Associated Universities, Inc.

THE NATIONAL RADIO ASTRONOMY OBSERVATORY AND THE 140-FOOT RADIO TELESCOPE

Summary of oral statement made by
Dr. Richard M. Emberson at the
National Science Foundation on
November 22, 1957 and of points
made in subsequent discussion.

STATEMENT

The purpose of this statement is to trace the history of the work done by Associated Universities, Inc., in planning the National Radio Astronomy Observatory and obtaining a design for the 140-foot radio telescope which will be its major research tool.

In January, 1954, a conference was held in Washington, at the instigation of California Institute of Technology, the Department of Terrestrial Magnetism (C.I.W.), and the National Science Foundation, to examine into the state of research in astronomy in the United States, the scientific problems to be considered, and the needs of astronomers for research tools and other means for doing more effective work. In the discussions much emphasis was laid on the importance of large antennas in carrying on research in radio astronomy. The importance of the large antenna is the high gain that makes possible the reception of very faint signals and the large aperture that provides the sharp resolution needed for locating sources accurately.

The results of the Washington meeting were embodied in an internal memorandum prepared by Dr. Jesse Greenstein and others. It was pointed out that the United States had lagged behind other countries in this scientific field. In Great Britain, Australia, The Netherlands, and probably Russia, there were active plans for the construction of large antennas, and some instruments of substantial size were already under construction.

Following the Washington meeting, Dr. Bart J. Bok of Harvard approached scientists working on radio communications at Massachusetts Institute of Technology, who were interested in large steerable antennas, and also Dr. John P. Hagen of the Naval Research Laboratory, where a 50-foot radio telescope had been constructed. Further discussions during the late winter and early spring of 1954 led Dr. Julius Stratton of Massachusetts Institute of Technology to suggest the desirability of a nationwide cooperative effort in radio astronomy, analogous to Brookhaven National Laboratory in nuclear research. These developments were discussed informally with Mr. Lloyd V. Berkner, President of Associated Universities, Inc., which operates Brookhaven. Mr. Berkner had already talked with Dr. Lovell at the University of Manchester, England, where a 250-foot radio telescope was then being erected. These early talks between Dr. Lovell and Mr. Berkner are important in the history of the Project, since they led to a meeting early in 1955 between Mr. Berkner and Mr. H.C. Husband, the engineer in charge of the design and construction of the 250-foot antenna, on one of the latter's visits to the United States. It was at this meeting that a sum in the neighborhood of $2,000,000 was first considered as a price for an initial radio telescope for a U.S. observatory.

The informal discussions in the spring of 1954 culminated in a meeting in the latter part of May, 1954, at the offices of Associated Universities, Inc., in New York. This meeting was called by Mr. Berkner at the request of Dr. Menzel of Harvard, and other interested scientists, and was attended by some forty people, representing twenty-eight institutions, all of whom were interested in astronomy in general, and most of them in radio astronomy. The outcome of this meeting was a formal suggestion that Associated Universities, Inc. apply to the National Science Foundation for a grant to finance a study of the feasibility of establishing a national radio astronomy observatory, At this meeting an informal ad hoc committee was set up under the chairmanship of Dr. Hagen to enable the interested scientists to remain in active touch with the situation. This committee was constituted as follows:

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

The Trustees of Associated Universities, Inc. authorized Mr. Berkner to apply for a grant in the manner proposed. Formal application was made in July 1954, and notice of award was received in January, 1955. Thereafter, the ad hoc committee was reconstituted as a formal Steering Committee to assist AUI in carrying on the study. This Committee served for nearly two years, and out of it has grown AUI's present Radio Astronomy Advisory Committee.

The first task assumed by AUI was the selection of a site for an observatory. The Foundation narrowed the scope of the search to practical proportions by imposing the requirement that the site be within a radius of approximately 300 miles of Washington. In making the search, AUI was assisted by an ad hoc committee, on which were Drs. Harold Alden and Edmond R. Dyer, of the University of Virginia; Dr. Carl K. Seyfert, of Vanderbilt University; Dr. John P. Hagen of the Naval Research Laboratory; and Dr. Paul L. Price, State Geologist of West Virginia. Noise measurements were made by the engineering firm of Jansky & Bailey, using equipment provided by the Naval Research Laboratory. These measurements failed to go down to the low signal levels of interest in radio astronomy, but they did produce data by which the relative merits of the otherwise acceptable locations could be judged. The search indicated the Green Bank location to be the best, and this choice was confirmed by the Steering Committee at a meeting in December, 1955, held at the office of the Foundation. At about that time, also, it was agreed with the Steering Committee and representatives of the National Science Foundation that AUI should embark on a program of acquiring options to purchase the necessary land in the Green Bank valley. One-year options covering more than 5,000 acres were acquired. The option prices, quite understandably, showed a wide variation and a general upward trend. When the prices asked reached what seemed to be an exorbitant level, the program was discontinued.

During this time, Dr. Bart J. Bok, with the assistance of other interested scientists, some of whom were members of the Steering Committee, produced a detailed description of the research problems which could be carried out at a national observatory, and what equipment would be appropriate. The consensus was that the basic instrument should be a very large steerable paraboloid. A diameter of 600 feet was considered to be the largest practical size, and Dr. Jacob Feld of New York City was asked to make an engineering study of such an instrument. Dr. Feld submitted his report in July, 1955. It was based on the following specifications:

Ratio of focal length/aperture to be between 0.35 and 0.5.
Surface tolerance ± 1 inch over entire surface, and ± 5/8 inch over the inner half aperture.
Sky coverage to be hemispheric (or as large as possible if an equatorial mount were employed).
Pointing accuracy to be 5% of the beamwidth for 10 cm radiation, or almost 7" of arc.

Dr. Feld concluded that it was technically feasible to construct a 600-foot telescope to meet these specifications. But he further concluded that if economical amounts of metal were to be employed, it would be necessary to incorporate compensating devices in the design.

The attitude of the Steering Committee, commencing in the spring of 1955, was that speed in obtaining effective observing equipment was of the essence, and that an instrument of as nearly "off the shelf" character as possible should be purchased. In an effort to meet the recommendations of the Committee, AUI sought proposals for the design, fabrication, and erection of a 40-meter (133-foot) telescope based on performance specifications only. These specifications called for the same ratio of focal length/aperture as for the 600-foot study; the surface tolerances were ± 3/8 inch over the entire surface with ± 1/4 inch over the inner half; and pointing accuracy was set at 5% of the beamwidth for 10 cm radiation, or 30" of arc, with some relaxation of the tolerances when the winds were greater than 30 mph.

This solicitation of proposals produced no acceptable proposal, because of technical inadequacies, but many of the responses received contained valuable information and suggestions. After a review of these proposals, the Steering Committee, in July 1955, arrived at the conclusion that the telescope could be built, complete with foundation, for about $2.2 million.

In October 1955, Associated Universities, Inc. received a second grant from the National Science Foundation. This enabled it to take another step in procuring a design for a large radio telescope. Contracts were made with D.S. Kennedy & Company, Husband & Company, and Dr. Jacob Feld, under which each contractor was to produce a design for a 140-foot radio telescope based on performance specifications prepared by AUI. The Husband and Kennedy designs were to be specific for the 140-foot size; the Feld design was primarily to gain experience with problems of the 600-foot telescope and, at the same time, was to be competitive in price with the other designs. The specifications for the 140-foot telescope were derived from those of the 40-meter telescope:

f/D to be 0.5
Surface tolerance to be $\pm$ 1/4 inch over entire surface.
Pointing accuracy to be 10" of arc.

In addition to the design of the telescope itself, control problems were considered by the Servo-Mechanisms Laboratory at the Massachusetts Institute of Technology.

During the summer and fall of 1955 and the early part of 1956, discussions were constantly held with the Steering Committee and with other astronomers in an effort to obtain an instrument of maximum utility. In this process, the idea of an off-the-shelf instrument disappeared, and it was recognized that a completely new design had been adopted. This placed more emphasis, therefore, on the early part of the telescope program for the observatory, which included a small (perhaps 20-foot) reflector on the roof of the laboratory building for easy access from the receiver design section, and a larger (60 - 85-foot) instrument.

As the Feld, Husband and Kennedy designs for altazimuth 140-foot telescopes proceeded, parallel studies indicated that the necessary conversion from altitude and azimuth coordinates to hour angle and declination could be accomplished with the necessary precision. But it was also apparent that this precision could be had only if the coordinate conversion device were a rather complex mixture of mechanical and electronic components. Astronomers who had observing experience with equatorially mounted optical telescopes were loathe to accept the complexities of an altazimuth telescope, and urged that we design the 140-foot telescope with an equatorial mount.

The three designs prepared by AUI's contractors were exhaustively reviewed by the Steering Committee and a special ad hoc committee of engineers. Cost studies, made by a competent engineers, Dr. Thomas J. Kavanagh of New York, indicated that any one of the three altazimuth designs would be structurally cheaper than equatorial designs, but that the cost of the coordinate convertor would increase the total to the same level as for an equatorial structure, which would probably be within the price of $2,200,000.

The need for a firm decision on the type of mount became apparent. The arguments for and against both the altazimuth and the equatorial mounts were carefully considered. The consensus was that the altazimuth mount required a somewhat more complicated control system, and further, that astronomers in general were strongly prejudiced in favor of the equatorial type. It was decided in the late summer of 1956 that the new instrument should be mounted equatorially, although it was recognized that probably this was the largest instrument for which this type of mount would be practical. Professor Ned L. Ashton, Iowa City, Iowa, agreed to undertake a complete design which could be used in obtaining lump sum bids and which would incorporate as many as possible of the suggestions made by the scientists. Professor Ashton agreed that his work would be subject to review by AUI as it progressed. The performance specifications provided him were revised as follows:

a) f/D = 60/140 = 0.428
b) Surface to be built of a small number of panels, each built to a ± 1/16 inch tolerance, and all adjustable to a ± 1/4 inch tolerance.
c) Angular precision of 10" of arc to be required only for winds of less than 16 mph.
d) Focal support truss to carry a load of 1000 pounds and hold it to within 1/8 inch of the correct position.

In his work Professor Ashton was thus governed by performance specifications even tighter than those previously used. For example, surface deflection was limited to plus or minus one-sixteenth of an inch, as against the previous requirement of a quarter inch. This change and others of a similar nature do not reflect a futile attempt to produce an instrument which will be fully effective under all conditions. The goal sought is complotely practical, namely, an instrument which under appropriate and foreseeable sets of conditions will be usable for a maximum range of research problems. The need for maximum attainable precision has been amply demonstrated by the serious disagreement which has developed between British and Australian scientists on the interpretation of data obtained from observations conducted with relatively imprecise instruments.

The Ashton design was completed in the summer of 1957, and it can fairly be claimed that when built this telescope will be the best in the world. Expert and detailed review at all stages assure the technical feasibility of the design. The only limitation in the design is the sacrifice of some sky coverage at the northern horizon. The hoped for savings in cost through this limitation have proved to be insignificant, and the sky coverage limitation may be eliminated during the preparation of the final detailed engineering and shop drawings.

DISCUSSION

Size and Precision

There is no question but that for an equivalent amount of money a telescope much larger than 140 feet could be built. However, the relaxing of tolerances necessary to achieve this result would seriously diminish the effectiveness of the instrument. Mere increase in the size of the aperture is not a substitute for precision. The potential observing power of the telescope can be measured in terms of the gain and the solid angle of the sky covered by the telescope beam. These factors are greater for larger apertures and for shorter wavelengths, the latter being limited by the surface tolerances of the reflector. By this measure, the 140-foot telescope will have greater potential than the British 250-foot telescope. In short, the precision of the design more than compensates for the difference in aperture.

The change in plan from an "off the shelf" instrument capable of being quickly fabricated and erected to a uniquely precise instrument of novel and complicated design was through an evolutionary process rather than by a clear-cut decision at the beginning of the plans for the observatory. However, the result has been to make it possible for the observatory to be equipped with an instrument of larger life and greater potential use than would have been attainable had AUI moved hastily.

Comparison with other Instruments

When completed, the 140-foot telescope will compare favorably with any known instrument existing, under construction, or planned in any other country. This superiority promises to continue for about five years. Without this instrument, the observing equipment in the United States will remain inferior to that in several other countries, notably Australia, Great Britain, The Netherlands, and probably Russia..

It should be emphasized that there is free exchange of research data and information about equipment with all but the Iron Curtain countries. It is certain, however, that the Russians have been ingenious in designing observing equipment and are obtaining important results.

Defense Implications

The 140-foot radio telescope has not been designed with an eye to the satellite program or to any but a general connection with the national defense.

Existing radio telescopes have been used in tracking the Russian earth satellites. However, such use is largely a matter of academic curiosity for astronomers, and unquestionably better tracking devices can be devised for this or similar specific purposes.

Information of interest to the armed services will doubtless be obtained from the various observing programs, and AUI has kept the services fully informed of its plans, including telescope designs. Moreover, the interest which has been aroused in steerable paraboloids has been of real benefit.

Alternative Plans

None of the alternatives to a 140-foot telescope built in accordance with the design obtained by AUI are attractive.

It would be possible, within the limits of the original budget, to build an instrument of much less precision. This choice would necessitate abandoning the precise, high-frequency research programs which are important for scientific progress and so of primary interest to astronomers.

Comparable gain and positional accuracy could be achieved with arrays or similar antenna systems, but these are characterized by the narrow wave band that can be studied as compared with a broadband parabolic reflector. Thus, any such limitation would deprive a large number of scientists of the opportunity to do research.

Careful study might produce some alternative to this 140-foot telescope which would be satisfactory in some respects. However, just what this alternative would be is far from clear.

Above all, it must be emphasized that failure promptly to adopt the plan proposed or some equivalent alternative will result in lengthy delays and proportionate irreparable damage to research in the United States.

Future Development

With a completed 140-foot radio telescope, the United States, for a period of about five years, in all probability will have research equipment at least equal to or better than that in any other country. Moreover, the 140-foot telescope will be a useful research tool for a much longer period. However, the art of telescope design is not static, and studies should be commenced at an early date, looking to the design of still larger instruments which will make it possible to probe even further into outer space. Just how large the next instrument should be and what other characteristics it should have cannot now be determined. There are many possibilities. For example, by sacrificing steerability, it would be possible to build an instrument of very great size -- perhaps over 1200 feet in diameter -- for a cost by no means proportionately greater than that of the 140-foot instrument. This much is certain -- if a systematic program of design development is not undertaken, at the end of five years, perhaps even sooner, the United States will again be lagging behind those other countries where planning has been more farsighted.

Radio Astronomy and Basic Research

The justification for the creation of a fully equipped radio astronomy observatory rests on the critical importance of basic research. It is safe to predict rapid growth in the importance of astronomy in general and radio astronomy in particular. Only through the work of astronomers can the frontiers of man's knowledge of space be pushed back. Moreover, not only will research in radio astronomy produce information of incalculable intrinsic importance, but it will stimulate activity and basic discoveries of an auxiliary sort in other fields -- notably electronics, through the need for more effective receiving equipment, and radio communications.