THE PHYSICAL DESIGN OF A 200-MEV LINAC FACILITY*

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Introduction

Brookhaven National Laboratory has undertaken a major program (the AGS Conversion Project) to increase the output beam intensity of the Alternating-Gradient Synchrotron from about 10^{12} to 10^{13} protons per second.[1] This program includes the design and construction of a 200-MeV high current linear accelerator as the new injector. The higher injection energy (previously 50 MeV) will increase the AGS space-charge limit by a factor of about 5 (from about 2×10^{12} to 10^{13} protons per pulse). In addition, the cycling time of the synchrotron will be decreased from 2.4 s to 1 s per pulse. Figure 1 shows the over-all AGS site plan as it will look after the completion of the Conversion program. The major features are the AGS ring, the 200-MeV linac injector, the 80-inch Bubble Chamber complex, the major (East) experimental area and the Service Building and offices.

Parameters

The new 200-MeV linear accelerator being designed has the following general parameters:

Output energy:	200 MeV
Peak current:	100 mA (with possibility of going to 200 mA)
Beam pulse length:	200 μs
Beam repetition rate:	10 pps (duty cycle 0.2%)
Operating frequency:	201.25 Mc/s
RF pulse length:	400 μs (duty cycle 0.4%)
Peak excitation power:	19 MW (76 kW avg)
Peak beam power at 100 mA:	20 MW (80 kW avg)
Total length of cavities:	450 ft (9 cavities)
Total length of accelerator:	500 ft
Total estimated cost:	$ 8,350,000 for linac
	3,440,000 for buildings
	$11,790,000

Buildings

Figure 2 shows the plan view of the linac complex. It consists of, from left to right: the Preinjector Building housing the Cockcroft-Walton preinjectors (the second unit for a spare and for development work) and also assembly areas, laboratories and control room; the Linac Building with its shielded linac tunnel and adjacent RF and mechanical equipment bays; and the connecting beam tunnel from the linac to the AGS. The 45° dead-ended tunnel at the end of the linac will provide access to the tunnel during construction and will house the output beam emittance measurement gear and a beam dump.

As the cost of the buildings is approximately one-quarter of the total cost of the linac complex, it is only fitting that they be described here. A major effort has been made to design for the lowest construction cost consistent with a practical and versatile design. Several factors influenced the final design: (1) Separate radiation-shielded linac tunnel, (2) an RF equipment bay providing space for the complex high power equipment, (3) the necessary space to provide maximum flexibility and accessibility to the cabling and piping connecting the multiplicity of components making up the accelerator, and (4) a building to house two preinjectors, a control room and service areas. Figure 3 is a typical cross section of the linac building showing the RF equipment bay above the space for interconnecting cables, pipes and other services. This latter space is set at the level of the linac for cost reasons, and so that the sand and gravel foundation for the accelerator will not be disturbed during construction resulting in long-term settlements which would be detrimental to a stable alignment of the machine.

Linac

Each preinjector consists of a 750-kV Cockcroft-Walton generator and high voltage terminal housing the ion source. The proton beam will be accelerated down a "short" (high gradient) column, a number of which are being developed at different laboratories, including Brookhaven.[2] The beam is then matched and bunched before entering the first 10-MeV accelerating cavity.

A brief summary of the characteristics of the linac cavities is given in Table I.

The nine accelerating cavities (averaging 50 ft in length, except for the first cavity which is about 25 ft long), will be fabricated of copper-clad steel (1/8 in. copper on 3/4 in. steel), in approximately 18 ft long sections bolted end-to-end to form a cavity. The design is very similar to that of the present AGS injector and the Argonne ZGS injector. This approach is superior to the split double liner design used in earlier linacs, even though the one-piece tank poses some access problems because of the use of multistem drift tubes. Each 18 ft section, fitted with flanges, will be supported at the flanges on a thin longitudinally flexible member to allow for thermal expansion. The alignment will be achieved by proper shimming on the pile caps (see Fig. 4).

The design of the accelerating structure is conventional with the exception that multistem (four) drift tubes are used in the long cavities to greatly improve the accelerating field characteristics.[3,4] Two stems (at 90°) have been used in the past only to bring the necessary services

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to the drift tubes, and have not had a large effect on field characteristics. Figure 5 shows the model of a 200 Mc/s cavity used for testing components and electrical joints under high power. The figure shows a three-stem drift tube (two of the stems are dummies), the slug tuners and a vacuum grid designed to improve the conductance through the cavity wall. Although conventional in its concept, the design effort is directed toward a simpler, less expensive, functionally more reliable accelerator, as well as fulfilling the rather stringent parameters required for a high performance machine.

The accelerator cavities require a total of 274 drift tubes, varying in length from 1.9 in. in the first cell to 17.9 in. in the last cell and each containing a focusing quadrupole magnet. The drift tube design is different from previous designs in that it uses only one vertical structural stem carrying all services to the drift tube body. This concept is carried all the way to the low energy end where the first stem measures one inch in diameter. Figure 6 shows a typical one-stem drift tube. The stem support system is a simple plate providing flexibility in the X,Z coordinate and rotation about the Y axis. It is locked in the aligned position. The alignment is performed with the help of an accurate fixture fitting on top of the tank. The vertical adjustment is achieved first by proper shimming. The primary vacuum seal is a Viton "O" ring evacuated on both sides; the bellow permits access to the inner seal. The stems are made of precipitation hardened stainless steel with electroformed OFHC copper 0.010-0.015 in. thick on the surface. The steels mentioned are noted for their lack of distortion and long-term stability. The stem has four drilled holes; two for the water passages and two for the magnet leads and rough vacuum. The drift tube body is a brazed assembly except that the final joints after assembling the quadrupole are made with an indium-tin alloy melting at 225°F. This joint is then copper-plated when located in a high electric field area.

Figure 7 shows a cross section of a cavity with a multistem drift tube, tuner and vacuum pump. The access problem mentioned earlier led to the design of externally demountable dummy stems so that access can be provided to any part of a cavity by removing stems without disrupting the alignment. These stems, with an external vacuum seal, are butted against a spherical shoulder to provide alignment flexibility and have a split bushing RF contact joint at the drift tube.

The focusing quadrupoles in the drift tubes will be pulsed because of the low duty cycle and the high gradients required in the low energy part of the linac. The following parameters are typical of the system:

Quadrupole number	1	50	250
Gradient, kG/cm	10.0	2.0	0.5
Pole tip radius, cm	1.1	1.7	2.2
Magnet length, cm	2.5	9	40
NI (ampere-turns)	5000	1600	1000
Power dissipated, W avg	120	15	5

Mode of operation, pulsed sine wave, 2250 μs, 10 pps

The pulsed mode of operation requires the use of a laminated core magnet, and the very tight quarters, limited by the drift tube boundaries, make it difficult to achieve very high gradients. Several designs have been tested[5] and the most promising is a split magnet with a simple pole geometry[6] as shown in Fig. 8. The four double-layer windings are assembled on the split laminated core and then the quadrupole is tightly fitted in a steel ring. The entire quadrupole assembly is then potted in epoxy and mounted in the drift tube in its proper position, its magnetic center and axes coinciding with those of the drift tube.

The vacuum system for the cavities consists of 1000 l/s ion pumps attached directly to the cavities through flexible expansion bellows. A total of 60,000 l/s capacity is required for the 450 ft long accelerator. Roots blowers will rough the tanks down to 10^{-4} mmHg when the ion pump power supplies will be switched on. Development has taken place at Brookhaven on optimizing the start of ion pumps through the use of variable current, variable voltage power supplies which allow the pumps to start with good pumping speeds at pressures of several microns.[7]

The alignment scheme for the linac tanks and drift tubes will make use of conventional optical tooling and cross-hair targets. The primary monuments will be placed at intertank drift spaces offset from the beam line by 3 ft and will retain an unobstructed parallel line of sight at all times to allow optical sighting or wire stretching techniques to be used for operational checks. Bench marks will have been provided on the tanks as necessary. The initial alignment will be done by transferring this line of sight to the tank center line and sighting on targets in drift tubes; obviously this direct method has to be used in any major realignment.

Eight identical radiofrequency systems and controls will be installed in the RF bay to power the eight long cavities. A ninth system consisting of two IPA stages will power the first 10-MeV cavity.[8] A typical system is shown in Fig. 9. Because of their multiplicity, the systems are developed on the concept that each subsystem (e.g. charge control, capacitor bank, modulator, driver, etc.) is modular, self-contained and easily removable through the use of quick-disconnect components so that in case of malfunction any subsystem can be replaced with minimum downtime. Figure 10 shows a typical module, a complete, self-contained modulator; other subsystems are built in similar enclosures. The final power amplifier[9] is the RCA 7835 triode mounted in a coaxial output cavity (Fig. 11). The power transmission lines and components between the 7835 and the accelerating structure are being designed as 12 inch, 50 ohm coaxial lines.

At the present time, all the ideas and design concepts as presented here are being put on drawings for fabrication. Long delivery items like accelerating cavities, drift tubes, various RF components, etc., are scheduled to be ordered within the next few months. It is planned to have a beam in early 1971.

References

1. "Alternating-Gradient Synchrotron Conversion Program, Scope of Phase I," Brookhaven National Laboratory Report BNL 9500, September 1965.
2. J. Huguenin et al., "The New 500 keV Single-Gap Preinjector Tube for the CERN Proton Synchrotron Linac," Proc. 1966 Linear Accelerator Conference, Los Alamos (CFSTI, Springfield, Virginia), p.355.
3. S. Giordano and J.P. Hannwacker, "Measurement on a Multistem Drift Tube Structure," ibid., p. 88.
4. S. Giordano and J.P. Hannwacker, "Studies of Multistem Drift Tube Accelerator Structures," to be published in Proc. 1967 U.S. National Particle Accelerator Conference.
5. A.N. Otis and R. Damm, "Drift Tube Quadrupoles," ibid.
6. G.T. Danby and J.W. Jackson, "Theory, Design and Measurement of the BNL Narrow Quadrupole," ibid.
7. T. Carides and J.G. Cottingham, "Economic Powering of a Large Multiplicity of Sputter-Ion Pumps," ibid.
8. J.F. Sheehan and R.L. Witkover, "The RF System for the AGS 200-MeV Linac," Proc. 1966 Linear Accelerator Conference, Los Alamos (CFSTI, Springfield, Virginia), p. 457.
9. J.T. Keane and A.J. McNerney, "Experimental Results on the RCA 7835, and Initial Operating Parameters of the FTH 515," ibid., p. 183.

TABLE I

Physical Parameters for the 200-MeV Linac

Cavity No.	1	2	3	4	5	6	7	8	9
Energy gain (MeV)	9.5	29.4	26.9	25.2	24.1	22.9	21.6	20.5	19.3
Cavity diameter (cm)	94	90	88	88	84	84	84	84	84
Drift tube diameter (cm)	18	16	16	16	16	16	16	16	16
Bore hole diameter (cm)	2.0 - 2.5	3	3	3	4	4	4	4	4
Cavity length (m)	7.5	18.6	15.8	16.1	15.5	15.5	15.8	15.9	15.7
Average axial field	1.60 - 2.31	1.80 - 2.69	2.57	2.60	2.56	2.58	2.58	2.57	2.56
Peak RF power (MW)	1.5	4.7	4.8	4.8	4.9	4.8	4.8	4.8	4.7

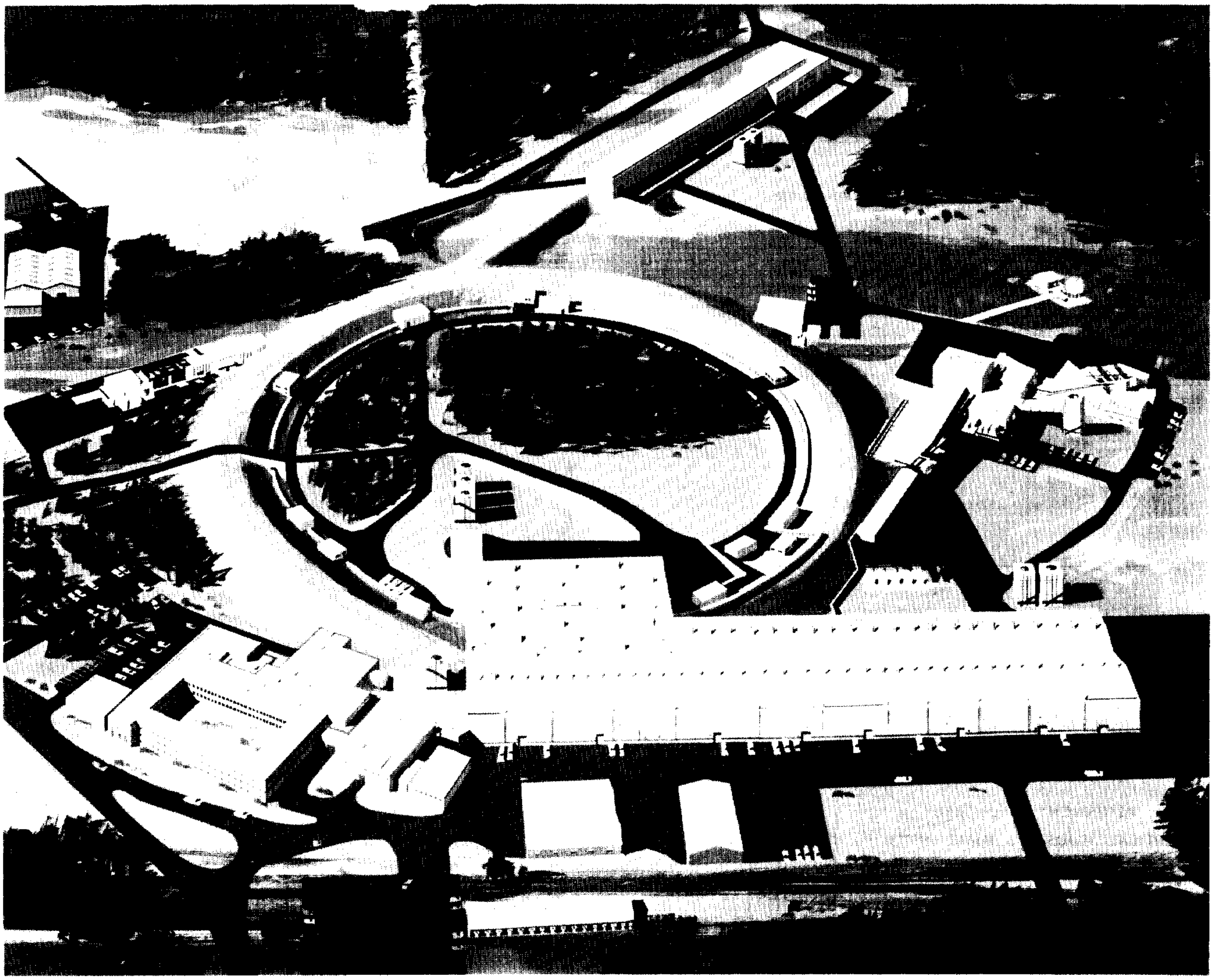

Fig. 1. AGS site plan.

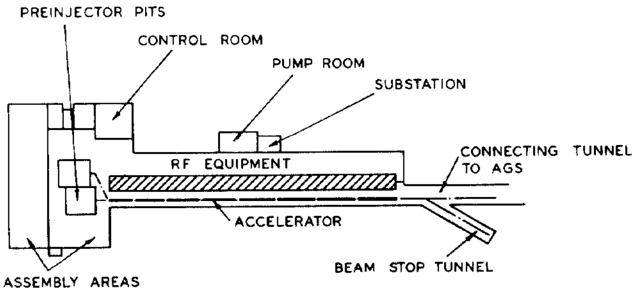

Fig. 2. Linac plan layout.

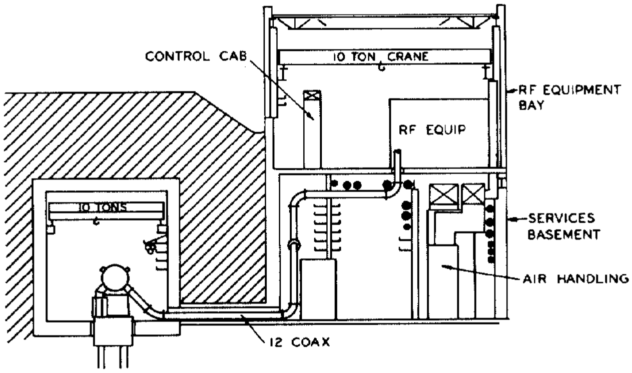

Fig. 3. Linac building cross section.

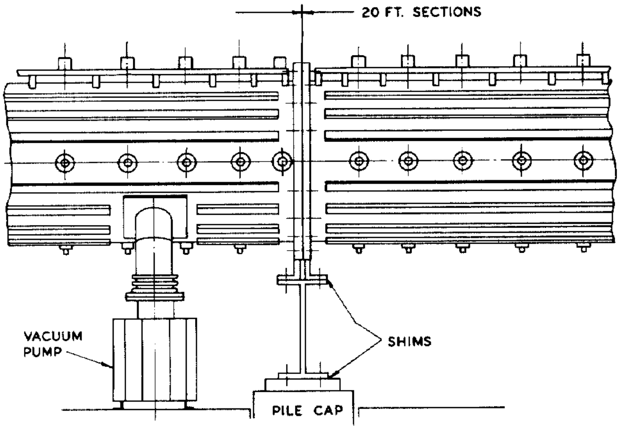

Fig. 4. Accelerator tank support.

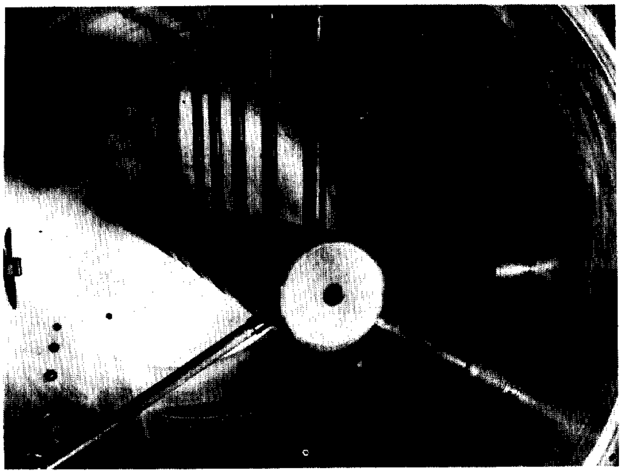

Fig. 5. 200 Mc model of accelerator tank.

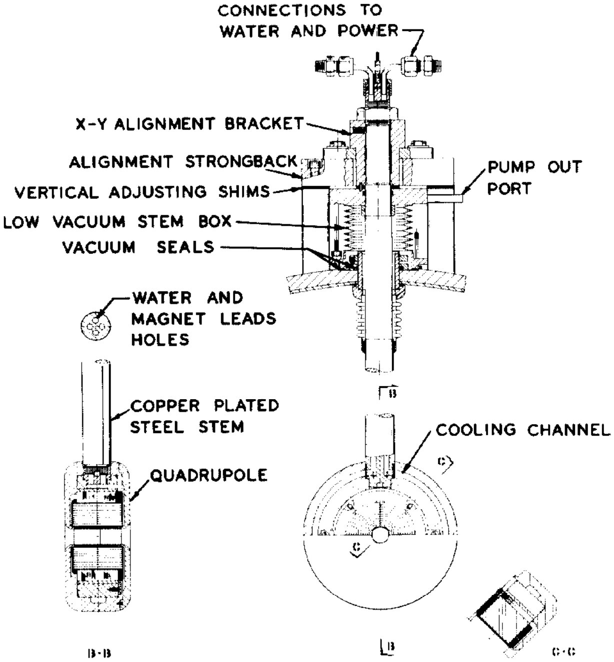

Fig. 6. Single stem drift tube.

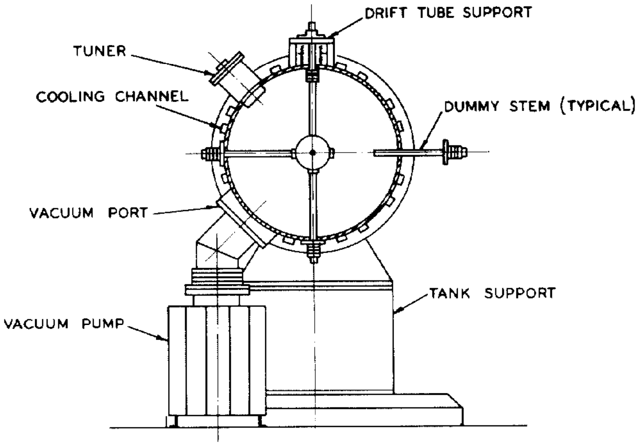

Fig. 7. Tank cross section with multistem drift tube.

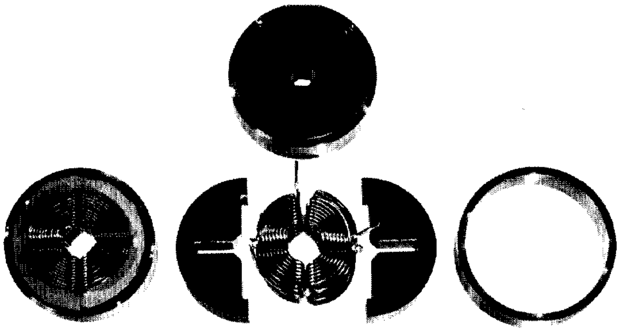

Fig. 8. Drift tube quadrupole.

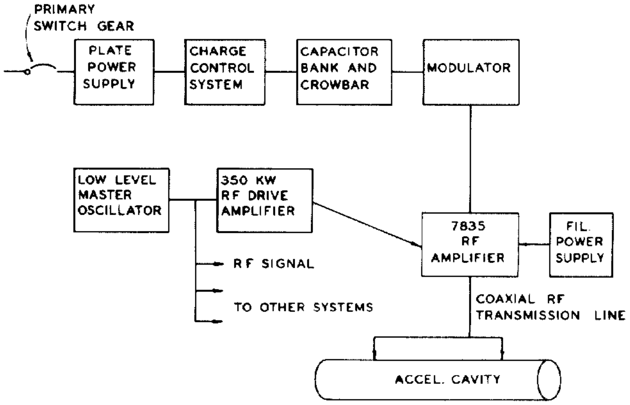

Fig. 9. RF system.

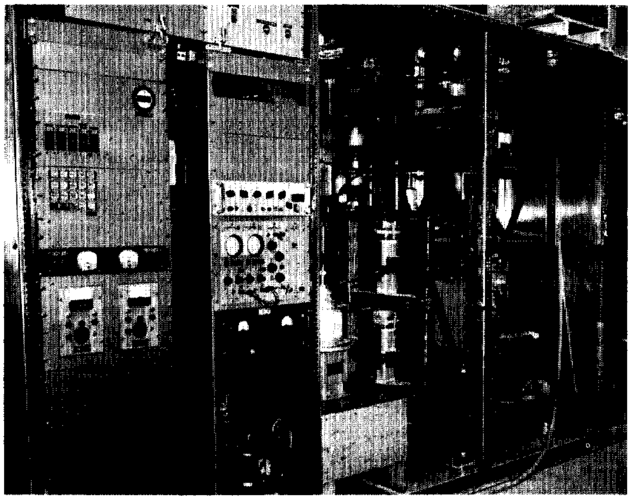

Fig. 10. Modulator cabinet.

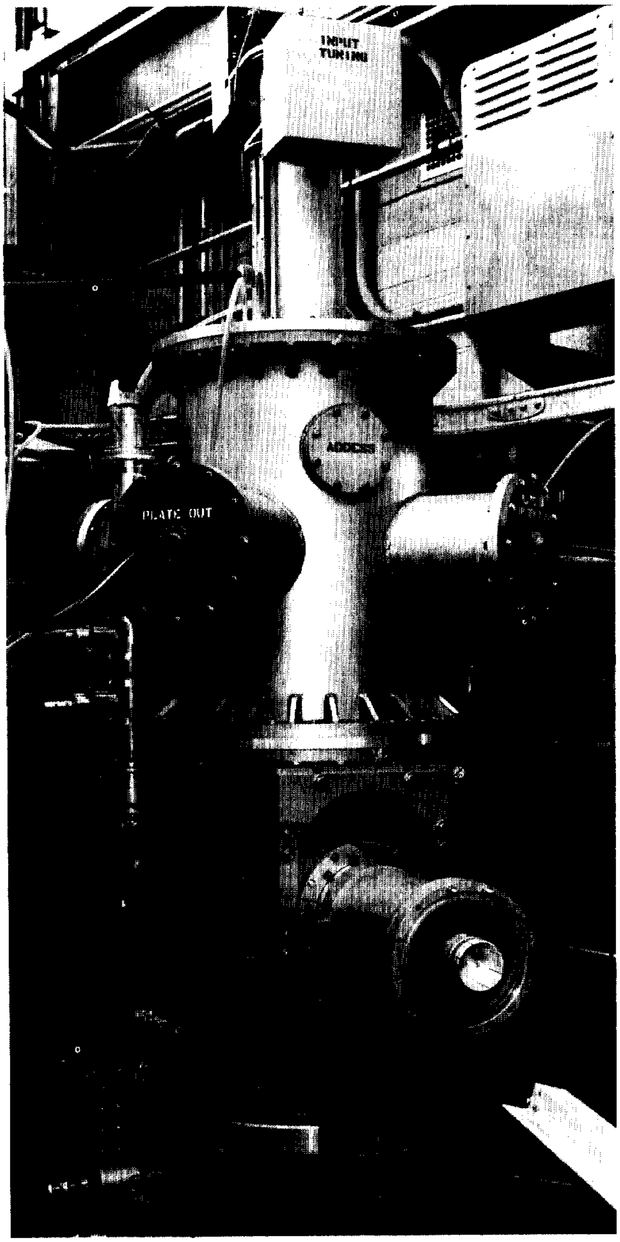

Fig. 11. 7835 cavity.