STATUS OF RF SUPERCONDUCTIVITY AT ARGONNE NATIONAL LABORATORY

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INTRODUCTION

Work on rf superconductivity at Argonne National Laboratory has, for the past twelve years, focussed on the development of superconducting structures for acceleration of heavy-ions. This work has resulted in the development of several niobium split-ring resonators for the acceleration of particles of velocity .04 < v/c < .2c, construction and operation since 1979 of a superconducting "booster" linac based on these resonators, and currently, the expansion of the booster into the Argonne tandem-linac accelerating system (ATLAS) - a national facility for nuclear structure research [1,2].

In what follows, we first give a brief description of the resonators developed for the Argonne superconducting heavy-ion linac [3,4]. This is followed by a description of the accelerator facility and its operational characteristics. Finally, current resonator development is discussed, together with implications for future upgrading of the ATLAS facility.

Current development includes work on superconducting resonators for very slow (.006 < v/c < .04) particles. Successful development of such resonators would enable replacement of the present electrostatic injector of ATLAS with an electron-cyclotron-resonance positive-ion source and a section of low-velocity linac [5]. Such an upgrading would substantially increase both the mass range and beam current of the ATLAS facility.

NIOBIUM SPLIT-RING RESONATORS

Early work at Argonne culminated with the operation, in 1975, of $\lambda/2$ helically-loaded resonators at accelerating gradients above 4 MV/m [6].

However, because of the difficulty of controlling the rf eigenfrequency of helix resonators, it was decided to attempt construction of the more mechanically stable split-ring design with niobium [6]. The development of this class of resonators is documented in detail elsewhere [2,3,4]; however, several features are worth recapitulating.

A demountable niobium superconducting rf joint was developed to permit access to the resonator interior, both to facilitate electro-chemical processing and also to permit diagnosis and treatment or defects of the superconducting surface [2].

An explosively-bonded copper-niobium composite material was developed to provide a conduction-cooled, mechanically stable outer housing for the resonator. Conduction cooling removed the necessity of immersing the outer wall in liquid helium and greatly simplified the cryostat design [2,3].

A PIN diode fast-tuning system was developed to overcome the effects of ambient vibration on the resonator eigenfrequency and control the rf phase of the resonators. The PIN diode tuning system operated at 77K, and is mounted within the cold region of the cryostat, and avoids the necessity of running several kilowatts of rf power from room temperature to 4.2K [2].

Figure 1 shows the three types of split-ring resonators so far developed at Argonne and produced in quantity for the heavy-ion linac. Table I shows the principal electrodynamic parameters of these resonators.

TABLE I. Properties of several Argonne split-ring resonator geometries.

Type	Optimum Velocity	Frequency	Peak Surface Fields electric*	magnetic*	rf energy*	length
L	0.066c	97.0MHz	4.8 units	129 G	0.073 J	20.3cm
H	0.106	97.0	4.8	182	0.147	35.6
V	0.155	145.5	4.8	240	0.120	35.6
S	0.155	145.5	3.9	140	0.159	35.6

* - referenced to an accelerating field level Ea = 1 MV/m.

As fabricated, some of these resonators have been limited in performance by thermal-magnetic instability caused by localized defects of the superconducting surface. A second-sound time-of-flight diagnostic technique was developed to locate such defects, which can usually be removed easily, once located [2]. Most defects have been found to be associated with welds; there are more than 50 electron-beam welds in each resonator.

Figure 2 shows the performance obtained with several of the low-beta resonators. While the performance shown is exceptional, virtually all of the resonators built have operated at surface electric fields in excess of 15 MV/m in off line tests, with most units operating at substantially higher fields.

The accelerating field levels obtained in the more than 50 resonators so far produced have averaged as follows:

3.7 MV/m for the S and V types (β_o = .16)

4.0 MV/m for the H type (β_o = .1)

4.5 MV/m for the L type (β_o = .06).

No intrinsic degradation of resonator performance has been observed after tens of thousands of hours of operation at high fields. Another paper in these Proceedings discusses the long-term performance so far obtained in detail [7].

THE ARGONNE SUPERCONDUCTING HEAVY-ION ACCELERATOR

The linac is formed by an array of independently-phased resonators. Since each resonator can accelerate a large range of particle velocities, the over-all velocity profile can be tailored to suit a variety of different beams.

The flexibility of the velocity profile can also be used to accomodate various linac configurations; to exploit this flexibility, the linac is formed of several cryostat modules, each typically holding six superconducting resonators and three superconducting solenoids. The cryostat modules can be operated independently of one another; thus a section can be removed for maintenance while the machine continues operation. The 70 KG, 1 inch bore solenoids provide transverse focussing, and are operated in the persistant mode [8].

First operation with beam was in 1978, with six H-type, β_o = .1 resonators on line. Since this time, the linac has been continuously evolving. Figure 3 shows the floor plan of the accelerator system. We distinguish several sections.

The booster linac was the first phase of construction, and consists of 11 L-type, β_o = .06 and 13 H-type, β_o = .1 niobium split ring resonators distributed into four cryostat modules. The booster is injected by a 9 MV tandem electrostatic accelerator and provides more than 20 MV of additional accelerating potential for beams delivered into target area II.

This portion of the accelerating system has been operational since 1979 and has, to date, accumulated more than 16,000 hours of operation with beam [9]. Operation has been characterized from an early stage by flexibility and high reliability. An outstanding characteristic of the accelerator is the ease with which beam energy can be changed.

The resonators are cooled by forced flow of liquid helium at 4.7K obtained from a CTI 1400 refrigerator which can provide 95 watts of refrigeration. A CTI 2800 refrigerator provides an additional 300 watts of cooling. The refrigeration system has been operated virtually continually since early 1979 and has proven very reliable [10].

The ATLAS linac addition and target area III are nearly complete and will become operational in 1985. The linac addition consists of 9 H-type, β_o = .1 and 9 V and S-type, β_o = .16 split-ring resonators and will add approximately 20 MV of accelerating potential for beams going into area III.

The shaded portion of Figure 3 shows a tentative layout for a low-velocity superconducting linac which would replace the tandem as the injector. The proposed machine would consist of an ECR positive ion source on a 350 KV voltage platform going into a superconducting linac matched to an input velocity of 0.008c [5].

CURRENT RESONATOR DEVELOPMENT

Split-ring Resonators

For the ATLAS accelerator, a split-ring resonator useful for particle velocities up to .25c was developed. This was accomplished primarily by increasing the frequency of operation of the existing H-type resonator. At the same time, in the initial version of this resonator, the drift-tubes were redesigned to substantially decrease the surface electric field. This was done in hope of obtaining higher accelerating gradients. In order to accomodate the larger drift-tubes, an elliptically-sectioned loading arm was required.

However, after building and testing three such resonators, we found that electron-loading was not reduced with respect to the H-type, but in fact was slightly worsened. Thus a simpler version (V-type) of this resonator was made by simply shortening the inductive loading arms of the H-type design until the desired frequency was obtained. The surface electric field was unchanged by this procedure, and the surface magnetic field increased by about 30%. However, since we are very far from the rf magnetic field limits of superconducting niobium, the increase in this parameter had no appreciable effect on performance. Performance of the V-class resonator, shown in Figure 4 curve V, is significantly better than for the S-class, even though the surface electric field is substantially higher. Also, the construction costs are lower, so that the V-class are being used to complete the ATLAS linac.

Coaxial-line Resonators

Figure 5 shows the several components of a $\lambda/4$ coaxial-line resonator before final welding. Design and construction of this resonator was stimulated by the work of Ben-Zvi and Brennan at SUNY at Stony Brook with a coaxial-line resonator[12]. The resonator shown extends the Stony Brook results in two respects: firstly, the superconducting material used is niobium, rather than lead electroplated onto copper, yielding a resonator of substantially higher performance; secondly, the optimum particle velocity has been increased from $\beta_o = v/c = 0.08$ to $\beta_o = 0.14$. This is a non-trivial extension, as a proportionally larger resonator is required, which must support larger rf voltages.

The resonator has an outer conductor made of niobium bonded to copper and formed into a 8 inch ID cylinder. The center conductor is 13 inches long and tapers from a diameter of 2.5 inches at the base to 1.25 inches where it joins a 4 inch OD drift tube with a 1.25 inch beam aperture. The resonant frequency is 140 MHz.

Figure 4 curve B shows the performance obtained at 4.2K. The maximum field level obtained was 4.7 MV/m with 2.8 watts of rf input. A thermal-magnetic instability caused by a defect on the outer housing limits cw operation at this level.

The mechanical stability of the resonator is excellent, the static rf eigenfrequency shift being 5 Hz at $E_a = 1$ MV/m.

Very-low Velocity Accelerating Structures

A primary reason for developing coaxial-line resonators at ANL is that the excellent mechanical stability opens the possibility of going to very low particle velocities.

Figure 6 shows a conceptual design for a very low velocity structure. There are 4 accelerating gaps formed by three drift tubes, two of the drift tubes being driven by a coaxial, quarter-wave line. With an active length along the beam axis (9aps plus drift tubes) of 10 cm, and a resonant frequency of 48.5 MHz, the structure shown would accelerate particles in the velocity range $.007 < v/c < .010$. The length of the quarter-wave, coaxial line would be approximately one meter.

Initial design work indicates that a superconducting resonator with the above characteristics can be made with acceptably low surface fields and adequate mechanical stability.

CONCLUSIONS

The use of superconducting niobium rf resonators for the acceleration of heavy-ions is an established technology. The velocity range presently covered is from .04c to .25c. The design and fabrication of the several inductively-loaded, drift tube type accelerating structures required to cover this range has so far proven straightforward.

For the near future, development work at ANL will focus on extending the velocity range down to at least .007c.

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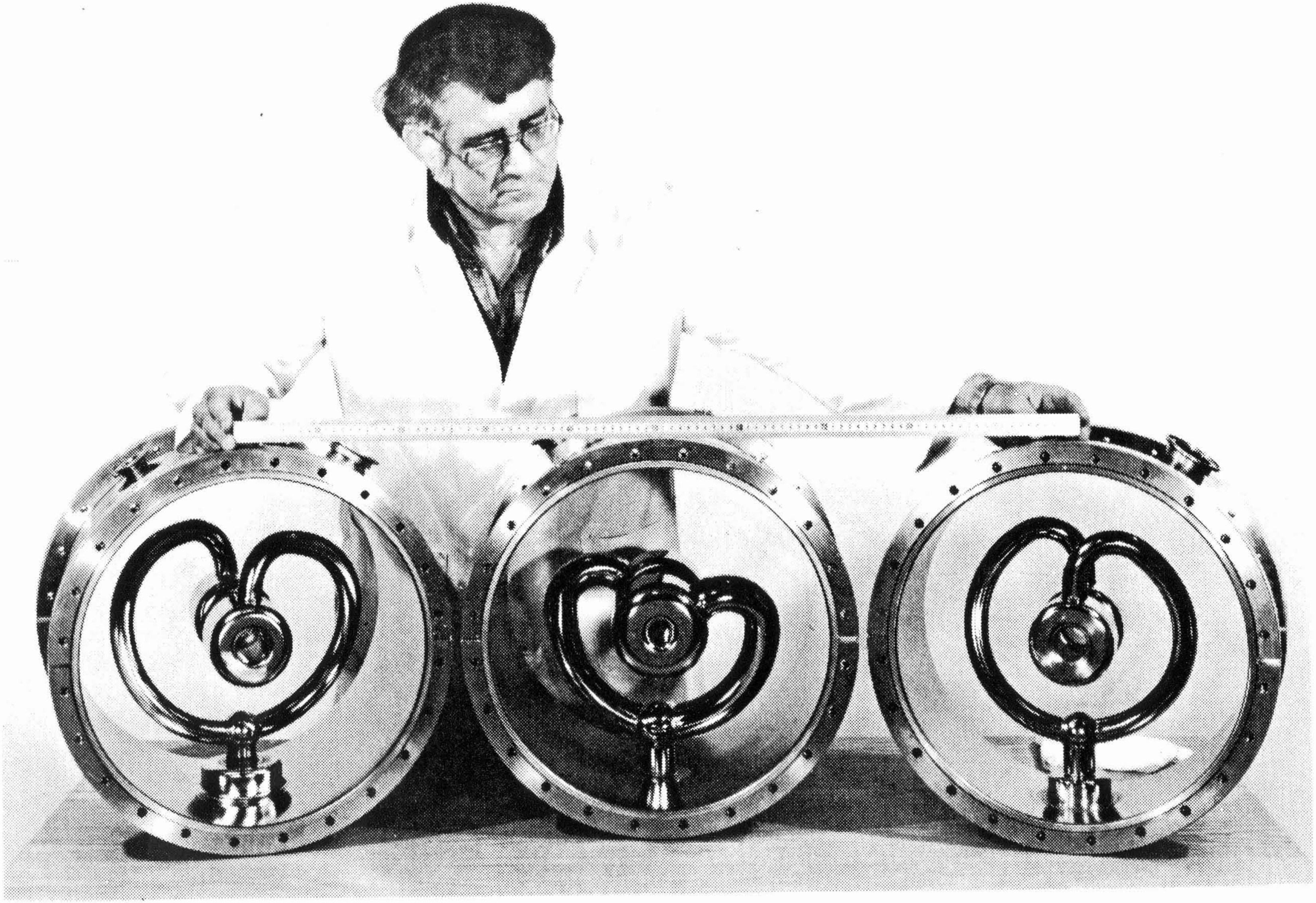

Figure 1. Three split-ring resonators used for the ATLAS accelerating system. From left to right are the H-type (97 MHz, β_o = .1); S-type (145.5 MHz, β_o = .16); and L-type (97 MHz, β_o = .06).

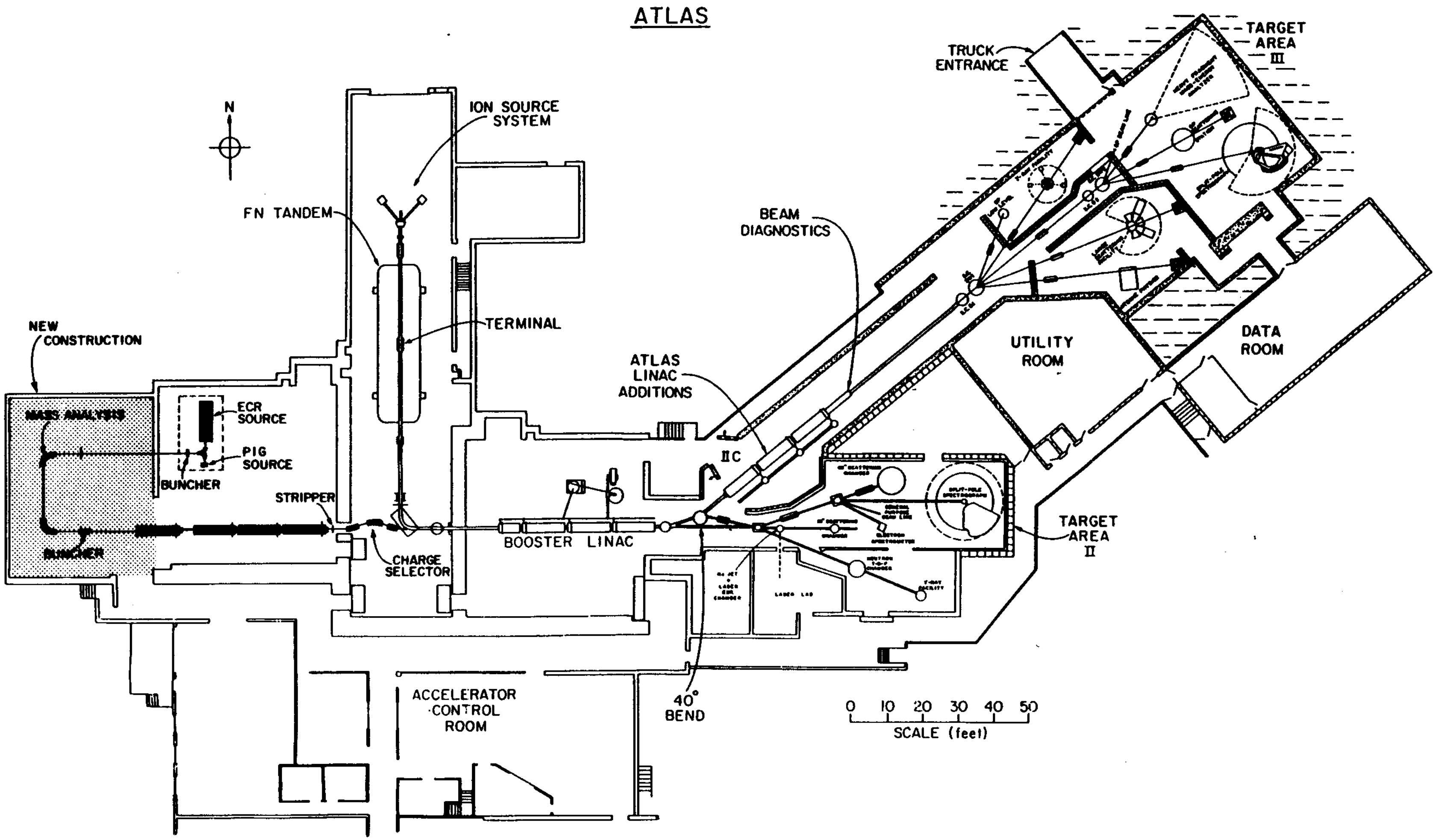

Figure 3. Floor plan of the ATLAS accelerator system. The shaded portion at the left is a proposed building addition for a contemplated low-velocity linac injected by an ECR positive ion source. Construction of the ATLAS facility, including target area III, is nearly complete.

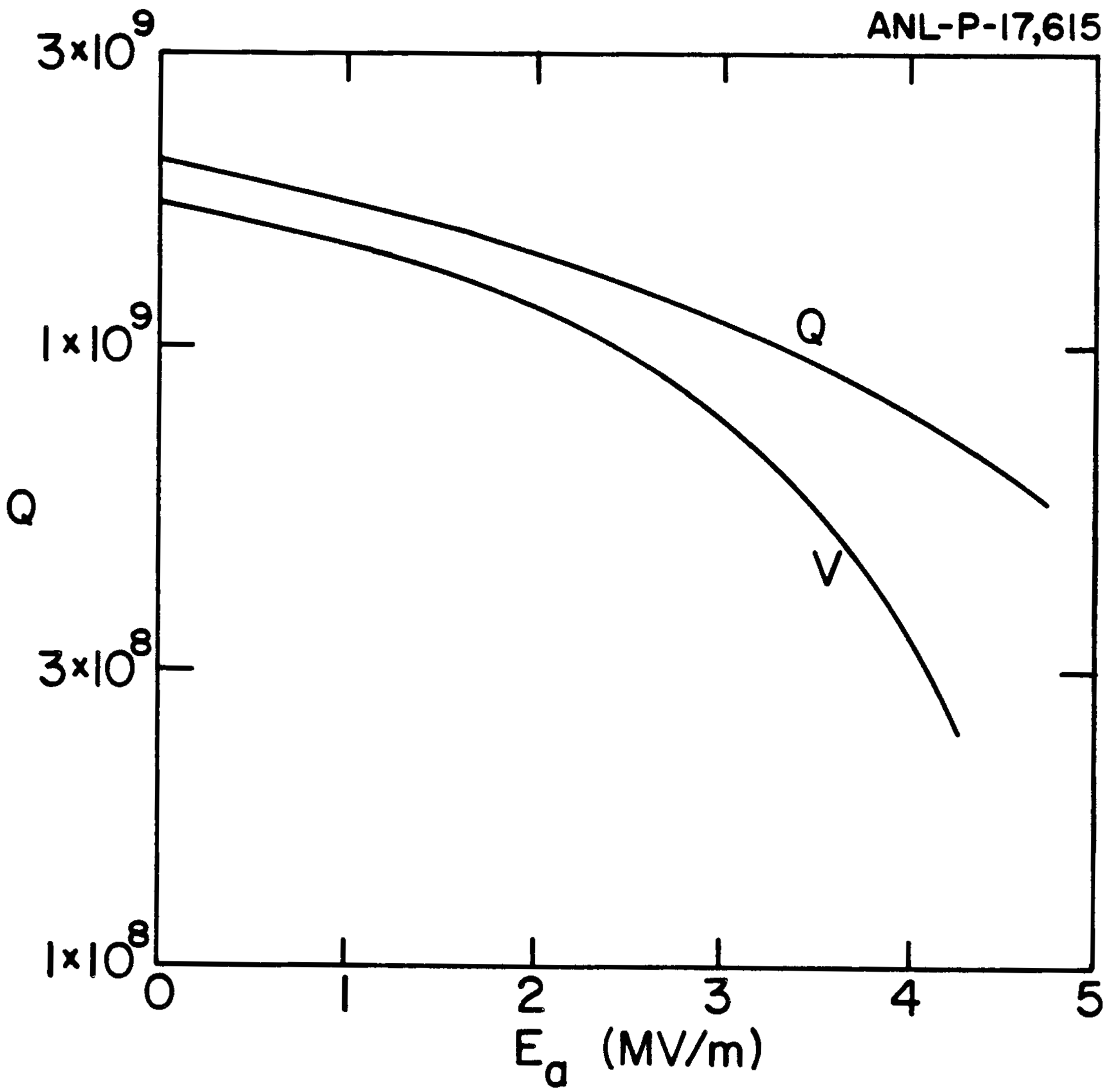

Figure 4. Resonator Q vs. accelerating field level Ea, measured at 4.2K. Curve V is for the V-type split ring resonator with an interior length of 35.6 cm. Curve Q is for a coaxial quarter wave line resonator with a 20.3 cm interior length.

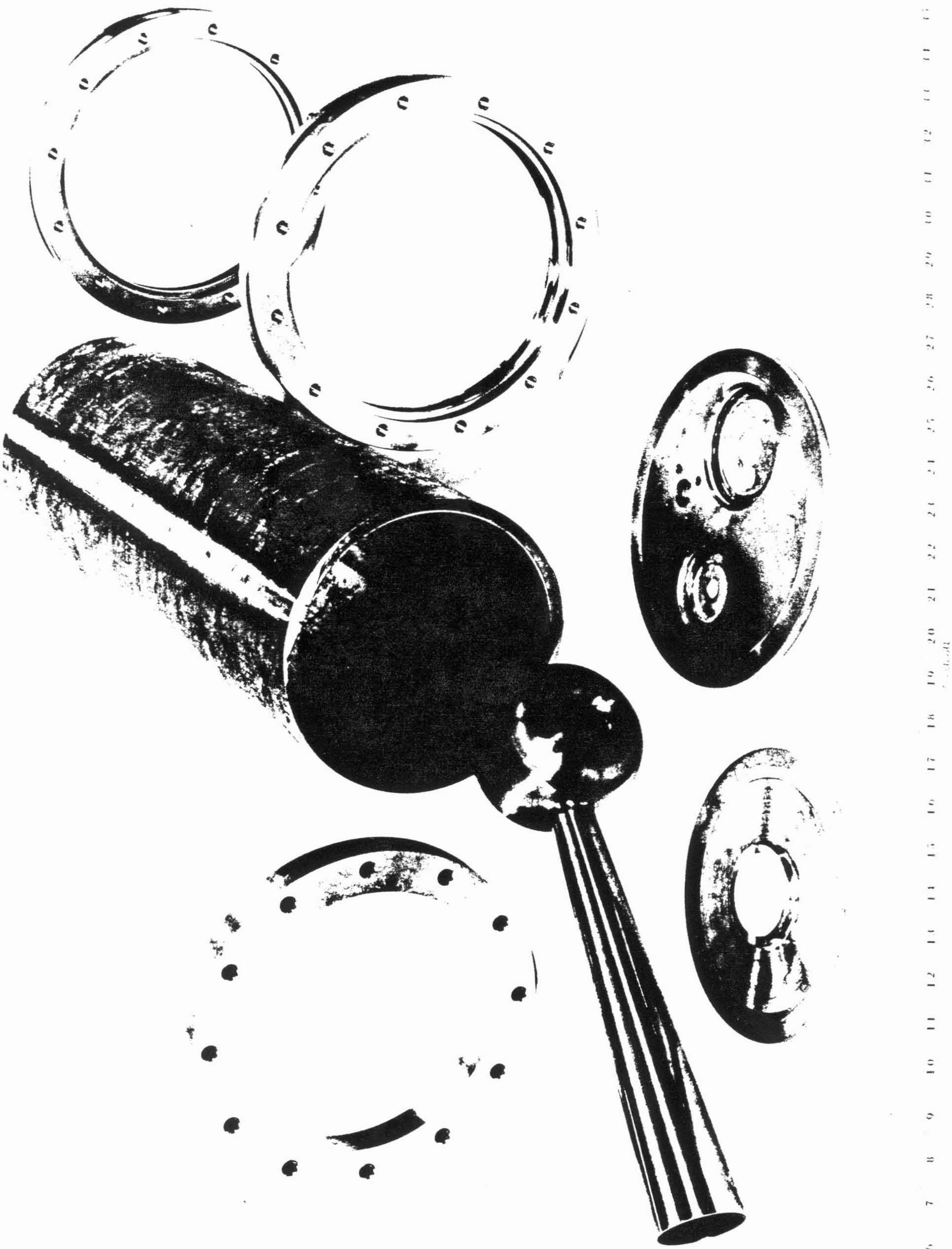

Figure 5. Components of a coaxial-line resonator before final assembly. The scale shown is in inches.

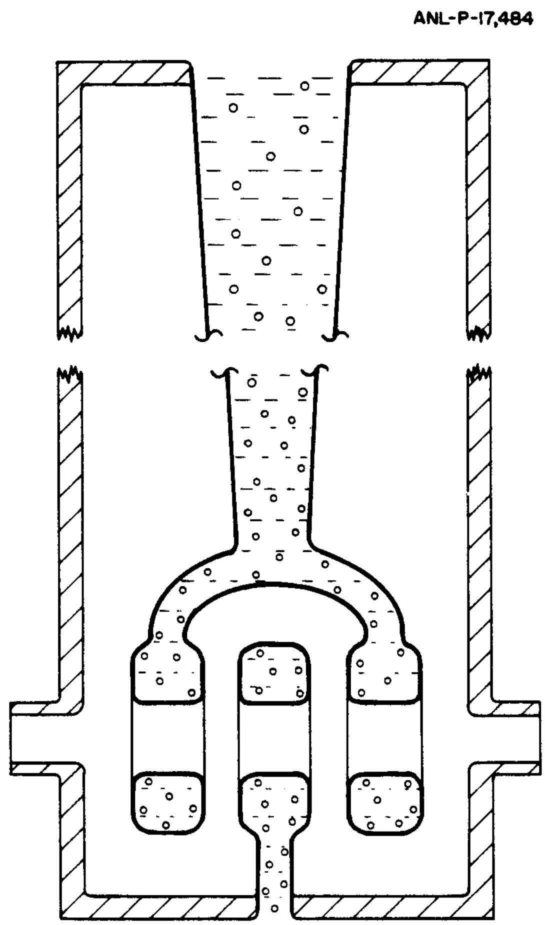

Figure 6. Cross-section of a conceptual design for a very low velocity superconducting resonator. The two high-voltage drift tubes are driven by a tapered coaxial line.