DRAFT
May 21, 1956

INTRODUCTION

Among all the sciences, astronomy has been recognized from the beginning of civilization as a most important basic activity in the growth of human thought. In explaining the nature of the universe around him, it has helped to dispell man's dependence on magic and mysticism, to unchain his mind, and to direct his imagination into useful and significant 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 cultural contributions to man's mind, the study of astronomy has provided much of the basis for the eingineering and mechanics that underlie our civilization. Only after the invention of the telescope and the observation of the stars and planets on the scale of the macrocosm was man led to the definite exposition of the basic laws of mechanics. The work of Galileo and of Newton in expounding the laws of falling bodies, the ideas of gravitation, and the laws of motion are clearly related to the study of the motions of the heavenly bodies. This was no accident, since the laws of motion and gravitation could only be clearly perceived on the scale of the universe.

More recently, the growth of astrophysics has interacted strongly with the development of nuclear physics and the tremendous growth in man's understanding of the fundamental structure of nature.

The discovery in our own generation that radio waves can be received from the universe adds tremendously to the power of astronomy. While the window through which visible astronomy can work through the atmosphere is 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 of the nature of the surrounding universe.

Radio astronomy brings a measure of the concentrations and motions of hydrogen gas in the universe and its relation to visible stars. It provides a means of seeing through the great dust clouds to determine the structure behind them that is obscured from visual observation. With large telescopes, radio astronomy promises to provide a far clearer description of the structure of galaxies. It gives a powerful tool in the study of the physical processes of the Sun, and the interaction of these processes on the Earth. Above all, it invites attention to those special objects in the sky which may involve the processes of star creation or star destruction, or other critical processes of the matter within the universe.

The application of radio astronomy to the planetary system has hardly begun. Already, the discovery of radio noise from Jupiter has drawn attention not only to unsuspected physical properties of that planet, but also to the most important naturally occurring source of terrestrial radio noise at high frequencies, other than very local thunderstorms. The potentialities of "active" radio astronomy, using radar-type techniques with large telescopes, offers a broad experimental approach to knowledge of the solar system.

Radio astronomy is intimately related to 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 atmosphere. Using the Moon as a target, the total of ionized matter in the vicinity of the Earth and its variation can be ascertained. 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 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 incentives to improved optical systems for telescopes have yielded innumerable practical applications in general optics for the benefit of society. In the same way, radio astronomy provides applications for electronics at the very vanguard of our knowledge. Already, electronics generally has greatly benefited from research toward more sensitive and suitable detection devices for improvement of radio astronomy capability. Thus, the new science of radio astronomy will generate instrumental research that will give great vigor to electronics and radar advancement.

It is never possible to predict the benefits that will be derived from vigorous support of a virile scientific activity such as radio astronomy. But the whole history of astronomy seems to give the promise that strong support of radio astronomy will produce major benefits to mankind. These may come from almost any direction, since the subject is most basic. The improvement 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 weather phenomena. The study of star making or destruction may answer questions involving basic nuclear reactions and the energy derived therefrom. Moreover, exact knowledge of the universe expressed in precise formulations could yield altogether new views on the general organization and origin of matter.

But quite aside from any immediate benefits that may accrue, the major benefit from strong support of radio astronomy lies in the growth of knowledge as an essential part of our total store of scientific comprehension. The greatest discoveries in science may well be blocked by ignorance in any one such basic field as astronomy. For the great benefits of science and their application to the problems of man are derived only when the whole store of knowledge is rounded and access to essential knowledge is complete.

In proposing a National Radio Astronomy Observatory, astronomers look to the very best of large telescopes and instrumentation to supplement their own facilities -- facilities that are now beyond their reach. Elsewhere, scientists have undertaken 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 plans are under way for a large steerable radio telescope in Australia by Dr. E. G. Bowen and his colleagues. Australia does have, of course, the great opportunity for coverage of the Southern skies. The Soviet Union is sponsoring two extensive facilities at Gorky and in the Crimea.

To partake of the challenging opportunities in the field of radio astronomy and to provide means of observation comparable to those of our colleagues elsewhere, American radio astronomers have been actively studying the action desirable in the United States to provide them with more adequate tools. Basically, the proposed National Radio Astronomy Observatory would provide a place where the most advanced radio telescopes and equipment could be conveniently available to radio astronomers under most favorable seeing conditions. The example of the effectiveness of very large and unique instrumentation made available to the scientific community through the National Laboratories, demonstrates that such a procedure is economical and the equipment is accessible to the scientists who desire to use it. The support of such a National Facility seems to offer the one way whereby radio astronomers can have large telescopes and facilities promptly available to them in this country, -- so that American radio astronomy has the opportunity to stay in the vanguard of its science.

The detailed thinking has proceeded largely along three lines.

1. The provision of radio telescopes of moderate size at private radio astronomical laboratories. This includes, for example, the 60-foot Harvard telescope, the California Institute of Technology twin 100-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

departmental activities in radio astronomy using smaller instruments.

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

3. The establishment of a National Radio Astronomy Facility where very 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 facilities available that are not feasible at the several individual locations, emphasis would be directed to big reflectors and antennas. The planning of such a National Facility that can supplement smaller activities has not only enjoyed the enthusiasm of many of the present researchers in the field, but also has played an important role in stimulating new activities at universities such as Yale and Pennsylvania.

The concept of the National Radio Astronomy Facility 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, on suggestion of Dr. Julius Stratton, to act on their behalf in exploring, with the National Science

Foundation, the feasibility of a radio astronomical facility that might have a national scope to 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, and 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 for advice and guidance at each stage of development. Under this group, known as the Advisory Committee, the study looking to the establishment of a National Facility has been broken down into three major parts:

1. Design studies and limitations of the characteristics of the large steerable radio telescopes.

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

3. The organization of such a Facility in the national interest.

This report 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 and far-reaching qualities, we urge the establishment of a National Radio Astronomy Facility 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 vigorous action in creation of a National Radio Astronomy Facility can be undertaken

BIBLIOGRAPHY

This will list the approximately 45 letters, reports, designs, conference minutes, etc. developed during the Feasibility Study and previously transmitted to the National Science Foundation.

DRAFT
April 17, 1956

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, investigation 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 only four U. S. institutions (CIW-DTM, Harvard, NRL, Ohio State) 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 NATIONAL 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 for growing deficiencies of research facilities. As already mentioned, only four 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 will soon be in operation at Harvard; an 84-ft. steerable paraboloid is under construction for NRL; two

100-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. Furthermore, no single institution can provide a staff large enough to make maximum effective use of such an installation. A national, cooperative enterprise is, therefore, 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 a variety of problems were discussed: the objectives and requirements of a radio astronomy program; the relationship of a national, joint facility to the smaller facilities of the universities and similar institutions; the staffing of a National Facility and the training of students; ways of supporting a National Facility 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.

A. Specific Objectives. A National 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 National 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 National Radio 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 National 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 institutions, and then expand and complete the research with the more powerful equipment at the National Facility, they will be stimulated to initiate many projects they might otherwise consider impossible.

4. A National 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 two 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 National Radio Observatory will make it possible for the astronomy departments at these universities to offer advanced research experience in radio astronomy, through the National Facility, 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 National Radio 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 National 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 National 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 National Radio Astronomy Observatory be a 140-ft. steerable paraboloid, with high precision of surface, motion, and position indication. Paraboloids of still larger aperture would be constructed somewhat later. 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*, who agreed that such instruments would have the greatest usefulness and versatility for a National Facility. A quotation from a letter by J. L. Greenstein to B. J. Bok is an example of this opinion:

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

> "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 exlude the possibility of acquiring other types of equipment. Ultimately, the National 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.* The remainder of this 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 of opinion 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 a 600-ft. antenna can be used effectively for 21-cm research.

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*See Chapter II.

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.

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.* 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

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

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 studies 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 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.

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 plans and to be available for use at all wavelengths.
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> "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."

DRAFT
May 1, 1956

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 National Facility. As a solid basis for discussion, the conference had a memorandum, "Survey of the Potentialities of Cooperative Research in Radio Astronomy," prepared by Dr. 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 Dr. 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 National Radio Astronomy Facility.

B. The Tentative Program. The conference discussed the immediate needs of a National Facility 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, and data processing, and 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

Dr. 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 problems might prove desirable. He also proposed, as an initial step, that an ad hoc committee be set up by agreement between Dr. Menzel, Dr. 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 Dr. Menzel and Dr. Tuve, following the meeting of May 20, 1954, Dr. Berkner set up an ad hoc committee, with Dr. Hagen as chairman, composed of the following:

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

At the first meeting of the Committee on July 26, 1954, at AUI's New York office, Dr. Berkner and Dr. Emberson presented a draft of 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, radio interferences, 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 Facility, 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 on a national basis, 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, but made no formal reply until January 13, 1955, when it informed AUI that they had been granted $85,000 for the purposes described in its 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, Dr. Berkner and Dr. Hagen had the advantage of an extended discussion with Mr. 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. Mr. Michael B. Karelitz, whose services AUI has on a consulting basis, also met with Mr. Husband. Mr. Karelitz is a mechanical engineer of high reputation and his advice on engineering problems has proved of great value. The meeting was also attended by Dr. Peter van de Kamp of Swarthmore University, then attached to the National Science Foundation.

C. The Steering Committee. On February 18, 1955 Associated Universities, Inc. received the funds granted by the National Science Foundation, and began active work. Dr. 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 Dr. 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.

Dr. 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, in western Virginia, West Virginia, or possibly in Tennessee. Dr. Emberson conferred with the Weather Bureau and the Geological Survey, and also obtained advice from various qualified people, among them Dr. Harold L. Alden and Dr. E. R. Dyer at the University of Virginia, and Dr. 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.

Dr. 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 a variety of problems were discussed. Dr. 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. 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. Dr. Haddock gave a description of the 50-foot reflector at the Naval Research Laboratory and of his experience during the design and construction phases, as well as in that of actual operation. Dr. Bok described both the small (24-foot) radio telescope at Harvard and the 60-foot reflector then planned. His description was supplemented by Mr. 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 Dr. Friis of Bell Telephone Laboratories, Dr. Van Atta of Hughes Aircraft Corporation, Dr. R. H. Dicke of Princeton University, and Mr. W. W.

Salisbury of Gray Scientific Division of the Remler Company. Dr. Emberson showed the model built in 1948 by Mr. 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. Seven members of the Committee (Messrs. Bok, Deutsch, Ewen, Goldberg, Haddock, Hagen and Tuve) were present, as well as Dr. 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 National Radio Astronomy Facility 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 planning for more ambitious 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 Dr. 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 28th, 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 Dr. John P. Hagen. The following members of the Committee were present: B. J. Bok, A. J. Deutsch, Leo Goldberg, W. E. Gordon, F. T. 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. Dr. 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 of $108,000 per annum for a total 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. Dr. 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. Dr. Emberson outlined the plans he has made 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:

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

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 will be erected at the Facility.

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 the very large radio telescope. 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 the 600-ft. radio telescope.

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 first phase of the establishment of the National Radio Astronomy Facility 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 National Radio Astronomy Facility 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 National Radio Astronomy Facility 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 the 600-ft. telescope.

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 National 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 Dr. 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 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 Mr. Husband, on the one hand, and Dr. Berkner, Dr. Feld, and Mr. M. B. Karelitz, representing AUI. Although in many respects the work done by Mr. Husband on the 250-ft. dish 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 decidely 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 Dr. 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 alt-azimuth mount, and agreed that for such a mount, less than atmospheric 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 National 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 hisstaff, 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 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 protection 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 Commission and the Inter-Departmental Radio Advisory Committee (IRAC). With a view to obtaining action from these bodies, AUI engaged the services of Mr. William A. Porter, formerly the President's Special Advisor on Telecommunications and Chairman of the Communications Committee of the American Bar Association. This method of protection has the advantage of being applicable not only to the proposed National Facility, but also to all other radio astronomy installations in the country.

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 advise of consulting engineers, all three designs call for an alt-azimuth 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 Mr. 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 a complete exposition of its ideas on organization, as indicated by Chapter VIII of this Planning Document. Discussions have been held with the Director of the Foundation and members of his staff, and the specific questions that must be answered before a contractor is selected and a definitive plan of organization worked out have been clarified to the satisfaction of both parties.

D. Estimated Cost. AUI has submitted to NSF revised cost estimates based on information gained through actual experience with the Green Bank site. The total capital expenditure required for FY 1957, if AUI's ideas are accepted, substantially exceeds the cost estimate prepared in July 1955 and subsequently reduced slightly in conferences between the NSF and the Bureau of the Budget. The new estimates are under consideration by the appropriate members of the staff of the NSF and of AUI, and the NSF has been furnished with complete explanations for the changes in the July 1955 figures. The great unsolved question, as of the end of March 1956, was the amount of capital funds that would be made available by the Congress.

DRAFT
April 27, 1956

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

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*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.

specification listed below is, beyond all question, the most important of those listed.

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 surrounding 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 surrounding 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 a 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 it should be at a minimum to prevent excessive "down-time" of radio telescopes.

E. Winds. The site 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:

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 scien-

tists 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."

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 incompatabile. 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 (Reference: U. S. Dept. of Commerce, Weather Bureau Technical Paper No. 20, "Tornado Occurrences in the United States" - Chart 13), 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 Virginia, 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 indication 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

Map - Showing all Tornadoes of Record

U. S. Dept. of Commerce, Weather Bureau
Technical Paper No. 20. Chart #13

(Previously Distributed to Committee Members at
December 11-13, 1955 Meeting)

Figure III-1

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.

III. THE SEARCH PROCEDURE

In the spring of 1955, an ad hoc panel was formed to assist in the search for possible sites. 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.
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*

The astronomers of this panel enlisted the assistance of associates who had personal knowledge of the region under search,

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*Affiliation at that time.

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, Dr. E. R. Dyer and Mr. 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 possibilities. 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* inspected six sites by car, the five mentioned above and a new one suggested by Dr. H. W. Wells: Nos. 1, 4, 11, 15, 18 and 21 on the discovery** list. The sites were rated on a number of points, such as the size of the valley, the ease with which it

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*Drs. H. L. Alden, E. R. Dyer, R. M. Emberson and J. P. Hagen.

**The complete discovery list is given in Section III-B.

could be developed, the degree of isolation, and travel time necessary to reach it (from New York as an arbitrary 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 Dr. 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 candidates 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, Drs. 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 Drs. 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 communication 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 relatively 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 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 will 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 Smoky 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 Mr. 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 observa-

tions 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 (mislabeled Arborvale) 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.

Histogram - Figure 2 of Jansky-Bailey Report

(Previously Distributed to Committee Members at Dec. 11-13, 1955 Meeting)

Figure III-2

Histogram - Figure 8 of Jansky-Bailey Report

(Previously Distributed to Committee Members at Dec. 11-13, 1955 Meeting)

Figure III-3

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	389	
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	410	

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.

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*See Page III-16 for explanation.

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 (GPO-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

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

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

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 mountain 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	Airport	Distance (miles)	Runways			Remarks
			No.	Length (feet)	Surface	
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 as ( ).

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. Mr. 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 meeting of the Steering Committee approached, when a recommendation of 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

Map of A. T. & T. Installations or Plans

(Previously Distributed to Committee Members at Dec. 11-13, 1955 Meeting)

Figure III-4

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.

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

Drs. Burke, Ekland, Firor, Franklin, Tatel, Tuve & Wells (Dept. of Terrestrial Magnetism, Carnegie Institution of Washington)
Dr. Dyer (University of Virginia)
Dr. Chambers (Univ. of Pennsylvania, AUI Trustee)
Dr. Cutts (National Science Foundation)
Mr. McFadden (Eggers & Higgins)
Mr. McClain (Naval Research Laboratory)
Messrs. Berkner, Dunbar and Emberson (Associated Universities, Inc.)

Sites 15 and 28 were visited in that order. Discussions took place enroute and at the sites. Dr. Tuve and his group returned to Washington from Site 28; those remaining proceeded to Site 18 on the same day. On December 3, Dr. 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.:

Map of Eastern U. S. Showing Sites 1, 11, 15, 18 and 28, and Distances to Colleges, Universities, or Major Towns

(In Preparation)

Figure III-5

J. P. Hagen, F. T. Haddock, & 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.)

Dr. 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 inspected 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, Messrs. Eckel, and Tuttle advised that the five sites under consideration appeared to be about the same insofar as the problem of subsurface 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, B. J. Bok, J. G. Bolton, H. I. Ewen, F. T. Haddock, E. F. McClain, H. E. Tatel, M. A. Tuve, L. V. Berkner, C. F. Dunbar, R. M. Emberson, N. H. Frank, M. B. Karelitz, E. R. Dyer, E. B. Eckel, J. Feld, H. S. Hogg, J. J. McFadden, D. C. Ports, R. W. Schloemer and C. R. Tuttle.

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

(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,

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*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.

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 recommendation 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 has been 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:

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*Figure III-6.

Map - A reproduction of a part of the Geological Survey Cass Quadrangle, showing the Green Bank region.

(In preparation; full-sized maps previously distributed at Dec. 11-13, 1955 meeting)

Figure III-6

	Green Bank	Deerfield	Massanutten
Radio Noise Measurements	1	2	3
Population Studies	1	2	3
Airport Activities	1-2	1-2	3
Mountain Shielding	1	2	3

DRAFT
May 18, 1956

Chapter 5

SITE DEVELOPMENT

Soon after the search for a site was started, the firm of Eggers and Higgins, Architects, of New York City, were engaged to prepare a "hypothetical" site development. Their instructions were based on advice by the Steering Committee, as well as on information from other relatively small research centers operating in isolated locations. Provision was to be made for a staff of about one hundred, including the permanent scientific staff, visiting scientists, and all supporting staff. 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 three largest 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.

A. The Hypothetical Development. Eggers and Higgins suggested that their study could be more meaningful if they worked on some existing location similar to a possible site. It was recognized that this procedure had the inherent risk of masking some construction problem not prominent at the hypothetical site, but that would be found at the site ultimately selected. As a safeguard, Eggers and Higgins were cautioned to develop fully all recognized construction problems; this procedure would, of course, make the hypothetical development more costly than any likely real development. But the detailing 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 had several extreme problems, particularly those involved with the access road to the site area -- hairpin turns on narrow mountain roads and inadequate bridges. Furthermore, the position selected for the site proved to have variations of elevation amounting to 50 to 100 feet, with rock close to the surface. Consequently, the cost of leveling areas for the radio telescopes would have been large, adding more than a million dollars to the site development costs.

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.

B. 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 the hypothetical site development for this specific site. The problems of site access and leveling, mentioned above, were virtually non-existent 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.

At the time that Eggers and Higgins undertook the Green Bank development study, the radio telescope program then being recommended by the Advisory Committee included five parabolic reflectors of the following diameters: 25 feet, 60 feet, 140 feet, 250 feet, and 600 feet. Although these telescopes and their foundations (with the exception of 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 provision must be made for them in such items as utilities and roads. The first construction phase was to include the three smaller radio telescopes.

In order to have 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 thatnot all the desired buildings could be started, because the first increments possible within the budget would be so small as to be very inefficient. Accordingly, it was necessary to drop some buildings from the first construction phase, the pertinent funds being diverted to other buildings that could now be started at an efficient threshold size. To illustrate this point, the proposed first phase construction on the housing and cafeteria building was dropped in order that the first part of the central building could be planned in an adequate manner. This necessitated, however, a temporary placement of the cafeteria in the central building.

In some cases, alternative solutions were possible. The outstanding example of this was the provision of electrical power. The choices were between on-site generation and commercial purchase. The latter included a sub-choice as to whether or not large emergency standby capacity should be provided.

The general site development is shown in Figures 5 - 102 and 103, 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.

C. Major Construction Items. The following itemization gives the names of the prinicipal buildings and their probable use in the ultimate development of the site. In a following section, the first construction phase will be described in detail.

1. Laboratory and Administration Building (two stories and basement), providing:

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) Provision for 25-ft. radio telescope on roof.

f) Air-conditioned rooms for computers.

g) Library, lounge, conference rooms and assembly room. (All as shown on Drawings--104 - 107, inclusive.)

2. Residence Hall and Cafeteria (two stories and basement):

a) The lower level of the Residence Hall includes five apartments for visiting scientists and families, and the upper level has 20 single, or double bedrooms with baths for visiting scientists and technicians without families.

b) The Cafeteria provides seats for a Dining Room and a Cafeteria, separated with a folding partition. Further space for kitchen, serving storage, freezers, small snack bar for employees who work late. (All shown on Drawing--108.)

3. Site Maintenance Building (one story): Provides small garage, filling station, waiting room for drivers, locker room for employees, storage space for materials and spare parts, and shops for automobile repair, carpenters, painters, electricians, plumbers and mechanics. (All shown on Drawing--109).

4. Radio Telescope Maintenance Building (one story): This building will provide spaces for storage of 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. (All shown on Drawing--110).

5. Electric Generator Building (one story): This building will house the generating plant for the entire facility, if on-site generation or on-site emergency standby capacity is provided. (All shown on Drawing--109.)

6. Radio Telescope Control Buildings (one story): There will be control buildings provided for the 60-ft. and 140-ft. radio telescopes (space for control of 250-ft. and 600-ft. radio telescopes will be provided within the framework of the supporting members for these telescopes). (All as shown on Drawing--110.)

7. Residential Buildings: Reference to Drawing--103 will indicate 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 Facility, the site superintendent, the chief radio telescope operator, and the chief engineer.

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

D. First Construction Phase. After preliminary costs had been estimated 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 following list is the maximum amount of construction that could be hoped for in the first phase. (Note: It has been assumed that land acquisition costs, surveys, test borings, and the radio telescopes and their foundations are included in another part of the budget. See Chapter VIII.) Prices are based on experience, information obtained from engineers and contractors, and on estimates of similar construction work published in technical literature for 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 (See Drawing No. 102) with 24-ft. wide by 8" deep, asphalt penetrated macadam 2/3 mile at $60,000 per mile.............	40,000.
3. Build on-site roads per Drawing 102, 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.		
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	
		618,000.

E. Commercial Power. If the choice is the purchase of 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.

F. Initial Costs. The secondary line bringing power to the site would be partially overhead, and, for the portion near the site, underground. It is important to note that this private supply line would be adequate not only for the first phase, but also for the ultimate maximum power requirements. There are various possible arrangements for financing this supply line. One would involve no capital investment on the part of the Facility, but there would be fixed charges, in addition to any for power consumed, to pay for the line maintenance and to amortize the initial investment by the power company. With this arrangement, the on-site power generation cost of about $157,000 and the generator building cost of $30,000 (see Nos. 8 and 12 of the preceding list) would be saved.

G. Annual Operating Costs. Initial construction costs are not the full story. To provide a rough basis for comparison, estimates have been made for the on-site generation of power, allowing for a payroll for 24-hour operation, 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 commercial power line fixed charges would be about $65,000, with a minimum of about added $14,000 for the power consumed (this latter figure would depend on the rate schedule that would apply). On the other hand, at the end of the second construction phase, there would be no additional commercial charges, except for the power actually consumed, estimated at $48,000. If on-site generation were the choice, the second phase 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.

H. Second Construction Phase. The cost estimates given here are current values. If the general rise of 4 to 5% per year for all types of construction costs continues, the cost estimates should be appropriately corrected at any later date. (Note: Item designation is a continuation of that in the list for the first construction phase.)

1. Rebuilding existing dirt roads to 600-ft. radio telescope from beginning of "S" turn (see Drawing No. 102) 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, per Drawing No. 102, 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 in accordance with Drawings Nos. 105 to 107 inclusive.

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 Drawing No. 108.

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 Drawing No. 109.

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 on Drawing No. 110.

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 Drawing No. 109.

60,000 cubic feet at $1.25 per cubic
foot.............................. 75,000.

10. Construction of ten residential buildings.

14,000 square feet at $15 per square
foot.............................. 210,000.

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

12\. Extension of utilities

Telephone conduits	$ 16,000	
Electric power distribution	299,000	
On-site power generation	385,000	
Sanitary	135,000	
		$835,000

I. 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.