

CONSTRUCTION PROGRESS AND INITIAL PERFORMANCE
OF THE NAL 200-MeV LINEAR ACCELERATOR

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ABSTRACT

Construction of the first section of the NAL 200-MeV linac was started in May, 1968 as a prototype to test the design and to allow the development of subsystems required in the final linac. Protons were first accelerated in this section in June, 1969. Construction of the final linac systems began in July, 1969. Many of the prototype units were moved to the permanent linac building in January, 1970. The first section (10 MeV) of the final linac operated in April 1970, the first three sections (66 MeV) in August, 1970, and the first six sections (139 MeV) in September, 1970. Initial performance data of these operating sections, problems experienced and design performance for the completed linac are presented.

I. Introduction

The operation of the 10-MeV section of the NAL 200-MeV linear accelerator which was built as a prototype has been described elsewhere.¹ On December 16, 1969, the cavity was moved to its present location in the permanent linac building. New subsystems associated with the 10-MeV section were installed shortly thereafter. These include the Cockcroft-Walton preaccelerator, new ion-source electronics controlled from ground potential by a fiber-optic light-link interface unit to the computer control system, a rebuilt rf system, new cooling systems and many new elements in the control and diagnostic systems. These systems became operational on April 17, 1970, when the first 10-MeV beam was accelerated. Experiments continued on this equipment for about four weeks until it became necessary to move tanks 2 and 3 into position to allow our next scheduled milestone, 66-MeV beam, to be achieved. The 66-MeV goal was achieved on July 30. Operation of the 66-MeV beam terminated on August 21. Protons were accelerated through 6 cavities (Fig. 1) on September 25 to produce a 139-MeV beam. Operation of the complete linac is scheduled for February 1, but it is hoped that a 200-MeV beam can be achieved earlier. Table I lists the significant events in the NAL linac schedule.

The linac construction philosophy at NAL is to achieve operation of systems as soon as possible consistent with good construction practice, but leaving as many options

*Operated by Universities Research Association, Inc. under contract with the U. S. Atomic Energy Commission.

open as possible for further improvements. Performance of systems will be improved with operational experience, being consistent with the requirements of other systems of the total accelerator. Accelerator components are tested with beam as early as possible.

II. Design Features

Basically, the NAL linac is patterned after the BNL linac which is partly the result of a collaborative effort that took place in this country starting in 1964. Table II and Table III list the design specifications and performance parameters respectively.

The linac has a single Cockcroft-Walton preaccelerator. The high-voltage equipment was purchased from the Haefely Company, Switzerland. The accelerating column and ion source are the same equipment used in the 10-MeV prototype.¹ A telemetry system using a light link was developed for controlling and monitoring the signals to the high-voltage electrode and is described in these proceedings.²

The single preaccelerator makes it possible to use a short, 12-foot long, beam-transport system (Fig. 2) to convey proton beams of 300 mA or greater to the linac. Its main features consist of three magnetic quadrupole triplets, two emittance-measuring systems, a single-gap buncher, four current-measuring toroids, two pairs of adjustable collimating slits at the entrance to the linac, and an isolation valve. A beam stop which will be safety interlocked is planned at a later date. The emittance-measuring equipment allows beam emittance measurements to be made on the pre-accelerator beam after the first triplet and at the entrance to the linac as a routine tune-up feature.

The linac tanks and drift tubes are quite different mechanically from the BNL design. The tanks are supported at either end by a two-legged stand fastened to the enclosure floor and at the center of the tank by a single support post. The tanks are made in three sections welded together (Fig. 3). To maintain tolerances so that the sections are close fitting, the ends of the tank sections are held in roundness by a heavy steel ring. Thin copper end plates support the half drift-tube whose centerline establishes the longitudinal axis for drift-tube alignment. The edges of the end plates are tapered to make a press-fit electrical contact to the copper wall of the tank. The steel exposed to the rf fields in other cavity penetrations are covered with copper-ring inserts which are tightly fitted by cooling the insert to liquid nitrogen temperature before insertion. Silver-plated compression contact stock ("D" stock) is used for making electrical contact to moveable tuners and drift-tube support stems. The frequency of the loaded cavity is adjusted to the design value by supporting a

water-cooled half cylinder from the cavity wall by posts of the desired length (Fig. 4). "D" stock is used to terminate the half cylinder electrically at either end. The tank-vacuum end enclosure is made by using a preformed stainless steel bell. Six 1000 1/sec ion pumps are used to achieve the desired vacuum in each of the longer tanks. Further details of the mechanical design are given in two other papers in these proceedings^{3,4} and by J. O'Meara, et al.⁵

The rf structure beyond tank 1 is stabilized using the LASL post couplers.^{6,7} The tanks are driven by a single coaxial drive line. The option of using a double drive line is available should this prove desirable at a later time. The drive loop is matched to the tank by adjusting the loop penetration into the tank; the rf-vacuum window is in the coaxial drive line about one-half wave length from the loop.

The rf systems are described elsewhere in these proceedings.⁸ They were fabricated to the NAL specifications by the Continental Electronics Manufacturing Co. of Dallas, Texas.

The proton beam from the linac which is not used for injection in the booster will be directed into either of two dumps. In the straight-ahead beam line, beam emittance measuring equipment of the non-destructive type will be installed.⁹ A 40° bending magnet will be used to make routine momentum measurements. These measurements will insure the proper linac beam for injection and acceleration in the booster.

The control system is developed around an XDS Sigma-2 computer using an alphanumeric scope, with keyboard, for communicating with the computer and a storage scope for graphic displays. The computer was first used for making rapid measurements of the rf fields in the linac cavities, which was a great help in minimizing the time spent in tuning the post couplers and adjusting the fields. The computer was next used to measure beam emittance allowing a rapid adjustment of the preaccelerator and 750-kV transport system. It is the intention that all components of the accelerator will be controlled and monitored by the control system. This will allow rapid optimization of the accelerator parameters so as to achieve the desirable beam properties and to monitor the status of components continually. The great capability of this system is rapidly being felt as new functions are brought into operation. As control loops are closed, accelerator operation should become stabilized and the tasks of the operator minimized. The details of the control system are described elsewhere in these proceedings.^{10,11}

III. Operation

Operation of the components is more generally described in other papers in

these proceedings. The experience to date with the use of the post couplers has been very satisfactory although they have not been tested under heavy beam-loaded conditions. They are mechanically simple and can be tuned easily. The time required to adjust them after the drift tubes have been aligned and the cavity frequency adjusted is the order of three or four hours. The cavity fields have been adjusted in most cases so that the deviation of the average field in each cell has been less than $\pm 1\%$ from the average cavity field. This adjustment is made by rotating the tabs at the end of the couplers.

The Q of the cavities loaded with drift tubes, post couplers and tuners have in almost all cases been within 90% of the theoretical values. The theoretical value is obtained from the MESSYMESH calculated values for the power losses; the power losses on the surfaces which do not have azimuthal symmetry are calculated from the MESSYMESH fields at their location.

The operation of the 10-MeV section which was built as a prototype has been described previously.¹ In summary, the record current achieved at 10-MeV was 160 mA (with 222 mA from the preaccelerator and with the buncher in operation). The emittance measured for 150 mA of beam was 16.5 mrad-cm in x and 21 mrad-cm in y for 90% of the beam. Total momentum spread measurements amounted to approximately 1.0% (90% of the beam) independent of beam current. The operating time on the permanently installed 10-MeV section was short and during this time, a beam current of 100 mA was the largest beam current accelerated which was done without the use of the buncher.

At 66 MeV, only mean energy measurements were made, which roughly confirmed the energy. The maximum beam current accelerated at this energy was 45 mA.

At 139 MeV (6 cavities) the beam was transported into the 200-MeV beam diagnostic area where the energy was confirmed with a momentum-analyzing magnet. The beam current was the order of a few milliamps. Because of the distance to the beam dump and the necessity of keeping the area free of radiation to allow other installation work to proceed, the beam intensity was intentionally reduced.

The operation of the linac at these energies is described in more detail in a paper by C. D. Curtis, et al., in these proceedings.¹²

ACKNOWLEDGMENTS

In addition to the entire staff at NAL who have labored tirelessly to achieve our goals, we are indeed deeply grateful to those linac groups at the other National Laboratories who have participated in the cooperative effort of bringing into existence the NAL linac. In particular, we thank ANL for the use of their high-voltage equipment, shops and computing facilities; BNL for our basic design and the help extended

in initiating our effort including the fabrication of the 10-MeV quadrupoles and the loan of a power-amplifier filament power supply (and many other benefits accruing from running close behind their fabrication and procurements); LASL, for post-coupler data, the PARMILA dynamics program, control-system hardware and philosophy, and the use of their stockroom; and LRL for the use of the MTA copper-clad steel from which tank 1 is fabricated. We have benefited greatly from the linac activity at other laboratories; we regret that there are signs of this golden era coming to an end.

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Table I. Chronology of Linac Events.

June 15, 1967	Start of NAL and the design of the 200-MeV linac.
April, 1968	Linac-personnel move to experimental building at NAL village.
May 1, 1968	Start construction of 10-MeV prototype.
December 1, 1968	Groundbreaking for linac building.
January 20, 1969	First proton beam at NAL, (from ion source). Energy 60 keV Intensity 300 mA
April 17, 1969	Proton beam from accelerating column. Energy 750 keV Intensity 60 mA
April 24, 1969	Beam-emittance measurement using computer control.
June 26, 1969	10-MeV beam from prototype.
July, 1969	Start construction of 200-MeV linac.
August 14, 1969	10-MeV intensity increased to 30 mA.
December 11, 1969	10-MeV intensity increased to 160 mA.
December 16, 1969	10-MeV cavity moved to permanent building.
April 17, 1970	First 10-MeV beam in permanent building.
May 15, 1970	Termination of 10-MeV beam studies. (100 mA w/o buncher)
July 30, 1970	66-MeV beam.
September 25, 1970	139-MeV beam.

Table II. 200-MeV Linear Accelerator Specifications.

	1	2	3	4	5	6	7	8	9
Cavity number									
Proton energy in (MeV)	0.75	10.42	37.54	66.2	92.6	116.5	139.0	160.5	181.0
Proton energy out (MeV)	10.42	37.54	66.18	92.60	116.5	139.0	160.5	181.0	200.3
Cavity length (m)	7.44	19.02	16.53	16.68	15.58	15.54	15.83	15.88	15.73
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	3.0	3.0	3.0	4.0	4.0	4.0	4.0	4.0
	2.5								
Cell length L (first cell) (cm)	6.04	22.2	41.1	53.3	61.8	68.2	73.3	77.6	81.3
(last cell) (cm)	21.8	40.8	53.0	61.5	67.9	73.1	77.4	81.1	84.3
Gap length G (first cell) (cm)	1.30	4.4	12.2	19.5	22.6	27.1	30.9	34.3	37.3
(last cell) (cm)	6.70	12.7	19.3	25.1	26.9	30.8	34.2	37.1	39.7
G/L (first cell)	0.21	0.20	0.30	0.37	0.37	0.40	0.42	0.44	0.46
(last cell)	0.31	0.31	0.36	0.41	0.40	0.42	0.44	0.46	0.47
Axial transit-time factor (first cell)	0.64	0.86	0.82	0.75	0.73	0.68	0.64	0.61	0.58
(last cell)	0.81	0.81	0.75	0.69	0.69	0.65	0.61	0.58	0.55
Effective shunt impedance (first cell) (MΩ/m)	27.0	53.5	44.6	35.0	29.6	24.8	21.5	18.9	16.7
(last cell) (MΩ/m)	47.97	44.8	35.2	28.5	25.0	21.7	19.0	16.8	14.9
Drift space following cavity (m)	0.22	0.6	0.75	1.0	1.0	1.0	1.0	1.0	--
Number of full drift tubes	55	59	34	28	23	21	20	19	18
Average axial field (MV/m)	1.60	2.0	2.60	2.60	2.56	2.56	2.56	2.56	2.56
Average gap field (first cell) (MV/m)	2.31	10.0	8.7	7.03	6.9	6.4	6.1	5.8	5.6
(last cell) (MV/m)	7.45	6.45	7.2	6.3	6.4	6.1	5.8	5.6	5.4
Peak surface field (first cell) (MV/m)	8.9	12.6	13.1	12.9	14.0	14.1	14.2	14.3	14.5
(last cell) (MV/m)	10.2	9.7	12.9	13.2	14.1	14.2	14.3	14.5	14.8
Cavity excitation power (MW)	0.61	1.38	2.245	2.48	2.49	2.33	2.65*	2.70*	2.75*
Total power per cavity for 100 mA (MW)	1.58	4.09	5.11	5.12	4.88	4.58	4.81	4.75	4.68
Total accumulated length									144.8 m
Total number of unit cells									286.0
Total number of full drift tubes									277.0
Total cavity excitation power									19.6 MW
Total linac rf power for 100 mA									39.6 MW

*Estimated

Table III. 200-MeV Linear Accelerator Design Performance Parameters.

Output energy	200.30 MeV
Output momentum spread, total for 90% of beam	2.7×10^{-3}
Peak beam current	100 mA
Emittance at 200 MeV (each transverse mode)	1.5 - 3.0 mrad-cm
Beam pulse length	100 μ sec
Pulse repetition rate	15 pps
Cavity resonant frequency	201.25 MHz
RF pulse length, variable to	400 μ sec
RF duty factor, maximum	.006
Synchronous phase angle, from rf peak	-32°

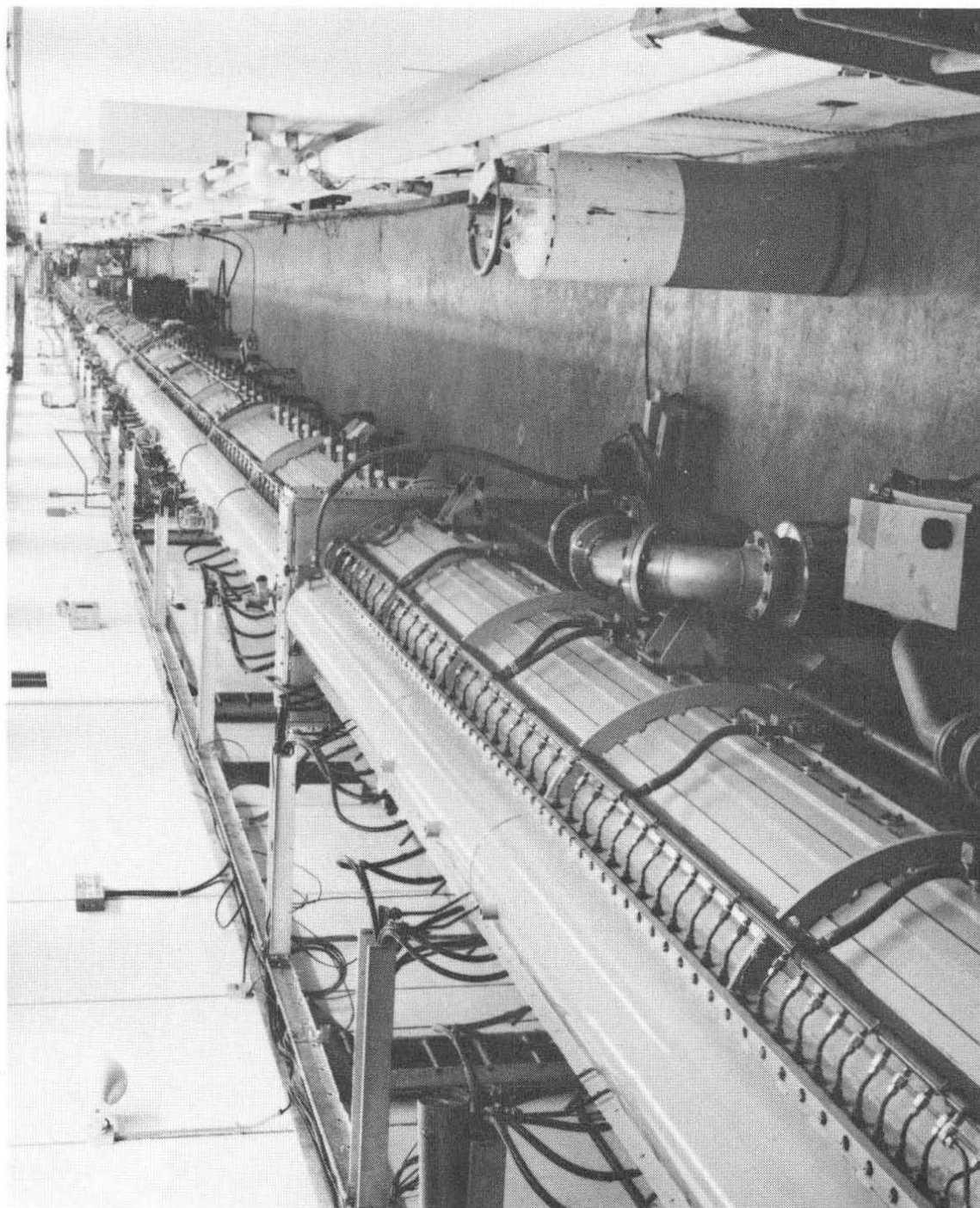


Fig. 1. Downstream view of the first six linac cavities as they appeared on September 25, 1970. The first 10-MeV cavity is shown in the foreground.

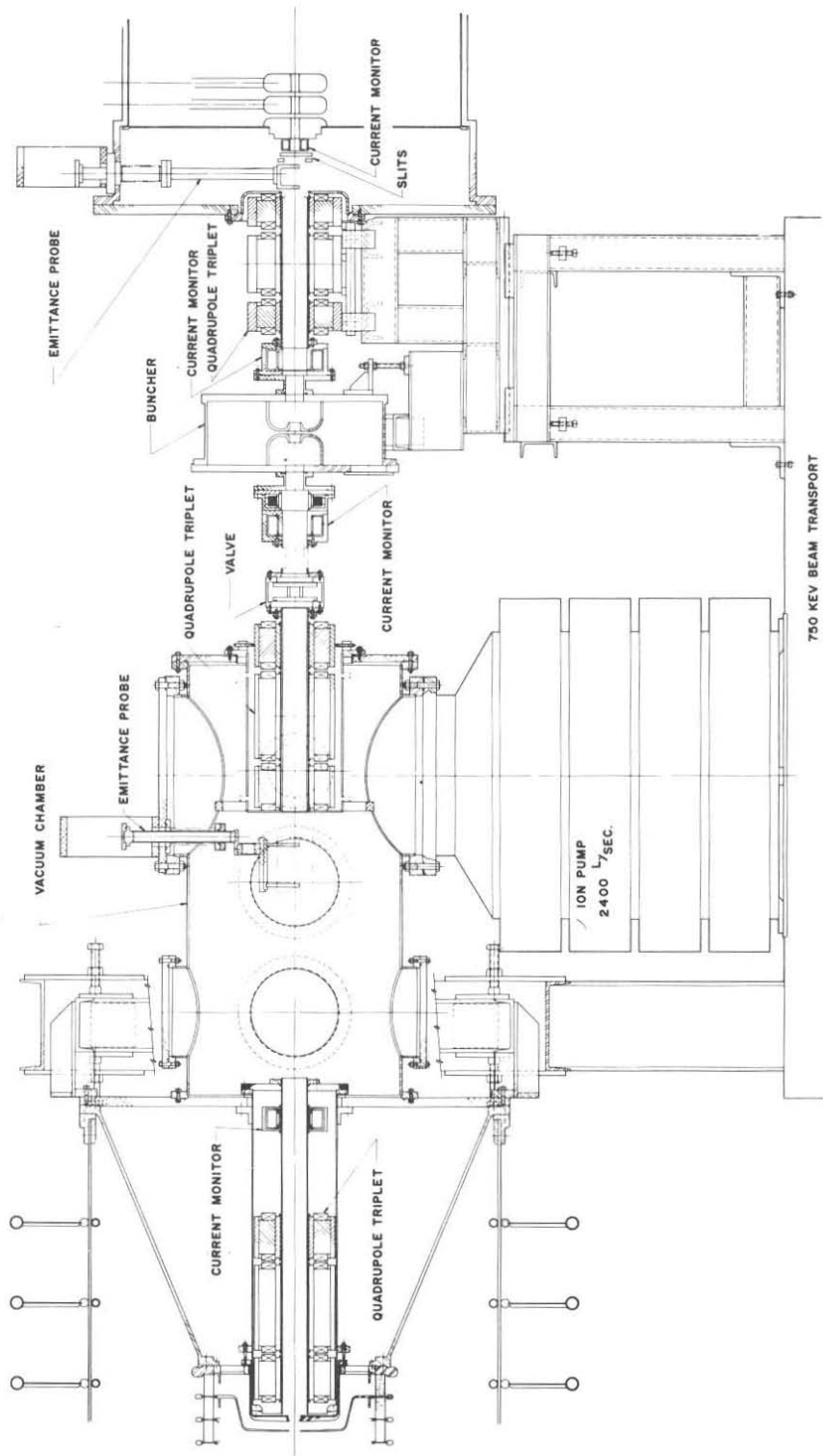


Fig. 2. The 750-keV beam transport line.



Fig. 3. Linac tank 2 being transported from the laboratory at the NAL village to the permanent buildings. The three separate sections have been welded together to form the 62-foot tank.

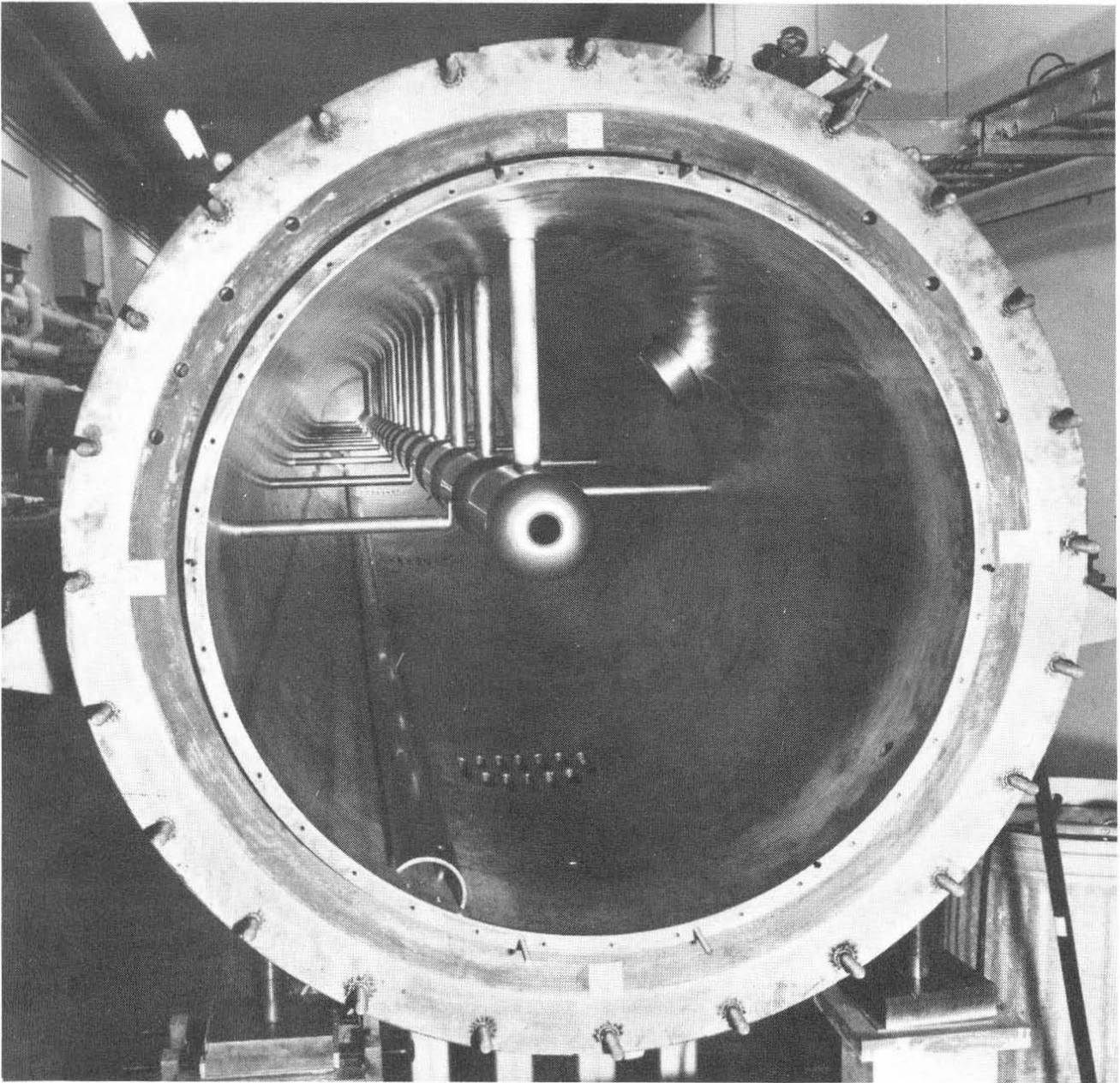


Fig. 4. High-energy end view of tank 9 showing the drift tubes, a moveable tuner, the post couplers and the bulk tuner. The bulk tuner is on temporary supports while the proper cavity frequency is being adjusted. The end termination on the bulk tuner is not shown.