PLAN

for a

RADIO ASTRONOMY OBSERVATORY

prepared for

NATIONAL SCIENCE FOUNDATION

August 1956

Associated Universities, Inc.
New York, New York

PLANNING DOCUMENT

FOR THE

ESTABLISHMENT AND OPERATION

OF A

RADIO ASTRONOMY OBSERVATORY

Prepared for

THE NATIONAL SCIENCE FOUNDATION

by

Associated Universities, Inc.

New York, New York

1956

This is a general report on work done under NSF Grants 1415 and 2035. Additional reports on specific problems will be prepared as the study proceeds.

Printed in United States of America

DESIGNED AND PRODUCED BY
CORYDON M. JOHNSON CO., INC., BETHPAGE, L. I., N. Y
LITHO IN U. S. A.

TABLE OF CONTENTS

List of Illustrations . . . iii
Introduction . . . v
Bibliography . . . ix

Chapter One
RADIO ASTRONOMY IN THE UNITED STATES

I. The Development of Radio Astronomy . . . 1
II. The Need for a Radio Astronomy Observatory . . . 1
III. Research Objectives . . . 2
IV. Conclusion . . . 4

Chapter Two
HISTORY OF THE RADIO ASTRONOMY PROJECT

I. Associated Universities, Inc. . . . 7
II. The First Phase . . . 7
III. Specific Plans . . . 10
IV. Summary . . . 12

Chapter Three
THE SITE

I. Specifications . . . 15
II. The Search Area . . . 16
III. The Search Procedure . . . 18
IV. Selecting the Most Promising Sites . . . 20
V. Recommendations . . . 25
VI. Summary . . . 29

Chapter Four
EQUIPMENT

I. Basic Equipment 31

II. The 140-Foot Radio Telescope Program 32

III. A Possible Radio Telescope Program 39

Chapter Five
SITE DEVELOPMENT

I. The Hypothetical Development 41

II. The Green Bank Development 41

III. The First Construction Phase 42

IV. Hypothetical Growth 55

Chapter Six
SUGGESTED ORGANIZATION

I. The Staff 57

II. The Basic Structure 59

III. Initial Budget for the Observatory 59

IV. Estimated Construction Budget 59

V. Estimate for the Fourth Year of Operation 60

Chapter Seven
PERSONNEL POLICIES AND PROCEDURES

I. Personnel Policies 61

II. Other Procedures 61

LIST OF ILLUSTRATIONS

Figure No.		*Page*
III-1	Tracks of all Tornadoes—1916—1950	17
III-2	Histogram of Noise Measurements at Massanutten Site Week-Day October, 1955	21
III-3	Histogram of Noise Measurements at Green Bank Site Week-Day October, 1955	21
III-4	Existing or Planned Commercial Communication Links in the Area Containing Five Possible Sites	24
III-5	Map of Eastern United States Showing the Location of Five Sites and the Airline Distance From Site 18 to Colleges, Universities and Major Cities	26
III-6	Photograph of Army Map Service three-dimensional model of part of Search area	27
III-7	Portion of U. S. Geological Survey Map of the Cass Quadrangle in West Virginia Showing the Green Bank Valley	30
III-8	Air Photograph of the Green Bank Valley	30
IV-1	General View of the 140-foot Altazimuth Radio Telescope Design Proposed by Dr. Jacob Feld of New York City	34
IV-2	Side Elevation of Feld Radio Telescope	35
IV-3	Cross-Section of Reflector, Ring Girder, and Truss and a Front Elevation of the Feld Design	35
IV-4	Four Drawings by Husband & Company of Sheffield, England for the proposed 140-foot Altazimuth Telescope Design. The two end elevations show the reflector pointed to the Zenith and Horizon. The front elevation again shows the reflector pointing to the Zenith. The Plan View shows the quadrapole support for the antenna feed	36
IV-5	General side elevation of 140-foot altazimuth telescope proposed by D. S. Kennedy Company of Cohasset, Massachusetts	37
IV-6	Rear Elevation of Kennedy Design showing truss structure of the reflector	37
IV-7	Cut-away view of Kennedy Design showing the torque tube connecting the altitude gear sectors	37
V-1	General Site Development Plan as Prepared by Eggers & Higgins Architects of New York City	43
V-2	Detailed Site Development for a portion of the area that would contain the Central Laboratory Building and other proposed structures such as Residential Buildings, Main Buildings and Individual Residences, as Prepared by Eggers & Higgins Architects of New York City	44
V-3	Central portion of the proposed Administration Building and Laboratories as Prepared by Eggers & Higgins Architects of New York City	45
V-4	First Floor Plan of Proposed Administration Building and Laboratories as Prepared by Eggers & Higgins Arcnitects of New York City	46

LIST OF ILLUSTRATIONS (Continued)

Figure No.		*Page*
V-5	Basement and Second Floor Plans of the Administration Building and Laboratories as Prepared by Eggers & Higgins Architects of New York City	47
V-6	Elevation of the Proposed Administration Building and Laboratories as Prepared by Eggers & Higgins Architects of New York City	48
V-7	Plan and Elevation for the Proposed Residence Hall and Cafeteria as Prepared by Eggers & Higgins Architects of New York City	49
V-8	Plan and Elevation for the Proposed Site Maintenance Building as Prepared by Eggers & Higgins Architects of New York City	50
V-9	Plan and Elevation for the Proposed Radio Telescope Maintenance Building as Prepared by Eggers & Higgins Architects of New York City	51
V-10	Plan and Elevation for the Proposed Electric Generator Building as Prepared by Eggers & Higgins Architects of New York City	52
V-11	Plan and Elevation for the Proposed Control Building for the 60-foot or 140-foot Radio Telescopes as Prepared by Eggers & Higgins Architects of New York City	53

INTRODUCTION

Among all the sciences, astronomy has been recognized since the beginnings of civilization as one of the most important basic factors in the development of human thought. The study of astronomy has helped to dispel man's dependence on magic and superstition, by explaining the nature of the universe around him; it has helped to unchain his mind, and to direct his imagination into useful and creative channels. Plato observes that astronomy is a science in which the leaders of his state must be proficient, in order that their culture may be suitably oriented.

But beyond its contributions to man's culture, the study of astronomy has provided much of the basic foundation for the engineering and mechanics that have made our civilization possible. Only after the telescope had been invented, and the motions of the stars and planets clearly observed, did man definitely formulate the basic laws of mechanics. The work of Galileo and of Newton, expounding the laws of falling bodies, of gravitation, and of motion, all clearly derived from the study of the motions of the heavenly bodies. The laws of motion and of gravitation were closely associated with the development of astronomy.

More recently, the sciences of astrophysics and of nuclear physics, developing simultaneously, have continuously interacted to stimulate a tremendous growth in man's understanding of the fundamental structure of the universe.

The discovery in our own generation that radio waves can be received from outer space adds enormously to the potential contribution of astronomy. While the window through which visible astronomy can work through the atmosphere is open to scarcely two octaves of radiation, the radio window is open for wavelengths substantially from 20 meters to one-half centimeter, or more than twelve octaves. Moreover, radio waves bring to the Earth an entirely new set of clues to the nature of the surrounding universe.

Radio astronomy makes possible the view of extragalactic nebulae in a new spectrum of radiation to see new aspects of those island galaxies. How far man may extend his vision in the Universe with this new tool is suggested by Sir Edward Appleton, in his Presidential address before the British Association (1953). "The radio-telescope has therefore shown itself to be an important adjunct to the world's greatest optical telescope. But, in addition, there is a further and far-reaching possibility. It is the astronomer's ideal to reach, with optical ranging, the hypothetical limit of the expanding universe, the distance where the extragalactic nebulae are receding from us with the velocity of light. So far he has reached very approximately halfway. But the fact that, already, the second most intense radio source can be detected without difficulty at a distance equal to one-tenth of the maximum distance plumbed by the 200-inch telescope suggests that it may, in time, be possible to detect sources at greater distances by radio than by optical means."

Radio astronomy makes it possible for us to measure the concentrations and motions of hydrogen gas in interstellar space and to relate these data to visible stars. It provides a means of seeing through the great dust clouds of space to determine the structure behind them, now obscured from visual observation. With large telescopes, radio astronomy promises to provide a far clearer description of the structure of galaxies than that given by visual astronomy alone. Radio astronomy is a powerful tool in the study of the physical processes of the Sun, and of their interaction with the Earth. Above all, it calls attention to those special objects in the sky which may make clear the processes involved in the creation or destruction of stars and illuminate other critical aspects of the material universe.

The application of radio astronomy to the study of our planetary system has hardly begun, but already, the discovery of radio noise from Jupiter has not only disclosed unsuspected physical properties of that planet, but has also revealed the most important naturally occurring source of terrestrial high frequency radio noise other than very local thunderstorms. "Active" radio astronomy, which uses radar-type techniques with large telescopes, offers a true experimental approach to our knowledge of the solar system.

Radio astronomy intimately concerns the study of our outer atmosphere and of the space immediately surrounding the earth. The observed scintillations of the radiation from radio stars provide direct evidence of the turbulence and winds in the upper atmosphere. By observing radiation reflected from the Moon, we can ascertain the total of ionized matter in the vicinity of the earth, and its variation. Similarly, the extension of the solar corona and its variation in the vicinity of the earth's orbit can be measured. The possibility exists that with "active" radio astronomy, or perhaps even with passive methods using large telescopes, we can detect particle streams as they traverse the space from the sun to the earth, or the formation of "ring currents" that circle the earth, several earth's radii from its surface.

In the case of optical astronomy, the efforts to create improved optical systems for telescopes have yielded innumerable practical applications in general optics for the benefit of society. In the same way, radio astronomy applies to electronics, a science at the very vanguard of our knowledge. Electronics has already greatly benefited from research designed to produce more sensitive detection devices to widen the scope of radio astronomy. This new science will undoubtedly stimulate instrumental research, and thus increase the potential advances of electronics and radar.

It is never possible to predict the benefits that will accrue from vigorous support of a virile science such as radio astronomy. But the whole long history of astronomy supports our conviction that the development of radio astronomy will produce, inevitably, concurrent developments of major benefit to mankind. These may come from almost any aspect of research since the science is most basic. The increasing of man's knowledge of the sun, and of the space through which the earth courses, may lead to understanding of our climatic changes and of weather phenomena. The study of star formation or destruction may answer questions involving basic nuclear reactions and the energy derived therefrom. Moreover, an exact knowledge of the universe, expressed in precise physical terms, could yield altogether new and productive concepts of the general organization and origin of matter.

But aside from any immediate benefits that may accrue from such research, strong support of radio astronomy will achieve the major goal, the growth of knowledge, and an essential addition to our total store of scientific understanding. The greatest discoveries in science could well be blocked by ignorance in any one basic field, such as astronomy. The potentially great benefits of science and their application to the problems of man can be achieved only when we have access to the whole store of knowledge, and can completely comprehend the fundamental laws of nature.

In proposing the creation of a Radio Astronomy Observatory, astronomers envisage the very best of large telescopes and instrumentation to supplement their own facilities—facilities that are now beyond their reach. Elsewhere, scientists have taken vigorous steps to provide themselves with more adequate instrumentation. In Great Britain, Lovell, and his colleagues, are now completing a 250-foot steerable paraboloid that will provide great versatility in the radio exploration of the universe. In the Netherlands, Oort, Van der Hultz, and their colleagues are now working with an 80-foot radio telescope that was completed last year. Active planning is under way in Australia, by E. G. Bowen, and his colleagues, for a large steerable radio telescope. Australia does have, of course, the great opportunity for observing the Southern skies. The Soviet Union is sponsoring two extensive facilities, one at Gorky and one in the Crimea.

To share in these challenging opportunities for work in radio astronomy and to provide means of observation comparable to those of our colleagues elsewhere, American radio astronomers have been actively studying desirable methods of providing more adequate tools in the United States. Basically, the proposed Radio Astronomy Observatory would serve as a place where the most advanced radio telescopes and equipment could be conveniently available to radio astronomers under the most favorable seeing conditions. The example of the National Laboratories of the Atomic Energy Commission has demonstrated the effectiveness of very large and unique instrumentation, made available to the scientific community, and has shown that such a procedure is economical and highly productive. The support of a radio astronomy facility seems to offer the one way whereby radio astronomers in this country can have access to large telescopes and facilities and the one way that radio astronomy in America can maintain its place in the vanguard of the science.

In attempting to deal with this problem, astronomers have considered in detail various solutions, largely along three lines.

1. The provision of radio telescopes of moderate size at private radio astronomy laboratories. This includes, for example, the 60-foot Harvard telescope; the California Institute of Technology twin 90-foot telescopes; and the 84-foot telescopes at the new station of the Naval Research Laboratory and under consideration by the Department of Terrestrial Magnetism of the Carnegie Institution of Washington, coupled with large-scale arrays such as the Mills Cross. In addition, at least two universities are now contemplating development of department activities in radio astronomy by using smaller instruments.

2. The construction of a survey telescope having a knife-edge beam, such as that proposed by John Kraus at Ohio State University.

3. The establishment of a Radio Astronomy Observatory where large steerable paraboloids, arrays, and special antennas can be erected for cooperative use of radio astronomers generally. Since the facility would be designed to make available equipment that is not feasible at the several individual locations, emphasis would be directed to big reflectors and antennas. The planning of such a facility to supplement smaller activities has not only evoked the enthusiasm of many of the present researchers in the field, but it has also played an important role in stimulating new activities at universities such as Yale and Pennsylvania.

The concept of the Radio Astronomy Observatory grew out of two conferences, one held in Washington under the sponsorship of the National Science Foundation, the Carnegie Institution of Washington, and the California Institute of Technology in January 1954, when the needs and objectives for large-scale instruments on the American scene were outlined. In the discussion following this conference, Associated Universities, Inc. was asked by a group of scientists from Harvard, MIT, and the Naval Research Laboratory, at the suggestion of Julius Stratton, to act on their behalf in exploring, with the National Science Foundation, the feasibility of a radio astronomy facility that might supplement the equipment at their individual laboratories. These ideas were formulated more sharply at a second conference held in New York on May 22, 1954, which led to the request for the initial grants from the National Science Foundation under which the present studies have been undertaken.

In carrying out this study, AUI has assembled a group of distinguished radio astronomers to provide advice and guidance at each stage of development. Under this group, known as the Advisory Committee, the study looking to the establishment of a facility has been divided into three major parts:

1. Studies of the design and limiting characteristics of the large steerable radio telescopes.

2. A search for and the selection of a suitable site with the preparation of a plan for its development.

3. The organization of such a facility.

The report that follows summarizes a multitude of intervening technical reports of various aspects of the study, leading to the present status of the plans.

Because of radio astronomy's fundamental nature and far-reaching possibilities, we urge the establishment of a Radio Astronomy Observatory to provide American science with the means and the tools to press our knowledge of the universe to the limits of our capabilities. The planning has now proceeded to the point where only vigorous action is needed to create a Radio Astronomy Observatory.

BIBLIOGRAPHY

1. Memorandum, dated March 8, 1955, Subject: Large Radomes.

2. Memorandum, dated March 21, 1955, Subject: Site Study—March 10 Meeting, AUI Ad Hoc Panel.

3. Agenda, Meeting AUI Steering Committee, March 26, 1955.

4. Minutes, Steering Committee for the Radio Astronomy Facility Study, Saturday, March 26, 1955; Site maps; Report by Dr. Hagen to the Interdepartmental Radio Advisory Committee.

5. Letter, dated May 6, 1955, from Richard M. Emberson to Dr. Raymond J. Seeger, Assistant Director, National Science Foundation.
   Attachments: Appendix A (Research Objectives for Large Steerable Paraboloid Radio Reflectors, A Report Prepared by A Panel of Associated Universities, Inc., dated May 6, 1955); Appendix B (On the Need for A Radio Astronomy Program in the United States); Appendix C (Organization of A National Facility for Radio Astronomy Research); Feasibility Report for the National Science Foundation Regarding Site Development and Building Requirements for A National Radio Astronomy Facility by Eggers and Higgins, Architects (dated May 5, 1955).

6. Request for A Bid Proposal to Furnish A 140-foot Radio Telescope, dated May 28, 1955.

7. Agenda for May 28, 1955 Meeting of the Steering Committee for the Radio Astronomy Facility Study.

8. Minutes, Steering Committee for the Radio Astronomy Facility Study, Saturday, May 28, 1955 (dated June 14, 1955).
   Attachment: Appendix 4A, dated May 13, 1955 (Memorandum to All Users of Frequency Bands for Radio Astronomy, from John P. Hagen).

9. Memorandum, dated June 21, 1955, from Richard M. Emberson to Members of the Steering Committee. Subject: Arrangements for the Monday-Tuesday, July 11-12 Meeting at Brookhaven National Laboratory.
   Enclosure: Copy of letter dated June 14, 1955 to Federal Communications Commission re: Radio Astronomy Frequency Requirements.

10. Folder for July 11-12, 1955 Steering Committee Meeting at the Brookhaven National Laboratory, containing the following:
   Agenda, July 11, 1955.
   Memorandum dated April 6, 1955 from M. E. Smith, Brookhaven National Laboratory. Subject: Variation of Winds with Height.
   Agenda, July 12, 1955, with the following attachments:
      Attachment A-1 (List of companies contacted concerning the design and construction of a 140-foot radio astronomy telescope and design studies for larger (300-, 450-, and 600-foot) sizes.
      Responses from the following Companies:
         American Machine & Foundry Co., dated July 8, 1955
         Bethlehem Steel Co., dated June 20, 1955
         Goodyear Aircraft Corporation, dated July 5, 1955
         Gray Scientific Division, Remler Co., dated July 5, 1955
         Husband & Co., dated June 8, 1955
         Husband & Co., dated July 4, 1955
         Sandberg-Serrell Corporation, dated July 7, 1955
      Appendix A-II (Advance Report on the Study of the Grote Reber Design for A Radio Telescope; "Cost Estimate, Mirror Design of 1948-49", by Grote Reber).

Attachment A-V (Site Survey Status Report).
Attachment A-VI-1 (Proposed Operating Budgets and Study Fund, October 1, 1955 to June 30, 1956).
Attachment A-VI-2 (Information from other observatories on staffs and operating budgets: Letter dated June 22, 1955 from Hamilton M. Jeffers, Lick Observatory; Letter dated June 22, 1955 from A. B. Meinel, Yerkes Observatory).
Attachment A-VI-3 (Budget Estimates, Other than Salaries & Operating Expenses, for the National Radio Astronomy Facility for FY 1957-60).

11. Minutes Steering Committee for the Radio Astronomy Facility Study, Monday-Tuesday, July 11-12, 1955, dated July 27, 1955.
Attachments: 600-foot Feasibility Study by Dr. Jacob Feld (in 2 parts); Letter dated July 18, 1955 from Richard M. Emberson to Dr. Raymond J. Seeger, Assistant Director, National Science Foundation with the following attachments:
Attachment A-1 (Budget Estimates for Facility Feasibility Studies to Continue in the Period October 1955-June 1956).
Attachment A-2a (Budget Estimates for the Establishment of the National Radio Astronomy Facility, Capital Funds for FY 1957 (July 1956)).
Attachment A-2b (Breakdown of Estimates on Minimal First Step of Site Development & Buildings).
Attachment A-3 (Budget Estimates for Minimal Salaries and Other Operating Expenses at the National Radio Astronomy Facility, FY 1957-60, Inclusive).
Attachment A-4a (List of companies contacted concerning the design and construction of a 140-foot radio astronomy telescope and design studies for larger (300-, 450-, and 600-foot) sizes.
Attachment A-4b (Letter to Companies Participating in the Requests for Proposals in the 140-foot Radio Astronomy Telescope).
Attachment A-5 (Site Survey Status Report).

12. Memorandum dated July 29, 1955 from Richard M. Emberson to Mr. Paul Kratz, National Science Foundation. Subject: Proposal on Radio Astronomy.
Attachment: Research Proposal to the National Science Foundation for a Grant in Support of a Program for the Establishment of a National Radio Astronomy Facility by Associated Universities, Inc. (dated July 29, 1955), with Appendix A attached (Budget Estimates for a Program for the Establishment of a National Radio Astronomy Facility, in the Period October 1955-June 1956).

13. Memorandum dated August 31, 1955, Subject: Distribution of Record of Symposium on Radio Astronomy Telescopes.
Attachments: Record of an Informal Symposium on Radio Astronomy Telescopes, Radomes, and Related Matters, March 25, 1955, with the following Appendices:
A-2-1 Summary Notes on Air-Supported Radomes.
A-4-1 M. B. Karelitz' Comments on the 250-foot Radio Astronomy Telescope at Jodrell Bank.
A-4-2 Portion of Initial Specification for the British Radio Telescope.
A-7-1 Bell Tel. Lab. Photo of a 60-foot Parabolic Reflector.
A-7-2 Bell Tel. Lab. Memo on the Effective Area of a Square Aperture.
A-7-3 Bell Tel. Lab. Sketch of a 300-foot Design.
A-8-1 Van Atta's 250-foot Design.
A-9-1-6 Charts—L. C. Van Atta.
A-10-1 "75 Mc and 400 Mc Dipole Linear Array Costs".
A-11-1 "Honeycomb Antenna for Radio Astronomy"—R. H. Dicke.
A-12-1 B. G. Hooghoudt's letter on the Design of the 25-meter Radio Telescope at Dwingeloo, Holland.
A-13-1 Sketches of Design discussed by W. W. Salisbury.
A-14-1 "Large Mirror Design"—Grote Reber.

A-15-1 Letter—R. B. Fuller.

A-15-2 Letter to Encyclopedia Britannica and to Gen. Watson, USAF.—R. B. Fuller

A-15-3 "Industrial Logistics and Design Strategy"—*Pennsylvania Triangle.*

A-15-4 R. B. Fuller Photographs of Models.

A-16-1 "Notes on the Stability of Reflectors"—D. D. Jacobus.

14. Memorandum dated September 8, 1955, Subject: Distribution of Record of Symposium on Electronic Problems in Radio Astronomy.
Attachment: Record of an Informal Symposium on Electronic Problems in Radio Astronomy, Friday, May 27, 1955, with the following Appendices:
A-3 Wave Front Distortion by a Turbulent Medium—W. E. Gordon.
A-5 Descriptive Charts and Bibliography on Paraboloid Reflectors—R. M. Brown.
A-6 Remarks on Paraboloid and Feed Designs—L. C. Van Atta.
A-8-1 Paraboloids for Radio Telescopes—C. J. Sletten.
A-8-2 Multiple Feed High-Gain Antennas for Radio Astronomy—R. C. Spencer.
A-10 Preliminary Description of the Harvard 21-cm. Receiver—H. I. Ewen.
A-11 Block Diagram of the Proposed NRL 21-cm. Receiver—E. F. McClain.
A-14-1 Letter Concerning Data Processing—Nat Rochester.
A-14-2 Letter Concerning Data Processing—J. P. Nash.

15. Memorandum dated September 9, 1955. Subject: Report by Professors Shore and Kane on a Study of a Radio Telescope Design Proposed by Mr. Grote Reber.
Attachment: Deflection Study of a 140 Foot Radio Astronomy Telescope Made for Associated Universities, Inc. by Sidney Shore and Thomas R. Kane, University of Pennsylvania (dated July 1955).

16. Specifications for the Development of A Design for the Construction of A 140-Foot Radio Telescope, dated October 25, 1955.

17. Program for the Steering Committee Meeting, Washington, D. C., Dec. 11-13, 1955.

18. Agenda for the Steering Committee Meeting, Washington, D. C., Dec. 11-13, 1955, with the following Attachments:
Appendix I-1 Site Survey Procedures: set of maps.
Appendix I-2 Report on Field Strength Surveys for A Radio Astronomy Facility, dated October 14, 1955, by Jansky & Bailey, Inc.
Appendix I-3 Installations (Existing or Planned) that Might Influence the Radio Noise Levels at the Possible Sites for the National Radio Astronomy Facility, with attachments: Some Transmsission Data on the KS-5759 Delay Lens Antenna; Photocopy Radio Relay Routes of A.T. & T. Co.; Photocopy Radiation pattern for an A.T. & T. parabolic reflector.
Appendix I-4 Climatic Information Concerning the Possible Sites for the National Radio Astronomy Facility, with attachments: Chart of Tracks of All Tornadoes, 1916-50; Chart—Annual Thunderstorms.
Appendix II Specifications for the Development of A Design for the Construction of a 140-Foot Radio Telescope, dated October 25, 1955.
Appendix V Provisional Schedule for the Establishment of the National Radio Astronomy Facility.
Appendix VI Summary of frequency requirements dated October 25, 1955, by John P. Hagen.
Letters from the following:
Armin J. Deutsch, dated December 1, 1955
Leo Goldberg, dated November 28, 1955

19. Minutes, Steering Committee for the Radio Astronomy Facility Study Meeting—Sunday-Monday-Tuesday, December 11-13, 1955.

20. Memorandum dated February 9, 1956—Subject—Equatorial Designs.
Attachments: Letter dated January 10, 1956 from Dr. Jacob Feld, Letter dated

January 7, 1956 from Husband & Company Consulting Engineers, Letter dated January 31, 1956 from D. S. Kennedy & Co.

21. Memorandum dated February 9, 1956—Subject—Standard Nomenclature for Radio Telescopes. (A copy of an appendix to radio telescope specifications prepared by the Division of Radiophysics, Commonwealth Scientific and Industrial Research Organization, Sidney, Australia).

22. Memorandum dated February 21, 1956—Subject—Conference on Site Protection Against Radio Interference.

23. Memorandum dated February 21, 1956—Subject—Meeting at the National Science Foundation of February 14, 1956 on the Protection of Radio Astronomy Sites Against Man-made Interference.

24. Memorandum dated March 8, 1956—Subject—Transmittal of 140-ft Radio Telescope Design by Dr. Jacob Feld.
Attachments: Description of Feld Design 140-ft. Radio Telescope Typical Stress and Deformation Analysis. Draft Invitation for Bids. 11—Drawings.

25. Transmittal Memorandum, March 19, 1956, 140-foot Radio Telescope Design by Husband and Company.
Attachments: 43—Drawings and Description.

26. Agenda for the AUI Advisory Committee Meeting March 26-27, 1956.

27. Minutes of AUI Advisory Committee Meeting March 26-27, 1956.
Attachments: Appendix A-11-1 Letter, March 14, 1956 to R. M. Emberson from M. A. Tuve.
Appendix A-11-2 Letter, March 20, 1956 to M. A. Tuve from R. M. Emberson.
Appendix A-12 Letter March 22, 1956 to L. V. Berkner from R. J. Seeger.
Appendix A-16 Letter March 30, 1956 to A. T. Waterman from L. V. Berkner.

28. Memorandum dated March 19, 1956—Subject—Wind Gust Frequencies.

29. MIT Servomechanisms Laboratory Progress Reports 1, 2 and 3.

30. Draft Zoning Legislation for the Green Bank Site.

(Documents submitted after March 31, 1956 will be listed in a subsequent report)

Chapter One

RADIO ASTRONOMY IN THE UNITED STATES

I. THE DEVELOPMENT OF RADIO ASTRONOMY

The detection by K. G. Jansky, in 1932, of radio waves emanating from "outer space" opened up a new and exciting field of scientific research. His initial observations were followed in the late thirties and early forties by the pioneering work of Grote Reber, who systematically investigated the background radio emission of our own galaxy. Both of these men were U. S. engineers.

During World War II a second field of radio astronomy came into being with the independent discoveries by Hey in England and Southworth in the United States of radio emission from the sun. A short time later discrete sources of cosmic radio waves were detected in Australia and in England. With the one exception noted below, the discovery phase of radio astronomy was thus completed.

Following the end of World War II, research in radio astronomy expanded greatly, largely because of technological advances made in electronics during the war. The United States, however, did not take part in this expansion. Except for the solar studies made at Cornell University and the Naval Research Laboratory, very little radio astronomy was carried out in the United States during the first five or six years after the war.

The next major contribution by U. S. scientists came in 1951, when Ewen and Purcell detected for the first time the 21-cm line radiation from interstellar hydrogen. Their observations completed the discoveries of the principal fields of radio astronomy known today,—galactic background emission, solar sources, discrete sources, and the 21-cm line. United States scientists initiated three of these four fields of study.

Following Ewen and Purcell's observations, 21-cm line studies were begun at three U. S. institutions: at Harvard, at the Naval Research Laboratory (NRL), and at the Carnegie Institution of Washington, Division of Terrestrial Magnetism (CIW-DTM). In this same period, investigations of discrete sources and galactic emission began at Ohio State, NRL, and DTM.

Significant contributions to radio astronomy have come from all of these projects, as well as from the solar work at Cornell and NRL mentioned earlier. In spite of this, however, the development of radio astronomy in the United States has lagged behind that in other countries.

There are at present six U. S. institutions (Carnegie Institute of Washington, Cornell, Harvard, Naval Research Laboratory, Ohio State and Stanford) actively engaged in observational research in radio astronomy. At several other institutions (e.g. California Institute of Technology (CIT), Michigan) radio astronomy projects are still in the planning and development stage.

II. THE NEED FOR A RADIO ASTRONOMY OBSERVATORY FACILITY

Although scientists in the United States have made many of the basic contributions to the new science of radio astronomy, this country is not maintaining its initial leadership in this rapidly developing field, not for lack of scientific talent, but because of growing deficiencies in research facilities. As already mentioned, only six institutions in the United States are now actively engaged in radio astronomy research. Fewer than thirty scientists and graduate students take a direct part in this research. We cannot investigate many of the more urgent problems in radio astronomy because we do not have the necessary equipment. If our research instruments continue to lag farther and farther behind those in other countries, we will be forced to abandon many important studies to foreign scientists.

In several countries radio astronomy is now well advanced, particularly in Australia, England, Holland, and in the Soviet Union. Scientists in these countries already have, or are planning better equipment than ours, and are able to carry out studies in both the solar and cosmic phases of radio astronomy, and at practically all wavelengths. Fixed paraboloids with apertures greater than 200 feet are in operation in Australia and England. A 250-ft. steerable paraboloid is nearing completion at Manchester, England, and a similar instrument is planned for Australia. Both Australia and England have large, high-resolution interferometer arrays in use. An 80-ft. steerable paraboloid is just getting into operation in Holland.

If the United States is to keep abreast of developments in radio astronomy, our scientists must have at their disposal larger and more powerful research equipment than is now available to them. The largest instruments in operation in the United States at present are the 50-ft. paraboloid at NRL and the 2600-ft. Mills Cross array at DTM. Several other paraboloids of 60- to 100-ft. aperture are under construction; a 60-ft. steerable paraboloid is coming into operation at Harvard; an 84-ft. steerable paraboloid is under construction for NRL; two 90-ft. paraboloids are planned for CIT. Nevertheless, there are no instruments in this country comparable with the large steerable paraboloid under construction in England, nor with the large interferometer arrays in Australia and England. The cost of such equipment places it beyond the likely means of any single institution. An observatory available to all qualified scientists is an obvious solution for the problem of inadequate research facilities.

Two recent conferences, the first held in Washington on January 4-6, 1954, and the second held in New York on May 20, 1954, showed clearly that a genuine need exists for large research equipment not now existing nor likely to be acquired by any of the universities or other institutions interested in radio astronomy. At these conferences various problems were discussed: the objectives and requirements of a radio astronomy program; the relationship of a joint or cooperative facility to the smaller facilities of the universities and similar institutions; the staffing of a Radio Astronomy Observatory and the training of students; ways of supporting a Radio Astronomy Observatory through staff, equipment, and direct participation in the research programs; and the basic goal: to provide the highest single-beam resolution and gain that is now feasible, both economically and technically. The proceedings of the Washington Conference were published in the *Journal of Geophysical Research,* Vol. 59, No. 1, March 1954. An abridged version appeared also in *Science,* Vol. 119, p. 588, April 30, 1954. These papers include a survey of world progress in radio astronomy and of some of the more pressing problems in the general field. As an outgrowth of the January 1954 conference the NSF established an Advisory Panel for Radio Astronomy on May 3, 1954.

A. *Specific Objectives.*

A Radio Astronomy Observatory would accomplish many important functions:

1. It would make available, to scientists throughout the United States, the large, powerful research equipment that is necessary to advance the science. Instruments of high angular resolution and sensitivity are essential in almost every phase of this research, and these requirements can be met only with large antennas. Some of the research potentialities of such equipment are discussed in Section III of this chapter.

2. A Radio Astronomy Observatory will make it possible in the United States to integrate optical and radio studies more effectively. The United States is a leader in optical astronomy; our optical observatories have excellent staffs and superb equipment. Unfortunately, however, most of our astronomers have been forced to be only bystanders in the field of radio astronomy, because their observatories cannot provide the large and expensive research equipment necessary. In a Radio Astronomy Observatory, all interested astronomers could carry out active research in radio astronomy, and a more complete integration of optical and radio studies would inevitably result.

3. A Radio Astronomy Observatory will encourage universities and other research institutions to plan radio astronomy projects of their own. If scientists know that they can begin a study at their own insitutions, and then expand and complete the research with the more powerful equipment at the Radio Astronomy Observatory, they will be stimulated to initiate many projects they might otherwise consider impossible.

4. A Radio Astronomy Observatory will be invaluable in the training of students. The continuing development of radio astronomy requires researchers who have a thorough knowledge both of optical astronomy and of the special techniques and problems of radio astronomy, but the number of scientists with the necessary background in both is still relatively small. Because of the extremely difficult instrumental problems, most of the investigations made so far have been the work of scientists expert in the instrumental fields, but with no formal training in astronomy. Only a few universities in the United States now have facilities for graduate training in radio astronomy. Other universities may soon acquire modest research facilities, but only the existence of a Radio Astronomy Observatory will make it possible for the astronomy departments at these universities to offer advanced research experience in radio astronomy to properly qualified graduate students. With an increasing number of trained radio astronomers, research in the field should develop and expand rapidly.

In summary, the establishment of a Radio Astronomy Observatory will provide the powerful tools necessary for research in radio astronomy; will stimulate interest and research in radio astronomy at other institutions throughout the country; and will assist in the training of competent scientific personnel. All these functions are vital, if the United States is to achieve a leading position in the field of radio astronomy.

III. RESEARCH OBJECTIVES

The principal objective of the Radio Astronomy Observatory is to advance our fundamental knowledge of the universe and of the laws that govern its behavior, by observing and investigating the radio frequency radiation emanating from celestial objects.

The Radio Astronomy Observatory will provide instrumentation for the investigation of:

(a) the continuous radiation from our own galaxy and from other galaxies;

(b) discrete sources of radio radiation;

(c) solar radio emission;

(d) the solar system, both by direct reception of emitted and reflected radiation and by radar techniques;

(e) 21-cm line emission, and other line emissions.

Such studies should contribute significantly to the fields of astronomy, physics, and geophysics. They can add to our understanding of many specific problems, including those of cosmology, astrophysics, galactic structure and dynamics, the interstellar medium, the ionosphere and upper atmosphere, radio propagation and communications, solar-terrestrial relationships, cosmic rays, theory of plasma oscillations, theory of shock waves, and microwave spectroscopy.

A. *Instrumentation.*

The continual research that will go on to improve and develop new instrumentation will also contribute to the fields of antenna theory and design; uhf and microwave receivers, tubes, and components; information theory and data handling; and electrical and communications engineering in general.

It is proposed that the first major instrument of the Radio Astronomy Observatory be a 140-ft. steerable paraboloid, with high precision of surface, motion, and position indication. Paraboloids of still larger aperture might be constructed at a later time. The decision to concentrate our attention at present on large steerable paraboloids was reached as the result of a number of conferences and discussions among scientists[1], who agreed that such instruments would have the greatest usefulness and versatility. A quotation from a letter by J. L. Greenstein to B. J. Bok is an example of this opinion:

> "It (a 140-ft. paraboloid) would be the largest single precision paraboloid in this country, and presumably could become an all-purpose instrument for use by all cooperating groups. Because of its precision construction, ability to track objects, versatility of uses, it is probably the most satisfactory single device for use by cooperating groups. Unlike special-purpose instruments, such as interferometers, it is very likely that receiving equipment and feeds can be changed rapidly, so that a large number of various programs can be carried out over a period of time. Therefore, as a nation-wide facility, it has very great promise and will undoubtedly lead to important results."

In concentrating our attention on single steerable paraboloids we do not mean to exclude the possibility of acquiring other types of equipment. Ultimately, the Radio Astronomy Observatory should have various types of antenna systems, in addition to paraboloids.

An ad hoc panel, under the chairmanship of B. J. Bok, has discussed the research potential of large steerable paraboloids.[2] The remainder of theis chapter which briefly lists some of the principal conclusions regarding the various fields of research is abstracted from their report.

B. *21-cm Research.*

The general consensus is that a large paraboloid will lead to remarkable advances in the study and interpretation of the 21-cm line of neutral hydrogen. A 140-ft. antenna with a precision surface that permits use of the full aperture should open entirely new areas for research in the structure of our own and other galaxies. It is too early to predict now what new frontiers will be revealed if larger antennas can be used effectively for 21-cm research.

Tuve and his associates at Carnegie Institution of Washington draw attention to the fact that for 21-cm research the resolving power of the 140-ft. reflector suffices to make available for analysis a long list of objects beyond the reach of existing equipment. Among these are atomic hydrogen (HI) shells around emission nebulae, HI clouds associated with absorbing clouds responsible for multiple interstellar absorption lines, HI clouds near associations of stars of spectral types O and B, HI clouds associated with dust clouds of modest dimensions, and with galactic and globular star clusters. With still larger equipment having more resolution and gain, objects with diameters of the order of 5′ or smaller can be studied adequately, and planetary nebulae, novae, shell stars and stars with very extended atmospheres should become accessible to observation and analysis with 21-cm techniques.

The potential results of 21-cm research in our own galaxy with instruments of increased aperture are very great; but the potentialities for research into the structure and dynamics of our neighbor galaxies and the remote, fainter galaxies may assume even greater magnitude. At the distance of the Andromeda Nebular (Messier 31) the spiral features have widths of the order of 5′, which means that with a 600-ft. telescope we shall be able to obtain adequate resolutions for measures of velocity over the entire accessible area of this spiral nebula. With the high precision of radial velocity measurements attainable in 21-cm research, we should obtain much needed basic information for dynamical studies not only for M 31, but also for M 33, NGC 6822 and other members of the Local Group. L. H. Aller points out that from these studies we should be able to deduce the mass distribution in several of these objects. The work of the Australian radio astronomers on the Magellanic Clouds has already demonstrated the power of such an approach. The recent detection by Heeschen at Harvard of 21 cm. line emission from the Coma Cluster of galaxies shows that the study of distant extragalactic objects is feasible with even moderate sized telescopes.

When we turn to the more distant galaxies, we find a variety of problems, of which we mention only two. Bolton recommends that a special attempt be made to measure the Doppler shift attributed to the expansion of the universe, to check whether or not it holds over the entire range from optical to radio wavelengths. Lilley and McClain at NRL have already succeeded in measuring the hydrogen line red shift of the radio source

[1] *Descriptions of these conferences, together with lists of participating scientists, will be found in Chapter II.*

[2] *See Chapter II.*

Cygnus A. *Zirin suggests a search for intergalactic absorption effects from HI seen in front of distant discrete sources. Again Doppler shifts and cut-offs should be noted as bearing on the expansion of the universe.

C. The Radio Continuum.

Complete agreement exists with regard to the great importance of paraboloids in the 140- to 600-ft. range for research in the continuum at wavelengths from 50-cm downward. The work of Haddock and others at the Naval Research Laboratory has demonstrated the importance of searches for and studies of emission nebulae that produce measurable radio radiation of thermal origin in the short wavelength range. Increased gain and resolution will not only lead to numerous discoveries of thermal radiation in the decimeter range, but will also make possible intensive detailed studies of radio brightness distribution for the larger ionized hydrogen (HII) regions. Comparative studies of radio and optical isophotes promise to yield very useful results regarding physical conditions in the emitting gas, and scattering effects by the interstellar medium between the HII region and the sun. Studies of the spectral intensity distribution in the continuum should certainly be extended to the shortest possible wavelengths, and the single large antenna should be helpful in attempts at the classification and sorting of emission mechanisms. It might be possible to distinguish several "spectral classes" among radio objects too faint at visible wavelengths for identification with optically observable objects.

Several correspondents have emphasized the importance of "spectral classification" based on studies of the distribution of radio brightness with wavelength, for fairly large numbers of discrete sources. M. A. Tuve lists the problems of radio spectral classification as among the most critical ones of radio astronomy. The large paraboloid, possibly fitted with multiple feeds, offers great possibilities for advance in this area, and the versatility of the instrument becomes here of prime importance.

At meter wavelengths, the large paraboloids are recognized to have important tasks ahead of them in the measurement of precise positions, radio magnitudes and radio colors for one hundred or so of the brightest sources. They will be the instruments used for the precise study of sources discovered by the search instruments. J. D. Kraus points out that the very large paraboloids may prove to be effective in overcoming ionospheric difficulties at long wavelengths, and in the range of several meters and longer.

Greenstein comments on the research value of a 140-ft. paraboloid as follows:

"A general sky survey for extended sources, distribution of sources in space, statistics, the frequency of different spectra, all can be carried out with a 140-ft. size, and should give us a clear picture of the radio universe in which we live."

D. Solar Research.

A paraboloid antenna with an aperture of 140 feet or more is justified primarily by its potential contributions to galactic and extra galactic research. In addition, however, the instrument has great possibilities for solar work and for sudies of the solar system.

Bolton and the Harvard solar physicists stress the importance of extending J. P. Wild's researches on dynamical spectra to short wavelengths and to weak disturbances. The broad band feature of the paraboloid, combined with its large collecting surface, renders the instrument particularly useful for this work.

Leo Goldberg and J. P. Hagen emphasize the importance of the relatively high angular resolution obtained in all directions with a large paraboloid. This feature should assist greatly in the disentangling of several simultaneous radio and optical disturbances during times of great solar activity. Goldberg attaches great importance to the high gain of large antennas, especially in the measurement of intensities at high frequencies of radio bursts associated with optical flares.

E. The Solar System; Radar Techniques.

Hagen and F. L. Whipple drew attention to the importance of direct high resolution studies of the surface of the moon and possibly of the planets. Detailed measurements of the thermal radiation from the moon at short wavelengths should add to our knowledge of the electrical and thermal properties of the soil of the moon. Large aperture antennas may also make it possible to measure thermal radiation from several of the planets, particularly Venus, Mars, and Jupiter.

Radar techniques offer another method of studying the solar system. This subject has been given special study by L. V. Berkner, whose conclusions are briefly summarized here. Berkner finds that with a 600-ft. antenna and appropriate radar equipment it should be possible to study a wide variety of solar phenomena, including solar eruptions, particle streams, the structure and composition of the corona, and magnetic fields in specific regions. In the case of Venus it should be possible to obtain echoes at all times, so that studies could be made of Venus' atmosphere, rotation, and possible magnetic fields. Radar techniques may be employed in many other investigations noted by Berkner; for example, in the study of reflections from interplanetary ionized clouds, of the ring current suggested by the Chapman-Ferraro theory of geomagnetic storms, and of ionospheric phenomena.

**Lilley, A. A. and E. F. McClain, "The Hydrogen-Line Red Shift of Radio Source Syngus A", Astrophysical Journal, 123, p. 172, 1956.*

IV. CONCLUSION

This discussion was not intended to be all-inclusive, but to demonstrate the potential usefulness of large steerable paraboloids in radio astronomy research. Striking as these potentialities are, the greatest value of these instruments lies in the unknown,—in their ability to extend still further the frontiers of science. In the words of Hagen:

> "The notion that the sky is full of stars and that we live in a universe of stars and clusters of stars is retreating. Radio astronomy looks into space and sees not the stars but the material that exists between and around the stars. The early work revealed the presence of the material, but now we must refine our tools and search for the nature and the disposition of this tenuous material out of which half the material in the universe is composed. Its true nature can be defined only when we have available instruments of great flux-gathering ability and great resolving power. In this we follow in the footsteps of the optical astronomers. Such a large instrument must be a parabolic reflector to give resolution in all planes and to be available for use at all wavelengths.
>
> "The availability of such an instrument will allow us to solve many of the vexing problems, raised by the limitations of present equipment, facing us today, but more important will bring to light many things that are today unknown and in that sense unpredictable. As in nearly every other science the experience in radio astronomy has been that the acquisition of new and superior equipment, designed to round out or fill in the picture obtained with present equipment, has led to new discoveries."

Chapter Two

HISTORY OF THE RADIO ASTRONOMY PROJECT

I. ASSOCIATED UNIVERSITIES, INC.

The formal association of Associated Universities, Inc. (AUI) with the Radio Astronomy Project began on May 20, 1954, when a conference was held at AUI's New York office. This meeting grew out of informal discussions among scientists at Harvard, Massachusetts Institute of Technology, Naval Research Laboratory, Columbia University and Franklin Institute, who canvassed the possibilities of a cooperative effort in the field of radio astronomy, and concluded that a broader cross-section of scientific opinion should be obtained. To achieve this end, Associated Universities, Inc., through its President, Lloyd V. Berkner, was asked to arrange a conference of representative scientists.

The meeting convened on May 20, 1954 at the New York office of Associated Universities, Inc. and was well attended. During most of the proceedings some 37 individuals from 28 institutions were present, representing every institution in the United States that is conducting research in radio astronomy, or in fields directly contributing thereto.

A. *Need for A Radio Astronomy Observatory*

As a solid basis for discussion, the conference had a memorandum, "Survey of the Potentialities of Cooperative Research in Radio Astronomy," prepared by Donald H. Menzel, Director of the Harvard College Observatory, and dated April 13, 1954. This memorandum gave a summary account of the scope of radio astronomy, including a description of radio emissions from celestial sources and the reflections of radio waves. It discussed the equipment required for research in this field, emphasizing the necessity for coordinated effort by electrical engineers, electronics experts, radio engineers and mechanical engineers; it pointed out the importance of theoretical laboratory studies; and finally, it recommended that a preliminary organization be formed to consider possible sites for a Radio Astronomy Observatory, and to plan a scientific program.

The group present at the May 20 meeting, representing widely diverse points of view, explored in detail the points suggested by Menzel, and firmly agreed in the conclusion that an urgent need exists for a radio astronomy research facility, which should be as large as possible, within the limits set by engineering and financial problems. The large aperture radio telescopes for such a facility are essential for high resolution studies, and would unquestionably stimulate work in theoretical astrophysics and the development of electronic equipment. A facility of this kind would also attract many scientists with a potential interest in astronomy, particularly if the project were operated on a genuinely cooperative basis. The Brookhaven National Laboratory was cited as an example of successful cooperation, and the conference hoped that the same principles could be applied to a Radio Astronomy Observatory.

B. *The Tentative Program.*

The conference discussed the immediate needs of a Radio Astronomy Observatory and agreed that the following staff, structures and equipment would be required:

1. Basic staff.
2. Laboratory buildings and maintenance quarters.
3. Power and power supplies.
4. Transmitters.
5. Receiver equipment.
6. A big parabolic radio telescope.
7. One or more smaller radio telescopes.
8. Network for interferometer antennas.
9. Strong supporting or training programs at many universities, with particular emphasis on the development of electronic components, on data processing, and on analysis procedures and techniques.

The conference also agreed that the creation of a large research facility would involve the following three phases:

1. Basic preliminary planning to formulate the principle objectives of the program, to select possible sites, to determine the best type of equipment, and to make preliminary feasibility studies of facilities and equipment.
2. Final design of facilities and equipment.
3. Construction of facilities and equipment.

The hope was expressed that if such a program could be followed, actual observation might begin sometime in the calendar year 1958.

II. THE FIRST PHASE

L. V. Berkner, speaking for Associated Universities, Inc., proposed that the Corporation apply to the National Science Foundation for a grant to defray the costs of the first phase. If such a grant were made, the Corporation would create appropriate committees to select possible sites and to consider the kinds of equipment required. Subcontracting of particular studies might prove desirable. He also proposed, as an initial step, that an ad hoc committee be set up by agreement between Menzel, M. A. Tuve, Director of the Department of Terrestrial Magnetism of the Carnegie Institution of Washington, and himself.

A. *The Feasibility Study.*

After consultation with Menzel and Tuve, following the meeting of May 20, 1954, Berkner set up an ad hoc committee, with Hagen as chairman, composed of the following:

Bart J. Bok	—Harvard College Observatory
Armin J. Deutsch	—Mt. Wilson & Palomar Obs. (Cal-Tech)
Harold I. Ewen	—Harvard College Observatory
Leo Goldberg	—University of Michigan
William E. Gordon	—Cornell University
Fred Haddock	—Naval Research Laboratory
John P. Hagen	—Naval Research Laboratory
John D. Kraus	—Ohio State University
Aden B. Meinel	—University of Chicago
Merle A. Tuve	—Carnegie Institution of Washington
Harry E. Wells	—Carnegie Institution of Washington
Jerome B. Weisner	—Massachusetts Institute of Technology

At the first meeting of the Committee on July 26, 1954, at AUI's New York Office, Berkner and R. M. Emberson presented a research proposal to be made to the National Science Foundation, for a grant of $105,000 to support a feasibility study of a National Radio Astronomy Facility.

The principal objects of the study were:

1. A survey of opinion among scientists who are now active or interested in the field of radio astronomy, to set up a program of research objectives.

2. An examination of the various suggestions made regarding the major items of equipment, to gain some understanding of the technical problems of design and construction that would have to be solved, and to be able to compare performances and costs.

3. An examination of possible sites and their comparative desirability, judged by the requirements of the research program and the staff, the possibilities of housing and transportation, meteorological factors, sources of radio interference, accessibility to other centers of intellectual activity, and by any other factors shown to be important by the first two parts of the study.

4. An examination of any other expenditures essential to the achievement of a functional Radio Astronomy Observatory, e.g., access roads, power lines or power generating equipment, laboratory buildings, etc.

5. Preliminary estimates of the costs involved in Phase 2 (see above); preliminary proposals of methods to finance these costs; and a consideration of how much time to allow for completing this phase.

6. Preliminary estimates of the organization and staff necessary to operate the completed facility and proposals of budgets, personnel policies, and methods of promoting cooperation among interested institutions.

The Committee approved the draft and then considered research objectives, observing techniques and possible site locations. Following the meeting, the proposal was forwarded to the National Science Foundation.

The Foundation took the proposal under consideration, and advised AUI on January 13, 1955, that $85,000 had been granted for the purposes described in the proposal. In the meantime, AUI had continued the preparatory work in the expectation that a grant would ultimately be forthcoming. In this connection, it should be noted that at a meeting held on April 16, 1954, the Board of Trustees of AUI had authorized the expenditure of $2,000 to defray the cost of these preparations. During this period of preparation, Berkner and Hagen had the advantage of an extended discussion with H. C. Husband of Husband and Company, Sheffield, England, the firm that is designing and constructing for Manchester University a 250-foot radio telescope. Mr. Husband gave a frank description of the problems presented in his work, and this information has unquestionably been extremely useful. Michael B. Karelitz, whose services AUI has on a consulting basis, also met with Husband. Karelitz is a mechanical engineer of high reputation and his advice on engineering problems has proved of great value. The meeting was also attended bv Peter van de Kamp of the National Science Foundation, (on leave from Swarthmore College).

C. *The Steering Committee.*

On February 18, 1955 Associated Universities, Inc. received the funds granted by the National Science Foundation, and began active work. Richard M. Emberson was named acting director of the Project and at once began to develop detailed plans for carrying out the study. The ad hoc committee appointed for the discussions in May 1954 was reconstituted as a Steering Committee for the Project, with Hagen as chairman. The function of this Committee was to provide expert scientific advice, and also to represent the scientific community in critically appraising the plans made by Associated Universities, Inc.

Emberson immediately attacked the problem of selecting a site. This question had been somewhat simplified by a request of the National Science Foundation that the site should be within a radius of 300 miles from Washington, D. C. A study of meteorological conditions indicated that, with this limitation on selection, the site would have to be somewhere to the southwest of Washington, D. C. in western Virginia, West Virginia, or possibly in Tennessee. Emberson conferred with the Weather Bureau and the Geological Survey, and also obtained advice from various qualified people, among them Harold L. Alden and E. R. Dyer at the University of Virginia, and Carl K. Seyfert at Vanderbilt University. This group rapidly developed criteria for selecting a site, and by the middle of March were considering 14 possibilities.

Emberson also devoted time to the problem of designing a large reflector and, with the assistance of the Steering Committee, began to look for engineering organizations that might be interested in undertaking this work. To facilitate this search, by assembling a group of people who were fully familiar with the large radio telescopes in this country and abroad, a symposium on design problems for radio astronomy was held at AUI's office on March 25, 1955. Members of the Steering Committee attended, and some 12 organizations, apart from AUI itself, were represented.

At this meeting many problems were discussed. Emberson reported on a preliminary investigation to determine the feasibility of constructing and maintaining a radome large enough to house a telescope perhaps 600 feet in diameter because this appeared to be the largest steerable paraboloid that might be practicable An air-supported radome made of fabric was considered, as well as a solid one such as has been used with considerable success on a much smaller scale. The discussion then turned to radio telescopes, with particular reference to the tolerances that would be necessary to obtain good performance characteristics for microwaves. Available information on the 250-foot instrument under construction in England was presented. F. T. Haddock gave a description of the 50-foot reflector at the Naval Research Laboratory and his experience during the design and construction phases, as well as in that of actual operation. B. J. Bok described both the small (24-foot) radio telescope at Harvard and the 60-foot reflector then planned. His description was supplemented by R. J. Grenzeback of the D. S. Kennedy Company, designer of the new instrument. Descriptions of possible designs and phases of designs were given by H. Friis of Bell Telephone Laboratories, L. H. Van Atta of Hughes Aircraft Corporation, R. H. Dicke of Princeton University, and W. W. Salisbury of Gray Scientific Division of the Remler Company. Emberson showed the model built in 1948 by Grote Reber to illustrate his design for a 220-foot reflector. Participants in the symposium submitted memoranda after the meeting summarizing their remarks, which formed an important part of the record of the conference.

On March 26, 1955, the day after the conference, an important meeting of AUI's Steering Committee for the Radio Astronomy Project was held, with Hagen presiding. Six other members of the Committee (Bok, Deutsch, Ewen, Goldberg, Haddock, and Tuve) were present, as well as Peter van de Kamp, Program Director for Astronomy at the National Science Foundation. Plans and time schedules for the preliminary study and for the establishment of the Radio Astronomy Observatory were discussed in detail, and several basic decisions were made, which greatly accelerated the pace of the work as originally contemplated by AUI. The Committee agreed that the process of site selection should proceed as rapidly as possible, and decided that the first piece of equipment for the facility should be a reflector with a diameter of about 150 feet, because in the judgment of the Committee, such an instrument could be constructed relatively quickly, and would thus establish the Facility as an operating research institution at the earliest possible date. This would help greatly in recruiting a staff, who could engage in active research while at the same time studying the feasibility of larger equipment. The Committee also urged the preparation, as soon as possible, of organizational plans and budgets for both capital expenditure and operating expenses, and of specifications which could be used to solicit proposals for the construction of the 150-foot reflector.

The time schedule contemplated by the Committee called for site selection and acquisition before the end of 1955, and for the beginning of actual operations in July 1956, with the 150-foot reflector.

C. First Report to the NSF.

After the March meetings Emberson, assisted by other members of the AUI staff, the members of the Steering Committee and various consultants, continued the exploration of sites begun during the winter. In addition, he engaged the architect-engineering firm of Eggers & Higgins to prepare a hypothetical site development plan (actually based on one of the sites under consideration). Eggers & Higgins were given no cost ceiling, but were instructed to prepare a plan which in effect would include every possible type of construction problem and everything needed for a fully equipped research facility. Thus, the plan prepared by Eggers & Higgins was intended to provide for the complete development of the hypothetical site, and hence to forecast a budget for the site development, other than the major research instruments that were being studied separately.

An extensive report of the decisions reached at the March 26 meeting of the Steering Committee, together with preliminary statements on the mode of operating the facility and its organizational plans; rough estimates of the money needed for construction and operation over the next five years; and a preliminary outline of a continuing study program, were delivered to the Foundation on April 22, 1955. Revised and amplified versions of this material were delivered to the Foundation on May 6, 1955, to be available for the meeting of the Foundation's Board on May 19 and 20, 1955.

The next important event in the history of the Project was a two-day meeting held on May 27th and 28, 1955 at AUI's office in New York. An informal symposium on electronic problems in radio astronomy took place on the first day. Some 20 individuals were present from 13 institutions. Many different electronic problems were discussed, and the experiences at different installations were compared. The list of appendices to the record of the conference indicates the many topics that were discussed: Wave Front Distortion by a Turbulent Medium, by W. E. Gordon (Cornell); Descriptive Charts and Bibliography on Paraboloid Reflectors, by R. M. Brown (Naval Research Laboratory); Remarks on Paraboloid and Feed Designs, by L. C. Van Atta (Hughes Aircraft); Paraboloids for Radio Telescopes, by C. J. Sletten (Air Force Research Center); Multiple Feed High-Gain Antennas for Radio Astronomy, by R. C. Spencer (Air Force Research Center); Preliminary Description of the Harvard 21-cm Receiver, by H. I. Ewen (Harvard); Block Diagram of the Proposed NRL 21-cm Receiver, by E. F. McClain (Naval Research Laboratory); Data Processing, by Nat Rochester (International Business Machines Corporation) and by J. P. Nash (Illinois).

On May 28 a meeting of the Project Steering Committee was held, under the chairmanship of Hagen. The following members of the Committee were present: Bok, Deutsch, Goldberg, Gordon, Haddock. The principal topic was the initial reaction of the Committee and of the Foundation's Advisory Panel on Radio Astronomy to the report submitted by AUI earlier in the month. This report, which has been described above, was very comprehensive and apparently was subjected to some criticism on this account. Emberson emphasized in discussion with the Committee that the report was in no sense a recommendation, but was intended simply to indicate to the Foundation what would be required for an "ideal" installation. The view of the Foundation was that AUI's efforts should be concentrated on a more modest plan, with particular emphasis on the design for an intermediate-size radio telescope with a diameter of 140 feet. The Committee devoted considerable time to considering a five-year budget proposed by the Foundation's Advisory Panel on Radio Astronomy, and felt that the budget proposed was too small for the phases of construction and initial operation. The Committee undertook to develop a minimum operating budget for an installation that included only a 140-ft. reflector; they arrived at a highly tentative figure for a total complement of 35 people. The role to be played by visitors at an establishment of this kind was also discussed.

The Committee reviewed the specifications which were to be sent out to invite bid proposals covering both a 140-ft. radio telescope and a larger one, up to perhaps 600 feet in diameter. Emberson had been in touch with a number of industrial companies, about 20 of which, including Husband and Company in England, expressed interest. These specifications were to be sent out immediately after the meeting, and it was hoped that replies would be available for discussion at the next meeting of the Steering Committee, which was set for July 11th and 12th at Brookhaven National Laboratory. Emberson outlined the plans for that meeting.

After adjournment of the May 28 meeting of the Steering Committee, performance specifications were mailed out to 20 industrial companies, requesting that informal proposals, including cost estimates, be submitted by the first of July. The work of site selection continued during the month of June 1955, with the help of consultants. At a meeting of the Site Selection Panel in Washington on June 10, the information on 19 site possibilities was reviewed in detail and a start was made toward determining priorities.

III. SPECIFIC PLANS

The July 11-12, 1955 meeting of the Project Steering Committee proved to be of great importance, and significant decisions affecting the future of the project were made. The meeting was held at Brookhaven National Laboratory so that the members of the Committee could observe the operation of a university-sponsored and managed research institution deriving its financial support from the Government. A substantial part of the time was devoted to exchanging ideas with the Laboratory Director and members of the staff, with particular emphasis on the relations between Brookhaven and the universities in the northeast. The Committee considered some five proposals submitted by industrial companies for the design and construction of a 140-ft. radio telescope. Although none of these proposals provided the basis for a contract or even a firm estimate, nevertheless they were a valuable indication of industrial interest in the project and gave a general idea of the cost of the major research tool.

A. Basic Premises.

The Committee adopted five premises on which its specific recommendations were to be based essentially as follows:

1. It is of prime importance that the country move as rapidly as possible toward the establishment of a Radio Astronomy Observatory.

2. The initial major instrument for the facility will be a precision 140-ft. parabolic reflector designed to provide a radio telescope of maximum flexibility of utilization.

3. The initial site acquisition, development, buildings and staff will be arranged to provide at least the minimum requirements for the operation of the 140-ft. radio telescope.

4. At some future time (five to ten years), a much larger radio telescope of perhaps 600-ft. aperture may be erected at the facility, if considered essential for continued advance in the science of radio astronomy.

5. The programs outlined in 3 above, and particularly those of site development and building, must be carried out in a way that will permit orderly growth of the facility to meet other possible needs.

B. *The Second NSF Grant.*

On the basis of these premises, the Steering Committee then considered three matters: the selection of a site and the establishment of the Facility, including the initial staffing; preparations for the construction of the 140-ft. reflector; and continued design studies on other and larger radio telescopes. The Committee recommended that application be made to the Foundation for a new grant in the sum of $234,500 to defray the cost of continued studies from October 1955 through June 30, 1956, and recommended a budget covering the expenditure of this amount. The principal items in this budget were as follows:

1. Development of designs for the 140-ft. telescope.

2. Careful exploration of the most promising site possibilities to permit final selection, in the anticipation that money for its acquisition will become available in July 1956.

3. The continuation of feasibility studies on radio telescopes of other designs and sizes.

4. Other expenses of AUI in carrying out the study.

This budget, set out in more detail, was embodied in a proposal submitted by AUI to the National Science Foundation on July 29, 1955.

C. Budget Estimates.

The Committee also studied budget estimates for the initial establishment of the Radio Astronomy Observatory and, being aware of the views of the NSF Advisory Panel, arrived at a total estimated capital expenditure of $3,862,000. This budget included the 140-ft. telescope, other observing equipment, electronic components and equipment, site acquisition, site development, buildings and other equipment such as furniture, tools, and books. The Committee also agreed on budget estimates for operating expenses, including minimum salaries at the Radio Astronomy Observatory during fiscal years 1957-60 inclusive. These estimates ranged from $99,000 during FY 1957 to $266,500 during FY 1960. The latter figure, in the judgment of the Committee, represented a reasonable operating level for the facility after its construction was completed, and could be used to prepare estimates for the future.

After adjournment of the Steering Committee meeting, the Project staff prepared a proposal (referred to above) which was submitted to the National Science Foundation on July 29, 1955. This proposal summarized the work under grant No. NSF-G1415, pointing out that the studies to date had demonstrated the general feasibility of a Radio Astronomy Observatory and had gone far towards detailed planning for such an institution. Additional funds in the sum of $234,500 were requested to permit the following:

1. Procurement of preliminary and alternative designs for a 140-ft. reflector, in order to obtain lump sum bids for detailed design, fabrication and erection of such an instrument.

2. Detailed design for the 140-ft. reflector, to be prepared by the contractor selected to fabricate and erect the instrument.

3. Continuation of studies on larger telescopes.

4. Final site selection, based on noise measurements and core borings, and the acquisition of options to purchase the site.

5. Other expenses to be incurred by AUI.

After the submission of this proposal to the National Science Foundation, work on the project continued during the remainder of the summer of 1955. The site selection process continued, and noise measurements were planned at two possible locations, Massanutten Mountain, Virginia, and Green Bank, West Virginia.

By letter dated October 11, 1955 from the Director of the National Science Foundation, AUI was advised of a new grant in the sum of $140,500 for the support of a program for the establishment of a radio astronomy facility.

D. The 140-Foot Reflector.

With additional funds assured, it was possible to enter into firm contracts for preliminary designs for a 140-ft. reflector. Contracts were entered into early in November with Jacob Feld of New York City, the D. S. Kennedy Company in Cohasset, Massachusetts, and Husband and Company in Sheffield, England. The contracts provided that to protect the interests of the National Science Foundation AUI should have proprietary rights in the designs and that the designs should be in sufficient detail to permit the soliciting of competitive bids for a lump sum contract for the fabrication of the instrument and its erection at a site to be selected. The total sum involved for the three contracts was $34,700. The selection of Husband & Company was the result of conversations in England late in the summer between Husband, on the one hand, and Berkner, Feld, and M. B. Karelitz, representing AUI. Although in many respects the work done by Husband on the 250-ft. telescope in England was not regarded as something we would want to copy, the fact that he has had more actual experience than any other engineer in the design of structures of this kind made it desirable to employ him.

The noise measurements made at Massanutten Mountain, Virginia, were decidedly discouraging because of some unidentified pulsed signals at microwave frequencies; a Steering Committee meeting scheduled for early in November was therefore postponed, so that measurements could be made at other sites. As the search had revealed some additional possibilities, a second series of radio noise measurements were made at five sites, including the two previously surveyed.

On December 11 through 13, 1955, another meeting of the Steering Committee for the Radio Astronomy Facility was held in Washington, D. C. Eight members of the Committee were present during most of the meeting, along with several special consultants and representatives of the Corporation.

The meeting on December 11, 1955 was devoted to informal discussion of possible sites and the noise measurements that had been made to assist in this selection. The consensus was that the choice lay among Green Bank, West Virginia, Deerfield, Virginia and Massanutten, Virginia. On December 12, a large group went by bus to inspect the Massanutten site and to compare it with others on which information was available. Following the trip, an informal discussion took place on some problems arising in designing a 140-ft. radio telescope.

On December 13 the Committee, representatives of AUI, and invited consultants met formally under the chairmanship of Hagen. The first item on the agenda was the selection of a site. After extensive discussion of the various criteria which a site must meet, including subsoil and weather conditions, the Committee took certain specific actions. It recommended that the Green Bank site be selected for the proposed 140-ft. radio telescope and further recommended that all of the land in the Green Bank valley be acquired by direct purchase, or that controls be arranged to insure continued suitability of this site in the future. The committee recommended, finally, that if serious difficulties developed with the Green Bank site, Deerfield and Massanutten be studied as alternates, in that order. The formal votes embodying these recommendations are set forth in full in Chapter III.

The Committee then considered the 140-ft. radio telescope program. The status of the work being done by AUI's three contractors was described, as well as the study which was being initiated at the Servomechanisms Laboratory at Massachusetts Institute of Technology. The schedule for the work was also reviewed; it called for completion of the designs in March and issuance of invitations for bids looking to the award of a contract in May or June 1956, with a completion date in December 1957.

The Committee recommended unanimously that the possibility be considered of an equatorial as distinct from an altazimuth mount, and agreed that for such a mount, less than hemispheric sky coverage would be acceptable. The Committee also concluded that, initially, two smaller instruments with diameters of approximately 25 and 60 feet should be provided at the facility.

The future of the entire Project was also discussed, particularly in the light of the possibility that Congress would not appropriate all the funds necessary for construction. A representative of the National Science Foundation expressed the opinion that by early spring it would be possible to form some idea of what funds might be expected. If at that time the prospect of favorable Congressional action appeared doubtful, the Foundation would ask AUI to submit a plan for continuing the work on a study basis after the exhaustion of the present funds. Under the budget set up by AUI, the second grant would be substantially exhausted by the first of August. The Foundation's representative also expressed the opinion that it was unnecessary at that time to consider the need for additional funds, estimated at $60,000, to meet the initial cost of shop designs under a contract for fabrication and erection of the 140-ft. dish.

E. Possible Sites.

Immediately after the December meeting of the Steering Committee, steps were taken to put its recommendations into effect. Through the good offices of Arthur D. Little, Inc., AUI established contact with the Governor of West Virginia, and described the project to him and some members of his staff, informally and confidentially. The West Virginia officials expressed themselves as favorably disposed toward the plan for an installation at Green Bank. Pocahontas County happens to be one of the areas in West Virginia where population has been declining, and the possibility of some development that would increase the prosperity of this area had been under earnest consideration by the Governor and members of his staff, in consultation with Arthur D. Little, Inc., which has a contract with the State to promote its industrial development on a broad basis.

With authorization from NSF, AUI undertook to obtain purchase options over as wide an area as might prove feasible in the Green Bank valley. For this purpose, the services of a local attorney Richard F. Currence, of Marlinton, were engaged, and in the latter part of February he began to acquire options on as favorable terms as possible.

Methods of solving the problem of noise control were also explored. AUI's general counsel, Messrs. Milbank, Tweed, Hope & Hadley, expressed grave doubts as to the constitutionality of zoning legislation directed toward the protecion of a radio astronomy installation. However, after consultation with the Attorney General of West Virginia, a draft statute was prepared, for the constitutionality of which both AUI's advisors and the Attorney General believed strong arguments could be made. Another promising avenue of approach seemed to be through the Federal Communications Commision (FCC) and the Inter-Departmental Radio Advisory Committee (IRAC). With a view to obtaining action from these bodies, AUI engaged the services of William A. Porter, formerly the President's Special Advisor on Telecommunications and Chairman of the Communications Committee of the American Bar Association. Protection through frequency allocation or by zoning has the advantage of being applicable not only to the proposed facility, but also to all other radio astronomy installations in the country.

Developments subsequent to March 1956 will be contained in later reports, thus completing the history of the radio astronomy project.

IV. SUMMARY

At the end of March 1956, the status of AUI's work can be summarized as follows:

A. Large Radio Telescope.

Three independent designs for a 140-ft. telescope have been developed, and each is undergoing careful review by independent consulting engineers. In AUI's judgment, invitations for bids could be issued by the contractor designated to operate the Facility, as soon as decisions concerning the operating contract for the Facility have been made, and a contractor chosen. Based on the advice of consulting engineers, all three designs call for an altazimuth type of mount, and pursuant to the express wish of NSF, AUI has also contracted for a design of an equatorial mount.

B. Site.

AUI has acquired purchase options running for a period of one year, covering about 6,200 acres in the Green Bank valley. The total purchase price called for by the options is $502,000. Although the acquisition of an additional 4,700 acres would be desirable, AUI considers it impractical to make further efforts to acquire options. Conferences with Porter indicate that there is a reasonable possibility of obtaining noise protection through action by the Federal Government, creating a zone of avoidance covering Green Bank; officials of West Virginia have indicated a willingness to undertake the enactment of special zoning legislation.

C. Organization.

AUI has given to NSF an exposition of its ideas on organization.

D. Estimated Cost.

AUI has submitted to NSF revised cost estimates based on information gained from a detailed examination of the Green Bank site.

Chapter Three

THE SITE

I. SPECIFICATIONS

The basic specifications for the site were derived from a series of studies and discussions among the scientists and engineers who are members of or associated with the Steering Committee of Associated Universities, Inc. (AUI)*. The first specification listed below is, beyond all question, the most important of those given.

A. Radio Noise.

The level of radio noise or interference on wavelengths below 10 meters (frequencies greater than 30 megacycles) must be extraordinarily low. The fundamental sensitivities to which the radio telescopes can operate on any frequency are directly proportional to the ratio of external noise to desired signal. Therefore, the usefulness of the site is directly proportional to the interference noise. To avoid noise the following conditions are necessary:

1. The telescopes should be within the view of the smallest possible number of close-by inhabitants who might generate noise in the course of their daily work.

2. The telescopes should not view high tension power lines that radiate radio noise through corona discharges or otherwise.

3. The site should be in a valley surrounded by as many ranges of high mountains in as many directions as possible, to attenuate direct radio propagation from neighboring radio stations and to reduce diffraction of tropospheric propagation into the valley.

4. The site should be at least 50 miles distant from any city or other concentration of people or industries, and should be separated from more distant concentrations by surrounding mountain ranges.

5. The site should not be near commercial air route with frequent over-flight of aircraft, nor in a region where commerce or industry are likely to intrude and grow in the future.

The quietness of the site must be assured for the future; for example, by appropriate zoning regulations to permit a control over the installation and use of equipment, devices, or systems of any type that might emit radio noise.

B. Location South.

The site should be as far south as possible with a southern obstruction not exceeding a few degrees to permit observation of the center of the Milky Way and other objectives having southern declinations. A site anywhere in the United States could view all celestial objects in the northern celestial sphere, but not all celestial objects in the southern celestial sphere. Therefore, the more southerly the site, the more of the sky it can view.

C. Location North.

The site should be in northern latitudes to permit researches that involve aurorae, ionospheric scintillation, and polar blackouts.

D. Snow and Ice.

The site should avoid an area of excessive snow and ice that would create great snow and ice loads on the radio telescopes. Snow and ice need not be entirely absent, but they should be at a minimum to prevent excessive "down-time" of radio telescopes.

E. Winds.

The sites should avoid a region subject to violent winds and tornadoes. The large exposed areas of telescopes present very difficult or impossible structural requirements if they are to be exposed to tornadoes or hurricanes. Moreover, strong winds are usually accompanied by periodic gusts of such force that they might cause the development of dangerous vibrations in large structural units.

F. Humidity.

The climate should be reasonably mild, and high humidity is undesirable. Since the radio telescopes operate in the open, the maintenance during excessively long cold periods becomes difficult and introduces problems of operation. Moreover, high humidity speeds the physical deterioration of materials and increases problems of electrical insulation.

G. Size.

The site should be large enough to allow adequate separation among the installations of many types and sizes of telescopes and arrays; the latter require relatively flat spaces of one or more square miles. A total area of as much as 5-10 thousand acres should be available for eventual use by the Observatory.

H. General Surroundings.

Within the limits set by the basic requirements, the site should:

**The members of the Steering Committee and consultant groups are specified elsewhere in the Planning Document; they include representatives of all observing radio astronomy groups in the United States.*

1. Provide as many as possible of the attributes of a university campus. These include, of course, the physical means for research,—laboratories and shops, libraries and conference rooms. It is also stimulating and helpful if scientists working in related domains of science are nearby—mathematicians, engineers, chemists and physicists, to name only a few.

2. The site should provide or have easy access to housing and other requirements of visiting scientists, the permanent staff, and their families. In addition to the obvious necessities of housing and meals, access to other amenities such as stores, theaters and recreational areas is desirable.

3. Within the limits of the basic requirements, the site should be easy to reach by plane, rail or automobile.

I. Geographical Location.

The National Science Foundation Advisory Panel on Radio Astronomy, at its meeting of November 18-19, 1954, established one additional criterion. The request specified:

> "The Panel requests that the site survey by AUI should either be omitted or be of a scope limited to within about 300 miles of Washington, D. C., under this initial grant."

This specification was based on the following considerations:

1. Observational astronomy at visual wavelengths is difficult, if not impossible, in many areas of research in the eastern part of the United States because the cloudiness and haziness of the area make "seeing" conditions impractical. Radio astronomy is not thus limited. The existence of a Radio Astronomy Observatory in this eastern region would bring the scientists of the eastern part of the United States into observational astronomy on a very much more substantial scale. A great density of research activity of the country lies within this area, and it is important that major intellectual resources of the United States be brought into more intimate contact with the field of astronomy. Much of American radio astronomy is already centered around this area. A facility with radio telescopes and equipment for specialized research and augmentation of graduate-student training in this general location would provide reasonable access to the largest number of colleges, universities, and other institutions.

2. Location in this vicinity would satisfactorily compromise the need for access to both northern and southern declinations.

3. At the New York conference of May 22, 1954, L. A. DuBridge, President of California Institute of Technology (CIT), stated that a West Coast radio astronomy facility would be established in relation to the CIT-Carnegie Institution of Washington (CIW), optical facilities at Mt. Wilson and Mt. Palomar that could be conveniently accessible to scientists in the west. This is proceeding under J. G. Bolton.

4. Weather and other protective considerations outlined previously in the specifications fitted this region.

It was decided that AUI should proceed with the site study, subject to the above limitation.

II. THE SEARCH AREA

An ideal site is manifestly impossible, for some of the desired characteristics are mutually contradictory and incompatible. Thus, from the outset, certain compromises had to be made and arbitrary limits established. The Weather Bureau provided information about high winds. Hurricanes may strike any point on the Atlantic Coast from Florida to New England, but are greatly attenuated upon reaching the Appalachian Mountains; all reported tornadoes are plotted on a map*, shown here as Figure III-1, that indicates a low rate of incidence throughout an oval section of the country lying in several states,—western Virginia and the Carolinas, southeastern West Virgina, and eastern Kentucky and Tennessee. It should be noted that the low incidence in this region may be accounted for in part by the fact that the inhabitants of the various valleys are characteristically preoccupied with their own affairs and hence not prone to report an event such as a tornado on a distant ridge. Nonetheless, the Weather Bureau states that the area is relatively free of tornadoes. An indiation of the extent to which the mountains dissipate hurricane winds was given in the hurricane of August 1955, when the fastest mile of wind reported at Roanoke was 35 mph and at Elkins 40 mph; peak values are usually 20 per cent higher than the fastest mile. Generally speaking, on the eastern side of the oval the highest expected winds would be of hurricane origin from the southeast, whereas on the western side of the oval the northwest winds of winter storms would be the stronger.

Thus the search area was delimited by the two independent criteria: (1) The site should be within a 300-mile radius about Washington, D. C.; and (2) somewhere in an oval roughly 300-miles long and 100-150 miles wide, extending in a northeast-southwest direction and centered slightly north and west of Roanoke. The area defined is a slowly rising coastal plain extending about 100 miles westward from the Atlantic Ocean; it then becomes a series of mountain ridges, running usually in a northeast-southwest direction and rising 4000 feet or more above sea level. A site in a cove or wide valley might thus have many of the desired characteristics, and the mountains would offer a shield against man-made radio noises as well as against winds.

*U. S. Dept. of Commerce, Weather Bureau Technical Paper No. 20, "Tornado Occurrences in the United States"—Chart 13.

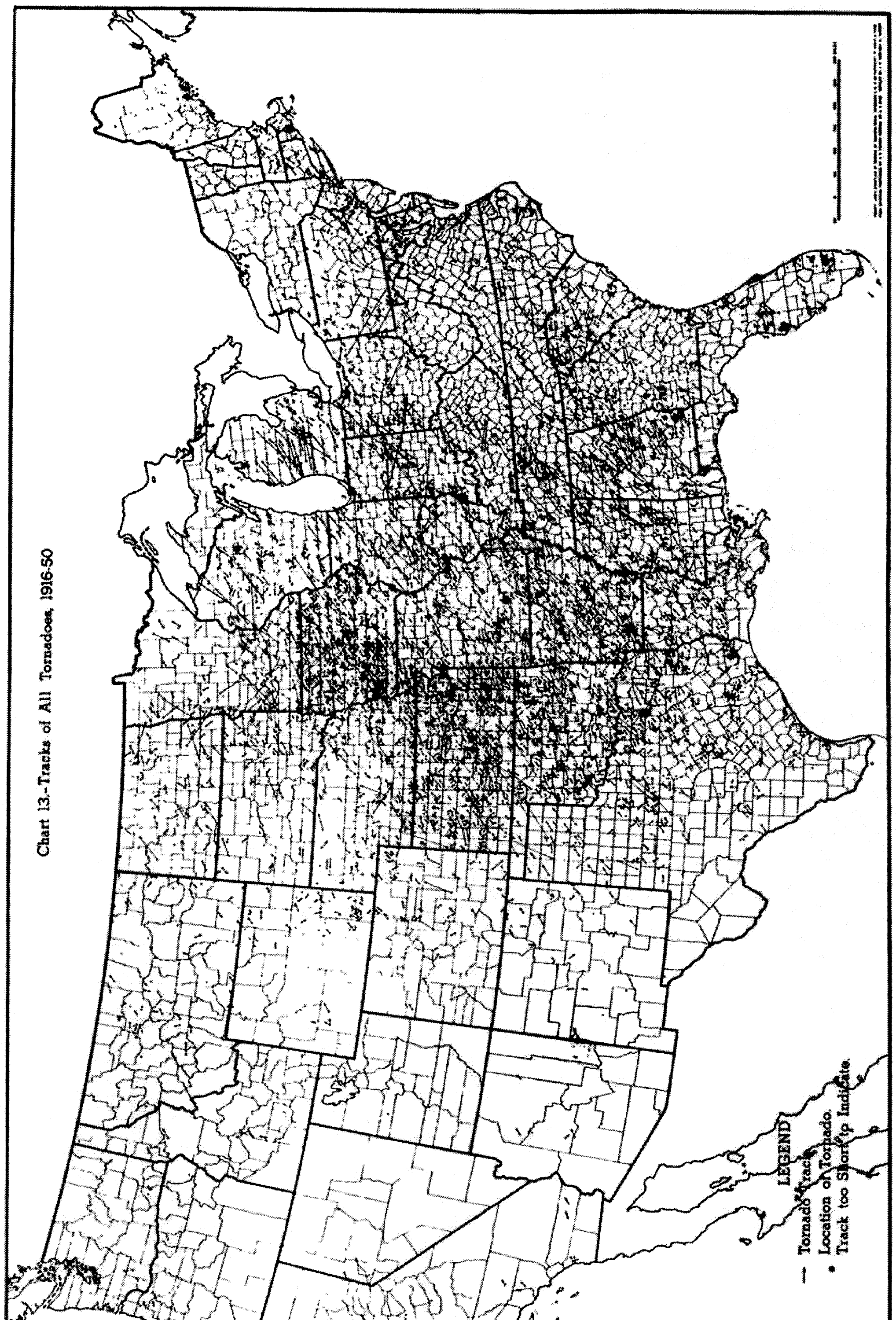

Figure III-1. Tracks of all Tornadoes—1916—1950

III. THE SEARCH PROCEDURE

In the spring of 1955, an ad hoc panel was formed to assist in the search for possible sites. Including the panel members, those who actively participated in all or part of the search were:

H. L. Alden, University of Virginia
J. E. Campbell, et al, Tennessee Valley Authority
C. E. Cutts, National Science Foundation
E. R. Dyer, University of Virginia
R. M. Emberson, Associated Universities, Inc.
H. I. Ewen, Harvard College Observatory
F. T. Haddock, Naval Research Laboratory
J. P. Hagen, Naval Research Laboratory
Wm. Hardiman, State Geologist, Tennessee
R. A. Laurence, Geological Survey, Knoxville
Wm. McGill, State Geologist, Virginia
W. A. Nelson, Univ. of Virginia
P. H. Price, State Geologist, West Virginia
C. K. Seyfert, Vanderbilt University
P. van de Kamp, National Science Foundation[1]

The astronomers of this panel enlisted the assistance of associates who had personal knowledge of the region under search, among whom were the State Geologists of Virginia, Tennessee and West Virginia.

The initial search, based on a study of Geological Survey maps and on personal knowledge of promising areas, soon discovered a total of 20 possibilities. A few of these were rejected after a study of more recent and detailed maps showed a high-voltage power line or similar undesirable features in the middle of the valley being considered. The remaining sites were then surveyed by a two-man party, E. R. Dyer and C. K. Seyfert, Jr., with several objectives: to look for any undesirable constructions such as power lines, broadcasting towers, radar installations, factories, or other similar sources of radio interference; to measure the angular elevation of the mountains surrounding the valley or cove; to obtain photographs of this horizon and of other features. The ad hoc panel analyzed all of the information obtained and tentatively narrowed the list to the five most promising possibilites. Meanwhile, the total list was growing slowly as the scrutiny of maps continued and additional possibilities were suggested.

On August 1, all panel members still in the country[2] inspected six sites by car, the five mentioned above and a new one suggested by H. W. Wells: Nos. 1, 4, 11, 15, 18 and 21 on the discovery[3] list. The sites were rated on a number of points, such as the size of the valley, the ease with which it could be developed, the degree of isolation, and travel time necessary to reach it (from New York as an arbitary starting point). These ratings indicated that two sites were preferable, 15 and 18.

A. Independent Searches.

Meanwhile, other search procedures were explored, first, to make sure that no good site had been missed, and second, to determine whether any land already owned by the Government might be suitable.

1. The U. S. Forest Service, Department of Agriculture, and U. S. Park Service, Department of Interior, provided timely and valuable assistance. It soon became clear that all of the more promising sites were privately-owned lands, which extended far up the mountain slopes before reaching the National Forest lands.

2. The Geological Survey also took part in the search, particularly R. A. Laurence, of the Knoxville office; on the basis of brief and sketchy specifications he independently prepared a list of site possibilities. Some of these were rejected after a more careful consideration of their closeness to urban and industrial centers. With two major exceptions, the remaining promising possibilities were found to be already on the discovery list, confirmation to the Panel members that their search had been thorough. One of these two exceptions was a site made undesirable by the very high mountain shielding at the southern horizon, and by the probability that its development and utilization might prove difficult. The second exception was indeed exciting, for it was Government-owned land overlooking Norris Lake.

3. The Tennessee Valley Authority was most cooperative. On a visit to the Knoxville office, Ewen and Emberson were given detailed information on all power lines throughout the area and on the amount of power lost through corona discharge. These data eliminated the Norris Lake site from further consideration and with it most of the other Tennessee sites that had tentatively been dropped for other reasons.

4. During the trip to Knoxville, a day was spent with Alden and Dyer in re-examining two sites that had been dropped earlier on the basis of map data and the Dyer-Seyfert survey: one northwest of Charlottesville and the other between Charlottesville and Lynchburg. This re-examination confirmed beyond any doubt that industrial and urban activities, including commercial communications systems, rendered these sites unsuitable for our purposes.

5. A visit was made, on an informal basis, to the Army Map Service. Although a subsequent formal request for an independent search was declined, the visit resulted in the initiation of an independent search procedure for most of the area, made possible by the comparatively recent development of precise three-dimensional maps. On the scale of these maps, any adequate site would have an easily discernible size of one-half inch or more. Since the maps also show cities, major highways, and similar developments, it is rela-

[1] *Affiliation at that time.*
[2] *H. L. Alden, E. R. Dyer, R. M. Emberson and J. P. Hagen.*
[3] *The complete discovery list is given in Section III-B.*

tively very easy to spot possible sites. A thorough search of these three-dimensional maps revealed two new possibilities, the first of which remains on the list of the more promising discoveries; the second appears to be less desirable on the basis of detailed information supplementing that on the map.

6. A final independent search attempt was made through the Real Property Disposal Office of the General Services Administration. Despite the best efforts of that office, it was found that their records were ideally suited for locating Government-owned buildings, but were not designed to cope with a search for undeveloped land having certain specified geological features. In view of the intensity of the previous surveys, however, it is highly improbable that any Government-owned land could provide a site that even partially meets the basic specifications.

7. On March 14, 1956, Representative C. M. Bailey, of the 3rd District of West Virginia, and a delegation from Richwood called at the Washington offices of the National Science Foundation, directing attention to and requesting consideration of a site at the Cranberry Glades, located in the southwest part of Pocahontas County. It was agreed that a personal inspection of the area would be made.

The area had been studied and rejected almost a year before during the initial search survey by the Site Panel. The Cranberry Glades area is entirely U. S. Forest land, which would minimize both the problems and the costs of acquisition, but it has two serious disadvantages. The Glades lie at an elevation of about 3600 feet and hence only about 400 feet below the average level of the protecting mountain ranges. By comparison, the Green Bank valley is at an elevation of 2700 feet. Thus the Glades are not nearly as well shielded from distant sources of radio interference.

From the point of view of total cost, the easy acquisition would be counterbalanced by the very large development costs. Except for the Glades, which might be used for linear arrays required for research at relatively long wavelengths, the area as it exists offers few locations for radio telescopes. Millions of cubic yards of earth and rock would have to be moved to form suitable locations; it is doubtful that this work could be done for much less than $2.00 per cubic yard. Furthermore, an access-road would have to be built. The present route through the heart of the nearby Federal Prison Camp is not suitable; an old lumber railroad right-of-way could probably be utilized for a major part of a new road that would be three miles long.

The Cranberry Glades site has been added to the discovery list as No. 30, in order that the list may show all the possibilities that were given careful and detailed study. For chronological purposes, it should be shown among the first dozen.

B. The Complete Discovery List.

The discovery list includes a total of 30, as follows:

Site No.	*Description*	*County*	*State*
1.	Burkes Garden	Tazewell	Virginia
2.	NE of Shady Valley	Johnson	Tennessee
3.	NW of Grassy Cove	Cumberland	Tennessee
4.	Sequatchie Valley	Bledsoe	Tennessee
5.	Cades Cove (Great Smokey Mountains National Park)	Blount	Tennessee
6.	Wear Cove, W of Gatlinburg	Sevier	Tennessee
7.	W of Elk Valley, N of Stanfield	Campbell	Tennessee
8.	Sandy Flats, E of Mountain Ash	Whitley	Kentucky
9.	Love Mountain, NE of Wartburg	Morgan	Tennessee
10.	Kelly Flats, NE of Kimbalton, NW of Mountain Lake	Giles	Virginia
11.	Little Meadows, NE of Mountain Lake	Giles	Virginia
12.	McDonalds Mill	Montgomery	Virginia
13.	Ellijay	Gilmer	Georgia
14.	Lafayette	Gilmer	Georgia
15.	Massanutten Mts., E of Edinburg	Shenandoah	Virginia
16.	Roseland, E of Massies Mill	Nelson	Virginia
17.	N of Crab Orchard, E of Crossville	Cumberland	Tennessee
18.	Green Bank	Pocahontas	W. Va.
19.	Beverly	Randolph	W. Va.
20.	N of Crozet, W of Earlysville	Albemarle	Virginia
21.	H. G. Wells property (NW Winchester)	Hampshire	W. Va.
22.	Goose Creek, NE of Roanoke	Bedford	Virginia

23.	Tellico Plains	Monroe	Tennessee
24.	Reed Creek, W of Wytheville	Wythe	Virginia
25.	Cold Spring Valley, NW of Mountain City	Johnson	Tennessee
26.	Tanner Hollow, N Shore Norris Lake	Union	Tennessee
27.	Lea Lake	Grainger	Tennessee
28.	Deerfield	Augusta	Virginia
29.	Green Valley	Bath	Virginia
30.	Cranberry Glades	Pocahontas	W. Va.

IV. SELECTING THE MOST PROMISING SITES

By careful study of the available published information and by visual inspection, in the fall of 1955 five sites had been selected as warranting further investigation, namely, Nos. 1, 11, 15, 18, and 28. If none of these proved usable, the next possibility was No. 4, but this was not included for several reasons, including northward urban and industrial expansion along the valley from Chattanooga, and the expanding TVA electric power system.

A. *Radio Noise Measurements.*

Radio noise measurements were undertaken through an arrangement between the National Science Foundation and the Department of the Navy, whereby certain equipment developed at the Naval Research Laboratory for other purposes was taken into the field by engineers supplied by contract with the firm of Jansky & Bailey, Inc. Measurements were made at sites Nos. 1, 11, 15, 18, and 28, for frequencies up to 10,000 mc/sec.

1. It will be useful to discuss in general terms the significance of such measurements before looking at the detailed results. The signal strength, in microvolts per meter, was measured for each individual signal obtained with the survey equipment. Although the equipment could not detect the so-called "white noise" or "random noise" that is the ultimate limitation on radio astronomy observations, the data are significant for the following reasons. At the site finally chosen, man-made radio noise will be of two kinds: (a) that from very local sources, within the line-of-sight, which is thus subject to local correction; and (b) that from sources outside the valley that enters by tropospheric or ionospheric scattering or diffraction over the mountains. The spot frequencies detected by the survey equipment (or capable of being detected, for those cases where none were observed) cover the frequency spectrum from 50 to 10,000 mc/sec. These relatively strong signals are scattered into the valley according to the same laws that apply to the much weaker white noise signals. To a first approximation, the amount of such man-made white noise existing outside any particular valley may be assumed to be proportional to the population in the outside regions, a subject that will be presented in more detail later. One other aspect of tropospheric scattering must be considered, namely, seasonal variations. Under the atmospheric conditions that characterize the summer months, such scattered signals will be more intense than in the colder air of winter. This fact is important because part of the survey was made during the early fall, when warm summer conditions prevailed, and the rest of the survey took place after the marked change to the cold conditions of winter. Fortunately, one site, No. 15 on our list, was measured under both conditions, and normalizing factors can thus be established (one for day, the other for night observations) by which all the results can be reduced to a common basis.

The same equipment and procedures were employed by the Naval Research Laboratory in searching for a site for a future radio telescope. These data have been kindly provided for comparison purposes by E. F. McClain of that Laboratory.

2. The Jansky-Bailey report was prepared in a limited number of copies and to duplicate all the material here does not seem justified, but the results will be summarized. The observations were given in tabular form and also as histograms. Two typical histograms are reproduced herewith as Figures III-2 and III-3: the first is Figure 2 of the original report and shows weekday observations at Site 15, Massanutten, in October; the second is Figure 8 of the original report and shows weekday observations at Site 18, Green Bank and also taken in October.

In the tabulation that follows, the various column headings have these meanings: (1) the place surveyed; the first four were a part of the Naval Research Laboratory search, and the numbered stations are those of the AUI study; (2) a distinction between day and night observations, made necessary because of the different atmospheric conditions, and because of significant differences in the broadcast schedules of many transmitters; (3) the actual date the observations were made; (4) a numerical figure of interference obtained by adding the intensity or strength of all signals observed in the frequency range from 50 to 10,000 mc/sec; and (5) normalized values, for comparison purposes, obtained by reducing all the preceding values to the summer conditions that prevailed in August, September and October.

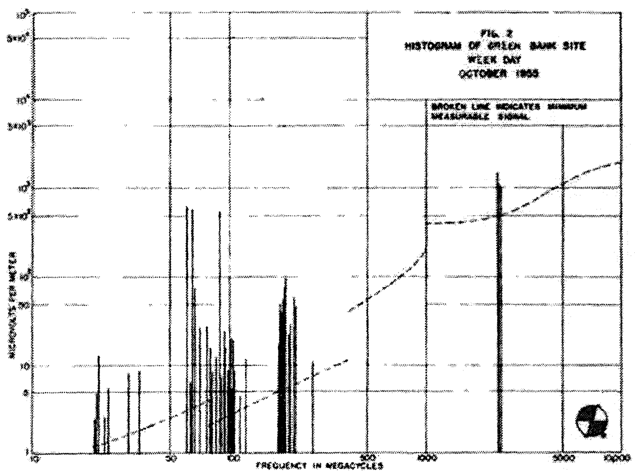

Figure III-2. Histogram of Noise Measurements at Massanutten Site Week-Day October, 1955

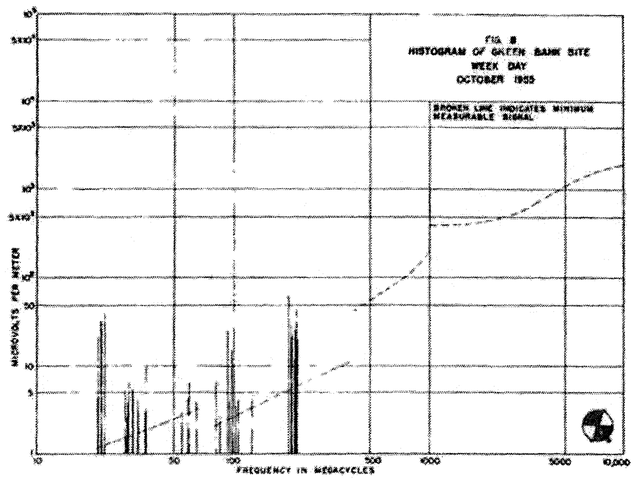

Figure III-3. Histogram of Noise Measurements at Green Bank Site Week-Day October, 1955

Station	*Day or Night*	*Date*	*Figure of Interference Actual*	*Figure of Interference Normalized*	*Order of Preference*
Naval Research Laboratory	D	Sept.	3,060,000	3,060,000	
	N	Sept.	1,350,000	1,350,000	
Hybla Valley	D	Aug.	150,000	150,000	
	N	Aug.	131,500	131,500	
Southern Maryland	D	Aug.	8,897	8,897	
	N	Aug.	546	546	
C. B. Annex	N	Aug.	274	274	
No. 1, Burkes Garden	D	Nov.	1,370	9,500	
	N	Nov.	—	—	
No. 11, Little Meadows, NE of Mountain Lake	D	Nov.	1,403	9,750	
	N	Nov.	56	130	
No. 15, Massanutten	D	Oct.	6,164	6,164	3
	N	Oct.	126	126	
	D	Nov.	888	6,164	
	N	Nov.	54	126	
No. 18, Green Bank	D	Oct.	339	339	1
	N	Oct.	24	24	
No. 28, Deerfield	D	Nov.	755	5,240	2
	N	Nov.	59	138	

Examination of the values given in the fifth column above shows that the southern Maryland site surveyed by NRL and all of the AUI sites are in the same category insofar as radio quietness is concerned. Within this group there are trends that can be easily explained by the protective mountain configurations, and by the location of the nearby towns and cities. Thus the low figures given for Site 18, Green Bank, indicate the superiority of this site to all the others in regard to radio noise.

B. *Population Studies.*

The relationship between the white noise existing outside a valley and the size of the corresponding population was referred to earlier. To measure the population around each site, a distribution map was used, prepared by the Bureau of Census on the basis of 1950 census figures (Government Printing Office-1954 #290739). Counts were made of the populations within 20- and 50-mile radii of the several sites. The smallest population unit shown on the map represents 500 persons, which is so large as not to be suitable for an examination of the fine-grain structure close by the sites. But at a distance of 20 miles, the 500-person units blend sufficiently to provide smooth and significant data.

	Total Population Within	
Site	*20-Mile Radius*	*50-Mile Radius*
No. 1, Burkes Garden	113,750	—*
No. 11, Mountain Lake	65,000	—*
No. 15, Massanutten	48,000	294,000
No. 18, Green Bank	18,000	218,000
No. 28, Deerfield	22,000	241,000

**Exact value not determined; perhaps of the order of one-half million.*

This table makes it clear that Sites 18 and 28 are both in the most desirable class and that Green Bank is the first preference.

C. *Nearby Urban and Industrial Centers.*

Site 1, Burkes Garden, is only about 10 air miles from Bluefield, West Virginia, with a population of about 20,000. It would share with Bluefield any radiation beamed from Roanoke to the east, or from Beckley to the north.

Site 11, Mountain Lake, is roughly midway between and 45 air miles from Roanoke and Bluefield. It is about 20 miles northwest of Blacksburg and a similar distance east of Pearisburg. Thus it might find itself sprayed by radiation beamed along the Roanoke-Bluefield line.

Site 15, Massanutten, is located between the two forks of the Shenandoah River. Although Front Royal, at an air distance of some 15 miles and with a population of about 10,000, is the largest nearby community, industry is moving into both river valleys, and already many types of noise-generating activities exist on both sides of the site.

Site 18, Green Bank, is not on a direct line between any population centers large enough to make it likely that a transmitter will be placed in one, beamed in the direction of the other. Furthermore, the largest nearby place is Elkins, at an air distance of about 40 miles and with a population of about 10,000.

Site 28, Deerfield, is on a direct westward extension of the line from Charlottesville to Waynesboro to Staunton, and thus might easily be sprayed by radiation beamed from either Charlottesville or Waynesboro to Staunton. Furthermore, Staunton is at an air distance of about 20 miles, with a population of about 25,000. Future urban and industrial growth might thus be expected to increase the radio noise levels at Deerfield sooner, and to a greater extent, than at Green Bank. Moreover, the high mountains between Staunton and Deerfield to the west is the most likely location for a transmitter to beam radiation from Staunton toward Waynesboro and Charlottesville, and eventually there will probably be an effort to establish such a station. However well it might be designed, the transmitter would spill some unwanted radiation into the Deerfield valley and would constitute a future problem for the site.

Although it is not easy to assign numerical values, first preference is obviously Site 18, Green Bank.

D. *Airport Activities.*

Attempts were made to determine other possible sources of radio interference, such as the activities associated with airports. The following table gives the name and distance away in air miles of airports near each of the five sites; a measure of the air traffic by the length and type of runways; and other remarks.

Site	Airports	Distance (miles)	Runways No.	Runways Length (feet)	Runways Surface	Remarks
1. Burkes Garden	Mercer County (Bluefield)	15	1	4745	Bituminous	Piedmont* (11)
	Princeton	22	1	2700	Turf Crushed-Slate	—
	Welch	23	1	2165	Turf	Attended Days
11. Mountain Lake	VPI (Blacksburg)	12	1	2850	Bituminous	—
	Hinton-Anderson	23	1	2775	Turf	—
	Roanoke	30	3	4274	Bituminous	American* (5) Piedmont* (24)
15. Massanutten	Stokes (Front Royal)	10	2	3100	Turf	—
	New Market	13	2	2100	Turf	—
	Winchester	25	2	2250	Turf	Attended Days
18. Green Bank	Hannah	12	1	2600	Turf	Closed Winter Months
	Keller	30	1	2500	Turf	—
	Elkins	31	2	4542	Concrete	American* (2)
28. Deerfield	Shen-Myer	23	2	2600	Turf	—
	Pure Village	26	2	1700	Turf	—
	Waynesboro	27	1	3400	Gravel-Turf	Closed for Construction
	Keller	28	1	2500	Turf	—

**Total flights per day, in both directions, shown in parenthesis.*

Numerical ratings of sites would have little meaning here. Sites 18 and 28, Green Bank and Deerfield, appear to be the best situated at the moment, with Site 15, Massanutten, the third preference.

E. *Installation and Plans of the American Telephone and Telegraph Co.*

C. A. Armstrong of A. T. & T. has kindly supplied data concerning existing or planned installations that might raise the radio noise levels nearby. This information is shown on a map, reproduced here as Figure III-4. It would appear from this information that only Site 11, Mountain Lake, might be affected. As it is at least 20 miles away from the proposed relay line, with intervening mountains, the danger is very small.

F. *Other Installations.*

Inquiries were made through the National Science Foundation to the Federal Communications Commission and the Interdepartmental Radio Advisory Committee, located in Washington. While the replies to date have been most sympathetic, they have not been particularly informative.

G. *Recapitulation.*

As the December 1955 meeting of the Steering Committee approached, when a recommendation of

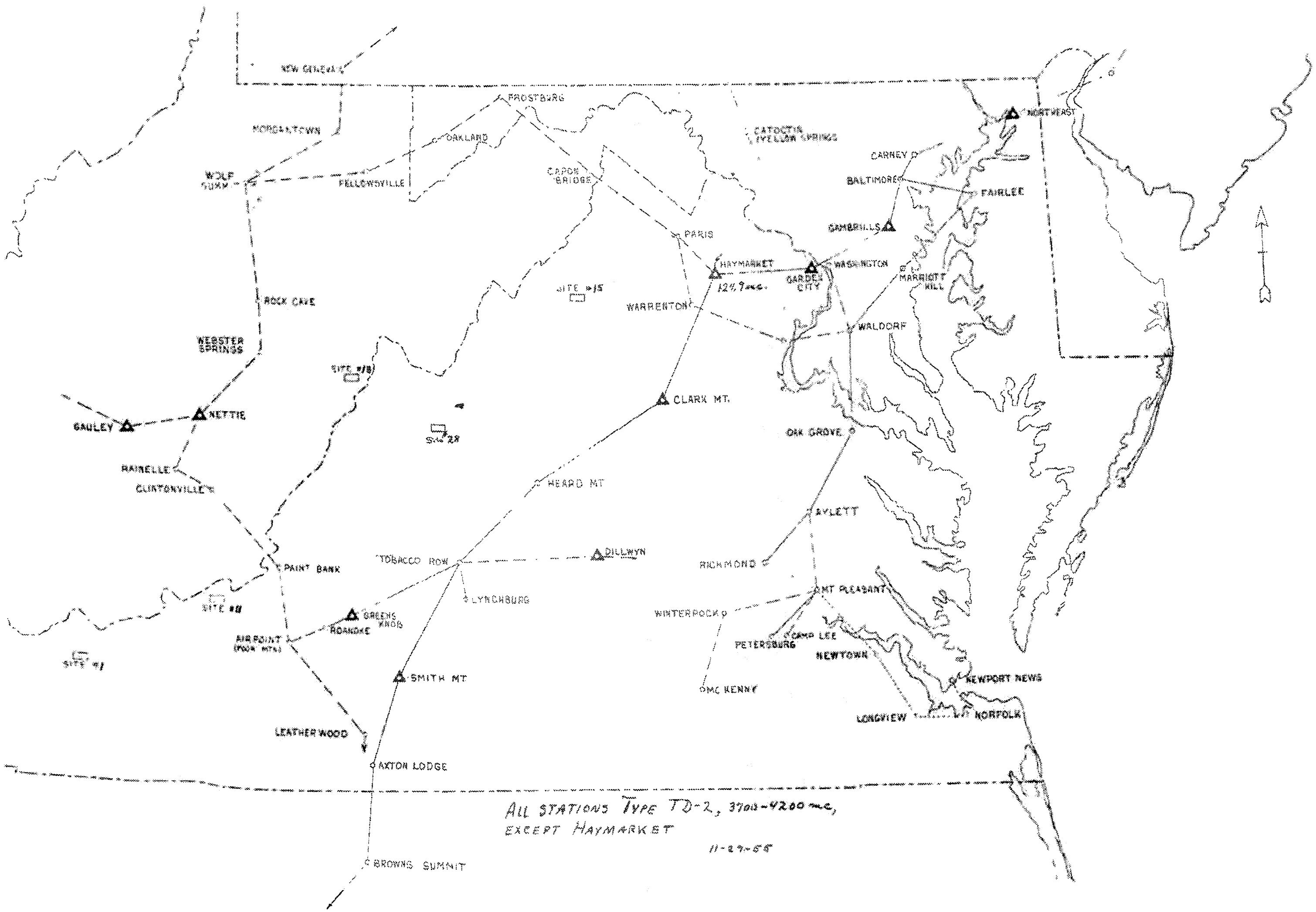

Figure III-4. Existing or Planned Commercial Communication Links in the Area Containing Five Possible Sites.

sites was expected, the survey had collected the following information concerning the five most promising sites:

Site 1, Burkes Garden, is a unique geological formation that somewhat resembles a lunar crater. The inner area covers almost 30 square miles. Because of the surrounding high mountain ranges, access to the site is difficult. The floor of the cove actually varies in level by 50-100 feet, with rock very close to the surface; hence, any leveling or foundation work would require considerable rock blasting. This site would probably be the most costly to develop. It stands fourth on the list on the basis of the radio noise measurements, and fifth on that of population studies. It is not particularly well placed with respect to nearby cities, and rates fourth or fifth on the basis of airport activities. Bluefield is reasonably accessible for shopping, transportation and other requirements of the staff.

Site 11, Mountain Lake, is the smallest of the sites and is largely covered by timber. Although it might be possible to arrange for timber clearing without cost, this extra step would certainly delay construction. If the site were cleared it would be adequate for the contemplated radio telescopes, but could not provide the flat areas needed for arrays. Only a mountain trail now enters the site area, and a complete road building program covering about 4 miles would be necessary. It is fifth on the list on the basis of radio noise measurements; fourth on the basis of population studies; it could be rated no higher than third in regard to nearby towns and cities; it is probably fourth on the basis of airport activities. Virginia Polytechnic Institute at Blacksburg would offer some academic attractions and Roanoke could provide other requirements.

Site 15, Massanutten, is actually a shallow gouge on the top of a mountain. Development costs would not be exceptional. Several placements could be made for the radio telescopes; with some leveling, arrangements could be made for arrays. The valley is so shallow, however, that very large telescopes would almost peek over the top of the shielding mountains at the rather extensive activities on either side. It is third in preference in regard to the radio noise measurements; third on the basis of population studies. Because the valley is so shallow, it is not well situated with respect to outside industrial and urban activity, and is third on the basis of airport activities. Strasburg and Front Royal could provide for the immediate requirements of the staff, with Warrenton and Winchester only a little farther. Washington, D. C., at a distance of about 100 miles by car, is the closest point for major requirements including transportation. This site is the closest to Washington, a fact that may be rated as an advantage or disadvantage according to the viewpoint of the rater.

Site 18, Green Bank, is a triangular-shaped valley, about 4 miles across at the southern base and extending about 3 miles northward. Deer Creek Valley on the west side is some 50 feet below the average elevation of about 2700 feet. Mountains of 4000 or more feet rise in multiple folds in all directions. The site would be easy to develop for all parts of the facility, including the installation of arrays. There are about 125 houses, stores, churches, and other buildings in the valley, so the level of internal activity is relatively low. On the basis of the radio noise measurements, Green Bank is clearly the first preference; it is first on the basis of the population studies, and the population has been decreasing in recent years; it is first on the basis of the location of nearby towns and cities, and first or second on the basis of airport activities. Although Green Bank offers a good school, churches, and two stores, Marlington 30 miles to the south, or Elkins 50 miles by car to the north, would provide for most staff requirements. Elkins offers both air and rail transportation; Davis-Elkins College is located there. The University of West Virginia at Morgantown, is approximately 100 miles distant.

Site 28, Deerfield, is a valley with physical characteristics intermediate between those of Massanutten and of Green Bank. Deerfield itself is actually smaller than Green Bank. It is second in preference on the basis of the radio noise measurements and second on the basis of population studies. Difficulties might develop in the future because of its closeness to Staunton, a situation similar to that of Burkes Garden with respect to Bluefield; it is first or second with respect to airport activities. Staunton could provide for most staff requirements. It is about 80 miles by car from the University of Virginia.

The five sites described above are shown on a map of the eastern United States in Figure III-5. Distances in miles from Green Bank (Site 18) to colleges, universities, and major cities are shown under the various names.

Figure III-6 is a photo of the Army Map Service three-dimensional model of part of the search area, showing sites 15, 18 and 28. Site 15, Massanutten, is the long gouge in the top center, running from east of north to west of south. In the lower part of the map will be found the east west population and industry axis from Charlottesville through Waynesboro to Staunton. Westward from Staunton along this axis will be found Site 28, Deerfield. Slightly north of this axis and on the western edge of the map will be found Site 18, Green Bank.

V. RECOMMENDATIONS

A meeting of the Steering Committee was scheduled for December 11-12-13, 1955, in Washington, D. C., chiefly to consider the information that had been collected on sites, and to recommend a specific site priority or preference.

A. *Inspection Trip December 2-3, 1955.*

Because of logistic difficulties aggravated by the uncertainties of winter weather, it did not seem feasible to attempt a flying trip on December 12 to inspect the five most promising sites. Accordingly, a preliminary inspection trip was arranged for December 2-3. The

Figure III-5. Map of Eastern United States Showing the Location of Five Sites and the Airline Distance From Site 18 to Colleges, Universities and Major Cities.

Figure III-6. Photograph of Army Map Service three-dimensional model of part of search area.

following group left Washington, D. C. by car on the morning of December 2:

Burke, Ekland, Firor, Franklin, Tatel, Tuve and Wells (Dept. of Terrestrial Magnetism, Carnegie Institution of Washington).

Dyer (University of Virginia).

Chambers (Univ. of Pennsylvania AUI Trustee).
Cutts (National Science Foundation).

McFadden (Eggers & Higgins).

McClain (Naval Research Laboratory).

Berkner, and Emberson (Associated Universities, Inc.).

Sites 15 and 28 were visited in that order. Discussions took place enroute and at the sites. Tuve and his group returned to Washington from Site 28; those remaining proceeded to Site 18 on the same day. On December 3, Chambers had to return to New York; the rest of the group visited Site 1. Site 11 could not be visited because recent rains and snow made it impossible to reach.

B. *Briefing.*

On Sunday evening, December 11, the following group met in Washington, D. C.:

J. P. Hagen, F. T. Haddock, and E. F. McClain (Naval Research Laboratory)

B. J. Bok, H. I. Ewen (Harvard)

J. G. Bolton (California Institute of Technology)

H. E. Tatel, M. A. Tuve, B. J. Burke, J. W. Firor (Dept. of Terrestrial Magnetism, CIW)

E. R. Dyer (Univ. of Virginia)

S. L. Bailey, D. C. Ports (Jansky & Bailey, Inc.)

C. E. Cutts, H. S. Hogg (National Science Foundation)

E. B. Eckel, C. R. Tuttle (U. S. Geological Survey)

J. Feld (Consulting Engineer)

J. J. McFadden (Eggers & Higgins)

L. V. Berkner, C. F. Dunbar, R. M. Emberson, M. B. Karelitz, and T. P. Wright, Trustee from Cornell, (Associated Universities, Inc.)

Emberson briefed the group, essentially with the data given in the earlier parts of this Chapter. Lengthy and, at times, detailed discussion followed on all aspects of the site problem: radio quietness, geographic requirements, and the philosophy of operation of the facility.

C. *Inspection Trip.*

On Monday, December 12, to inspect a more-or-less typical site situation, the following group visited Site 15 by chartered bus:

B. J. Bok, J. G. Bolton, F. T. Haddock, E. F. McClain, L. V. Berkner, C. F. Dunbar, R. M. Emberson, M. B. Karelitz, T. P. Wright, E. R. Dyer, E. B. Eckel, J. Feld, H. S. Hogg, J. J. McFadden and C. R. Tuttle.

Again, all aspects of the site problem were discussed during the day and, of course the characteristics of Site 15 were critically considered. During these discussions, Eckel and Tuttle advised that the five sites under consideration appeared to be about the same insofar as the problem of sub-surface geology and foundations is concerned and that this was not, therefore, a determining factor.

D. *Steering Committee Recommendations.*

The Steering Committee met in the Board Room of the National Science Foundation on Tuesday, December 13, the following being present:

J. P. Hagen, Chairman	N. H. Frank
L. V. Berkner	F. T. Haddock
B. J. Bok	H. S. Hogg
J. G. Bolton	M. B. Karelitz
C. F. Dunbar	E. F. McClain
E. R. Dyer	J. J. McFadden
E. B. Eckel	D. C. Ports
R. M. Emberson	R. W. Schloemer
H. I. Ewen	H. E. Tatel
J. Feld	C. R. Tuttle
	M. A. Tuve

After more discussion, the following actions were taken, the quotations being from the Minutes of the meeting:

"At the conclusion of the discussion, on motion by Dr. Tuve, and seconded by Dr. Bok, all members of the Committee present voting, it was unanimously

"VOTED (1) It is the recommendation of the Committee that the site near Green Bank, West Virginia, subject to verification* down to very low field intensities of the expected low radio interference level, be selected specifically for the proposed 140-foot parabolic reflector, and possibly for two or three antennae rays or other equipments of modest cost; and

**At the March 26 meeting of the Committee, the matter of additional noise surveys was discussed. It was recognized that no available portable equipment could measure the extremely low levels of interest to radio astronomy and that the relative measures already completed were as much as could be expected. Accordingly, the requirement of additional noise measurements was rescinded.*

(2) This recommendation is made without prejudice to the possible location or locations which may in the future be recommended if this National Radio Astronomy Facility grows to include other specialized equipment or laboratory facilities.

"There followed a discussion on the need for acquiring a large area to insure protection against interference. The consensus was that the area to be acquired or controlled should be as large as feasible.

"At the conclusion of the discussion, on motion by Dr. Tuve, seconded by Dr. Bok, all members of the Committee present voting, it was unanimously

"VOTED: It is the recommendation of the Committee that all or nearly all of the land in the Green Bank, West Virginia, valley, as shown on the attached map*, be acquired by direct purchase or as an alternative, suitable controls, e.g., by some agency of the State of West Virginia, be arranged to insure the future continued suitability of this valley for this National Radio Astronomy Facility; and the Committee is confident that the U. S. Forest Service will assist in maintaining radio quietness of the surrounding forest and overlooking mountain heights.

"There followed a discussion on the desirability of making an alternate recommendation with respect to a site to meet the contingency that the Green Bank site may prove unsuitable. Dr. Berkner pointed out that the selection of an alternate or alternates would have the further advantage of strengthening the bargaining position in acquiring land.

"After discussion, on motion by Dr. Tuve, seconded by Dr. Bok, all members of the Committee present voting, it was unanimously

"VOTED: It is the recomendation of the Committee that, if preliminary detailed studies indicate difficulties with the Green Bank site, the Deerfield and Massanutten sites are to be studied as alternates, in that order."

VI. SUMMARY

A recommendation was made by a unanimous vote of the Steering Committee, that Site 18, Green Bank, Site 28, Deerfield, and Site 15, Massanutten, be considered as sites for the National Radio Astronomy Facility, the preference being in the order listed above. The technical basis for this recommendation is condensed in the following tabulation of ratings:

	Green Bank	*Deer-field*	*Massa-nutten*
Radio noise Measurements	1	2	3
Population Studies	1	2	3
Airport Activities	1-2	1-2	3
Mountain Shielding	1	2	3

**Figure III-7 Portion of Geological Survey map, and Figure III-8 Air Photograph of Same Region.*

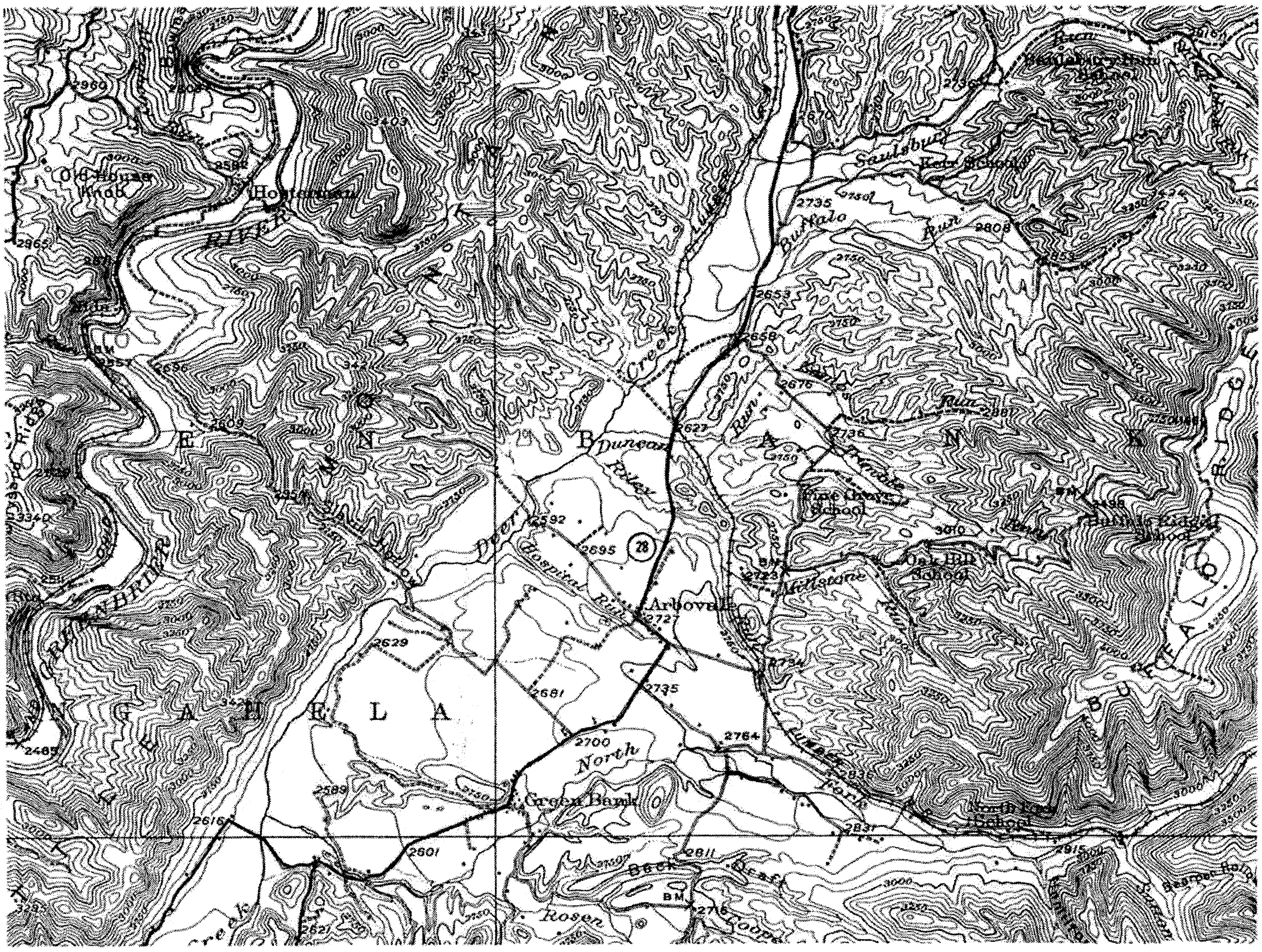

Figure III-7. Portion of U. S. Geological Survey Map of the Cass Quadrangle in West Virginia Showing the Green Bank Valley.

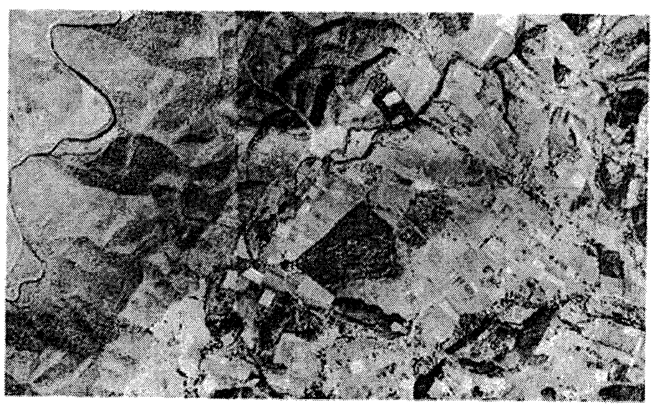

Figure III-8. Air Photograph of the Green Bank Valley.

Chapter Four
EQUIPMENT

The research equipment for the Radio Astronomy Observatory may be divided into two large categories. The first consists of antenna systems, which may be arrays of dipoles or similar elements, fixed segments of a parabolic surface or the equivalent thereof, or steerable parabolic reflectors. All of these antenna systems present structural problems and radio frequency (rf) problems. Pointing or tracking may be accomplished with arrays by purely rf phasing techniques or sometimes by a combination of rf and structural devices. For the steerable paraboloids, pointing and tracking is essentially a mechanical problem, combined with various electrical and electronic devices involved in the indicator and power control components.

The second category consists of the receivers, special test calibration instruments, devices for the presentation, storage and analysis of data, precision time references, regulated power supplies, and similar electronic and electro-mechanical devices. It should be noted that in this discussion of equipment the obviously necessary laboratory aids such as typewriters, calculating machines, books and journals, lathes, drill presses, and hand tools are intentionally omitted.

I. BASIC EQUIPMENT

This chapter will discuss primarily the equipment in the first category. The second category is, of course, important also but all radio astronomy programs have basically the same requirements for carefully designed receiver and other electronic components. The receiver, for example, must be very stable, have a very low noise figure, and provide a satisfactory coverage of some prescribed portion of the electromagnetic spectrum. Beyond such general characteristics, the receiver must be designed to meet the requirements of a particular research program, and for this reason no effort has been made to prepare detailed specifications or designs for the electronic equipment before the staff of the facility is organized. Since it is generally agreed, however, that the large radio telescopes must be designed for the most efficient and effective use possible, there will be justification for building receivers and other devices more elaborate than might be deemed practical for smaller installations.

A. *Philosophy.*

The choice of antennas for the Radio Astronomy Observatory is based on the philosophy that the facility should provide research opportunities not available elsewhere. The availability of the large steerable paraboloids (radio telescopes) depends to a large extent on the cost, which varies probably as the cube of the diameter of the reflector. In offering the use of other types of antenna systems that cost less, and are thus more widely available, the facility is nevertheless offering unusual research opportunities: a favorable intellectual environment and an observational environment that will probably become more and more unique with the passage of time as a consequence of the growth of electromagnetic transmitting systems elsewhere throughout the United States. In fact, the low level of radio interference at the facility site may induce other research groups, whose equipment construction programs are financed quite independently of the facility, to arrange on a relatively long-term basis for the location of their equipment at the facility site.

As pointed out in Chapter One, many research projects require the use of very large radio telescopes; since their cost is beyond the means of the average university, it has been agreed that such instruments should be the prinicipal items in the equipment program for the Facility.

B. *Very Large Reflectors.*

At the outset, we face the question: Are there any real technical limitations of construction on the maximum size of steerable radio telescopes? A fixed system such as a parabolic bowl hollowed out of the earth, might conceivably be made a mile or more in diameter. But when we require also that the reflector be steerable, we confront serious structural problems and one of the most fundamental is the strength of the materials. This question has been put to several structural experts and the consensus is that diameters of several thousand feet are feasible with the structural materials now available, provided that cost is no object. No serious problems of phase coherence were anticipated across apertures of such dimensions.

The Steering Committee meeting of March 26, 1955 discussed the design and construction of a radio telescope, much larger than the 250-foot instrument under construction in England. They agreed, in general, that size had to balanced against cost, even when planning for a facility supported by the Government. As a result of this compromise, a diameter of 600 feet was selected and Jacob Feld of New York City was asked to undertake a design study, not only to provide information on the construction of a 600-foot radio telescope, but also to present the basic factors that should be considered in the design of any large radio telescope.

The Feld study was based on the following specifications:

> Paraboliod reflector, 600-foot diameter, f/d ratio between 0.35 and 0.5, with a preference for the longer focal length.

Surface tolerance ± 1 inch over the entire aperture and ± 5/8 inch over the inner half aperture.

Surface material, to be sheet or any continuous material; so-called "woven" materials must be bonded at all points. If open type material is used, the largest dimension of such openings must not be greater than 1/4 inch.

RF feed at focal point to be based on a load of 500 pounds and to be held in the proper position to within 1/8 inch, for winds up to 30 mph or for any altitude of the reflector.

Sky coverage to be hemispheric, with the ability to point below the horizon in at least one position. If an equatorial mount is utilized, sky coverage may be decreased to a motion of 8 hours (120°) about the polar axis and a declination motion from 5° below the pole to 5° below the southern horizon.

Rigidity and Pointing Accuracy to be designed for 5 per cent (1 per cent might sometime be desirable) of the half-power width for 10 centimeter radiation, or about 7′ of arc.

Slewing Rate, two speed, or variable, between 5 and 30 degrees per minute of time; or not more than 20 minutes to move the telescope from one point in the sky to any other point.

Tracking and Guiding Rates to compensate for the rotation of the earth with an added rate, in either direction for either coordinate of 30 minutes of arc per minute of time.

Feld started his study on April 27, 1955 and reported to the Steering Committee at the July 12, 1955 meeting. The lengthy report, of a highly technical nature, was reproduced in a limited number of copies and, therefore, has not been widely distributed. In brief, he concluded with certain qualifications, that a 600-foot radio telescope was feasible; that the desired surface tolerances and over-all rigidity could not be obtained with standard structural design and construction unless a prohibitive amount of steel was employed; and that the alternative is a basically simple structure, servo-corrected to stay within the specified tolerances. To illustrate this point with a specific example, consider the support for the rf feed, to be located at the focus of the paraboloid. As the focus was to be located 300 feet from the vertex of the paraboloid, our requirements were for a mast or other support 300 feet long that would carry a load of 500 pounds and not move more than ± 1/8 inch when turned from a vertical to a horizontal position. No practical amount of steel, in the mast or guy-cables, could give the desired rigidity. But a simple arrangement to vary the guy-cable tension as a function of the sine of the zenith angle will achieve the desired result. The application of adjusting devices to the paraboloid surface is admittedly a more complex problem; but the same principle applies, and future studies on the construction of large radio telescopes will include this aspect of the problem.

C. *Radomes.*

Early in the program for large radio telescopes, the question arose as to which type of telescope to choose: one designed to stand in the open, or a structurally simpler telescope protected from the weather by a radome. Investigation showed that radomes with a radius as large as 1000 feet were technically feasible, and two types were considered. A self-supporting structure was rejected on the basis of its rf-characteristics; the "shell" of such a radome would be two sheets separated by a cellular structure, and if the spacing happened to be some even multiple or fraction of the wavelength being observed, serious interference complications might result. For military purposes, where wavelengths in a relatively narrow portion of the spectrum are employed for any one piece of equipment, the shell thickness can be chosen so as to prevent interference difficulties. Radio astronomy, however, is interested in all wavelengths than can be observed with the radio telescope, within the limits at the short wavelengths set by the surface defects of the reflector, and those at the long wavelengths set by the diameter of the reflector or other such dimensions. Therefore no practical shell thickness could be chosen. Furthermore, the interior strut system for a self-supporting radome might introduce diffraction and reflection effects that would needlessly complicate precise observations.

Air-supported radomes were deemed to be technically feasible. Tests made and reported by L. C. Van Atta, Hughes Aircraft Company, indicated that the rf characteristics of the radome materials would be satisfactory but the life predicted for the material was no more than ten years. While this might be deemed satisfactory for military purposes, it did not seem practical for a Radio Astronomy Observatory in view of the initial high costs (several million dollars for a radome for a 600-foot telescope). On the basis of thorough discussions at the March 25, 1955 conference, and later with other consultants, the decision was made to build all radio telescopes to stand in the open.

II. THE 140-FOOT RADIO TELESCOPE PROGRAM

At its March 26, 1955 meeting, the Steering Committee concluded that the Radio Astronomy Observatory should be established and put into operation as promptly as possible. The Committee therefore proposed that immediate steps be taken to provide a radio telescope with an aperture of about 150 feet. It was suggested that several military designs for paraboloids in the 50- to 80-foot diameter range might be extrapolated to a greater than 100-foot size and still be essentially an "off-the-shelf" design and construction task. It was suggested that bid proposals be requested on the entire task of designing, fabricating and erecting a radio telescope to meet performance specifications prepared by us.

An initial draft of such specifications was prepared in April, 1955, and discussions began with representatives of firms selected because of their known competence and interest in devices comparable in size and complexity to the desired radio telescope. As a consequence of these discussions, the request for proposals and the specifications went through several revisions, ending with a May 28 version calling for a 140-foot radio telescope.

A. *May 28, 1955 Specifications.*

These specifications permitted a choice of altazimuth or equatorial mount, with complete hemispheric-sky coverage, plus an ability to point below the horizon in some position.

Other specifications were as follows:

- Focal length/diameter ratio 0.35 to 0.5, with the larger value preferred.
- Surface tolerance ± 3/8 inch over the entire aperture and ± 1/4 inch over the inner half aperture.
- Surface material to be electrically equivalent to a continuous sheet, with the largest dimension of any opening not more than 1/4 inch.
- RF feed support capable of a 500 pound load held to 1/8 inch of correct position.
- Rigidity and drive and control system to be capable of an accuracy of 5 per cent of the beam width at half power for 10 centimeter radiation, or about 30" of arc.
- Design for normal use in winds to 30 mph, and with slight reduction of accuracy in winds to 45 mph.

Suitable provisions were made for slewing, tracking and manual guiding rates. Also, a programmer was requested that would perform the necessary conversion from altitude and azimuth to hour angle and declination, in the case of an altazimuth mount, and would for all cases provide for tracking non-sidereal objects such as the sun or moon, and would permit devices to be added later, for tracking in galactic coordinates.

Twenty firms responded to the request for proposals. Some eventually replied that the problem was beyond their capabilities. Others indicated that they would be happy to attack a part of the problem that was within their special experience, but that they would hesitate to undertake the entire task. Five replied that they would be willing to undertake the entire task. Their estimates of the cost varied widely. No firm seemed to have in mind a design that we could expect, with confidence, to produce a radio telescope with the desired performance characteristics. Informally we were advised that a more satisfactory program would entail two steps; first, to obtain a design in which we had confidence; and second, to seek bids for its fabrication and erection.

B. *Designs for the 140-Foot Telescope.*

The Steering Committee at its July 11-12, 1955 meeting reviewed this situation and agreed that the suggested two-step program should be adopted. Arrangements were then made for the development of three designs (the listing below is in alphabetical order and has no other significance).

1. Feld indicated that he would welcome an opportunity to test design solutions from the 600-foot telescope study on a smaller instrument. He also believed that he could make a 140-foot design with this purpose in mind that would compete in cost with designs made specifically for the 140-foot size. Accordingly, he was asked to develop a 140-foot design.

2. H. C. Husband, who is responsible for the preliminary studies, the design and the current construction of the 250-foot telescope for the University of Manchester, was asked to develop a 140-foot design in order that we might benefit from his vast experience.

3. Finally, D. S. Kennedy and Company was asked to undertake a 140-foot design, because of their experience in constructing parabolic reflectors for special military purposes, and radio astronomy telescopes for several institutions in the United States.

Work on these designs was not started until November 1955, after the second Foundation grant became available. Meanwhile, several conferences on specifications were held in the fall. Those of May 18 were revised and issued on October 25, 1955. The significant changes were as follows:

1. The alternative of an equatorial mount was dropped, because all the engineering consultants agreed that for a 140-foot size the structural complications of an equatorial mount were greater than for the coordinate converter necessary for an altazimuth mount.

2. The surface tolerance was changed to ± 1/4 inch over the entire surface, which would be quite satisfactory surface for 5 or 6 centimeter wavelengths and probably would be good over a considerable portion of the area for wavelengths as short as 3 centimeters.

3. The requirements for rigidity and drive and control accuracy were reduced to 10" of arc, which corresponds to 5 per cent of the beam width at half power for 3 centimeter radiation.

C. *The Drive and Control.*

Both the Husband and Kennedy designs were to include a drive and control system. Dr. Feld claimed no capabilities in this field, and it was agreed that his design should provide only for the installation of the necessary drive and control motors, and not include plans for a complete system.

Recognizing the difficulty of the drive and control problem, the Advisory Committee suggested that additional work be done on it. Accordingly, a general study of the problem of drive and control was initiated with the Servomechanisms Laboratory of the Massachusetts Institute of Technology. Although the study was intended to lead to specifications for the drive and control system for the 140-foot radio telescope, this objective had to be revised when it became clear (see tabulation in next section) that the three structural designs exhibited very large differences in the weights and moments of inertia and in the estimated power required to move the telescopes. The MIT study, therefore, was confined to more general considerations.

While this study was proceeding, several commercial firms with known abilities in the servomechanisms field, particularly with respect to large equipment, were advised of our 140-foot radio telescope program. These firms started a study to determine what they might contribute to the solution of the problem. At the time of writing this document, there are indications that several firms would be interested in undertaking the entire drive and control system, while others would be willing to undertake only a part of the system.

The reports from all of the above studies are not yet available, but it appears that they will agree on the following points:

1. The desired precision of 10″ of arc is at the limit of present technical capabilities.

2. The 30″ specification of May 28, 1955, could be achieved without too much difficulty; a 20″ precision could probably be obtained; the 10″ precisions may have to wait on the development of improved techniques and components.

3. An ideal drive and control system would compensate for any changes in the structure of the radio telescope due to gravity, temperature differences, winds, and similar causes, and would constantly point the rf beam of the telescope in the proper direction.

4. For practical reasons, it will probably not be possible, generally, to employ a closed servo system, similar to a military fire control system that locks on and follows a target.

5. It will probably be necessary to separate the drive and control commands, developed from the known coordinates of the celestial object and a precision time source, from compensations for gravity, thermal, and similar effects. This type of "open-ended" system places a premium on a rigid telescope structure.

D. *The Feld, Husband and Kennedy Designs.*

It is beyond the scope of this chapter to discuss in detail the three designs for the 140-foot radio telescope. The designs were not competitive, in the sense that no effort would be made to select a single design in advance of actual bidding.

Figure IV-1 is a general view of the Feld design. The parabolic reflector is mounted on two towers supported on a cross-bridge that rotates on a central azimuth bearing. The ends of the bridge, under the towers, are extended and provided with rollers that rest on concentric railroad tracks; these end wings will take care of any wind moments. Figure IV-2 is an end view, showing the vertical tower with an altitude bearing at the top. Figure IV-3 shows in the top drawing a cross-section of the reflector, and in the lower drawing shows a broadside view of the radio telescope. The reflector itself is a thin shell supported only at its perimeter by a massive ring girder. A truss braces across the ring between the tower bearings, to take care of lateral wind forces; this truss is not attached to the parabolic shell.

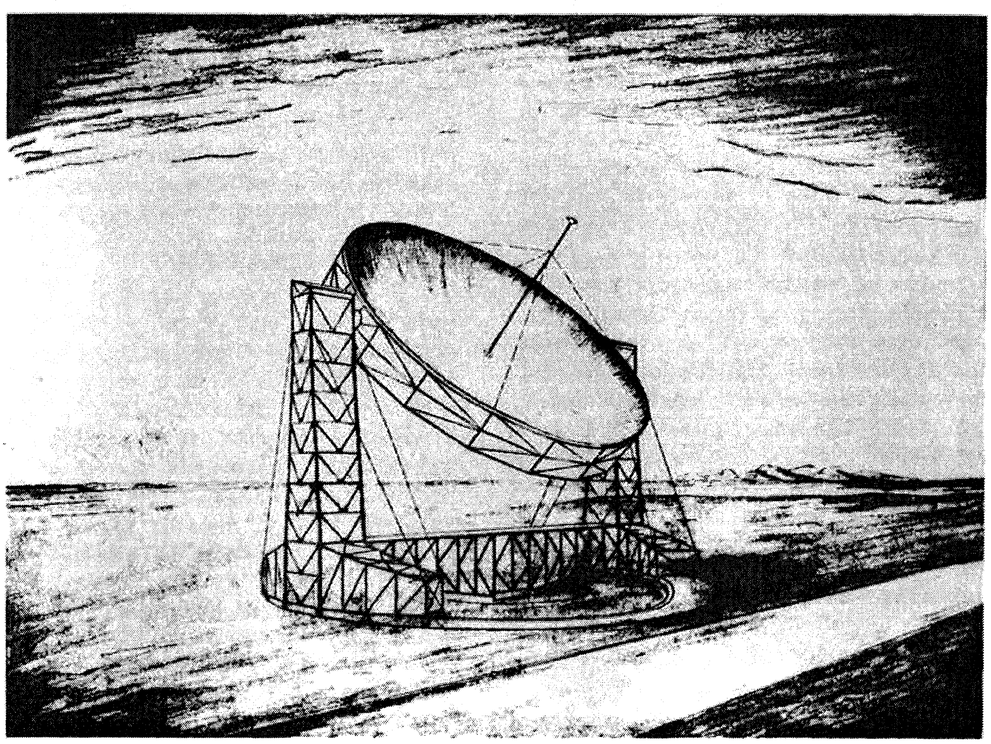

Figure IV-1. General View of the 140-foot Altazimuth Radio Telescope Design Proposed by Dr. Jacob Feld of New York City.

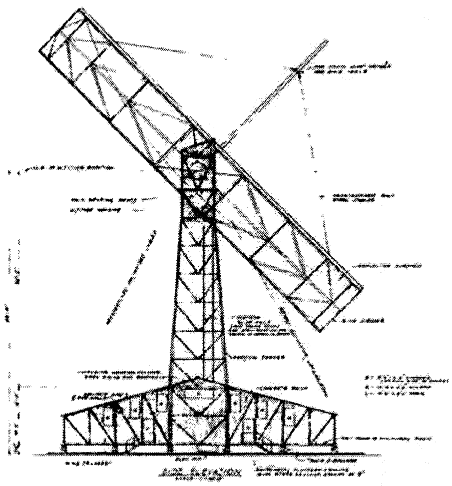

Figure IV-2. Side Elevation of Feld Radio Telescope.

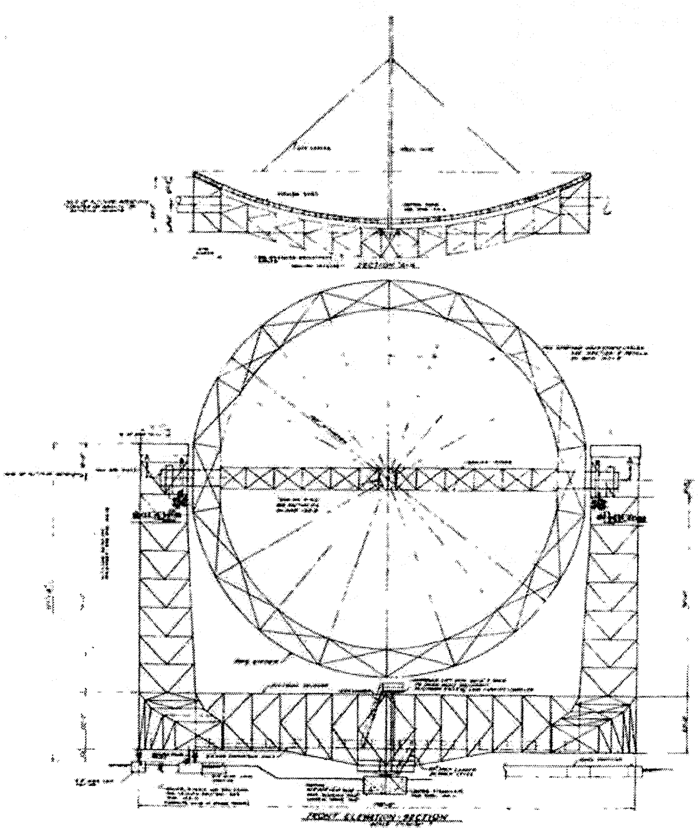

Figure IV-3. Cross-Section of Reflector, Ring Girder, and Truss and a Front Elevation of the Feld Design.

Figure IV-4 shows four drawings of the Husband design. The configuration was independently conceived but is somewhat similar to a model built by Grote Reber in 1948. The outstanding characteristic of this design is the great thickness of the reflector and its support. The reflector is built into one side of a cylinder; the length and diameter of the cylinder are a large fraction of the diameter of the reflector. The cylinder is mounted between two altitude bearings at the top of two towers, as in the Feld design. But in the Husband design most of the weight of the reflector and cylinder is carried by four circumferential bands that rest on rollers mounted on the cross-bridge. Also unlike the Feld design, the Husband design places only a fraction of the total dead-weight on the central azimuth bearing and the wing extension rollers put most of the weight plus any wind loads on the concentric tracks.

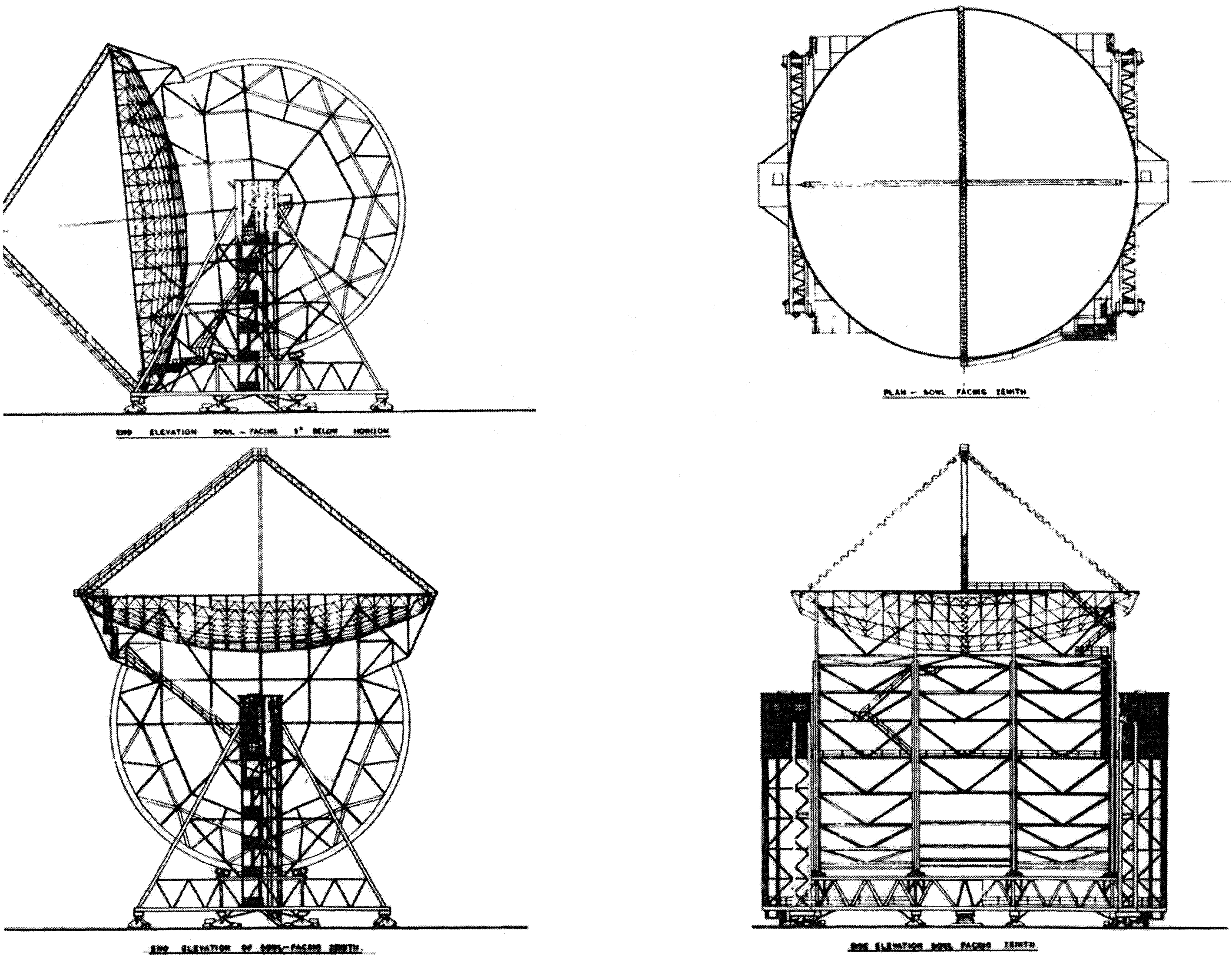

Figure IV-4. Four Drawings by Husband & Company of Sheffield, England for the proposed 140-foot Altazimuth Telescope Design. The two end elevations show the reflector pointed to the Zenith and Horizon. The front elevation again shows the reflector pointing to the Zenith. The Plan View shows the quadrapole support for the antenna feed.

Figure IV-5 is a side view of the Kennedy design and Figure IV-6 is a rear view. The reflector is built integrally with a system of rear supporting trusses. The entire assembly is carried by altitude bearings at the end of a horizontal D-shaped turret. The reflector is balanced about the altitude axis by counterweights on the large-radius gear sectors. The D-shaped turret rests on an oil-pad bearing ring mounted at the top of a rigid concrete (or possibly steel) silo, thus providing a very smooth operating azimuth bearing. Figure IV-7 is a cut-away view of the Kennedy design. Note that the symmetrical altitude gear sectors are cross-connected by a large diameter torque tube in a manner to provide the reflector and trusses with an equivalent thickness and rigidity comparable to the cross-section of the sectors. The concrete silo is protected from direct sunlight or other possible causes of variable temperature changes by a stand-off metal shield.

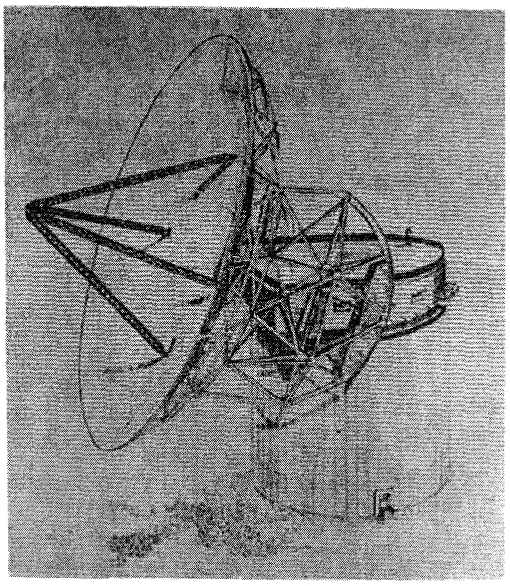

Figure IV-5. General side elevation of 140-foot altazimuth telescope proposed by D. S. Kennedy Company of Cohasset, Massachusetts.

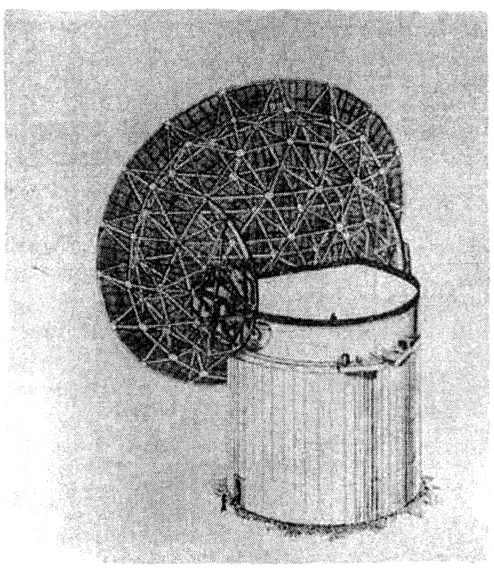

Figure IV-6. Rear Elevation of Kennedy Design showing truss structure of the reflector.

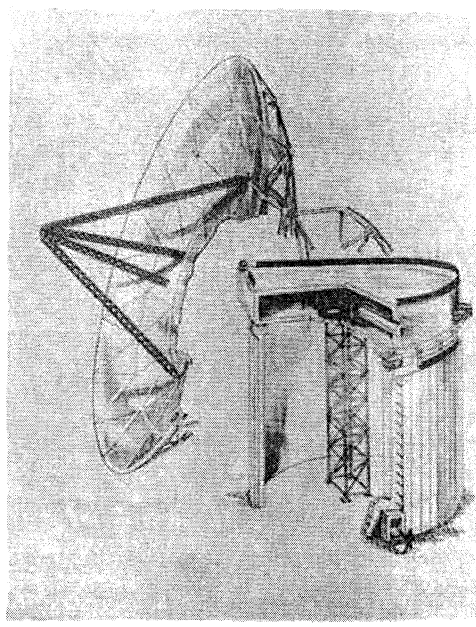

Figure IV-7. Cut-away view of Kennedy Design showing the torque tube connecting the altitude gear sectors.

The following table gives a brief summary of the weights, moments and power requirements.

PRELIMINARY TABULATION OF
WEIGHTS, MOMENTS, AND DRIVE POWER REQUIREMENTS

Item	*Feld*	*Husband*	*Kennedy*
Reflector weight (tons)	219	130	146
Elevation axis load (tons)	333	735	248
Azimuth axis load (tons)	520	1385	1713
Structural steel (tons)	410	1125	778*
Machined parts (tons)	110	260	365
Moment of Inertia (lb-ft^2)			
Elevation	9.5×10^8	36.4×10^8	3.9×10^7
Azimuth	30×10^8	71.7×10^8	1.8×10^8
Horsepower (hp)			
Elevation—fast	2-60	4-40	1-25
—slow	2-7.5	geared 120:1	
Azimuth —fast	2-30	4-40	2-25
—slow	2-3	geared 120:1	

**About 45 tons of aluminum would also be used, e.g., for the surface of the reflector; almost 700 tons of concrete would be used in the D—turret and counterweights.*

E. *A 140-Foot Equatorial Mount.*

In a previous section it was mentioned that the alternative of an equatorial mount was dropped from the October 25, 1955 specification for the radio telescope. Our consultants believed that an equatorial mount was technically feasible in the 140-foot size, but estimated that the structural costs would be 25 to 50 per cent greater than for the equivalent altazimuth mount, because of greater off-axis distances, heavier counter weights, bigger bearings or other arrangements for distributing the added load, more weight (and larger moments) to be moved and, hence, heavier gears and similar devices. It was generally believed that the added complexity of a drive and control system for an altazimuth mount would more than compensate for the $400,000 or so thus added to the structural costs. Furthermore, there was general agreement that any larger radio telescopes would not be equatorial mounts; this suggested that we should learn as much as possible from the 140-foot telescope to help with the future design of larger instruments.

On the other hand, some members of the Advisory Committee, and other astronomers interested in the program, had serious reservations concerning the operating reliability of an altazimuth telescope as compared to an equatorial instrument. As a result of their view, the National Science Foundaton asked (by letter from Raymond Seeger to L. V. Berkner, dated March 22, 1956) that a 140-foot equatorial design be developed.

The Advisory Committee reviewed the matter carefully at its March 27-28, 1956 meeting and recommended that we proceed with an equatorial design development to meet the same specifications as required of the altazimuth designs. It was the consensus that the altazimuth program should proceed as rapidly as other controlling factors would permit, up to and including an invitation for bids, but no contract should be awarded on the basis of such bids until the equatorial design was available for consideration. Indications were that this stage might be reached by August 1956.

F. *Review Procedures.*

It was obvious that two reviews would be needed. First, before any bids are invited, the telescope designs must be independently and objectively reviewed for adequacy, to make sure that fabrication and construction according to any one of the designs might be expected to produce a radio telescope having the desired performance capabilities. Second, bids on the designs must be reviewed in order to determine which bid or combination of bids promises the best telescope for the money spent. Because of the importance of the above tasks, it was decided to augment the engineering talent represented by various members of the Advisory Committee and M. B. Karelitz, who had joined the study at an early stage as an engineering consultant.

The following list of consultants is divided into five groups. The first three are groups of structural experts, initially assigned to review the Feld, Husband, and Kennedy designs, respectively; the fourth group is primarily concerned with drive and control problems and the fifth with rf characteristics.

Robert S. Ayre	—Johns Hopkins University
P. P. Bijlaard	—Cornell University
Sidney Shore	—University of Pennsylvania
N. A. Christensen	—Cornell University
Alfred N. Freudenthal	—Columbia University
T. R. Kane	—University of Pennsylvania
Ned L. Ashton	—University of Iowa
N. J. Hoff	—Polytechnic Institute of Brooklyn
Thomas C. Kavanagh	—Prager and Kavanagh, N. Y. C.
Dana Young	—Yale University
Ralph J. Kochenburger	—University of Connecticut
David P. Lindorff	—University of Connecticut
Wilbur E. Meserve	—Cornell University
E. J. Poitras	—Holliston, Mass.
C. E. Wilts	—California Institute of Technology
L. C. Van Atta	—Hughes Aircraft Company

III. A POSSIBLE RADIO TELESCOPE PROGRAM

In a letter of May 6, 1955, to the National Science Foundation, provisional estimates for study purposes were given for five-year budgets for construction and operations. This tentative proposal included four radio telescopes, having diameters of 25 to 50 feet, 140 feet, 250 feet, and 600 feet. The Steering Committee, and later the Advisory Committee, reviewed this matter and by January 1956 the tentative long-range radio telescope program suggested the possibility of five instruments, as follows:

1. 28-foot (a "standard" size; although small, it would be very useful in the development of electronic components and is also capable of making worthwhile observations).

2. 60-foot (another "standard" size; the specifications would be similar to those of the new telescope at the Harvard Agassiz Station, although the suggestion was made to mount it on tracks to provide for possible use with the 140-foot telescope as an interferometer).

3. 140-foot (a precision instrument, as already described).

4. 250-to 300-foot (which might also be a scale model of a larger instrument).

5. 600-foot (generally according to the specifications given for the Feld study).

At the March 1956 meeting of the Advisory Committee, the consensus was that four telescopes be included in the initial construction: one 28-foot, two 60-foot, and one 140-foot. Two 60-foot telescopes were included because of the prospects of increased demands for observing time by college and university faculty members and students. Also, two identical instruments would facilitate their possible use as an interferometric pair.

A. Interferometers.

It has been proposed that the radio telescopes be located at the site in a manner to facilitate their possible use as interferometer pairs. But it was pointed out that the interferometer problem is difficult even if two identical telescopes are employed. The problem becomes very complicated if the two telescopes are not of the same size and if one is an equatorial mount, while the other is an altazimuth or other configuration. Accordingly, the decision has been made to locate the telescopes in pairs on east-west lines, in order to take advantage of the topography of the site; but no extra effort will be made at this time to provide for the possible future use of the telescopes for interferometric work.

B. Test Procedures.

The specifications for the 140-foot radio telescope call for precision beyond that of ordinary construction. None of the general test procedures used on structures of comparable size will be suitable. Neither does it appear feasible to employ procedures that are satisfactory for much smaller reflectors, e. g., a template is satisfactory for small paraboloids, but seems impossibly unwieldy and unreliable for such large sizes.

Several test schemes have been suggested and are being investigated. The most promising are those that employ some type of optical arrangement. Such schemes are generally of two types. In one, the equivalent of a topographic survey is made; this type is obviously self-calibrating. In the other type, optical devices are employed to establish one or a series of base lines to which the reflector surface is referenced. Most such schemes require that the surface first be adjusted to a paraboloid by some other test procedure, and the optical base lines then provide a means for precise relative measurements.

No scheme so far proposed has adequately met all the desired requirements of precision, speed, and self-calibration; the question is still open for additional study.

Chapter Five

SITE DEVELOPMENT

Soon after the search for a site began, the firm of Eggers and Higgins, Architects, of New York City, was engaged to prepare a "hypothetical" site development. For this study it was necessary to make certain assumptions concerning the development of the site, but these assumptions implied no commitment for the construction of any part of the resulting hypothetical plan. The instructions to Eggers and Higgins were based on advice by the Steering Committee, as well as on information from other relatively small research centers operating in isolated locations. The hypothetical development was to provide for a staff of about 100, including the permanent scientific staff, visiting scientists, and all supporting staff. The assumption was made for the study of the hypothetical site that the major radio telescopes were to be four parabolic reflectors, respectively of 25- to 50-foot, 140-foot, 250-foot, and 600-foot diameters. Buildings on the site were to include a central laboratory and administrative building, a site maintenance building and garage, a telescope maintenance building, control buildings for each of the large radio telescopes, a dormitory and apartment building in combination with a cafeteria, several on-site residences for essential staff members and for visiting scientists, and such service or utility construction as seemed necessary.

I. THE HYPOTHETICAL DEVELOPMENT

Eggers and Higgins suggested that their study would be more meaningful if they prepared it for an actual place, similar to those on the list of possible sites. This procedure obviously involved the risk of overlooking some construction problem of little importance at the hypothetical site, that might be a major problem at the site ultimately selected. As a safeguard, Eggers and Higgins were cautioned to develop fully all recognized constructions problems. This procedure would, of course, make the hypothetical development more costly than any likely real development, but a detailed presentation of the separate problems would permit an early understanding and appreciation of their relative costs.

The location actually used for the hypothetical development was the first site on the discovery list, Burkes Garden, Virginia. A position within this area was arbitrarily selected as the site. Much later we realized that Burkes Garden exhibited several unusually difficult problems, particularly those involved with the access road to the site area—hairpin turns on narrow mountain roads and inadequate bridges. Furthermore, the position thus selected for the site proved to have variations of grade amounting to 50 to 100 feet, with rock close to the surface, so that the cost of leveling areas for the radio telescopes would have been large, adding more than a million dollars to the expense of site development.

The hypothetical study was submitted to the National Science Foundation on May 6, 1955, as one of the principal appendices to a letter of that date concerning a provisional estimate of a five-year construction and operating budget.

II. THE GREEN BANK SITE DEVELOPMENT

When it became clear that site No. 18 at Green Bank, West Virginia, had very good characteristics for radio astronomy observations, Eggers and Higgins were asked to revise their hypothetical development to fit this specific site. The problems of site access and leveling, mentioned above, were virtually non-existant at Green Bank, because West Virginia State route 28 runs through the valley, and the area of interest was almost all open, level farm land. Whereas the hypothetical study proposed a three-step construction program, the Green Bank development was to be divided into two parts. The first construction phase was to be accomplished within the terms of the budget that went to the Congress in the President's January, 1956, message. The remainder of the site development might be accomplished in a single second construction phase, or drawn out in time through a series of smaller construction activities, as might subsequently be determined for the orderly growth of the facility.

Although the telescopes assumed to be present at the hypothetical site and their foundations (except for the smallest, which is to be mounted on the laboratory building) are carried as separate items and hence are not a part of the development plan devised by Eggers and Higgins, nevertheless they must be provided for in the planning of utilities and roads. The first construction phase was to include the three smaller radio telescopes.

In order to keep the first construction phase within the President's budget, it was recognized early that certain buildings, such as the central laboratory and administration building, would have to be built in steps. When Eggers and Higgins looked into this matter more carefully it became apparent that not all the desired buildings could be started, because the first increments possible within the budget would be too small for efficient construction and operation. Accordingly, it was necessary to omit some buildings proposed for the first construction phase, and divert the pertinent funds to other buildings that could now be started at an efficient threshold size. To illustrate this point, the proposed first phase construction of the housing and cafeteria building was dropped in order that the first part of the central building could be adequately planned. It then became necessary, however, to place the cafeteria, temporarily, in the central building.

In some cases, alternative solutions were possible, as in providing electrical power. The choices were between on-site generation and commercial purchase. The latter permitted a further choice as to whether or not large emergency standby capacity should be provided.

The general site development is shown in Figures V-1 and V-2, taken from the Eggers and Higgins report. On-site roads will be made 24 feet wide of asphalt, penetrated macadam, eight inches deep. Although the entire area appears to be very flat, until a detailed topographical survey is made, it was assumed that any roads and other construction would require some clearing and leveling.

A. Major Construction Items.

The following list gives the names of the principal buildings and their probable use when the site is fully developed. A later section, will describe the first construction phase in detail.

1. Laboratory and Administration Building (two stories and basement), as shown in Figures V-3 to 6, will provide:

(a) Office space for the administration.

(b) Laboratories for instrument testing and repair.

(c) Laboratories for data processing.

(d) Laboratories for staff scientists and visiting scientists.

(e) Roof space for 25-ft. radio telescope.

(f) Air-conditioned rooms for computers.

(g) Library, lounge, conference rooms and assembly room.

2. Residence Hall and Cafeteria (two stories and basement), as shown in Figure V-7.

(a) The lower level of the Residence Hall includes five apartments for visiting scientists and their families; the upper level has 20 bedrooms with baths for visiting scientists and technicians without families.

(b) The Cafeteria provides space for a Dining Room and a Cafeteria, separated by a folding partition. Further space is provided for kitchen, serving, storage, freezers, and small snack bar for employees who work late.

3. Site Maintenance Building (one story) as shown in Figure V-8. Provides small garage, filling station, waiting room for drivers, locker room for employees, storage space for materials and spare parts, shops for automobile repair, and for carpenters, painters, electricians, plumbers and mechanics.

4. Radio Telescope Maintenance Building (one story) as shown in Figure V-9. This building will provide space for storing equipment, such as a large crane, a hydraulic extension ladder, special jigs and templates, and other necessary materials and equipment. It will also provide toilet, locker and rest room spaces for employees.

5. Electric Generator Building (one story) as shown in Figure V-10. This building will house the generating plant for the entire facility, if on-site generation or on-site emergency standby capacity is provided.

6. Radio Telescope Control Buildings (one story) as shown in Figure V-11. Control buildings will be provided for the 60-ft. and 140-ft. radio telescopes; space for control of larger radio telescopes would be provided within the framework of the supporting members for these telescopes.

7. Residential Buildings. Reference to Figure V-2 will show provision for 10 residential buildings as follows:

(a) Four buildings to be used for permanent residences by responsible, permanent personnel, such as the director of the Observatory, the site superintendent, the chief radio telescope operator, and the chief engineer.

(b) Six residences which would be rented to visiting scientists who desire to live with their families on the site for extended periods.

III. FIRST CONSTRUCTION PHASE

After preliminary cost-estimates had been made for the various items desired in the first construction phase, the matter was carefully reviewed. It was concluded that in the light of the President's budget, the maximum amount of construction that could be hoped for in the first phase is that in the following list. (Note: It has been assumed that the costs of land acquisition, surveys, test borings, and the radio telescopes and their foundations are included in another part of the budget. See Chapter Six.) Prices are based on experience, information obtained from engineers and contractors, and on estimates, published in technical literature, of the costs of similar construction work at remote locations such as this. Fees for architects, engineers, consultants, and legal work are not included.

1.	Topographical survey (approximately 500 acres at $25 per acre) and water tests	$17,000.
2.	Rebuilding existing dirt road to 140-ft. telescope from Route No. 28 northwesterly to beginning of "S" turn (Figure V-1) with 24-ft. wide by 8″ deep, asphalt penetrated macdam 2/3 mile at $60,000 per mile	40,000.

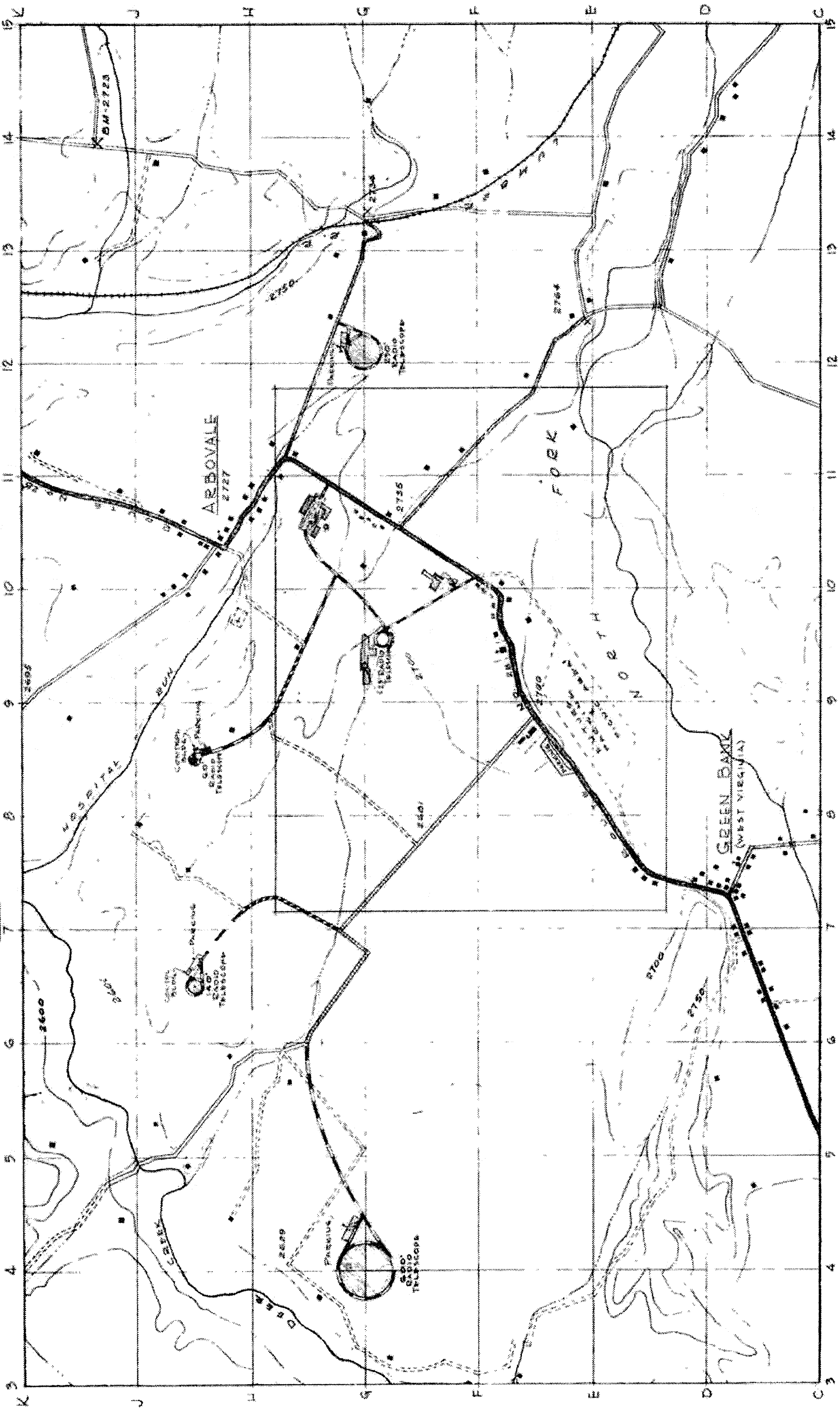

Figure V-1. General Site Development Plan as Prepared by Eggers & Higgins Architects of New York City.

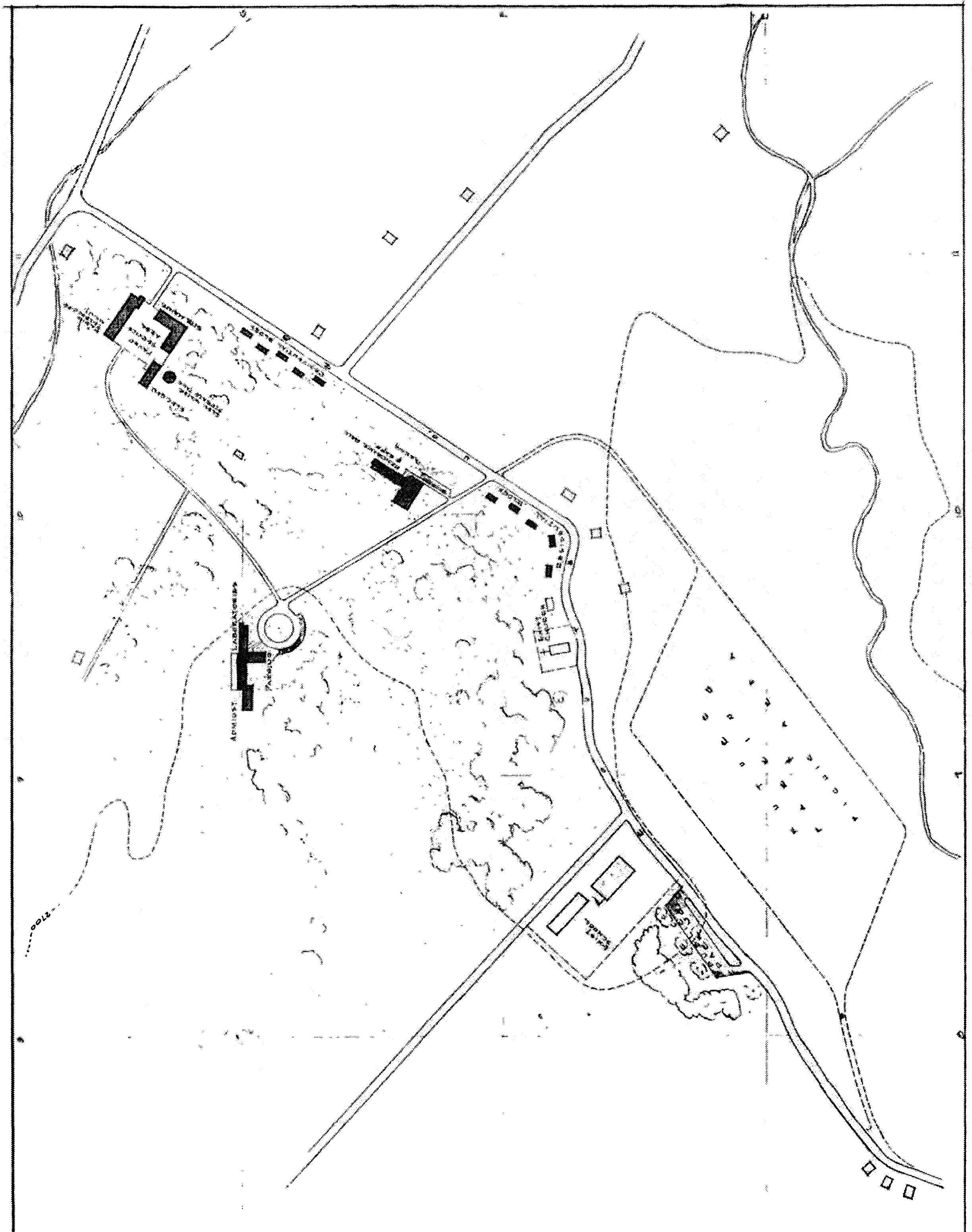

Figure V-2. Detailed Site Development for a portion of the area that would contain the Central Laboratory Building and other proposed structures such as Residential Buildings, Main Buildings and Individual Residences, as Prepared by Eggers & Higgins Architects of New York City.

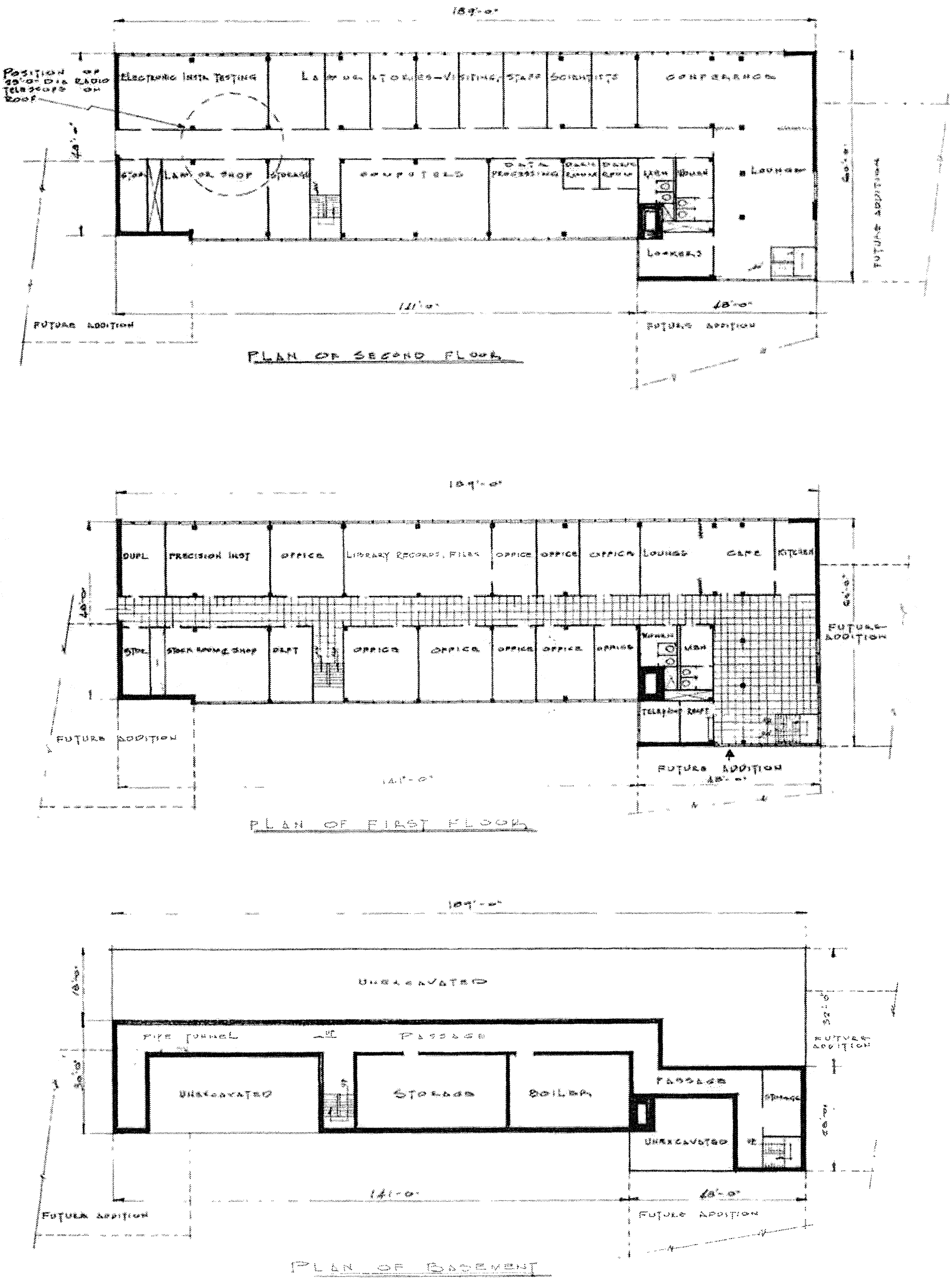

Figure V-3. Central portion of the proposed Administration Building and Laboratories as Prepared by Eggers & Higgins Architects of New York City.

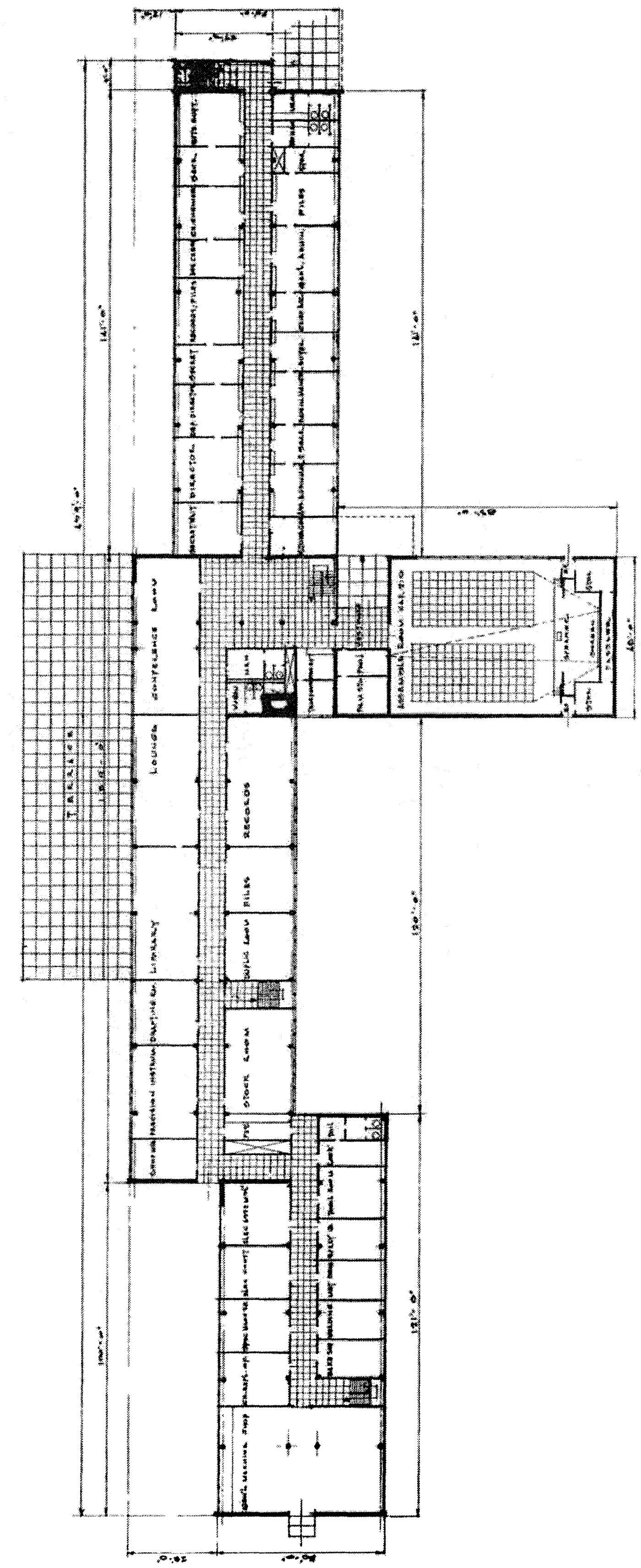

Figure V-4. First Floor Plan of Proposed Administration Building and Laboratories as Prepared by Eggers & Higgins Architects of New York City.

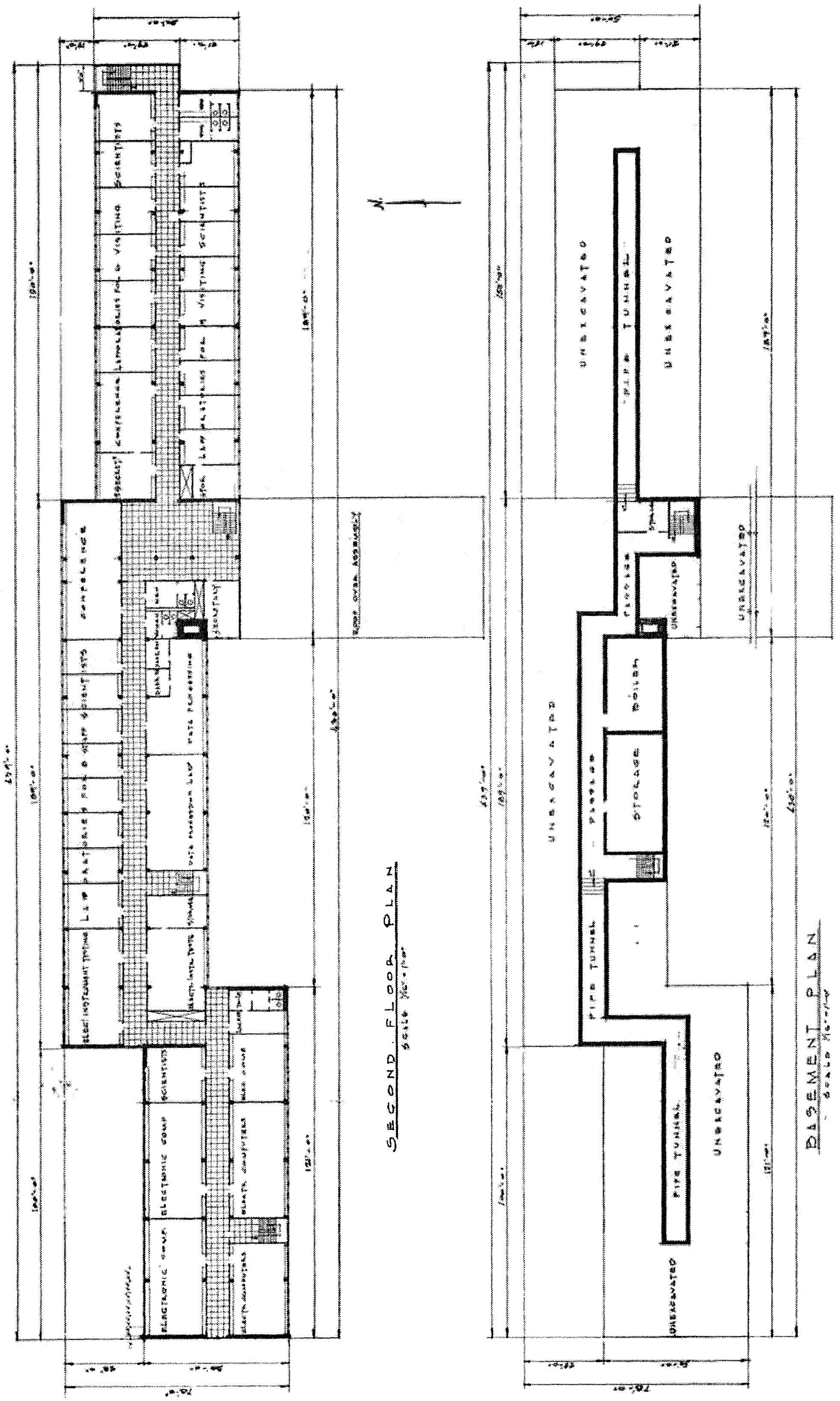

Figure V-5. Basement and Second Floor Plans of the Administration Building and Laboratories as Prepared by Eggers & Higgins Architects of New York City.

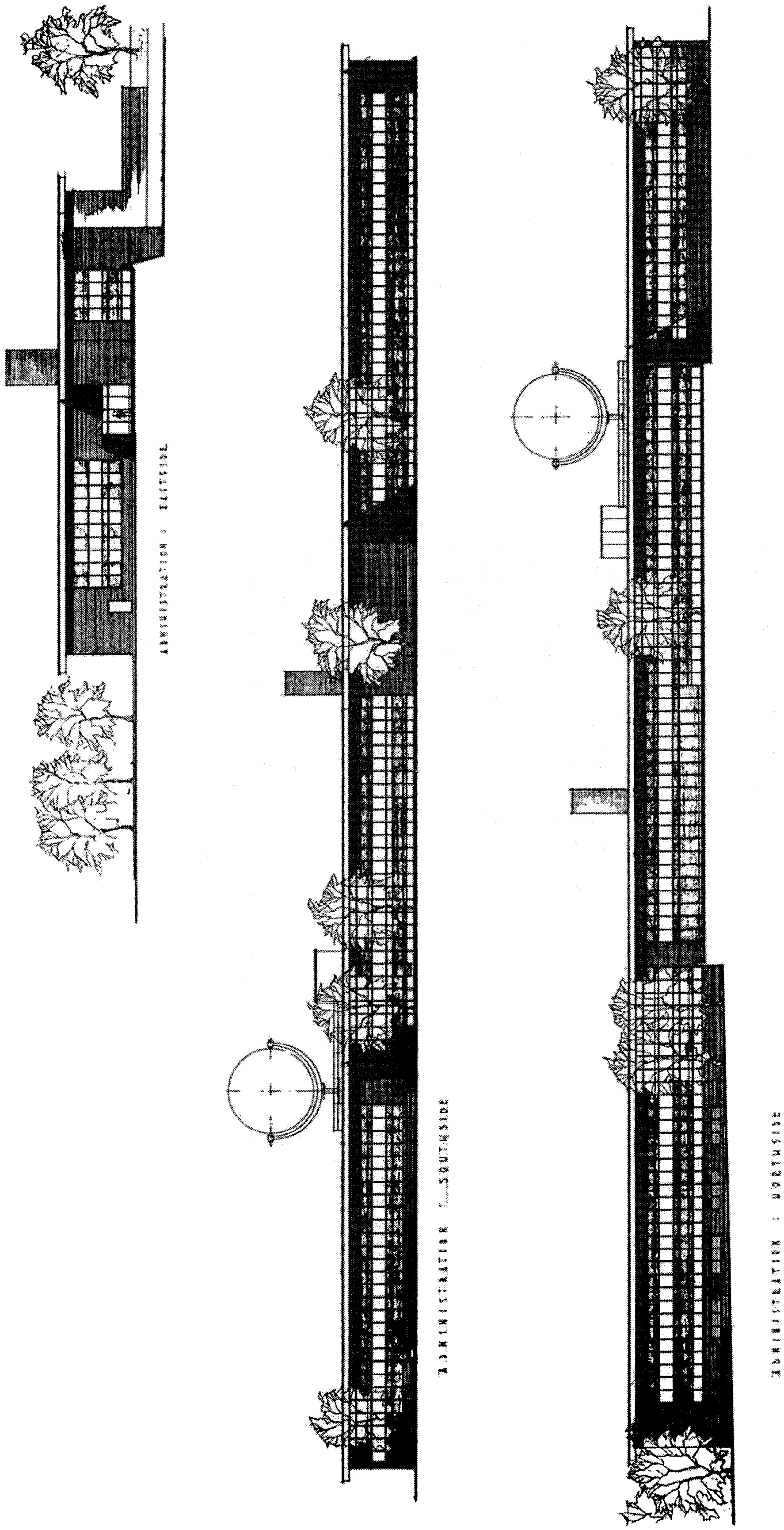

Figure V-6. Elevations of the Proposed Administration Building and Laboratories as Prepared by Eggers & Higgins Architects of New York City.

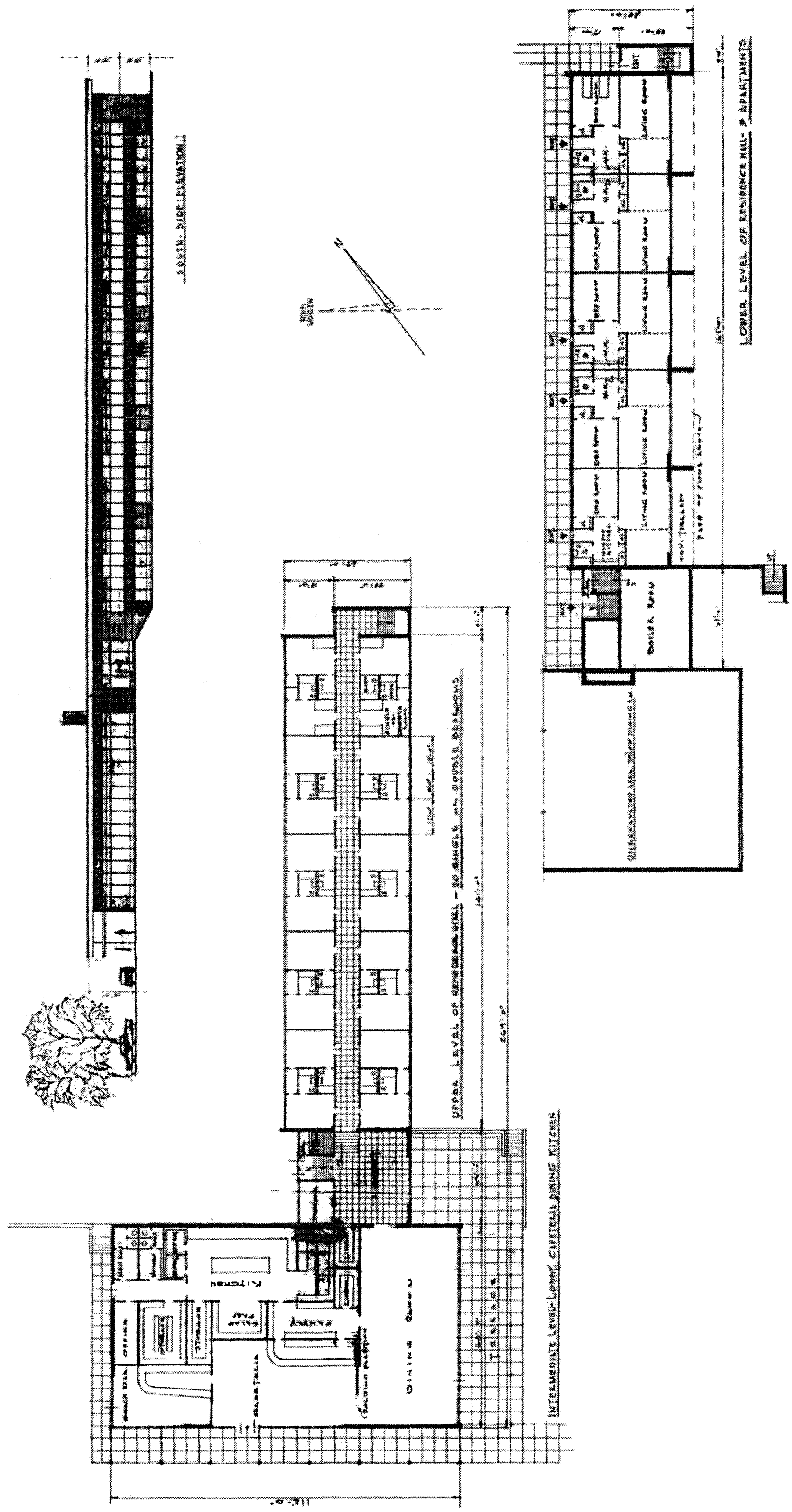

Figure V-7. Plan and Elevation for the Proposed Residence Hall and Cafeteria as Prepared by Eggers & Higgins Architects of New York City.

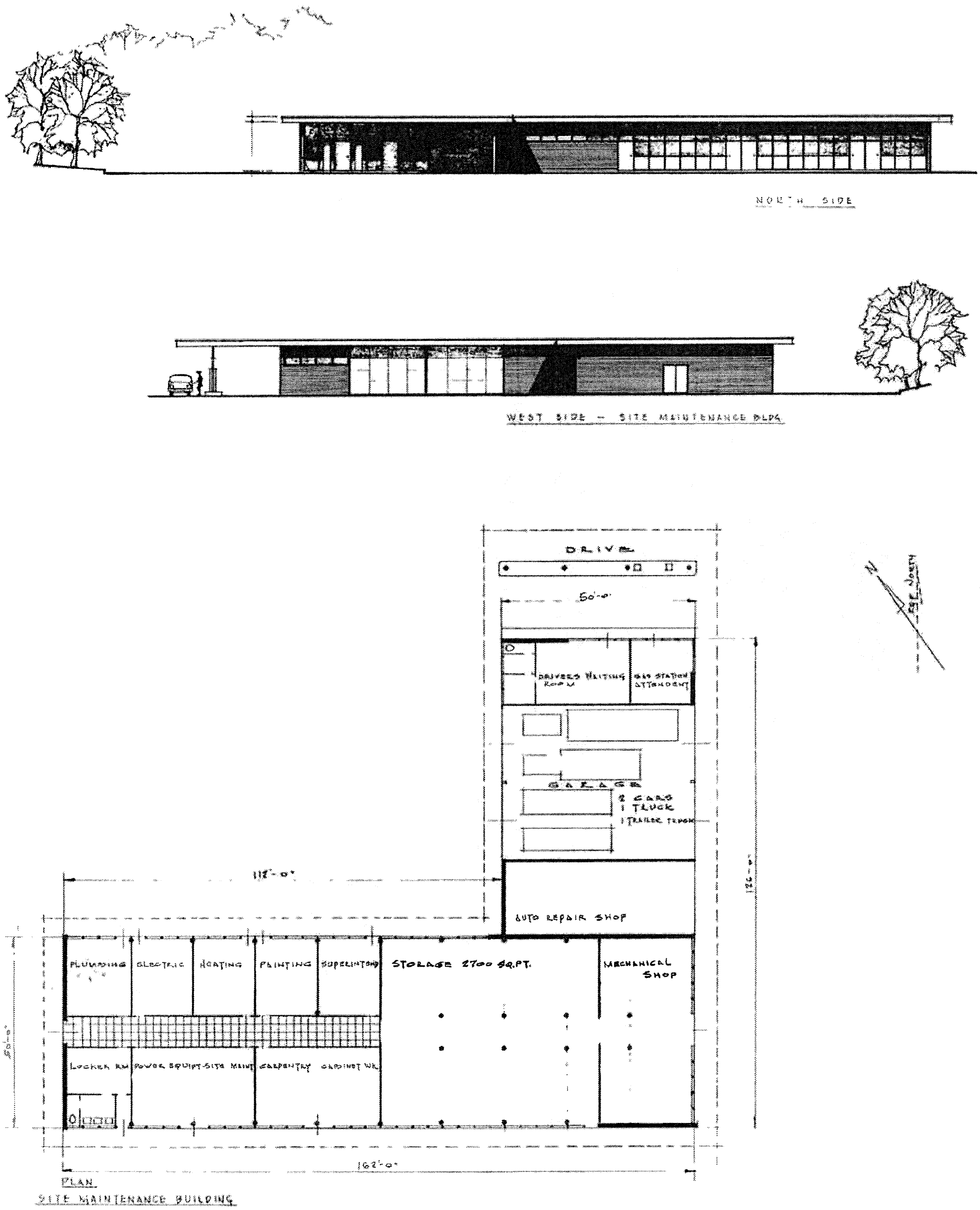

Figure V-8. Plan and Elevation for the Proposed Site Maintenance Building as Prepared by Eggers & Higgins Architects of New York City.

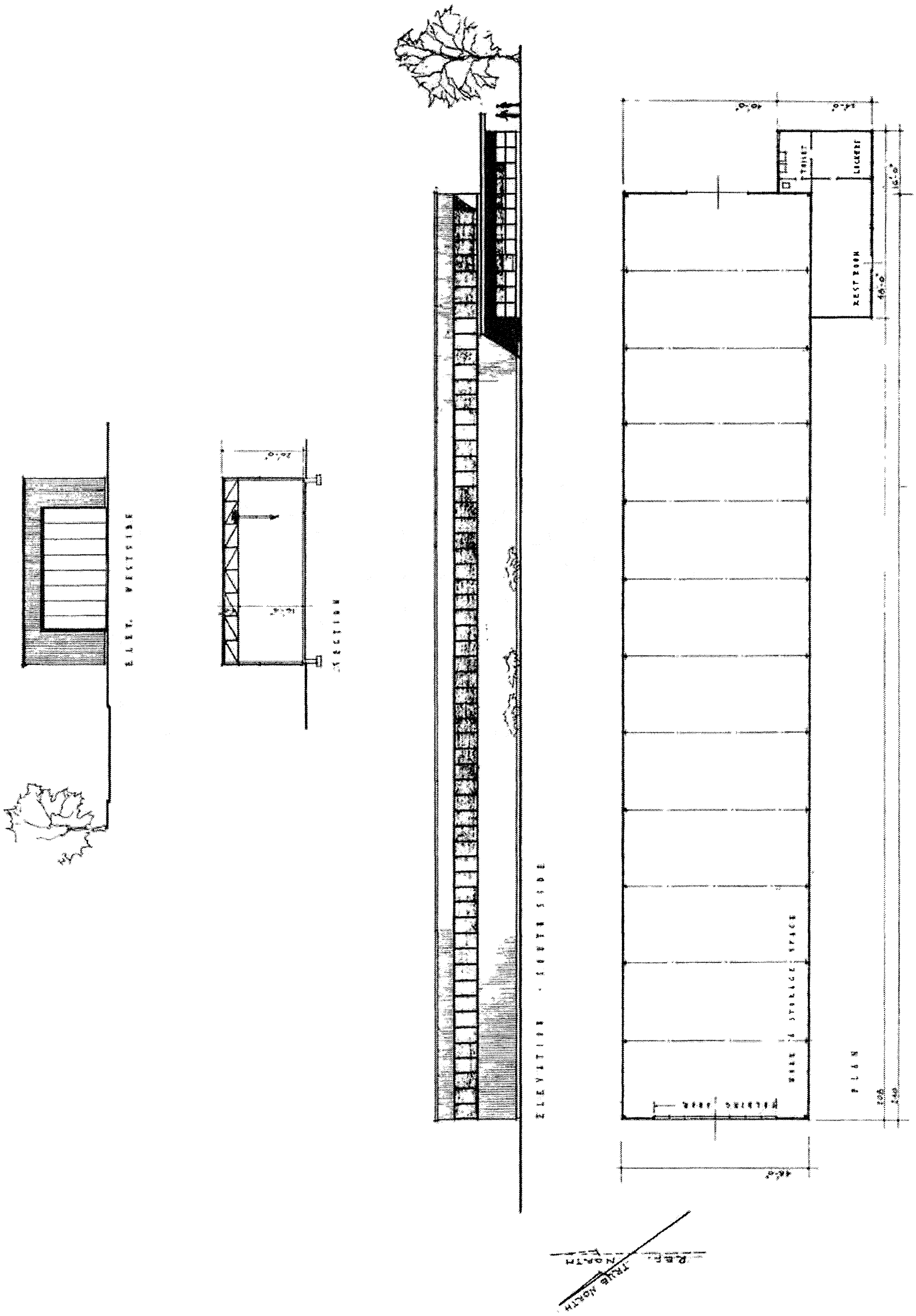

Figure V-9. Plan and Elevation for the Proposed Radio Telescope Maintenance Building as Prepared by Eggers & Higgins Architects of New York City.

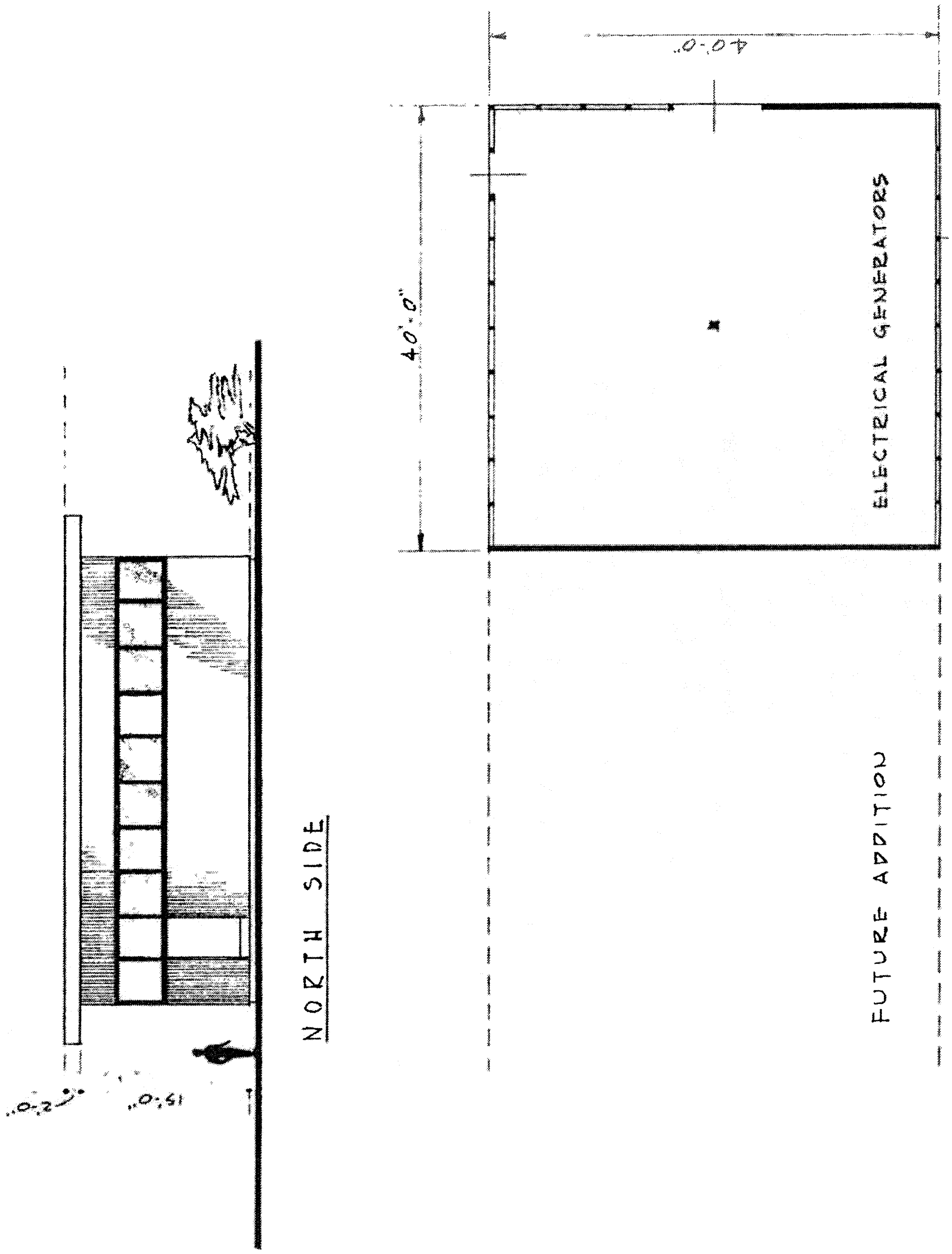

Figure V-10. Plan and Elevation for the Proposed Electric Generator Building as Prepared by Eggers & Higgins Architects of New York City.

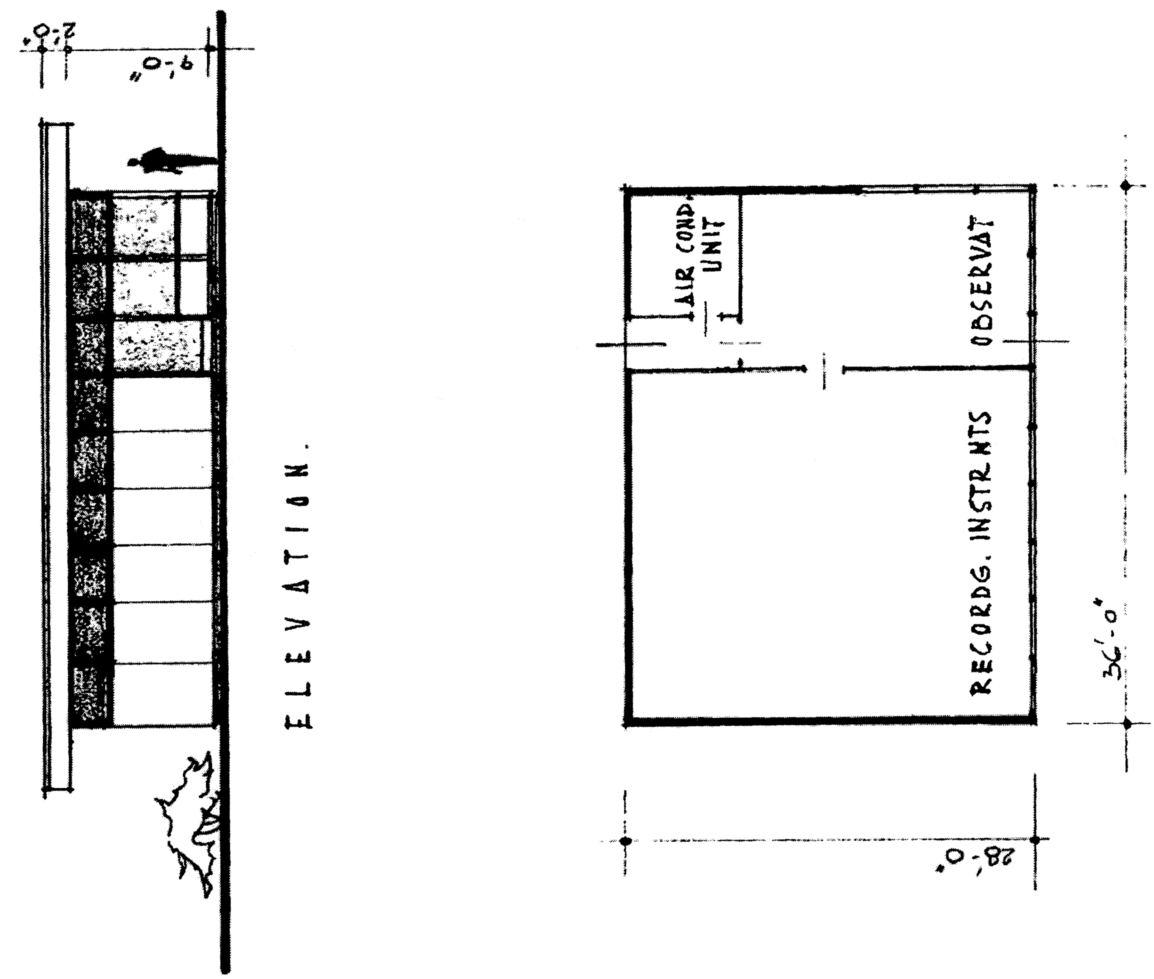

Figure V-11. Plan and Elevation for the Proposed Control Building for the 60-foot or 140-foot Radio Telescopes as Prepared by Eggers & Higgins Architects of New York City.

3. Building on-site roads as indicated in Figure V-1 24-ft. wide by 8" deep, asphalt penetrated macadam
   1-5/6 miles at $70,000 per mile ...... 128,000.

4. Parking (black top) at various facilities and paving of utility area.
   7,000 square yards at $3.25 per square yard .... 22,800.

5. Necessary site clearing at each facility.
   Approximate total of 70 acres at $300 per acre .... 21,000.

6. Construction of center portion of Administration and Laboratory Building temporarily rearranged to include Cafeteria.
   245,000 cubic feet at $1.80 per cubic ft. 441,000.

7. First portion of radio telescope Maintenance Building.
   67,500 cubic feet at $1.00 per cubic foot .... 67,000.

8. First portion of electric generator building, assuming the choice is on-site generation of power or that a large standby capacity will be provided if the choice is to purchase commercial power.
   27,200 cubic feet at $1.10 per cubic foot .... 30,000.

9. Two control Buildings for 60-ft. and 140-ft. radio telescopes; about one-half would be eliminated if the 60-ft. telescope is not included in the first phase.
   11,100 cubic feet each at $1.50 per cubic foot .... 33,000.

10. Repair and remodeling of four existing residences to be used temporarily in lieu of residence hall.
    Approximately $5,000 each .... 20,000.

11. Furniture and equipment for the above buildings .... 20,000.

12. Utilities. 618,000.

On-site electric power distribution system	$243,265
On-site telephone conduits, buried with electric system	18,000
On-site power generation	156,735
Sanitary work	200,000

A. Commercial Power.

If it is decided to purchase commercial power, there are several alternatives. One involves the question of emergency standby capacity. The foreseeable emergencies are:

1. Ice storms, that might destroy a large portion of the primary high voltage line from which the site draws its power; such an outage might last for days, but certainly there would be some advance warning of the icing condition.

2. Hurricane winds, that might inflict damage over a wide area; again there would be some warning and the telescopes could be stowed in the safest position.

3. Tornadoes, that would inflict quite local damage, either to the power lines or to the radio telescopes; there would be practically no warning, and there would be little need for power immediately after the storm had passed.

In view of the above, and in the interest of economy, it would appear that no large standby capacity is warranted. There should be some small capacity, sufficient to operate the motors on the heating plants so that the various buildings would not freeze up during a winter storm.

B. Initial Costs.

Part of the secondary line bringing power to the site would be overhead, and the portion near the site would be underground. It is important to note that this private supply line would be adequate not only for the first phase, but also for any eventual maximum power requirements. Various arrangements are possible to finance this supply line. One would involve no capital investment on the part of the Observatory, but there would be fixed annual charges, in addition to those for power consumed, to pay for the line maintenance and to amortize the initial investment by the power company. This arrangement would save the cost of on-site power generation, about $157,000 and of the generator building, $30,000 (see Nos. 8 and 12 of the preceding list).

C. Annual Operating Costs.

Initial construction costs are not the full story. To provide a rough basis for comparison, cost-estimates have been made for the on-site generation of power, which allow for a payroll for 24-hour operation, for fuel oil, amortization of the equipment, and the interest on the money invested. Fixed charges are about $27,000 per year and a minimum of $9,000 would be spent for fuel. For comparison, the fixed charges for a commercial power line would be about $65,000, with an added minimum of about $14,000 for the power consumed (this latter figure would depend on the rate schedule that would apply). On the other hand, if the Observatory grows in size as hypothesized in the study, there would be no additional commercial charges, except for the power actually consumed, estimated at $48,000. If on-site generation were chosen, hypothesized growth would require an outlay of $385,000 for additional generation capacity, and $75,000 to enlarge the power station. The increment in the annual operating cost has been estimated at $70,000. Thus the ultimate minimum annual cost of operating an on-site generation system would be about $106,000 as compared to about $127,000 for commercial purchase.

IV. HYPOTHETICAL GROWTH

The cost estimates given here are current values. If the general rise of 4 to 5 per cent per year for all types of construction costs continues, the cost estimates should be appropriately corrected at any later date. (Note: The items designated are a continuation of the projects listed for the first construction phase.)

1. Rebuilding existing dirt roads to 600-ft. radio telescope from beginning of "S" turn (Figure V-1) to point of departure from existing dirt road, with 24-ft. wide by 8″ deep asphalt penetrated macadam.
   1/3 mile at $60,000 per mile .... $20,000.

2. Building on-site roads to 250-ft. and 600-ft. telescopes, and Residence Hall, (Figure V-1) with 24-ft. wide by 8″ deep asphalt penetrated macadam.
   1-1/2 miles at $70,000 per mile ..... 105,000.

3. Parking (black top) at 250-ft., 600-ft. telescopes, and Residence Hall, also 12-ft. wide driveways for ten residences.
   3,200 square yards at $3.25 per square yard .... 10,400.

4. Site clearing for 250-ft. and 600-ft. telescopes, Residence Hall and ten residences
   Approximately 60 acres at $300 per acre .... 18,000.

5. Construction of remaining portion of Administration and Laboratory Building to complete building, as in Figures V-3, 4, 5, 6
   425,000 cubic feet at $1.80 per cubic foot $765,000
   4,000 square feet of air-conditioning at $3. per square foot .... 12,000 — 777,000.

6. Construction of Residence Hall and Cafeteria in accordance with Figure V-7
   300,000 cubic feet at $1.50 per cubic foot .... 450,000.
   Note: If any portion of the Residence Hall is omitted, the above cost should be reduced at the rate of $1.35 per cubic foot of space omitted.

7. Construction of Site Maintenance Building in accordance with Figure V-8
   185,000 cubic feet at $1.25 per cubic foot .... 231,000.

8. Construction of remaining portion of radio telescope Maintenance Building to complete building in accordance with ultimate building shown by Figure V-9
   185,000 cubic feet at $1.00 per cubic foot .... 185,000.

9. If on-site generation of power has been the choice, construction of remaining portion of electric generator building to complete ultimate building in accordance with Figure V-10
   60,000 cubic feet at $1.25 per cubic foot 75,000

10. Construction of ten residential buildings.
    14,000 square feet at $15 square foot. . 210,000.

11. Furniture and equipment for the above portion of program (except residential buildings) .... 75,000.

12. Extension of utilities — $835,000.

Telephone conduits	$ 16,000	
Electric power distribution	299,000	
On-site power generation	385,000	
Sanitary	135,000	

Grand Totals of Estimated Development Costs

	On-site Power	*Commercial Power*
Phase One	$1,459,400.	$1,272,665.
Phase Two	2,991,400.	2,531,400.

The above studies formed the basis for the actual site development described in Chapter Six.

Chapter Six

SUGGESTED ORGANIZATION

In discussing the organization of the Radio Astronomy Observatory, we assume that the contract for operating it will be in the hands of a parent organization which will establish the operating policies, controls, and all other supervisory functions.

The staff that operates the Observatory will have its character and structure shaped largely by the fact that its functions are separate and different from those of the parent contractor. The Director and his staff will bear full, direct responsibility for operating the Observatory, in accordance with the general policies, controls, and supervisory structures defined by the parent management. Because the successful operation of the Observatory, within the policies defined by the management, will depend directly on the Director and his staff, they must have the special qualifications necessary to fit them for this task. In planning the organization of the operating staff, the extent of their responsibilities should be clearly understood, and the staff must be large enough to perform all the functions delegated to it.

I. THE STAFF

The definitive organization of the operating staff cannot of course be completed without a full knowledge of the qualifications of the chief officers who may finally be chosen. If we assume, however, that certain basic responsibilities must be met, it is possible to outline a hypothetical plan of organization.

Successful operation of the Radio Astronomy Observatory will probably require four key persons, whose skills, training, and experience should be varied and complementary, so that, among them, they can perform all the functions necessary to the success of the facility.

The organization of the Observatory should contain at least three main departments, each administered by a Head who is responsible to the Director of the Observatory. We may tenatively specify these three divisions as the departments of Research, of Engineering, and of Business Administration. In suggesting this type of organization, we are considering the fact that during the early years of the Observatory, construction will be a large and important function, and it must be taken into account in establishing the organization.

If and when construction is no longer a necessary major activity, it may be desirable to modify the plan of organization, but when the Observatory is just coming into existence, construction, as well as research, is an extremely important objective.

A. The Director.

The Director must bear the overall responsibility for the Observatory. He must be not only a research scientist of recognized ability; he must also have proved his ability to administer scientific projects; and he must possess special aptitude in selecting and supervising scientific personnel. These qualities will be essential, particularly during the early life of the Observatory.

The Director must be responsible for every phase of the operation of the Observatory. His duties will include not only the normal internal activities involved in the general direction of the Observatory itself, such as personnel, budgets, financial control, and planning of research and construction; but also a great many external functions as well. Since the facility will inevitably be isolated, the Director will frequently be required to make trips away from the site, to carry out external responsibilities that cannot well be delegated. The Director must, for example, maintain contact with the universities, to stimulate cooperative research arrangements; take steps to achieve and preserve good public relations with the surrounding community and the state; make plans for receiving casual visitors to the Observatory; communicate with and make formal presentations to the National Science Foundation; appear when necessary at Congressional hearings; and keep in contact with the parent organization.

With so many outside duties to perform, the Director must delegate a large measure of responsibility for the day-to-day functioning of the facility to Department Heads, whose skill, experience, and judgment qualify them to operate the Observatory effectively.

Three Department Heads, responsible to the Director, will supervise the major aspects of the operation of the Observatory. They will be directly responsible for proper, intelligent and effective application of the management policy, and their initative will substantially determine the extent to which this policy is translated into creative and significant research.

B. Chief Scientist and Deputy Director.

The Chief Scientist will be responsible for all research at the Observatory. As the Deputy Director, he should have authority to act during the Director's absence, and should act as Chairman of the Scheduling Committee. The Chief Scientist must be recognized by his colleagues to be a leader in the field, so that he commands the unquestioned respect of individual scientists whose possibly conflicting interests in the Observatory must be adjusted by him.

C. The Chief Engineer will be responsible for the satisfactory operation and maintenance of the radio telescopes and other research and supporting equipment, as well as for the detailed planning of construction at the site, and of its future facilities. He must have an intimate knowledge of the construction and performance of radio telescopes, and a general knowledge of engineering matters relating to the site, its maintenance and development. He must be responsible for the construction of new antennas and supplementary equipment.

D. The Business Manager.

The Business Manager will be responsible for administrative and fiscal matters and for personnel records. He must have had experience in effectively adjusting business procedures to the administration of scientific research institutions, including cost accounting for such projects, and be competent to understand the research performance of such institutions in terms of a business management designed to keep them creative and productive.

E. The Scientific Staff.

The scientific staff at the Facility should comprise about equal numbers of permanent or semi-permanent members, and of qualified visitors from universities and other institutions.

1. The Observatory will provide, in addition to superb apparatus, a unique opportunity for the carrying out of extremely important experiments that demand equipment beyond the resources of the average university. Therefore the organization must be of a kind to permit a large number of the best qualified American scientists and their graduate students to work at the Observatory.

2. Experience has shown that visitors can work most productively when they collaborate with staff scientists who are wholly familiar with the capabilities and idiosyncracies of the equipment and who are themselves creative scientists, each with his own projects. In addition, a highly trained supporting staff is required to maintain and manipulate the heavy and complex telescopes and auxiliary apparatus. The visiting staff works most efficiently when guided by staff scientists who are regularly attached to the site.

3. Experience suggests that the most effective ratio of permanent to visiting research staff is probably about half and half. When the permanent research staff is more than half, visitors have little chance to use the equipment; when the permanent staff is smaller they usually cannot fully exploit the expensive apparatus. Exchange of ideas between the permanent and visiting scientists is the most effective way to spread new concepts throughout the academic world.

F. Scientific Visitors.

The contractor must encourage use of the Observatory by qualified visiting scientists.

1. The Observatory is intended to supplement the scientific apparatus available at other institutions; therefore, qualified scientists should receive easy access to the Facility, with a minimum of red tape.

2. The contractor should assist visiting scientists in transferring to the Facility from their own institutions by making simple arrangements for reimbursement of expenses, housing, transportation, continuation of retirement and similar benefits.

(a) For visiting scientists who wish to conduct their own experiments, the contractor should provide adequate means for assembling and testing special equipment and installing it in the radio telescopes, together with reasonable technical and scientific assistance, including shop and library facilities. In some cases, it may be necessary for the Observatory to construct or purchase such apparatus.

(b) The contractors should arrange frequent seminars, discussions, and scientific meetings to keep the staff informed of significant progress in the field.

3. Visiting scientists should be selected with complete objectivity. Their selection must not depend on the relationship between their institutions and the management; but solely on their individual qualifications and the significance of their research.

4. The contractor, acting through the Director, must have the ultimate responsibility of selecting the visiting scientists. The following factors must be considered:

(a) Qualifications and scientific and technical background of the visitor.

(b) Significance of the proposed research.

(c) Relative importance of the research as compared to that of other projects.

(d) The possible contribution of the visitor to the scientific staff.

(e) Availability of necessary equipment.

(f) Feasibility of financial support.

Scientists from the sponsoring institutions should receive no special preference, and under no circumstances should an appointment be made except on the criteria just stated, nor should any sponsoring insitution require proprietary rights.

5. In arranging for research by visiting scientists, the contractor,so far as possible, should deal directly with the scientists rather than with institutions. This does not mean that the institution or university should not be fully informed, but no institution should have a vested right to designate an individual to work at the Facility. The selection must be based not on the status of an institution, but only on the six criteria set forth above.

II. THE BASIC STRUCTURE

The structure of the proposed organization is shown schematically in the following chart:

	Contractor	
		Policy Level
Scheduling Committee	DIRECTOR Radio Astronomy Observatory	*Management Level*
Chief Engineer	Chief Scientist and Deputy Director	Business Manager

Operation of Major Facilities	Staff Scientists	Budget Planning
Maintenance of Site & Major Facilities	Research Technicians	Budget Control
Buildings and Grounds	Visiting Scientists	Accounting
Maintenance & Operating Personnel	Research Operations	Purchasing
Shops	Electronics Development	Personnel Records
Drafting	Recruitement of Scientific Personnel	Recruiting Non-scientific Personnel
Planning of Site Development & New Facilities	Research Planning	Housing
Noise Reduction	Scheduling	Office Services
Scientific Research Projects	Public Education	Warehousing
	Publications	Inventory & Stock Control
	General Administration	

III. INITIAL BUDGET FOR THE OBSERVATORY

As outlined in earlier chapters, the initial facilities consist of a 140-foot radio telescope, perhaps one or more smaller auxiliary radio telescopes, an adequate supply of electric power, laboratory buildings, and ancillary equipment necessary to the operation of the Observatory.

During FY-1956, the principal items in the budget are the requirements for studies of site development, for studies of designs for radio telescopes, and for building the staff. The following is the FY-1956 budget for the second grant from the Foundation:

1. 140-foot Reflector Studies	$ 40,000.
2. Other Reflector Studies	10,000.
3. Site Studies (Purchase options) (Test borings) (Preliminary engineering)	30,000.
4. Other Activities (Including consultants, Advisory Committee, Travel, etc.)	44,500.
5. Staff Recruitment	16,000.
Total FY-1956 Budget	$ 140,500.

IV. ESTIMATED CONSTRUCTION BUDGET (as of March 31, 1956)

The estimated budget for construction follows.

A. *Site Development:*

Site acquisition	$ 800,000.
On-site secondary roads	190,000.
Utilities (other than electric power) Drainage system Water supply (well, pump, etc.)	135,000.
Electric power (on-site generation	418,000.
Total Site Development	$1,543,000.

B. *Buildings:*

Diesel generator building (includes cooling tower)	$ 30,000.
Control buildings (60- & 140-ft. telescopes)	33,000.
Maintenance building (first section)	68,000.
Laboratory and administration building (central section)	441,000.
Housing (remodel existing houses)	20,000.
Total, Building and Housing	$ 592,000.

C. *Radio Telescopes and Other Research Equipment:*

Design, fabrication & erection of 140-ft. radio telescope	$1,800,000.	
Excavation, clearing, foundation etc. for 140-ft. telescope	400,000.	
RF components & other electrical equipment	200,000.	
Other observing equipment (including 28-ft. and one 60-ft. telescopes)	350,000.	
Total, Construction & Equipment	$2,750,000.	

D. *Service Equipment:**

Library	10,000.	
Machine shop & repair	60,000.	
Electronic test & repair	65,000.	
Furniture & equipment for offices, cafeteria, guest house, etc.	50,000.	
Total	$ 185,000.	
		$5,070,000.

E. *Salaries, Operation, and Maintenance for the first year* ....$ 100,000.

V. ESTIMATE FOR THE FOURTH YEAR OF OPERATION

It is estimated that in the fourth year of operation of an Observatory such as that proposed in Section IV above, the operating budget for a staff of 35 (including visitors) will be $267,000.

Obviously, these operating estimates will have to be increased if additional research instruments are constructed, and also if the Observatory operations budget is expected to carry all or part of the salaries and other expenses of the visiting scientists, whose number will increase steadily through the period ending in FY 1960.

**An additional sum of $115,000 in this category will be required at a later time.*

Chapter Seven

PERSONNEL POLICIES AND PROCEDURES

I. PERSONNEL POLICIES

A. *Detailed Policies.*

A discussion of general personnel would require a lengthy manual, which need not be reproduced in this document. To illustrate the material covered, we give a possible Table of Contents, which is illustrative of the types of problems likely to be met:

Non-Exempt Employees on Weekly & Hourly Wage Payrolls

A. Basis of Wages and Hours of Work
B. Shift Premium
C. Overtime Hours
D. Work on the 7th Consecutive Day of the Work Week
E. Emergency Call-In
F. Holiday Pay
G. Vacations
H. Sick Leave
I. Absences
J. Reporting Allowance
K. Probationary Period
L. Termination Allowance
M. Wage Administration

Non-Exempt and Exempt Employees on Monthly Salaried Poyroll

A. Basis of Salary and Hours of Work
B. Overtime and Compensatory Time
C. Vacations
D. Sick Leave
E. Absences
F. Appointment to the Scientific Staff (see above)

General

A. Holiday
B. Retirement
C. Group Insurance Plan
D. Selective Service
E. Health and Morale Program
F. Patent Incentive Award
G. Travel
H. Military Leave
I. Jury Duty
J. Voting Time
K. Leave of Absence
L. Employee Consultation with Supervisors
M. Termination for Reasons of Maternity
N. Wage and Salary Policy
O. Employment and Promotion Policy
P. Outside Employment Policy

B. *Travel Awards.*

Members of the scientific staff should be able to visit other institutions, both in this country and abroad, for extended periods. A travel award policy is deemed essential, under whose terms the Corporation may pay to an employee during his absence an amount not to exceed the salary he would have received at the Observatory during the same period, or half his annual salary, whichever is less. In addition, the contractor would continue to pay its share of the cost of the employee's insurance benefits (retirement, etc.) during the time he is away. These awards would be made in recognition of distinguished scientific work.

II. OTHER PROCEDURES

"Standard Practice Instructions" should be adopted for the guidance of the staff in the day-to-day operation of the Observatory. Operating rules of this sort are essential in any institution. The following are given as illustrations:

General

Signature Authorizations
Control of Private Information
Public Statements and Addresses
Transportation—Use of Government Vehicles
Traffic and Parking Regulations
Use of Telephones and Telegraph
Mail Service and Distribution Lists—Bulletin Boards—Laboratory Forms
Archives
Laboratory Housing

Employment and Employee Relations

Personnel Requisitions, Interviews—and Salary Approvals (Scientific Staff)
Personnel Transfers, Rate Changes, Classification Changes
Termination of Employment
Change in Name or Address
Personal Injury or Sickness

Fiscal

Time Records—Hourly and Weekly Employees
Time Records—Monthly Employees
Petty Cash Vouchers
Intra-Laboratory Requisitions and Services

Travel

General Travel Instructions
Travel Authorizations
Travel Reservations
Travel Reimbursement—Petty Cash Voucher, Travel Voucher
Travel Arrangements for Conference Speakers and Other Guests

Procurement—Property Management

- Procurement—Policy and Procedure
- Capital Improvement Proposal and Authorization
- Property Management

Technical Papers and Reports—Patents

- Consultants Memorandum Report and Statement of Account
- Pre-Publication Review of Scientific or Technical Abstracts, Papers, or Reports
- Laboratory Notebooks
- Patent Disclosures