processing that could be done away from the VLA site, and a small group to design and implement such a system in Charlottesville was formed.

In 1979 the first stage of functioning software for spectral line operation of the synchronous system was completed. This interim system was designed to allow test operation of spectral line hardware in preparation for the development of the complete spectral line system. The PDP 11/70 with array processor went into operation as a map making system controlled from the DEC-10. The postprocessing development in Charlottesville was developed in both a DEC VAX 11/780 and a Modcomp Classic. With common development on separate hardware it was hoped that the software would be largely transportable to other computer systems such as might be available to outside users. Both systems were provided with array processors and 512 x 512 image display devices.

D. Computer Status and Developments Underway at the End of the Construction Project

During 1980 full operation with up to 27 antennas operating as a continuum system was achieved. Data reduction in the DEC-10, PDP 11/40, and PDP 11/70 systems was being carried out with considerable difficulties. Even with full pipeline operation scheduled in 1981 it was decided to both upgrade the DEC-10 to a more powerful (KL) processor and to add a VAX 11/780 dedicated to handling of calibration programs. These additions were to be operational in 1981. They and the other VLA computer additions of previous years raised the total expenditure for VLA computer hardware and software to $6.5 million during the course of the construction project.

In December 1980 the VAX 11/780 with the post-processing software developed in Charlottesville was moved to the VLA Site and put into operation with the Modcomp Classic system remaining as Charlottesville-based post-processing system.

XI. THE DESIGN AND CONSTRUCTION OF THE CONVENTIONAL FACILITIES

A. The Scope of the Conventional Facilities

Late in 1972 work began on determining the scope of the conventional facilities starting with the Limbaugh Engineering report as a guide, (Reference No. 4 and 5). A task force was formed consisting of members in each of the technical groups to determine requirements.

B. The VLA Site Layout

The VLA Site layout was dictated by a number of items, among them the following:

1. The center of the wye and the orientation of the arms had been fixed by the Site Selection Group and frozen by the Environmental Impact Statement.

2. To allow for future additional telescopes or other expansion near the center of the array, it was decided to keep all permanent buildings at least 1,500 feet from the center, Exhibit 21 entitled Site-Wye Layout - Inner Wye Plan and Exhibit 22, entitled Site-Wye Layout - Outer Wye Plan. This criteria agreed with the soil conditions as it would be expensive to build foundations on the clay-silt-loam soil near the center, but good foundation conditions existed on the out-wash plain to the south.

3. The Antenna Assembly Building should be adjacent to the main access road, near the wye trackage and at a good distance from the other VLA buildings. This was as the antenna subcontractors personnel would be unionized and should strikes, picketing or other activities occur, they would not affect the balance of the VLA work.

4. The Service Area consisting of water supply, electrical sub-stations, service buildings, shops, garages, warehouses, stock-yards, etc., should be near the main access road and the wye trackage but away from the main buildings. It was thought that a large laboratory building, such as the Jansky Laboratory at Green Bank, might be built in the future between the Control Building and the service buildings.

5. The Control Building was to be the central hub of the site, and for communication reasons, as close to the center of the array as possible.

6. The Cafeteria Building was to be between the Control Building and the Visiting Scientists Quarters, which in turn were to be in a quiet location some distance from the main buildings, but with scenic outlooks.

7. Utilities were to be run in a corridor behind the buildings where they could be reached without disturbing the landscaping.

C. The Selection of the Engineer - Architect

On 12 January 1973 solicitation letters were sent to a large number of apparently qualified firms and an ad was placed in the Commerce Business Daily on 17 January. By the first of February, 78 firms had requested consideration. This group was reduced by a Selection Committee to 11 firms which received a formal request for a proposal to accomplish the E/A work. Nine firms responded on 19 March, of which 7 were selected for interviews. These interviews were held during April, final selection was made by 24 April and the recommendation of award was presented to the Foundation 30 April. Approval to negotiate was granted 2 May. Negotiations were then held and a contract was awarded 17 June to the BWH/CVR Joint Venture, a composite firm consisting of Bohannan, Westman, Huston & Associates, Inc., and

Cottrell, Vaughan, Rowland & Associates, Inc., of Albuquerque, New Mexico. Value of the contract was as follows:

Preliminary Design	$224,626
Reimbursable Costs for Soils Exploration, etc.	128,200
Detailed Design	441,896
Reimbursable Costs for Surveying, etc.	49,850
TOTAL	$844,572

D. Preliminary Design Work

Work began 18 June 1973 with a week-long general meeting in Charlottesville and Green Bank. On 12 and 13 September a review meeting was held in Charlottesville where general approval was given to the concepts proposed by the E/A. Preliminary design proceeded and resulted in a draft Title I Preliminary Design Report, which was received November 26. Estimated construction costs set forth considerably exceeded allowable budgeted funds and a redesign and retrenching effort was ordered. This was completed 12 December and the total 1973 estimated cost of the site and wye construction to be designed by the E/A was reduced from $23,827,000 to $18,616,000, or a total of $5,210,000. The "Title I Design Report - Very Large Array Project", dated 1 February 1974 is (Reference No. 24).

The overall scheme proposed was that the basic central utilities and sufficient trackage would be completed in Phase I construction so that an interferometer test could be held as soon as the antennas and electronics were ready. Phase II was to consist of the permanent buildings which were planned to be ready in 1975 when the Project personnel would move west from Charlottesville. Unfortunately the reduction in CY 1974 financing from $10M to $5M resulted in a delay of these buildings for one year and forced the construction of temporary facilities. The balance of the wye work would be bid as rapidly as funds became available. It was thought that five or six separate construction contracts would be required.

Another far reaching decision which was made was that NRAO would be its own Construction Manager and Inspection Agency using the E/A for consultation only when required.

E. Procurement of Railroad Track & Accessories

The very early estimates for the VLA estimated that used rail could be procured for $90 per ton and the complete track placement for $8.00 per linear foot. By late 1973 due to the oil embargo and other factors a severe steel shortage had occurred and at one time used rail had increased to $330 per ton delivered to the site. It was not possible to get new rail until 1977 and then the cost would have been prohibitive. A massive campaign was started to find surplus U.S. Government rail throughout the United States. All field offices of the General Services Administration were contacted as were the armed services. The property officials at the Foundation were a great help in this search which began to yield results rapidly.

Over the next four years many sources were found where NRAO could take the rail on an "as is where is" basis, pick it up using local contractors and ship it to the VLA Site. Over the years two retired track foremen were hired to act as our superintendents and one local Socorro contracting and trucking firm became very adept at going anywhere in the United States picking up the rail in wooded, swamp or urban areas and getting it to the VLA. In nearly all cases the "owning" agency overstated the available quantity and in many cases the rail was so badly rusted or twisted that it had to be sold for scrap.

The first big break came at the Crab Orchard National Wildlife Refuge which was formerly the Southern Illinois Ordinance Depot. Here 1,273 tons of rail materials were obtained at a cost delivered of $62.00 per ton. In all, rail was obtained from 28 locations. In 1979 the pickings got very thin and when the Rapid

Deployment Force concept was proposed by President Carter all sources dried up immediately. In all, 14,031 tons of material were shipped to the site at a total cost of $748,804 or an average of $53.36 per ton. After the surplus rail dried up, the final 221 tons of rail had to be purchased on the open market for an average of $197 per ton. This price was down from the peak as the U. S. Transportation Department had outlawed the use of 90#/yd. or lighter rail on all main or main spur lines and so this weight rail was selling near scrap prices.

A record of the various rail salvage jobs is included as Exhibit 23, entitled Summary of Rail & Accessories Salvage.

F. The Various Site Construction Contracts

Phase I consisted of 1.25 kilometers (7/10 mile) of trackage, six antenna foundations, water supply facilities, well building, roadwork and other minor items. Bids were received from seven concerns and the subcontract was awarded to the Burns Construction Company at a price of $605,000. Work began 24 June 1974 and was completed 31 March 1975.

Phase II consisted of the Control and Cafeteria Buildings and the central utilities. Bids were solicited from 28 prospective contractors with four bids received. The subcontract was awarded to George A. Rutherford Construction Company on 16 December 1974 at a cost of $2,386,000. Work began 8 January 1975 and was completed 14 May 1976.

Phase III consisted of earthwork, 13.1 kilometers (8.1 miles) of VLA trackage, 49 antenna stations and electrical utility work. Bids were received from 12 contractors. The subcontract was awarded to the Burns Construction Company in the amount of $2,913,000. Work began 20 October 1975 and was completed 31 March 1977.

Phase IV consisted of 12.4 kilometers (7.7 miles) of VLA trackage, five antenna foundations, electric utility work and was issued for competitive bids on 4 October 1976. On 29 October the Washington Office of the Department of Labor issued a determination that Phase IV work should be constructed using the Heavy Engineering Construction wage classification. This matter is discussed elsewhere in this report but it resulted in a postponement of the bid due date. Rebid of Phase IV was issued on 3 April 1978 after a delay of 18 months. During this time as additional funds had been received the scope of work was increased to 21 kilometers (13.6 miles) of VLA trackage, twenty-one remaining antenna stations and electric utility work. Three bids were received with a subcontract awarded to Pacific Railroad Constructors, Inc. on 23 June 1978 in the amount of $2,916,000. Work began on 1 July 1978 and was completed on 9 June 1980.

Phase V - In January 1979 it appeared that with the current reductions in funding it would be necessary to have two more construction contracts. However, it was decided to use all available contingency funds and to bid Phase V with a large unilateral option for the balance of the work. Bids were requested in February covering 25 kilometers (15.5 miles) of wye trackage and electric utility work. Five bids were received 27 March and a subcontract in the amount of $2,820,000 awarded to Wm. A. Smith Contracting Co. on 26 April 1979. Work began on 11 June 1979 and was completed on 25 September 1980.

During this time a large number of subcontracts were awarded for smaller portions of the work. Among these were the following:

Site Well	Awarded 02/22/74	$ 17,932
Technical Service Building	Awarded 10/03/75	111,281
Warehouse and Shop Buildings	Awarded 01/06/76	147,805

Visiting Scientists Quarters No. 1	Awarded 10/07/76	$ 28,123
Wye Telephone System	Awarded 10/05/76	72,980
Visiting Scientists Quarters No. 2	Awarded 01/16/78	40,182
Library Office Building	Awarded 01/16/78	51,818
Garage Building	Awarded 05/03/78	17,000
Cryogenics Addition to Service Bldg.	Awarded 05/17/78	48,335
Stone Ballast for Wye No. 1	Awarded 11/02/77	659,328
Stone Ballast for Wye No. 2	Awarded 01/08/79	669,860
VAX Office Building	Awarded 05/01/80	80,000
Visiting Scientist Quarters No. 3	Awarded 05/01/80	43,500
Fire Sprinkler Systems	Awarded 02/20/80	57,840
Archaeological Excavation	Awarded 09/20/77	107,000

G. The Appeal of the Davis-Bacon Wage Determination

As mentioned above the Washington Office of the Department of Labor on 29 October 1976 issued an order that the Phase IV construction work could not be constructed using the Wage Determination used since the beginning of the VLA construction and approved by the Dallas office of DOL. To use the Heavy Engineering rates would have increased the total cost of the VLA by at least $2,500,000. The Department of Labor was asked to reconsider this decision and a great deal of research was done by the VLA staff to determine the aptness of the Department's wage survey as well as to determine the prevalent practice for this type of work in New Mexico. After several conferences, discussions and negotiations, the Department refused to revise its determination and an appeal was filed with the Department's Wage Appeals Board. In April 1977 the Washington legal firm of Steptoe & Johnson was retained by Associated Universities, Inc. to handle the appeal. Briefs were filed and a hearing was finally scheduled for the week of 10 October 1977. This was postponed several times but was held on 8 December 1977. The Appeals Board ruling, dated 9 January 1978, supported AUI on all counts and instructed the Wage-Hour section

to issue a new Wage Determination. This the Department did on 10 March 1978.

The 29 October 1976 Department of Labor decision delayed wye construction 18 months and cost the Project $59,000 in legal fees plus a considerable additional expense in NRAO payroll and travel expense. During this 18 months construction costs escalated by 10-15%. On the plus side additional funds were in hand 18 months later for a larger construction package and the original funds had been put to good use in purchasing waveguide. The Project cost $2,500,000 less than it would have if the Department of Labor adverse ruling had been accepted. Also on the plus side is that proper Wage Determinations were received throughout the balance of the Project.

H. Summary of Site Building Areas

Building	1969 Concept	Present
Control Building	20,250SF	22,060SF
Cafeteria Building	7,900	5,320
Visiting Scientists Quarter No. 1	Incl. above	1,584
Visiting Scientists Quarter No. 2	Incl. above	1,825
Visiting Scientists Quarter No. 3	Incl. above	1,825
Antenna Assembly Building	14,600*	14,600
Service Building	15,120	6,000
Technical Service & Cryo Add.	-	2,000
Well House	-	380
Garage Building	-	960
Shop & Engine Generator Bldg.	-	6,200
Warehouse Building	-	5,000
Library-Office Building	-	2,120
VAX Building	-	3,217
Total Area	57,870SF	73,091SF

*Mentioned but no area given.

I. TE_{01} Mode 60 mm Waveguide Installation

1. History

Prior to the start of the VLA Construction Project in 1973, it had been decided to eliminate a considerable number of 41 mm and 22 mm coaxial cables on each arm of the wye for signal transmission and to substitute single runs of 60 mm TE_{01} mode waveguide. The Japanese were ahead in the manufacture of this type of waveguide and so 200 meter test sections were obtained from each of the two manufacturing companies. Both met the VLA electronic specifications when tested at Green Bank. 100 meters of one manufacturer were shipped to the VLA Site where direct burial tests were conducted.

During the period NRAO was very concerned over direct burial techniques and long-term stability after burial. The Bell Telephone Company Long Lines Division was developing their system which was based on enclosing the waveguide in a larger steel pipe which would enclose special spring holders to minimize rapid curvatures and protect the waveguide from physical damage. This was thought necessary as attenuation increases rapidly with waveguide curvature. For the VLA waveguide a minimum radius of curvature of 1200 meters and a maximum attenuation of 1.6 dB/km at a wavelength of 50 GHz was selected. To follow the Bell design would nearly double the waveguide system cost and hence make it prohibitively expensive. To assist in the solution of this dilemma, a subcontract was awarded to Bechtel, Incorporated of San Francisco on 3 July 1973 in the amount of $65,000 to study and recommend the best system. Bechtel had worked closely with Bell for 10-12 years on installation methods. Bechtel concluded that it was possible to eliminate the pipe sheath but recommended a costly support system which was not used, although other valuable Bechtel suggestions such as coating and pretensioning of the waveguide before backfill were used. Bechtel report is entitled

"Assessment of direct Burial Methods for 60 mm Waveguide - VLA Installation", (Reference No. 25).

The small scale direct burial tests at the site proved successful so it was decided to procure waveguide for the 1.25 km run required for the prototype interferometer tests. Quotations were solicited from seven firms, only three of which met NRAO specifications. Prices ranged from $61 to $74/meter but negotiations in Japan brought this price down to $43.80/meter. The prototype waveguide was placed in May-June 1975 and initially tested at an attenuation of 1.31 dB/km at 50 GHz. However this attenuation increased rapidly over the next several months to nearly 1.4 dB/km. Early in 1976 test sections with the waveguide in a separate plastic sheath, directly buried in a concrete enclosure and directly buried in a very carefully prepared earth enclosure, were tried. The eighteen-step procedure for direct earth burial was selected as satisfactory and most cost effective. This method involved digging the trench six to eight inches deeper, compacting the bottom, placing good granular fill to just above the bottom of the waveguide location, compacting this backfill, placing waveguide to line and grade, compacting around it with a special "U" shaped tool head, compacting over it with equal care using good granular fill, then using compacted earth for twelve more inches, then ordinary backfill methods were used to the surface. Two zinc ribbons were placed above the waveguide for cathodic and lightning protection. It was also decided to place all waveguide using contract labor who would be working directly under the technical supervision of VLA personnel.

The new burial technique worked very well and gave very good results. Final results for the balance of the waveguide using the detailed techniques and directly supervised workmen varies from 1.04 to 1.1 dB/km at 50 GHz which is very remarkable as the manufacturer only guarantees his waveguide at delivery to 1.40 dB/km at 50 GHz. Through 1979 no increase in attenuation was found in the ori-

ginal 1.25 km prototype waveguide which remained at 1.42 dB/km. For attenuation results for the waveguide installation see Exhibit 19 and 20 entitled 60 mm Helix Waveguide - Average Attentuation and 60 mm Helix Waveguide Attenuation vs. Time at 50 GHz.

2. The Procurement of the TE_{01} 60 mm Waveguide

The procurement of the waveguide was one of the most difficult actions of the VLA Construction, principally because of severe fund limitation which prevented the placement of a single order, but also because its source was in a foreign country and then only one company, Sumitomo Corporation, made waveguide with the coupling requirements necessary.

As outlined above, two small sections of waveguide were purchased in 1972 for evaluation purposes at a cost of $32.00 and $35.96 per meter. When serious procurement began in 1974 the asking price of the three Japanese companies jumped to $69-$79 per meter. This was negotiated down to $43.82 per meter. The next purchases after competitive bidding and negotiation in Japan was at $66.16 per meter which increased during the years to $79.34 per meter paid for the final 15,000 meters. Waveguide purchased from Sumitomo increased 20% in about four years or 5% per year. This was well below the inflation rate in Japan which was running near 20% and 10-12% in the United States. Also during this time the value of the dollar against the yen dropped from 295 to 1 to under 200 to 1 or 32%. It is remarkable that the Sumitomo Company kept to their contractual commitments.

The actual procurement from Sumitomo was only one element of the procurement of the waveguide. The purchase was FAS San Francisco. To this price handling at the port, brokerage fees, transportation to the coating plant, corrosion coating, shipping to VLA site and the purchase of shrink sleeves had to be added. The

Waveguide Procurement Account gives a total of $4,736,000 or an average cost of $75.42 per meter as a total procurement cost for the waveguide. For additional information see Exhibit 24, entitled Analysis of Procurement Cost - 60 mm TE_{01} Waveguide.

3. Burial of the TE_{01} 60 mm Waveguide

As outlined above, it was decided that the waveguide would be installed by contract labor working under the direct supervision of NRAO employees. It had been determined at the beginning of construction that the ditching and other earthwork connected with the waveguide placement were "covered work" as set forth in the "Davis-Bacon Determination for the VLA Project", dated 7 October 1974. (Reference No. 26). The first subcontract was sent out for bid on 20 January 1975 (VLA 101). In all, five subcontracts were bid and awarded for this work.

Total installation cost for the waveguide including labor, equipment, fuel and miscellaneous supplies was $1,387,000 for the 62,421 meters actually buried. This amounts to $22.22 per meter.

J. Electric Utility Power Supply

The Limbaugh Engineers Report, (Reference No. 4), forecast a maximum electric power demand at full operation of 1600 kW with a normal load of 800 kW at a 90% power factor utilization.

The Title I Design Report prepared by the BWH/CVA Joint Venture in February 1974, (Reference No. 24), forecast a maximum demand occurring in 1981 of 2,239 kVA or 1,791 kW at 80% power factor. By 1974 growth to the west of Magdalena had utilized all but 600 kVA of the reserve power which the Socorro Electric Cooperative could make available to the site through its existing 14.4/24.9 kV transmission

line. In addition to capacity, this line lacks the reliability and quality required for the VLA final operation.

After considerable negotiation and the execution of a subcontract which provides for a termination payment should the VLA cease operations within 20 years, the Socorro Electric Cooperative agreed to install about 26 miles of high-grade 14.4/24.9 kV transmission line from its 69 kV substation in Magdalena to the VLA Site. In addition, it will install a 2,500 kVA substation on the VLA Site to step the power down to 7,200/12,470 volts. This new line will have all necessary protection, voltage regulators near the site and be tied into the existing feeder for emergency use. Estimated cost of the SEC line and equipment is $450,000. This new line is dedicated to VLA use only.

To February 1981 maximum demand has reached 1,644 kW and maximum monthly usage 1,393,200 kWh. In 1980 a new subcontract rate was negotiated with the utility company which resulted in a 4-6% decrease in the permanent rate structure. However, the fuel adjustment costs have been so high, up to 42% of the total bill, that the permanent rate decrease is insignificant.

K. Approach Road to the VLA Site

The central VLA Site was crossed by abandoned U. S. Highway 60 when possession was taken in 1973. This road had lain in disuse for over twenty years but was usable at that time. The first construction truck which went over it broke great holes in the decayed pavement and by 1976 the road was in very poor shape. Two and one-half miles of the highway were in use from State Route No. 78 to the west boundry of the VLA central site.

Beginning in September 1975 approaches were made to the New Mexico State Highway Department and the State Highway Commissioners to

see if the State would reconstruct the highway. The Commissioners did agree to do the work in late 1976 and the Socorro County Commissioners seceded the right-of-way back to the State who accepted it on 21 March 1977. Due to lack of funds the State pushed construction back several times but did complete the basic work by 1 November 1977. Estimated cost of the work accomplished by the New Mexico State Highhway Department is $45,000. The District Highway Engineer has promised to apply a 1-1/2 to 2 inch thick topping coat over the existing surface. However, as the New Mexico State Highway Department funding is based on the State Gasoline Tax and receipts have fallen off severely in recent years, final completion of the road may be some years away.

The next project that the State Highway Department was asked to do was the widening and reconstruction of State Route New Mexico 78 which runs for 2 miles from new U.S. 60 to old U.S. 60. This road was maintained very well by the State since the VLA took over the site, but was narrow and bumpy. The leverage used here was the VLA Dedication and so during the summer of 1980 the New Mexico State Highway Department spent approximately $40,000 on the widening and rebuilding of this road. No funds were available for the planned hot-mix overlay.

Late in 1980 the District Highway Engineer stated that it did not appear that they could complete the planned hot-mix overlay of the two sections of road during 1981 as planned due to lack of funds. He was optimistic that it could be done in 1982.

L. Use of the Wye Trackage System for Antenna Maintenance

During the early discussions with the ranchers on the VLA Site, it developed that they were very insistent that no permanent roads should exist along the arms of the VLA. This provision was included in the Final Environmental Statement of 6 October 1972, Reference No. 11.

The years of construction showed how very difficult and time-consuming it would be to accomplish all maintenance using only rail-riding vehicles. Two such vehicles were obtained in 1974 and additional vehicles in later years. In 1980 a calculation was made as to the extra cost in manpower which would be involved should the roads be shut off except for emergency use. This amounted to $35,000 per year (Memo John H. Lancaster to The Director of 14 April 1980). It was decided to offer the two ranchers whose land would suffer the majority of the traffic, a yearly payment for the right to pass over their land to service the antennas. The yearly sum was taken as one-half the potential savings divided into six portions depending on miles of track, number of antenna stations and period of use of each antenna station. The largest payment of $6,981 per year would go to rancher Bruton with $828 per year to rancher Benton.

The ranchers were approached informally with this proposal and were not very receptive. On 15 May 1980 rancher Bruton insisted on a payment three times the offer and rancher Benton concurred. It was then decided to drop the matter and close off all wye roads. To date, four special track-mounted vans have been purchased, two pick-up trucks, two special light weight rail cars and the old RR maintenance vehicles are available. In addition, electric gates will be placed at the 24 fence crossings, and the vans will be equipped with special turntables. $130,000 will be spent on the vehicles and $12-15,000 on the gates and turnarounds.

M. Change Order Percentage on Construction Contracts

One long "tried and true" method of analyzing the effectiveness of a construction program is to compare the original price of a construction contract with the final price. This gives a very good indication of the quality of the Engineer/Architect's drawings and specifications, the bid procedures, and the supervision of construction by the owner. To be correct it is necessary that any supple-

mental work awarded to the contractor by the owner for his convenience, and not part of the original work, be subtracted out of the computation.

For the five major VLA construction contracts, the record looks as follows:

Contract	Original Price	Supplemental Work	Change Orders	Final Price	% Change Order Sum
Phase I	$ 605,000	(-15,627)	$27,535 [1]	$616,908	4.6%
Phase II	2,386,600	9,582	18,790	2,414,971	1.2%
Phase III	2,913,000	88,826	11,026	3.012.852	0.4%
Phase IV	2,916,080	(- 3,504)	1,297	2,913,873	0.0%
Phase V	2,820,000	11,441	2,920	2,834,361	0.1%
Total	$11,640,680	$ 90,718	$61,568	$11,792,965	0.5%

Note [1] - Of the $27,535 in total Change Orders, $20,840 was due to an unexpectedly high compaction factor for the sand-loam-clay material in White Lake, which required extra backfill.

In a "normal" construction contract 10% overrun due to change orders is often encountered, 5% is considered very good, 0.5% is ten times better. It is very remarkable that the Site & Wye people could supervise the design and construction so well that the Project did not have to budget and expend sums for costly change orders.

N. Cathodic Protection

During the early days of detailed design it was known that the waveguide system, with a value exceeding $5,000,000 and as the main nerve trunk for the entire VLA, must be protected from corrosion. Bechtel studied this matter and in their report (Reference No. 25)

recommends that two zinc strips be buried above the waveguide to provide cathodic protection of the waveguide. Bechtel did caution that the site area was very caustic through old White Lake and that measurements should be taken at the conclusion of construction to ensure that protection was adequate.

In early 1980 it was found that in places the zinc ribbon had been completely eaten away. After a search for possible engineers experienced in protection of structures, Pacific Corrosion Research, Inc. was given a subcontract on 24 July 1980 (Purchase Order S-12840, $15,380) to design a system which would protect all buried structures at the VLA. To lower costs VLA personnel, assisted by contract manpower, completed all necessary measurements under the general supervision of PCR. Several conferences were held to make sure that the measuring techniques were correct and the various measurements taken within reason. The final measurements could not be made until the final wye trackage, waveguide and electrical system was completed in December 1980.

Pacific Corrosion Research, Inc. completed their detail design and submitted their final report on 20 March 1981 which was entitled "Corrosion Survey National Radio Astronomy Observatory Underground Waveguide, VLA Site", dated March 1981 (Reference No. 29). They found that 2% to 10% of the measurements were in the severe corrosion category and 30% to 54% in the moderate corrosion category. They recommended a cathodic protection system consisting of 11 air cooled rectifiers, 186 4" x 40" graphic anodes and 35 4" x 4" x 56" prepackaged magnesium anodes. Estimated cost of the system is $76,400 for materials and $57,300 for installation labor, or a total of $133,700. Materials will be purchased by NRAO and installation made by subcontract and contract labor closely supervised by VLA personnel.

O. SEEDING

Seeding of areas denuded of vegetation during construction operations will be done during August and September 1981. A mixture of native grasses for this area and altitude will be used with a slow release high nitrogen fertilizer. Recommendations of New Mexico Crop Improvement Association and the Soil Conservation Service are being followed.

XII. ADMINISTRATION AND BUSINESS

A. Contract Authority and Delegations of Authority

Authority to design and construct the VLA was contained in Amendment No. 24 to Contract NSF-C450 between The Associated Universities, Inc. and The National Science Foundation, dated 8 November 1972. This contract was succeeded by Contract NSF C780 (NSF AST 74-13427), dated 1 January 1974, and Contract NSF AST 79-08925, dated 1 January 1979. All contracts contained the same authority.

The Delegation of Authority to AUI varied with written approval (consent) of the NSF Contracting Officer required prior to AUI being allowed to take contractual actions exceeding the following:

Action	C450	C780	AST 79-08925
Time & Material	$ 500	$ 500	$ 10,000
Labor - hour	500	500	10,000
Cost - reimbursement	10,000	10,000	10,000
Fixed Price	50,000	50,000	100,000
Acquisition - Industrial Facil.	0	0	10,000
Exp., Devel., Research Work	0	0	0
Architectural or Engineering	0	0	10,000
Construction	10,000	10,000	25,000

It was not until the last year of the program that the limits were lifted. For a $76,000,000 engineering and construction project the original limits on Time & Material, Labor-hour, Architectural or Engineering and Construction were too low and caused a certain amount of delay and unnecessary paperwork. The comment on

page 12 of the Ad Hoc Advisory Panel Report (Reference No. 27) on this matter is as follows:

> "Review of delegation of contracting approval authority indicates that the Program Manager at the job site is limited to $25,000 or less. Contract awards involving larger sums must be submitted to NRAO and/or NSF for approval prior to contract award. If the delegated authority had been $350,000 in lieu of $25,000, only nine of 69 contract packages would have required NRAO/Charlottesville in addition to NSF/Washington approval prior to award. The NSF requirement for approvals currently set at $10,000 for construction, zero dollars for engineer-architect services, and zero dollars for time and materials contracts are extremely low thresholds for the program. Substantial increases in delegated approval authority could reasonably be expected to have improved job progress and increased dollar savings. The maximum possible dollar levels, perhaps $250,000 to $500,000 or more, of contract approval authority should be delegated to the competent Program Manager at the site. This would reduce staff work at higher echelons and provide for more timely contract awards. Shorter schedules and more economic procurements should both result."

In actual practice these limitations, although bothersome, did not in any way seriously harm the progress of the Project. Foundation personnel at all times were cooperative and reasonable and ways were found to keep the work going around any bottlenecks which occurred.

B. The National Science Foundation Organization

The lines of authority and responsibility from AUI through the Foundation are sound and worked very well, with the exception of the VLA Field Project Officer appointed to be resident at Charlottesville and the VLA Site. Although an experienced man with proper responsibility and authority in such a position would have been of tremendous help in speeding authorizations and approvals, and in dealing with other Governmental units, the man selected and the refusal or inability to give him any authority made the position useless.

The Project was very fortunate in having two good men at the Project Officer level and strong men at the Assistant Director level. There were a considerable number of times where the strong AD's cut through red tape and greatly assisted the Project.

C. Fiscal Authority

One of the main items which made for a financially successful Project was the ability of AUI to switch yearly funding around without prior approval of the Foundation. NSF gave AUI this authority provided AUI, near the end of each year, would give a detailed accounting as to how the money was used. This was so that the Foundation could answer any Congressional inquiries. Funds were continually switched from items which slowed down or were delayed, such as when the Davis-Bacon matter stopped Phase IV construction for 18 months, to buy waveguide, order antennas quicker, etc. This ability, as much as any, helped in reducing the effects of inflation. Exhibit 10, Funding and Expenses by Years, shows how well the available funds were used. The Total Expenditures and Commitments curve follows the Actual Funding curve very closely.

D. AUI Internal Delegations of Authority

AUI delegated all contractual authority to the NRAO Director who in turn delegated commitment authority of $25,000 to the VLA Project Manager, $10,000 to the VLA Business Manager and $500 to the Buyers. Commitment authority in other amounts was delegated to the Division Heads, but this commitment authority was never used.

This limited commitment authority on a Project as large as the VLA, and separated by over 2,000 miles from NRAO headquarters, would be a tremendous handicap if a system of rapid approvals was not worked out. The VLA system was that bid documents would be sent to Charlottesville. Then when bids were in hand, a summary and justification of the award would be sent by wire transmission to the Director. If everything was in order, the Director or his deputy would authorize the Project Manager to execute the contract by telephone call, with the papers following in a week or so. Usually such approval was granted in a matter of hours, seldom did it exceed one day.

E. The Preparation and Submission of Yearly Project Plans

The basic NSF-AUI contract provides for the yearly submission of Program Plans. In the case of the VLA, it was decided to submit a very comprehensive plan each year giving basic information on the instrument, the AUI-NRAO-VLA organization, accomplishments during the preceeding year, sections on planned activities for the out years of the project, cost estimates, budget analysis, commitment and expenditure schedules, fiscal review of the past year, project construction schedules, and similar data (Reference No. 13 through No. 20). These were prepared each fall and submitted to the Foundation between October 30th and December 1st. The intent was that a reason-

ably detailed record would be available at all times of the advance plans and their execution.

It is believed the effort which went into these plans was well spent and that a useful step-by-step record now exists explaining the tortured path of the Project.

F. Administration and Procurement Policies and Practices

At the beginning of the Project the existing AUI and NRAO policies were examined and found to be completely adequate for the VLA Project. They were used throughout the Project.

G. Construction Cost Estimation

Each summer all Divisions of the VLA organization were requested to make complete new estimates of the cost to complete their portions of the Project. These estimates became better as the Project progressed and more experience was gained. For about half the years of the Project these estimates were bound into volumes.

The costs were estimated for the current year and then 6% compounded escalation was added to the uncommitted balances for the out years. Contingency sums varied from year to year, but in general were maintained in the 6-8% range of the uncommitted balance of funds.

For a complete tabulation of the various cost estimates, see Exhibit 8, entitled Table of Cost Estimates.

H. Escalation and its Effect on the Project

The VLA Project was constructed during one of the most violent escalation eruptions the nation has gone through. A record

of some of the key indicators is as follows:

Index	Original Budget 3/71	Present	Increase
All Industrial Commodities	114.0	286.1 (12/80)	151%
Metal & Metal Products	119.0	290.7 (12/80)	144%
Machinery & Equipment	115.5	249.5 (12/80)	116%
Consumer Price Index	116.3	256.4 (11/80)	120%
ENR Constrution Cost	1496	3388 (3/81)	126%
ENR Building Cost	905	2018 (3/81)	123%
ENR Construction Materials	330	1477 (3/81)	348%
VLA	$76,000,000	$78,578,000	3%

From this table, escalation caused costs to at best double in the 1971-1980 period. This is also shown on Exhibit 25 entitled Department of Labor - Bureau of Labor Statistics. This chart also shows clearly why E-Systems was so violently concerned when one looks at the jump which occurred in 1974.

The effect on the Project fortunately was much smaller than would be indicated by the indexes. The E-Systems $17,000,000 contract was a lump sum contract negotiated before the main rise, computer equipment held stationary or reduced slightly per computer cycle, electronics rose but at a slower pace, construction rose quite fast but larger subcontracts diminished the rise by increasing the efficiency of operations. In general, a review of repetitive procurements show that the procurement people were able to hold to a 6-8% rise per year on the majority of items. It would be prohibitively time consuming to determine the exact effect of the inflationary cycle on VLA construction, but reasonably safe to assume that it was in the 8% per year range.

I. Reporting Procedures

The VLA design and construction was subject to an extensive series of reports and reviews. Among them were the following:

1. Informal Reports to NRAO superiors and NSF Project Officers. These occurred almost daily and the weekly coordination meetings were monitored by Charlottesville personnel.

2. Formal Monthly Reports to NSF - These reports included sections on the activities of each VLA Division, Procurement, Project Management, Personnel, Monthly and Overall Cost Data, Estimated Cost Forecast, a progress schedule and usually photographs.

3. Quarterly Reports to the AUI Board of Trustees - A comprehensive oral report delivered by the Project Manager.

4. Quarterly Reports to the AUI Executive Board - Delivered by the NRAO Director between the Board of Trustees meetings.

5. Semi-Annual Reports to the VLA Advisory Committee - Comprehensive oral reviews delivered usually during a two-day visit to the site by the Committee.

6. Semi-Annual Report to the National Science Foundation - A pictorial and view graph report delivered in Washington, Charlottesville or at the Site to the senior staff of the Foundation.

7. Yearly Presentation to NSF as a portion of the NRAO Program Meeting.

8. Yearly Presentation to the NRAO Visiting Committee

In addition, various other fiscal and activity reports were made as portions of the overall NRAO reports, or at special requests.

J. New Mexico Gross Receipts and Compensatory Tax

During the preparation of the Request for Proposals for the antennas, it became apparent that the Project might be liable for the payment of the 4% New Mexico State Gross Receipts and Compensating Tax. Based on a $76,000,000 estimated cost of the Project, this could mean a tax of $3,040,000. The Santa Fe law firm of Montgomery, Federici, Hannahs and Buell was requested to look into this matter on 5 January 1973. Their study indicated that although there is a clear question concerning the applicability of the tax to U. S. Government personnel property, there is no doubt that the Project is liable for the 4% tax on the so-called conventional or "Bricks and Mortar" construction. Based on a current estimate of $29,000,000 for this type of construction, the liability would amount to $1,160,000.

At the request of the Foundation, no action was taken on the Gross Receipts Tax matter until a pending Federal case (the Zia case) was settled. AUI will pay the tax on construction services through its construction contractors and will issue tax exemption certificate to E-Systems and its other vendors and supply contractors.

In March 1976 the New Mexico Bureau of Revenue made an audit of E-Systems work on antenna fabrication and assembly which concluded that E-Systems, Inc. owed $140,800 in Gross Receipts Tax for the period through 30 December 1975. This audit was completed in February 1977 and an assessment of $127,122.59 was filed against E-Systems. Upon advice of the attorneys of AUI and the NSF, E-Systems was authorized to pay this amount under protest, which was done on 10 May 1977. Upon this payment, an application for a tax refund was filed with the Bureau of Revenue, which was denied on 1 September 1977. On 30 September 1977, the United States Department of Justice filed suit against the State of New Mexico and assumed the responsibility for recovery of the amounts paid to the Bureau. No further action

occurred until August 1978 when Interrogatory documents were received and answers prepared.

This trial was held in Santa Fe on 2 April 1979 before Judge Santiago Campos and resulted in a favorable decision for the United States. The State was instructed to return the $127,122.59 paid under protest and not to assess additional taxes against E-Systems, Inc.

On 15 June 1979 the State filed a Notice of Appeal with the court, based on the denial of a jury trial for the original proceedings. It is understood that the 10th U. S. Circuit Court of Appeals in Denver held during March 1981 that Judge Campos erred in denying the State a trial by jury. At present the U. S. Department of Justice is considering whether to carry the matter to the U. S. Supreme Court.

K. NSF Oversight Hearings Before the Subcommittee on Science, Research and Technology of the Committee on Science and Technology, U. S. House of Representatives

During the spring and summer of 1976 the staff of the House Subcommittee on Science, Research and Technology spent considerable time reviewing the VLA, culminating in a 34-page report by R. E. Williams, Technical Consultant, dated 6 August 1976 and entitled "FACILITIES REPORT - VERY LARGE ARRAY". By letter of 15 September 1976, Representative James W. Symington, Chairman, Subcommittee on Science, Research and Technology, requested the NSF to attend a hearing on 30 September 1976 to review the current status and future plans for the VLA.

The hearing was held as scheduled and statements were made by Dr. David Heeschen of NRAO and Dr. Robert E. Hughes of the Foundation. The hearing went very well, a considerable number of

questions were answered at the hearing and additional questions were answered in writing during October.

No adverse comment or information was received subsequent to the hearing.

L. The Ad Hoc Advisory Panel for the Very Large Array

When the House Committee on Science and Technology reported (Report 94-930, dated 18 March 1976), it stated the following:

> "The Committee has reviewed and followed with great interest the plans for VLA construction. The Committee is very pleased with the close agreement between the original and current budget and time schedules and commends the project's accomplishments to date."
>
> Summary - Therefore, the Committee strongly recommends that the Director of the Foundation establish an ad hoc advisory panel after legislation authorizing appropriations for the NSF for fiscal year 1977 has been signed into law. The functions of this panel should be to examine VLA management and technical plans and activities and report findings and recommendations. Additionally, the panel should direct its attention to long-range plans (through the 1980's) for expanding the capabilities of the facility.

The Foundation proceeded to appoint a panel of distinguished representatives from industry, universities, independent experts and other Government agencies which was chaired by Mr. Robert M. Matyas, Vice President for Facilities and Business Operations of

Cornell University. The panel was established 12 November 1976, met five times and visited the VLA Site. Its Report of the Ad Hoc Advisory Panel for the Very Large Array (VLA) was dated 31 December 1977 (Reference No. 27).

The report of the panel is quite complimentary to the Project. Its ten findings are too long to detail in this report. However, its general conclusion was the following:

> "The Very Large Array Program is a bold concept which will contribute significantly to the United States retaining a forefront position in advanced astronomy research. The program has now progressed far enough to state with assurance that it will be both a technical and scientific success. Not only is the VLA an exciting instrument for astronomers, but it also has the potential for discovery in allied fields. All who have contributed: Congress, the Office of Management and Budget (OMB), NSF, the community of radio astronomers and other scientists, and the AUI/NRAO/VLA mangement and staff, deserve strong commendation for their respective roles."

M. Spare Parts for Equipment and Electronics

The procurement of spare parts for major items of mechanical and electrical equipments, and electronic and computer systems is always a problem for any major project. Spare parts are usually purchased with pre-operating funds or in a number of major Governmental agencies special inventory funds are made available for their purchase. As the parts are withdrawn for use, their value is charged to the operating accounts for that year and the part is repurchased for the inventory account.

It was realized that in the early years of the VLA before operating funds became available, spare parts would have to be purchased from project construction funds and $421,000 was expended for parts, from construction funds, through 1977. In 1977 it was estimated that the balance of the funds required for a proper spare part inventory, estimated at $735,000, would come from the operating budget, principally in 1979 and 1980. For various reasons operating funds for spare parts did not become available and it was necessary to make sizable additional allocations of construction funds for parts which would be required to prevent long downtime periods upon failures. Many of the parts were unique to the VLA and had to be purchased while manufacturers had production lines going and production workers trained. This need put an unexpected stress on the availability of construction funds.

The identifiable spare parts cost are tabulated below. In addition, many other spares, such as special electronic integrated circuits, were purchased with the main purchase orders and are not readily identifiable.

Period		Operating	Construction
Construction Funds through	1977	-	$ 421,000
	1978	-	52,000
	1979	-	377,000
	1980	-	49,000
	1981	-	92,000
Operating Funds	1976	$ 45,000	-
	1977	117,000	-
	1978	47,000	-
	1979	10,000	-
	1980	0	-
Sub-total		$ 219,000	$ 991,000
Total		$1,210,000	

It is interesting to note that many of the spare parts ordered in 1980 from construction funds will not be delivered and paid for until 1981 ($92,000 in value). This illustrates the downtime which would be encountered if one of these elements failed and no spare part was immediately available. It must also be remembered when the cost of the spare part inventory is analyzed that the parts are for a 28 antenna system plus a very complex electronic system.

The spare part inventory is one of many areas which absorbed large portions of contingency funds.

N. The VLA Site Visitors Center

As the buildings and antennas began to take shape in 1976, casual visitors to the site began to create some problems. They would be attracted by the antennas and would find their way into the complex even though no highway direction signs had been erected. By 1979-1980 some 3,000 such visitors per year found their own way to the VLA Control Building. Very early, project personnel had discussed the need for a rest stop along U.S. Route 60 with officials of the State Planning and State Highway Departments. Some planning resulted, but the available Federal Highway Beautification funds were expended on other projects on the main Interstate System and nothing was done.

In the summer of 1978 the Engineer/Architect was asked to prepare sketches, outline specifications and a cost estimate for a small 2,400 square foot Visitors Center. The need for the Center was mentioned in the Project Program Plans for 1979 and 1980 but AUI was informed that it was not Foundation policy to fund Visitor Centers at its National Research Centers. In 1979 AUI requested funds from the Fleishman Foundation but was turned down.

During the Dedication of the VLA in October 1980, the need was discussed with Congressional and State officials. Senator Pete Domenici of New Mexico discussed the matter with Dr. Lewis Branscomb, Chairman of the National Science Board at the Senate Budget Committee hearings on 26 January 1981 and on 2 February called the VLA for details as to what was required. During a visit to Santa Fe on 9 February the Senator discussed the matter with the Governor and State Legislators and suggested that Representative James L. Martin of Socorro-Catron County sponsor legislation providing State funds for the construction, it being understood that NRAO would operate the facility using current operating funds.

Full information was furnished Representative Martin who submitted the bill on 19 February, Exhibit 26, entitled House Bill 607, 35th Legislature, State of New Mexico. Hearings before the House Appropriations and Finance Committee were held 28 February and the bill passed the House 56-3 on 9 March. Hearings before the Senate Finance Committee were held 16 March. The Senate passed the bill 33-0 on 21 March and the Governor signed it on 7 April 1981, effective date 19 June 1981. During the legislative session full information on the VLA and the proposed Visitors Center were provided the members of both House and Senate Appropriations and Finance Committees as well as key State Officials.

The bill provides $182,000 of State funds for the construction of the Visitors Center provided the land on which the Center is placed is given to the State.

O. The "Friday" Letters

One very effective monitoring device for both in-house and external approvals was the so-called Friday letter to the National Science Foundation. This letter was sent or telecommunicated each

Friday whenever a number of items were awaiting Foundation action. The first letter was sent on 8 March 1974 and the last 16 September 1977. The maximum number of items on any one letter was eleven.

P. Magazine Articles Concerning the VLA

As one of the premier observing instruments of the 1970 decade, the Very Large Array Radio Telescope has received a considerable amount of publicity. Some of the articles of a non-technical nature which have appeared in the more popular publications, are listed on Exhibit 27.

XIII COST CONTROL AND REPORTING

A. Cost Control - Cost Control was exercised principally by a detailed Chart of Accounts for each division of the Project, a yearly allocation of funds for each active account which only the Project Manager could change, and a monthly cost report which compared all expenses and commitments against the current allocation. These monthly cost reports were reviewed by each Division Head every month and with the Project Manager as necessary. The reports were also forwarded to Charlottesville for the review of the Associate Directors of Technical Services and Administration & Finance and the Director. Summary cost reports were furnished the Foundation as part of the Monthly Progress Report.

In addition, a special FINANCIAL STATUS REPORT, to show the financial outlook of the Project, was compiled and distributed monthly. Typical copies of these reports are included in the Appendix as Exhibit 28, entitled Status as of October 31, 1978 and Exhibit 29, entitled Financial Status Report as of 30 November 1978.

B. Cost Reporting - In addition to the two cost reports distributed monthly, cost data from the VLA was compiled as a portion of the NRAO and AUI monthly and yearly cost reports. This data was distributed to the NRAO and AUI officials and to the AUI Board of Trustees.

C. Audits - The VLA Fiscal Group, its records and procedures, and the entire business procedure of the VLA were under constant review and audit by the NRAO Fiscal Officer and by the Internal Audit Staff of Associated Universities, Inc. In addition, once or twice each year an audit of the VLA activity was performed by the AUI external audit firm, Haskins & Sells.

In 1976 a comprehensive audit of the VLA Project, its inter-relationship with NRAO and AUI, and its relationship with the Foundation was made by the Audit Office - Office of Planning and Resources Management of the National Science Foundation. (Reference No. 28) "Report on Audit - Very Large Array Radio Telescope Project - National Radio Astronomy Observatory" by NSF Staff, report dated 4 May 1977.

D. Common Cost Distribution - In 1976 when formal operations started at the VLA Site, it was necessary to establish a method where-by costs, common to both Construction and Operating budgets, could be distributed. Such a method was devised by the NRAO Associate Director of Administration & Finance. Common costs included: bus and other transportation, administration, purchasing, operation of stockrooms, cafeteria and housing operations, fiscal operations, site maintenance and similar items. For a complete itemization see Exhibit 28, Status as of October 31, 1978.

Prior to each year a tentative distribution of common cost centers was established, based on proposed labor costs for that year. This provisional distribution was used for budget and allocation of funds. Each month the actual allocation was calculated and the proper distribution made. This system woked extremely well for the period 1977 through 1980 and gradually transferred the common costs from Construction to Operations. There follows a table showing the provisional and final allocations for each year.

Analysis of Common Cost Distribution

	Provisional		Final	
Year	Construction	Operations	Construction	Operations
1977	83.7%	16.3%	83.0%	17.0%
1978	62.5%	37.5%	64.8%	35.2%
1979	43.3%	56.7%	42.5%	57.5%
1980	30.8%	69.2%	30.9%	69.1%
Overall	55.1%	44.9%	55.3%	44.7%

It is remarkable that although in some years the provisional rate varied by over 2% from the final rate, nevertheless on an overall basis the rates were within 0.2% of each other - an accounting system that really worked.

E. Final NRAO-VLA Construction Expenditures by Year

Exhibit 30, entitled NRAO-VLA Construction Expenditures by Year gives the latest cost figures for each of the Chart of Accounts items projected into 1981. It does not distribute direct NRAO labor costs, travel, personnel relocation costs and some general materials, as well as general and administrative expense. It can be used to find the direct "out-of-pocket" costs for the various items but not their overall cost. Thus the TE_{01} 60 mm waveguide cost would show the following:

Waveguide procurement 60 mm	$ 4,736,000
Waveguide Installation	1,387,000
Cathodic Protection	97,000
Waveguide Antenna Stations	381,000
Antenna Coupler, Waveguide	253,000
Total	$ 6,854,000

Or the average cost of an antenna would be the following:

Antenna Design	$ 230,000
Antenna Fabrication	17,491,000
Cryogenic Platforms	20,000
Antenna Electric Installation	67,000
Antenna Field Modifications	163,000
Focusing Feed Mounts	971,000
Antenna Feed Structure	232,000
Subreflector Support	96,000
L-Band Feed Mount	34,000
Total	$19,304,000
For each of 28 Antennas	$ 689,430

Or the cost of the wye system would be the following:

Earthwork/Drainage		$ 2,997,000
Trackage		7,185,000
Legal Fees (Davis-Bacon Appeal)		59,000
Wye Seeding Repair		76,000
Antenna Foundations		1,797,000
Electric Distribution		1,199,000
Telephone Distribution		299,000
Total		$13,612,000 *
Cost per Mile	(37.84 miles)	$359,700/Mi **
Cost per Kilometer	(60.9 km)	$223,500/km **

* Does not include design, survey or soils investigation costs.

** Does not include length of Antenna Station or switching runs.

F. Capital Equipment Retirements

The Fiscal Office at various times during the life of a long project must transfer construction costs to fixed asset accounts. There is attached as Exhibit 31, entitled Fixed Assets, a summation of the amounts transferred through 31 January 1981, and a notation of the sums yet to be transferred. In this accounting NRAO labor, EDIA and General & Administrative costs have been allocated to the various fixed assets.

XIV. EARLY TEST AND RESEARCH OPERATIONS

A. Early Operations

Initial test and research operations of the VLA officially began in January of 1977 although certain test observations were made beginning in November of 1975 when scheduled 88-hour operating runs were undertaken. The early runs showed that a number of the electronic components were unreliable and a series of retrofit programs were begun to change-out the failing components. There follows as Figure 3 entitled Operational Summary of The VLA, a table showing the average operating usage of the VLA during the years between 1976 and 1981 when all 27 antennas were on line.

B. Reliability Studies

As indicated above, considerable effort was expended in determining which elements of the instrument were causing the major downtime. Included as Exhibit 32, entitled Analysis of VLA Downtime - 1980, is a record of the downtime which occurred during that year.

NATIONAL RADIO ASTRONOMY OBSERVATORY
VLA PROGRAM COMPLETION REPORT

OPERATIONAL SUMMARY OF THE VLA

PERIOD	OPERATIONAL TIME SCHEDULED	MAXIMUM ANTENNAS IN USE	MAXIMUM NUMBER BASELINES	ON-WYE BASELINE LENGTH	AVERAGE UNSCHEDULED DOWNTIME
YEAR ENDING:					
DECEMBER 1977	39%	10	45	10.5 km	21%
DECEMBER 1978	54%	15	105	19.1 km	12%
DECEMBER 1979	54%	19	171	28.1 km	15%
QUARTER ENDING:					
MARCH 1980	57%	23	253	32.4 km	15%
JUNE 1980	62%	24	276	34.6 km	15%
SEPTEMBER 1980	45%	25	300	1.7 km	8%
DECEMBER 1980	47%	26	325	57.1 km	7%
MONTH ENDING:					
JANUARY 1981	43%	27	351	60.9 km	4%

XV. THE FINAL INSTRUMENT

A. Comparison to Original Design

There is no doubt that the VLA as constructed is a more powerful and versatile instrument than that comtemplated during its conception. Some of the major parameters are set forth below:

Review of Performance Goals for VLA

Item	Goal (1967)	Achieved
Resolution	1 arc second	0.1 arc second
Sensitivity	10^{-3} to 10^{-4} JY	5×10^{-5} JY
Sidelobes	-20 dB	-30dB W/Clean & Self Cal.
Wavelengths	5 and 11 cm	1.2, 2, 6, 20 cm
Field of View	1 to 10 arc minutes	1 to 30 arc minutes
Polarization	Linear & Circular	Linear (<1%) Circular (10%)
Sky Coverage	-20° to +90° Dec.	-40° to +90° Dec.
Speed	8 to 10 hours per observation	100 maps per day
Spectral Line	To not design out	256 Channels (full array)
Map Size	About 100x100 points per side	512x512 points (Routine) 4096x4096 Points (Maximum)

NATIONAL RADIO ASTRONOMY OBSERVATORY
VLA PROGRAM COMPLETION REPORT

EXHIBITS

NATIONAL RADIO ASTRONOMY OBSERVATORY
VLA PROGRAM COMPLETION REPORT

EXHIBITS

NATIONAL RADIO ASTRONOMY OBSERVATORY
VLA PROJECT ORGANIZATION
PEAK STAFFING

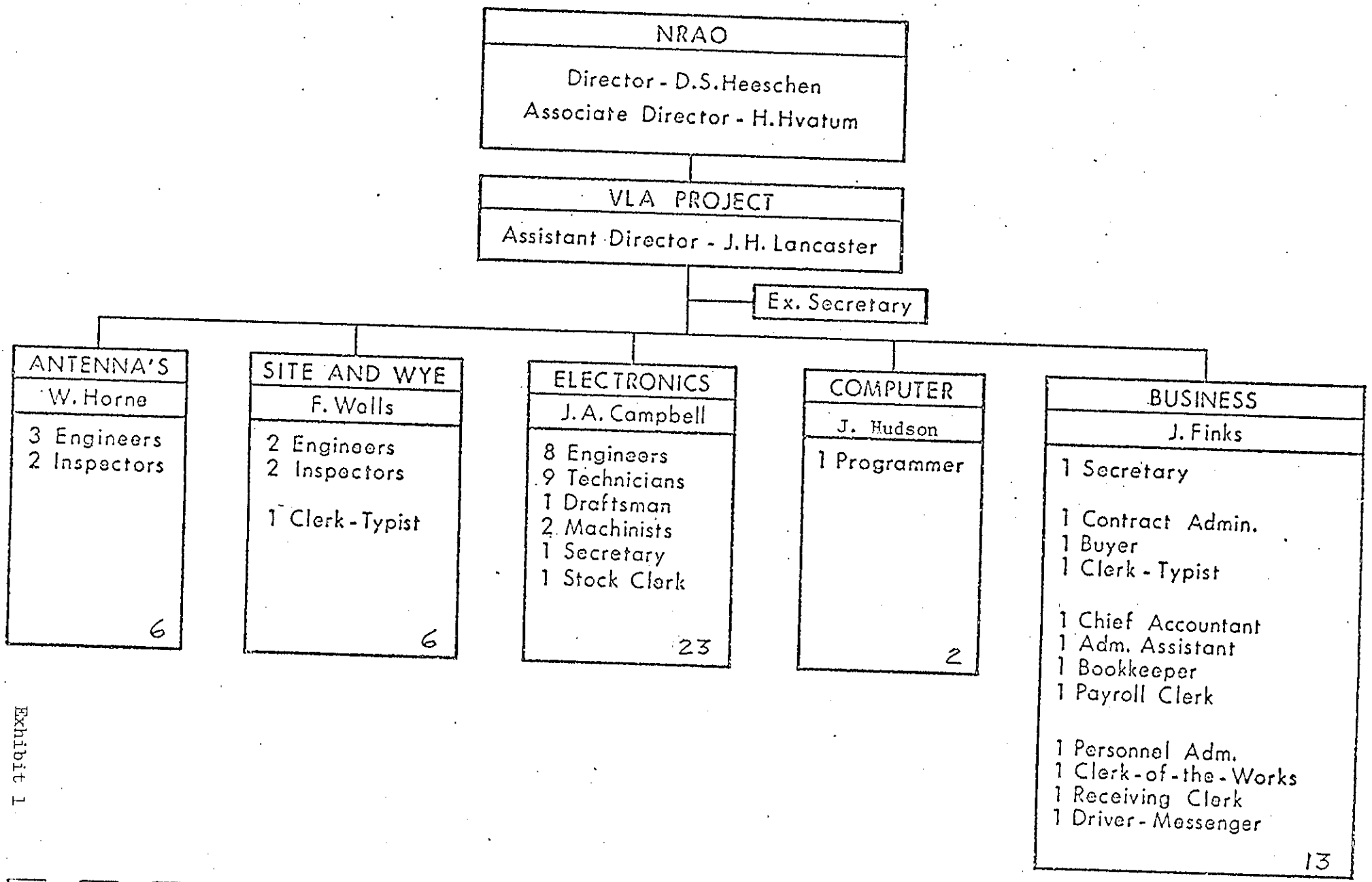
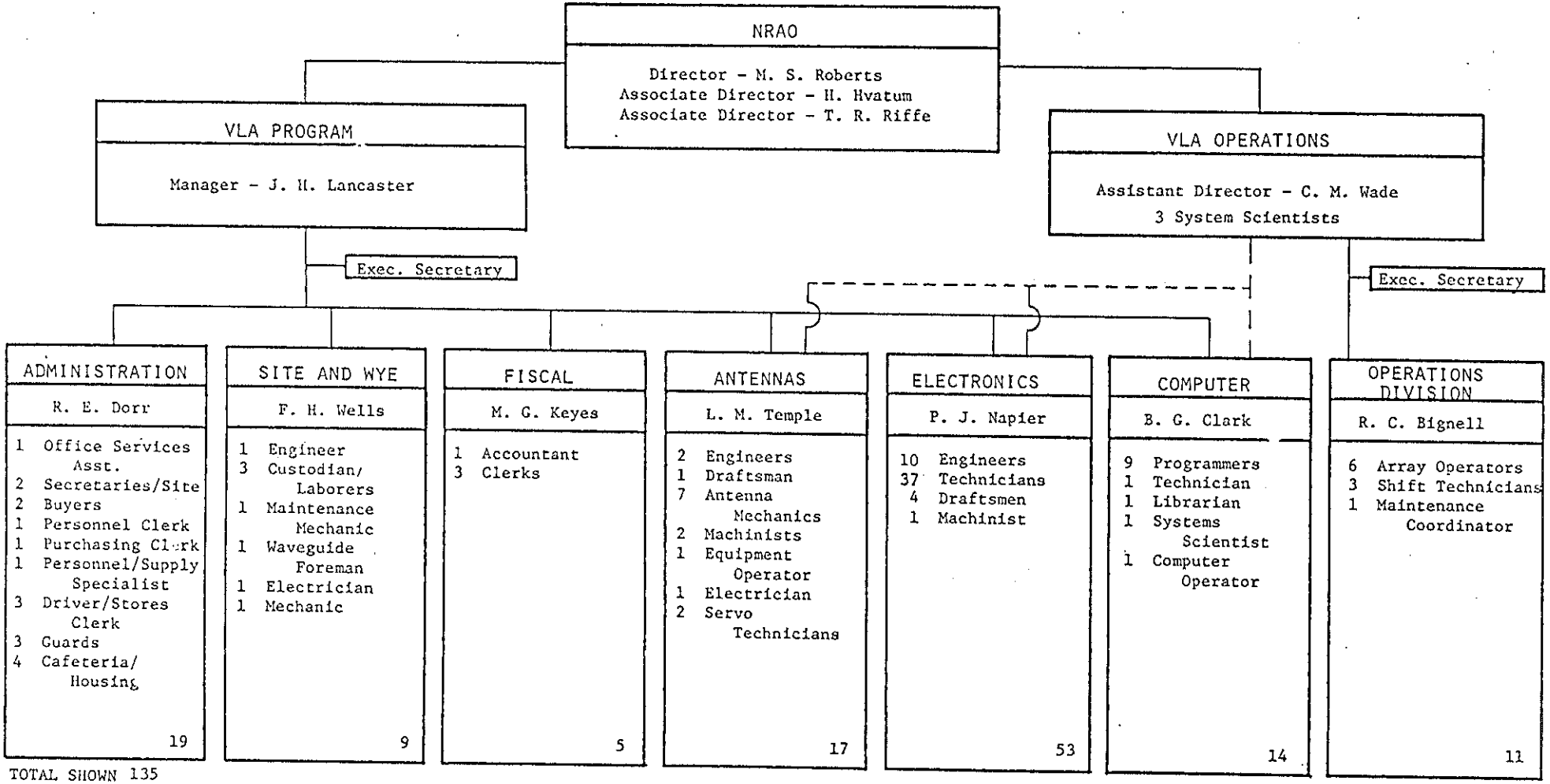


Exhibit 1

NATIONAL RADIO ASTRONOMY OBSERVATORY

VLA PROGRAM ORGANIZATION

JANUARY 1, 1980



TOTAL SHOWN 135

Exhibit 2

NATIONAL RADIO ASTRONOMY OBSERVATORY
VLA PROGRAM COMPLETION REPORT

MEMBERSHIP OF THE VLA ADVISORY COMMITTEE

B. Balick	University of Washington	1977-1980
W. N. Brouw	Westerbork	1980-1983
B. F. Burke	Massachusetts Inst. of Technology	1973-1980
J. N. Douglas	University of Texas	1973-1979
F. D. Drake	Cornell University	1973-1979
R. D. Ekers	Kapteyn Labs	1973-1980
C. E. Heiles	University of California	1973-1980
K. J. Johnston	Naval Research Laboratory	1980-1983
P. P. Kronberg	University of Toronto	1978-1982
M. R. Kundu	University of Maryland	1973-1979
A. T. Moffett	California Inst. of Technology	1973-1981
P. Palmer	University of Chicago	1980-1983
A. E. E. Rogers	Haystack Observatory	1973-1979
D. H. Rogstad	California Inst. of Technology	1979-1982
L. Rudnick	University of Minnesota	1980-1983
G. W. Swenson	University of Illinois	1973-1981
H. Zirin	California Inst. of Technology	1979-1982

NATIONAL RADIO ASTRONOMY OBSERVATORY
VLA PROGRAM COMPLETION REPORT

MEMBERSHIP OF THE VLA POST-PROCESSING COMMITTEE

R. C. Bignell	3/1979-3/1981
R. L. Brown	3/1979-3/1981
J. J. Condon	1/1980-3/1981
R. M. Hjellming	3/1979-3/1981
W. Jaffe	3/1979/1/1980
R. N. Owen	3/1979-3/1981
M. J. Reid	3/1979-8/1981
L. Rudnick	3/1979-3/1981
R. A. Sramek	3/1979-3/1981
C. M. Wade	3/1979-3/1981
R. C. Walker	8/1979-3/1981

NATIONAL RADIO ASTRONOMY OBSERVATORY
VLA PROGRAM COMPLETION REPORT

MEMBERSHIP OF THE VLA STEERING COMMITTEE

R. C. Bignell	1978-1979
D. Buhl	1973-1974
W. R. Burns	1976-1979
R. L. Brown	1976-1979
B. G. Clark	1973-1979
L. R. D'Addario	1976-1979
J. W. Dreher	1978-1979
J. W. Findlay	1973-1976
E. Fomalont	1973-1979
E. Greisen	1974-1979
D. S. Heeschen	1976-1978
V. Herrero	1976-1978
R. M. Hjellming	1973-1979
D. E. Hogg	1973-1979
H. Hvatum	1973-1979
W. Jaffe	1978-1979
K. I. Kellermann	1973-1976
J. H. Lancaster	1976-1979
P. J. Napier	1976-1979
F. N. Owen	1975-1979
R. A. Perley	1978-1979
M. S. Roberts	1978-1979
L. Rudnick	1976-1979
R. P. Sinha	1978-1979
S. R. Spangler	1978-1979
R. A. Sramek	1978-1979
A. R. Thompson	1976-1979
N. Vandenberg	1976-1977
C. M. Wade	1973-1979

NATIONAL RADIO ASTRONOMY OBSERVATORY
VLA PROGRAM COMPLETION REPORT

Listing of VLA Personnel

(Employed for more than one year)

Employees	Title	Dates of Employment
Steve Aragon	Antenna Mechanic	11/13/78 -
John Archer	Engineer II	09/06/77 - 01/01/79
David Archuleta	Special Services Asst.	04/21/75 -
Rosalina Armijo	Head Cook	06/21/76 - 09/07/79
Ellen Ary	Assistant Cook	09/24/79 -
Cynthia Baca	Senior Secretary	03/04/74 - 01/27/78
Dan Baca	Maintenance Trainee	03/10/76 -
Frank Bacon	Auto Diesel Mechanic	03/27/78 -
Durgadus Bagri	Engineer I	01/14/76 - 03/14/78
Kenneth Barbier	Technical Specialist II	04/07/75 - 01/31/78
Garey Barrell	Technical Specialist II	12/18/72 - 08/15/80
John Basart	Systems Scientist	08/20/79 -
Rick Bearfield	Advanced Technician	02/17/76 - 08/15/80
Harry Beazell	Engineer	01/01/75 - 11/01/76
Sylvia Bennetts	Technical Trainee	09/26/77 - 03/26/80
Larry Beno	Electronics Engineer I	03/26/79 -
John Benson	Buyer	09/18/78 - 04/15/80
Carl Bignell	Systems Scientist	10/18/76 -
Barry Blaisdell	Accountant	03/01/73 - 10/07/77
Gary Bonebrake	Electronics Engineer II	01/01/74 - 06/01/76

Employees	Title	Dates of Employment
James Brannan	Draftsman	04/16/79 - 12/31/80
Al Braun	Senior Systems Analyst	12/19/76 -
Alan Bridle	Visiting Scientist	08/05/80 -
Charles Broadwell	Electronics Engineer II	04/11/73 -
Willem Brouw	Visting Scientist	09/24/80 -
James Brunner	Laborer	06/12/78 - 08/21/80
Jack Burns	Research Assistant	11/01/78 - 08/15/80
W. R. Burns	Head/Computer Division	09/01/67 -
Ernest Caloccia	Electronic Engineer I	11/17/75 - 04/18/79
Jack Campbell	Elec. Eng. I/Assoc. Div. Head	06/27/72 -
Larry Carlisle	Designer	08/25/75 - 07/06/79
Luis Casiano	Junior Technician	05/16/77 - 05/19/80
Anita Chavez	Housekeeper/Food Handler	12/29/80 -
Annie Chavez	Technician Trainee	02/13/78 - 12/31/80
Charles Chavez	Bldg.-Grounds & Util. Wkr.	11/24/80 -
Martin Chavez	Maintenance Trainee	06/21/76 -
Pat Chavez	Telescope Mechanic	11/26/79 -
Scott Christiansen	Junior Technician	05/16/79 - 08/01/80
Barry Clark	Senior Scientist	11/30/64 -
Kerry Clark	Technical Specialist II	07/03/80 -

Employees	Title	Dates of Employment
Walter Clayton	Senior Technician	01/08/79 -
Bobbie Cohee	Technical Specialist II	01/05/76 -
Ina Cole	Technical Specialist IV	08/29/77 -
David Coombs	Technician Specialist I	01/20/75 - 02/17/78
Thomas Cote	Technical Specialist II	08/18/76 -
Charles Cottom	Waveguide Foreman	05/10/76 - 03/31/78
William delGiudice	Mechanical Engineer I	08/03/70 -
Dylon Dillon	Staff Shop Technician I	11/06/72 - 12/29/80
Jon DiMarco	Advanced Technician	01/01/74 - 01/01/75
James Dolan	Electronics Engineer I	04/16/62 - 06/23/78
Philip Dooley	Electronics Engineer II	08/15/74 -
David Doro	Mechanical Engineer III	03/03/75 - 07/16/76
Robert Dorr	Business Manager/VLA	08/15/73 -
John Dreher	Research Associate	06/27/78 -
Michael Duggan	Scientific Programmer I	02/15/78 - 07/31/80
William Dumke	Electronics Engineer I	07/29/74 - 12/31/80
Fred Dunn	Technical Specialist II	01/05/76 -
Robert Duquet	Scientific Program Analyst I	07/01/80 -
Larry D'Addario	Electronics Engineer I	09/03/74 - 01/01/79
John Earnest	Designer	01/01/75 - 03/01/76
Emory Egler	Construction Engineer I	09-01-73 -

Employees	Title	Dates of Employment
David Ehnebuske	Senior Systems Analyst	07/09/73 - 02/02/79
Ron Ekers	Director, VLA Operations	08/28/80 -
David Emary	Technical Specialist II	06/23/80 -
Raymond Escoffier	Electronics Engineer	02/20/73 - 04/30/80
Robert Eskanazy	Administrative Aide	07/01/75 - 08/31/76
Susan Eveleth	Clerk Typist	01/14/80 -
Rosalie Ewald	Technical Trainee I	09/11/79 - 02/20/81
Shawn Ewald	Scientific Programmer II	05/19/80 -
Marcello Felli	Visiting Associate Scientist	08/20/79 - 08/21/79
Florence Foster	Administrative Aide	04/10/75 - 01/14/80
Michael Fusco	Senior Technician	09/13/76 - 12/30/77
Leo Gabaldon	Draftsman	05/15/78 - 08/22/80
J.C. Gainer	Technical Specialist II	07/21/80 -
Kevin Gallaher	Intermediate Technician	09/11/78 - 12/31/80
Marion Gallagher	Executive Secretary	05/05/75 - 01/31/79
Doris Gill	Executive Secretary	06/28/76 - 03/23/80
Raymond Gonzalez	Technical Specialist II	01/26/81 -
Eric Graham	Scientific Program Analyst I	12/14/79 -
Daryl Grant	Technical Specialist II	07/05/78 -
Steven Grayson	Telescope Mechanic	12/03/79 -

Employees	Title	Dates of Employment
James Gregg	Advanced Technician	08/14/78 -
Robert Greiner	Transporter Operator Mech.	11/15/77 - 02/23/79
Joseph Grey	Senior Designer	07/14/75 - 05/31/77
James Guin	Intermediate Technician	08/14/75 -
Ramon Gutierrez	Transporter Operator Mech.	10/06/77 -
Richard Hagen	Accountant	10/29/79 -
Paul Harden	Technical Specialist II	05/09/77 -
George Harris	Diesel Mechanic	01/03/77 - 03/02/79
Ronald Harris	Electronics	11/27/72 - 01/01/81
Francis Hart	Technical Specialist II	08/29/77 - 09/09/78
Irene Hernandez	Housekeeper/Food Handler	07/07/78 -
Victor Herrero	Research Associate	06/01/70 - 08/15/78
Adrian Herzog	Technical Specialist II	09/15/76 - 08/31/78
Phillip Hicks	Technical Specialist II	09/01/78 -
Robert Hill	Technical Specialist II	01/02/79 -
Kerry Hilldrup	Scientific Programmer	06/06/77 - 01/01/80
Bruce Hillhouse	Laborer	09/21/76 - 02/14/78
Robert Hjellming	Scientist	05/31/68 -
David Hudson	Intermediate Technician	05/02/77 - 04/28/78
Jerome Hudson	Scientific Program Analyst	05/01/73 - 07/31/78

Employees	Title	Dates of Employment
Gareth Hunt	Associate Division Head	08/11/74 -
Mark Jenkins	Advanced Technician	03/11/80 -
Jerry Kaber	Antenna Mechanic	08/02/76 - 10/14/77
Judith Kampf	Secretary B	05/27/75 - 06/16/78
Jarold Kaplan	Scientific Programmer I	10/02/79 - 12/31/80
Michael Keyes	Chief Accountant/VLA	06/02/75 -
Wayne Koski	Advanced Technician	06/26/78 -
Mark Kostora	Intermediate Technician	02/20/79 - 02/08/80
Donald Krieger	Trans. Equipment Operator	08/18/75 - 06/23/78
Robert Kummerer	Scientific Programmer II	03/31/80 -
John Lagoyda	Business Manager/CV	11/11/74 - 09/14/79
John Lancaster	Asst.Director/Prog.Mgr.VLA	10/25/72 - 03/31/81
Felix Landavayo	Assistant Cook	12/01/76 - 08/31/79
Jess Landers	Technical Specialist II	05/15/78 -
Dorothy Larkin	Administrative Aide	01/22/79 -
Rudy Latasa	Technical Specialist II	08/14/75 -
Joseph Lee	Procurement Officer	04/15/74 - 10/28/77
Patrick Lewis	Technical Specialist II	10/21/74 -
John Liebenroad	Research Assistant	06/20/75 - 09/03/76
Paul Lilie	Electronics Engineer I	07/31/78 -

Employees	Title	Dates of Employment
Jerry Long	Senior Technician	08/01/77 - 07/20/79
Isidro Lopez	Bldg.-Grounds & Util. Wkr.	03/31/75 -
Martin Lopez	Transporter Operator/Mech.	11/26/79 -
Millie Lopez	Secretary A	11/01/76 -
Arsenia Lucero	Head Cook	05/21/79 -
Stephen Maas	Electrical Engineer	03/15/75 - 01/06/78
James Manning	Junior Technician	05/16/77 - 01/22/79
Judth Martin	Secretary B	10/20/75 - 11/30/76
Emily Mathieu	Senior Accounting Clerk	05/05/75 -
Steve McCrary	Advanced Technician	07/17/78 -
Elaine McKee	Technician Trainee	08/05/76 - 03/30/79
Paul Mehle	Accountant	12/19/77 - 08/31/79
Shirley Melton	Accounting Clerk B	05/12/80 -
Al Miller	Technical Specialist II	06/01/76 -
Robert Mitchell	Electrical Engineer	01/19/76 - 08/31/79
Ramon Molina	Technical Specialist II	07/07/75 -
Manuel Montoya	Technical Trainee II	10/07/77 -
Nicholas Montoya	Transporter Operator	09/23/75 -
Irene Morris	Technical Trainee	07/16/79 - 10/31/80
Judith Myers	Prog. Sec. Librarian	08/09/76 - 07/29/77

Employees	Title	Dates of Employment
G.G. Nadkarni	Technical Specialist	12/13/76 - 05/23/80
Peter Napier	Deputy Site Manager - Engr.	04/18/72 -
Eric Nelson	Computing Aide	10/26/78 - 12/14/79
Theodore Neubauer	Staff Shop Technician	01/05/76 - 07/15/77
Zbigniew Nosal	Electronics Engineer II	03/27/80 -
Mikio Ogai	Electrical Engineer	05/09/75 - 04/07/77
Joe Ortiz	Intermediate Technician	12/02/75 -
James Oty	Technical Specialist II	09/02/75 -
Frazer Owen	Scientist	08/29/73 -
Nadine Owens	Technical Trainee	11/13/79 - 10/31/80
Nat Pargas	Special Services Asst-LD	06/06/77 -
Robert Pariseau	Scientific Programmer	07/19/76 - 10/07/77
Alison Patrick	Secretary A	02/13/79 -
George Patton	Electronics Engineer	10/01/76 - 04/28/78
Robert Payne	Scientific Prog. Analyst II	09/05/78 -
Ed Pencak	Senior Technician	02/27/78 -
Melcolm Peralta	Antenna Mechanic	09/10/79 -
Robert Peralta	Maintenance Trainee	01/18/81 -
Peg Perley	Technical Specialist II	07/02/79 -
Rick Perley	Systems Scientist	10/31/77 -

Employees	Title	Dates of Employment
Arthur Pino	Laborer	08/02/78 -
William Randolph	Scientific Programmer I	02/20/73 -
Jean Ray	Executive Secretary	01/01/75 - 02/01/77
Ernst Raymond	Visiting Scientist	07/07/75 - 08/20/76
D.Dawn Reiche	Drafting Tracer	09/30/76 - 01/21/78
Henry Richards	Electronics Engineer I	01/03/77 -
Paul Riehle	Designer	02/04/80 - 02/18/81
Eva Rigby	Secretary A	06/09/80 -
Terry Romero	Secretary B	12/29/80 -
Ben Ross	Technical Specialist II	10/22/79 -
Arnold Rots	Systems Scientist	07/20/79 -
June Rowe	Secretary A	05/22/74 - 02/14/75
Thomas Royston	Machinist	10/01/73 - 07/04/80
Mervel Runion	Intermediate Technician	11/02/70 - 10/01/76
Robert Runyon	Lead Designer	08/18/75 - 07/20/79
Eric Russell	Scientific Prog./Analyst	07/09/79 - 01/16/81
Chris Salter	Scientific Prog./Analyst II	06/12/80 - 03/27/81
Fred Sanchez	Staff Shop Technician II	08/04/80 -
John Sanchez	Intermediate Technician	03/05/78 -
Patricia Sanchez	Accounting Clerk A	05/15/78 -

Employees	Title	Dates of Employment
Ruth Saunders	Intermediate Technician	02/28/77 - 12/01/80
Robert Schweigert	Technical Specialist II	04/14/75 -
Robert Sefcovic	Senior Technician Designer	01/03/78 -
Keith Seglem	Junior Technician I	12/19/77 - 01/22/78
Lewis Serna	Technical Specialist II	06/01/76 -
Rey Serna	Technical Specialist II	08/25/75 -
Arthur Shalloway	Electronic Engineer	01/01/75 - 01/01/76
Alice Shiflette	Intermediate Technician	03/07/77 - 12/01/80
Malcolm Sinclair	Electronic Engineer	09/06/77 - 10/05/79
Ramesh Sinha	Scientist	07/19/78 - 10/17/80
Cheryl Slocum	Technician	03/07/77 - 09/04/78
Lewis Somers	Physicist	01/01/75 - 04/28/78
Kenneth Sowinski	Scientific Prog./Analyst II	11/04/74 -
Linda Sowinski	Technical Specialist	07/07/72 - 03/18/81
Steven Spangler	Assistant Scientist	07/01/76 -
Jonathon Spargo	Technical Specialist I	05/29/67 -
Eugene Spaulding	Technical Specialist II	04/11/77 -
Richard Sramek	Systems Scientist	07/06/70 -
Linda Staley	Secretary A	02/11/80 -
Robert Stidstone	Antenna Engineer I	09/04/74 -

Employees	Title	Dates of Employment
Andrew Strong	Advanced Technician	04/23/79 -
Donovan Swann	Senior Administrative Asst.	05/05/75 -
Frank Tafoya	Laborer	04/04/77 - 06/01/78
Les Temple	Mechanical Engineer I	04/07/75 -
Patrick Temple	Intermediate Technician	03/22/76 - 12/31/80
Karen Thach	Electronics	01/29/75 - 12/29/80
June Thomas	Secretary A	05/22/74 - 06/25/76
A. R. Thompson	Systems Engineer I	01/05/73 -
Edwin Thoroughman	Technical Specialist II	12/13/76 -
Richard Timmey	Intermediate Technician	09/26/79 - 12/31/80
Luis Torres	Equipment Mechanic - Optr.	03/16/79 -
James Torson	Scientific Prog./Analyst II	01/14/74 -
Gary Towner	Intermediate Technician	10/15/79 - 12/31/80
Sandy Treppa-Richards	Programming Secy/Librarian	08/03/78 -
Stephen Troy	Air Cond-Heat-Plb. Eng.	02/17/76 -
Betty Trujillo	Secretary A	10/20/80 -
Robert Turner	Technician	06/03/74 - 06/03/75
Emilio Vallez	Stores Clerk I	04/01/75 -
Nancy Vandenberg	Mathematician	08/14/74 - 12/30/77
David VanHorn	Technical Specialist II	09/01/64 -

Employees	Title	Dates of Employment
Esther Vigil	Secretary B	05/27/80 -
Campbell Wade	Scientist	02/01/60 -
Harold Ward	Draftsman	04/16/74 - 06/04/76
David Weber	Electronics Engineer I	04/24/74 -
Forrest Wells	Head/Plant Maint. VLA	01/15/73 -
Ronald Widener	Senior Technician	10/02/78 -
Alfred Zerwas	Technical Specialist II	04/17/79 -

THE VLA BUDGET

	OPTIMUM CONSTRUCTION (VOL. III)				3-10-10→ FUNDING			3-5-10-10→ FUNDING		3-5-13-10-10→ FUNDING	
	1 Vol.III 1972 Start	2 x 1.06 1973 Start	3 Adjusted I 1973 Start	4 Adjusted II 1973 Start	5 3-10-10→ 1973 Start	6 3-10-10→ Adjusted I 1973 Start	7 3-10-10→ Dist.Esc. 1973 Start	8 3-5-10-10→ 1973 Start	9 3-5-10-10→ Dist.Esc. 1973 Start	10 3-5-13-10→ 1973 Start	11 3-5-13-10→ Dist.Esc. 1973 Start
ronics	7 939	8 415	8 415	15 335	16 302	11,451	14,117	14 117	14 585	14 585	14 352
s	15 896	16 850	16 850	16 850	17 855	17 855	22 012	22 012	22 741	22 741	22 377
ter	4 049	4 292	4 292	4 292	4 292	4 292	5 291	5 291	5 466	5 466	5 379
and Wye	13 090	13 875	13 875	13 875	14 473	19 324	23 823	23 023	24 612	24 612	24 218
uum and Spectral Eq.	6 528	6 920	6 920								
t Management	1 638	1 736	1 736	1 736	3 532	3 532	4 354	4 354	4 498	4 498	4 426
gency	4 658	4 938	4 938	4 938	5 194	5 194	6 403	6 403	6 616	6 616	6 510
otal	53 798	57 026	57 026	57 026	61 648	61 648					
tion*	5 680	6 021	6 007	6 007	14 352	14 352		2 518		-1 256	
PROJECT BUDGET	59 478	63 047	63 033	63 033	76 000	76 000	76 000	78 518	78 518	77 262	77 262

1 Original budget as described in VLA Proposal, Vol. III, Chapter 9 (update 2, 7/27/70, and update 3, 3/10/71).
2 Original budget escalated to 1973 start at 6%/year rate.
3 Same as 2, with minor adjustment of the funding schedule.
4 Same as 3, with continuum and spectral line equipment transferred to electronics.
5 Budget, with a 3-10-10→ funding schedule. Inefficiency costs for electronics, antennas, site and wye are included.**
6 Same as 5, with the waveguide budget transferred from electronics to site and wye (4851k$).
7 Same as 6, with escalation distributed.
8 Budget, with a 3-5-10-10→ funding schedule.
9 Same as 8, with escalation distributed.
10 Budget with a 3-5-13-10-10→ funding schedule.
11 Same as 10, with escalation distributed.

calation caused by multi-year construction, rate: 6%/year.
lternate Funding Schedules for the VLA" dated 15 February 1972

740925 - H. Hvatum

Exhibit 7

NATIONAL RADIO ASTRONOMY OBSERVATORY
VLA PROGRAM COMPLETION REPORT
TABLE OF COST ESTIMATES

(IN THOUSANDS)

NO.	ITEM	CALENDAR YEAR PROGRAM PLAN									
		INITIAL 3/10/71	1973 11/17/72	1974 12/1/73	1975 11/15/74	1976 12/1/75	1977 11/1/76	1978 11/1/77	1979 12/1/78	1980 11/1/79	1981 2/1/81
11000	SITE & WYE	$ 23,823	$ 18,055	$ 29,651	$ 27,904	$ 27,811	$ 26,779	$ 27,103	$ 27,067	$ 26,846	$ 27,143
12000	ANTENNA SYSTEMS	22,012	22,815	20,581	20,983	21,396	21,866	22,115	22,724	22,722	22,812
13000	ELECTRONICS SYSTEMS	14,117	20,984	16,638	16,043	17,226	17,154	17,225	17,640	17,995	17,761
14000	COMPUTER SYSTEMS	5,291	4,553	4,500	4,850	5,245	5,526	5,598	6,182	5,969	6,437
16000	SYSTEMS INTEGRATION	-	-	-	400	368	261	205	201	201	201
17000	PROGRAM MANAGEMENT	4,354	3,373	2,654	2,654	2,877	1,968	2,103	2,102	2,115	2,133
18000	COMMON COST	-	-	-	-	-	2,071	1,961	2,114	2,134	2,091
19000	CONTINGENCY/RESERVE	6,403	6,220	4,166	1,475	3,200	2,527	1,733	1,000	593	-
	TOTALS	$ 76,000	$ 76,000	$ 78,190	$ 74,309	$ 78,123	$ 78,152	$ 78,043	$ 79,030	$ 78,575	$ 78,578
	NOTES	1	2	3	4	5	6	7	8	9	10

1 ESTIMATE OF 3/10/71. REVISED FOR YEARLY FUNDING OF $3-10-10-10-10-10-10-10-3 M
2 ESTIMATE MADE PRIOR TO THE FORMAL START OF THE PROGRAM. FUNDING AS ABOVE.
3 BASED ON FUNDING OF $3-5-10-10-10-10-10-10-10.2 M
4 BASED ON FUNDING OF $3-5-13-16-13-13-7-4.3 M
5 BASED ON FUNDING OF $3-5-13-12-13-13-13-6.M
6 BASED ON FUNDING OF $3-5-13-16-12.5-13-13-2.6 M
7 BASED ON FUNDING OF $3-5-13-16-12.5-12.5-13-3 M
8 ESTIMATE REDUCED ON 3/1/79 TO $78,570. BASED ON FUNDING OF $3-5-13-16-12.5-13-11.5-4.6 M
9 & 10 BASED ON FUNDING OF $3-5-13-16-12.5-13-11.5-4.6 M

Exhibit 8

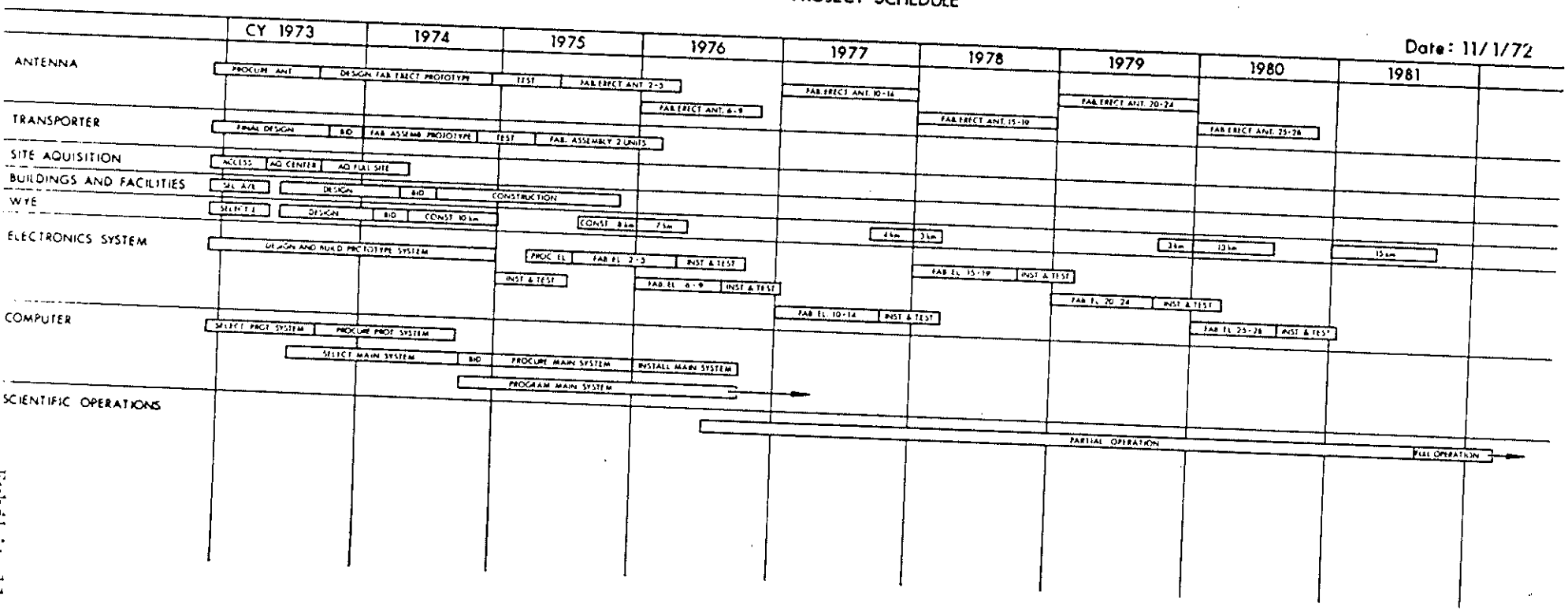
NATIONAL RADIO ASTRONOMY OBSERVATORY
VLA PROGRAM COMPLETION REPORT

FUNDING STATUS

Contract No.	Amendment No.	Date	Amount	Amount to Date	Amount for Calendar Year
C-450	24 (CY-73)	11/08/72	$3,000,000	$3,000,000	
	27 -	04/11/73	- 165,000	2,835,000	$ 2,835,000
	32 (CY-74)	12/13/73	750,000	3,585,000	
	-	12/31/73	-2,051,766	1,533,234	
C-780	1 (CY-74)	12/31/73	3,878,000	5,411,234	
	2 (CY-74)	06/04/74	356,300	5,767,534	4,984,300
	4 -	06/14/74	2,051,766	7,819,300	
	5 (CY-75)	07/10/74	3,500,000	11,319,300	
	7 (CY-75)	11/26/74	6,927,000	18,246,300	
	9 (CY-75)	03/12/75	1,000,000	19,246,300	
	10 (CY-75)	04/11/75	465,000	19,711,300	
	12 (CY-76)	07/22/75	3,000,000	22,711,300	
	13 (CY-75 Def)	08/14/75	1,000,000	23,711,300	12,891,000
	15 (CY-76)	10/03/75	3,000,000	26,711,300	
	17 (CY-76)	01/16/76	6,400,000	33,111,300	
	18 (CY-76)	04/26/76	90,000	33,201,300	
	20 (CY-76)	07/02/76	3,500,000	36,701,300	15,990,000
	23 (CY-77)	11/02/77	7,000,000	43,701,300	
	24 (CY-77)	01/31/77	4,450,000	49,151,300	

Exhibit 9

VLA PROJECT SCHEDULE

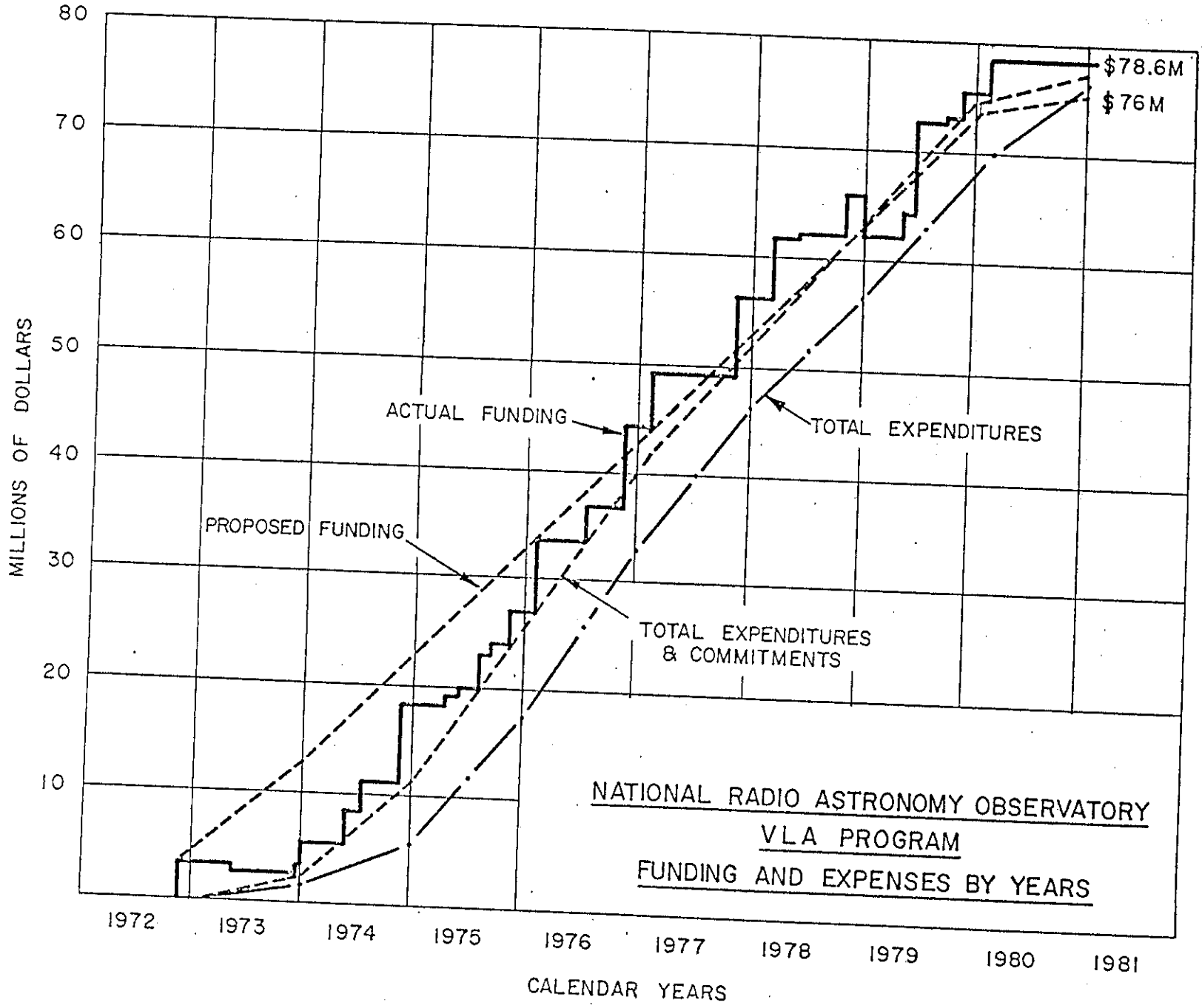


NATIONAL RADIO ASTRONOMY OBSERVATORY
VLA PROGRAM COMPLETION REPORT

FUNDING STATUS

Contract No.	Amendment No.	Date	Amount	Amount to Date	Amount for Calendar Year
AST-74-13427	26 (CY-77)	09/09/77	23,000	49,174,300	
	28 (CY-77)	09/30/77	1,889	49,176,189	12,474,889
	29 (CY-78)	11/03/77	7,200,000	56,376,189	
	30 (CY-78)	01/26/78	5,280,000	61,656,189	
	32 (CY-78)	06/05/78	218,000	61,874,189	
	33 (CY-78)	09/26/78	175,000	62,049,189	12,873,000
	34 (CY-79)	10/31/78	3,700,000	65,749,189	
	-	12/31/78	-9,297,648	56,451,541	
AST-79-08925	1 (CY-79)	01/01/79	5,675,000	62,126,541	
	4 (CY-79)	04/06/79	2,105,000	64,231,541	
	5 -	05/07/79	9,297,648	73,529,189	
	9 (CY-79)	08/13/79	20,000	73,549,189	
	10 (CY-79)	09/04/79	203,000	73,752,189	11,703,000
	12 (CY-80)	11/05/79	1,300,000	75,052,189	
	14 (CY-80)	02/01/80	3,200,000	78,252,189	4,500,000
			Totals	$78,252,189	$78,252,189
Direct Expenditures by NSF			Corps of Engineers	293,000	
			Transfer to ECAC	15,700	
			Ad Hoc Advisory Panel	17,111	
			Sub-Total	325,811	325,811
			TOTALS	$78,578,000	$78,578,000

Exhibit 9



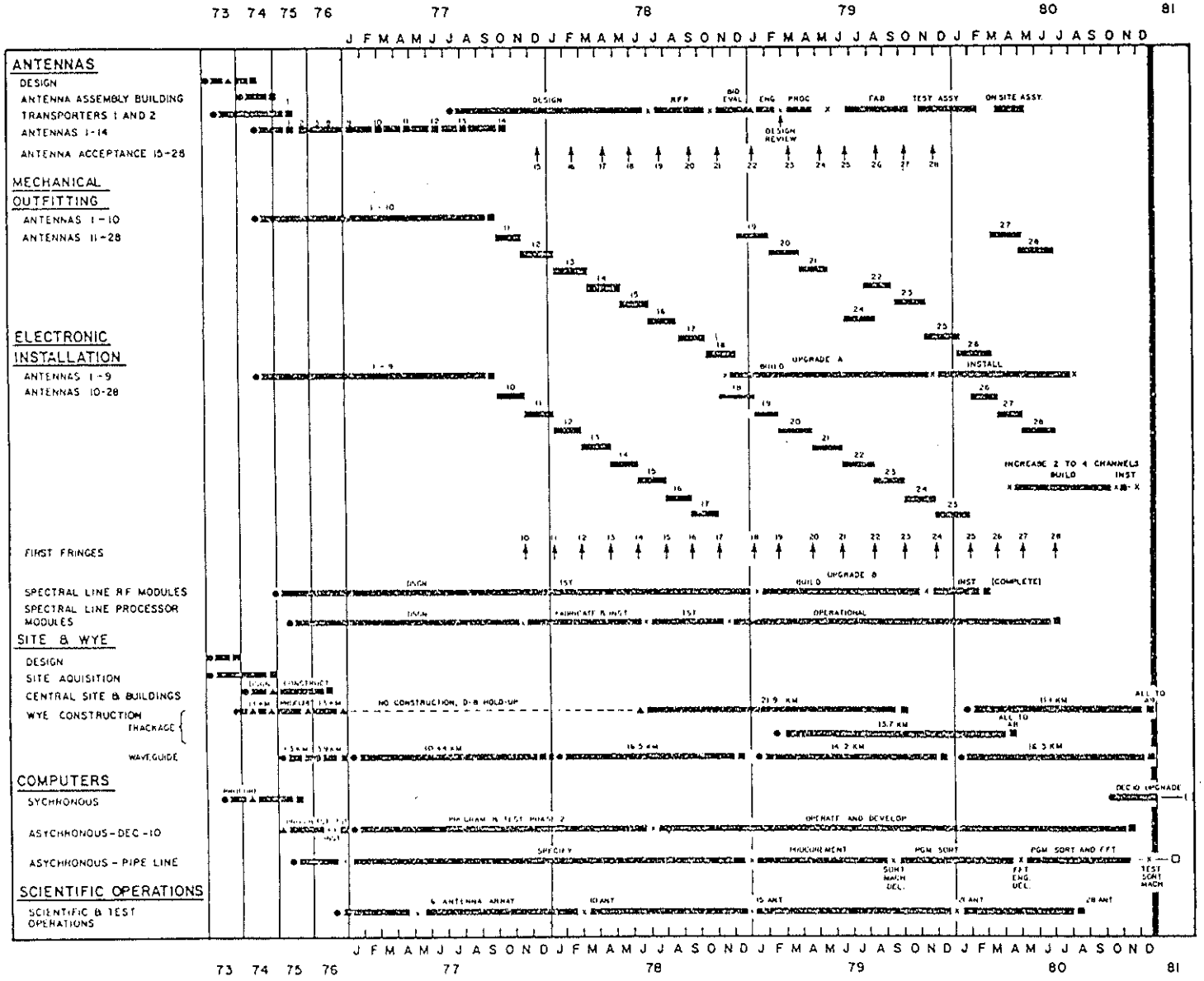
2/6/81

Exhibit 10

NATIONAL RADIO ASTRONOMY OBSERVATORY

VLA ACTIVITY SCHEDULE

UPDATE DATE: 01/01/81



TASKS

UPGRADE A	RECEIVER FRONT-END FILTERS, MODULES F4, F7, F8. INSTALL 9 ANT/MO. (25 MODULES)
UPGRADE B	SPECTRAL LINE IF MODULES T3, T4, T5, T6. INSTALL 4 SYSTEMS (24 MODULES) PER MONTH. (COMPLETED 03/03/80)
INCREASE 2 TO 4 CHANNELS	ADDITIONAL MODULES OF ABOVE TYPES. TOTAL 224. INSTALL 36 PER MONTH.

ABBREVIATIONS

DSGN — DESIGN	TST — TEST
LAB — LABORATORY	PRELM — PRELIMINARY
INST — INSTALL	OPNS — OPERATIONS
ANT — ANTENNA(S)	PGM — PROGRAM
	DEL — DELIVERY

SYMBOLS

○ START OF A PHASE	△ CONTRACT AWARD
X END OF AN ACTIVITY	□ END OF A PHASE
↓ SCHEDULED	↓ COMPLETED

REV. NO	REV DATE	DESCRIPTION
1	12/1/78	UPDATE PROGRAM PLAN '79
2	11/1/79	UPDATE PROGRAM PLAN '80
3	2/1/80	MISC. PLAN CHANGES
4	9/1/80	SHOW BUILD & INST. 2 TO 4 CHAN
5	10/31/80	DEC 10 UPGRADE ADDED

NATIONAL RADIO ASTRONOMY OBSERVATORY
VLA PROGRAM COMPLETION REPORT

A CHRONOLOGICAL HISTORY OF THE VERY LARGE ARRAY RADIO TELESCOPE PROGRAM

1972	August		Congress approves VLA Project.
	October		Issued Program Plan and detailed budget.
	November	08	Received NSF authorization to proceed ($3,000,000 funding).
		24	Corps of Engineers authorized to commence land acquisition.
	December	08	Issued RFP for twenty-eight antennnas to ten concerns.
1973	January	01	VLA Construction Project begins operations as a Division of NRAO.
		09	Contract awarded for mapping the VLA Site.
	February		Established an RFI monitoring station at Site.
	April		NRAO established a field office in Magdalena, N.M.
	June	17	Subcontract awarded to Engineering Firm, Bohannan, Westman, Huston/Cottrell, Vaughan, Rowland & Associates of Albuquerque, to design all site facilities and railroad.
	August	23	Issued RFP for Synchronous Computer.
		28	Issued RFP for Antenna Transporter to twenty-five concerns.
	October	18	E-Systems, Inc. of Dallas, Texas awarded sub-contract to design and fabricate the VLA antennas.
	November	02	NRAO takes possession of central VLA Site.
		29	Issue RFP for TE_{01} mode circular waveguide.
	December	13	Completed 100 meter 60 mm waveguide test section.
1974	January	30	E-Systems, Inc. of Dalles, Texas, awarded sub-contract to design and fabricate Transporter No.1.

1974	June	17	Digital Equipment Corporation awarded subcontract for the asynchronous (scientific) computer.
		17	Burns Construction Co. awarded subcontract for construction of first portion of wye trackage and power system.
		24	Modular Computer Systems awarded subcontract for synchronous (on-line operating) computer system.
			Completed design and started fabrication of electronics for Antennas 1 and 2.
	July		Synchronous Computer installed at Charlottesville.
	August	22	Fabrication of two prototype antennas authorized.
	October	04	Awarded contract for 6,000 square foot Service Building at Site.
	December	29	George A. Rutherford, Inc. of Albuquerque awarded Phase II subcontract to construct permanent buildings, site work and utilities for VLA.
1975	January	06	Asynchronous Computer installed at Charlottesville.
	March	31	Phase I construction completed.
			Service Building completed.
			Antenna Assembly Building completed.
	April		Agreement reached for completion of Antennas 3 through 10.
	May		The VLA organization moved from Charlottesville, VA. to the Site and offices in Socorro, N.M.
	June	23	Synchronous Computer shipped to Site and installed in trailer.
			1.24 km waveguide installation completed.
	July	18	Transporter moved Antenna No. 1 to Master Pad.
	August	13	Land acquisition of Wye completed
	September	22	Accepted Antenna Transporter No. 1.
			Accepted Antenna No. 1.

	September	25	Contract awarded for Phase III construction to provide C & D array plus southwest arm to AW-6.
	October	24	First radio observation by Antenna No. 1 Virgo - A, 3C274 at 6 cm.
	November	12	RFP issued for Warehouse and Shop Buildings.
		13	Accepted Antenna No. 2.
			Electronics for Antennas No. 1 and No. 2 fabricated, tested, and installed in antennas and control trailer.
			Fabrication of Electronics for Antennas 3 through 10 started.
	December	12	Antenna No. 1 under computer control through wave guide.
1976	January		Began regular 40 hour per week runs.
	February	18	First fringes, Antennas 1 and 2, 6 cm, 1.24 km baseline.
	April	20	Accepted Antenna No. 3.
	May	14	Phase II construction completed. Outfitting of Control Building started.
	June	07	Accepted Antenna No. 4.
		16	E-Systems advised they would not complete Antennas No. 11 through No. 28.
		29	First fringes, Antennas 1 and 2, 2 cm.
			Asnychronous Computer and 13 employees moved from Virginia to New Mexico.
	July	13	First fringes, Antennas 1 and 2, 1.3 cm.
		16	Accepted Antenna No. 5.
		21	Agreement reached on fabrication of Antennas 11-28.
	August	05	Shutdown to move into Control Building.
		23	Resumed operations from Control Building.

	September	03	Accepted Antenna No. 6.
		08	First fringes, three element array, 6 cm.
		14	First fringes, two element array, 18-21 cm.
		23	Baseline increased to 1.9 km.
	October	07	Construction of four-unit VSQ started.
		19	First fringes, four element array, 6 cm.
		26	First operation of two independent sub-arrays.
		29	Accepted Antenna No. 7.
			Received adverse Department of Labor Davis-Bacon Wage Determination. Phase IV wye construction indefinitely postponed.
			First non-NRAO astronomer utilizes the VLA for test observations.
	November		Began 88 hour operating runs. Total 38% uptime.
	December	17	Accepted Antenna No. 8.
			First fringes, five element array, 6 cm.
			Baseline increased to 5.2 km.
			Conceptual design of Spectral Line System electronics completed; procurement started.
1977	January	04	Antenna No. 6 joined array and received first fringes.
	February	25	Accepted Antenna No. 9.
	March	28	Six antenna array used in 40 hours observing run.
	April	26	Accepted Antenna No. 10.
			Completed three 60 mm waveguide test sections on north arm.
	May	10	First fringes, Antenna 7.
	June	09	Accepted Antenna No. 11.
			First fringes, Antenna 8.

	July	12	Accepted Antenna No. 12.
	September	02	Accepted Antenna No. 13. Electric power line from Magdalena to Site completed.
	October	21	Accepted Antenna No. 14.
	November	21	First fringes, Antenna No. 10.
			Waveguide installation on East arm complete.
	December	07	Accepted Antenna No. 15.
			Waveguide installation on North arm complete.
			U.S. District Court in Albuquerque issued "Writ of Assistance" to permit VLA to have access on the Ake property for the Archaeological Survey.
			Hearing on the Davis-Bacon wage matter was heard by the Wage Appeal Board of the Department of Labor.
1978	January	09	The Wage Appeal Board of the Department of Labor issued their David-Bacon Wage Decision, which was completely favorable to the VLA.
		16	Contract placed for Office-Library Building and second Visiting Scientist Quarters.
			Antenna No. 10 declared operational.
			Ten antenna elements in operation, using a 10.6 km baseline.
	February	01	First fringes, Antenna No. 11.
		14	Accepted Antenna No. 16.
		20	Archaeological work on west arm started by NMSU.
	March	10	Department of Labor Determination issued fully supporting NRAO request.
		27	First fringes, Antenna No. 12.
		27	Antenna No. 11 declared operational.
	April	03	Phase IV construction IFQ issued for bid.
		04	Accepted Antenna No. 17.

April	28	First fringes, Antenna No. 13.
May	11	Bids received for Phase IV construction.
		All excavation for archaeological work on west arm completed.
June	19	Accepted Antenna No. 18.
	23	Phase IV construction contract awarded, $2,916,080.
	28	Burns Construction Company protested to the GAO the award of Phase IV construction contract to Pacific Railroad Constructors.
		Visiting Scientist Quarters No. 2 occupied.
		Formal announcement published in the Bulletin of the American Astronomical Society, Volume 10, Number 1, that the VLA was open for scientific proposals.
July		Antenna No. 12 declared operational.
August	08	First fringes, Antenna No. 15.
	09	RFP for Transporter No. 2 issued.
	21	The General Accounting Office denied the Burns protest covering the award of the Phase IV construction contract.
September		Antenna No. 13 declared operational.
October	06	First fringes, Antenna No. 16.
		Proposals on Transporter No. 2 received.
		Negotiations started.
November	29	Commission was appointed by U.S. District Court to consider Ake-Taylor-Dunlap request for additional compensation for land taken for the VLA.
		Antenna station CE9 occupied. Maximum baseline increased to 15.6 km.
		New Spectral Processor placed in operation.
		New cryogenics facility completed.

	November	29	Sixteen antennas operating on a maximum "on-wye" baseline of 15.6.
	December	04	First fringes, Antenna No. 17.
			Antenna station AW8 occupied. Maximum "on-wye" baseline increased to 19.1 km.
			Antenna No. 14 and 15 declared operational.
			Fringes were obtained from 15 antennas simultaneously.
1979	January	08	Subcontract for crushed rock issued $668,660.
		17	Subcontract for Transporter No. 2 issued $788,758.
			Antenna Station DN8 occupied. North arm of wye activated. Baseline 0.4 km North.
	February	15	First fringes, Antenna No. 18.
		19	Phase V wye construction plans issued for bid.
	March	21	First fringes, Antenna No. 19.
		23	Antenna No. 17 declared operational.
		27	Five bids received for Phase V construction.
		28	Burns Construction Co. protested the award of Phase V construction to Wm. A. Smith Contracting. Protest rejected by AUI on March 29.
			Decision made to limit operating antennas to 17 and to hold operating time to approximately 50% of available hours each month.
	April	02	New Mexico Gross Receipt Tax trial held. Judge Campos rendered judgement in favor of the U. S. Government and against State Bureau of Revenue and Taxation. He instructed the State to return $127,000 paid under protest and not to assess additional taxes against E-Systems, Inc.
		26	Phase V wye construction contract issued in the amount of $2,820,000.
	May	25	Accepted Antenna No. 24.
			First fringes, Antenna No. 20.

	May	25	Antenna Station CN7 occupied. Maximum baseline 19.1 km E-W; 1.1 km N.
	June	15	New Mexico Gross Receipts Tax Final judgement in favor of U. S. Government appealed by the State.
		25	Land Commission held second meeting in Albuquerque. Would not accept additional testimony form the Government.
		28	Accepted Antenna No. 25.
	July	05	U. S. Attorney for the State of New Mexico filed Memorandum Brief to the Land Commission refuting certain claims made by Ranchers Ake, Taylor and Dunlap.
		13	First fringes, Antenna No. 21.
		27	Land Commission submitted its report which recommended $219,000 as just compensation to the three ranchers.
			Antennas No. 18 and 19 declared operational.
	August		The U. S. Attorney filed objections to the Commission's recommendations.
	September	26	Antenna No. 20 declared operational.
			First fringes, Antenna No. 24 (22 and 23 to follow).
			Antenna Station BE6 occupied. Maximum baseline 20.4 km E-W; 1.1 km N.
	November	05	Antenna No. 21 was declared operational.
		09	Last Antenna, No. 28, accepted from E-Systems.
		14	Final Judgement made by Federal Judge Bratton for $205,448 on Ranchers claim.
		26	First fringes, Antenna No. 22.
			Antenna Station AE6 occupied. Maximum baseline 27.6 km.
	December		State Highway Dept. agreed to widen & improve Route 78 at their expense.
1980	January	14	First fringes, Antenna No. 23.

January	15	Antenna No. 24 declared operational.
		Placed order for PDP 11/44 to replace PDP 11/40 output map display computer.
February	01	Final increment of funds received by NSF to complete VLA construction.
	07	First fringes, Antenna No. 25.
March	07	Proposal sent out for VSQ #3 and VAX Computer addition Library/Office Building.
	13	Antenna No. 22 declared operational.
April	14	First fringes, Antenna No. 26.
	15	Assembly started on Transporter No. 2.
	30	Antenna No. 23 declared operational.
May	01	Contract awarded VSQ #3 & VAX Computer addition $123,500.
	20	Antenna No. 25 declared operational.
June	09	Phase IV Construction complete.
	17	Hearing before New Mexico Public Service Commission concerning electrical rate increase.
July	10	First fringes, Antenna No. 27.
	22	Antenna No. 26 declared operational.
August	25	Antenna No. 27 declared operational.
	28	Array used as a portion of VLBI network.
		First fringes, Antenna No. 28.
		VAX addition to Library/Office Building and VSQ#3 are complete and occupied.
September	25	Phase V Construction complete.
	26	Antenna No. 28 declared operational
		Decision made and request for approval sent to

			NSF to replace DEC-10 computer KI CPU processor with KL CPU to increase system capacity by 3.3.
	October	10	VLA formally dedicated, attended by 600 guests and staff members.
		25	VLA open house, attended by 2,000 persons. Array reconfigured from C to A.
			Order placed to upgrade computer DEC-10 KI to to KL $850,000.
1981	January	22	All 27 antennas working on the A configuration.

NATIONAL RADIO ASTRONOMY OBSERVATORY
VLA PROGRAM COMPLETION REPORT

ANTENNA PARAMETER COMPARISONS

Parameter	NRAO Feasibility Design	E-Systems Design 7/30/74
1. Antenna Base Triangle Dimensions	27'-6"	32'-0"
2. Heighth of Antenna - Foundation Interface above rail	6'-4 1/2"	6'-4 1/2"
3. Reflector Weight	207,090 lbs.	256,150 lbs.
4. Yoke and Alidade	52,200 lbs.	63,952 lbs.
5. Tower including Kingpost	84,500	50,546
6. Lower Equipment Room	8,000	4,589
7. Drives, Platforms, Ladders	12,000	21,903
8. Misc. (connections, equip. etc. cables)	18,690	22,023
9. Total Weight	392,480 lbs.	419,073 lbs.
10. Resonant frequency		
Rocking Mode	2 CPS	2.07 CPS
Torsional Mode	2 CPS	2.15 CPS
11. Azimuth Gear Ration	15,750:1	10,342.5:1
Bullgear/Pinion	21:1	10.5:1
12. Elevation Gear Ratio	31,500:1	20,704:1
Bullgear/Pinion	37.5:1	36.71:1
13. Az. Drive Motors (2)	5 H.P.@1750 rpm	5H.P. - 1150 rpm
14. El. Drive Motors (2)	5 H.P.@1750 rpm	5H.P. - 1150 rpm
15. Az. Gear Box		
Ratio	750:1	985:1
Stiffness	1.5x106 ft.lb/rad	5x106 ft.lb./rad.
16. El. Gear Box		
Ratio	840:1	564:1
Stiffness	3.56x105 ft.lb/rad	3.5x106 ft.lb/rad.

NATIONAL RADIO ASTRONOMY OBSERVATORY
VLA PROGRAM COMPLETION REPORT

VLA ANTENNA PARAMETER COMPARISONS

Surface Error Budget

(1) Panel	AUI Feasibility Design	E-Systems Design
Panel Mfg.	.020 inches RMS	.015 inches RMS
Panel Setting	.015 inches RMS	.018 inches RMS
Gravity on Panels	.007 inches RMS	.004 inches RMS
Wind	.004 inches RMS	.003 inches RMS
Thermal	.001 inches RMS	.003 inches RMS
(2) Reflector Structure		
Gravity	.016 inches RMS	.0118 inches RMS
Wind	.012 inches RMS	.0024 inches RMS
Thermal	.004 inches RMS	.005 inches RMS
RSS	.031 inches RMS	.027 inches RMS

VLA Antenna Comparison

Non-Repeatable
Precision Pointing Error Table

Wind from rear - Zenith angle 30°

Component	AUI Feasibility Design	E-Systems Design 7/30/70
Servo System	2.35 arc seconds	3.24 arc seconds
Data System	3.0 arc seconds	1.51 arc seconds
Reflector & El. Struct.	3.4 arc seconds	0.60 arc seconds
Yoke	3.7 arc seconds	6.63 arc seconds
Pedestal	3.2 arc seconds	3.08 arc seconds
Kingpost & Bearings	3.7 arc seconds	--
Azimuth Bearing (wind)	--	0.53 arc seconds
Azimuth Bearing Run-out	--	0.85 arc seconds
Foundation	1.0 arc seconds	1.22 arc seconds
El. Bearing	negl.	0.50 arc seconds
R.S.S.	15.48 arc seconds	12.61 arc seconds
Repeatable error	120 arc seconds	86.72 arc seconds

NATIONAL RADIO ASTRONOMY OBSERVATORY
VLA PROGRAM

ANTENNA MECHANICAL PARAMETERS

ITEM	UNIT	SPEC.	AVERAGE ANTENNAS 1-28
PANEL MANUFACTURE	IN RMS	0.015	0.0133
PANEL SETTING AT 50° EL.	IN RMS	0.018	0.0106
AZ CENTER TO FDN CENTER	IN	0.500	0.332
AZIMUTH LEAN	ARCSEC	18	11.5
ELEVATION ORTHOGONALITY	ARCSEC	18	6.5
ELEVATION OFFSET	IN	0.100	0.035
COLLIM. ORTHOGONALITY	ARCSEC	18	8.9
COLLIMATION OFFSET	IN	0.250	0.053
ALIGNMENT FOCAL MOUNT TO COLLIM. AXIS	ARCSEC	18	9.3
SERVO ERROR	ARCSEC RMS	3.24	---
RESONANT FREQUENCY ROCKING	HZ	2.07	2.32
RESONANT FREQUENCY TORSIONAL	HZ	2.15	2.38
SLEW RATE ELEVATION	O/MIN	20	20
SLEW RATE AZIMUTH	O/MIN	40	40

Exhibit 16

NATIONAL RADIO ASTRONOMY OBSERVATORY

VLA PROGRAM COMPLETION REPORT

SUBCONTRACT VLA-6 ANTENNA FABRICATION E-SYSTEMS, INC.

SUMMARY OF AMENDMENTS

Amendment No.	Date	Description	Amount	Total Contract Amount Building	Antennas
Basic	10/18/73	Design and supply 28 antennas	--	--	$16,893,757
1	11/09/73	Minor specification changes	None		--
2	01/04/74	Option exercised for Antenna Assembly-Maint. Bldg.	$311,579	$311,579	--
3	01/30/74	Increase of Vertex Room size from 82 to 212 sq. ft.	75,439		16,969,196
4	03/18/74	Authorization for procurement of long lead items	None		--
5	05/13/74	Increase in air conditioning capacity	7,332		16,976,528
6	06/17/74	Change delivery schedule of Item 1.1 of Schedule A from April 18, 1974 to July 31, 1974 and authorization date from June 18, 1974 to August 30, 1974	None		--
7	08/22/74	Authorization to manufacture, deliver, assemble on Site, align and test Antennas No. 1 and 2	None		--
8	10/22/74	Improve the tolerance for alignment of the antenna elevation axis to the azimuth axis	7,863		16,984,391
9	05/15/75	Authorized advance procurement for Antennas No. 3 through 10	(-8,545)		16,975,846
10	05/16/75	Authorizes the installation of an additional electronic cabinet in the Pedestal Equipment Room of Antennas No. 1 through 10.	3,295		16,979,141

Exhibit 17

Amendment No.	Date	Description	Amount	Total Contract Amount Building	Total Contract Amount Antennas
11	05/16/75	New Mexico Gross Receipts or Compensating Taxes on the Antenna Assembly Building	12,463	324,042	--
12	05/28/75	Performance of additional work and modifications which were made during the antenna design review stage on Antennas No. 3 through 10	215,408		17,194,549
13	09/24/75	Provides additional compensation to E-Sytems for the redesign and the resulting heavier foundation and larger structural frame of the Antenna Assembly Building.	63,290	387,332	--
14	09/30/75	Addition of two access doors complete with hardware and mountings to the VLA Assembly Building	9,381	396,713	--
15	10/17/75	Authorization of additional funds in the amount of $2,437,830 available for expenditure for Antennas No. 3 through 10	None		--
16	11/04/75	Modify the Servo Control System for Antennas No. 3 through 10	4,077		17,198,626
17	12/12/75	Installation of an access ladder to the five ton traveling crane and across travel platform on top of the crane in the Antenna Assembly Building	4,083	400,796	--
18	07/09/76	Procurement authorization for equipment and materials for Antennas No. 11 through 28 and making available an amount of $5,000,000 for the procurement. Authorization of price increases for Antennas No. 11 through 28 for changes agreed to in Amendments 10, 12 and 16	532,345		17,730,971

Amendment No.	Date	Description	Amount	Total Contract Amount: Building	Total Contract Amount: Antennas
19	11/08/76	Authorization to proceed with the completion of Antennas No. 11 through 20	None		--
20	12/29/76	Modification of the air conditioning system on Antennas No. 1 through 28	23,357		17,754,328
21	11/16/77	Modification to the air conditioning system of Antenna No. 9	930		17,755,258
		Totals		$400,796	$17,755,258
		Percent Increase		28.6%	5.1%
		Total Contracts			$18,156,054

NATIONAL RADIO ASTRONOMY OBSERVATORY
VLA PROGRAM COMPLETION REPORT

STATUS - PROCUREMENT OF ANTENNAS 3 THROUGH 28

E-SYSTEMS DELIVERY DATES

Antenna Number	Scheduled	Acceptance	Antenna Number	Scheduled	Acceptance
3	04/15/76	04/20/76	16	02/15/78	02/14/78
4	05/24/76	06/07/76	17	04/07/78	04/04/78
5	07/15/76	07/16/76	18	05/31/78	06/19/78
6	08/30/76	09/03/76	19	07/21/78	08/25/78
7	10/15/76	10/29/76	20	09/13/78	10/20/78
8	11/30/76	12/17/76	21	11/03/78	12/19/78
9	01/17/77	02/25/77	22	01/12/79	02/20/79
10	03/01/77	03/26/77	23	03/07/79	03/30/79
11	04/29/77	06/09/77	24	05/03/79	05/24/79
12	06/22/77	07/15/77	25	06/22/79	06/28/79
13	08/12/77	09/02/77	26	08/15/79	08/13/79
14	10/12/77	10/21/77	27	10/05/79	10/04/79
15	12/09/77	12/07/77	28	11/30/79	11/09/79

Exhibit 18

60MM HELIX WAVEGUIDE

AVERAGE ATTENUATION
EAST ARM – 21.0 KM
WEST ARM – 21.0 KM
NORTH ARM – 18.935 KM

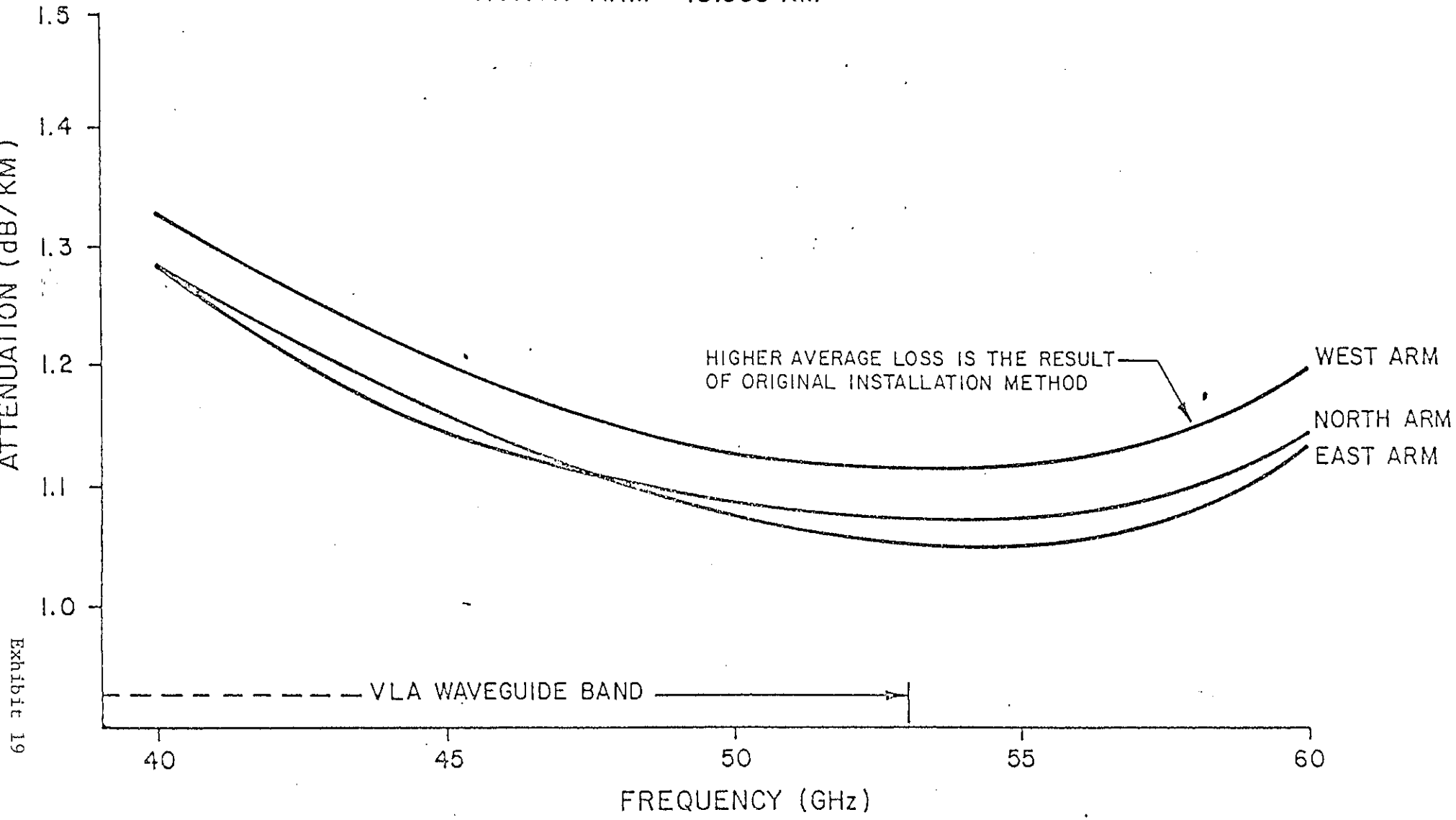


Exhibit 19

60 MM HELIX WAVEGUIDE

ATTENUATION vs TIME at 50 GHz

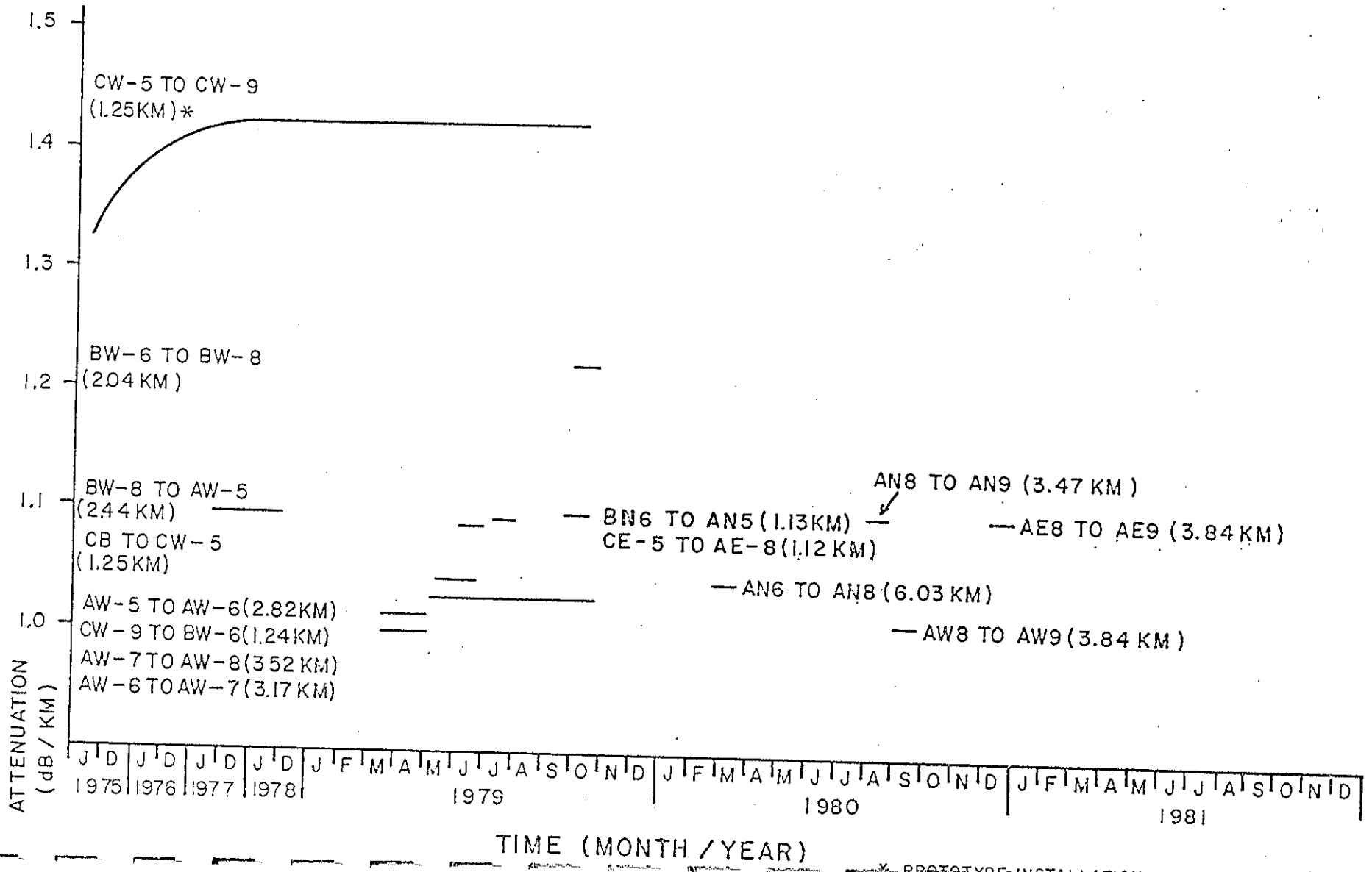
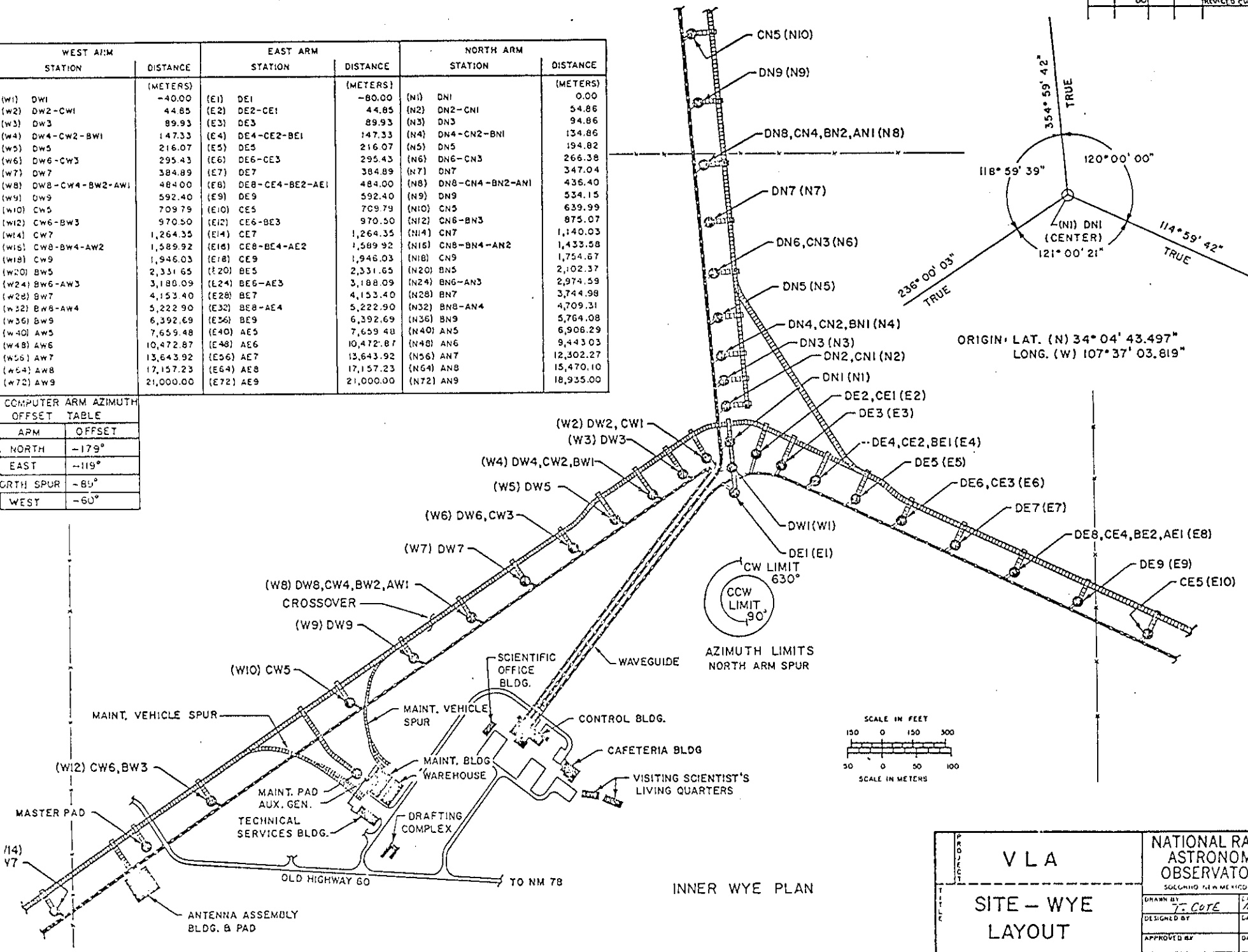


Exhibit 20

RE		DWN	SCRI.
A	3 25 80	PJR	ADDED FENCE LINE AZIMUTH LIMITS NAS REVISED CHART

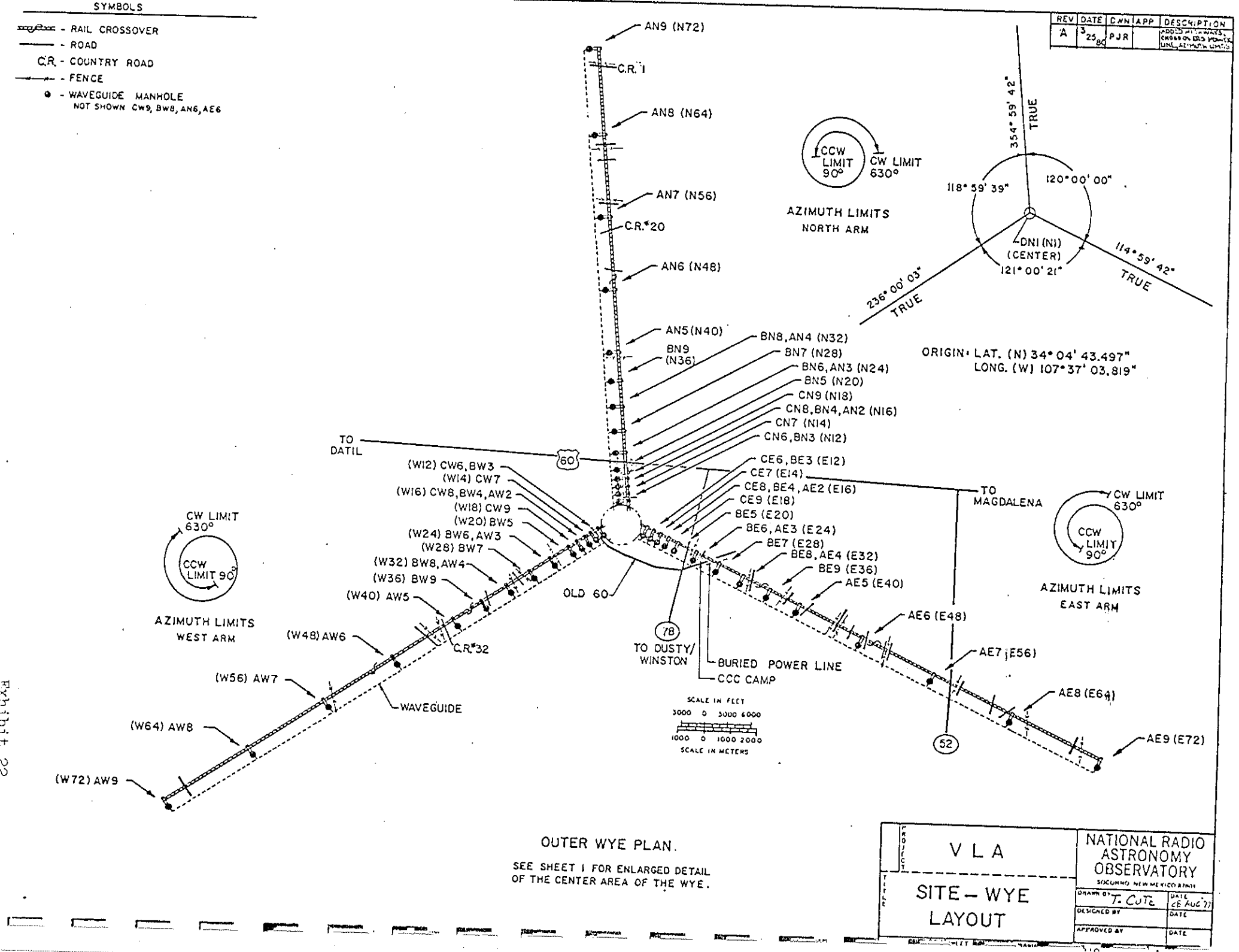
WEST ARM STATION	DISTANCE (METERS)	EAST ARM STATION	DISTANCE (METERS)	NORTH ARM STATION	DISTANCE (METERS)
(W1) DW1	-40.00	(E1) DE1	-80.00	(N1) DN1	0.00
(W2) DW2-CW1	44.85	(E2) DE2-CE1	44.85	(N2) DN2-CN1	54.86
(W3) DW3	89.93	(E3) DE3	89.93	(N3) DN3	94.86
(W4) DW4-CW2-BW1	147.33	(E4) DE4-CE2-BE1	147.33	(N4) DN4-CN2-BN1	134.86
(W5) DW5	216.07	(E5) DE5	216.07	(N5) DN5	194.82
(W6) DW6-CW3	295.43	(E6) DE6-CE3	295.43	(N6) DN6-CN3	266.38
(W7) DW7	384.89	(E7) DE7	384.89	(N7) DN7	347.04
(W8) DW8-CW4-BW2-AW1	484.00	(E8) DE8-CE4-BE2-AE1	484.00	(N8) DN8-CN4-BN2-AN1	436.40
(W9) DW9	592.40	(E9) DE9	592.40	(N9) DN9	534.15
(W10) CW5	709.79	(E10) CE5	709.79	(N10) CN5	639.99
(W12) CW6-BW3	970.50	(E12) CE6-BE3	970.50	(N12) CN6-BN3	875.07
(W14) CW7	1,264.35	(E14) CE7	1,264.35	(N14) CN7	1,140.03
(W16) CW8-BW4-AW2	1,589.92	(E16) CE8-BE4-AE2	1,589.92	(N16) CN8-BN4-AN2	1,433.58
(W18) CW9	1,946.03	(E18) CE9	1,946.03	(N18) CN9	1,754.67
(W20) BW5	2,331.65	(E20) BE5	2,331.65	(N20) BN5	2,102.37
(W24) BW6-AW3	3,188.09	(E24) BE6-AE3	3,188.09	(N24) BN6-AN3	2,974.59
(W28) BW7	4,153.40	(E28) BE7	4,153.40	(N28) BN7	3,744.98
(W32) BW8-AW4	5,222.90	(E32) BE8-AE4	5,222.90	(N32) BN8-AN4	4,709.31
(W36) BW9	6,392.69	(E36) BE9	6,392.69	(N36) BN9	5,764.08
(W40) AW5	7,659.48	(E40) AE5	7,659.48	(N40) AN5	6,906.29
(W48) AW6	10,472.87	(E48) AE6	10,472.87	(N48) AN6	9,443.03
(W56) AW7	13,643.92	(E56) AE7	13,643.92	(N56) AN7	12,302.27
(W64) AW8	17,157.23	(E64) AE8	17,157.23	(N64) AN8	15,470.10
(W72) AW9	21,000.00	(E72) AE9	21,000.00	(N72) AN9	18,935.00

COMPUTER ARM AZIMUTH OFFSET TABLE	
ARM	OFFSET
NORTH	-179°
EAST	-119°
NORTH SPUR	-89°
WEST	-60°



INNER WYE PLAN

PROJECT	VLA
	NATIONAL RADIO ASTRONOMY OBSERVATORY SOCORRO, NEW MEXICO 87801
TITLE	SITE – WYE LAYOUT
DRAWN BY	T. COTE 1/14/81
DESIGNED BY	DATE
APPROVED BY	DATE
SHEET 1 of 2	DRAWING D81D210



OUTER WYE PLAN.

SEE SHEET 1 FOR ENLARGED DETAIL OF THE CENTER AREA OF THE WYE.

PROJECT	VLA
TITLE	SITE – WYE LAYOUT
	NATIONAL RADIO ASTRONOMY OBSERVATORY SOCORRO, NEW MEXICO 87801
DRAWN BY	T. CUTE
DATE	28 AUG '79
DESIGNED BY	
DATE	
APPROVED BY	
DATE	

Exhibit 22

NATIONAL RADIO ASTRONOMY OBSERVATORY
VLA PROGRAM COMPLETION REPORT

SUMMARY OF RAIL & ACCESSORIES SALVAGE

VLA Spec No	Date	Location	Tonnage Received	Total Cost	Cost per Ton
	/74	Mountain Home AFB	102.3	$ 4,523	$ 44.21
48	6/74	Crab Orchard	1,272.7	78,894	61.99
78	1/75	Holloman AFB	944.5	72,181	76.42
79	1/75	Fort Hood	299.6	23,269	77.66
95	3/75	Lincoln Ord. Depot	450.6	12,363	27.44
116	6/75	Redstone Arsenal	2,016.3	13,768	6.83
132	11/75	Sunflower Ord. Plant	111.4	7,223	64.84
165	11/75	Myrtle Bch. AFB	1,141.3	103,960	9.11
	11/75	Eglin AFB	430.6	22,907	53.20
186	3/76	Fort Sam Houston	-	-	-
	3/76	Webb AFB	-	-	-
	3/76	Reese AFB	402.0	9,220	22.93
	3/76	Bastrop	-	-	-
191	4/76	Crab Orchard	3,591.9	266,155	74.10
206 & 7	5/76	Mare Island	24.2	(18,331)	(75.75)
	5/76	McClellen AFB	65.9	(982)	(14.90)
	5/76	Torrance	150.4	(47,594)	(316.45)
223	9/76	Hill AFB	614.7	16,956	27.58
261	3/77	Pantex	271.7	17,796	65.50
279	9/77	Hill AFB	196.2	16,911	86.19
309	4/78	Morganfield, KY	475.9	24,143	50.73
342	10/78	Ft. Huachuca	152.5	10,736	70.40
350	8/79	Presidio	134.7	6,583	48.87
351	8/79	Mare Island	96.8	8,969	92.65
352	10/79	Ft. Levenworth	627.5	25,675	40.92
353	10/79	Chattanooga	180.4	37,117	205.74
358	2/80	Camp Parks	183.9	21,989	119.57
360	4/80	Hill AFB	92.8	14,374	154.89
		Totals	14,030.8	$748,804	

Average Cost Per Ton Delivered to Site $53.37

NATIONAL RADIO ASTRONOMY OBSERVATORY
VLA PROGRAM COMPLETION REPORT

ANALYSIS OF PROCUREMENT COST - 60 mm TE_{01} WAVEGUIDE

Order	Vendor	Date	Pieces	Total length @4.95 m/piece	Cost	Unit Cost/m inc. couplings	Notes
SO44234 (VLA12)	Fujikura	2/15/74	253	1,252	$ 54,860	$43.82	
CO 1	Fujikura	2/21/75	-	-	860	-	Couplings only
	Sub-total		253	1,252	$ 55,720		
SO52322 (VLA70)	Sumitomo	1/27/75	1,313	6,499	429,975	66.16	
CO 1	Sumitomo	8/14/75	1,000	4,950	327,577	66.18	
CO 2	Sumitomo	9/5/75	1,000	4,950	327,577	66.18	
CO 3	Sumitomo	5/5/76	1,060	5,247	361,505	68.90	
CO 4	Sumitomo	11/8/76	1,000	4,950	355,192	71.76	
CO 5	Sumitomo	11/2/77	3,000	14,850	1,083.300	72.95	
CO 6	Sumitomo	9/27/78	1,060	5,247	330,720	63.03	
CO 7	Sumitomo	11/3/78	3,000	14,850	1,178,190	79.34	Couplings cancelled
CO 8	Sumitomo	5/4/79	55	-	N/C*	-	
CO 9	Sumitomo	3/18/80	13	-	N/C*	-	
	Sub-total		12,433	61,543	$4,394,036		
	Totals		12,686	62,795	$4,449,756	$70.86	

*Quantities to replace defective materials. Not included in totals.

Exhibit 24

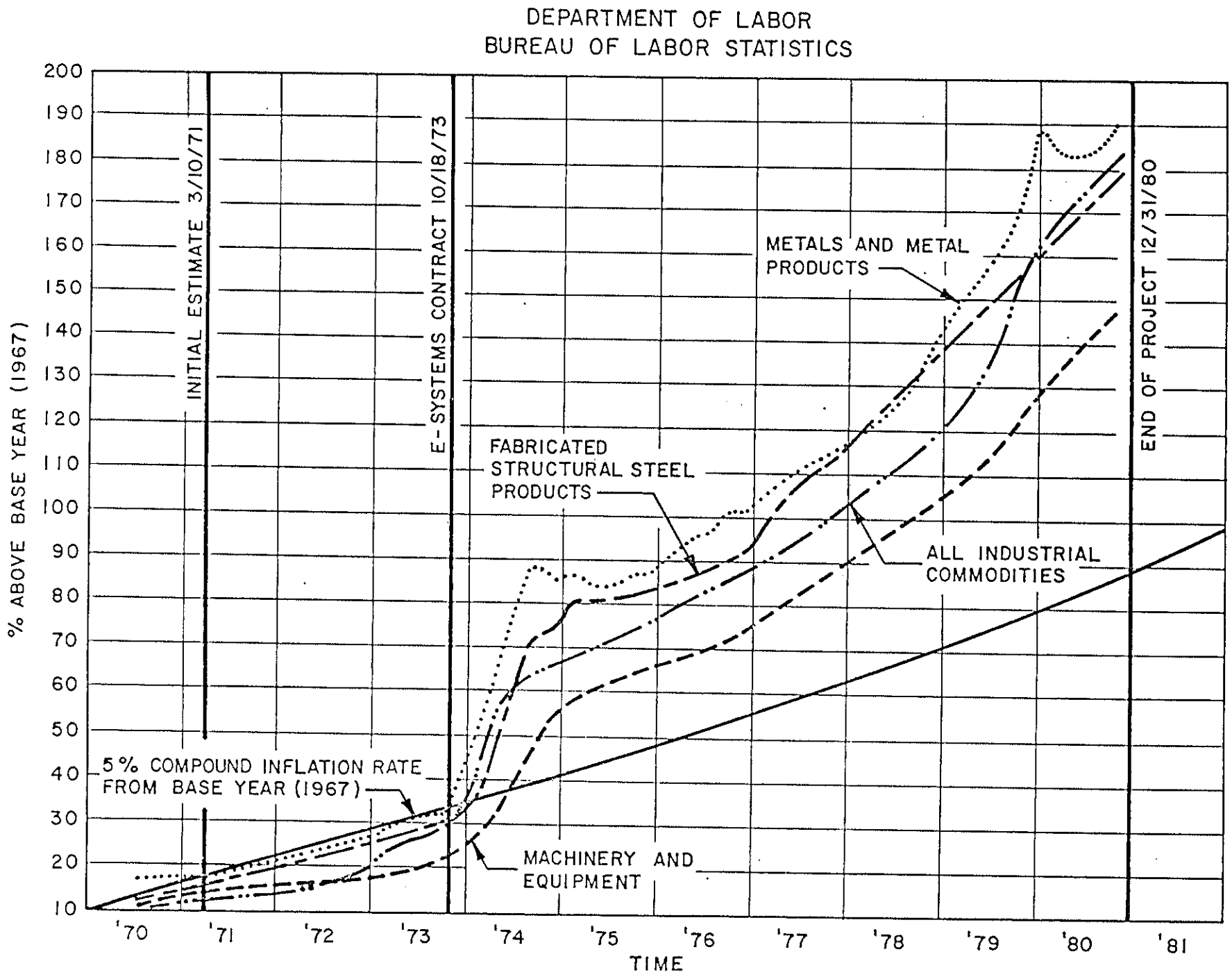

DEPARTMENT OF LABOR
BUREAU OF LABOR STATISTICS
% ABOVE BASE YEAR (1967)
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
INITIAL ESTIMATE 3/10/71
E-SYSTEMS CONTRACT 10/18/73
END OF PROJECT 12/31/80
METALS AND METAL PRODUCTS
FABRICATED STRUCTURAL STEEL PRODUCTS
ALL INDUSTRIAL COMMODITIES
5% COMPOUND INFLATION RATE FROM BASE YEAR (1967)
MACHINERY AND EQUIPMENT
'70
'71
'72
'73
'74
'75
'76
'77
'78
'79
'80
'81
TIME

Exhibit 25

APPROPRIATIONS & FINANCE

HOUSE BILL 607

35TH LEGISLATURE - STATE OF NEW MEXICO - FIRST SESSION, 1981

INTRODUCED BY

James J Martin

AN ACT

RELATING TO TOURISM; PROVIDING FOR THE CONSTRUCTION OF A VISITORS CENTER AT THE SITE OF THE VERY LARGE ARRAY TELESCOPE; MAKING AN APPROPRIATION.

BE IT ENACTED BY THE LEGISLATURE OF THE STATE OF NEW MEXICO:

Section 1. APPROPRIATION.--One hundred eighty-two thousand dollars ($182,000) is appropriated from the general fund to the property control division of the department of finance and administration to be expended in the sixty-ninth and seventieth fiscal years for the purpose of constructing a visitors center at the site of the very large array radio telescope on the plains of San Augustin. The release of these funds shall be contingent upon the state securing title to the land upon which the visitors center shall be built. Unexpended or unencumbered balances from this appropriation at the end of the seventieth fiscal year shall revert to the general fund.

.48714.1

[bracketed material] = deletion

NATIONAL RADIO ASTRONOMY OBSERVATORY
VLA PROGRAM COMPLETION REPORT

Magazine Articles Concerning the VLA

ENGINEERING NEWS RECORD, "Radio Telescope Cluster Will be World's Largest", February 3, 1972.

SKY AND TELESCOPE, May, 1972.

ENGINEERING NEWS RECORD, "Largest Rotating Telescope to Have 375-ft. Dish", December 21, 1972.

SKY AND TELESCOPE, January, 1973.

READER'S DIGEST, "The Speeded-Up Search for Life in Space", May, 1973.

NEW MEXICO PROFESSIONAL ENGINEER, "World's Largest Radio Telescope, The V.L.A.", February, 1974.

MACHINE DESIGN, "Telescopes on Tracks", May 16, 1974.

NEW MEXICO PROGRESS, "Very Large Array (VLA) - World's Largest Telescope Project", July, 1974.

SCIENCE NEWS, "Future World Center of Radio Astronomy", August 24 and August 31, 1974.

COLORADO BUSINESS, "A $76 Million Eye On the Sky", Sept/Oct., 1974.

SKY AND TELESCOPE, "The National Radio Astronomy Observatory", December, 1974.

ENGINEERING NEWS RECORD, "Giant Antenna Takes Shape in Desert", January 9, 1975.

SKY AND TELESCOPE, "The Very Large Array", June, 1975.

PHYSICS TODAY, "Progress Report on The VLA", February, 1976

SKY AND TELESCOPE, "The VLA Takes Shape", November, 1976.

ENCHANTMENT, "Listening to Space", December, 1976.

MICROWAVE JOURNAL, "Waveguide System for a Very Large Antenna Array", March, 1977.

POPULAR SCIENCE, "17 Movable Dishes: World's Largest Radio Telescope", March, 1977.

HAM RADIO HORIZONS, "An Oracle Comes of Age: The National Radio Astronomy Observatory", May, 1977.

NEW MEXICO, "Caution: Radio Telescope Crossing", May, 1977.

UMSCHAU, "Very Large Array", June 15, 1977.

DER SPIEGEL, "Amerikanische Radio-Astronomen bauen eine Horch-Anlage, die bis aum Rand des Universums lauchen kann NR. 14/1977.

UMSCHAU, "Neue Grossteleskope fur die Radioastronomie", 12, 1977.

MOSAIC, "The V(ery) L(arge) A(rray) Turns On", March-April, 1978.

SMITHSONIAN, "Huge New Radio Telescope Array Extends Man's Celestial Vision", July, 1978.

ELECTRONICS, "Giant Radio Telescope uses 19,500 chips for complex signal processing at 100 MHz", October, 1978.

SCIENCE, "The Double Quasar 0957 + 561 - A Radio Study at 6-Centimeters Wavelength", August 31, 1979.

OUTLOOK, "Tracking the World with Wm. A. Smith Co.", November, 1979.

VIVA NEW MEXICO, "VLA Telescope", April, 1980.

EL PALACIO, "The Very Large Array: Frontier of Radio Astronomy", Summer, 1980.

LIFE MAGAZINE, "Seeing Past The Sky - VLA", October, 1980.

DISCOVER, "The Ears of Socorro", October, 1980.

NEW SCIENTIST, "Tuning in on the Universe", 88, 1980.

NATURE, "Biggest Radio Telescope in the World", 1980.

SKY AND TELESCOPE, "Radio Astronomy: Achievements & Propects", 60, 1980.

SCIENCE NEWS, "VLA Field Day", February 21, 1981.

NATIONAL RADIO ASTRONOMY OBSERVATORY
VERY LARGE ARRAY
STATUS AS OF OCTOBER 31, 1978
TOTAL PROGRAM

PROJECT NUMBER	DESCRIPTION	ALLOCATION	EXPENDED MONTHLY	TOTAL EXPENDED	TRANSFER TO FIXED ASSETS	BALANCE CONSTRUCT. IN PROGRESS	TOTAL COMMITTED	TOTAL EXPENDED & COMMITTED	NET BALANCE
11000	SITE AND WYE	19,291,250	36,680	15,158,559	7,144,010	8,014,549	3,940,960	19,099,519	191,731
12000	ANTENNA	21,080,862	14,589	18,542,229	10,246,032	8,296,197	2,547,260	21,089,489	(8,627)
13000	ELECTRONICS	14,076,128	134,522	12,673,862	2,862,763	9,811,099	875,121	13,548,983	527,145
14000	COMPUTER	4,140,338	14,229	3,385,318	1,363,608	2,021,710	9,336	3,394,654	745,684
16000	SYSTEMS INTEGRATION	200,894	996	197,156	128,759	68,397	706	197,862	3,032
17000	PROGRAM MANAGEMENT	1,799,110	9,001	1,764,112	1,575,819	188,293	4,416	1,768,528	30,582
18000	COMMON COST	1,249,221	19,479	1,109,862	643,693	466,169	9,817	1,119,679	129,542
19000	CONTINGENCY	206,341	---	---	---	---	---	---	206,341
20000	CY-79 FUNDING	3,700,000	---	---	---	---	---	---	3,700,000
	TOTAL PROGRAM	65,744,144	229,496	52,831,098	23,964,684	28,866,414	7,387,616	60,218,714	5,525,430

Notes: Project allocation does not include the following amounts which were withheld by the NSF: 1) $293,000 for the Army Corp. of Eng.; 2) $15,700 for the ECAC Study; 3) $17,111 for the NSF Hoc Advisory Panel.
In May, 1978, $82,000 in allocation transferred from Contingency to Site and Wye for Cryogenic facility.
As of June 30, 1978, CY-78 funds were re-allocated to reflect revised estimates plus new funds received.
In June, 1978, $200,000 in new funds were made available under Amendment No. 32. In addition, $18,000 of the $20,000 in funds withheld under Amendment No. 30 were made available with the remaining $2,000 being used for the NSF Ad Hoc Advisory Panel.
In September, 1978, $175,000 in new funds were made available under Amendment No. 33. As of October 31, 1978, the NSF advanced $3,700,000 in CY-79 funds.

Exhibit 28

NATIONAL RADIO ASTRONOMY OBSERVATORY
VERY LARGE ARRAY
STATUS AS OF OCTOBER 31, 1978

CY - 78

PROJECT NUMBER	DESCRIPTION	ALLOCATION	EXPENDED MONTHLY	TOTAL EXPENDED	TRANSFER TO FIXED ASSETS	BALANCE CONSTRUCT. IN PROGRESS	TOTAL COMMITTED	TOTAL EXPENDED & COMMITTED	NET BALANCE
11000	SITE AND WYE	5,336,200	34,828	1,689,169	16,211	1,672,958	3,465,971	5,155,140	181,060
12000	ANTENNA	3,752,500	15,590	1,215,366	13,332	1,202,034	2,546,761	3,762,127	(9,627)
13000	ELECTRONICS	3,710,920	130,711	2,318,662	37,772	2,280,890	865,952	3,184,614	526,306
14000	COMPUTER	967,760	14,189	213,545	50	213,495	8,531	222,076	745,684
16000	SYSTEMS INTEGRATION	22,600	1,984	18,905	1,133	17,772	663	19,568	3,032
17000	PROGRAM MANAGEMENT	121,000	12,366	90,272	4,926	85,346	146	90,418	30,582
18000	COMMON COSTS	605,527	19,479	466,168	---	466,168	9,817	475,985	129,542
19000	CONTINGENCY	206,341	---	---	---	---	---	---	206,341
	TOTAL PROGRAM	14,722,848	229,147	6,012,087	73,424	5,938,663	6,897,841	12,909,928	1,812,920

Notes: Project allocation consists of $12,873,000 in new funding plus $1,849,848 in prior year funds re-allocated in CY-1978.
In May, 1978, $82,000 in allocation transferred from Contingency to Site and Wye for Cryogenic facility.
As of June 30, 1978, CY-78 funds were re-allocated to reflect revised estimates plus new funds received.
In June, 1978, $200,000 in new funds were made available under Amendment No. 32. In addition, $18,000 of the $20,000 in funds withheld under Amendment No. 30 were made available with the remaining $2,000 being used for the NSF Ad Hoc Advisory Panel. In September, 1978, $175,000 in new funds were made available under Amendment No. 33 and $160,000 in allocation was transferred from the Computer Div. to Site/Wye for additional waveguide procurement.

ER
COMM[illegible] ANALYSIS
AS OF OCTOBER 31, 1978

No. Employed 10/31/78	Account Number	ACCOUNT NAME	ALLOCATION	EXPENDED OCT. 31	TOTAL EXPENDED OCT. 31	COMMITMENTS	TOTAL EXPENDED COMMITTED	NET BALANCE
		ADMINISTRATIVE SERVICES						
	18911	SALARY/WAGES	219,200	18,395	182,952	---	182,952	36,248
	18921	BENEFITS	50,400	4,799	43,801	---	43,801	6,599
	18931	TRAVEL	4,500	---	4,649	---	4,649	(149)
	18941	MISC. MATERIALS/SERVICES	114,548	3,466	73,186	6,726	79,912	34,636
	18942	UTILITIES-ELECTRICITY	165,000	---	124,196	---	124,196	40,804
	18943	GSA RENTALS	40,000	(3,700)	31,109	---	31,109	8,891
	18944	BUSES	17,319	(2,842)	5,276	1,541	6,817	10,502
	18945	FREIGHT/DISCOUNTS	21,000	741	18,268	---	18,268	2,732
	18947	COMMUNICATIONS	75,240	385	56,537	---	56,537	18,703
	18952	CAFETERIA & VSQ EXPENSE	16,000	1,729	14,420	25	14,445	1,555
	18953	MISC. RECEIPTS	(20,000)	(2,727)	(23,479)	---	(23,479)	3,479
21		TOTAL ADMIN. SERVICES	703,207	20,246	530,915	8,292	539,207	164,000
		FISCAL						
	18914	SALARY/WAGES	54,200	4,784	43,358	---	43,358	10,842
	18924	BENEFITS	12,200	1,248	10,306	---	10,306	1,894
	18934	TRAVEL	2,100	---	2,119	---	2,119	(19)
	18970	MISC. MATERIALS/SERVICES	4,317	---	3,059	488	3,547	770
5		TOTAL FISCAL	72,817	6,032	58,842	488	59,330	13,487
		PLANT MAINTENANCE						
	18915	SALARY/WAGES	89,900	7,604	74,220	---	74,220	15,680
	18925	BENEFITS	20,700	1,984	17,610	---	17,610	3,090
	18935	TRAVEL	1,500	---	785	---	785	715
	18980	MISC. MATERIALS/SERVICES	63,681	(2,765)	33,417	7,902	41,319	22,362
7		TOTAL PLANT MAINTENANCE	175,781	6,823	126,032	7,902	133,934	41,847
33 A)		TOTAL COMMON COSTS	951,805	33,101	715,789	16,682	732,471	219,334
		DISTRIBUTED TO CONSTRUCTION	(605,527)	(19,479)	(466,168)	(9,817)	(475,985)	(129,542)
		DISTRIBUTED TO OPERATIONS	(346,278)	(13,622)	(249,621)	(6,865)	(256,486)	(89,792)
		TOTAL	---	---	---	---	---	---

Note:

A) Includes two part-time employees.

AS OF OCT 1978

ACCOUNT NUMBER	ACCOUNT NAME	ALLOCATION	EXPENDED OCT. 31	TOTAL EXPENDED OCT. 31	COMMITMENTS	TOTAL EXPENDED COMMITTED	NET BALANCE
	ANTENNA MAINTENANCE						
46101	SALARY/WAGES	98,300	6,872	74,455	---	74,455	23,845
46102	BENEFITS	21,900	1,664	17,546	---	17,546	4,354
46104	TRAVEL	1,000	---	494	---	494	506
46105	MISC. MATERIALS/SERVICES	21,169	(140)	14,377	4,383	18,760	2,409
46107	SPARES	39,210	---	30,132	1,812	31,944	7,266
	TOTAL ANT. MAINTENANCE	181,579	8,396	137,004	6,195	143,199	38,380
	SCIENTIFIC SERVICES						
46201	SALARY/WAGES	228,600	21,259	173,583	---	173,583	55,017
46202	BENEFITS	46,000	4,175	33,722	---	33,722	12,278
46204	TRAVEL	4,000	23	17,280	---	17,280	(13,280)
46205	MISC. MATERIALS/SERVICES	25,421	(219)	16,046	5,628	21,674	3,747
46206	COMPUTER MAINTENANCE	87,439	(271)	65,990	23,850	89,840	(2,401)
46207	SPARES	---	---	---	11	11	(11)
46213	LIBRARY	12,216	154	11,110	179	11,289	927
	TOTAL SCIENTIFIC SERVICES	403,676	25,121	317,731	29,668	347,399	56,277
	ELECTRONIC MAINTENANCE						
46301	SALARY/WAGES	161,400	14,089	128,894	---	128,894	32,506
46302	BENEFITS	37,800	3,029	29,694	---	29,694	8,106
46304	TRAVEL	3,000	580	6,527	---	6,527	(3,527)
46305	MISC. MATERIALS/SERVICES	20,271	1,402	17,071	6,190	23,261	(2,990)
46307	SPARES	8,238	---	3,450	3,526	6,976	1,262
	TOTAL ELECT. MAINTENANCE	230,709	19,100	185,636	9,716	195,352	35,357
	ARRAY OPERATIONS						
46401	SALARY/WAGES	94,700	8,577	75,971	---	75,971	18,729
46402	BENEFITS	19,300	1,712	14,157	---	14,157	5,143
46404	TRAVEL	1,000	240	1,565	---	1,565	(565)
46405	MISC. MATERIALS/SERVICES	1,400	---	86	428	514	886
46406	WYE COMMUNICATIONS	2,000	---	141	---	141	1,859
46407	SPARES	---	---	---	---	---	---
46408	FACILITIES MAINTENANCE	---	---	---	---	---	---
	TOTAL ARRAY	118,400	10,529	91,920	428	92,348	26,052
	TOTAL OPER. BEFORE COMMON COST	934,364	63,146	732,291	46,007	778,298	156,066
46999	UNDISTRIBUTED COMMON COSTS	346,278	13,622	249,622	6,865	256,487	89,791
	TOTAL VLA OPERATIONS	1,280,642	76,768	981,913	52,872	1,034,785	245,857

CY -

V E R Y L A R G E A R R A Y

STATUS AS OF OCT 31 1978

SITE/WYE

PROJECT NUMBER	DESCRIPTION	ALLOCATION	EXPENDED MONTHLY	TOTAL EXPENDED	TRANSFER TO FIXED ASSETS	BALANCE CONSTRUCT. IN PROGRESS	TOTAL COMMITTED	TOTAL EXPENDED & COMMITTED	NET BALANCE
	SUBTOTAL EDIA	7320000	585143	5795455	99790	5695665	4500	5799955	1520045
	TOTAL SITE/WYE	533620000	3482791	168916861	1621130	167295731	346597183	515514044	18105956

CY -

VERY LARGE ARRAY

STATUS AS OF OCT 31 1978

SITE/WYE

PROJECT NUMBER	DESCRIPTION	ALLOCATION	EXPENDED MONTHLY	TOTAL EXPENDED	TRANSFER TO FIXED ASSETS	BALANCE CONSTRUCT. IN PROGRESS	TOTAL COMMITTED	TOTAL EXPENDED & COMMITTED	NET BALANCE
11101	ARCHAEOLOGICAL PRESERV.	.00	.00	30750	.00	30750	.00	30750	30750-
	SUBTOTAL ARCH. PRESERVATION	.00	.00	30750	.00	30750	.00	30750	30750-
11212	DETAILED DESIGN								
11213	CONSTRUCTION SUPERVISION	21800.00	.00	563455	.00	563455	416045	979500	1200500
11214	SURVEY/SOILS	38500.00	.00	209852	.00	209852	2939940	3149792	700208
	SUBTOTAL DESIGN/SUPERV.	13500.00	.00	463956	.00	463956	604797	1068753	281247
		73800.00	.00	1237263	.00	1237263	3960782	5198045	2181955
11240	CONSTRUCTION SITE PREP.								
11243	TRACK MAINT. EQUIPMENT	500.00	.00	44262	.00	44262	.00	44262	455738
11250	COMPUTER SITE TRAILERS	15000.00	.00	201774	150000	51774	403345	605119	894881
11251	VISITOR TRAILER DISPLAY	3000.00	.00	354689	231435	123254	.00	354689	54689-
	SUBTOTAL CONST. EQUIPMENT	6000.00	.00	.00	.00	.00	130313	130313	469687
		29000.00	.00	600725	381435	219290	533658	1134383	1765617
11310	ROADS/PARKING AREAS								
11320	LANDSCAPING/SIDEWALKS	10000.00	.00	95784	.00	95784	.00	95784	904216
11330	WATER SUPPLY/DISTRIBUTION	10000.00	211397	945361	.00	945361	150.00	960361	39639
11340	SEWAGE PLANT	3000.00	.00	70140	.00	70140	73842	143982	156018
11350	CENTRAL TELEPHONE SYSTEM	2000.00	.00	9094	.00	9094	.00	9094	1590.06
11360	ELECTRICAL SERVICE BLDGS.	3000.00	.00	224803	.00	224803	.00	224803	75197
	SUBTOTAL SITE WORK	6000.00	240000	417379	.00	417379	.00	417379	182621
		34000.00	451397	1762561	.00	1762561	88842	1851403	1548597
11410	CONTROL/LAB/OFFICE BLDG.								
11411	CONTROL BLDG.-ELEC. FACILITY	6000.00	.00	100476	.00	100476	4574	105050	494950
11421	GARAGE BUILDING	2000.00	.00	17220	.00	17220	.00	17220	182780
11422	CRYOGENIC FACILITY	17000.00	62.00	1673631	.00	1673631	11253	1684804	15116
11430	CAFETERIA BLDG.	88000.00	5909.78	6776571	.00	6776571	2167520	8944091	1440.91-
11440	VSD	1000.00	.00	5652	.00	5652	81540	87192	12808
11450	EQUIPMENT/FURNISHINGS	55000.00	.00	5166863	.00	5166863	155666	5322529	177471
11451	EQUIP.-FIRE,MEDICAL, & SAFETY	50000.00	404285	3330994	481265	2849729	697320	4028314	971686
11460	LIBRARY-OFFICE BUILDING	.00	150317	176967	.00	176967	321154	498121	498121-
	SUBTOTAL BUILDINGS/FURNISHINGS	85000.00	.00	6488390	.00	6488390	485314	6973704	1526296
		304000.00	1151780	23736764	481265	23255499	3924341	27661105	2738895
11510	EARTHWORK/DRAINAGE								
11520	TRACKAGE	794078.00	.00	23084249	.00	23084249	563550.73	794393.22	31522-
11521	LEGAL FEES	1618449.00	184399	5234436	560000	5170436	1128975.01	1652416.37	3396737-
11530	ANTENNA FOUNDATIONS	10000.00	.00	9217.11	.00	9217.11	.00	9217.11	78289
11540	ELECTRICAL DISTRIBUTION SYS.	787094.00	.00	1172697.1	.00	1172697.1	673314.13	1905838.4	148934-
11550	WAVEGUIDE PROCUREMENT	227279.00	.00	4971165	.00	4971165	1775666.8	2272783.3	.67
11560	WAVEGUIDE INSTALLATION	738100.00	156.00	188297.3	.00	188297.3	7194546.9	7382844.2	184.42-
11570	WAVEGUIDE-ANTENNA STATIONS	421200.00	1094472	2719485.2	98640	2709621.2	8764086	3597893.8	6141062
11580	TELEPHONE DISTRIBUTION	174000.00	.00	1039352.4	.00	1039352.4	1819530	1281305.4	5186946
	SUBTOTAL WYE DISTRIBUTION	50000.00	.00	323376.2	.00	323376.2	1195320	442908.2	570918
		4822200.00	1294471	13375334.3	658640	13509470.3	33808506.0	47323840.3	8361597
11910	SALARY/WAGES								
11920	BENEFITS	47000.00	455180	3961872	.00	3961872	.00	3961872	738128
11930	TRAVEL	10200.00	89637	832938	.00	832938	.00	832938	187062
11940	MISC. MATERIALS/SERVICES	4000.00	.00	162333	.00	162333	.00	162333	837667
11949	SPARES	10000.00	40326	667412	99790	567622	4500	671912	328088
		2000.00	.00	170900	.00	170900	.00	170900	329100

CY -

VERY LARGE ARRAY

STATUS AS OF OCT 31 1978

ANTENNA

PROJECT NUMBER	DESCRIPTION	ALLOCATION	EXPENDED MONTHLY	TOTAL EXPENDED	TRANSFER TO FIXED ASSETS	BALANCE CONSTRUCT. IN PROGRESS	TOTAL COMMITTED	TOTAL EXPENDED & COMMITTED	NET BALANCE
12120	ANTENNA FABRICATION	3136000.00	.00	6989280.00	.00	6989280.00	2437052.00	3135980.00	20.00
12130	CRYOGENIC PLATFORMS	80000.00	.00	694188	.00	694188	.00	694188	105812
12140	ANTENNA ELECT. INSTALL.	25500.00	3218	2084218	.00	2084218	1327207	3411425	861425-
12160	ANTENNA FIELD MOD.	29800.00	.00	2525424	.00	2525424	2363240	4888664	1908664-
	SUBTOTAL ANTENNA ELEMENT	3199300.00	3218	75196630	.00	75196630	247395647	322592277	2662277-
12210	FOCUSING FEED MOUNTS	213700.00	.00	2134898	.00	2134898	.00	2134898	2102
	SUBTOTAL FOCUSING FEEDS	213700.00	.00	2134898	.00	2134898	.00	2134898	2102
12430	TRANSPORTER ASS./TEST/MOD.	160000.00	.00	530531	.00	530531	15123	545654	1054346
	SUBTOTAL TRANSPORTER	160000.00	.00	530531	.00	530531	15123	545654	1054346
12510	FEED STRUCTURE	43800.00	.00	4270924	.00	4270924	4281774	8552698	4172698-
	SUBTOTAL FEED STRUCTURE	43800.00	.00	4270924	.00	4270924	4281774	8552698	4172698-
12610	SUBREFLECTOR SUPPORT	200000.00	.00	1454400	.00	1454400	.00	1454400	545600
	SUBTOTAL SUBREFLECTOR	200000.00	.00	1454400	.00	1454400	.00	1454400	545600
12710	L-BAND FEED MOUNT	80000.00	.00	707052	.00	707052	799272	1506324	706324-
	SUBTOTAL L-BAND MOUNT	80000.00	.00	707052	.00	707052	799272	1506324	706324-
12910	SALARY/WAGES	1536700.00	1256237	12133499	.00	12133499	.00	12133499	3236501
12920	BENEFITS	332000.00	247388	2531732	.00	2531732	.00	2531732	768268
12930	TRAVEL-GENERAL	90000.00	40676	654334	.00	654334	.00	654334	245666
12931	TRAVEL-RELOCATION	40000.00	.00	58843	.00	58843	.00	58843	341157
12941	MACHINE SHOP TOOLS	45000.00	4270	66854	.00	66854	28746	95600	35400
12942	MACHINE SHOP EQUIP./TOOLS	174000.00	.00	1451215	1333193	118022	8700	1459915	280085
12943	MECHANICS-TOOLS & EQUIPMENT	30000.00	9769	317776	.00	317776	22600	340376	40376-
12944	ANTENNA MATERIALS-MISC.	70000.00	2379-	417564	.00	417564	39185	456749	243251
12945	DRAFTING SUPPLIES	15000.00	.00	95611	.00	95611	.00	95611	54389
12946	ENGINEERING SERVICES	60000.00	.00	280724	.00	280724	772440	1053164	453164-
12947	ENGINEERING EQUIPMENT	6000.00	.00	19955	.00	19955	62700	82655	22655-
12949	SPARES	120000.00	.00	.00	.00	.00	125000.00	125000.00	50000-
	SUBTOTAL EDIA	2517000.00	1555761	18028107	1333193	16694914	2184371	20212478	4957522
	TOTAL ANTENNA DIV.	37525000.00	1558979	121536632	1333193	120203439	25467687	37681219	962819-

CY -

VERY LAR ARRAY

STATUS AS OF OCT 31 1978

ELECTRONICS

PROJECT NUMBER	DESCRIPTION	ALLOCATION	EXPENDED MONTHLY	TOTAL EXPENDED	TRANSFER TO FIXED ASSETS	BALANCE CONSTRUCT. IN PROGRESS	TOTAL COMMITTED	TOTAL EXPENDED & COMMITTED	NET BALANCE
13020	TEST EQUIPMENT	45000.00	.00	3412376	2729376	683000	161195	3573571	926429
13021	TEST UNITS	15000.00	379.00	181523	.00	181523	80203	261726	1238274
13030	CABINETS/RACKS	253400.00	1611119	13060574	.00	13060574	2141159	15201733	10138267
13040	DC POWER	35600.00	19250	3871576	.00	3871576	145006	4016582	456582-
13060	R.F.I. PROTECTION	7000.00	110.00	58223	.00	58223	522970	581213	118787
13070	SHOP/LAB EQUIPMENT	1600.00	.00	261313	79500	181813	95936	357249	197249-
13080	MISCELLANEOUS CABLE	3000.00	.00	250662	.00	250662	21005	271667	28333
13090	WEATHER INSTRUMENTATION	3500.00	.00	427000	.00	427000	.00	427000	77000-
	SUBTOTAL GENERAL ELECT.	364100.00	1679269	21523247	2808876	18714371	3167494	24690741	11719259
13110	F.E. DEVELOPMENT-GENERAL	12000.00	.00	124296	.00	124296	258298	382594	817406
13120	F.E. DEVELOPMENT-CRYOGENICS	6820.00	93552	602015	33600	568415	297347	899362	217362-
13130	CRYOGENIC SYSTEM	200600.00	528219	6569682	116100	6453782	17727310	24297192	4237192-
13140	PARAMP AND PUMPS	149000.00	75316	10516660	.00	10516660	4222796	14739456	160544
13150	UPCONVERTER AND PUMPS	109000.00	.00	4784881	.00	4784881	17156100	21940981	11040981-
13160	1.3/2.0 CM	26400.00	33500	2092964	.00	2092964	1704870	3887834	1247834-
13170	R.F. COMPONENTS	147600.00	.00	13954226	.00	13954226	1839256	15793402	1033402-
13180	FREQUENCY CONVERTERS	50300.00	71638	1557166	.00	1557166	139641	1696807	333193
13190	F.E. FILTER UNIT	170200.00	200.00	210909	.00	210909	208558	419467	16600533
	SUBTOTAL FRONT-ENDS	871920.00	822225	40412999	1497.00	40263299	43644176	84057175	3134825
13210	L.O. DEVELOPMENT	7000.00	.00	173040	.00	173040	3300	176340	523660
13220	MASTER LOCAL OSCILLATOR	11700.00	.00	97807	58151.5	39649.2	114200	1092207	77793
13230	SLAVE LOCAL OSCILLATOR	140900.00	65648	13120080	.00	13120080	1260302	14380382	890382-
13240	L.O. CORRECTOR	80600.00	10050	7412248	.00	7412248	1292658	8704906	644906-
13250	2-4 GHZ SYNTHESIZER	70500.00	15674	5575112	.00	5575112	177678	5752790	1297210
	SUBTOTAL L.O. SYSTEM	310700.00	91372	27258487	581515	26676972	2848138	30106625	963375
13310	GENERAL DEVELOPMENT-WAVEGUIDE	15000.00	.00	1453587	19600	1433987	91061	1544648	44648-
13320	DEVELOPMENT-INSTALLATION	10000.00	74166	1508947	.00	1508947	9179	1518126	518126-
13330	TEST SETS-WAVEGUIDE	26600.00	.00	1054704	198260	856444	544300	1599204	1060796
13360	ANTENNA WAVEGUIDE-20MM	69000.00	4560	6901362	.00	6901362	.00	6901362	1362-
	SUBTOTAL WAVEGUIDE	120600.00	78726	10918600	217860	10700740	644740	11563340	496660
13420	I.F. DEVELOPMENT-MODEMS	11000.00	.00	562891	.00	562891	3436	566327	533673
13440	I.F./L.O. MODEM A & B	376900.00	2253733	20462245	.00	20462245	12996110	33458355	4231645
13450	I.F. RECEIVER	130300.00	50400	1183733	.00	1183733	35275	1219008	11810992
13460	SIGNAL DISTRIBUTOR	7200.00	.00	10294	.00	10294	.00	10294	709706
	SUBTOTAL I.F. TRANSMISSION	525400.00	2304133	22219163	.00	22219163	13034821	35253984	1728616
13520	SAMPLER SYSTEM	11800.00	.00	162322	.00	162322	.00	162322	1017678
	SUBTOTAL DELAY/MULTIPLIER SYS.	11800.00	.00	162322	.00	162322	.00	162322	1017678
13610	DEVELOPMENT-FEED SYSTEM	10000.00	.00	.00	.00	.00	201889	201889	798111
13620	SUBREFLECTOR	25800.00	900969	2254349	.00	2254349	3956000	6210349	3630349-
13630	CALIBRATION COMPONENTS	5800.00	.00	803600	.00	803600	351800	1155400	375400-
13640	FEED MOUNT/DEICER	21600.00	.00	20504	.00	20504	.00	20504	2139496
13660	18-21 CM FEED	111600.00	11204	7787494	.00	7787494	3524848	11312342	152342-
13670	6 CM FEED	48600.00	.00	478937	.00	478937	4355500	4834437	25563

VERY LARGE ARRAY

STATUS AS OF OCT 31 1978

ELECTRONICS

PROJECT NUMBER	DESCRIPTION	ALLOCATION	EXPENDED MONTHLY	TOTAL EXPENDED	TRANSFER TO FIXED ASSETS	BALANCE CONSTRUCT. IN PROGRESS	TOTAL COMMITTED	TOTAL EXPENDED & COMMITTED	NET BALANCE
1.3680	2 CM FEED	3420000	.00	2339690	.00	2339690	968250	3357940	62060
1.3690	1.25 CM FEED	3580000	.00	2797608	.00	2797608	799350	3596958	16958-
	SUBTOTAL FEED SYSTEM	29340000	912173	16532182	.00	16532182	14157637	30689819	1349819-
1.3720	MONITOR/CONTROL MODULES	6900000	15930	5690242	.00	5690242	193962	5884204	1015796
1.3730	CONTROL ROOM EQUIPMENT	520000	.00	13700	.00	13700	4500	18200	501800
1.3740	FOCUS POLARIZATION DRIVER	447000	1593	3392920	.00	3392920	3329825	6722745	2252745-
	SUBTOTAL MONITOR/CONTROL	11890000	17523	9096862	.00	9096862	3528287	12625149	735149-
1.3810	SPECTRAL PROCESSOR, I.F. DEVEL	300000	21480	532055	.00	532055	601745	1133800	833800-
1.3820	SPECTRAL PROCESSOR, I.F. SYS	9000000	66350	835922	.00	835922	459772	1345694	7654306
1.3830	SPECTRAL PROCESS., D/M DEVEL.	500000	.00	.00	.00	.00	.00	.00	500000
1.3840	SPECTRAL PROCESSOR DELAY/MULT	2080000	26731	1880096	.00	1880096	424758	2304854	224854-
1.3850	SPECTRAL PROCESSOR, C/I DEVEL.	500000	.00	55220	.00	55220	.00	55220	444780
1.3860	SPECTRAL PROCESSOR, CONT/INTER	1860000	45257	1078344	.00	1078344	83112	1161456	698544
	SUBTOTAL SPECTRAL PROCESSOR	14240000	159818	4431637	.00	4431637	1569387	6001024	8238976
1.3910	SALARY/WAGES	64110000	5268240	33223930	.00	33223930	.00	33223930	10886070
1.3920	BENEFITS	13780000	1037465	11001924	.00	11001924	.00	11001924	2778076
1.3930	TRAVEL-GENERAL	3070000	171264	2903347	.00	2903347	.00	2903347	166653
1.3931	TRAVEL-RELOCATION	930000	.00	442601	.00	442601	.00	442601	487399
1.3940	MISC. MATERIALS/SERVICES	13280000	528923	10367693	192.90	10348403	1751600	12119293	1160707
1.3949	SPARES	.00	.00	1371171	.00	1371171	2249000	3620171	3620171-
	SUBTOTAL EDIA	95170000	7003892	79310666	192.90	79291376	4000600	83311266	11858734
	TOTAL ELECTRONICS DIV.	37109200.00	13071131	231866165	377241	228088924	86595280	318461445	52630555

CY -

VERY LAR ARRAY

STATUS AS OF OCT 31 1978

COMPUTER

PROJECT NUMBER	DESCRIPTION	ALLOCATION	EXPENDED MONTHLY	TOTAL EXPENDED	TRANSFER TO FIXED ASSETS	BALANCE CONSTRUCT. IN PROGRESS	TOTAL COMMITTED	TOTAL EXPENDED & COMMITTED	NET BALANCE
14110	SYNCHRONOUS COMPUTER	23000.00	.00	.00	.00	.00	.00	.00	23000.00
14112	SYNCHRONOUS REPAIR SYS	15000.00	.00	134166	.00	134166	1900.00	324166	1175834
	SUBTOTAL SYNCHRONOUS SYSTEM	38000.00	.00	134166	.00	134166	1900.00	324166	3475834
14212	INTERFACE EQUIPMENT	30000.00	.00	1026400	.00	1026400	2750.00	1301400	1698600
14220	DISPLAY EQUIPMENT	115000.00	576515	8927133	.00	8927133	16500	8943633	2556367
14240	SPECTRAL LINE COMPUTER	180000.00	.00	.00	.00	.00	.00	.00	180000.00
14242	MAP MAKING PROCESSOR	440000.00	.00	.00	.00	.00	.00	.00	440000.00
	SUBTOTAL ASYNCHRONOUS SYSTEM	773000.00	576515	9953533	.00	9953533	291500	10245033	67054967
14910	SALARY/WAGES	87600.00	663320	7607655	.00	7607655	.00	7607655	1152345
14920	BENEFITS	18800.00	130626	1613599	.00	1613599	.00	1613599	266401
14930	TRAVEL-GENERAL	5300.00	550	146954	.00	146954	.00	146954	383046
14931	TRAVEL-RELOCATION	5000.00	.00	.00	.00	.00	.00	.00	500000
14940	MISC. MATERIALS/SERVICES	17560.00	14630	1372524	49.95	1367529	214720	1587304	168696
14949	SPARES	.00	.00	.00	.00	.00	.00	.00	.00
14950	COMPUTER MAINTENANCE	22500.00	33268	526075	.00	526075	156795	682870	1567130
	SUBTOTAL EDIA	156760.00	842394	11266807	49.95	11261812	371575	11638382	4037618
	TOTAL COMPUTER DIV.	967760.00	1418909	21354506	49.95	21349511	853075	22207581	74568419

CY -

V E R Y L A R G E A R R A Y

STATUS AS OF OCT 31 1978

SYSTEMS INTEGRATION

PROJECT NUMBER	DESCRIPTION	ALLOCATION	EXPENDED MONTHLY	TOTAL EXPENDED	TRANSFER TO FIXED ASSETS	BALANCE CONSTRUCT. IN PROGRESS	TOTAL COMMITTED	TOTAL EXPENDED & COMMITTED	NET BALANCE
16910	SALARY/WAGES	1520000	160275	1339391	.00	1339391	.00	1339391	180609
16920	BENEFITS	320000	31562	277745	.00	277745	.00	277745	42255
16930	TRAVEL-GENERAL	100000	.00	44135	.00	44135	.00	44135	55865
16940	MISC. MATERIALS/SERVICES	320000	6551	229265	113290	115975	66300	295565	24435
16949	SPARES	.00	.00	.00	.00	.00	.00	.00	.00
	TOTAL SYSTEMS INTEGRATION	2260000	198388	1890536	113290	1777246	66300	1956836	303164

CY -

VERY LARGE ARRAY

STATUS AS OF OCT 31 1978

PROGRAM MANAGEMENT

PROJECT NUMBER	DESCRIPTION	ALLOCATION	EXPENDED MONTHLY	TOTAL EXPENDED	TRANSFER TO FIXED ASSETS	BALANCE CONSTRUCT. IN PROGRESS	TOTAL COMMITTED	TOTAL EXPENDED & COMMITTED	NET BALANCE
17910	SALARY/WAGES	7470000	646328	6313349	.00	6313349	.00	6313349	1156651
17920	BENEFITS	1610000	131615	1318604	.00	1318604	.00	1318604	291396
17930	TRAVEL-GENERAL	850000	135432	602391	.00	602391	.00	602391	247609
17940	MISC. MATERIALS/SERVICES	1570000	301213	716896	492595	224301	14637	731533	838467
17942	LEGAL FEES	600000	.00	75960	.00	75960	.00	75960	524040
17949	SPARES	.00	.00	.00	.00	.00	.00	.00	.00
	TOTAL PROGRAM MANAGEMENT	12100000	1236608	9027200	492595	8534605	14637	9041837	3058163

NATIONAL RADIO ASTRONOMY OBSERVATORY
VLA PROGRAM

FINANCIAL STATUS REPORT
(in thousands)

As of: November 30, 1978

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	(A)	Allocation to Date				Outlook		
Item	Original Program Ceiling	Allocated	Expended and Committed	Allocated Balance	Unallocated Balance	Estimate to Complete	Estimate Total	(Over) Under Ceiling
Site & Wye	27,860	19,219	19,135	84	8,641	7,932	27,067	793
Antennas	20,400	21,089	21,033	56	(689)	1,691	22,724	(2,324)
Electronics	17,000	14,265	13,640	625	2,735	4,000	17,640	(640)
Computer	4,850	3,913	3,665	248	937	2,517	6,182	(1,332)
Systems Integration	400	201	202	(1)	199	(1)	201	199
Program Management	2,650	1,787	1,777	10	863	325	2,102	548
Common Cost	-	1,249	1,170	79	(1,249)	944	2,114	(2,114)
Subtotal	73,160	61,723	60,622	1,101	11,437	17,408	78,030	(4,870)
Contingency	2,840	326	-	326	2,514	1,000	1,000	1,840
TOTAL	76,000	(A) 62,049	60,622	1,1427	13,951	18,408	79,030	(3,030)

NOTES: (A) Includes $293K for site acquisition, $15.7K for ECAC STudy, and $17.1K for NSF Ad Hoc Advisory panel.
(B) Estimate to complete is a of November 1978 and it excludes $172K for airstrip.
(C) Escalation included for future years for Site/Wye work (8%); NRAO labor (6%); and certain electronic elements (8%). Antenna estimate is based upon the existing contract costs for fabrication of the antennas.
(D) The antenna estimate includes $800K for Transporter No. 2.
(E) Allocated includes new funds received from the NSF in the amounts of $200K on Amendment No. 32 and $175K on Amendment No. 33.
(F) The above statement does not reflect the $3,700K advanced by the NSF for CY 1979 commitments and expenditures on Amendment No. 34 dated October 31, 1978.
(G) Allocated and Expended includes $5K in assets which were retired in prior years.

Exhibit 29

NATIONAL RADIO ASTRONOMY OBSERVATORY
VLA PROGRAM

NRAO-VLA COMMON COST BY YEAR
(in thousands)

Account No.	Description	1973	1974	1975	1976	1977	1978	1979	1980	1981	Total
	PLANT MAINTENANCE										
18915	Salaries					81	91	103	110		385
18925	Benefits					15	22	20	23		80
18935	Travel					1	1	3	2		7
18980	Misc. Material & Services					36	48	55	76		215
	TOTAL					775	913	1,093	1,237		4,018
	Distribution										
	Construction					644 83.10%	592 64.84%	463 42.36%	392 31.69%		2,091 52.04%
	Operations					131 16.90%	321 35.16%	630 57.64%	845 68.31%		1,927 47.96%

NATIONAL RADIO ASTRONOMY OBSERVATORY
VLA PROGRAM

NRAO-VLA EXPENDITURES BY YEAR
(in thousands)

SITE & WYE

Account No.	Description	1973	1974	1975	1976	1977	1978	1979	1980	1981	Total
11100	Land Acquisition							205			205
11101	Archaelogical Preserv.					95			3		98
11211	Preliminary Design	225									225
11212	Detailed Design	443	30		11		6	10			500
11213	Const. Supervision		30	51	14		31	12			138
11214	Survey/Soils	223	4	34	27		5	3	18		314
11240	Const. Site Prep	15	33	8	11	2		4	3		76
11241	Prefab Buildings			141	4						145
11242	Equipment/Construction			16	43	17		6	1	30	113
11243	Equipment/Track Vehicles				11	11	6	18	49	35	130
11250	Computer Site Trailer			36	1		4				41
11251	Visitors Center						1			25	26
11310	Roads & Parking			10	5	10	1	9	20	8	63
11320	Landscape & Sidewalks			169	44		10		8		231
11330	Water Supply			158	3		1		1		163
11340	Sewage Plant			114	1						115
11350	Telephone - Central Site						2				2
11360	Electric Service-Bldgs.			163	1	2	7	3	4		180
11361	Emergency Generator				9	76		3	9	75	172
11362	Fuel Facilities					10		8		8	26

NATIONAL RADIO ASTRONOMY OBSERVATORY
VLA PROGRAM

NRAO-VLA EXPENDITURES BY YEAR
(in thousands)

SITE & WYE

Account No.	Description	1973	1974	1975	1976	1977	1978	1979	1980	1981	Total
11410	Contr/Lab/Office Bldg.			1,506	28	10	1	3	2	7	1,557
11411	Contr. Bldg/Elec. Fac.				28	7	1				36
11412	Synchr. Motor Gen.				47						47
11420	Service-Maint. Bldg.				150				7		157
11421	Garage Building						16				16
11422	Cryogenic Facility						89				89
11430	Cafeteria			305	4		1				310
11440	VSQ 1,2 & 3				31	11	53		58		153
11450	Equipment/Furnishings			2	108	23	44	11	38	1	227
11451	Fire-Med-Safety Equipment						5	11	4		20
11460	Library/Office Bldg.						70		122		192
11461	Fire Sprinkler								77		77
11510	Earthwork/Drainage		195	3	524	8	801	1,461	1	4	2,997
11520	Trackage		290	761	1,588	381	1,678	1,515	948	24	7,185
11521	Legal Fees					50	9				59
11527	Wye Seeding Repair								1	75	76
11530	Foundations (antenna sta.)		131		811	5	791	39	20		1,797
11540	Elec. Distribution		1	73	470	1	227	261	166		1,199

NATIONAL RADIO ASTRONOMY OBSERVATORY
VLA PROGRAM

NRAO-VLA EXPENDITURES BY YEAR
(in thousands)

SITE & WYE

Account No.	Description	1973	1974	1975	1976	1977	1978	1979	1980	1981	Total
11550	Waveguide Procurement		60	1,114	413	1,100	741	1,291	17		4,736
11560	Waveguide Installation			116	134	284	388	261	170	34	1,387
11563	Cathodic Protection								18	79	97
11570	Waveguide Ant. Stations				121	81	127	41	11		381
11580	Telephone Dist.				76	54	46	94	26	3	299
11910	Salaries	31	57	85	114	44	48	55	64		498
11920	Benefits	5	12	18	24	8	10	10	13		100
11930	Travel	14	13	6	5	3	2	1	1		45
11931	Relocation				2						2
11940	Misc. Material & Services	8	20	33	12	10	7	6	1		97
11949	Spares						2	48		1	51
	TOTAL	964	876	4,922	4,875	2,303	5,231	5,389	1,881	409	26,850

Does not include 293K paid to Corps of Engineers for Site Acquisition

NATIONAL RADIO ASTRONOMY OBSERVATORY
VLA PROGRAM

NRAO-VLA EXPENDITURES BY YEAR
(in thousands)

ANTENNA DIVISION

Account No.	Description	1973	1974	1975	1976	1977	1978	1979	1980	1981	Total
12110	Antenna Design	225				5					230
12120	Antenna Fabrication		1,497	2,322	7,222	3,326	3,124				17,491
12121	Gross Receipts Tax					127					127
12130	Cryogenic Platforms					6	7	7			20
12140	Antenna Elec Install.					11	28	27	1		67
12160	Ant. Field Modifications				12	41	28	29	33	20	163
12161	Antenna Pointing Mods.									42	42
12210	Focusing Feed Mounts		86	121	122	200	213	229			971
12310	Antenna Assembly Bldg.		312	86	5			6	20		429
12410	Transporter Design		83								83
12420	Transporter Fabrication		311					789	1	35	1,136
12430	Transporter Assembly/Test			6	16	11	8	14	8	1	64
12431	Transporter Redesign					37					37
12510	Ant. Feed Structures		29	4	65	43	43	48			232
12610	Subreflector Support		12	7	28	17	15	17			96
12710	L-Band Feed Mount				11	8	7	8			34
12910	Salary	56	81	112	150	188	145	107	56		895
12920	Benefits	10	17	23	31	34	30	20	12		177
12930	Travel	5	19	14	13	9	10	11	6		87
12931	Relocation			11	1	10	2				24

NATIONAL RADIO ASTRONOMY OBSERVATORY
VLA PROGRAM

NRAO-VLA EXPENDITURES BY YEAR
(in thousands)

ANTENNA DIVISION

Account No.	Description-	1973	1974	1975	1976	1977	1978	1979	1980	1981	Total
12940	Materials & Services	20	8	33	36	29	39	19	11		195
12949	Spares						13	100	8	91	212
	TOTAL	316	2,455	2,739	7,712	4,102	3,712	1,431	156	189	22,812

NATIONAL RADIO ASTRONOMY OBSERVATORY
VLA PROGRAM

NRAO-VLA EXPENDITURES BY YEAR
(in thousands)

ELECTRONICS DIVISION

Account No.	Description	1973	1974	1975	1976	1977	1978	1979	1980	1981	Total
13010	Systems Development		13								13
13020	Test Equipment	46	45	69	51	44	40	40	19		354
13021	Test Units				17	5	3	33	16	1	75
13030	Racks	5	4	23	71	112	237	32			484
13040	D. C. Power		10	21	24	48	40	10			153
13050	Modules/Bins		35	67							102
13060	RFI Monrorino	49	24	7	3	4	6	7	1	1	102
13070	Lab Equipement	13	10	48	11	1	4	1	2		90
13080	Misc. Cable		4	13	55	18	3	4			97
13090	Weather Instruments		1	9	1		4	14	12		41
13110	F.E. Dev. Gen	70	46	48	19	14	4	39	12		252
13120	F.E. Dev. Cryogenic	27	18	33	4	4	10	4	4		104
13130	Cryogenic System		50	104	104	92	248	134	16		748
13140	Parametric Amplifiers		66	119	77	93	110	143	11	4	623
13150	Upconverters		33	49	61	86	220	6	21		476
13160	1.3 & 2.0 cm LO		10	25	33	34	39	19	6	71	237
13170	RF Components		23	73	99	104	158	131	19	7	614
13180	Frequency Upconverters		32	15	21	29	18	128	39	1	283
13190	F.E. Filter Unit					30	201	100	17		348

NATIONAL RADIO ASTRONOMY OBSERVATORY
VLA PROGRAM

NRAO-VLA EXPENDITURES BY YEAR
(in thousands)

ELECTRONICS DIVISION

Account No.	Description	1973	1974	1975	1976	1977	1978	1979	1980	1981	Total
13210	L.O. Development	33	20	4	29	10	2	5	6		104
13220	Master L.O.		21	18	16	26	11	5	15	2	114
13230	Slave L.O.		16	62	57	174	146	8	3		466
13240	L.O. Corrector		12	18	39	67	87	2			225
13250	2.4 GHz Synthesizer		30	20	28	49	57	6			190
13310	Waveguide Genl. Dev.	17	2	17	25	6	15	11	3		96
13320	Waveguide Install Dev.	66	10	15	31	16	19	2	2		161
13330	Waveguide Test Set	45	3	14	19	24	20	5		14	144
13360	Antenna Coupler W.G.		25	7	99	46	69	7			253
13410	I.F. Development		5	80							85
13420	Modem Development	52	23	10	2	3	6	1			97
13430	I.F. Receiver	11	3	3							17
13440	Modems		86	114	178	172	332			1	883
13450	I.F. Receiver		16	24	28	38	12	3			121
13460	Signal Dist.			150	1	1	4	1			157
13470	Data Modems			1							1
13510	Delay/Multi System	7	14	1							22
13520	Sampler System	3	8	3	9	13	10	11	19		76
13530	Delay System	16	31	44	10						101
13540	Multiplier System	5	24	75	2	4					110

NATIONAL RADIO ASTRONOMY OBSERVATORY
VLA PROGRAM

NRAO-VLA EXPENDITURES BY YEAR
(in thousands)

ELECTRONICS DIVISION

Account No.	Description	1973	1974	1975	1976	1977	1978	1979	1980	1981	Total
13610	Feed System Develop.		80	1	50	2	1	3			137
13620	Subreflector		15	13	17	33	62	3			143
13630	Calibration Components		9	9	20	34	12	46			130
13640	Feed Deicer		1	8				10	1		20
13650	Dieroic Ref.		4								4
13660	18-21 cm Feed		38	5	80	121	156	54			454
13670	6 cm Feed		16	1	61	34	84	8			204
13680	2 cm Feed		13		41	27	67	7			155
13690	1.25 cm Feed		10		43	28	68	8			157
13710	Monitor Control Devel.	74	9	2							85
13720	Monitor Control Mod.		3	42	67	90	77	41	40	11	371
13730	Display Equipment		5	18	2				26	2	53
13740	Focus/Polar Drive		7	24	27	43	74	16	8	1	200
13810	Spec Proc/I.F. Dev			4		4	9	1			18
13820	Spec Proc/I.F. System						16	381	39	18	454
13830	Spec Proc Delay Dev.				16	89	1	1			107
13840	Spec Proc Delay Sytem					321	23	142	14		500
13850	Spec Proc Control Inter				9	3	1	1			14
13860	Spec Proc Control Inter				3	216	12	70			301

NATIONAL RADIO ASTRONOMY OBSERVATORY
VLA PROGRAM

NRAO-VLA EXPENDITURES BY YEAR
(in thousands)

ELECTRONICS DIVISION

Account No.	Description	1973	1974	1975	1976	1977	1978	1979	1980	1981	Total
13910	Salaries	185	312	466	582	614	653	431	321	21	3,585
13920	Benefits	34	64	97	120	112	136	83	67	7	720
13930	Travel	12	28	29	25	32	40	16	10		192
13931	Relocation			35	28	16	5	15	10		109
13940	Misc. Material & Services	51	70	138	96	99	133	87	26		700
13949	Spares						37	229	41		307
	TOTAL	821	1,457	2,295	2,511	3,285	3,802	2,565	846	162	17,744

Does not include 15.7K for ECAC Study.

NATIONAL RADIO ASTRONOMY OBSERVATORY
VLA PROGRAM

NRAO-VLA EXPENDITURES BY YEAR
(in thousands)

COMPUTER DIVISION

Account No.	Description	1973	1974	1975	1976	1977	1978	1979	1980	1981	Total
14110	Synchronous Subsystem		246		21	51		17	12	15	362
14112	Synchronous Repair Sys.					96	1				97
14210	Cont Asynch Subsystem			871	19	88		15	17	12	1,022
14212	Interface Equipment				7	3	13	3	15		41
14213	DEC-10 Upgrade								21	843	864
14220	Display 1.0 Equipment			33	88	59	89	34		15	318
14221	Map/Image Processor							331	57	64	452
14240	Spectral Line System					212	304	376	93	261	1,246
14241	Optical Proc. Devel.				95	2					97
14243	Mass Store								99		99
14244	Observor Image Proc.								11	5	16
14910	Salaries	22	82	200	228	183	89	88	127	60	1,079
14920	Benefits	4	17	42	47	33	19	16	26	18	222
14930	Travel	3	10	14	14	8	2	3	10		64
14931	Relocation			10	30	3		2	21		66
14940	Misc. Material & Supplies		58	71	50	24	16	10	14		243
14950	Computer Maintenance			48	62	19	8	9	3		149
	TOTAL	29	413	1,289	661	781	541	904	526	1,293	6,437

NATIONAL RADIO ASTRONOMY OBSERVATORY
VLA PROGRAM

NRAO-VLA EXPENDITURES BY YEAR
(in thousands)

SYSTEMS INTEGRATION

Account No.	Description	1973	1974	1975	1976	1977	1978	1979	1980	1981	Total
16910	Salaries			27	48	37	19				131
16920	Benefits			6	10	6	4				26
16930	Travel		1	2	1	2	6				12
16931	Relocation			5	2	5					12
16940	Misc. Material & Services			6	18	2	(6)				20
	TOTAL		1	46	79	52	23				201

NATIONAL RADIO ASTRONOMY OBSERVATORY
VLA PROGRAM

NRAO-VLA EXPENDITURES BY YEAR
(in thousands)

PROGRAM MANAGEMENT

Account No.	Description	1973	1974	1975	1976	1977	1978	1979	1980	1981	Total
17100	Transportation				97						97
17200	Support Services				67						67
17300	Utilities				97						97
17910	Salaries	109	147	206	276	70	77	76	66	15	1,042
17920	Benefits	20	31	43	58	13	16	15	14	5	215
17930	Travel	13	23	18	14	7	7	6	3	2	93
17931	Relocation			18	3	3					24
17940	Misc. Material & Supplies	17	35	216	64	5	11	7	27	12	394
17950	Freight In				14						14
17960	Discounts				(12)						(12)
17951	Freight Out				1						1
17942	Legal Fees						1	2	2		5
17941	Empl Termination Costs									80	80
	TOTAL	159	236	501	679	98	112	106	112	114	2,117

Does not include 17K to NSF Ad Hoc Advisory Panel.

NATIONAL RADIO ASTRONOMY OBSERVATORY
VLA PROGRAM COMPLETION REPORT

FIXED ASSETS

Account Number	Item	Amount
Research Facilities		
12401	Test Equipment	$371,922
12411	Research Equipment	50,618
12438	VLA Antenna Systems-structures	20,870,053
12439	VLA Antenna Systems-electrical	73,067
12440	General Electronics	1,852,007
12441	Front Ends	6,176,013
12442	L.O. System	1,870,133
12443	I.F. Transmission	2,345,660
12444	Delay/Multiplier System	525,811
12445	Feed System	2,432,679
12446	Monitor/Control System	1,170,575
12447	Spectral Processor	2,362,699
12499	Antenna Design Studies	229,857
	Sub-total	40,331,094
Operating Equipment		
12502	Shop Maintenance	172,352
12503	Special for Telescopes/Shop	3,747
12504	Safety Equipment	23,808
12507	Automotive/Site	275,796
12508	Automotive/Special	55,359
12511	Office Machines, Furniture & Fixtures	307,487
12541	Engineering Equipment	41,510
12542	Photographic Equipment	4,502
12543	Scientific Computer System	6,066,948
12544	Rail Vehicles	1,514,194
	Sub-total	8,465,703

Other VLA

12401	Land	$205,448
12602	Land Improvements	180,685
12603	Paved Areas, Roads, Walks	129,818
12604	Site Development	1,386,800
12605	Electrical Distribution System	448,821
12606	Water & Sewer	309,763
12607	Buildings	3,284,484
12608	Other Structures	9,385
12609	Railroad Track & Bed	10,621,048
12611	Antenna Foundations	2,948,327
12612	Waveguide	7,264,648
12613	Wye Communication System	311,706
12675	Other	10,094
	Sub-total	27,111,027
Total Construction Transferred to Fixed Assets		$75,907,824

Construction in Progress

1977 Gross Receipts Tax	$127,123	
1981 Site/Wye Division	409,404	
1981 Antenna Division	188,721	
1981 Electronics Division	162,520	
1981 Computer Division	1,284,323	
1981 Program Management	113,295	
Total Construction in Progress at 1/1/81		$2,285,386
Assets Donated by Various Governmental Agencies		(9,000)
Assets Retired Prior to Completion of Program		67,979
Total Allocated to NRAO		$78,252,189
Expenditures Paid Directly by the NSF:		
Land Acquisition	$293,000	
ECAC Study	15,700	
Ad Hoc Advisory Panel	17,111	
Sub-total		$325,811
Total Appropriation for Very Large Array		$78,578,000

NATIONAL RADIO ASTRONOMY OBSERVATORY
VLA PROGRAM COMPLETION REPORT

ANALYSIS OF VLA DOWNTIME

1980

Item	January	February	March	April	May	June
HARDWARE						
F.E.	12.5%	12.23%	6.71%	8.8%	5.6%	9.00%
LO/IF	.5	.03	.22	.4	.6	.90
DCS	.1	.01	.32	-	.1	.04
F/R	1.7	.41	.59	.1	.3	.60
DL/M	-	.10	.29	3.5	-	.01
Cryogenics	.1	.23	.31	-	.2	.05
Antennas	.1	.02	.64	1.9	1.0	1.10
Waveguide	-	-	-	-	-	-
Computer	.4	-	-	-	.3	-
Sub-total	15.4%	13.0%	9.1%	14.7%	8.1%	11.7%
Computer Software	1.3%	1.8%	1.4%	1.9%	1.7%	1.8%
Weather	-	1.6%	0.5%	-	1.1%	-
Electric Power	.5%	-	0.6%	.01%	0.3%	2.6%
TOTAL	17.2%	16.4%	11.6%	16.7%	11.2%	16.1%
Downtime Excl Long-term problems	-	6.3%	6.1%	8.6%	5.9%	8.5%
No. of Antennas	20	22	22	23	23	24
Scheduled Up-time	54%	57%	61%	57%	66%	64%

Exhibit 32

ANALYSIS OF VLA DOWNTIME

1980

Item	July	August	September	October	November	December
HARDWARE						
F.E.	3.0%	1.6%	1.9%	3.0%	2.9%	2,1%
LO/IF	.6	.9	.3	.6	.3	.2
DCS	.2	–	–	–	–	–
F/R	1.4	1.6	.4	.1	.2	.1
DL/M	–	.2	–	–	–	.1
Cryogenics	–	–	–	–	.1	.1
Antennas	.4	.6	.9	.5	.4	.8
Computer	–	1.6	–	.9	–	–
Sub-total	5.6%	6.5%	3.4%	5.3%*	3.9%	3.4%
Computer Software	1.7%	3.1%	3.1%	2.8%	1.1%	2.1%
Weather	–	–	–	–	–	–
Electric Power	0.3%	.3	–	2.1%	–	0.1%
TOTAL	7.6%	9.9%	6.5%	10.2%	5.0%	5.6%
Downtime Excl Long-term problems	5.5%	8.5%	5.3%	7.9%	2.6%	3.8%
No. of Antennas	24	25	25	26	25	26
Scheduled Up-time	36%	43%	54%	36%	44%	60%

* Inc. 0.1 Wye Com.

NATIONAL RADIO ASTRONOMY OBSERVATORY
VLA PROGRAM COMPLETION REPORT

REFERENCES

Reference Number	
1	The Very Large Array - D. S. Heeschen, National Radio Astronomy Observatory published in Sky & Telescope Vol. 49, No. 6, June 1975
2	The Very Large Array - D. S. Heeschen, National Radio Astronomy Observatory. Telescopes for the 1980's, Astronomical Review Monograph, 1981, pp 1-61.
3	The Very Large Array - A. R. Thompson, B. G. Clark, C. M. Wade and P. J. Napier, 26 December 1979 as published in The Astrophysical Journal Supplement Series 44-151-167, October 1980
4	Site Development and Facilities Requirements for the Very Large Array Limbaugh Engineers, Inc., November 1966
5	Site Development and Facilities Requirements for the Very Large Array Limbaugh Engineers, Inc., December 1969
6	A Proposal for A Very Large Array Radio Telescope, The VLA Concept, January 1967, Volume I
7	A Proposal for A Very Large Array Radio Telescope, System Design, January 1967, Volume II
8	A Proposal for A Very Large Array Radio Telescope, An Update of Work Accomplished Since January 1967, January 1969, Volume III
9	A Proposal for A Very Large Array Radio Telescope, The Site, Volume IV
10	A Proposal for A Very Large Array Radio Telescope, The San Augustin Site, Volume IVA
11	"Final Environmental Statement - Very Large Array", The National Science Foundation, August 1, 1973.
12	"VLA Feasibility Study" by the Stanford Research Institute dated February and March 1972 Part One - A Summary Part Two - The Report Part Three - Technical Memoranda

13 VLA Project Plan - CY 1973 - National Radio Astronomy Observatory October 30, 1972

14 VLA Project Plan - CY 1974 - National Radio Astronomy Observatory December 1, 1973

15 VLA Project Plan - CY 1975 - National Radio Astronomy Observatory November 15, 1974

16 VLA Project Plan - CY 1976 - National Radio Astronomy Observatory December 1, 1975

17 VLA Program Plan - CY 1977 - National Radio Astronomy Observatory December 1, 1976

18 VLA Program Plan - CY 1978 - National Radio Astronomy Observatory December 1, 1977

19 VLA Program Plan - CY 1979 - National Radio Astronomy Observatory December 1, 1978

20 VLA Program Plan - CY 1980 - National Radio Astronomy Observatory November 1, 1979

21 "The Ake Site: Collection and Excavation of LA13423, Catron County, New Mexico": Patrick H. Beckett, New Mexico State University, Report 357, June 1980

22 Real Estate Planning Report, Corps of Engineeers December 5, 1972

23 "RFP-VLA-01 Antenna Procurement - Contract Selection Committee" - Final Report, July 30, 1973

24 "Title I Design Report - Very Large Array Project", BWH/CVR Joint Venture, February 1, 1974

25 "Assessment of Direct Burial Methods for 60mm Waveguide" - VLA Installation", Bechtel, Inc., October 1973

26 "Davis-Bacon Determination for the VLA Project", NRAO-VLA staff paper, October 7, 1974

27 "Report of the Ad Hoc Advisory Panel for the Very Large Array (VLA)" National Science Foundation, December 31, 1977

28 "Report on Audit - Very Large Array Radio Telescope Project - National Radio Astronomy Observatory", NSF Staff Report May 4, 1977

29 "Corrosion Survey National Radio Astronomy Observatory Underground Waveguide, VLA Site", Pacific Corrosion Research. Inc. March 1981