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Electrostatic Accelerator Development at Wisconsin

R. G. HERB
Department of Physics, University of Wisconsin, Madison

1. Introduction

My decision to go into nuclear physics came when I was an undergraduate at the University of Wisconsin. J. H. Van Vleck was then holding a professorship in theoretical physics at Wisconsin and C. E. Mendenhall had an extensive experimental program underway on measurement of photoelectric work functions of metals. R. H. Fowler of the Cavendish Laboratory had done theoretical work predicting temperature effects on photoelectric yield curves near the threshold. He came for a visit in 1930, as I recall, to discuss his photoelectric work and incidentally to give a talk on nuclear physics work at the Cavendish Laboratory.

I was astonished to hear for the first time about results clearly leading to a complete new world of physics.

The possibility of an opportunity to work in nuclear physics looked very remote. There was none at Wisconsin and practically none in the United States. Physicists then were not so numerous but money and jobs in the early 1930's were even scarcer than physicists.

When I was a first year graduate student at Wisconsin, G. G. Havens, who was holding a postdoctorate appointment, became interested in Van de Graaffs development'. He obtained support to build a small vacuum insulated device utilizing belt charging. I joined Glen Havens in this development.

2. Vacuum Insulated Electrostatic Generator

The steel vacuum tank was 3 feet in diameter and 6 feet long. It was sealed with rubber gaskets and could be pumped down to about 2×10^{-6} torr by a mercury diffusion pump. From one end a textolite (paper bonded with shellac) tube extended inward about 18 inches to support a copper sphere about 16 inches in diameter. Sphere and tube were sealed so that atmospheric air inside gave no detectable leak to the exterior vacuum region.

To carry charge, a silk ribbon belt passed over an exterior driven pulley, through the insulating tube, and over a pulley mounted inside the sphere. We improvised a number of voltage measuring devices of rather marginal dependability.

Two hundred kilovolts came with reassuring ease. We could work up to *250* KV and we reached at times a maximum of about 300 KV.

Here we were stopped, with no understanding of the discharges we observed, and with little freedom of action for significant changes of the vacuum chamber walls.

In 1933, Glen Havens left to take a position with the U. S. Rubber Company. I stayed on and decided to convert to insulation by high pressure gas which had shown promise in an experiment by Barton, Mueller and Van Atta[2]. Soon after this project was started, D. B. Parkinson and D. W. Kerst joined in this work.

3. First Accelerator Insulated by High Pressure Gas

For a total expenditure of about $100.00 we built the accelerator[3] shown in Figure 1. Voltage came easily up to about 500 KV and the machine

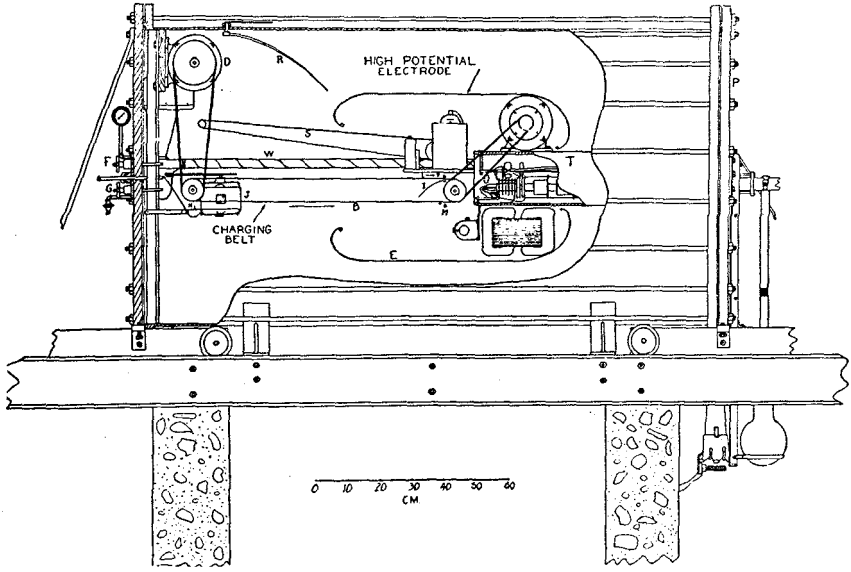

Fig. 1 - First Electrostatic Accelerator Insulated by High Pressure Gas.

immediately showeú qualities of dependability, steadiness, and ease of adjustement that later characterized those generators. When I accidentally discovered the beneficial effects of adding C Cl_4 vapor to air we were able to reach a maximum of 1 million volts. About one tenth of our work was probably expended on successfully achieving high voltage. The difficult and time-consuming problems proveú to be in proceeding to a complete accelerator, with accelerating tube, ion source, beam handling and target.

Tubes to withstand gradients obtainable in high pressure gas had not been developed. We built and tested great numbers of tubes, all of glass, and all with wax and rubber for vacuum seals. We tried spiral lines of India ink and sputtered gold films for potential distribution. Most dependable behavior was achieved with the subdivided tube of Figure 2 which withstood up to 400 KV over a length of 22 inches.

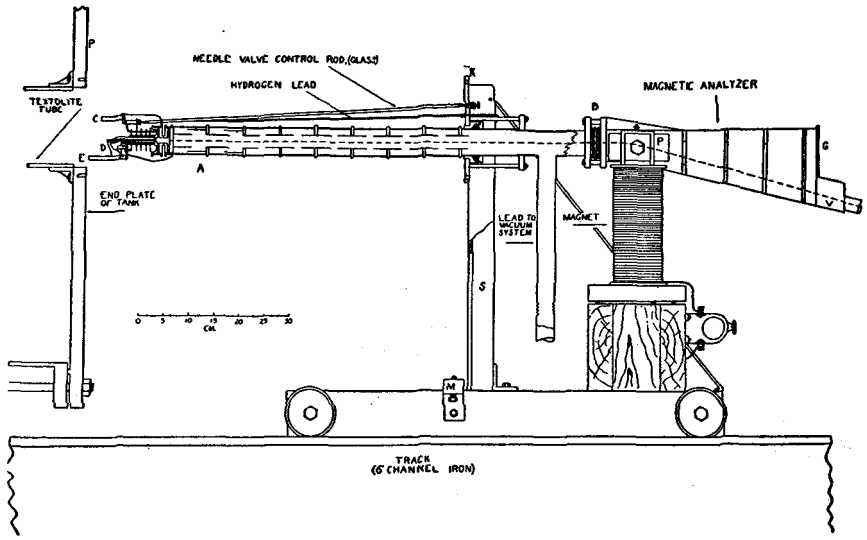

Fig. 2 - Accelerator Tube of First Electrostatic Accelerator.

We devoted much time to development of an ion source with the simplicity, dependability, compactness and low power consumption required for successful operation in the high voltage terminal.

First transmutations observed were from lithium bombarded by protons, with visual observation of the a particle scintillations on zinc sulfide.

Finally after construction of an ionization chamber and Dunning linear amplifier we obtained a $Li^7(p\alpha)$ yield curve over the energy range from 100 KeV to 400 KeV. This was my Ph. D. thesis, completed in June of 1935.

After a profitable summer with Tuve, Hafstad and Dahl, in their high voltage laboratory in Washington, D. C., I returned to Wisconsin in September of 1935 with a postdoctorate appointment.

4. The 2.4 MV Accelerator

Parkinson, Kerst and I then made plans, made measurements on critical parameters of the column, and then wnstructed the accelerator[4] of Figure 3.

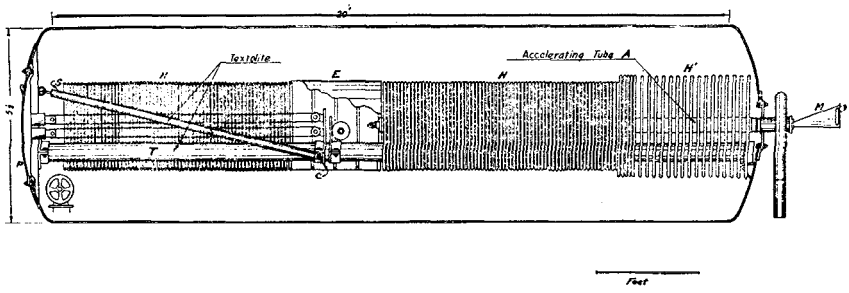

Fig. 3 - The 2.4 MV Electrostatic Accelerator.

This accelerator provided the first high voltage column, a region of uniform potential gradient housing supports, charging mechanism, and accelerating tube, and provided with a smooth exterior to minimize diameter required for the enclosing tank. All later accelerators insulated by high pressure gas have utilized columns closely following the design of the machine of Figure 3.

Proportions chosen for the radial gap length relative to the accelerating tube length and the belt length represented our best estimates of safe relative gradients. These proportions show clearly the extremes to which we can go in gradients between properly shaped electrodes in high pressure gas.

The column must be very long relative to the radial gap because surface flash-over along solid insulators, such as supports and charging belts, does not in general rise linearly with gas pressure. To avoid disappointing

results, great care must be exercised in design and gradients must be moderate.

Of most importance in limiting accelerator voltage from the first accelerator of Figure 1 to the most advanced machines of 1971, has been the accelerating tube.

The accelerator of Figure 3 held up to about 2.4 MV easily and data was taken up to 2.6 MeV. It was easy to operate. Parkinson and Kerst used this machine for their Ph. D. theses.

Following this development, large accelerators were constructed at several laboratories in attempts to reach voltages of 10 MV or more. Extrapolations were in each case unsuccessful.

5. The 4.5 MV Accelerator

Experience with our 2.4 MV accelerator convinced me that our understanding of accelerator behavior was too shallow for safely proceeding with a large machine. I obtained funds for revision of the 2.4 MV accelerator, including modification of the tank and provision of a completely new column. C. M. Tumer and J. L. McKibben made very important contributions leading to the accelerator of Figure 4, which by late in 1940 was providing a beam of 4.5 MeV protons[5].

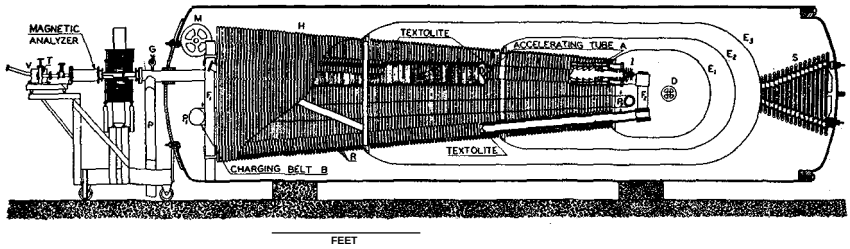

Fig. 4 - The 4.5 MV Electrostatic Accelerator.

Our progress on equipment development, along with nuclear physics research, had carried us at very low expense from .4 MeV ion beams in 1935 to 4.5 MeV in 1940. Again, we had a machine unique in its capabilities, superior to all others at that time for accurate measurements in nuclear physics.

We appeared at that time to have excellent reasons for optimism in regard to the future of electrostatic methods. No restriction had appeared to prevent extension up to tens of megavolts. Instead, further energy extension came very slowly. Ion beams above 4.5 MeV from electrostatic accelerators were not achieved until about 15 years later when the HVEC Model CN started operation at about 5.5 MV at Oak Ridge.

6. Further Development Work at the University of Wisconsin

In 1946, when I returned to Wisconsin after a 5 year period at MIT, difficulties had already been met in attempts to extend energies for electrostatic accelerators above 4.5 MeV. Over the next few years difficulties mounted, especially with accelerating tubes. Most disturbing was the complete lack of understanding of mechanisms leading to a self-sustained discharge in the accelerating tube. I decided during this period to stay with electrostatic methods. Clearly they were in trouble at voltages above 5 MV but they had excellent advantages and no limitation imposed by laws of physics had appeared.

During the period from 1946 to 1950 I initiated development programs along five principle lines.

1. Ultra high vacuum techniques.
2. High temperature metal to metal and metal to ceramic bonding.
3. Negative ion beam formation.
4. Electrostatic charging systems.
5. Electrical breakdown studies in a vacuum.

Work on vacuum techniques and on bonding was motivated by the urgent need for accelerator tube improvement. Rubber gaskets and organic cements in use yielded vapors that could condense on electrode surfaces. Electrode surfaces were therefore not aluminum or stainless steel. They were complex, unknown and beyond control. A layer of vapor on an electrode surface might be like an explosive, with a slight discharge releasing vapor which is partially ionized to increase the discharge, releasing more vapor, and thus spreading to disruptive proportions.

Work on formation of negative ion beams followed from revival by Alvarez of interest in this possibility, and made use of the measurements of Whittier[6].

In regard to charging, the advantages of the belt had been well demonstrated. Its disadvantages did, however, seriously restrict electrostatic methods. Need for adjustment, damage by high voltage discharge, lint and dust, and voltage fluctuations were inherent. Elimination of these shor-

comings with retention of the advantages appeared to me to be necessary for substantial expansion of utilization of electrostatic methods.

7. Vacuum Techniques

This I initiated as a general program to search for pumping methods free of vapor. Reports of the high activity of titanium and availability of titanium sponge puriíied by the iodide process led to successful evaporation of sponge in a bell jar which gave spectacular reduction of pressure. D.

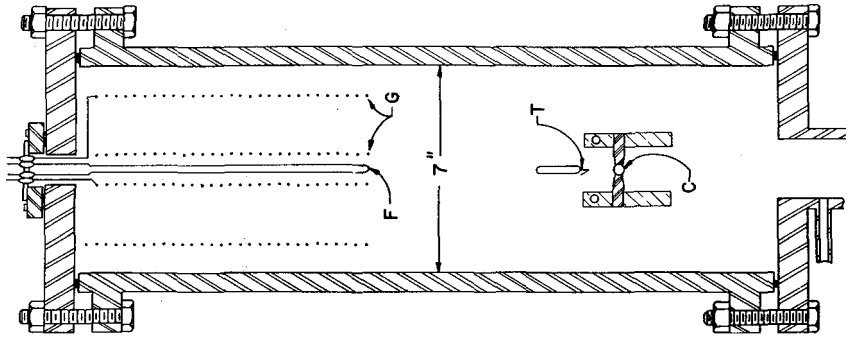

Fig. 5 - First Getter-Ion Purnp. Titanium wire T was fed to graphite crucible C. Electrons from filament F were accelarated through grid G. Ions forrned were driven into wall and were buried by condensing titanium.

Saxon, R. Davis and A. Divatia[7] perfected evaporation methods. Ionization was then included to provide the first practical getter-ion pump. (Figure 5).

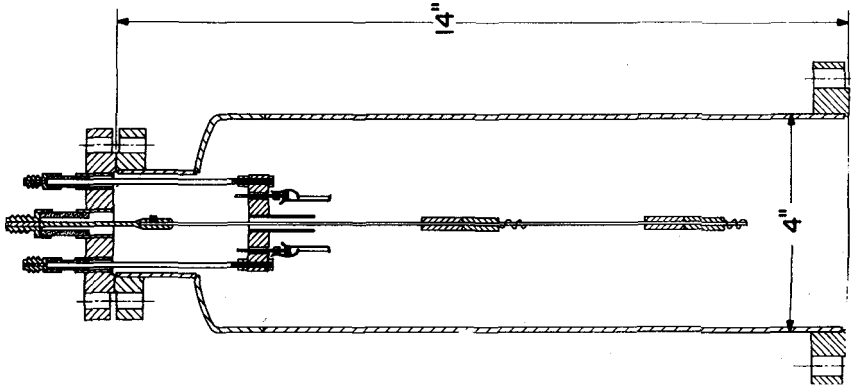

Fig. 6 - First successful getter-ion purnp utilizing electrostatic electron orbiting and titanium sublimation.

Later work by L. Hall at Varian led to the Penning discharge sputter-ion pump. Still later work at Wisconsin in which W. Mourad[8], R. Douglas[9] (Figure 6), T. Pauly[10] (Figure 7), J. Maliakal[11] and others participated, first demonstrated the advantages of titanium sublimation and provided an electrostatic ionizer called the orbitron.

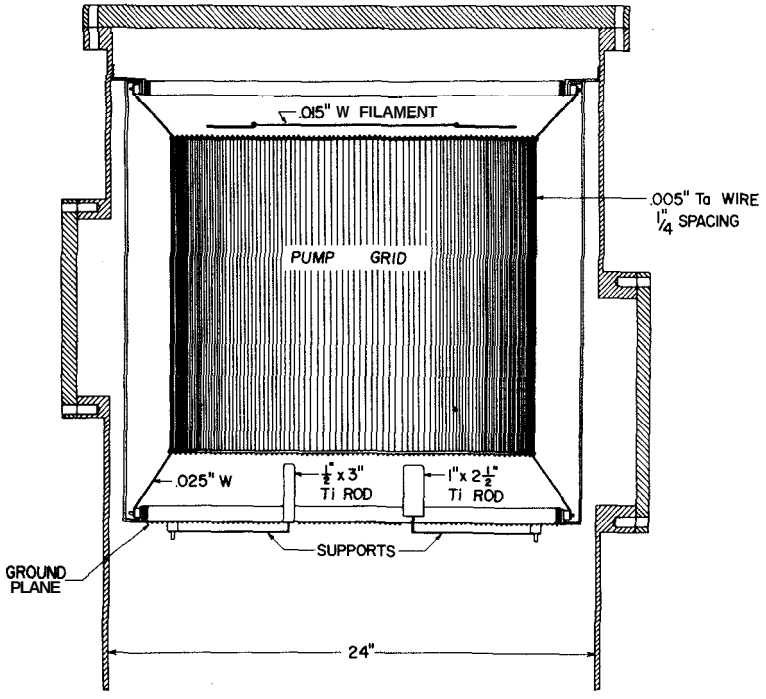

Fig. 7 - Getter-Ion Pump with grid ionizer and with titanium rods for sublimation.

8. Bonding

As in the other deveiopment programs, this work was carried out by beginning graduate students and by undergraduates. In bonding, major contributions were made by J. McGruer, F. Eppling and I. Michael. In metal to metal bonding, our work followed methods developed elsewhere. In high temperature ceramic to metal bonding, a number of methods gave good adherence but intolerable stresses were developed in the ceramic. Finding compatible materials and stress relief design were the problems. We obtained spectacular results with alumina ceramic and Kovar (Figure 8)

and later with alumina and titanium. Later, for the moderate temperature range, we developed the aluminum bonding method.

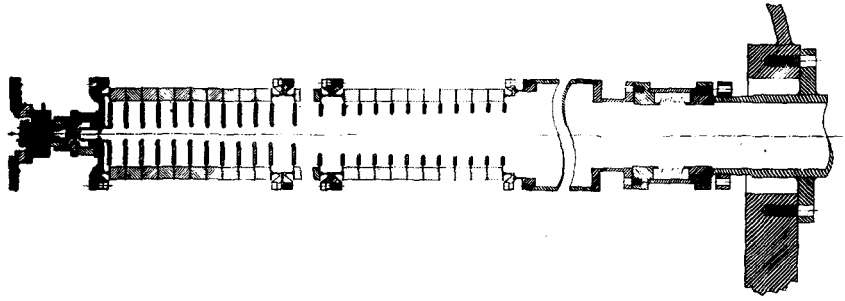

Fig. 8 - Accelerating Tube utilizing Kovar electrodes bonded with eutectic mixture of silver and copper, used with accelerator of I. Michael et al. (Reference 14).

9. Negative Ion Beams

Following revival of interest in negative ions by Alvarez and cross section measurement by Whittier, we undertook formation of useable negative beams. Here major contributions were made by J. Cameron, J. Weinman[12] and P. Windham[13] and Per Dahl. We introduced the use of a charge

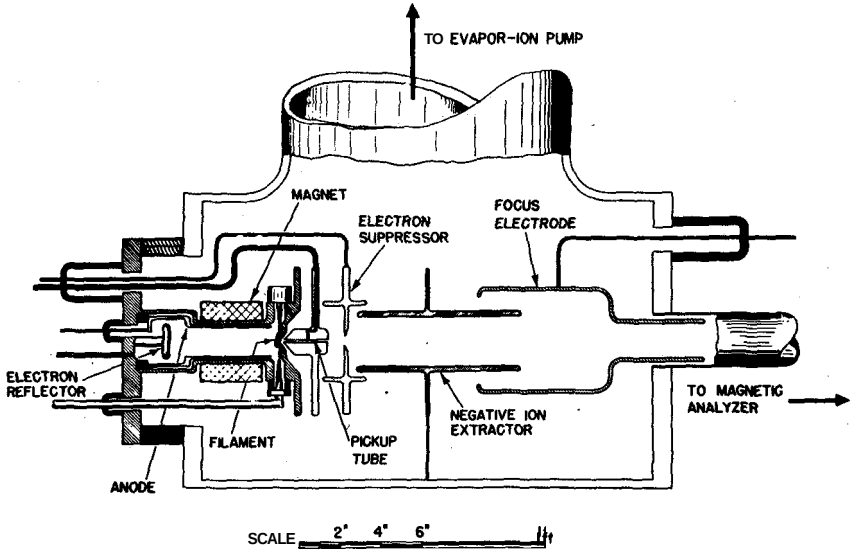

Fig. 9 - Apparatus used in work giving first successful negative ion beams. First charge exchange canal used.

exchange canal as shown in Figure 9 and obtained H^- beams up to 20 microamperes. Later, utilizing the charge exchange canal, we obtained He^- beams up to .06 microamperes.

10. Charging

First successful utilization of metallic charge carriers was in the late 1940's by use of properly spaced paper staples in a rubberized fabric belt[14]. For this, the major contributor was Dorr Ralph. This method gave excellent voltage stability and life but much time was required for application of the staples.

Following this early work, came many years of development and tests by Victor Fung and then by J. A. Ferry, who started on this program as an undergraduate.

After a great many promising attempts that ended in failure, the "string of beads" charging method was carried to a practical form by J. A. Ferry. A. Isoya who visited and saw this method, became interested and is now utilizing a similiar method at Kyushu University.

11. Electrical Breakdown Studies in a Vacum

Early work, starting in about 1947, in this area at Wisconsin was in unbaked metal systems with O-ring seals and utilizing diffusion pumps. Results were confusing and unrewarding. Following our development of pumping methods, of bonding and of string of beads charging, we constructed small high voltage devices, utilizing ultra-high vacuum systems, and bakeable metal to ceramic bonding for study of electrical breakdown in miniature uccelerating tube sections. This work extended over almost two decades. A great many undergraduate students contributed. Major contributions were made by J. Raatz and J. A. Ferry.

In these studies we learned much about practical details. We made little progress toward undersianding the mechanism of discharge.

12. National Electrostatics Corporation

Development work was continued at the University of Wisconsin until 1965 when the National Electrostatics Corporation was forrned. Most of this work was then transferred to our company. Some experimentation in vacuum techniques and on electricai breakdown in a vacuum continues at the University of Wisconsin. It is supported by grants to the University by the National Electrostatics Corporation.

13. Column Modules and Building Blocks

One of the first important projects at NEC was construction of a 2 MeV test accelerator. With this we proceeded vigorously toward development of components suitable for factory produced machines.

Probably our most important step was the decision to utilize modular construction, with a 1 MV module.

Next in importance was the building block concept. For support and for the accelerating tube we chose units to be identical for all machines with these units or building blocks conveniently chosen for our column module.

Production methods were of great concern to us. Our insulating material was the finest and most expensive alumina ceramic. The metal giving best performance was titanium. It is one of the more expensive metals and one of the more difficult to work. We could compete only with highly efficient methods.

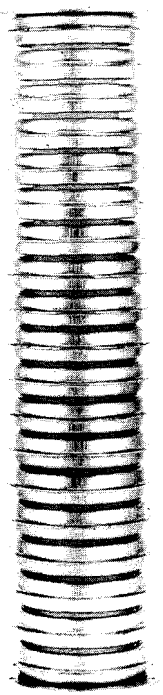

Fig. 10 - Standard 1 MV Insulating Support Post.

We adopted stamping. Suitable dies developed by our die maker, utilized with a punch press, reduced cost to a very favorable level.

Figure 10 shows our standard 1 MV support post. It is equipped with toroidal spark gaps to give very complete protection.

Figure 11 shows a standard tube section. It has a $\frac{1}{2}$ foot module and has a four inch inside diameter. Inner electrodes are removable. For standard accelerator application, flat electrodes are used with openings 2f inches in diameter.

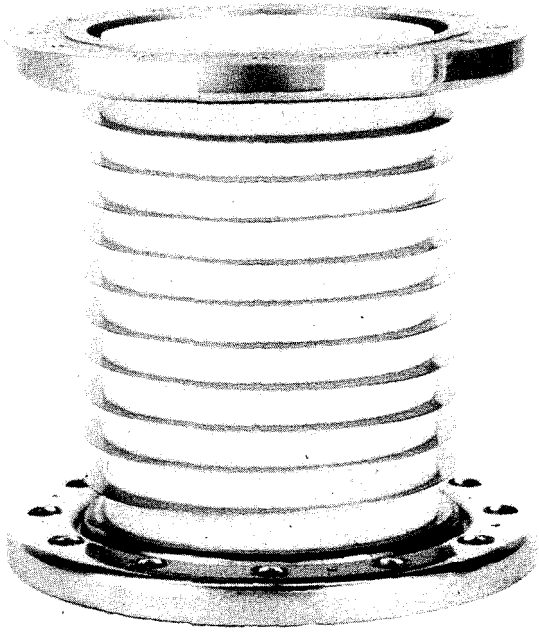

Fig. 11 - Accelerating Tube Unit. Three of these units are used per 1 MV column module.

In use, these tube sections are equipped with toroidal spark gaps to give very complete protection. Adjoining tube sections are separated by decoupling sections containing diaphragms with one inch openings. Provision is made for interna1 heating to avoid condensed vapors.

A support column module is shown in Figure 12. Total height is nearly two feet. Insulating height of a support post is approximately 18 inches.

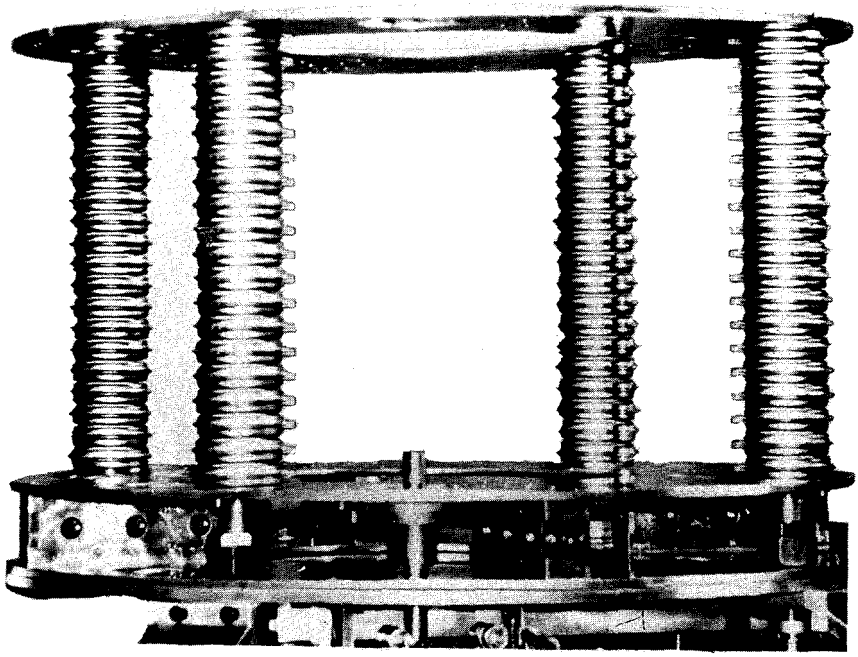

Fig. 12 - Standard 1 MV Column module.

14. Charging

The "string of beads" we developed at the University of Wisconsin gave good performance on two test machines we built and used at the University. These assemblies consisted of metal cylinders held by a rope made up of twisted strings. They were not well suited for efficient machine production methods and they were relatively fragile.

What we wanted was a rugged chain, suitable for a machine of any size, a chain that would run very long periods without attention, without dust and lint, and with low current modulation. It was also essential that the chain that would run very long periods without attention, without dust of beads was changed to the chain of Figure 13. The steel pellets are cut from tubing and are completely formed by the punch press. This method permits us to hold tight dimensional tolerance to give mechanically stable

operation with a minimum of current variation. Insulating links are of nylon. The metal pellets are charged by induction as they pass over pulleys.

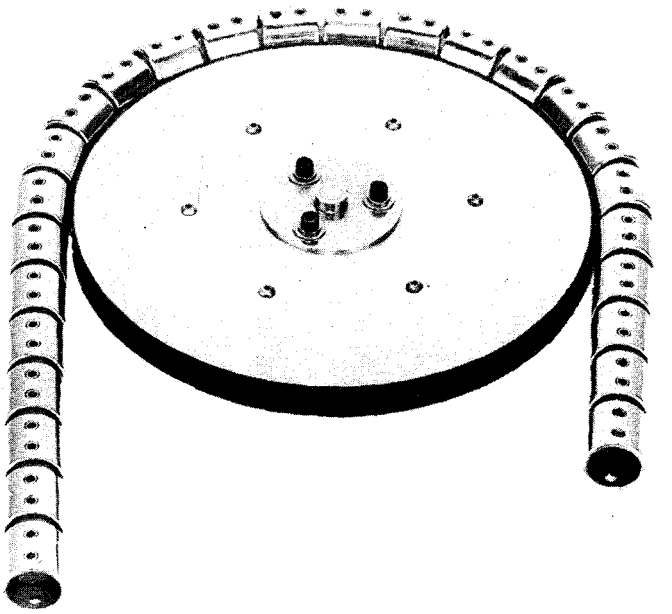

Fig. 13 - Charging Chain.

These chains show excellent promise for extension of electrostatic methods to industrial and medical applications where there is requirement for dependable operation with push button control by an unskilled operator.

15. The São Paulo Installation

The 22 MeV São Paulo facility, Figures 14 and 15, was our first important assignment. When the order came, we had first to build a manufacturing plant and a test tower. Dies had to be built and efficient assembly methods had to be perfected.

That we were able to meet our commitments demonstrates the soundness, not only of our electrostatics, but of our modular arrangement, our building blocks and our punch press fabrication.

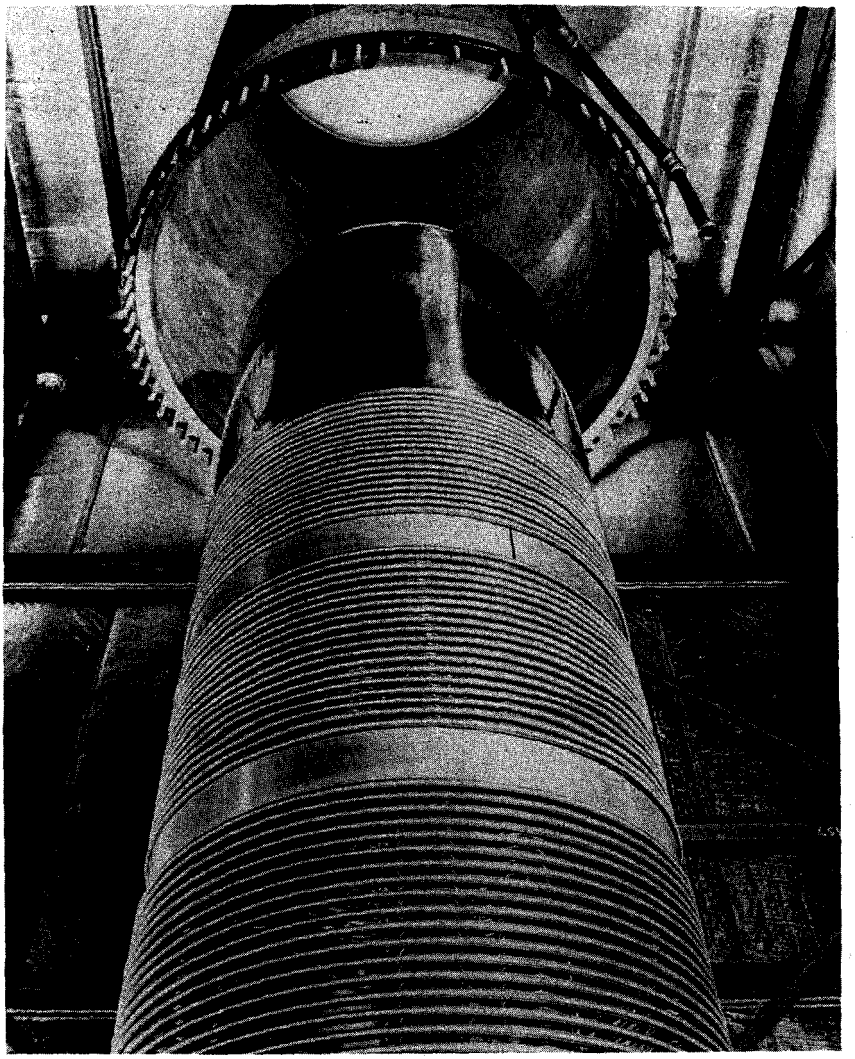

Fig. 14 - Pelletron Model 4 U.

As yet, we have seen no evidence of deficiencies in our choice of modular dimensions, in the design and dimensions of the support post and the tube section. We expect dimensions of these components to remain unchanged

for an extended period. Interchangeability of parts for machines throughout the world will simplify maintenance.

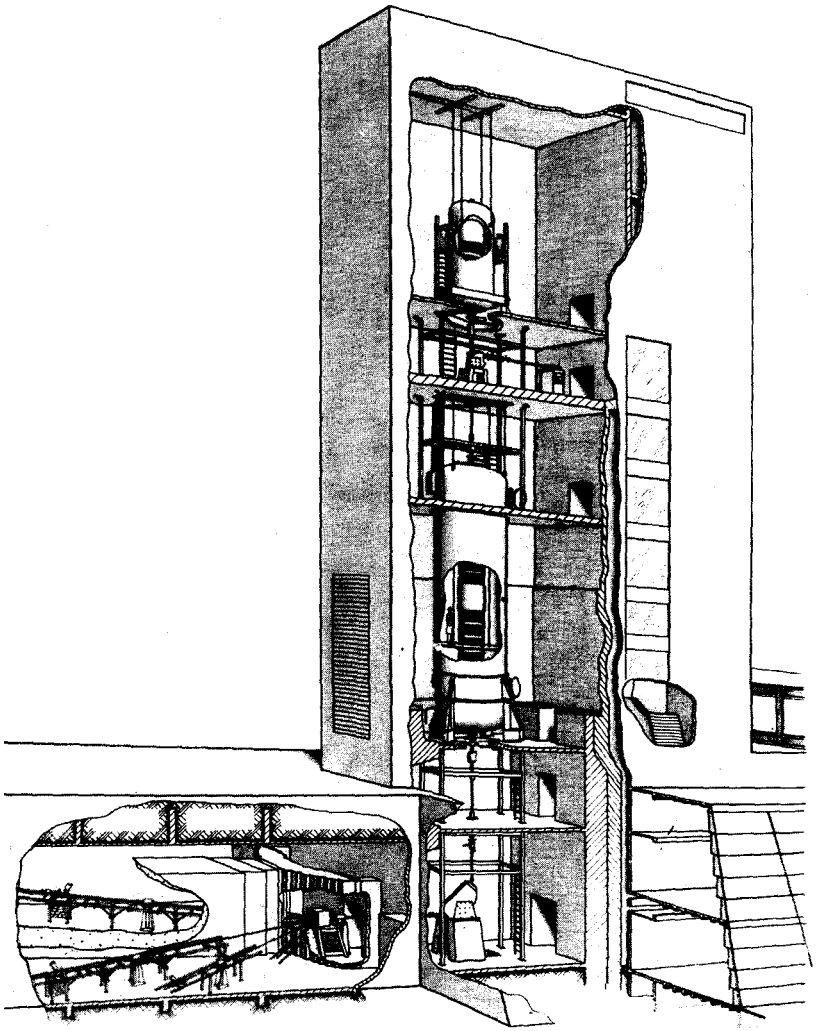

Fig. 15 - São Paulo Pelletron Facility. It consists of a Model 4 U injector and a Model 8 UD two stage accelerator.

16. Accelerators under Construction

We now have under construction a 1 MV electron accelerator for biological studies, a 2 MV heavy ion single stage accelerator for ion implantation studies and a 14 MV (28 MeV) two stage ion accelerator for nuclear physics work. The two small accelerators are horizontal. The large accelerator is vertical All use the same modular length (or height) and all use the support post and accelerating tube building blocks of Figure 10 and 11.

17. Future Plans

Our largest accelerator offering up to the present is the 20 UD of figure 16, which will operate with a terminal potential of 20 MV to provide 40 MeV protons. The design is conservative. Electric fields are moderate. We believe this is a safe extrapolation from test results achieved with the São Paulo 8 UD. After the 14 UD has been put into operation we expect to be able to extend our offerings to voltages beyond 20 MV.

The 20 UD will use the same support posts and accelerating tube units as our smaller machines. For these larger machines the all metal and ceramic tube will be very advantageous. After outgassing there will be very little gas to pump. We shall be able to maintain pressures lower by about 100 from pressures typically achieved in tubes now in use that are sealed with organic cements. For heavy ion work this will be especially advantageous.

We believe our methods are also advantageous for smail machines and, for completeness, I shall briefly describe the smallest machine we' have constructed, Figure 17.

It operates up to 300 KV and serves as a fast neutron detector for time-of-flight work. Photons from a flat scintillator above the photo-tube eject electrons from a spherical photo surface. They are focussed, are accelerated, and pass through a thin foil to a solid state detector at atmospheric pressure. The first unit is now under test.

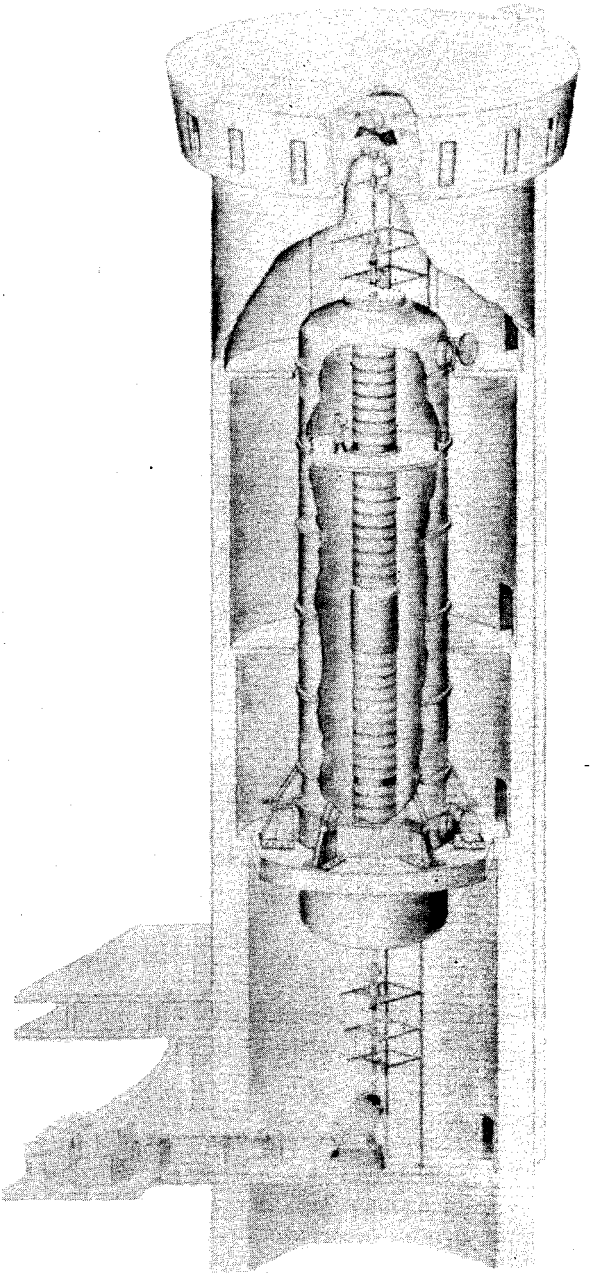

Fig. 16 - Model 20 UD Pelletron Accelerator. Terminal voltage is 20 MV to give 40 MeV protons.

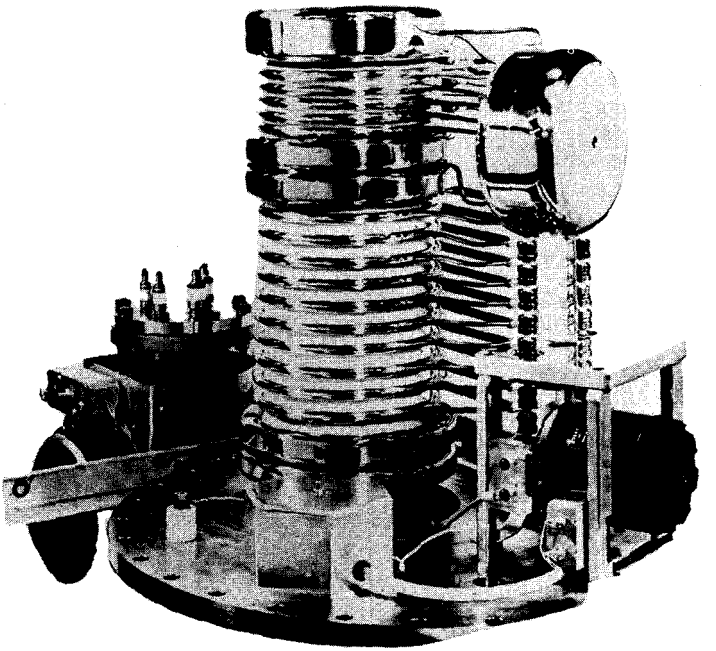

Fig. 17 - 300 KV Pelletron Accelerator for very rapid photomultiplier.

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