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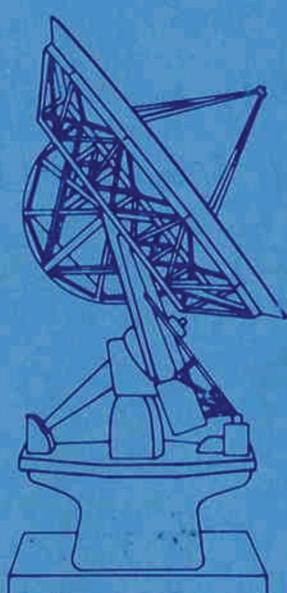
NATIONAL RADIO ASTRONOMY OBSERVATORY

"FIRST"

Annual Report

JULY 1, 1959



Associated Universities, Inc.
under contract with the
National Science Foundation

Annual Report

JULY 1, 1959

NATIONAL RADIO ASTRONOMY OBSERVATORY
Green Bank, West Virginia

Operated By

ASSOCIATED UNIVERSITIES, INC.
under contract with the
National Science Foundation

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Board of Trustees
Associated Universities, Inc.

Gentlemen:

Transmitted herewith is the first Annual Report of the National Radio Astronomy Observatory. This report has been prepared with the joint assistance of the Departmental Chairmen of the Observatory and Dr. R. M. Emberson, Acting Deputy Director.

It is a distinct pleasure to transmit this report at the time of transition of the Observatory from the initial construction to the research phase. The enormous progress at the Observatory since the initial signing of the contract between Associated Universities, Inc., and the National Science Foundation on November 17, 1957, has been due to many scientists and engineers. In particular, the initial staff have given their effort, loyalty, and enthusiasm without stint to bring the plans to fruition in the shortest possible interval. It has been a real pleasure to work with these men of imagination and vision.

While many names should be mentioned, I should feel remiss if I did not name Dr. R. M. Emberson as the man above all others who is responsible for making the Observatory possible. Dr. Emberson has mothered the whole plan and followed every detail until the present plan has come to fruition.

In making this report, it is my honor to pass on the reins to the first Director of the Observatory, the illustrious astronomer, Dr. Otto Struve, who assumes the post on July 1, 1959. In assuming this post, Dr. Struve follows the long tradition of his family as founders of pre-eminent observatories. It is my sincere hope and belief that the beginnings, reported here, represent the first of many significant and conspicuous contributions to science from the Observatory.

L. V. Berkner
Interim Acting Director,
National Radio Astronomy Observatory
President,
Associated Universities, Inc.

ASSOCIATED UNIVERSITIES, INC.

The National Radio Astronomy Observatory is operated by Associated Universities, Inc. under contract with the National Science Foundation. Associated Universities, Inc. is organized under the Education Law of the State of New York and is sponsored by nine northeastern universities. Its governing body is a Board of Trustees consisting of nominees of the sponsoring universities and Trustees-at-Large. Each university nominates two Trustees, one of whom is a principal administrator or corporate officer, and the other a scientist. These Trustees, in turn, select three Trustees-at-Large. The President is a Trustee ex officio. The composition of the Board is such as to insure adequate representation of any scientific discipline in which the corporation may undertake work, and to provide general flexibility in methods of operation. The Trustees and corporate officers, as of July 1, 1959, are shown in the table below. To provide a continuing, independent evaluation of the research programs at the Observatory, the Trustees have appointed an Advisory Committee, made up of nine scientists selected with a view to their specialized knowledge of various phases of the Observatory work. The names and affiliations of the members of the Committee are shown below.

BOARD OF TRUSTEES

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Associated Universities, Inc.

As of July 1, 1959

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National Radio Astronomy Observatory	Lloyd V. Berkner (Acting) Nov. 17, 1957 - June 30, 1959 Otto Struve July, 1959

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INTRODUCTION

The National Radio Astronomy Observatory is a unique institution in radio astronomy. It is designed with the support of the Federal Government, through the National Science Foundation, to provide outstanding research tools of astronomy to permit scientists to press outward to the most distant reaches of the universe.

Beginning in 1955 as a mere vision, the Observatory commenced a substantial program of astronomical research during the past year. With the first phase of construction nearing completion, Professor Otto Struve became the first Director of the Observatory on July 1, 1959, the end of the period covered by this report.

In moving from construction to the research activities, the Observatory is initiating its first Annual Report. Since the contract between Associated Universities, Inc. and the National Science Foundation was signed on November 17, 1957, this report necessarily outlines the Observatory activities from then until June 30, 1959, and thus covers a time span of more than one year.

In view of the special character of the Observatory, partaking of the objectives of a "national" laboratory, some comments on the general purposes and objectives of such laboratories seems appropriate. The national laboratory as an adjunct to American research activity is emerging in our lifetimes as an essential element of scientific progress. Examples in the United States are Brookhaven, Argonne, and the Berkeley Radiation Laboratory, which are under the aegis of the Atomic Energy Commission, the National Institute of Health, and the National Astronomical Observatory, at Kitt Peak, Arizona, and the National Radio Astronomy Observatory, both sponsored by the National Science Foundation.

Tycho Brahe taught us that one great observatory was necessary and sufficient to obtain the data that caused the fourteenth century revolution introducing modern science. But that observatory had to be large and expensive to do the job—as expensive in terms of the money of the time as the national laboratory is today.

From Brahe's observations, Kepler formulated his laws of planetary motion, and these led Newton to state the laws of mechanics—laws on which almost all of our present day engineering, construction and transportation are founded. From this we draw the lesson that research facilities must be adequate to the problem at hand—often the scope of the facility is beyond the capability of a university to manage. For this, the specialized observatory or national laboratory or the Russian "research institute" provides the means.

The departmental staffs of the universities, with some few exceptions, find the design, construction, and operation of very large research tools burdensome, with a tendency to divert their staffs from the broad range of activities expected at the university to the more restrictive range of activities imposed by the requirements of the machine itself. Above all, the large cost of the machine means that not many, and perhaps only one machine of a kind can be built. Therefore, it is necessary that each machine be accessible to qualified members of the faculties of many universities and institutions—men who are peculiarly oriented in their thinking to deal with the results from the machine, or to stimulate new lines of experiment, wherever these men can be found.

This has led to the conclusion that the most suitable organizational device for the construction and operation of very large-scale and often unique, research tools for the benefit of American universities was the national laboratory. These research tools are planned to supplement the facilities available to the scientists at a large number of universities, so that any qualified scientist can feel that he has access to machines of whatever size his experimental program requires. But the necessary greatness of such laboratories must not be confused with prodigality or luxury—the national laboratory can be as spartan as the individual experimenter. Waste in science comes most often by misdirection of able scientists with tools that are inadequate to the task at hand.

Experience has shown that optimum progress and most effective use of research tools at the national laboratories seem to be achieved when the research effort of the permanent research staff of the laboratory and of the visiting scientists from the universities is about equal. Among the advantages to be acquired by these cooperative arrangements are: First, the visiting scientist can work with experienced people in setting up his experiment on a large and perhaps unfamiliar machine. Second, the extended contact between visiting scientists and permanent staff leads to an important interaction of ideas among both groups. Third, the growth of thought in the national laboratories can serve as a stimulus to the thinking of the university faculties. There we are led back once more to Tycho Brahe; for, as his biographer so aptly observes, "The mighty impulse Tycho Brahe and Johann Kepler gave to astronomy caused the science to be taken up at the universities, and among them Copenhagen and Leyden were the first to found observatories."

SCHEDULING TELESCOPE OPERATIONS

The research facilities at the NRAO are a very special sort of national asset. If not used, but merely hoarded, they would be of little value. If used continuously but by unqualified people and, hence, in a non-productive manner, the net value would again be very small and there would would be the added waste of operating expenses. Obviously, the Director of the Observatory must be responsible, through the staff, that the research facilities are used as efficiently and effectively as possible. This is particularly true of the large radio telescopes, which represent considerable investments of public funds.

It has been found possible to schedule research programs on a telescope so as to minimize the amount of equipment changes between observers and thus to achieve essentially 24-hour use of the instrument. Under this procedure, an observer who requires a very special arrangement of the telescope appartus must wait for a time on the schedule that will minimize the denial of the telescope to others, particularly if considerable effort is required to install the special apparatus and the telescope would not be available to others for many hours or perhaps days.

This latter situation will demand judgment on the value of a proposed research program. If it appears trivial, it cannot be permitted to interfere with other promising programs. This judgment may not always be easy. It is not possible to set numerical values on research proposals. The past record of productivity of a research scientists is one factor that must be taken into consideration. But in no event may a scientist claim time with any of the NRAO facilities because of his institutional affiliation or financial backing, for to submit to such claims would take the responsibility and authority for the Observatory operations from the hands of the Director.

While American scientists had pioneered all major discoveries of which the science of radio astronomy is founded, American radio astronomy has fallen far behind other nations for want of

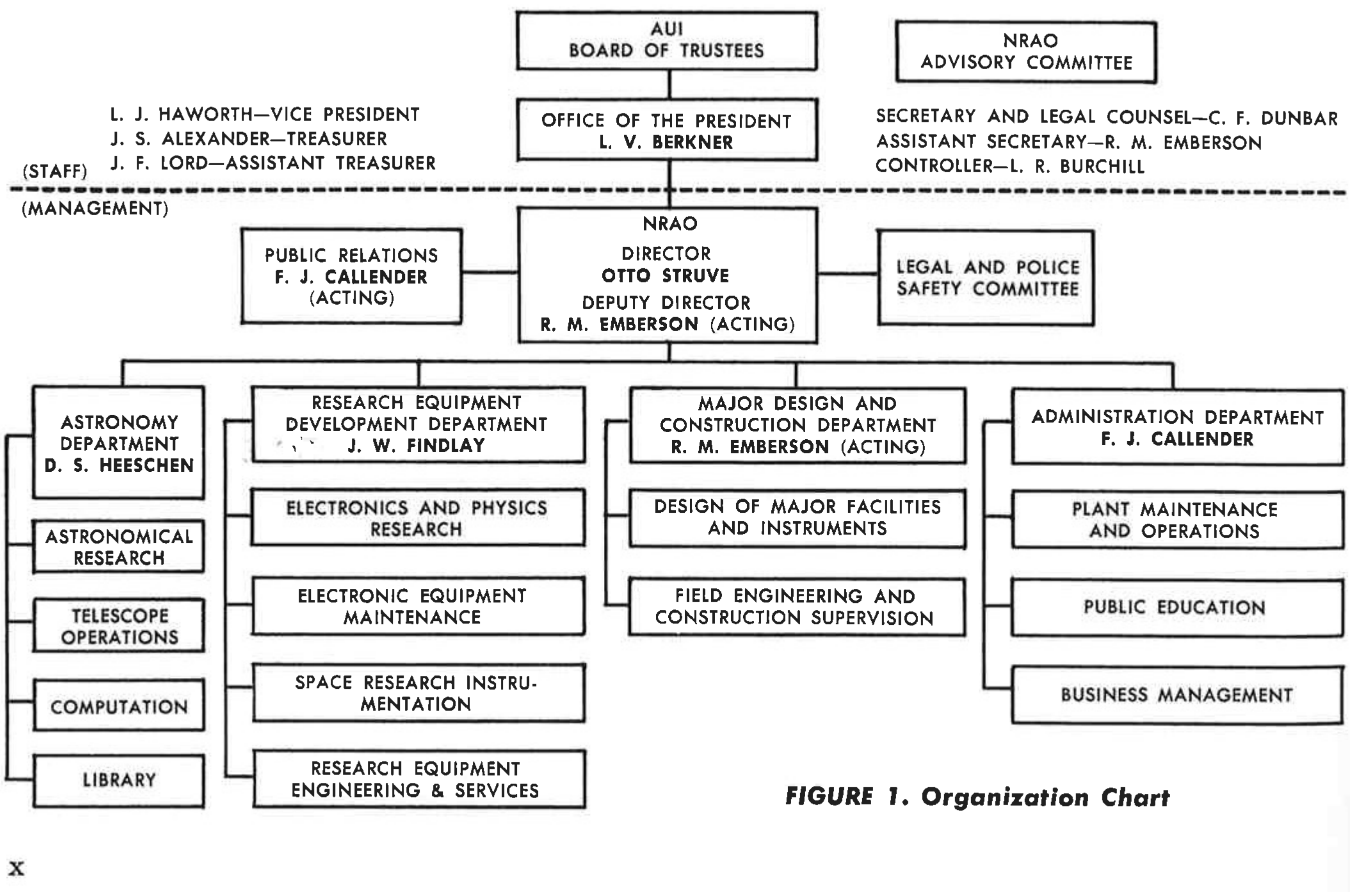


FIGURE 1. Organization Chart

even a single large radio telescope. Now the National Science Foundation has sponsored the National Radio Astronomy Observatory under management of Associated Universities, Inc., to provide to American science what will probably become the most advanced facility available.

The National Radio Astronomy Observatory is organized into four departments: Astronomy, Research Equipment Development, Major Design and Construction, and Administration. During the early life of the Observatory, the small staff was not thus subdivided, but worked more in the fashion of a committee-of-the-whole. The corporate officers have devoted a disproportionate amount of time to the affairs of the Observatory through its formative period, which has been characterized by site development and construction activities.

Reports have been prepared by the Astronomy, Research Equipment Development, and Major Design and Construction Departments, which stand as separate portions of this document. Affairs and interests of the Administration Department are interwoven throughout the bulk of the report and no effort has been made to distill these into a separate section.

STAFF

The total Observatory payroll on June 30, 1959, exclusive of research collaborators and guests, was sixty-four, making a net increase of thirty-two in the preceding twelve months. The growth of the Observatory staff from June, 1957 through June, 1959 is shown in Figure 2. This table demonstrates the marked change in the character of the staff that has taken place during the past year, and the changing emphasis and growth of Observatory programs.

The growth development of the scientific portion of the staff in the past year marks the emergence of the Observatory as an operating research institution. Until December, 1958 the scientific staff was small. Its primary duties and activities were directed toward organization and program planning, supervision of equipment and instrumentation development contracts, and such small research projects as were then possible with the limited facilities available. In the past six months, with the advent of the 85-foot Howard E. Tatel radio telescope and its several receivers, the attention of the scientific staff has turned more and more to observational and other research programs. The dramatic increase in the size of the scientific staff in June 1959 heralds the start of the first full summer observing program. In this last month of the fiscal year, in addition to the regular scientific staff of seven, there were on the staff as salaried visitors two associate astronomers, one associate physicist, two graduate research assistants, and six junior research assistants (undergraduates).

Three foreign scientists have participated in research activities at the Observatory during the past six months. The presence of foreign scientists working in cooperation with others at the Observatory provides continued stimulation of scientific advancement and mutual understanding.

The engineers on the Observatory payroll at this time are almost solely concerned with the design and construction of large instruments and facilities. Figure 2 shows the gradual increase of this portion of the staff, beginning early in Fiscal Year 1959. This increase is consistent with the rise in construction activity, which reached its peak in the late Spring of 1959. The completion of all current construction projects by the fall of 1959, with the exception of the 140-foot radio telescope, will have a noticeable impact on the character and size of the engineering staff.

The number of technicians has increased along with the growth of scientific activities. The operation of the 85-foot radio telescope and the strong and growing electronics development and maintenance program require a steady increase in the quality and number of skilled technicians.

Until the winter of 1958, virtually no maintenance activities were necessary. However, as the physical plant approaches completion of the first planned phase, operation and maintenance personnel have had to be added. By the spring of 1959 there were being maintained 2,650 acres of land, approximately 5 miles of secondary roads, 1 mile of underground electrical power lines, 6 residences, 4 offices, and the new Works Area building. In addition, in the last three months of the year this maintenance group assumed responsibility for the regular protective mechanical maintenance of the 85-foot radio telescope and its control building. In the autumn of 1959 the Laboratory building and the Residence Hall and Cafeteria will also be added to their responsibilities.

During the past year the size of the Administrative clerical and employees' services staff increased from seven to thirteen. Half of this increase was accounted for by the need to handle housing and also the food service, which was started in January, 1959. A secretary for the Research Equipment Development Department, a second bookkeeper, and a telephone operator for the central switchboard, which was installed during the year, were also added.

A review of Figure 2 will indicate a wide fluctuation in the number of people charged to construction. Particularly noticeable is the large bulge in the spring, summer and fall of 1958. The on-site home renovation program was at its peak during that period. Since November of 1958, the number of temporary employees charged to construction has remained roughly constant. Their activities have been largely confined to such projects as the corner reflectors, the 120-foot horn antenna, and the reconstruction of the Grote Reber radio telescope.

FACILITIES

The National Radio Astronomy Observatory was established to provide astronomers and scientists working in related fields the best possible research facilities. These facilities may be divided into three principal groups: the radio telescopes; the receivers and associated electronic equipment; and the site, including the buildings and other developments.

The antennas or telescopes employed in astronomical researches may take a variety of forms, depending on the objectives of the experiments and, particularly, on the wavelength or frequency of the celestial signals that are to be studied. Our atmosphere is transparent for wavelengths in the range from 1 centimeter to 10 meters, or more. Wavelengths at the short end of this range are best handled by means of parabolic reflectors, which are made as large as practicable, both to increase the resolution that is possible and to increase the total energy that may be collected and, hence, to make possible observations of very faint sources. Paraboloids are broadbanded in the sense that they are effective over a wide wavelength range, the limitation being that the dimensions of the reflector, or the sub-panels that form its surface, must be large compared with the wavelength. If such paraboloids are suitably mounted so that they can be pointed to any object in the sky and made to track or follow the object precisely, the resulting radio telescope is a versatile, general purpose research instrument, comparable in applicability to the Mt. Wilson and Palomar optical instruments. On the other hand, antennas such as are employed for television reception are effective for the longer wavelengths of astronomical interests. Such simple antennas are frequently employed in multiples that form arrays, the linear dimensions of which may be very large in order that the resolution at the longer wavelengths may be similar to the resolution possible at shorter wavelengths with the large paraboloids. The arrays are not as broadbanded as paraboloids, and are designed for a particular, limited band of wavelengths. Arrays are less expensive than the paraboloid type of radio telescope, but they are also much less flexible in their operation. In view of this difference, the first major radio telescopes at the NRAO will be steerable reflectors, in order to fill a need for expensive research tools that could not be met at individual, private institutions. The first telescope in operation at NRAO is the

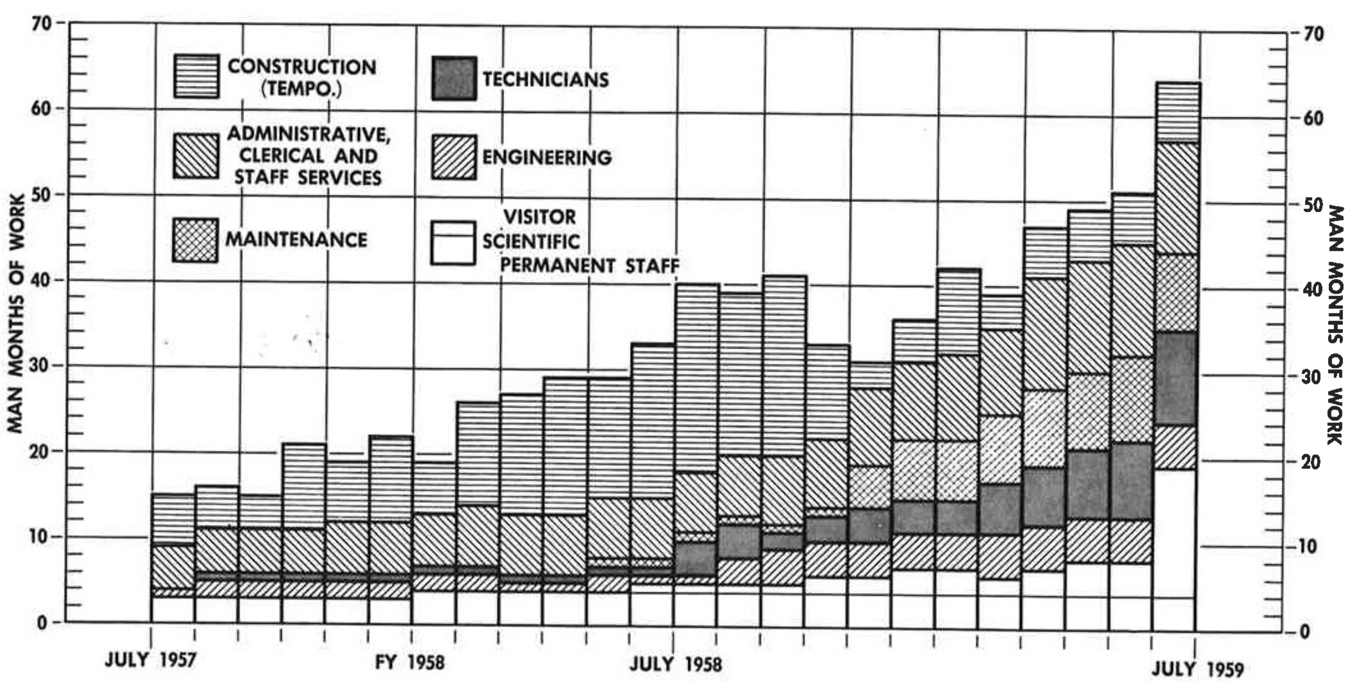


FIGURE 2. Personnel Chart

Howard E. Tatel* 85-foot telescope. A 140-foot telescope is being constructed which has been designed to be the most precise instrument of its kind of which we have knowledge. Of course, the permanent staff and visitors may wish to undertake experiments requiring arrays or other special types of telescopes, but these will be designed and built as needed, and are treated on an expendable basis. In this category is an interferometer, consisting of two corner reflectors 38 x 38 x 50 feet, set up on a 2000 east-west base line. (Observational use of this is described in the report of the Astronomy Department; other telescopes are described in the report of the Research Equipment Development Department.) Primary NRAO emphasis, however, will be placed on radio telescopes that are too large, complex, and expensive for private institutions.

Radio astronomy deals with celestial signals far weaker than those employed in normal commercial channels or even in special military equipment such as radar. Although a receiver for radio astronomy serves the same function as the receiver in any other radio system, the radio astronomy receiver is a very sensitive device of considerable complexity and, hence, expensive. Receivers must be designed for some limited wave band, comparable to an array rather than to the broad-band characteristics of a paraboloid. Furthermore, research receivers must incorporate special features for each of many research programs and a so-called "all purpose" receiver would be an awkward inefficient, impractical device. The NRAO at all times will endeavor to have receivers that represent the most advanced state of the electronic art, that operate effectively and efficiently in the wave bands of current interest to astronomers, and that permit maximum utilization of the radio telescopes. The inventory of receivers will always be in a state of flux. Other electronic equipment is also required to store or process the data that comes from the receivers. By means of these equipments and associated electronic computers, the raw observational data may be reduced and analyzed rapidly. To a certain extent, these auxiliary electronic devices will be standardized to a greater degree than the receivers. These electronic devices are discussed in the report of the Research Equipment Development Department, and Appendix B lists the receivers available at the Observatory.

The NRAO site at Green Bank, West Virginia, was selected primarily because of its excellent observational environment. It is in an isolated region of low levels of man-made radio interference.

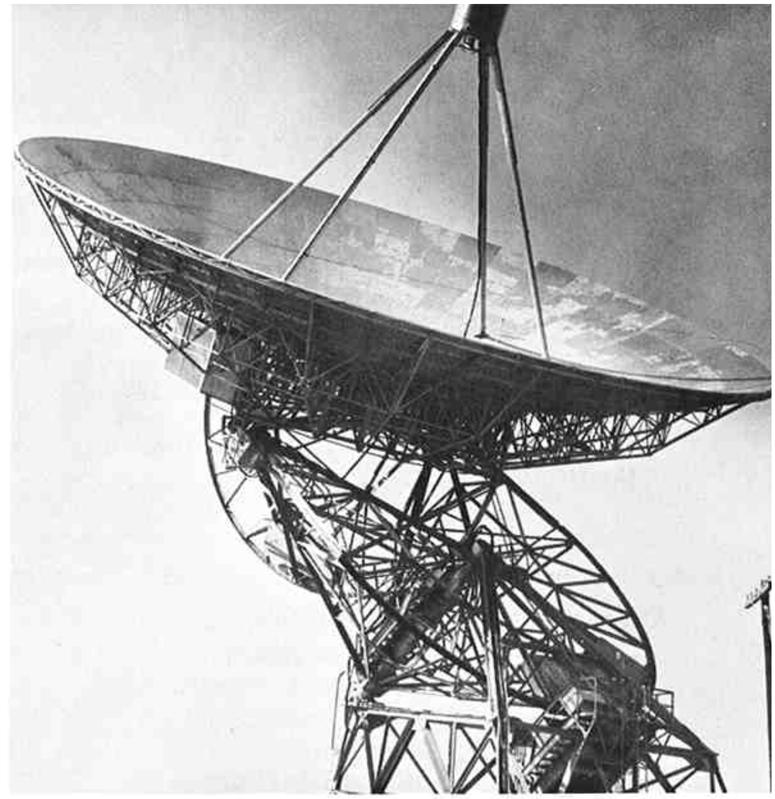


FIGURE 3. Howard Tatel 85-foot Radio Telescope

In all directions it is shielded by mountain ridges against more distant transmitters and against winds that might do physical harm to the giant telescopes. The site of about 2700 acres offers many opportunities for the temporary installation of experimental apparatus in addition to the permanent radio telescopes. Efforts have been made to protect the site against future encroachment of man-made interference, through legislative and administrative regulations. Some of these protective measures were feasible only because the site is now radio quiet and is in a region that is not likely to see tremendous commercial development.

On August 9, 1956, the West Virginia Radio Astronomy Zoning Act became the first such legislation anywhere in the world, to the best of our knowledge, that was intended specifically to protect basic research. The Federal Communications Commission has established a radio quiet zone, approximately 120 miles north to south and 105 miles east to west. This zone includes the Naval station at Sugar Grove, West Virginia. Similar observational environments are desired at both Sugar Grove and Green Bank and the two establishments are working closely to protect the surrounding region from man-made interference. The Federal Aviation Agency is re-locating air lanes and markers to avoid Sugar Grove, and efforts have been initiated through the National Science Foundation to obtain similar protection at Green Bank.

Named in memory of the late Howard E. Tatel, who was one of the principal contributors to its design.

FINANCIAL REPORT

The tables are, respectively, comparative balance sheets and summaries of operations for the three periods indicated.

ASSOCIATED UNIVERSITIES, INC.

NATIONAL RADIO ASTRONOMY OBSERVATORY

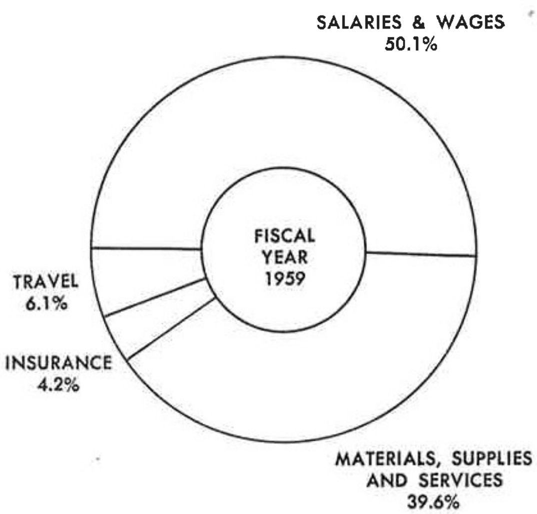
COMPARATIVE BALANCE SHEET

Assets	June 30, 1957	June 30, 1958	June 30, 1959
Cash	$130,357	$ 597,471	$ 748,938
Accounts receivable		402	2,485
Advances and prepaid expenses	488	900	867
Property, plant, and equipment	1,874	40,039	580,999
Construction in progress	24,724	603,915	3,251,052
	$157,443	$1,242,727	$4,584,341
Liabilities			
Accounts payable	$ 15,557	$ 123,524	$ 532,439
Account with National Science Foundation	141,886	1,119,203	4,051,902
	$157,443	$1,242,727	$4,584,341

NOTE: Although the Observatory has custody and use of the assets shown on the balance sheet, title remains vested in the United States Government.

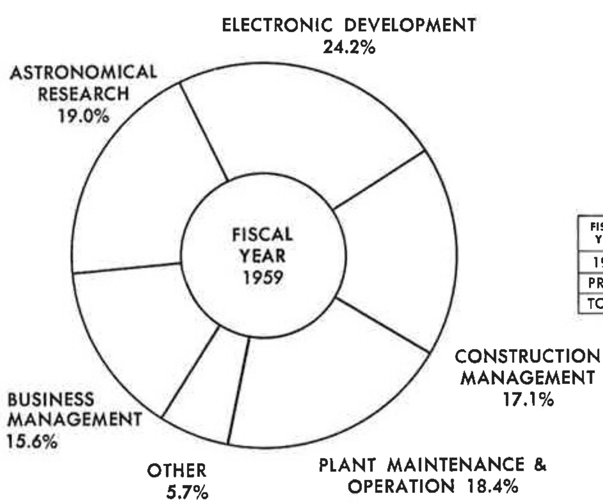
COMPARATIVE SUMMARY OF OPERATING EXPENSES

	November 17, 1956 to June 30, 1957	Year Ended June 30, 1958	Year Ended June 30, 1959
Salaries, wages and consultants' fees	$25,448	$103,983	$179,768
Materials, supplies and services	22,421	86,540	153,129
Travel	8,694	24,805	21,958
Retirement contributions, group life and other insurance	1,550	8,678	14,816
Total	$58,113	$224,006	$369,671
Deduct Miscellaneous Income		1,323	10,870
	$58,113	$222,683	$358,801



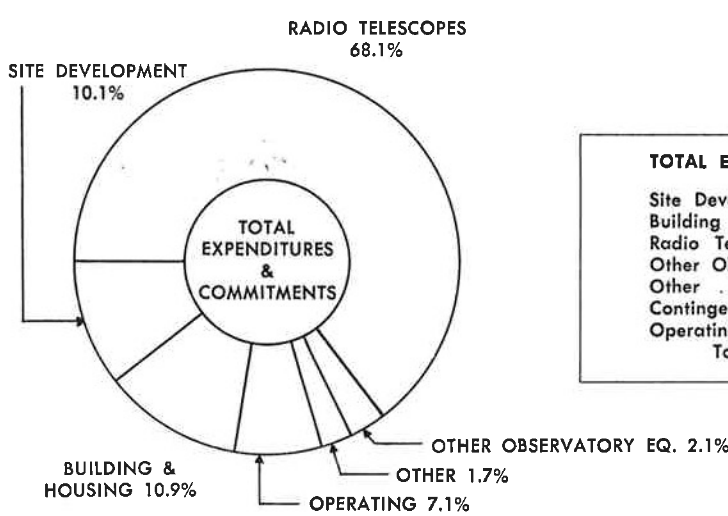
MAJOR CATEGORIES OF OPERATING EXPENDITURES

FISCAL YEAR	SALARIES & WAGES	MATERIALS, SUPPLIES AND SERVICES	TRAVEL	INSURANCE	TOTAL
1959	179,768	142,259	21,958	14,816	358,801
1958	103,983	85,217	24,805	8,678	222,683
1957	25,448	22,421	8,694	1,550	58,113
TOTAL	309,199	249,897	55,457	25,044	639,597



OPERATING COST DISTRIBUTION BY PROGRAM—FY 1959

FISCAL YEAR	ASTRONOMICAL RESEARCH	ELECTRONIC DEVELOPMENT	CONSTRUCTION MANAGEMENT	PLANT MAINT. & OPERATION	BUSINESS MANAGEMENT	OTHER	TOTAL
1959	68,259	86,809	61,455	66,124	55,902	20,252	358,801
PRIOR						280,796	280,796
TOTAL	68,259	86,809	61,455	66,124	55,902	301,048	639,597



TOTAL EXPENDITURES AND/OR COMMITMENTS THROUGH FY 1959

Site Development	$ 911,600
Building and Housing	988,700
Radio Telescopes	6,158,900
Other Observatory Equipment	187,600
Other	150,100
Contingency Reserve	-0-
Operating Costs	643,100
Total	$9,040,000

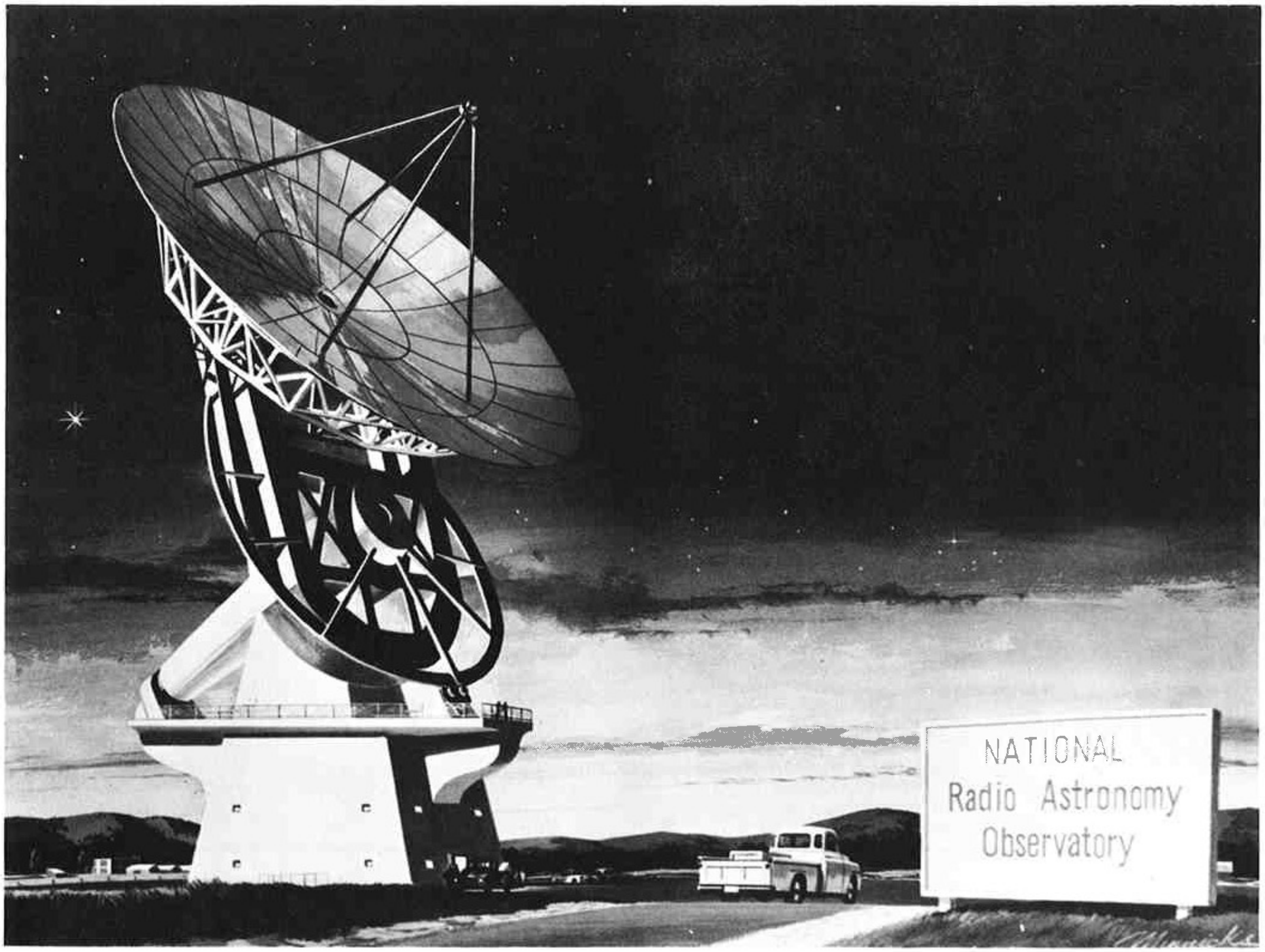


FIGURE 4. An artist's conception of the complete 140-foot telescope. The top will be 210 feet above the ground. Over 2500 tons will be carried by the hydrostatic polar shaft bearings. The massive concrete foundation will house machinery essential for the telescope, as well as the apparatus required by the astronomical research programs.

ASTRONOMY DEPARTMENT

PERSONNEL

The permanent staff of the department consists of two astronomers—F. D. Drake and D. S. Heeschen—, five telescope operators, and a secretary. This number is inadequate to maintain a desirable level of staff research and still provide the necessary services to visitors that are expected of the staff. On commencement of observing with the 85-foot telescope, and the resultant increase in visitor activity, it has become apparent that the demands on the time of the permanent scientific staff, by visitors and by the equipment, are considerably greater than was at first anticipated. The planned growth of the Observatory called for a substantial increase in the staff of astronomers after July 1, 1959. It is probable that the staff will be materially increased above the initially planned level.

Since completion of the Tatel 85-foot telescope there has been an increasing stream of scientific visitors, including both those who come for only a few days, and those who stayed long to make use of the Observatory's research facilities. Those in the latter category to date are:

F. Bartlett	Graduate Student, Yale University
G. B. Field	Princeton University
R. Fleischer	Rensselaer Polytechnic Institute
H. Hvatum	Chalmers Institute, Gothenburg
T. K. Menon	University of Pennsylvania
D. E. Osterbrock	University of Wisconsin
D. C. Peaslee	Purdue University
G. Reber	Research Corporation
M. S. Roberts	University of California at Berkeley
R. Stockhausen	Graduate Student, University of Wisconsin
G. Westerhout	Leiden Observatory, The Netherlands

It is encouraging and significant that of the eleven visitors, five — four astronomers and a physicist — are men with no previous experience in radio astronomy. Seven are from institutions which do not have any facilities for radio astronomy research. These visiting scientists have worked on a variety of astronomical problems, some of which are described in the following section.

Some research visitors spent only a week at the Observatory, others were there several months or made several extended trips. On the basis of the experience gained thus far, it appears that short visits — up to one or two months — are generally not as satisfactory to either the visitor or the Observatory as are visits of longer duration. Unless the visitor is thoroughly familiar with the equipment and techniques to be used, it is usually not feasible to attempt a program in a very short time, though there are, of course, exceptions to this. Therefore, the Observatory will especially encourage visits of longer duration — preferably six months to a year.

RESEARCH

The first observing program at the NRAO was begun in the fall of 1956. With the aid of the radio astronomy branch of the Naval Research Laboratory, a simple interferometer was set up to observe radio sources and measure the noise on the site at a frequency of about 30 mc. From that time until completion of the 85-foot telescope, some further work was done which is described in the report of the Research Equipment Development Department.

Most of the research at the Observatory is at present centered around observations made with the 85-foot telescope. The characteristics of the telescope are described in a later section, while descriptions of the receivers will be found in the report of the Research Equipment Development Department. Since this instrument has been in operation only a few months, most of the visitor and staff programs are just getting under way. At the time of this writing, two short programs have been essentially completed. Eleven others, by six visitors and the permanent staff, are in progress. Some of these are described below.

Solar System Studies

Hvatum is studying the brightness distribution of the moon at 3.75 cm and 22 cm wave lengths. There are small but well-determined changes in brightness distribution with phase which should give information about the nature and conductivity of the surface, to the depths from which these radiations are emitted.

The microwave emission from Jupiter has been intensively observed by Drake and Hvatum. They found that Jupiter radiates non-thermal emission, in the region from 75 cm to 3.75 cm, as well as the usual thermal emission. Drake has proposed that the non-thermal radiation originates as synchrotron emission from belts of relativistic electrons trapped in the Jovian magnetic field, a process analogous to that responsible for the terrestrial Van Allen belts of radiation. This work is continuing to determine whether there are detectable variations in the intensity of the non-thermal emission. Preliminary evidence obtained thus far suggests that there are intensity variations, and that these variations may be correlated with solar activity.

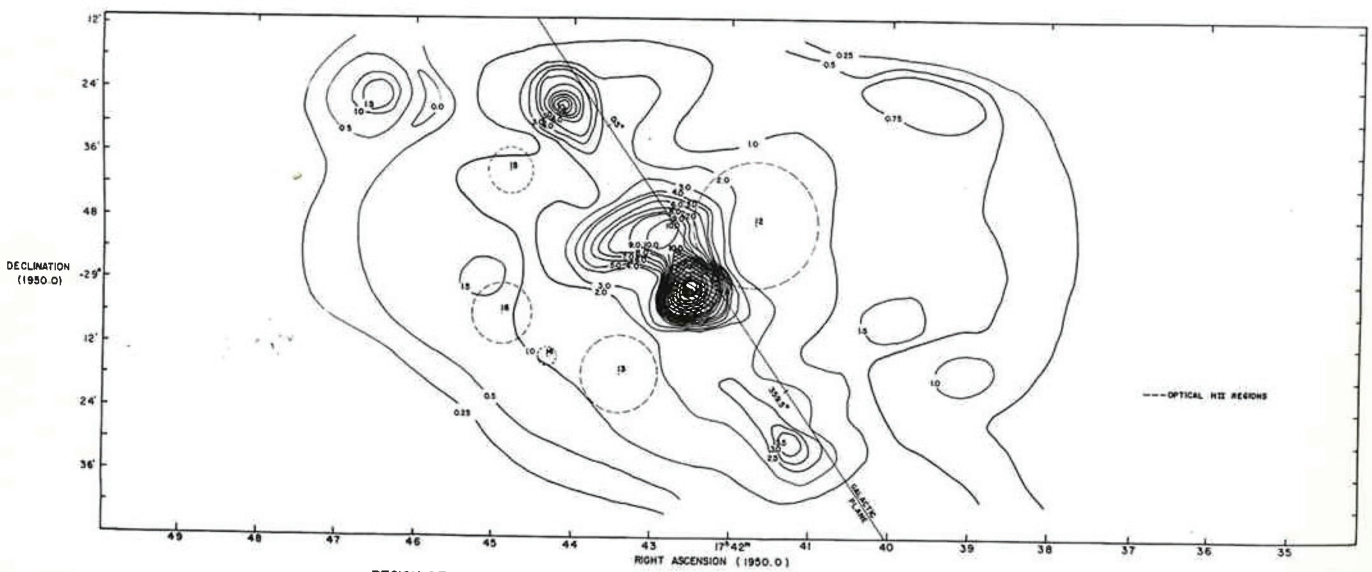
In other programs, Drake is maintaining a routine monitor for low frequency emission from Jupiter and other planets, using a pair of corner reflectors as an inteferometer, and has begun observations of the centimeter wave emission from Venus.

Galactic Studies

One of the first programs undertaken with the 85-foot telescope was an attempt, by Roberts, to detect 21-cm line emission from the globular clusters M3 and M13. Roberts obtained negative results, and in each case puts an upper limit of 0.4°K on the antenna temperature due to neutral hydrogen emission. From this he concludes that the amounts of neutral interstellar hydrogen in M3 and M13 cannot be greater than 700 and 200 solar masses, respectively.

Drake is making a study at 3.75 cm wave length of the region of the galactic center. The results obtained thus far indicate that this is a very complex region. There appear to be two thermal sources of very small linear extent at the galactic center. In addition, two other sources lie in the galactic plane, symmetrically placed with respect to the center, and at a distance of about 3/4 degree from it. These appear to be non-thermal sources, and suggest the existence of a ring, or double spiral, of non-thermal radiation in the plane of the galaxy and centered on the galactic center. In this interpretation, the two non-thermal sources appear at those points where the line of sight is tangential to the ring, or spirals, and thus traverse the greatest distance through the emitting regions.

Menon is studying the HI emission from the region of the Cygnus Loop, and the thermal emission at 3.75 cm from the Orion nebula. The distribution of neutral hydrogen in the vicinity of the Cygnus Loop is clearly associated with the phenomenon of the Loop, in that there is an increase in HI in the vicinity of the edge of the Loop. Menon's program is designed to obtain more detailed information about the distribution



REGION OF GALACTIC CENTER — ISOPHOTES OF BRIGHTNESS TEMPERATURE IN °K AT 8000 MC.

FIGURE 5. A contour diagram of brightness temperature at 8000 mc in the region of the galactic center, made by F. D. Drake with the NRAO 85-foot telescope. The two sources at the center, and the two in the plane about 3/4 degree either side of the center, are the most prominent features. The other weak sources that appear out of the plane, are probably HII regions.

of HI relative to the Loop. His other program is providing a high resolution picture of the brightness distribution of the Orion nebula at 3.75 cm wave length. In the inner region of the nebula the distribution is quite regular and symmetric, but does not show the very narrow peak of intensity of the center which is the prominent feature of recent models based on optical data. In the outer regions the radio brightness distribution becomes more complex, but appears to agree fairly well with the distribution of light. The effects of differing pressures around the perimeter of the nebula are clearly visible.

Heeschen is observing, at several wave lengths, some of the galactic radio sources which are thought to be remnants of supernovae explosions, in order to obtain information about the spectra and luminosity of these sources. Preliminary observations show that the sources have comparable absolute luminosities, but rather different spectra, ranging from the well-known flat spectrum of Taurus A to the equally well-known steep spectrum of Cassiopeia A. There appears to be a relationship between the spectra and luminosities of these sources.

Osterbrock and Stockhausen have started a program of observations of planetary nebulae at 3.75 cm and 22 cm wave lengths. Their initial program consists of trying to detect emission from the planetary nebulae NGC 6543, NGC 6826, and LC 418. By combining radio and optical observations, it should be possible to obtain information about electron densities and temperatures in these objects. While only a few observations have been made thus far, it appears that there may be detectable emission from NGC 6543 and IC 418.

Extragalactic Studies

Field is observing Cygnus A at a number of frequencies between 1250 mc and 1500 mc, in an attempt to detect any absorption of the Cyg A radiation by intergalactic neutral hydrogen. Any HI between Cygnus A and the sun will produce a broad, shallow absorption line in the spectrum of the source. This program is a repeat of one Field did previously at Harvard, in the expectation of obtaining somewhat greater precision. Field believes, on theoretical grounds, that most intergalactic hydrogen will be ionized. These observations, if sufficient accuracy can be obtained, may help strengthen some of the theoretical arguments.

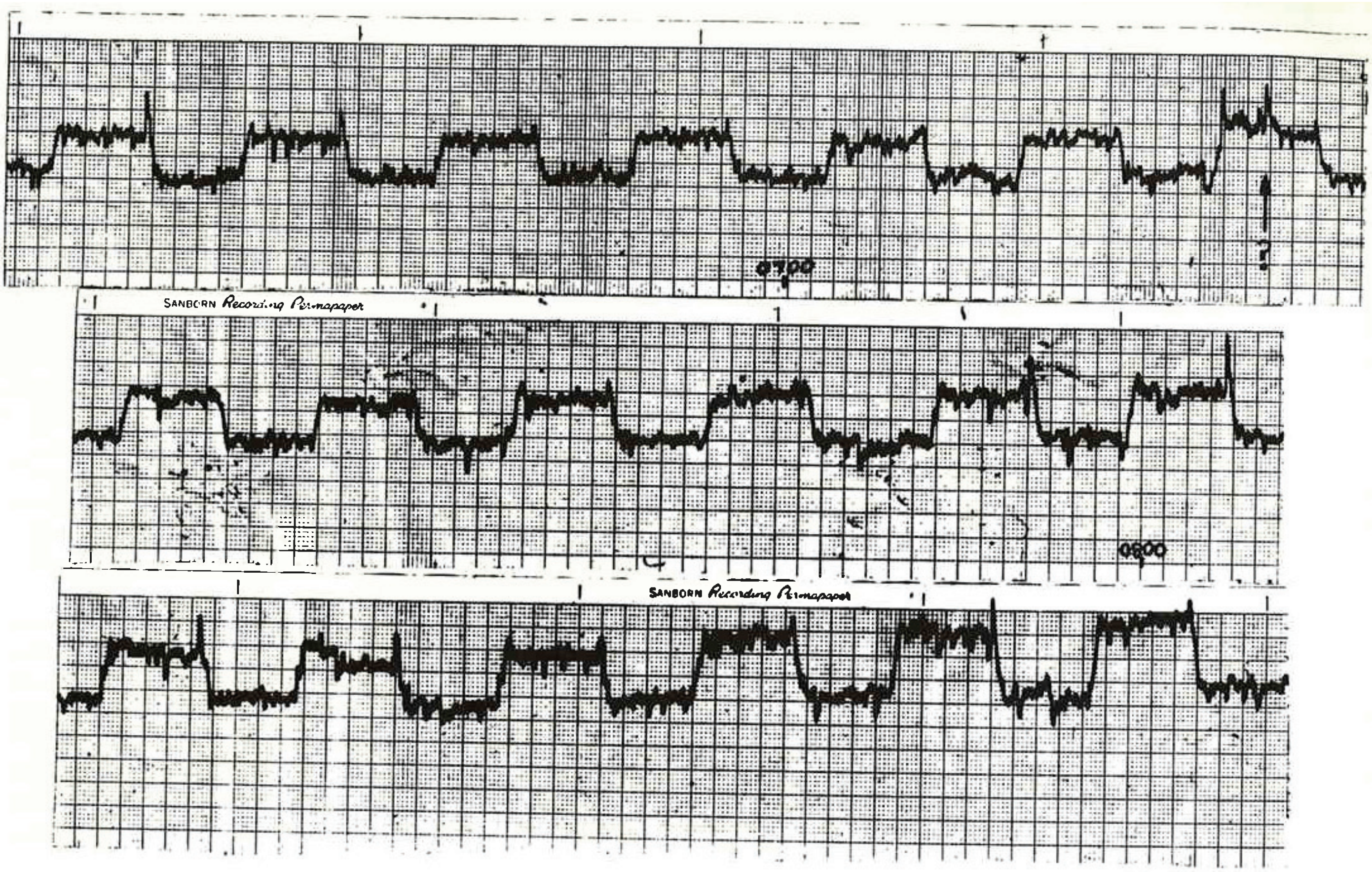
As part of his program, Field is determining the atmospheric extinction at 22 cm wave length. A previous determination of extinction at this wave length, made at Leiden, produced a considerable discrepancy between theory and observation.

Heeschen is attempting to observe 3.75 cm and 22 cm radiation from elliptical galaxies. The so-called "normal" spiral and irregular galaxies do not emit detectable r.f. radiation, but "normal" ellipticals have not yet been observed, presumably because their emissivity is less, and/or because the distance to the nearest giant ellipticals is considerably greater than that of the nearest spirals and irregulars. Optical observations of the λ 3727 line of O_{II} show that there is ionized interstellar hydrogen in some elliptical galaxies, which might be observable at 3.75 cm wave length. Efforts thus far have been concentrated on the ellipticals NGC 1052, 3115, and 4278. NGC 1052 and 4278 have strong lines of λ 3727, while NGC 3115 has no detectable λ 3727 line. The radio observations to date show that there is no detectable emission from NGC 3115 or 4278 at either 3.75 cm or 22 cm wave length, but that NGC 1052 probably has detectable emission in both wave lengths.

In another program, Heeschen is studying the spectra and luminosities of extragalactic radio sources in the wave length range 75 cm to 22 cm. The observations will be extended shortly to 10 cm and 3.75 cm. Observations have been made of 6 peculiar galaxies and 2 normal galaxies. The peculiar galaxies, while having a wide range in absolute luminosity, show only relatively small differences in spectra. The spectral differences appear to be real, however, and, as in the case of the galactic sources, seem to be related to absolute luminosity.

During the course of these and other observing programs, several phenomena were found which may affect the precision of certain types of observations. Westerhout, while attempting a 3.75 cm survey of the Milky Way, found that under cloudy or foggy atmospheric conditions, the receiver output would fluctuate by as much as 0.5°K over periods of 5 minutes of time. His conclusion, in complete agreement with theory, is that these fluctuations are due to variations in atmospheric emissivity, resulting principally from variations in the water vapor and O_2 content of the atmosphere. This effect makes survey observations involving long integration intervals and requiring high zero level stability over extended periods difficult at 3.75 cm, except under ideal weather conditions. Use of a slightly longer wave length would alleviate this difficulty by escaping the foot of the variable atmospheric absorption or emission bands.

Early observations at 22 cm showed marked differences between daytime and nighttime, which could be explained if, during the day, the sun were



JUPITER, MAY 27, 1959 – 440 MC.

FIGURE 6. Observations of Jupiter at 440 mc, made with the 85-foot telescope. The record shows the changes in receiver output as the telescope is pointed alternately towards and away from the planet. The antenna temperature shown here is about 0.5° Kelvin.

being picked up in a weak side lobe of the antenna. Subsequent observations by Findlay, using a transmitter on a distant mountain, show that there is, in fact, a complex side lobe pattern at large angles from the main lobe. The far side lobes are all more than 50 db down from the main lobe, but the sun in a 50 db side lobe will produce a relatively large effect. The observed effect is of the order of 0.1°K.

In addition to the above programs already in progress, preparations are being made for a number of others for the coming year, by visitors and staff. These include:

A) A program to detect, or put a meaningful upper limit to, galactic magnetic fields in certain regions, by means of the zeeman splitting of the 21 cm line;

B) A preliminary search for extra terrestrial coherent signals;

C) Studies of a number of HII regions, at 3.75 cm and 22 cm wave lengths;

D) A 3.75 cm survey of the region of the Cygnus X radio source;

E) Studies of the neutral hydrogen content of galaxies;

F) A program to determine positions of radio sources with an accuracy better than 20 seconds of arc.

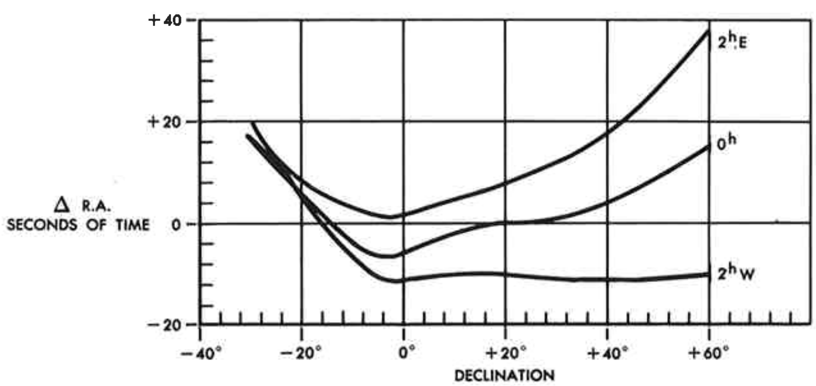
Special equipment is being built at the NRAO for several of these programs. In addition, a frequency scanning hydrogen line receiver, and instrumentation at 700 mc and 3000 mc will soon be available. These will be used for a variety of galactic and extragalactic programs, and for studies of discrete sources.

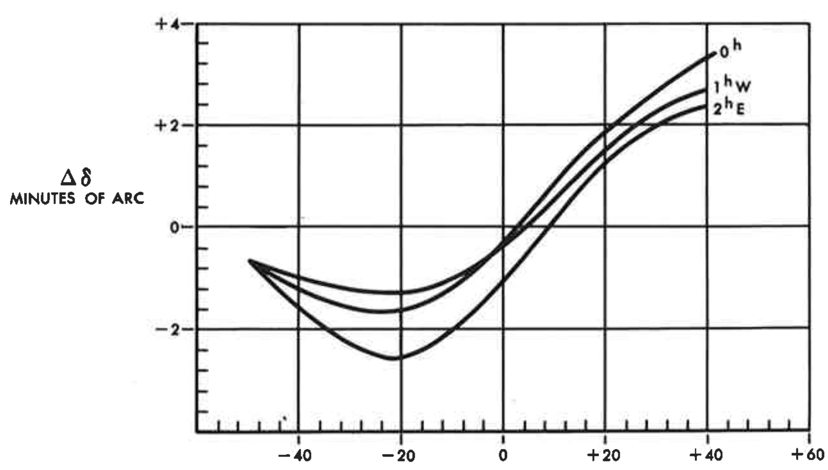
TELESCOPE OPERATIONS

The first radio astronomy observations were made with the 85-foot Tatel telescope in mid-February of 1959, and by the end of April, the telescope was in essentially full-time operation. From that time until the end of this report year, a total of about 900 hours were scheduled for observing, out of a possible 1500 hours. Of the hours scheduled, only 40 were lost because of breakdown of the telescope or receivers. Much of the time not scheduled for observing was required for testing and calibrating the telescope and equipment, for making minor changes and repairs to the telescope and equipment, and for the general "debugging" that is required of a new instrument.

Prior to, and during the early stages of operation with the 85-foot telescope, certain of its characteristics were carefully measured. The surface of the 85-foot reflector was measured with tapes from the focus to a point on the surface, and from the vertex to the same point on the surface. The accuracy of this measuring technique was found to be just better than 1/16-inch. All 400 points where the surface panels connect to the back-up structure were measured several times, and adjusted to be within 1/8-inch of the required parabolic contour. Contours of individual surface panels were checked with templates and found to be generally within the required 1/8 inch tolerance. Radio measures of the flux densities observed from particular discrete sources give a further indication of the accuracy of the surface. At 22 cm wave length the reflector efficiency is about 60 per cent, while at 3.75 cm wave length the efficiency is about 30 per cent. The efficiency at 22 cm is determined almost entirely by the primary feed pattern and indicates that at this wave length the surface is an excellent reflector. At 3.75 cm wave length some sensitivity is clearly being lost by deviations of the surface from a true parabola. Qualitatively, the loss appears to be not inconsistent with the measured deviations of the surface.

The polar axis of the telescope was adjusted to be parallel to the earth's axis of rotation to within 10 seconds of arc, the declination axis was adjusted perpendicular to the polar axis to within 20 seconds of arc. Measurements of these misalignments were made by optical observations of the stars. Pointing errors of the telescope depend on axial misalignments, on deflections of the feed, and on deflections of the dish structure itself. These errors were calibrated by radio observations, at 3.75 cm wave length and 22 cm wave length, of the stronger radio sources whose positions are accurately known. The resultant calibration curves, at 22 cm, are shown in figures 7 and 8. Positions may be set, after correction for the calibrated pointing errors, to an accuracy of about one minute of arc. A major portion of this remaining error is inherent in the synchros used to measure the position of the axes. A different type of synchro will be installed shortly, and should make it possible to determine positions with an accuracy of better than 20 seconds of arc.





FIGURES 7 and 8. Pointing errors of the 85-foot telescope, determined from observations of bright radio sources.

The beamwidths of the telescope, with present feeds, are 2° at 75 cm, 36′ at 21 cm, and 6′ at 3.75 cm.

Because much of the telescope time is used by visitors who are not, and cannot become, familiar with all of the details of operation and spot maintenance of the telescope and associated electronic equipment, it is necessary that there be trained operators to handle the routine work of observing and on-the-spot trouble shooting and repair, to keep down-time due to breakdowns to a minimum. Two telescope operators joined the staff in the fall of 1958, and three more during the spring of 1959. The Observatory now has a telescope operator on duty at all times—24 hours a day, 7 days a week. The men are becoming very proficient in the operation and maintenance of the telescope and other observing equipment, and in the techniques of radio astronomy observations. They have proven invaluable to both visitors and permanent scientific staff in increasing the efficiency of operation of the telescope, and in releasing scientists from many of the purely routine aspects of observing.

LIBRARY AND COMPUTER

The library now contains about 900 volumes, half of which are bound periodicals. Seventy-seven scientific journals are subscribed to on a current basis. While the library can meet most of the more usual needs of visitors and staff, it is far from being an adequate research library. A major effort is being made during the coming year to increase its scope and usefulness.

An IBM-610 computer was acquired in the spring of 1959. It has proven very valuable, and has been in almost continuous use. When the 85-foot telescope first went into operation, it was found that the ratio of data reduction time to observing time varied from 5:1 to 20:1, depending on the type of observing program. By digitizing receiver outputs and utilizing the 610 computer, data reduction time and observing time are now generally comparable.

FUTURE PLANS

A) The Observatory is now planning a fixed spherical antenna. The reflector will have a total aperture of about 420 feet. By illuminating 300 feet of aperture and moving the feed, about 30° of sky coverage may be obtained. Illuminating greater aperture will give greater gain and decreased sky coverage, while illuminating a smaller aperture will give less gain and more sky coverage. The instrument will be usable to 21 cm wave length, and should thus be a powerful instrument for a wide variety of problems. It is hoped that this telescope may become available in the summer of 1961, depending on budget allocations.

B) While the instrument described above will provide a significant increase in the capabilities of the Observatory, it is clear that many types of radio astronomy work now require a very much more powerful instrument. The Observatory staff and advisors must vigorously undertake without delay the steps necessary to obtain a very large antenna. Such an antenna will require considerable time to develop, and work must be started immediately if the Observatory is not to be left behind foreseeable developments in radio astronomy. As a first step in this program, it is necessary that the Observatory staff and advisors decide what general types of problems the Observatory should instrument for, and, therefore, what the general characteristics of the instrument should be. This is a major undertaking for the coming year.

C) The Observatory has initiated preliminary development of a program of radio astronomy using the vehicles of space research. It seems clear that as a national institution serving all radio astronomers, the Observatory has an obligation to develop work in this field. The Observatory staff feels that a long range program of very short wave satellite radio astronomy should be developed, to bridge partly, at least, the wave length gap between radio and optical work.

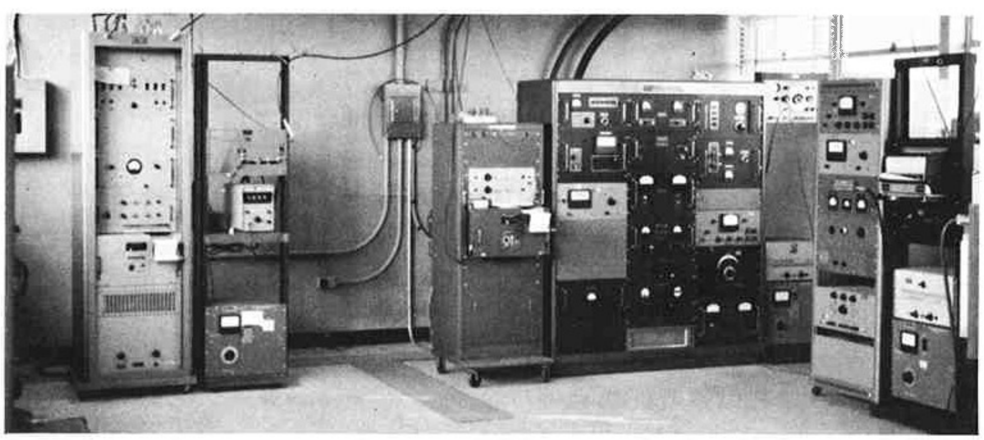


FIGURE 9. The three receivers in the Control Room of the 85-foot telescope. From left to right they are the Ewen-Knight 8000 mc/s receiver, the Airborne Instruments Laboratory 1200-1400 mc/s receiver, and the NRAO 440 mc/s receiver.

RESEARCH EQUIPMENT DEVELOPMENT DEPARTMENT

HISTORICAL SUMMARY.

The task of building up the electronic work at the Observatory started in June 1957, when two out-buildings of the Kessler house were remodeled and put to use as an electronic laboratory. The first technician, W. Wooddell, joined the staff in July 1957. The first few months were spent in purchasing equipment and during this stage considerable use was made of the provisions for the purchase of excess property through the General Services Administration. As soon as simple basic equipment had been acquired, work started on the following projects.

Low Noise Preamplifiers.

The performance of a receiver using a conventional crystal mixer depends considerably on the excellence of the preamplifier which follows the mixer. Work on this subject has continued and will continue for sometime to come.

Stability of Amplifiers and Oscillators.

The performance of a total power receiver depends on the stability of both the amplifying stages and the local oscillator. Measurements were started on both these subjects.

30 Mc Total Power Interferometer.

A simple total power interferometer was set up using equipment loaned to the Observatory from the Naval Research Laboratory. This was used for gaining experience in the noise levels at the site.

The same interferometer was used to observe the transits of the first Russian satellite over Green Bank in October 1957. For this purpose the equipment was used at 40 Mc.

A Phase-Switched Interferometer.

Mr. H. W. Wells of the Department of Terrestrial Magnetism in Washington lent the Observatory the equipment to set up a two dipole phase-switched interferometer, which was used for measuring the flux from the Cas A source on a frequency of 30 Mc.

In January 1958 the electronics group moved from the first location at the Field Office to a second renovated farm residence, the Beard House, which was shared with the astronomy group. The laboratory facilities occupied the ground floor. A second electronic technician, D. Ross, joined the staff on July 1, 1958. The construction of the first total power hydrogen line receiver was begun during this time. The summer of 1958 saw the start of the project to build a large standard gain horn for use in calibrating the Cas A radio source over as wide a range of frequencies around 1400 Mc as possible. This project is described in more detail later in this portion of the report.

Also during the summer of 1958 the 12-foot aluminum spinning was delivered to the site and mounted on a war surplus radar turning gear. The whole mount was supported on the roof of a small building constructed close to the temporary laboratory. This reflector was chosen because it is electrically a perfect scale model for both the 85-foot and the 140-foot telescopes. The first use for the model reflector, the measurement of the effect of feed supports on the polar diagram, is described later in this report.

A start was made in the summer of 1958 on the measurement of various possible interfering radio signals. Not much work was possible, but checks were made on a few proposed VOR sites which the Federal Aviation Agency were testing.

A large corner reflector interferometer was also designed and built during the Summer and Fall of 1958. In October 1958 Dr. Hein Hvatum arrived at the Observatory as a visitor from the Chalmers Institute of Technology at Gothenburg, Sweden. He started a program of work in radio astronomy and also a program on the development of diode switches satisfactory for use at both 400 Mc and 1400 Mc.

During the summer of 1958 the electronic staff was augmented by the assistance of three temporary employees.

The Department was moved again in February 1959 to the Works Area. This move provided 3500 square feet of space for electronic work and also offices, and for the first time had adequate machine shop space. The Departmental machine shop was set up and J. Elliott joined the staff as machinist in January 1959. The present machine shop equipment is outlined in Appendix D of this report.

M. Waslo joined the staff as a senior electronic technician in April 1959. The final move of the electronic laboratory and machine shop into the new laboratory building is now scheduled for October 1959. This move will provide 4500 square feet of laboratory space with a machine shop and storage area adjacent to it, and with offices for both staff and visitors close to the laboratory.

This report now turns in more detail to the specific projects on which the Research Equipment Development Department has worked during the past year.

RECEIVER PROCUREMENT.

The Observatory has been fortunate in having been able to buy from commercial sources excellent radio astronomy receivers. Appendix B of this report is a technical summary of the receivers which are presently available at the Observatory. This appendix is amplified in the following notes on some of the receivers:

The AIL Hydrogen Receiver.

Airborne Instruments Laboratory designed and built this receiver to specifications which were agreed between the Observatory and AIL. The receiver was intended primarily for studies of the red-shifted hydrogen line and of continuum radiation anywhere within the wave length range from 20 cm to 26 cm. It can be used as both a total power receiver or as a DC comparison receiver. The equipment was delivered to the Observatory in September 1958 and was subjected to extended tests before it was used for observations with the 85-foot telescope. These observations started in March 1959.

The Ewen-Knight Traveling Wave Tube Receiver

The Ewen-Knight Corporation had developed a traveling wave tube receiver with a bandwidth of 1000 Mc at a center frequency of 8000 Mc. This receiver incorporated several novel design features and these combined with its great bandwidth gave promise of an order of magnitude improvement over any other receiver in the same wave length range. The receiver was purchased from the Ewen-Knight Corporation and was delivered to the Observatory in early August 1958. After a satisfactory test period it has been used on the 85-foot telescope since March 1959.

Horn Feeds.

Dr. Jasik, of Jasik Laboratories, has designed and built a number of feeds for the 85-foot telescope. The focal length to diameter ratio of this telescope and of the 140-foot telescope are identical so that these feeds can be used on either instrument. The most interesting of these horn feeds is one that can be used both for observations between 1250 and 1400 Mc and also for observations at 8000 Mc. This dual horn feed has two concentric horns with identical phase centers. Tests have shown that the primary patterns for both horns are good and that a satisfactory impedence match is achieved for both over their working frequency ranges. This feed was installed at the 85-foot focus and has permitted the simultaneous use of both the AIL hydrogen receiver and the Ewen-Knight TWT receiver. In addition to the saving of time which can result from simultaneous observations, this facility has been very valuable in easing the problems of scheduling telescope time between various observing programs.

Daptis.

A completely digitalized indicator system, which can be used for measuring and recording the antenna position and the time pertaining to an observation, has been built by the Control Equipment Corporation. The shaft positions of the polar axis and declination axis of the telescope are measured by the use of 12-inch Farrand inductosyns. These shaft positions are converted to digital outputs and the equipment allow these positions to be read instantaneously and printed by an electric typewriter. The equipment permits reading and printing the sidereal time, and the frequency at which the receiver is operating, in addition to the output of the receiver. This equipment has only just been delivered to the Observatory, so that a full report on its performance will be deferred.

EQUIPMENT DEVELOPMENT.

In addition to the procurement of observing equipment, the Observatory is engaged in its own programs of equipment development. There are many reasons why such a program is an essential part of the work of the Observatory. Experience of the overall design of receivers is needed so that new techniques and new systems can be suggested to the radio astronomers. Furthermore, without this experience good specification and procurement of equipment from commercial sources is impossible. There are numerous design features, some of them matters of quite minor detail, which are capable of improvement in commercially available equipment. There is also always the need at the Observatory for receiving equipment of special characteristics to be rapidly available so that it can be applied to a particular interesting scientific problem, in order that some new phenomenon may be examined quickly. The possibilities of new technical advances, as for example the use of diode switches, are not always explored fully by commercial firms. There will always be techniques such as the development of reactance amplifiers and masers where a large part of the research and development will be done by other research workers because of its great commercial and military importance. Nevertheless, there will always be an equal need for experience in these techniques in order that they may be used as quickly and as well as possible in the development of good radio astronomy receivers. The following program of equipment development is the beginning of a continuing program based on the premises that have been outlined.

The 30 Mc Total Power Receiver.

The technique by which a receiver is made in which the overall gain is stable enough for it to be used for radio astronomy is basically the simplest which can be devised. Accordingly work has been continuing on the development of what might be described as the "back-end" of such a total power receiver. It consists of a 30 Mc intermediate frequency amplifier followed by a detector and suitable integrating, and display circuits. Such a "back-end" can be used with various combinations of local oscillators, mixers and pre-amplifiers to give a total power receiver capable of operating at various frequencies. So far two "front ends" have been made for this receiver. One of these operates at about 1400 Mc and the other operates at about 440 Mc. The problems of achieving good sensitivity and stability in such a receiver appear to have been reasonably well overcome. Figures 10 and 11 show records obtained with this receiver working both at 1400 Mc and at 440 Mc. This receiver has now gone into use at the 85-foot telescope with the 440 Mc

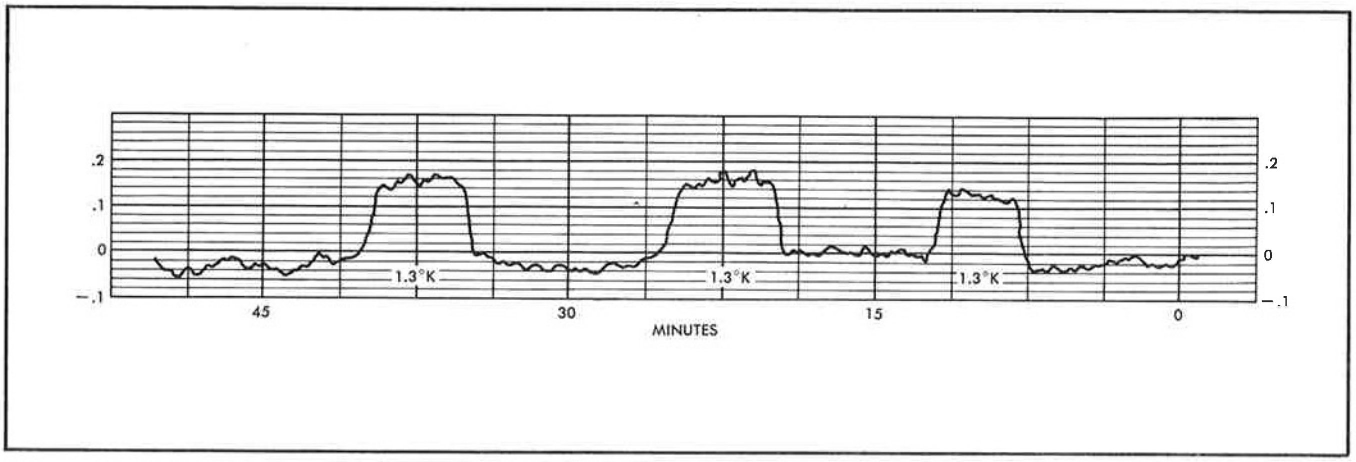


FIGURE 10. Typical record from the 1400 mc/s total power receiver, using an integration time of 20 seconds. The time scale increases to the left. The calibrated power increments correspond to a temperature of 1.3°K.

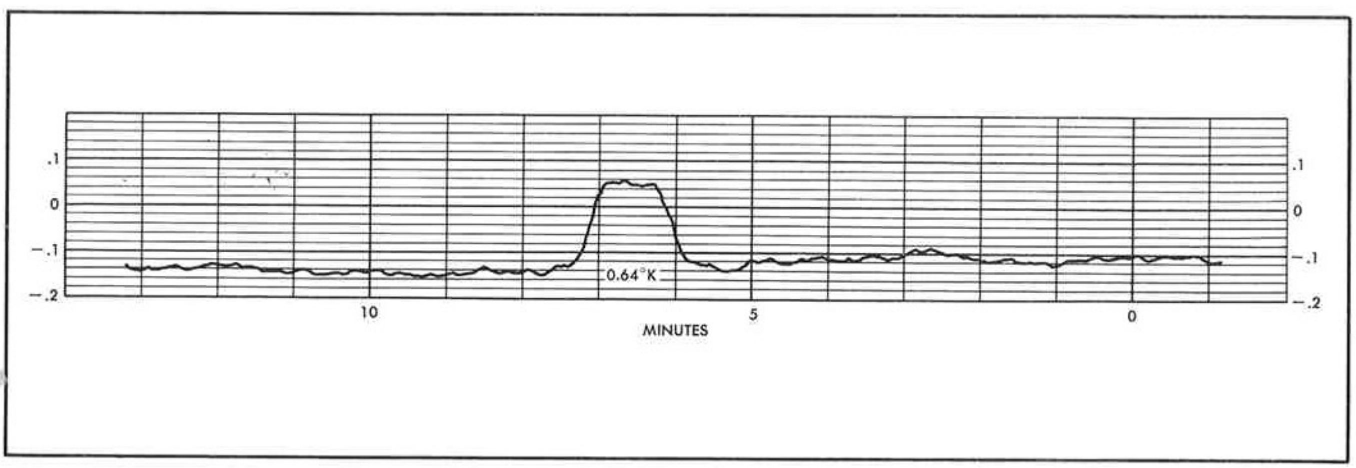


FIGURE 11. Typical record from the 440 mc/s total power receiver using an integration time of 6 seconds. The time scale increases to the left. The calibrated power increment corresponds to a temperature of 0.64°K.

front end and with a feed system added to the dual horn feed. The new feed consists of two dipoles which lie on either side of the 1400 Mc horn. Tests indicate that all three feeds on the receiver can be used simultaneously without serious mutual interference. A second receiver which is somewhat more advanced in design is now under construction and this will be used for the calibration system (described under calibration equipment).

Switches for 400 Mc and 1400 Mc.

The key component in a switched radiometer is the front end switch. Several different types of front end switches have been developed, both mechanically operated switches utilizing mechanical contacts or rotating capacitors, and pure electronic switches. In the following, a crystal diode switch designed for use in radio astronomy at 1400 Mc will be described.

The purpose of the front end switch in radiometry is to switch the receiver input at some audio frequency switching rate between the antenna and a comparison load. The general requirements of the switch are low insertion loss, high isolation, high stability and sufficient bandwidth. One straight-forward possible design is shown in Figure 12.

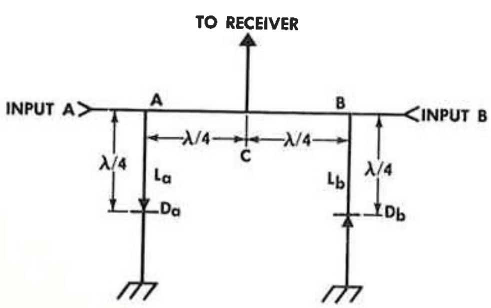


FIGURE 12. A simple diode switch circuit.

The switch is assembled of coaxial transmission lines as shown. The two input lines are connected together with the output to the receiver at C. At points A and B, located a quarter of a wavelength from C, the two diode lines L_a and L_b are connected through lengths of a quarter wavelength to the respective diodes, D_a and D_b.

Assuming ideal switch diodes with zero admittance when back-biased, and infinite admittance when forward-biased, the switch will operate as follows: With D_a forward-biased and D_b back-biased, the diode lines L_a and L_b which both are one quarter wavelength will place an open circuit and a short circuit across the input lines at points A and B respectively. In this condition the signal coming through input A will pass on towards the junction C without being affected by the presence of line L_a, and the signal through input B will be reflected at point B where the short is placed. This short will be transformed to an open circuit across the junction C through the quarter wave section between B and C. As a result, the signal from input A can pass unattenuated to the receiver, but the signal from input B is shut off.

Although practical diodes do not perform in the idealized way assumed above, but show a certain susceptance both when forward-biased and when back-biased, it is still possible by proper adjustment of the line lengths L_a and L_b, to satisfy either the short condition at point A (B) when the corresponding diode D_a (D_b) is forward-biased. In other words, if the switch is adjusted for minimum insertion loss the corresponding isolation will not be optimum, and vice versa. It is, however, possible to introduce an independent adjustment which makes it possible to optimize the two conditions simultaneously. This is shown in Figure 13.

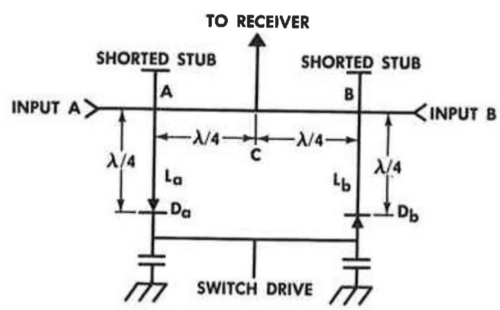


FIGURE 13. A diode switch circuit with independent adjustments for insertion loss and isolation.

The difference between the circuits in Figure 12 and Figure 13 is the addition of two tuning stubs at the points A and B.

If now the line lengths L_a and L_b are adjusted for maximum isolation as outlined above, a short will be placed across A or B when the corresponding diode is back-biased, and the presence of the stubs will have no influence, (A short remains a short with or without a stub in parallel.) In the forward-biased condition of the diode, however, the stub may be used to tune out the susceptance introduced across the junction point A (B) by the diode and its line L_a (L_b). Thus minimum insertion loss is obtained. The shorted stubs also give a convenient DC return for the switching voltage which is introduced to the diodes through a decoupling network also indicated in Figure 13.

A picture of a complete switch operating around 1400 Mc is shown in Figure 14.

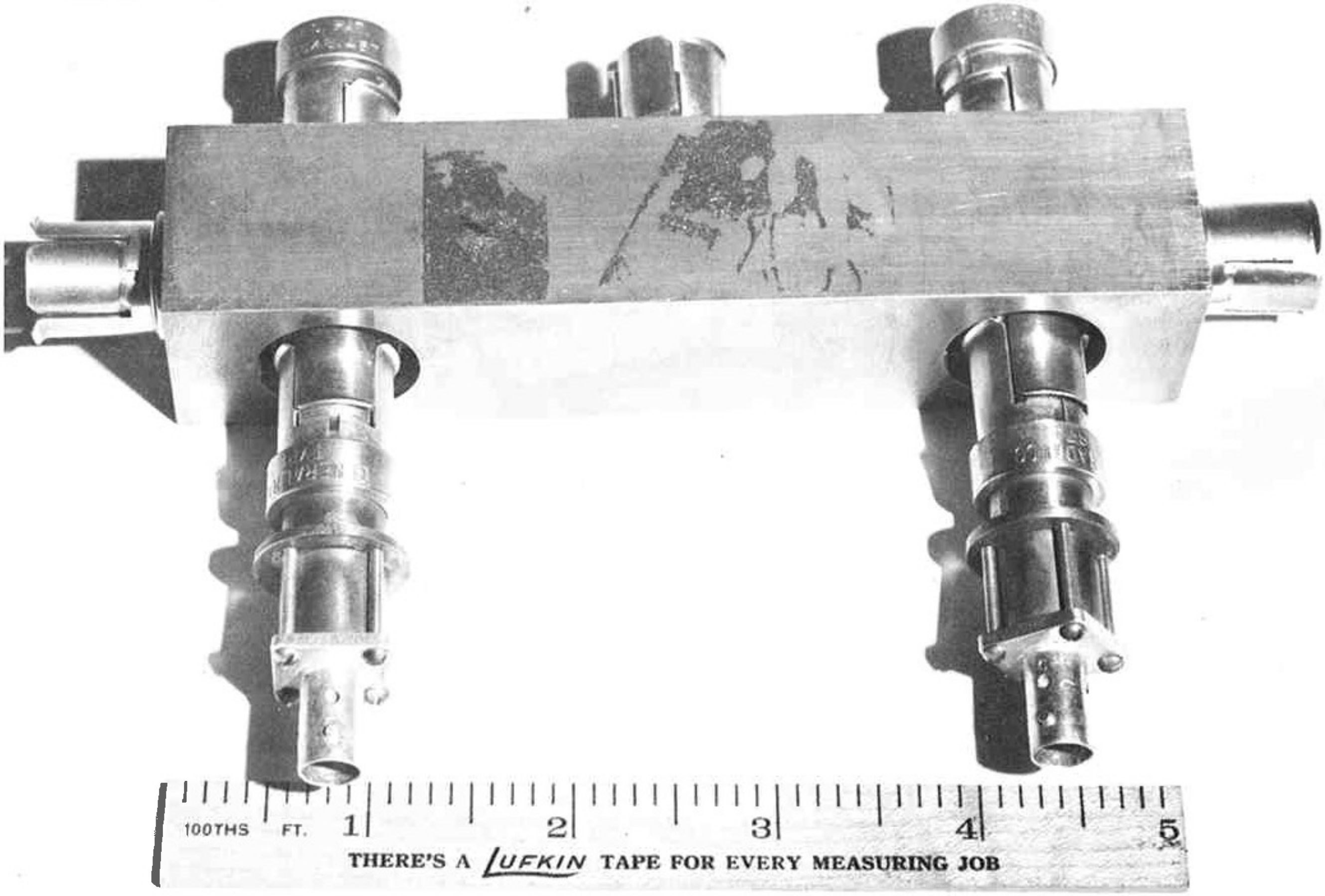


FIGURE 14. A completely assembled diode switch designed for 1400 mc/s.

The main body of the switch is drilled out of a piece of brass, and GR type 874-B basic connectors provide all the necessary inputs. Both adjustment of the stub lengths and the diode line lengths are made by sliding a pair of these connectors into each other. Thus the slight adjustment necessary to compensate for possible differences between different samples of the diodes is made possible. The crystal diodes with switch voltage inputs and HF decoupling network are made as plug-in units. One such unit is shown in Figure 15.

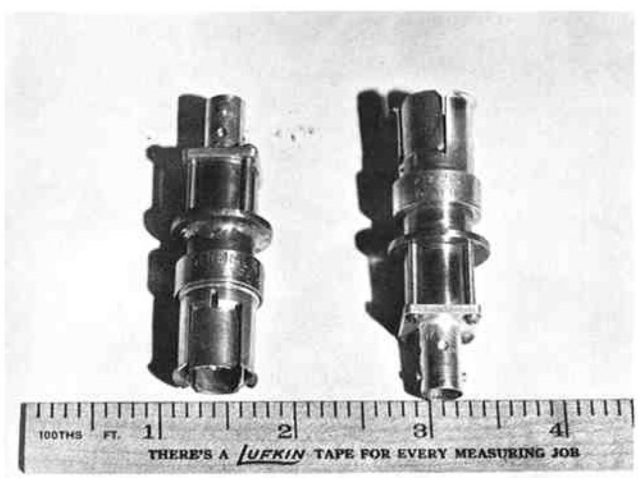


FIGURE 15. The crystal switch unit.

Static measurements of this switch showed insertion losses well below 1 db and isolations well above 25 db over more than 60 Mc/s bandwidth. The performance as a function of frequency is shown in Figure 16.

Short preliminary tests with the switch in actual operation at 1400 Mc have given a receiver stability of about 0.1° K over a period of several hours.

Broad Band Interferometer Receiver.

In order to make the best use of the corner reflector interferometer for the study of planetary radiations over a wide frequency band a phase switched receiver has been built. The interferometer feeds signals to wide band pre-amplifiers

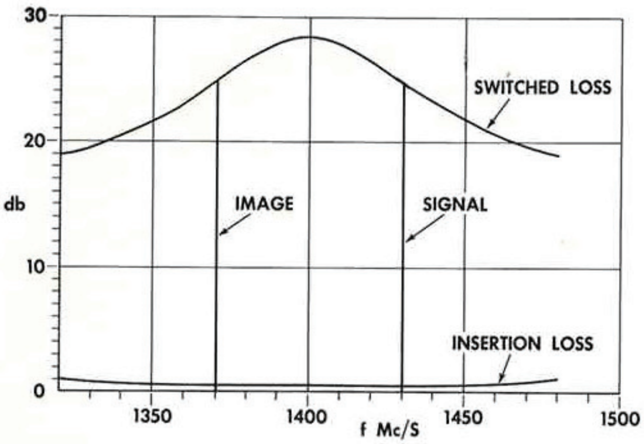


FIGURE 16. The Insertion Loss and Isolation, in decibles, as a function of frequency, for the crystal diode switch shown in Figure 6. The receiver signal and image bands, which are both sensitive, are indicated.

which can work over the frequency band 15 to 25 Mc. These are followed by a broad band phase switch and then by a receiver which can be tuned to any point within the band. Observations are thus possible anywhere within this band and in fact could be made simultaneously at several frequencies simply by the addition of further receivers. This equipment has been running for nearly a year on the corner reflectors.

Reactance Amplifiers.

A reactance amplifier capable of working in the frequency range 350 to 500 Mc has been procured from Micro-Wave Associates. This is a "Harris" amplifier and is of the negative resistance type. It is thus very unstable in gain. Nevertheless, experiments have started to see the best way of using this kind of low noise amplifier in a radio astronomy receiver. Other reactance amplifiers will soon be delivered to the Observatory and the work of developing suitable receivers using them will continue to expand.

Zeeman Effect Receiver.

There is a program to use the 85-foot telescope in an attempt to measure the Zeeman splitting of the hydrogen line as seen in absorption due to a possible magnetic field in instellar space. This experiment requires a receiver of rather specialized design and the use of a feed capable of accepting either right-handed or left-handed circularly polarized waves. Such a feed has been designed and built by Dr. Jasik. Parts of the receiver have now arrived and are being tested. Design of other elements of this receiver is now in progress.

Digital Outputs From The Receivers.

Since the Tatel 85-foot telescope started operation, a study has been made on using various methods of extracting the data in digital form from the receiver. Two ways of doing this have been developed, which make use of commercially available components. In the first the receiver output is integrated over a pre-determined time in a specially designed integration circuit and at the end of the integration time the output is displayed on a digital voltmeter, the output of which can be printed. In the second method of obtaining digital output, the received signal is converted to a variable frequency by a "voltage to frequency converter". The frequency developed is measured on a frequency counter for a pre-determined integration time. The total number of cycles of frequency at this time is counted, printed or used to operate directly a tape puncher.

The IBM-610 computer has been used very extensively already on reducing data produced in these ways. Various programs have already been standardized and there will be considerable expansion in this field of automatic data extraction and computation in the future.

CALIBRATION EXPERIMENT.

Many workers in Radio Astronomy measure the flux received from radio sources in the sky. To make such measurements at all accurately is a difficult experimental problem, as can be seen from the following brief analysis.

Suppose the flux of power at the earth from a radio source is W_f watts per square meter in one cycle per second of bandwidth at a radio frequency of f Mc/s. The problem is to measure W_f as accurately as possible.

The best method to choose is to collect the incident radiation in an antenna of known collecting area, say A square meters. The collected power is now W_fA watts/c/s. This power is fed to a receiver and detector which detects the radio frequency power over a frequency range centered on f Mc/s. The pass band of the receiver is always a somewhat irregular function of frequency and is represented by a response function R_f which varies with frequency and which is zero outside the frequency limits f_1 and f_2, so that the energy detected must be written

$$(1) \qquad P_a = A \int_{f_1}^{f_2} W_f R_f \, df$$

The simplest method of measuring W_f is to measure P_a in equation (1). The brightest source in the sky, Cas A, would give a value for P_a of about 5 x 10 $^{-14}$ watts when observed at a frequency of 1400 Mc/s with the 85-foot telescope and a receiver with a pass band 5 Mc/s wide. Thus the measurement of P_a in absolute units requires the measurement of a very small power indeed.

The best method to adopt is essentially to make a comparison by substituting for the antenna a source of noise power the output of which is known. A resistor at an absolute temperature T°_s K can deliver a maximum power P_{as} into a receiver where

$$(2) \qquad P_{as} = KT_s \int_{f_1}^{f_2} R_f \, df$$

The receiver is assumed to have the same response function when connected to the heated resistor as when connected to the antenna and it is assumed that both antenna and heated resistor are so matched that both deliver maximum power to the receiver.

Let us now adjust T_s so that the receiver deflexion is the same for the antenna and the heated resistor (which we call a thermal source).

Then $P_a - P_{as}$

$$\text{And} \qquad A \int_{f_1}^{f_2} W_f \, R_f \, df = KT_s \int_{f_1}^{f_2} R_f \, df$$

We can take W_f outside the integral, since by so doing we are obtaining a mean flux over the frequency range covered by the receiver and then

$$A \, \overline{W}_f = KT_s$$

$$\overline{W}_f = KT_s/A$$

This shows that to measure W_f, the flux from the source, we need only measure to know T_s and A.

In the experiment planned for the Cas A source, a horn antenna has been designed and is nearing completion.

The dimensions have been so chosen that the collecting area, A, can be calculated accurately from the linear dimensions of the horn. The effective collecting area of the antenna is about 9.5 square meters. Careful measurement of the horn dimensions and its loss should insure that this figure is known to within about 2%.

Such a collecting area will ensure that the antenna temperature of the Cas A source at 1400

FIGURE 17. A side view of the horn that will be used for precision calibration measurements of the radio source Cas A. The horn is 120 feet long and the rectangular cross-section is 13x17 feet at the upper end. The horn is fixed with an orientation such that once each day the rotation of the earth sweeps the axis of the horn across Cas A.

Mc/s should be about 20°K. The receiver which will be used can measure this temperature to about 1%.

To calibrate the receiver, a thermal source will be used. This will be compared with the antenna temperature, probably via the intermediate use of a gas discharge noise source as a secondary standard. This part of the experiment should be accurate within about 4%.

The whole experiment will therefore be capable of measuring the flux from Cas A to an overall accuracy of about 5%.

Secondary, but important results of the experiment will be:—

(a) Absolute knowledge of the spectrum of Cas A over a frequency band from 1400 Mc/s down to about 900 Mc/s.

(b) A check that the flux from Cas A is invariant with time.

(c) The possibility of a measurement of the absolute temperature of the sky background.

(d) A new comparison of the effective temperature of a gas tube noise source and a thermal noise source.

The horn antenna is almost complete. Its loss has been calculated and is satisfactorily low. A stable receiver is now under test. The first experimental work on the comparison of thermal sources and a noise tube has been started.

ANTENNA STUDIES

One problem in antenna work has been considered. The feed supports of a radio telescope obstruct an appreciable area of the telescope aperture. This obstruction results in a small decrease in the gain of the radio telescope and also a possible increase in the side lobes of the telescope. This is not a simple subject to deal with theoretically, but an elementary study of the diffracted pattern of a circular aperture obstructed by a feed support has been made. The illumination of the aperture was assumed to be

$$E = E_0 \, [1 - r^2/a^2]$$

where r is the radial distance from the center of the aperture and a is the radius of the aperture. The radiation pattern of such an aperture has been calculated both for the unobstructed aperture and also for an obstruction such as might be produced by a feed support. The area obstructed was about 5% of the total aperture. The results of this study are given in Table 1.

	Unobstructed	Shadowed By Feed Support
Power in first side lobe	24.6 db down	20.8 db down
Change in the aperture gain due to shadowing	0 db	0.28 db down

TABLE 1

The 12-foot model reflector is being used to make measurements to extend these theoretical results. A photograph of this instrument is shown in Figure 18. The focal length to diameter ratio of this reflector is 0.435 while the 140-foot telescope ratio is 0.429. Using the 12-foot reflector at a 3 cm wave length will, therefore, be a good model experiment of how the 140-foot reflector will behave at a wave length of about 36 cm.

A model of the 140-foot telescope feed support has been built and mounted on the 12-foot instrument and a 3 cm receiver and transmitter have been made. Tests are just beginning over a ground range of about 1 mile to measure the polar diagram of the reflector.

FIGURE 18. The 12-foot precision paraboloid that has the same f/d ratio as the reflectors of the 85-foot and 140-foot telescopes.

The Observatory is providing space and a small amount of effort to maintain and run a very long wave Whistler experiment which is being conducted by Professor R. A. Helliwell of Stanford University. The receiving equipment has been provided by Stanford and has been installed in the Hannah house and a large single turn loop antenna has been erected on the slope of the hill behind the house. Professor Helliwell visited the Observatory for a day and his assistant, Mr. Wiesenbach, was at the Observatory for about ten days, testing and setting up the equipment.

SITE PROTECTION

The Department has a continuing responsibility to insure that the Observatory site is kept as free as possible from radio signals of all kinds. There are several ways in which this problem has to be attacked. First the radio environment at the site has to be monitored. All signals received at the site have to be identified and any unrecognized sources of signal or noise have to be located. Only preliminary work has so far been possible in this monitoring program. This work has included measurements of field strengths from various existing stations and also from tests which have been conducted by the Federal Aviation Agency of proposed sites for enroute navigational facilities. Tests have also been made of various sources of noise interference such as automobiles, medical equipment, welders, and household appliances. Plans and designs have been prepared for a mobile laboratory that will be capable of detecting noise sources with sufficient precision to permit a determination of their location. A local program will be conducted to minimize the noise sources in the neighborhood of the Observatory. The truck laboratory will also be capable of secondary standardization work and as it will be able to travel to other radio astronomy observatories, it should prove to be useful to others.

The second way in which work on the site protection is necessary is in the operation of the protected zone which the Federal Communications Commission has set up surrounding the Observatory. This zone is about 105 miles by 120 miles in extent, and is shown in Figure 19. This zone was established after active representations by Associated Universities, Inc., the Naval Research Laboratory, the National Science Foundation, and the Navy, and formal hearings on the subject. It includes the NRAO and also the large Naval Radio Research Station under construction at Sugar Grove, West Virginia. In accordance with the FCC rules for the zone, all requests to the FCC for new or changed radio transmitter facilities within this geographic area have to be submitted concurrently to NRAO and NRRS before the FCC will consider their application. The Observatories have the right to object to the FCC if any proposed application appears likely to damage the radio environment. In operating this zone arrangement the NRAO takes prime responsibility for all applications to the FCC, and NRRS does the same thing with all governmental proposals. So far, a total of 26 cases have been dealt with since the FCC rule came into force on December 31, 1958, and no objections have been raised to any applications to the FCC. Considerable engineering discussions have, however, been going on with the FAA as a result of proposed new air routes through the protected zone.

The third way in which work has been done to protect the Observatory from interference has been to attempt to get cleared frequencies allocated for radio astronomers on an international basis. Dr. Findlay is the Chairman of an URSI Sub-Commission Ve which has been preparing for the Administrative Radio Conference at Geneva in the Fall of 1959. Proposals satisfactory to radio astronomers have been formulated and approved by the CCIR (Consultative Committee for International Radio). These are outlined in Appendix IV. A considerable measure of international support has been achieved for these proposals and they will be considered at the Administrative Radio Conference.

Finally, the Observatory is faced with the danger that noise producing facilities may be erected beyond the limits of the site but within the view of the telescopes. The Observatory hopes that private facilities for personnel will be expanded off site. At the same time, the character of these facilities must be within the noise limitations imposed by the telescopes. The West Virginia Radio Astronomy Zoning Act gives the Observatory the privilege of monitoring such installations to keep noise down to low levels. Nevertheless, since loss to private builders may be substantial in event of misunderstanding. The Observatory, with the National Science Foundation and the Army Corps of Engineers, has surveyed surrounding areas in view of the telescopes with the intent of providing further protection of the now unique and substantial facilities at the Observatory.

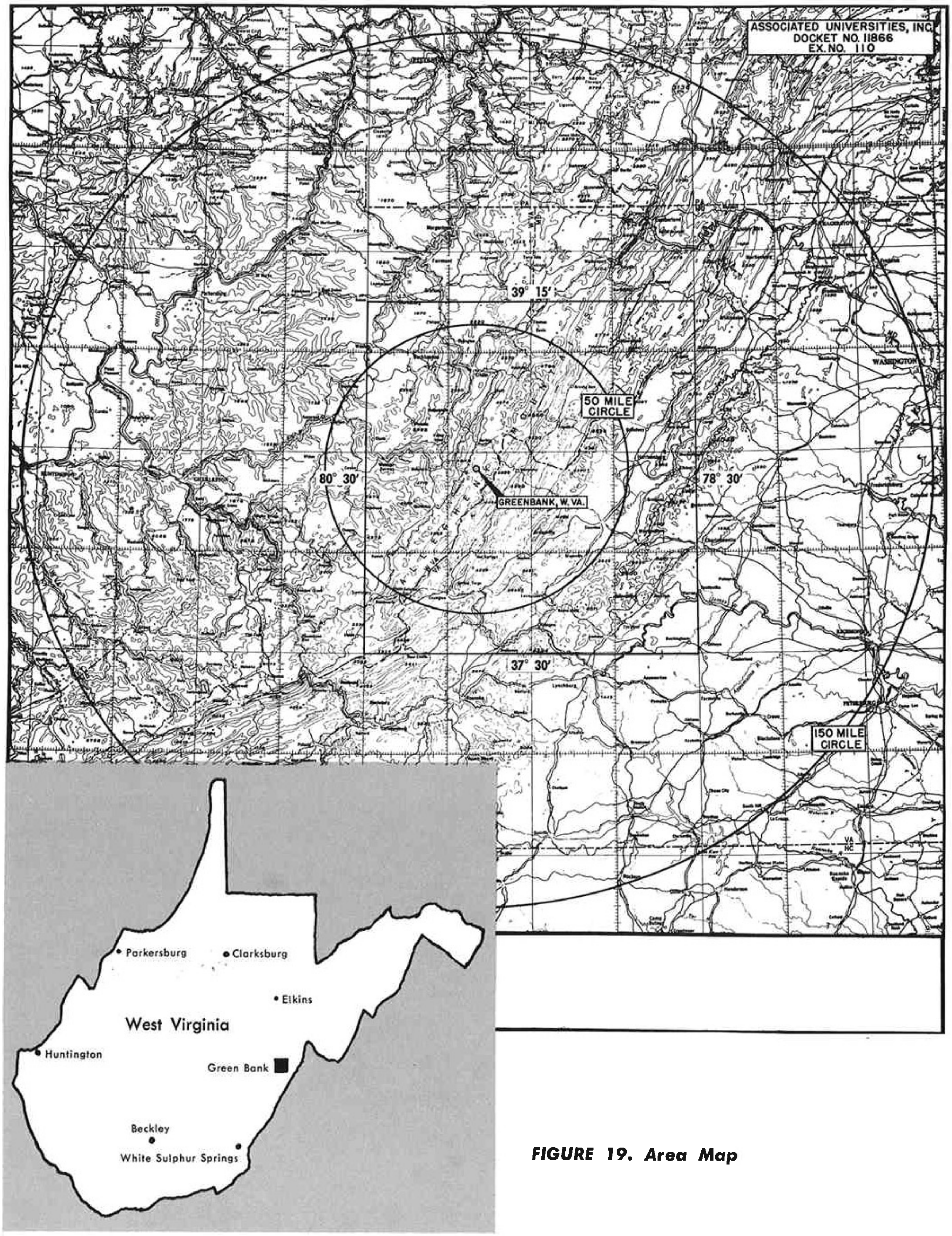


FIGURE 19. Area Map

MAJOR DESIGN AND CONSTRUCTION

The organization necessary to support the astronomical work at the Observatory is, of course, conditioned by certain fundamental policy decisions on the nature of the Observatory. As an example, the National Optical Observatory is divided, with the offices, shops and laboratories in Tucson, and the telescopes at Kitt Peak. The corresponding decision concerning the NRAO was that it should be self-sufficient at Green Bank. Consequently, some of the early thinking on the Observatory organization presumed the establishment of an engineering group at Green Bank. This group would be responsible for all technical aspects of the Observatory's architectural and engineering requirements and would be responsible for seeing that designs would meet the requirements of the scientific groups and that construction was in accord with these designs.

In the first 2-1/2 years of the Observatory's existence, the staff operated as a committee-of-the whole and no formal organizational divisions were established. Each member of the staff played some role in the construction of the 85-foot telescope and its control building. The principal day-to-day responsibility of supervision was taken by the business manager. This general pattern of operations was followed, too, with respect to the main road, the underground electric power distribution system, the Works Area building, and at the start of the construction of the Residence Hall and Laboratory. In the autumn of 1958 it became clear that the operations of the Observatory had grown to the point that departmentalization of the staff was in order. This report, however, details much that was accomplished prior to the establishment of the present Major Design and Construction Department.

A search was made for a West Virginia firm to take over the architectural and engineering services that were supplied by the New York firm of Eggers and Higgins during the feasibility study. Irving Bowman and Associates was selected early in 1957. Much of the basic site planning and development, which is described elsewhere in this report, was accomplished with the services of this firm. They were not asked, however, to participate in the preparation of specifications and designs for the radio telescopes and other specialized apparatus for the Observatory.

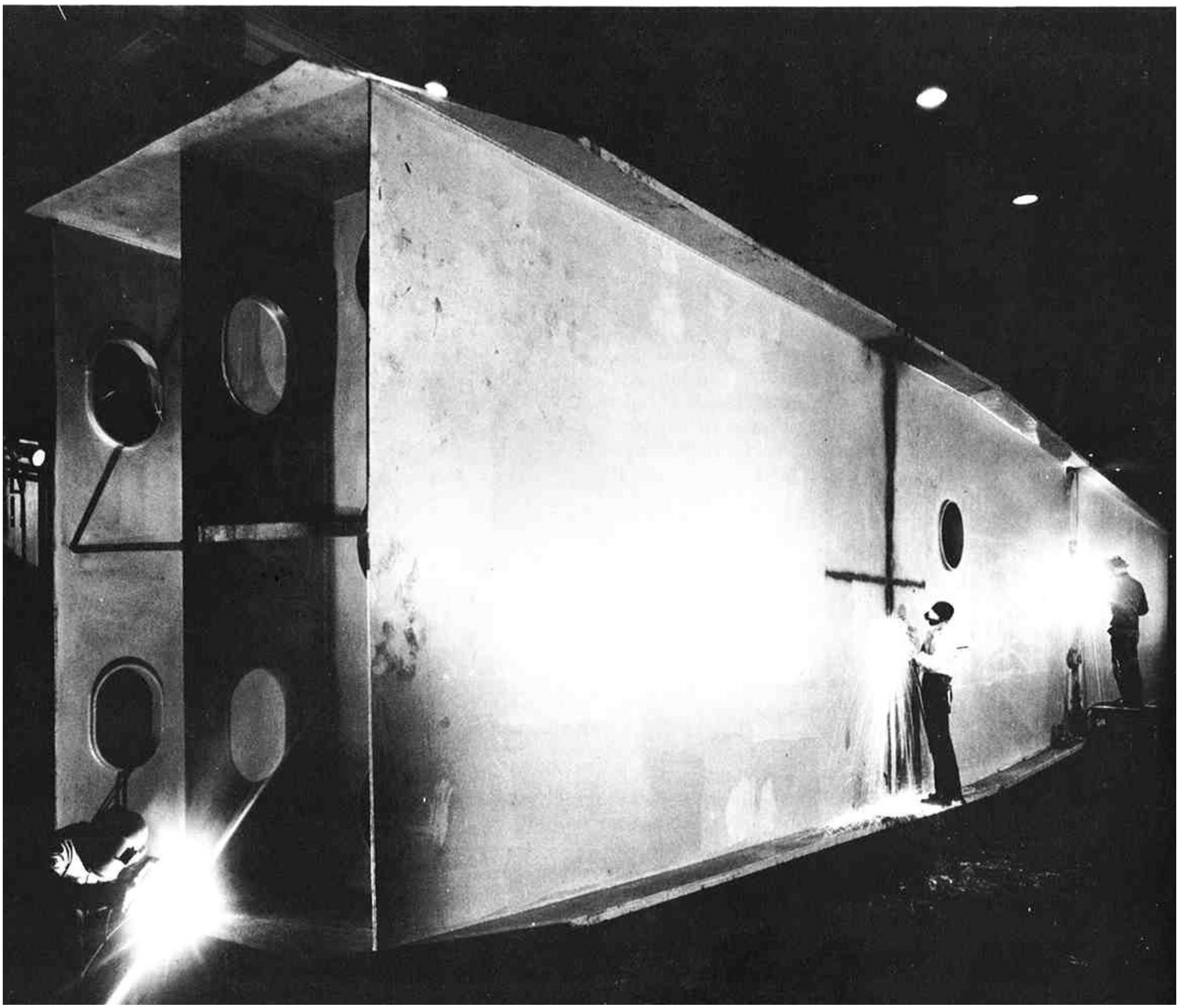
The Steering Committee for the feasibility study that preceded the establishment of the Obervatory visualized a number of radio telescopes for the Observatory of which one of the first would be an "off-the-shelf" design that could be constructed without delay and, hence, permit prompt initiation of centimeter-wave researches. The 140-foot telescope, to be discussed in more detail later, is in no measure an "off-the-shelf" design. Soon after Dr. D. S. Heeschen joined the permanent staff, he reviewed the situation, correctly concluded that a smaller telescope should be procured if research programs were to be possible in the near future, and he strongly championed the feasibility study conclusion and recommendation to that effect. The NSF staff approved efforts to expedite research at the new Observatory and agreed that a radio telescope was needed as soon as possible. Accordingly, performance specifications were prepared on the basis of a parabolic telescope with an aperture of 60 feet or more. The Harvard College Observatory had acquired such an instrument; the Naval Research Laboratory was placing an order for an 84-foot telescope; the California Institute of Technology was pushing plans for the construction of two 90-foot telescopes; the National Bureau of Standards at Boulder, the University of Michigan and several other institutions were at various stages of planning for radio telescopes. In view of this much activity, it was apparent that several companies might submit proposals on immediate construction of a telescope without need for a long period of design and development.

In their final form, the NRAO specifications were very similar to those of the University of Michigan, a similarity that was a direct consequence of the close liaison between the two groups. Proposals were requested from many firms and replies were received from four. Of these, two were low in price and close together— one from the D.S. Kennedy Company and the other from the Blaw-Knox Company. The final decision to award the contract to the Blaw-Knox Company was based on judgments of the relative research values of certain telescope characteristics that were not identical in the two proposals. The decision for Blaw-Knox was also made by the University of Michigan, which meant that the two telescopes would be identical except for minor changes made necessary by the slight difference in latitude between the two Observatories.

The basic design concept for the Blaw-Knox 85-foot telescope came from the radio astronomy group working with Dr. M. A. Tuve at the Department of Terrestrial Magnetism of the Carnegie Institution of Washington. The late Howard E. Tatel was one of the principal contributors to this design and the NRAO instrument has been officially named as the "Howard E. Tatel Telescope" of the NRAO. The telescope specifications called for a solid surface, adjusted to fit a paraboloid to ± 1/4 inch, the individual panels and the bolting surfaces to be true to 1/8 inch. Its equatorial mount permits sky coverage similar to the Hale telescope at Palomar: In declination from the southern horizon to the pole, and in hour angle from the eastern to western horizon. The specifications called for a quadrapod system capable of supporting a total load of 1000 pounds; for a 500 pound load at the paraboloid focus, 20 m.p.h. wind and gravity deflections were to be held to 1/8 inch. The f/d ratio of the paraboloid is 0.43. Scan and rapid slew motions were called for about the declination axis and an additional tracking capability was specified for the polar axis. A precision of 30″ of arc was specified for the position indicating system.

A contract was signed with Blaw-Knox on October 1, 1957. The work was divided at the ground level, and the Observatory put in the foundations according to detailed shop drawings and dimensions supplied by Blaw-Knox. At the suggestion of Dr. A. J. Deutsch, a member of the NRAO Advisory Committee, the base plates and foundations were modified to facilitate, at a

FIGURE 20. The yoke for the 140-foot telescope must be shipped to the Green Bank site in sub-assemblies. This photograph shows part of one arm of the yoke at the E. W. Bliss plant in Canton, Ohio.



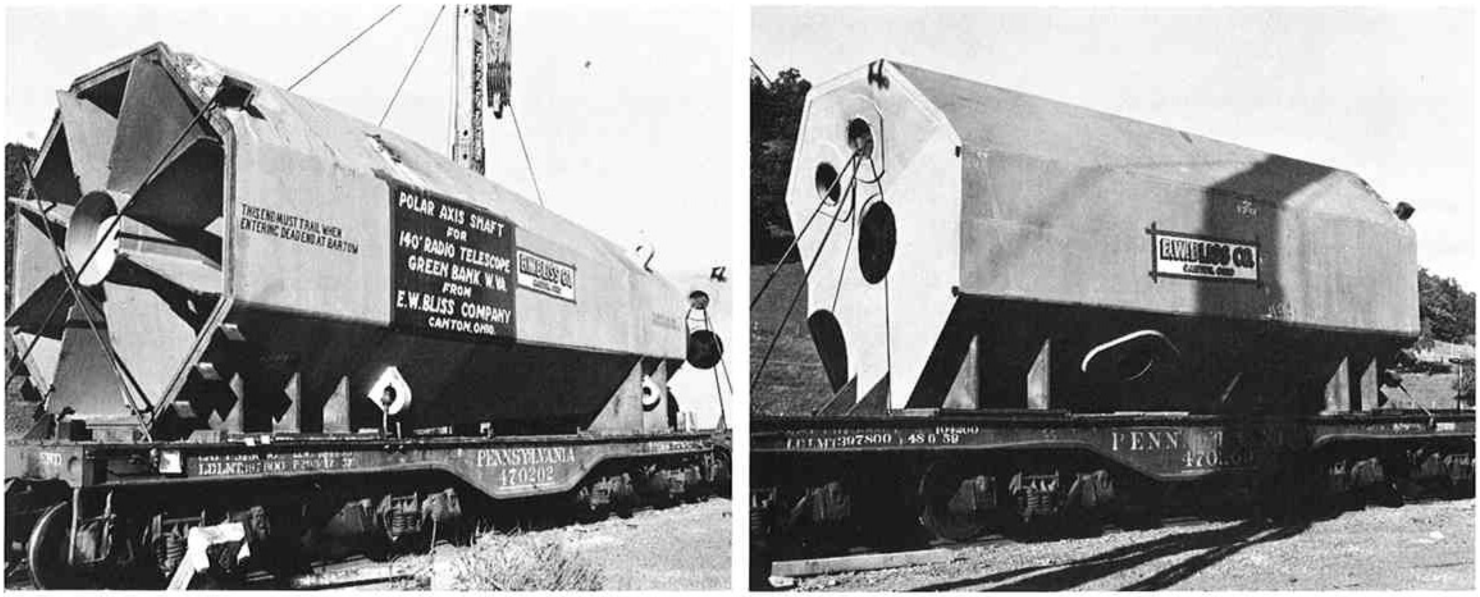


FIGURE 21. Two sections of the polar shaft that were the first sub-assemblies of the telescope shipped to Green Bank. The larger section weighs 160 tons.

later date, putting the telescope on rails so that it would be moved with respect to the 140-foot telescope as an interferometric pair.

The Blaw-Knox execution of its contract with NRAO was influenced by the entry of missile and space interests, particularly the Jet Propulsion Laboratory. Thus the Michigan and NRAO telescope fabrication finally was completed on a schedule that meshed with similar work on the first telescope for the Jet Propulsion Laboratory programs. Erection at Green Bank started in the summer of 1958. This phase of the work, including the necessary tests and adjustments, had been underestimated. The NRAO staff, particularly members of the Astronomical Department under Dr. Heeschen's personal supervision, worked regularly on the telescope in order to expedite the erection and adjustments.

The control building for the 85-foot telescope was designed by Irving Bowman and Associates; it was built by the Ivy Construction Company under an NRAO contract and was ready early in the summer of 1958. The building is a self-contained unit. The control room proper is provided with year-round air conditioning in order to control the humidity and to obtain reasonably constant temperatures for the components of the receivers located there. Approximately 1100 square feet of floor space is provided.

The Howard E. Tatel telescope was dedicated on October 1958; it has been used regularly for research purposes since March 1959; plans have been made for Blaw-Knox to complete final checks and adjustments in September, prior to final acceptance.

The specifications for the 140-foot telescope evolved from discussions of an ad hoc committee of consultants, under the chairmanship of Dr. T. C. Kavanagh, and that included astronomers and engineers as well as members of the NRAO staff. The design also went through several study phases. The final design was primarily the work of Professor Ned L. Ashton. The Franklin Institute developed the basic designs for the polar axis bearings. In brief, the specifications are as follows:

Parabolic reflector, true in any position $\pm$ 1/4 inch; the 72 individual panels to be true to 1/16 inch; f/d ratio of 0.43; a polar mount with sky coverage essentially the same as that of the Hale telescope at Palomar; anti-friction bearings for the declination axis; special hydrostatic bearings for the polar shaft; a precision drive and control system, capable of motions from the slowest tracking rate to a rapid slew of 50°/minute; positional accuracy of 10″ of arc; survival in winds of 70 knots under all conditions and to 120 knots if properly stowed.

Proposals were received from nine companies for the construction of this precision research instrument. After careful study and many discussions, a contact was made with the E. W. Bliss Co. in June 1958. The contract divides the work into two parts. Phase I called for all necessary engineering work; a letter of intent was issued in December 1957 to permit this portion of the work to start promptly and thus be far ahead of the Phase II fabrication and erection. Phase II was entered as an option in the contract, contingent upon the availability of necessary funds. The funds were provided by the Congress and the National Science Foundation and a release in Phase II was possible in August 1958. The contract left open the specifications for the drive and control system. The performance specifications for the drive and control system were critically reviewed by the Observatory staff and by the summer of 1958 revisions had been made that promised to make the telescope a more versatile research instrument. A design to meet these revised performance specifications was developed on a consulting basis by Mr. T. W. Brown, assisted by members of the staff and Mr. M. B. Karelitz. At this stage Bliss engineers entered the work, particularly with respect to assembly and test problems. These details were worked out and proposals were invited by Bliss in the autumn of 1958. This sub-contract was awarded to the Electric Boat Division of General Dynamics; the contract between Bliss and Electric Boat was signed in April 1959. The Darin and Armstrong Company was selected by Bliss to do all necessary field work at Green Bank.

At the date of writing this report, the concrete foundation at Green Bank is completed except for the placement of less than 200 cubic yards of concrete at the top of the central pier. Bliss has shipped two sections of the polar shaft and most of the heavy steel components for the remainder of the polar shaft and yoke have been or are being fabricated and a good start has been made on the aluminum structure for the reflector. The precision performance of the telescope will depend on some crucial components still in the shops or on the design boards: the special bearings for the polar shaft, the gears, and the reflector surface panels. The Bliss engineering did not get off to the early start that was hoped; it appears that in some cases the easier components were done first, and a number of difficult problems now await completion.

The Works Area building was designed by Irving Bowman & Associates to meet the Observatory requirements for space to house activities such as the maintenance and service shops,

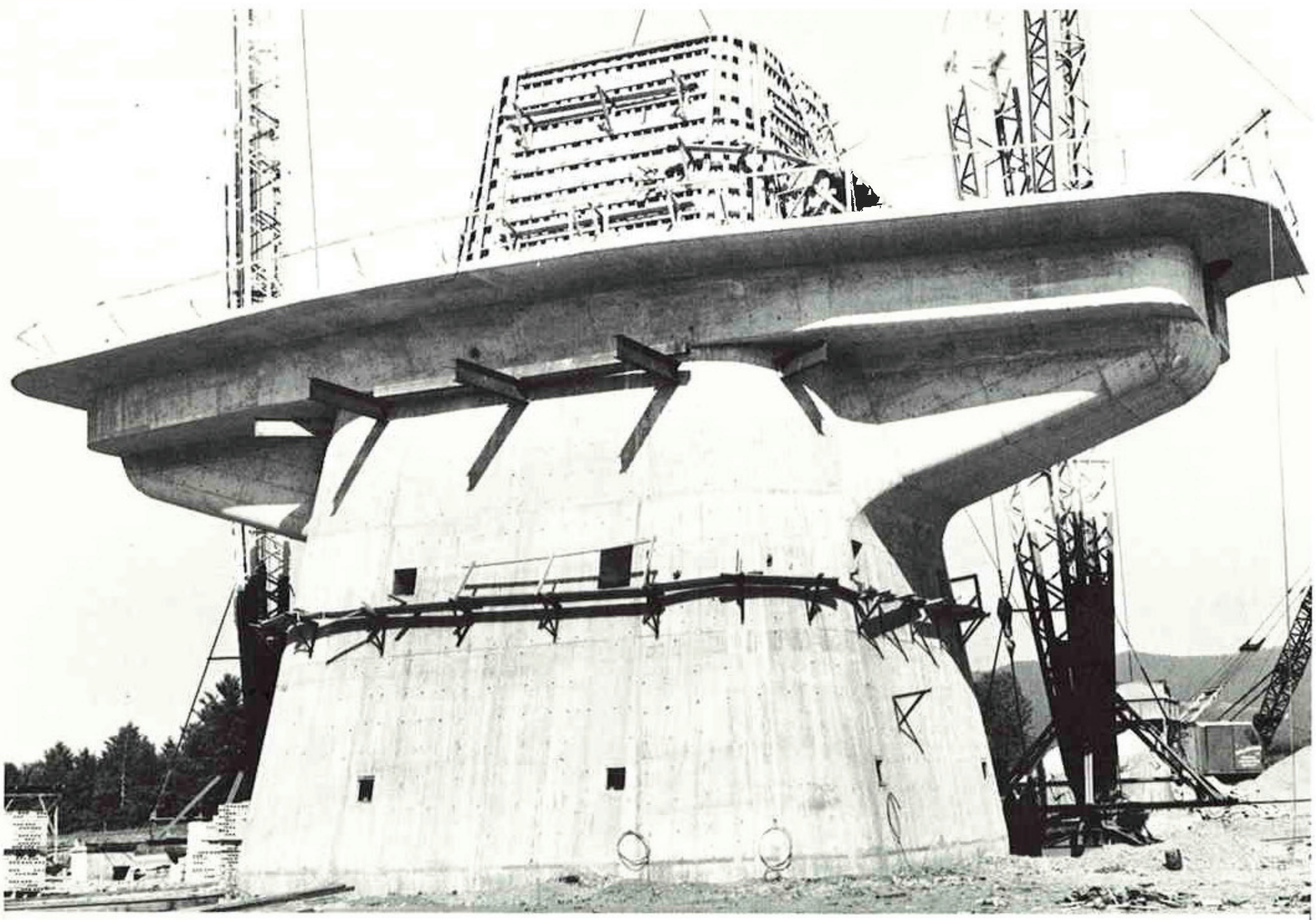


FIGURE 22. ***The field work at Green Bank is being done by Darin & Armstrong, under a subcontract with E. W. Bliss. When this picture was taken, less than 200 cubic yards of concrete remained to be placed on the pier. The walkway on the east side of the deck will be completed after the huge derricks have lifted the telescope components into place.***

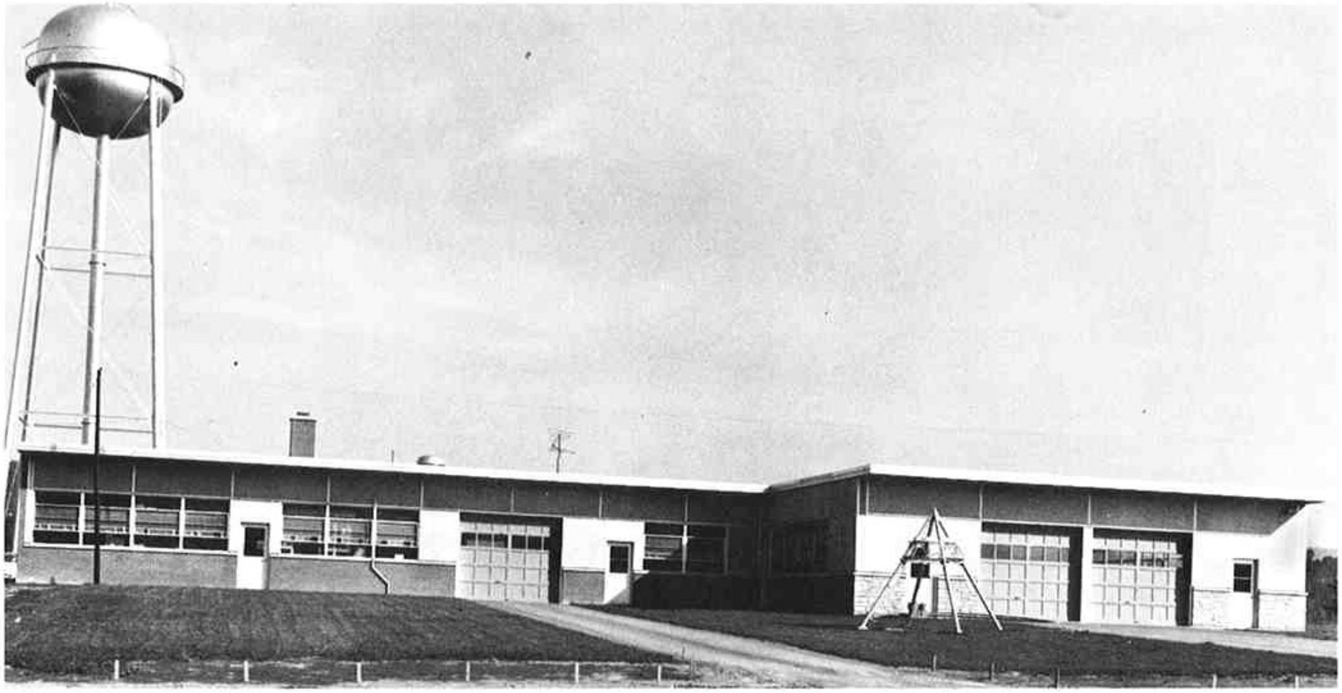


FIGURE 23. A view of the west side of the Works Area building. Site maintenance shops (carpentry, plumbing, electrical, etc.) will be located in the south wing, which extends eastward parallel to the main road. Vehicular repair, receiving and shipping, and power and heating facilities are located in the central section. A full-scale wooden model of the focal apparatus support system of the Howard E. Tatel telescope is standing on the lawn in front of the building.

receiving and shipping, warehousing, and in a north wing, which had to be postponed because of budget limitations, to provide a clear space to permit work under protection from the weather on bulky apparatus and equipment. The B. F. Parrot Company contracted to construct this building of 11,000 square feet; work started in July 1958 and was completed in January 1959. Statistics concerning the building are as follows:

Dimensions 50x154 and 40x80 feet, a total of about 11,000 square feet, with average wall height of 13 feet. Hardened concrete floor, no basement. Steel frame-bar joist construction. Walls combination concrete and face brick with aluminum windows. Cost $11.29 per square foot, including walks, parking lot, drives, and electrical power. Water and sewer systems for this and the residence hall and laboratory building were constructed under a separate contract.

As soon as the B. F. Parrot Company had finished its work, the Observatory maintenance force put in temporary partitions and electrical fixtures to permit the Research Equipment Development Department to use space in the Works Area Building pending completion of the Laboratory.

The Laboratory and Residence Hall and Cafeteria were handled as a single construction project which resulted in a larger gross activity with some resultant economics. Again, budget limitations forced a decision to construct as Phase I only the central section of the Laboratory and one-half of the Residence Hall capacity. The cafeteria section of the Residence Hall could not be split with any obvious economy.

Irving Bowman & Associates developed plans and specifications for these buildings in accordance with Observatory requirements and preliminary outlines. Bidding proved to be very tight, the lowest being from Darin and Armstrong, the E. W. Bliss sub-contractor for the site work on the 140-foot telescope. Work started in these buildings in October 1958 and as this report is being drafted it appears that the buildings will be substantially completed by October 1, 1959. The statistics for these buildings are as follows:

Laboratory

Dimensions 40x267 feet, basement and two floors; interior wall height of 10 feet; over 9,000 square feet of usable space in basement and each floor.

Steel frame—bar joist construction.

Walls combination concrete, face stone, porcelain steel and aluminum windows.

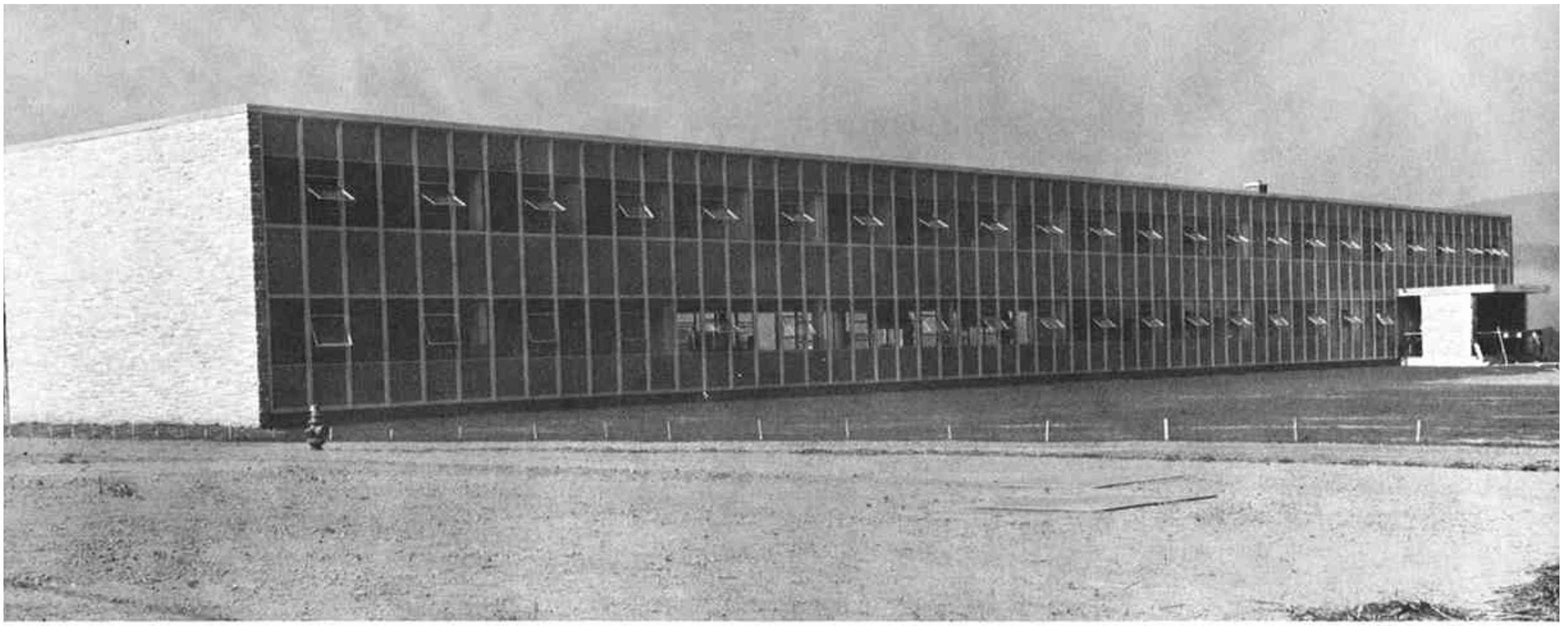


FIGURE 24. The nearly completed central section of the Laboratory. The second floor provides for the office of the Director, the Astronomy and Administration Departments, library and conference rooms. The first floor accommodates offices, laboratories, shop and stock rooms for the Research Equipment Development Department, and offices for engineering and construction. Dark room facilities are located in the full basement.

Interior gypsum board and plaster finished.

Cost $12.27 per square foot, including walks, drives and electrical power.

Residence Hall and Cafeteria

Dimensions 27x156 feet, basement and first floor of four apartments 45x156 feet, second floor of sixteen rooms, and 46x69 feet for basement and cafeteria, for a total of 20,000 square feet; 10 foot interior height.

Steel frame—bar joist construction

Walls combination concrete, face brick and stone, aluminum siding and windows

Interior gypsum board and plaster finished; floors hardened concrete, rubber and vinyl tile.

Cost $18.00 per square foot, including walks, parking lot and drives and electric power.

Because of the large amount of construction carried out at places distant from the Observatory, the Major Design and Construction Department operates from two locations, the AUI Office in New York as well as an office at the Observatory. The acting chairman of the De-

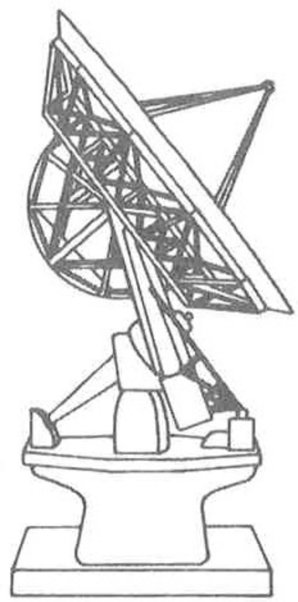
FIGURE 25. The Residence Hall, with cafeteria attached at the south end. The sixteen rooms on the second floor are served by a lounge and entrance hall next to the cafeteria. The four first-floor apartments have individual entrances sheltered by the overhang of the rooms above.

partment, R. M. Emberson, and E. E. Halik are stationed primarily in New York; J. D. Cunningham, S. S. Greenwood, John N. Ralston, and Sidney Smith work from the Observatory field office, which is headed by H. L. Lake. Mr. Greenwood spends a considerable portion of his time at the E. W. Bliss Plant in Canton, Ohio.

The Observatory construction program has benefited from the services of two other men. Mr. M. L. Westman joined the Observatory in March 1957 as construction superintendent and he also served as manager of the AUI field office during its early months. He was called to an important task in connection with the Brigham Young University building program and resigned from the Observatory staff in February 1958. Mr. John J. Carroll joined the group in July 1957, primarily to work on the 140-foot telescope project. He was fatally involved in an automobile accident a few miles south of Green Bank on June 16, 1958.

In addition to the Observatory staff members listed above, valuable advice and assistance has been obtained by contract or equivalent arrangements with expert consultants. Professor N. L. Ashton has already been mentioned and others who have assisted frequently throughout the report period include Mr. T. W. Brown, Dr. Jacob Feld, The Franklin Institute (Prof. D. D. Fuller and Mr. A. M. Loeb), Mr. M. B. Karelitz, and Dr. P. H. Price.

FIGURE 26. A general view of the Observatory site, looking west from the top of the water tank. The Works Area building is immediately below. The 12-foot and 85-foot telescopes may be seen to the center left, and construction work on the 140-foot telescope may be seen in the far center, a mile away.



ADMINISTRATION AND OPERATIONS

When the decision was made to establish the National Radio Astronomy Observatory at Green Bank, the acquisition of the site was the first order of business. As a part of the feasibility study, Associated Universities, Inc. had obtained options on approximately 6,000 acres in the valley. These options were transferable to the Federal Government. After careful consideration, the National Science Foundation decided that the site acquisiton should be accomplished by the Army Corps of Engineers on behalf of the Government. This course of action had several distinct advantages, including an independent and equalized appraisal of property values and, when necessary, the power of condemnation which was not available to Associated Universities, Inc., as a National Science Foundation contractor.

SITE ACQUISITION

The initial appropriation for the National Radio Astronomy Observatory carried a site acquisition item which was to include not only the cost of the land and improvements required, but also all costs of surveys, title searches, and similar activities of the Corps of Engineers. It was decided to divide the area covered by the original options into zones and to work outward, starting in the central zone. For reasons of efficiency, however, some of the surveys and related work were done for the entire area, because it was clear that this would be necessary whether the land was purchased or limited by easements or otherwise as a buffer against the intrusion of human activities and their concommitant radio interference. As the work of the Corps of Engineers proceeded, it became evident that a major portion of the available funds would be committed when only the central zone of about 2,700 acres had been purchased, and so it was agreed that the first phase of site acquisition should stop at this point.

In May 1957, Associated Universities, Inc. was given access to the first piece of property, a small plot on Route 28. The house, garage, and combination workshop and storage shed were speedily converted into a field office. At the outset this housed all the activities at Green Bank, but when other farm plots became available the scientific and technical groups were moved elsewhere on the site.

Formal ground-breaking ceremonies were not held until October 17, 1957. Through the kindness of Mr. Virgil Harris, Principal of the Green Bank School, and the Pocahontas County School Board, the program was held in the school gymnasium. The program consisted of an *Introduction* by Dr. Richard M. Emberson, the *Invocation* by Rev. Edward Thomas, *How Science Can Meet World Problems* by Senator Chapman Revercomb, *Congress, and Scientific Research* by Representative Harley O. Staggers, *Green Bank and the Observatory* by Mrs. Virgil Harris, *The Role of the National Science Foundation in the Support of Research* by Professor E. J. McShane, *The National Radio Astronomy Observatory* by Dr. Alan T. Waterman, *Associated Universities, Inc., Acceptance of Responsibility* by Dr. Joseph C. Elgin, *Plans for the Observatory* by Dr. Lloyd V. Berkner, *Radio Astronomy* by Dr. John W. Findlay, *Radio Astronomy Telescopes* by Mr. John J. Carroll, and *Development of the Observatory* by Dr. Lloyd V. Berkner.

In addition to these ceremonies, exhibits were placed in other rooms made available to the Observatory for the day. The weather was very inclement, but over two hundred people attended. Lunch and dinner were served in the school cafeteria.

SITE DEVELOPMENT

For a number of reasons it seemed preferable to engage a West Virginia firm for architectural and engineering services, rather than to continue with the New York firm of Eggers & Higgins, which had been employed for the feasibility study; Irving Bowman and Associates of Charleston were selected. Under their supervision the following major projects were started: a topographic survey of the site; the design of a "master plan" for the Observatory's principal structures, including a Laboratory, Residence Hall, Works Area, and two Telescopes (85- and 140-foot), placed along a high ridge that extends in a general east-west direction across the site from Route 28 on the east to Deer Creek on the west; the design and construction of a road along this ridge, adequate to serve for the heavy construction at the telescopes and buildings and later to serve as the main Observatory road; the design and construction of an underground conduit system parallel to the road for the Observatory electric power, telephone, time signal, and other circuits; and preparation of plans and specifications for the control building for the first telescope to be constructed, the 85-foot.

At the time the main project road was built, the location of the Laboratory was determined and the parking area for this building was leveled and surfaced with crushed stone. Similar provisions were made for access to the 85-foot telescope.

The underground power distribution system consists of four 4-inch conduits connecting a series of 16 double pits or vaults on the south side of the main road. The double arrangement was adopted to afford a proper separation of the 4160-volt power circuits and the low voltage telephone and signal circuits. From the 16 pits mentioned, lateral branch circuits will be laid to the various structures and instruments on the site. The Monongahela Power Company installed a temporary transformer substation at the eastern end of the site, drawing power from 12-KV pole lines that run across the site in that area. To meet the estimated Observatory requirements for more power and to provide better service with respect to voltage regulation and continuity, work has been started on a new 66-KV line that will pass along the Greenbrier River about 7 miles west of the site. A 12-KV branch will bring power to the Observatory site. That portion in "view" of the radio telescopes will be a specially constructed shielded line. A substation to provide 4160-volt current for the underground distribution system will be located on the bluff on the east side of Deer Creek, northwest of the 140-foot telescope. When power is available from this new route, a planned program of removing all pole lines on the site will be initiated. Houses, stations for the temporary installation of observing equipment, and other similar permanent installations will be supplied by direct-burial or parkway type cables.

The telephone facilities at the Observatory have been improved greatly by the Telephone Utilities Co., but will be sorely taxed until completion of a new exchange, to be relocated from the town of Cass, seven miles away, to a plot in the village of Arbovale on the northeast corner of the Observatory property. This new exchange will provide adequate trunk lines to the Laboratory building, where the cental Observatory switchboard will be located. The Observatory network will provide connections to each telescope, building, house, and other permanent installation on the site.

HOUSE RENOVATION PROGRAM

The building program proposed in the feasibility study included separate residences to supplement the apartments and rooms in the Residence Hall. Because of the great need for housing and the delays apparently inherent in new housing programs, the Observatory proceeded to remodel all the farm houses on the site that were worth preserving. The criteria for remodeling was that equivalent new home facilities should be provided at about half the cost of new construction. Seven houses have been rebuilt. One of the largest of these is used as a dormitory, and meals have been served there since January 1959. An eighth house was suitable for a dormitory for the summer program with few alterations, but extensive repairs were necessary on the access road and bridge across Deer Creek; it is planned to use this house as a family residence during the coming winter. Two other houses are being used by the Observatory and the Darin & Armstrong constructions groups. These latter two houses will be demolished when the 140-foot telescope is completed, because their general structural condition is too weak to permit moving them from the present location between the 85-foot and 140-foot telescopes.

The renovated houses will continue to be used by visiting scientists who come to the Observatory with their families, and also, by new members of the permanent staff until they have had an opportunity to make suitable arrangements of their own. On-site residences are deemed necessary for some members of the permanent staff, including the Director, and perhaps the heads of maintenance, safety (including fire) and telescope operators. All on-site housing is provided at rentals comparable to those charged elsewhere in the area.

WATER AND SEWER SYSTEMS

Careful study was given to the problems of water supply and sewage disposal. Contamination from an old buried gasoline tank made the water supply at the field office immediately unacceptable, and early experience was gained with wells in the area. With few exceptions, new wells had to be drilled for all the remodeled houses. At a depth below 100 feet, an individual well can be counted on to supply about 20 gallons per minute. Thus it was decided to employ individual wells at the isolated installations, including the two telescopes. On the other hand, a supply of greater capacity was necessary for the complex of laboratory, residence hall and works area, where larger peak demands could be expected and fire protection should be maximized. Accordingly, three 8-inch wells were drilled and interconnected to an elevated 100,000 gallon storage tank located near the Works Area building. This tank supplies water for the three principal buildings as well as for fire hydrants between them. Similarly, a common sewer system has been constructed for these buildings, whereas smaller, individual systems have been provided for each of the more isolated installations.

SITE MAINTENANCE AND MISCELLANEOUS ACTIVITIES

In addition to the obvious elements of site development that have been described, there have been many small but nevertheless important tasks. Old fence rows have been cleared. Areas have been graded and seeded or, as appropriate, covered with stone to provide access roads and parking areas at the various houses and other installations. A small building was constructed on which is mounted a 12-foot reflector that will be used for antenna patterns and similar experimental programs. Barns and sheds have been demolished. A temporary high-overhead shop was constructed to house the fabrication of the Little Big Horn, described elsewhere. The original 30-foot telescope built and used by Grote Reber in the 1930's, which was requisitioned by the Federal Government during World War II and was found in the custody of the Bureau of Standards at Boulder, Colorado, has been obtained by the National Science Foundation. All component parts have been completely refurbished under the personnel supervision of Mr. Reber, and the telescope is currently being reassembled on a foundation to the east of the Laboratory building. Because of the important role it has played in radio astronomy, the telescope should be of great historical interest to the public. In addition it will be utilized in certain experimental programs.

LEASES

Much of the site has been used for farming—livestock or hay—for a number of years, and sufficient fences were on hand to permit effective isolation of specific areas. Accordingly, arrangements were made to lease the areas not immediately required for Observatory purposes. In many instances, the former owners or tenants arranged to use the land they had formerly occupied. Lease terms were at the prevailing local rates. For the first year, these operations produced a net cash income of about $2,000. The 1959 summer was not so favorite for the growth of grass and the net income is lagging behind that of the previous year. In addition to the cash value, these leasing operations have saved the Observatory the expense of mowing many large areas and have retarded or prevented the growth of brush that always occurs on abandoned farm lands.

PERSONNEL

Mr. F. J. Callender joined the Observatory staff in November 1957 as the Business Manager, which covered a wide variety of activities, including purchasing, payrolls, personnel, site management, construction supervision, budgets and accounts, contract officer, food services and housing, and public relations. He now heads the Administration Department. He has been assisted by: F. L. Beverage, N. F. Daniels, R. F. Elliott, M. Irvine, E. M. Lambert, J. A. Sheets, and H. E. Wooddell.

The following tabulation gives a breakdown for the entire Observatory staff, by appointment grades, as of June 30, 1959. A distinction is made between the scientific members of the staff and all others.

NRAO Personnel Levels
June 30, 1959

Scientific	
Associate Astronomers	1
Assistant Astronomers	3
Research Assistant (part time)	9
Research Associates	4
Physicist	1
Associate Physicist	—
Deputy Director	1
Sub-Total	19
Other	
Business Manager	1
Plant Superintendent	1
Associate Engineer	1
Assistant Engineer	1
Junior Engineer	1
Draftsman	1
Administrative Aide	1
Technician A	1
Technician B	1
Technician C	1
Staff Shop Technician	1
Mechanics (part time)	5
Laborers (part time)	3
Telescope operators	4
Secretary B	3
Accounting Clerk B	2
Driver	1
Cook	1
Housekeeper	2
Chief Accountant	—
Telephone operator	1
Property & procurement clerk	1
Sub-Total	34
Total	53

APPENDIX A

PUBLICATIONS

Drake, F. D., *The Nature of the Radio Source Cygnus X,* Proceedings of the Paris Symposium on Radio Astronomy, Stanford University Press, 1959

A radio map of the region of Cygnus X, made at 1400 megacycles with the Harvard 60-foot radio telescope, is given. The map shows resolution of the source into a complex of small discrete sources. Comparison of these sources with optical photographs shows that nearly all of them may be associated with visible H_{II} regions. However, no such association is apparent with the strongest source, which is coincident with the star Gamma Cygni. Optical photographs made of Gamma Cygni in H alpha light with the Harvard 61 telescope show the existence of an intense nebulosity very near Gamma Cygni. It is suggested that this may be the source of the most intense radio radiation in the Cygnus X complex.

Drake, F. D., *Neutral Hydrogen in Galactic Clusters,* Proceedings of the Paris Symposium on Radio Astronomy, Stanford University Press, 1959

Observations at 21 cm of neutral hydrogen in the clusters H and Chi Persei, the Pleiades, Praesepe, Coma Berenices, and M67 are given. Amounts of neutral hydrogen which correlate inversely with the ages of the clusters are found. It is shown that a plausible explanation of this hydrogen may be given in terms of the gaseous residue remaining from the primordial cluster mass. There is quantitative agreement between the amount of hydrogen in the clusters, and the amount which might be present on the basis of existing theories of stellar formation. The frequency profiles of the hydrogen show extended wings. These must be interpreted as due to Doppler effect, and it is shown that this requires the presence of an intrinsic cluster magnetic field of the same order of magnitude as the general galactic field.

Drake, F. D., *Radio Resolution of the Galactic Nucleus,* Sky and Telescope, *81,* p. 428, 1959

Observations of the Sagittarius A radio source, made with the NRAO 85-foot telescope, are given. The observations at 3.75-cm wavelength, at which the beamwidth is six minutes of arc, show resolution of the SGR A source into at least four components. It is also found that the position of the brightest source component deviates by about .05° from the new zero of galactic longitude.

Drake, F. D., *Hydrogen Line Observations,* IRE Student Quarterly, in press

An elementary description of the basic receiving systems used in 21-cm observations is given. This is followed by a general survey of the results obtained to present from 21-cm observations.

Emberson, R. M., *The Telescope Program for the National Radio Astronomy Observatory at Green Bank,* West Virginia, Proc. IRE *46,* 23, 1958

A brief account is given of the initiation of the feasibility study on the establishment and operation of the National Radio Astronomy Observatory at Green Bank, West Virginia. The principal research facilities will be the radio telescopes, and a series of such telescopes have been proposed. The desired performance characteristics are reviewed. A 140-foot steerable paraboloid on an equatorial mount has been designed. The steps leading to this design are described, as well as the general features of the designed and the expected operating performance. The National Radio Astronomy Observatory is being sponsored by the National Science Foundation.

Findlay, J. W., *Noise Levels at the National Radio Astronomy Observatory, Proc. IRE, 46,* 35, 1958

The measurements which have been made of the field strengths of radio signals received at the Green Bank site of the National Radio Astronomy Observatory are described. The site is relatively free from interference and the measures which are being adopted to preserve its radio quietness are discussed.

Findlay, J. W., *Frequency Allocations for Radio Astronomy,* URSI/IRE Meeting May 4-7, 1959, Washington, D.C. (Abstract to be published, IRE)

Heeschen, David S., *Neutral Hydrogen Emission from the Hercules and Corona Borealis Clusters of Galaxies,* PASP *69,* 350, 1957

Heeschen, David S., *Neutral Hydrogen in M32, M51 and M81,* Ap. J. *126,* 471, 1957

Observations of M32, M51, and M81 in the 21-cm line of hydrogen are described, and the mass of neutral hydrogen in each galaxy is determined. The extent of hydrogen in the two spiral galaxies appears to be much greater than the visual extent of the galaxies.

Heeschen, D. S. and Dieter, N. H., *Extragalactic 21-cm Line Studies.* Proc. IRE, *46*, 234, 1958

The study of neutral hydrogen in extragalactic systems by means of its 21-centimeter line emission is a relatively new field of radio astronomy research. To date, radiation has been observed from seven galaxies and three clusters of galaxies. In this paper some of the results of these observations are described. Although the observational material presently available is quite limited, it does indicate the great potential power of extragalactic 21-centimeter studies.

Heeschen, D. S., *Book Review of Radioastronomie*, by R. Coutrez, Science, *127*, 153, 1958

APPENDIX B

RECEIVERS IN USE AT THE OBSERVATORY

1. L-Band Receiver—*Airborne Instruments Laboratory*

   Total power or comparison

   Frequency range 1170 Mc/s—1430 Mc/s

   I.F. 33 Mc/s

   I.F. Bandwidth 6 Mc/s

   Comparison Bandwith 1 Mc/s

   Signal Bandwidths 30 kc, 200 kc/s, 1 Mc/s

   Time Constants 1, 5, 20, 60 and 180 seconds

   Total power gain stability: 0.1% over several hours.

2. X-band Receiver—*Ewen Knight Corporation, TWT Receiver, using noise compensated Dicke system.*

   Frequency: 8000 Mc/s Other frequencies in range 7.3-10.3 kMc/s and other bandwidths can be made available

   Bandwidth: 1000 Mc/s

   Time constants: 1, 2, 5, 10, 20, 40, 80, 160, 320 and 640 seconds

   Noise Figure: 10 db

   Hrs. Stability: 0.1°K per hour

3. 440 Mc/s Total Power Receiver—*NRAO.*

   Frequency range 300-500 Mc/s

   IF 30 Mc/s

   IF Bandwidth 5 Mc/s

   Time Constants 1—30 seconds

   Total Power gain stability 1°K over several hours.

APPENDIX C

RESEARCH EQUIPMENT DEVELOPMENT DEPARTMENT ELECTRONIC TEST EQUIPMENT

Signal Generators

G.R. Type 1021-AV	40-250 Mc/s	2
G.R. Type 1021-AU	250-920 Mc/s	1
G.R. Type 1001-A	5 kc/s-50 Mc/s	3
H.P. Type 620-A	7-11 kMc/s	1
H.P. Type 614-A	800 Mc/s-2100 Mc/s	1
H.P. Type 202-A	.008-1200 cps	1
Kay Electric Type IF (Vari-sweep)	4-120 Mc/s	1

Unit Oscillators

G.R. Type 1218-A	900-2000 Mc/s	1
G.R. Type 1215-B	50-250 Mc/s	1
G.R. Type 1211-B	0.5-50 Mc/s	1

Impedance Measuring Equipment

G.R. Impedance Bridge Model 650AP	1
G.R. Admittance Meter—Model 160B	1
G.R. VHF Bridge—Model 1601A	1

Vacuum Tube Volt Meters

Kintel-Microvolt Meter (Model 202BR)	1
Hewlett-Packard Model 410B	2
Hewlett-Packard Model 400D	1

Noise Generators

A.I.L. 7050—10000 Mc/s Model 70B-51	1
Kay Electric, Mega-Node Model 240A	1
AIL, 200-2600 Mc/s Model 70A	1

Power Supplies and Regulators

Sorenson—Model 1001 Regulator	5
Sorenson—Nobatron 3032—Reg. D.C. Power Supply	1
Hewlett-Packard—Model 710B—Reg. D.C. Power Supply (Variable 100-300 VDC)	3
Hewlett-Packard—Model 715A—Klystron Power Supply	1
FXR—Model 2819B—Klystron Power Supply	1
Kintel—Model 30B-50-DC Power Supply	1
G.R. Model 1263-A—Amplitude Reg. Power Supply	1
Kron-Hite—Model UHP-230R—Dual Power Supply	1

Q-Meters

Marconi Circuit Magnification Meter, Model TF3296 50 kc/s-50 Mc/s	1

Misc. Test Equipment

Hewlett-Packard—Oscilloscope Model 120A	2
Tektronix, Oscilloscope Model 541	1
Tektronix, L.C. Meter Model 130	1
General Radio—Sweep Drive, Model 1750A	1
Millen-Grid Dip Meter, Type 90651	1
Hickock Tube Tester Type 539B	1
Precision Tube Tester Type 10-12	1
Hewlett Packard-Standing Wave Indicator, Model 415B	1
Freed-Megohmmeter Model 1620	1
Hewlett-Packard—VHF Detector—Model 1810	1

Amplifiers

LEL IF Amplifier Model IF 20B (30 Mc/s)	1
Inst. for Industry IF Amplifier Type N230 (30 Mc/s)	1
Kintel D.C. Amplifier Model 111 BF	1
G.R. IF Amplifier Model 1216A	1

Microwave Accessories

FXR Slotted Section Type L310A, 1.12-1.7 kMc/s	1
FXR Slotted Line Type L101A, 1.12-1.7 kMc/s	1
Jasik Slotted Line, Type 239, 100 Mc-2000 Mc/s	1
Jasik L-Band Matched Load, Type 242	1
Jasik E/H Coax Tuner, Type 224-C	1
FXR Slotted Line-Type L101-A	1
FXR Tunable Probe Type E200A	1
Waveline Variable Attenuator, Type 512	1
FXR W. G. to Coax Adaptor, Type L600B, 1.12-1.7 kMc/s	1
AIL Variable Attenuator Type 30	1
DICO—Low Power Termination, 1.12-1.7 kMc/s (VSWR 1.05)	1

APPENDIX D

RESEARCH EQUIPMENT DEVELOPMENT DEPARTMENT MACHINE TOOLS

1—Bridgeport Vertical Milling Machine
1—9″ South Bend Lathe
1—24″ Cincinnati Drill Press
1—14″ South Bend Drill Press
1—Queen City 1/2-HP Grinder
1—48″ Pexto Shear
1—24″ Di-Acro Spartan Box and Pan Brake
1—9″ x 10″ Keller Power Hacksaw
1—Linde Pure-Ox Welding Machine

APPENDIX E

IXth Plenary Assembly
C.C.I.R.
Los Angeles, 1959

Doc. 437-E (revised)
27 April 1959
Page 1

RECOMMENDATION No. . . . *

PROTECTION OF FREQUENCIES USED FOR RADIO ASTRONOMICAL MEASUREMENTS

(London 1953 — Warsaw 1956 — Los Angeles 1959)

The C.C.I.R.,
CONSIDERING

a) that the development of radio astronomy has already led to major technological advances, particularly in receiving techniques, and to improved knowledge of fundamental radio noise limitations of great importance to radio communication, and promises further important results;

b) that protection from interference on certain frequencies is absolutely essential to the advancement of radio astronomy and the associated measurements;

c) that, for the observation of known spectral lines, certain bands at specific frequencies are of particular importance;

d) that account should be taken of the Doppler shifts of the lines, resulting from the motion of the sources which are in general receding from the observer;

e) that for other types of radio astronomical observations a certain number of frequency bands are in use, the exact positions of which in the spectrum are not of critical importance;

f) that the sensitivity of radio astronomical receiving equipment, which is still steadily improving, greatly exceeds the sensitivity of communications and radar equipment;

g) that a considerable degree of protection can be achieved by appropriate frequency assignments on a national rather than an international basis;

h) that, nevertheless, it is impracticable to afford adequate protection without some international agreement;

RECOMMENDS

1. that radio astronomers should be encouraged to choose sites as free as possible from interference;

2. that Administrations should afford all practicable protection to the frequencies used by radio astronomers in their own and neighbouring countries;

3. that particular care should be taken to give complete international protection from interference to observations of emissions known or thought to occur in the following bands:

Line	*Line frequency (Mc/s)*	*Band to be protected (Mc/s)*
Deuterium	327.4	322 - 329
Hydrogen	1420.4	1440 - 1427
OH	1667	1645 - 1675

4. that the bands allocated for standard frequency and time signal emissions at 2.5, 5.0, 10.0 and 20.0 Mc/s should not include anything other than the standard frequency and time signal emissions, thus permitting their use for reception in radio astronomy;

5. that consideration be given to securing adequate international protection of a number of narrow frequency bands throughout the spectrum above 30 Mc/s for the purpose of reception in radio astronomy (see Note);

6. that Administrations, in seeking to afford protection to particular radio astronomical observations, should take all practicable steps to reduce to the absolute minimum amplitude harmonic radiations falling within bands of frequencies to be protected for radio astronomy.

NOTE

Radio astronomers in a number of countries have indicated their desire to use for this purpose one frequency band at each of the following approximate positions (not necessarily in harmonic relation):

Frequency (Mc/s)	*Bandwidth (Mc/s)*
40	± 0.75
80	± 1.0
160	± 2.0
640	± 2.5
2560	± 5.0
5120	± 10.0
10240	± 10.0

**This Recommendation replaces Recommendation No. 173.*

APPENDIX F

HISTORICAL SUMMARY

The August 1956 report to the National Science Foundation, "Plan for a Radio Astronomy Observatory", gives an account of steps that were taken by a number of individuals in bringing the project to the point of completion of the feasibility study. The contract for the establishment of the National Radio Astronomy Observatory was signed by Dr. Alan T. Waterman, Director of the National Science Foundation, and Dr. Lloyd V. Berkner, President of Associated Universities, Inc., on November 17, 1956. Dr. Berkner became the Acting Director of the Observatory.

The Steering Committee for the feasibility study continued to serve after submittal of the feasibility report, the membership at that time being B. J. Bok (chairman), J. G. Bolton, A. J. Deutsch, W. E. Gordon, F. T. Haddock, E. F. McClain, A. B. Meinel, H. C. Wells, and J. B. Wiesner. The Committee worked closely with the ad hoc Committee of engineers on the design of the 140-foot telescope. Professor F. K. Edmondson, who at that time was Program Director for Astronomy at the National Science Foundation, regularly participated in these affairs. Dr. D. S. Heeschen joined the AUI staff in July, 1956, and Dr. J. W. Findlay came in December of 1956.

Pursuant of the terms of the new contract, the AUI Trustees formally established the Advisory Committee for the National Radio Astronomy Observatory, which Committee held its first meeting in Cambridge, Massachusetts, on May 7, 1957, the members being R. N. Bracewell, A. J. Deutsch, W. E. Gordon, F. T. Haddock, E. F. McClain, D. H. Menzel (chairman), G. C. McVittie, A. B. Meinel, and J. B. Wiesner. Appointments to the Committee were in three groups, with one-, two-, and three-year terms, in order to insure continuity but providing for a gradual rotation.

The site was first occupied in May, 1957, at which time a temporary AUI office in Marlinton was moved to Green Bank. Ground-breaking ceremonies were held on October 17, 1957. (See also the chapter on site development) The dedication ceremonies for the Howard E. Tatel telescope were held on October 16, 1958. Dr. Berkner presided. Dr. Waterman, Representative H. O. Staggers, and Dr. Otto Struve spoke. Mrs. Tatel was introduced. Professor E. J. McShane represented the National Science Board. The NRAO Advisory Committee, the AUI Trustees and officers, Mr. A. H. Jackson and Mr. R. D. Hall representing the Blaw-Knox Company, and others particularly interested in the Observatory and telescope were present, including Dr. M. A. Tuve, who collaborated with the late Mr. Tatel in the design of the telescope, and Mr. C. M. Jansky, Jr., brother of the late Karl Guthe Jansky.

The first new building (Works Area) for the Observatory was occupied in January, 1959, and the Residence Hall and Laboratory will be occupied in the autumn of 1959.

Initial observations with the Tatel telescope were made in February 1959, with both the Ewen-Knight 3.75 cm receiver and the Airborne Instruments Laboratory 21 cm receiver. Research programs were scheduled on a routine basis beginning in March.