# PROGRESS REPORT ON THE AGS CONVERSION PROJECT*

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## Introduction

The Alternating-Gradient Synchrotron at the Brookhaven National Laboratory first came into operation in 1960. The design intensity of $10^{10}$ protons per pulse was quickly exceeded, and with a continuing program of improvements the intensity has continued to increase. At this time, the maximum intensity achieved is $2 \times 10^{12}$ ppp. Furthermore, the AGS has proven to be an extremely versatile and tractable machine for high energy physics experiments. However, the demand for experimental time quickly exceeded the available time with present intensities. Thus in 1963, studies were begun on methods of increasing the useful output of the AGS.

In 1964, a proposal[1] was submitted to the U.S. Atomic Energy Commission. It was proposed to increase the intensity to $3 \times 10^{13}$ ppp and make various other modifications. For financial reasons, this proposal was reduced in scope to supply only $1 \times 10^{13}$ ppp and was resubmitted in 1965. This second proposal,[2] known as the "AGS Conversion Project, Phase I," was fully funded by the USAEC for $47.8 million in 1967.

There are three major objectives of the Project:

1. To increase the accelerated beam intensity per pulse.
2. To modify the main AGS ring, so as to increase the cycling rate and duty cycle of the synchrotron, and to improve its reliability, serviceability and safety.
3. To provide additional experimental facilities.

## Increase of Intensity per Pulse

The number of protons that can be injected into and accelerated by the AGS is limited by space-charge forces. This limit can be increased by a factor of about five by increasing the injection energy from the present 50 MeV to 200 MeV, thus increasing the intensity from the present $2 \times 10^{12}$ to $10^{13}$ protons per pulse. A high intensity, high brightness linear accelerator has been selected for the new injector. The general parameters of this linac are given in Table I.

The design for 100 mA peak current seems conservative on the basis of the dynamics calculations and of the experience at CERN. In fact, the linac is being designed with the capability of accelerating 200 mA, which appears quite practical. Unfortunately, it will not be possible initially to install sufficient rf power to accelerate 200 mA.

At 750 keV, the transverse acceptance of the linac will be about $20\pi$ cm-mrad. Recent measurements[3] on the high gradient preinjector indicate an emittance of about $3\pi$ cm-mrad for a 200 mA beam from the preinjector. Calculations indicate that at 200 MeV and 100 mA, an emittance of about $0.5\pi$ cm-mrad should be achieved with an energy spread of about $\pm$ 500 keV.

The design of the linac is generally that of a conventional drift tube linac except for one important innovation. All of the linac cavities (except the first) will be fitted with "multistem" drift tubes.[4] Figure 1 shows a four stem arrangement which will be used, although other configurations are possible. One stem is the structural support stem which carries the alignment mechanism and services to the drift tube, while the other three are required only to make electrical contact to the drift tube, but must be located in a symmetrical arrangement.

The multistem arrangement provides a substantial reduction in the sensitivity of the cavity to amplitude and phase distortion which are a function of detuning perturbations and beam loading. The normal operating mode of the cavity (the $TM_{010}$) is at the end of the TM dispersion curve and so shows the low group velocity which is characteristic of the end of the dispersion curve. The addition of multiple stems moves the stem resonance dispersion curve close to the TM dispersion curve resulting in $\pi/2$ mode performance at the operating mode, Fig. 2. Reduction in the cavity sensitivity by factors of ten or more are easily achieved.

The rf power for the linac will be supplied by the RCA 7835 triode. There will be one amplifier operating at the 5 MW level for each cavity except the first. Each of the eight final amplifiers will have its own complete driver chain and two additional driver chains will be used to power the first short cavity. For each cavity, servo systems will be supplied to maintain the cavity on resonance, to maintain the proper amplitudes and phase of the accelerating voltage and to maintain the correct phase relations between the cavities.

Radial focusing in the linac will be provided by pulsed quadrupole magnets in each drift tube. These magnets will have the capability of containing a 200 mA beam. Vacuum in the linac cavities will be produced by sputter-ion pumps. Two preinjectors will be installed in order to improve the preinjector reliability. They will be 750 kV Cockcroft-Walton generators with duoplasmatron sources and high gradient accelerating columns. A complete beam analysis area will be provided at the output of the linac.

At this time, a prototype of one complete rf station is in operation. The 7835 amplifier has been tested in excess of 6 MW into a resistive load and is being tested into a resonant load. Most details of the design of the drift tubes, stems, and quadrupole magnets have been finalized. Final design of the cavities is nearing completion.

## Modifications to the AGS Ring

The time average intensity of the synchrotron can be increased by increasing the cycling rate in addition to increasing the intensity per pulse. It is planned to double the rate at which the main magnetic field rises and falls. This requires doubling the voltage available at the magnet terminals and doubling the particle energy gain per turn. Furthermore, the usefulness of the synchrotron can be improved by increasing the duty cycle of the beam which will be accomplished by making available flat-tops of one or more seconds duration. The present and proposed magnet cycles are shown in Fig. 3. Table II lists the major parameters of the new motor-generator set. In addition to its size, the principal difference between the old and new sets will be the use of a separate set of mercury arc rectifiers for flat-top service. Negotiations for purchase of the new power supply are now in progress.

The parameters of the new rf system are listed in Table III. The peak voltage per station is increased by a factor of 3 rather than 2 in order to permit a reduction in the number of stations. The new rf power amplifiers will be centrally located in a new building with coaxial lines feeding the cavities. The present amplifiers are located in the magnet tunnel next to the cavities, where they are exposed to radiation and are inaccessible during operation. A prototype of the amplifier is now being tested. Completely new ferrite-tuned cavities are being designed.

At the present intensity of the AGS, radiation damage to and activation of machine components are creating serious problems. If the beam intensity interacting inside the accelerator were increased by a factor of ten, these problems would become excessive. Therefore, it will be necessary to limit the amount of beam used on internal targets and lost during the beam extraction process. A maximum of $2 \times 10^{12}$ pps will be used on internal targets in the G superperiod. Extraction efficiencies of better than 90% are expected for both fast and slow external beams, so that extraction losses should be held to about $1 \times 10^{12}$ pps. Even at these levels, steps must be taken to reduce the worst of the radiation damage effects.

Organic materials, particularly vacuum seals, will be eliminated wherever possible. A completely new vacuum chamber incorporating all metal seals will be installed. New vacuum pumps of the sputter-ion type will be used; one for each main magnet. The new pumps and vacuum chamber are on order. A new, more radiation-resistant type of magnet coil insulation is being used as the magnet coils are replaced. As much as possible of the auxiliary equipment will be removed from the magnet tunnel to eliminate irradiation of these units.

There will be very high residual activity levels, particularly near internal targets and extraction mechanisms. In order to minimize the time required to make repairs, the entire main magnet system is being modularized and fitted with quick-disconnect devices. Any complete magnet module may be removed in a minimum time and replaced with a fresh unit. The module will include the vacuum chamber, vacuum pump, bus bar and water connections as well as the magnet. Surveying of the magnet ring will be accomplished with remotely viewed and operated theodolites located on monuments within the magnet enclosure. A development program on special and general purpose remote handling devices is being carried out.

Additional shielding for the magnet enclosure will be required in the areas where the beam losses will occur. All targeting and extraction losses will be confined to the superperiods F to I and most injection

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losses will occur at the B superperiod. Twenty feet of sand or the equivalent will be used. Concrete arches with sand above will be used over these areas which are in the tunnel and a combination of steel and ilmenite concrete will be used in the Target Building (see Fig. 5).

Additional Facilities

In order to make the fullest use of the increased intensity and duty cycle of the AGS, additional experimental facilities are needed. Also, the utilities system must be expanded and buildings erected to house the new accelerator components. Figure 4 shows an aerial photograph of the AGS complex as it looks today, and Fig. 5 shows a plot plan of the complex as it will look.

A high bay experimental building of 50,000 $ft^2$ will be constructed adjacent to the existing East Experimental Building. The slow external beam which is about to be installed at the F-10 location will ultimately extend into this new building. A 25,000 $ft^2$ addition is planned for the West Target Building. A new fast external beam will be installed at H-10 to feed the North Experimental Area, which it is hoped will become the center of the bubble chamber activity. The Southwest Area, off of B-10, will be abandoned when the new linac is in operation.

Two new buildings will be erected inside the ring to house the new motor-generator-rectifier set and the centralized rf power supply. The new linac complex will be located to the northwest of the ring as shown in Fig. 5. Construction of these new facilities will commence over the next six months.

The general time schedule for the Project expects that the increased repetition rate (new motor-generator set and rf system) will become operative early in 1970. The linac should produce a first beam late in 1970 and the Project be completed during 1971.

References

1. A Proposal for Increasing the Intensity of the Alternating-Gradient Synchrotron at the Brookhaven National Laboratory, BNL 7956, May 1964.

2. Alternating-Gradient Synchrotron Conversion Program, Scope of Phase I, BNL 9500, September 1965.

3. T. Sluyters, V. Kovarik, R. Amari, S. Senator, to be published in the Proceedings of the VI Intern. Conf. High Energy Accelerators, Cambridge, Mass., September 1967.

4. S. Giordano and J.P. Hannwacker, IEEE Trans. Nucl. Sci. NS-14, No. 3 (1967), p. 290; S. Giordano and J.P. Hannwacker, Proc. 1966 Linear Accelerator Conference, Los Alamos, 1966 (LA-3609), p. 88.

DISCUSSION (condensed and reworded)

K. H. Reich (CERN): Is it possible to use a shorter cycle for lower energies?

Wheeler: There is not much demand for lower energies. If there were demand, then the magnet cycle could be extended substantially, e.g., 1 second flat top at 33 GeV and 4 second flat top at 30 GeV.

White (PPA): How much down time do you expect for the AGS during the conversion?

Wheeler: Five months in 1969 and seven months in 1971. These are in addition to the regular shutdowns.

Swanson (Los Alamos): At one time there was a plan to modify the 200 MeV linac to 500 MeV. Do you still consider this a possibility?

Wheeler: We do not plan to modify the 200 MeV linac. One would prefer a booster over a 500 MeV linac. However, at present we have chosen to use the 200 MeV linac.

TABLE I

General Parameters of the 200 MeV Linac

| | |
|---|---|
| Preinjector energy | 0.75 MeV |
| Output energy | 200.3 MeV |
| Peak beam current | 100 mA |
| Beam pulse length | 200 μsec |
| Pulse repetition rate (max.) | 10 pps |
| Rf pulse length | 400 μsec |
| Operating frequency | 201.25 MHz |
| Number of cavities | 9 |
| Total length of accelerator | 144.8 m |
| Number of drift tube cells | 286 |
| Total peak rf excitation power | 22 MW |
| Synchronous Phase Angle | -32° |

TABLE II

Magnet Power Supply Parameters

| | Present | Future |
|---|---|---|
| Initial dc volts at magnet terminals | 6000 V | 12,000 V |
| Maximum current | 6150 A | 6150 A |
| Zero to maximum current (rectify) | 1 sec | 0.5 sec |
| Maximum current to zero (invert) | < 1 sec | < 0.5 sec |
| Motor rating | 5500 hp | 12,000 hp |
| Maximum flat-top at 30 BeV | 200 ms | 4 sec |
| Maximum flat-top at 33 BeV | - | 1 sec |
| Fastest repetition cycle time at 30 BeV | 2 sec | 1 sec |
| Total number of mercury arc rectifiers | 24 | 96 |
| Number of rectifiers used for flat-top service only | 0 | 48 |
| Number of ac phases | 12 | 24 |
| Speed change at maximum duty cycle | 3% | ≤ 4% |
| Nominal rotational speed | 900 rpm | 1200 rpm |
| Rotational energy at nom. rpm | $220 \times 10^6$ joules | $\geq 250 \times 10^6$ joules |

TABLE III

Rf System - Major Parameters

| | | |
|---|---|---|
| No. of accelerating stations | 12 | 8 |
| Accel. voltage per station (peak) | 16 kV | 48 kV |
| Driving power per station | 15.4 kW | 80 kW |
| No. of gaps per station | 2 | 4 |
| Frequency sweep | 1.38 to 4.2 MHz | 2.5 to 4.2 MHz |
| Power amplifier and dc bias supply location | at station | remote |

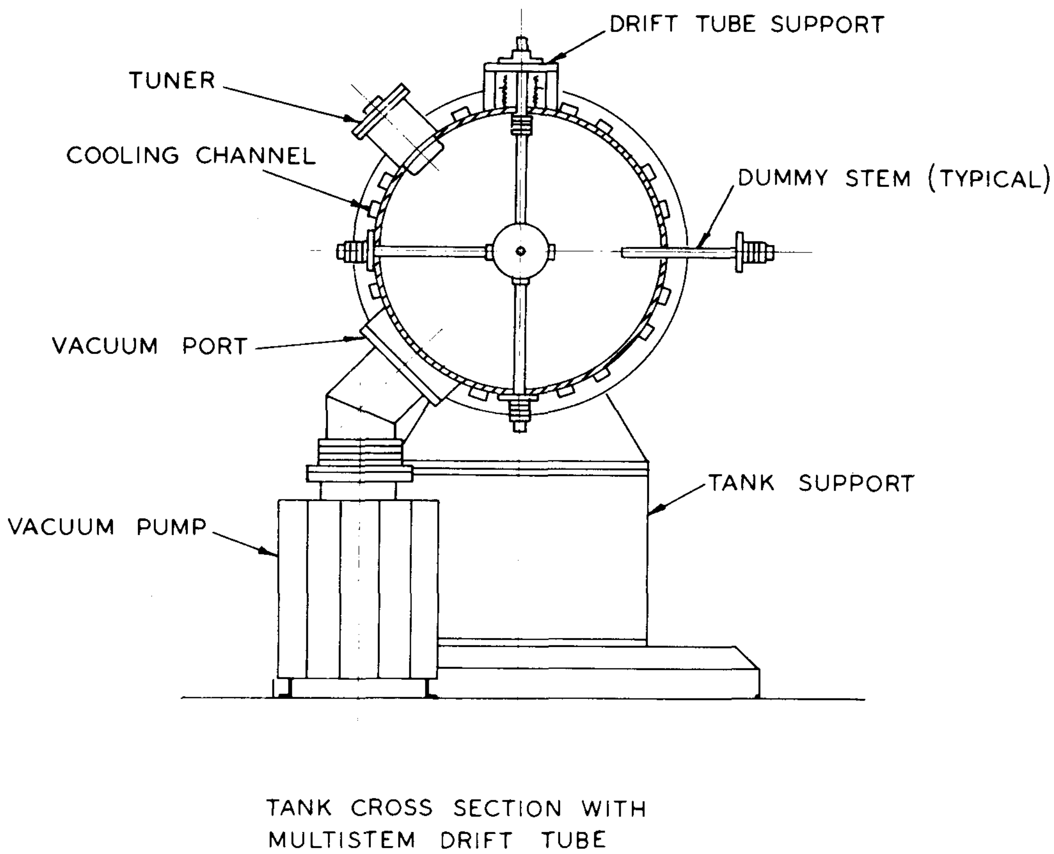
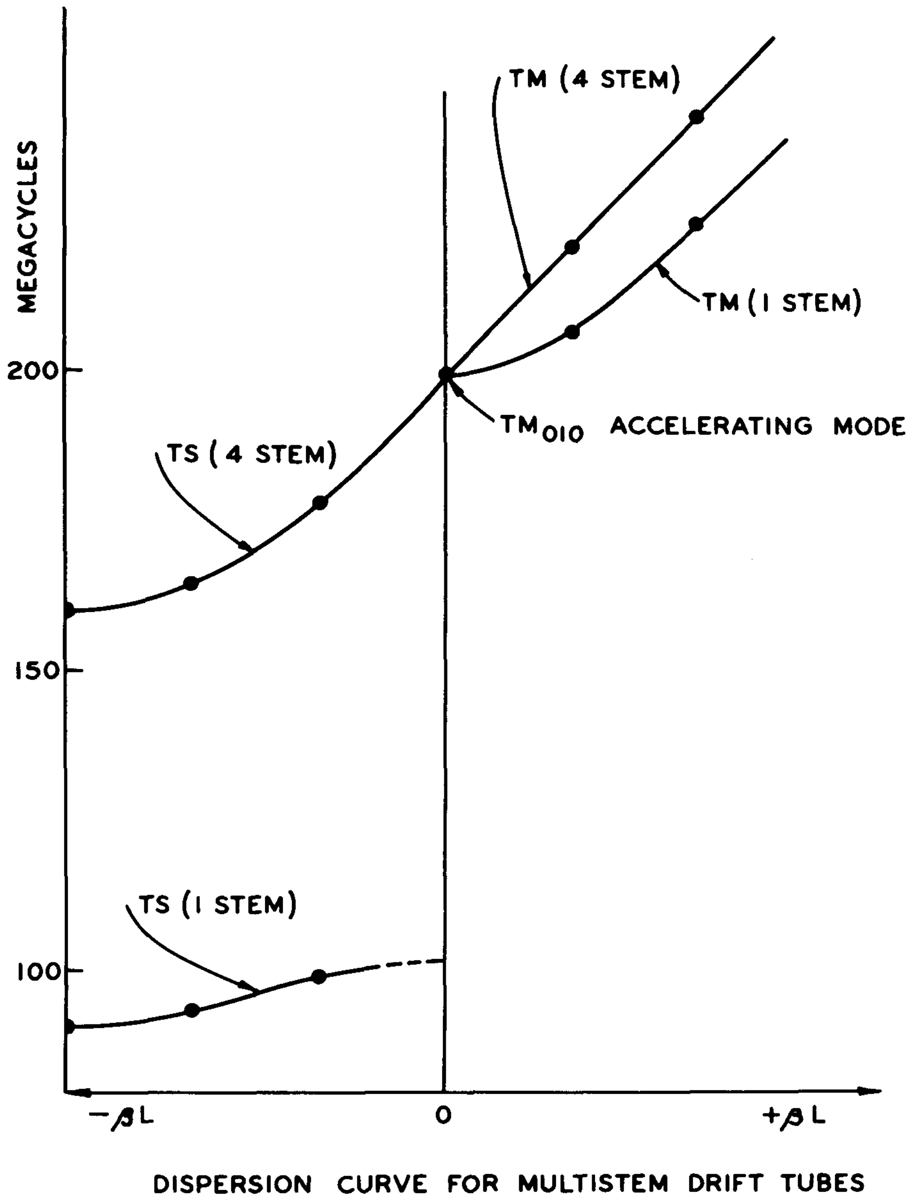



Fig. 1. Cavity cross section with multistem drift tube.

Fig. 2. Linac cavity dispersion curve with multistems.

Fig. 3. Present and converted main magnet cycles.



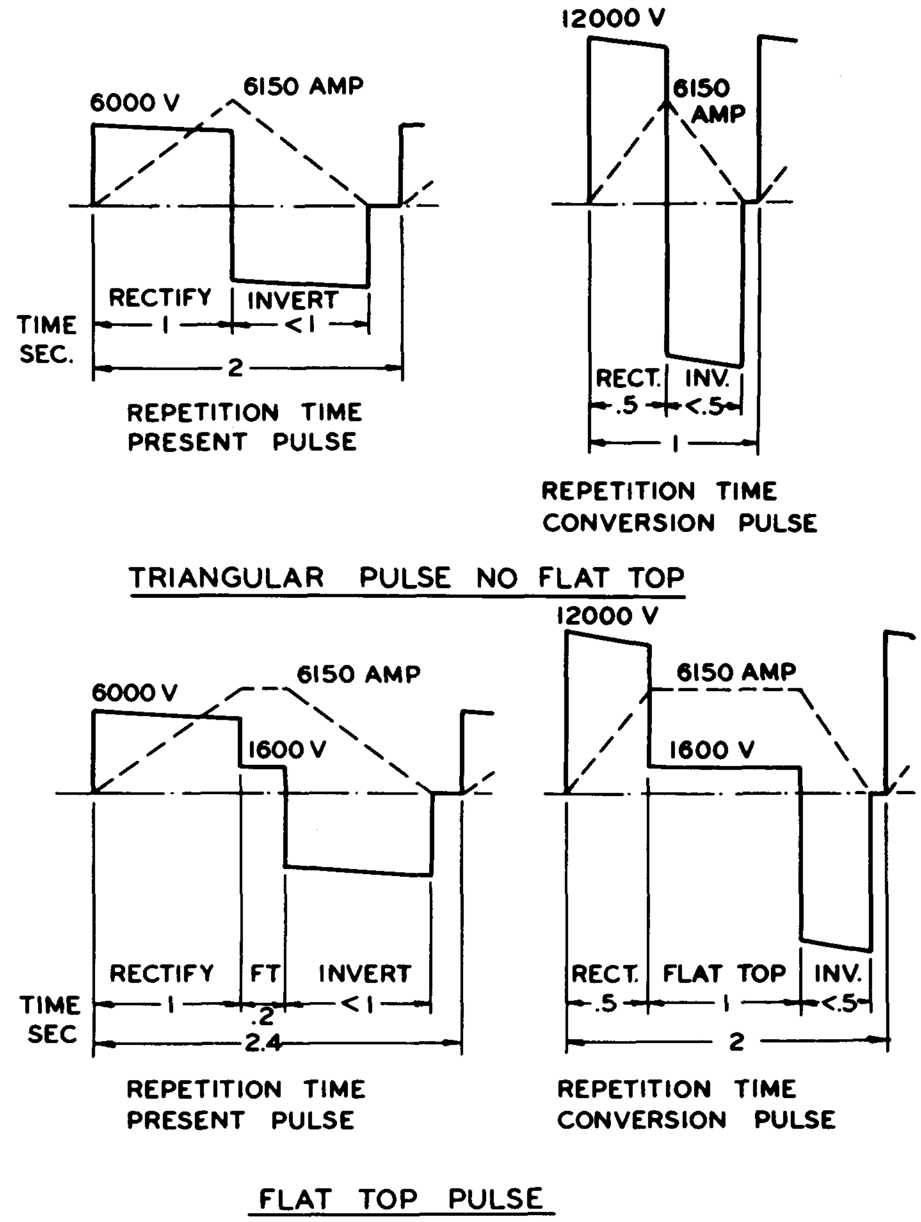



Fig. 4. Aerial photograph of AGS Complex.

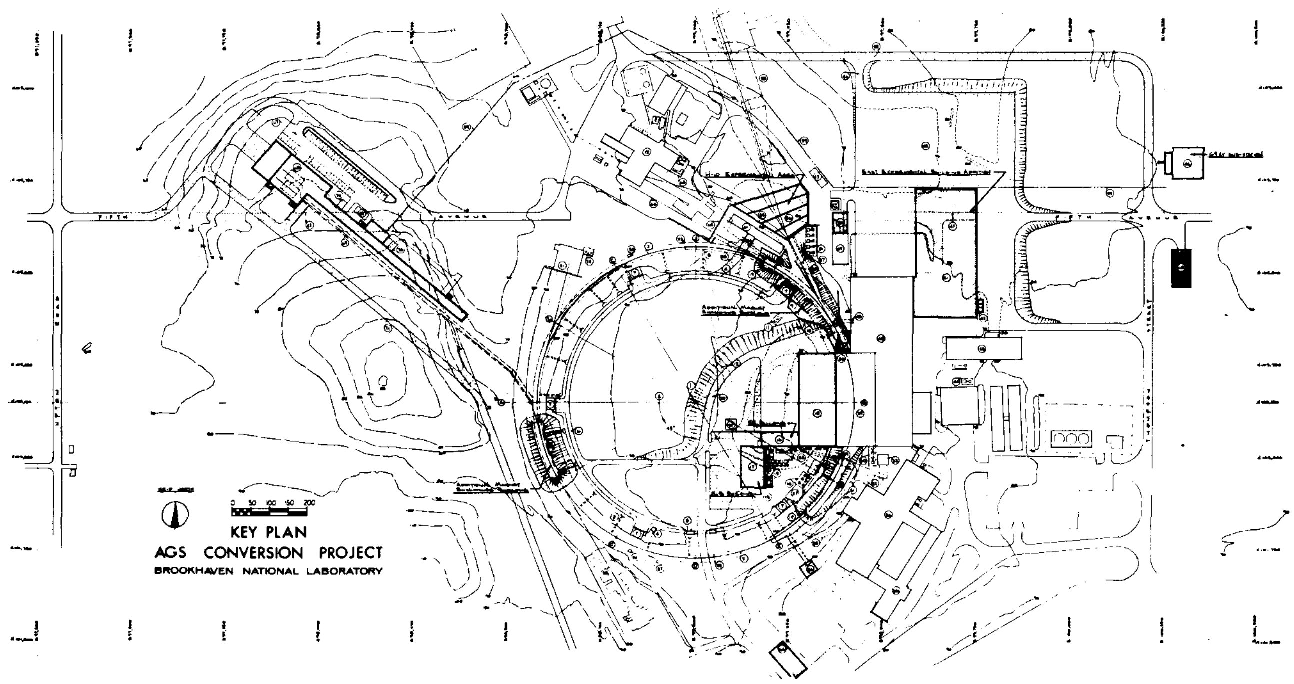



Fig. 5. Plot plan for the AGS Conversion Project.