THE FIRST ACCELERATOR AT NOTRE DAME *

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Ours was not the very first electrostatic accelerator, of course. It was probably the fourth, and the third one to be located at a university. Still, we have indeed an anniversary worth celebrating, in that we have now had, continuously for fifty years, at least one electrostatic accelerator functioning on the campus. This is the story of the first one, that ran from about 1935 to 1942.

The story actually begins in 1928 when the engineering building at Notre Dame was partly destroyed by fire. It was decided to replace it with a larger building to take care of the needs far into the future. That building is the present Gushing Hall of Engineering. In the planning, it was agreed that the building was to include certain rooms set aside specifically for the purpose of research. The professor of Electrical Engineering (Dr. Jose Caparo) visited some other schools, and in particular at Purdue he saw a room that was set aside for the testing of high-voltage electrical equipment. That room was 20 feet long and 20 feet wide and 20 feet high. He asked for a room in our engineering building that would be twice as large in each dimension, and he got it. The room was and is somewhat over 40 feet in length and width, and originally was over 40 feet high. The building was completed in 1933; while the huge room was understood to be for high-tension testing, there was no immediate plan for its use, and it stood empty for about two years.

In the winter of 1934-35, Harold Edgerton (the "E" in "EG&G") visited Notre Dame, on his way back to MIT from a trip through the Midwest. He stopped off here to visit the same Profesor Caparo, who happened not to be here that day. Edgerton ran into one of the Physics instructors, who showed him around the (engineering) building. When he saw the room, he exclaimed, "Oh, my, wouldn't Van de Graaff love to have a big room like this!" Later in his visit, Edgerton met George Collins. Collins was a young Physics instructor here at that time. He became prominent later, particularly as the builder of the Cosmotron at Brookhaven. When they met, Edgerton repeated his remarks about the room and urged Collins to get in touch with (Robert) Van de Graaff. Apparently Collins never did communicate with Van de Graaff, but this encounter prompted him to look into some work that he already was aware of, that of Merle Tuve and Lawrence Hafstad at the Department of Terrestrial Magnetism or the Carnegie Institution. It happens that Collins* home town is Washington, D.C., so during his Christmas vacation of 1934 he went to visit them. The outcome of this was the decision to build, at Notre Dame, a scaled-up version of the Tuve and Hafstad open-air machine.

The large metal spinnings that were used even then for the terminals of accelerators were much too costly for Notre Dame, so a different method of construction was adopted, a method proposed

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* From a presentation given at the Notre Dame workshop “50 years of accelerated based physics”. Figures were added by M. Wiescher.

by Father John Steiner, the Dean of the College of Engineering. This same Father Steiner also provided the use of the special room; he arranged for some materials to be donated and for others to be diverted from the maintenance budget, and he even arranged for a grant of $900 that was appropriated by the University in May 1935 for the construction of the accelerator.

One of the other principals in the story is Edward Coomes. A Notre Dame product, he had a Bachelor degree in Electrical Engineering and a Master degree in Mathematics. He stayed on for a few years as an instructor in Physics. (After the war, Coomes returned to Notre Dame with an Sc. D. degree from MIT and made his career here in another branch of Physics.) Notre Dame did not grant any degrees in Physics up to that time. Master-degree candidates were first admitted in 1934; two who came in that year, Edward Kenefake and Alfred Hiegel, plus Richard Schager who arrived the following year, completed the roster of accelerator builders, along with Collins and Coomes. Their three Master Essays make up a good part of the documentation of the accelerator.

The terminal, by its sheer size, dominated the scene. It had two hemispherical sections 12 feet in diameter, joined by a vertical cylindrical section only 18 inches tall. The design and construction is demonstrated by figure 1. The terminal consisted of a frame made out of white pine ribs, covered entirely with sheet copper. It is said that there were no blueprints, yet photographs from the construction phase show that the terminal went together beautifully. Each copper panel was hammered into shape with an air hammer, and then cut to fit the spaces in the frame, and nailed in place. Adjacent panels butted together over a rib so that there wouldn't be any projecting seams, and of course the nail heads were sunk into the copper. There were

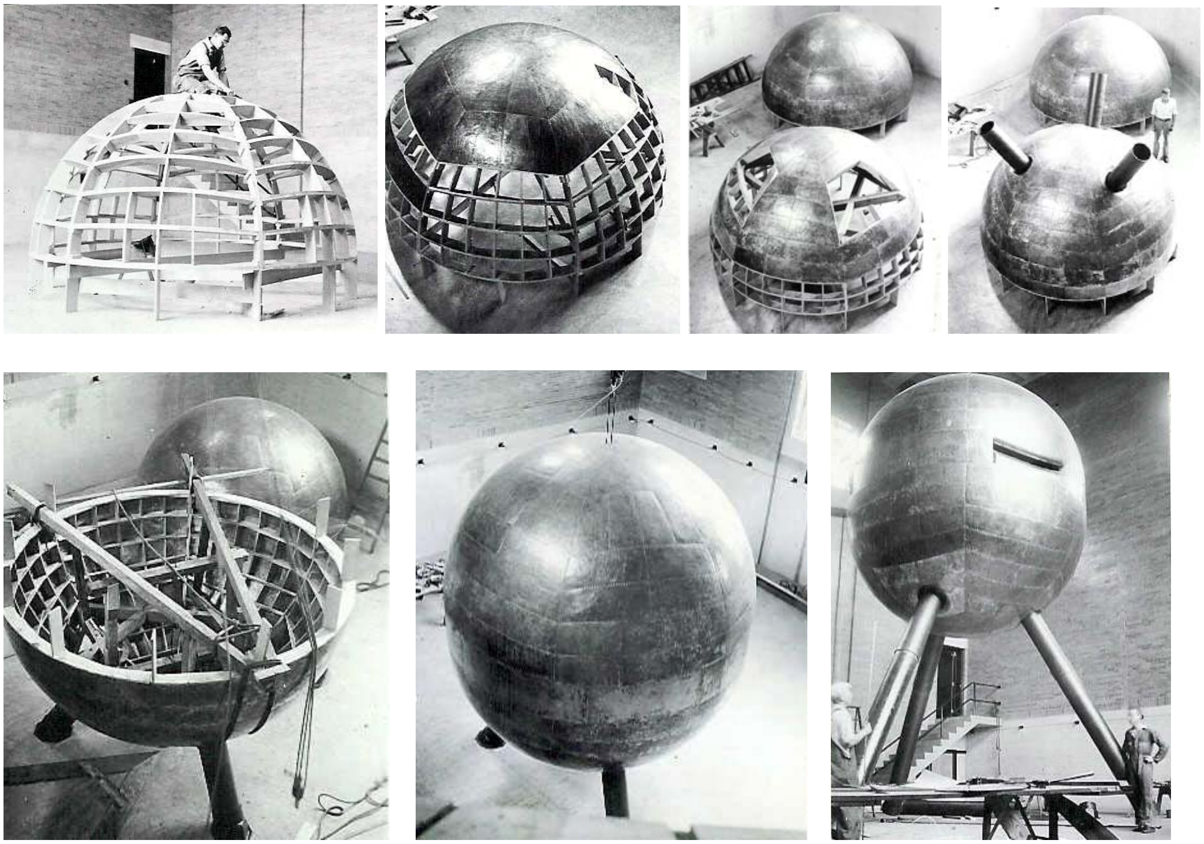
Figure 1: Assembling of the high voltage terminal for the accelerator.

empirical formulas available at the time for the corona current to be expected for the sphere as such, and that was one of the major design factors, but they were very concerned about the possible effects of any irregularities stemming from the novel method of construction.

The legs were made of an insulating tubing called Herkolite, which was not available in lengths of more than 6 or 8 feet, so it had to be pieced together to make long enough sections to raise the terminal to the center of the room. The original belts were made of paper, sometimes varnished and sometimes not. The belt was 70 feet long and almost 3 feet wide and ran to the very corner of the room. Belt pulleys were fashioned out of brass tubing. They were crowned by layers of newspaper glued to the center of each pulley, and that seemed to work very satisfactorily.

Testing began in August of 1935; as soon as the atmospheric humidity decreased to a reasonable value, the machine began to make big sparks, as much as 19 feet long. On the 9th of October, rough measurements indicated terminal potentials of 1.25 MV negative and 2.25 positive. Many tests of the charging system, with variation of parameters such as belt speed and tension, were carried out that winter, and materials for future tube supports were tested. One feature rarely found on Van de Graaffs any more was a radiant heater that helped to dry the belt as it ran.

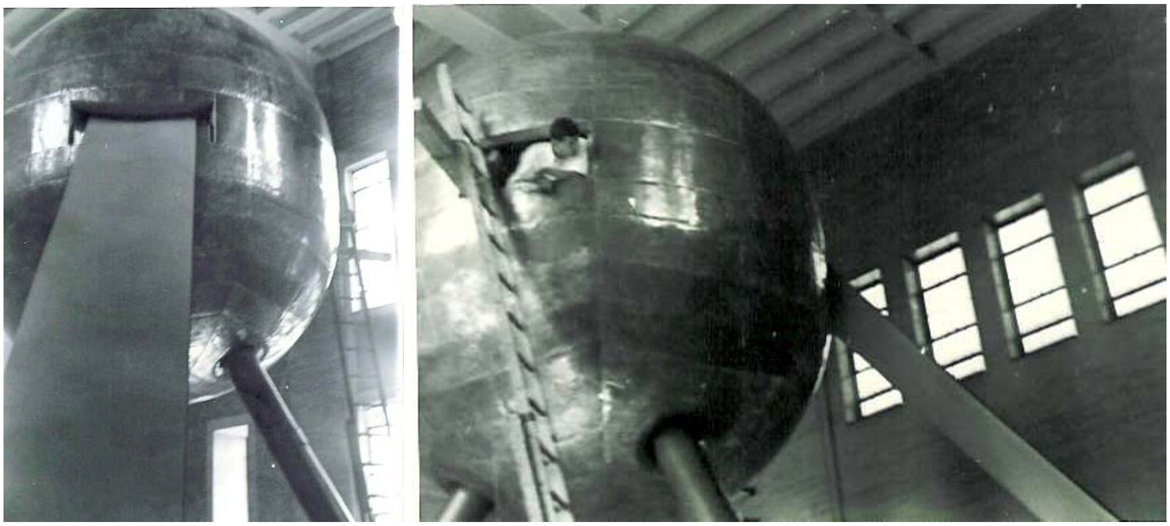

Figure 2: The belt charging system, the first belt itself was made of paper.

The belt charging supply was an X-ray power supply that was rectified but not filtered. Collins felt that it was important to filter the DC on the charging pins, but there were no condensers (capacitors) to be had with an adequate voltage rating, so they bought panes of window glass, 40 inches square, and pasted tinfoil to both sides to make their own. Luckily, compactness was not a requirement.

A DC motor, with a rather sophisticated electrical feedback system for speed control, drove the belt. As it was DC operated, it was easy to make accurate measurements of the input power. The first determinations of the terminal voltage mentioned above were made by measuring the power required to drive the belt with the charging on, subtracting the value with it off, and dividing the remainder by the charging current.

Still in the 1935-36 academic year, high priority was given to the construction of a "rotating" voltmeter, now known as a generating voltmeter. The principle was not entirely new, but in this realization a null-method was developed for balancing the field of the sphere against that of a counter-electrode of known adjustable potential. The operator listened with headphones for a null in the amplified audio-frequency signal, thus completely avoiding the problems of rectifying a small signal. The method was continued on the second Notre Dame accelerator until about 1954.

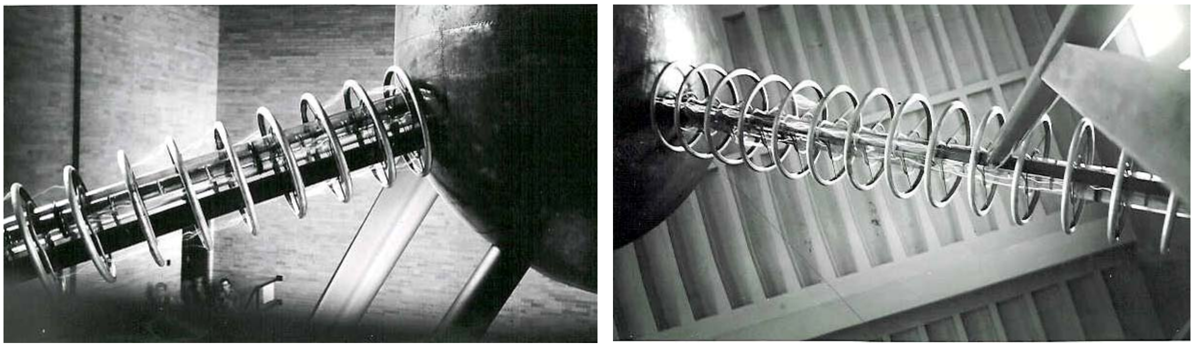

Figure 3: The acceleration tube.

Construction of the tube and vacuum system was in its own way as great an undertaking as that of the generator proper. As shown in figure 3 the tube was made of six glass sections, each four feet long and about 10 inches in diameter, and each section contained four brass drift tubes with just a half-inch accelerating gap between them. Each drift tube was mounted on a ball joint on a single bolt through a hole in the glass. The drift tubes in each section were aligned on an optical bench. The bolts through the glass were then sealed with sealing wax; in fact, all the glass-to-glass and glass-to-metal joints in the entire system were made with sealing wax.

The whole tube was assembled on and supported by a 4" by 6" redwood beam, 27 feet long. It had been specially dried in a kiln to less than 2% moisture content, and sealed with several coats of varnish while in the kiln. Samples of other wood had previously been tested with the generator and had fallen far short of the necessary resistance. The highest published resistivity value for redwood was at 7% moisture content, and was about three orders of magnitude too low for the purpose. Consequently, the decision to go ahead with the redwood anyhow, and its complete success, is perhaps the most surprising feature of this whole story.

There were originally 19 corona rings, 28 inches in diameter, around the tube and supporting beam. Sometimes, a spark down the tube would knock a chip out of the redwood, and then the operator had to go out and find where the chip came from and varnish over the spot, because the moisture must never be allowed to get back in after the redwood had been dried. Also, sparks would sometimes knock pieces of sealing wax off the tube joints, and of course that would ruin the vacuum, causing serious problems. Inner corona rings, that followed closely the outline of the tube and supporting beam, were added later to protect the seals against sparks.

The tube ran slanting downward across the room and through an opening through the wall into what was called the "disintegration room". Here was located the vacuum system featuring a homemade, state-of-the-art oil diffusion pump. This was scaled up to four inches diameter from a design in a current issue of the Review of Scientific Instruments. Several months of 1936 were spent in optimizing the performance of the diffusion pump. There was a thin aluminum window for the beam to come out into the air.

Inside the terminal, at the other end of the tube, was the electron gun. The generator.had been initially tested with both polarities, and fairly late in the construction it was decided to accelerate electrons. That started a tradition that lasted for 40 years at Notre Dame. In fact, every Notre Dame accelerator has accelerated electrons at least some of the time.

One of the initial design objectives for the machine was that it be able comfortably to exceed the threshhold for pair production, about 1.02 MeV, and that was part of the reason for scaling up the DTM design. Things haven't changed much in 50 years, it seems, because to this day one of the goals in planning any big new accelerator is to exceed the threshhold for production of some particle or other. Fifty years ago it was the positron. The electron gun ran on batteries, as did a lot of electronics at that time. Someone had to ride in the terminal to adjust the gun controls each time they ran, until a satisfactory beam was obtained; then they could turn off the charging, put up the extension ladder and let him out.

The first beams (whose anniversary we're observing) were obtained in October 1936. On the 19th of that month, the log records that with 1100 kilovolts on the terminal, the filament was heated until electrons were detected, by means of a fluoroscope, at the lower end of the tube. And on the 23d, there is a more definitive statement that the beam was able to penetrate GO sheets (1.27 mm) of aluminum. This confirmed that they were accelerating electrons to about 1.2 MeV. A serious vacuum accident then held up the work for a few months. By February of 1937, however, with the introduction of electrostatic focusing at the terminal end, the beam current had been raised to 30 microamperes on a 1-cm spot, and thereafter beam current was never much of a problem.

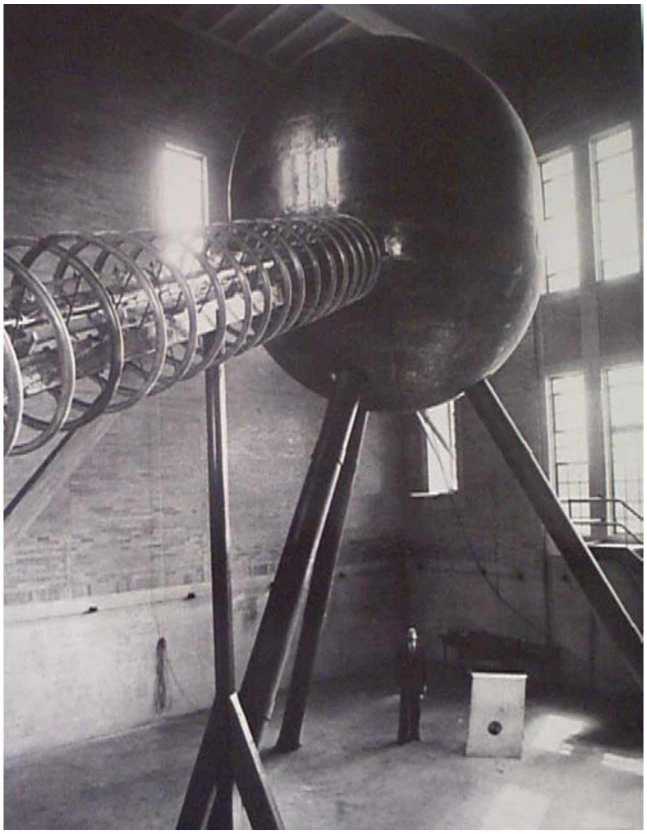

Figure 4: A photograph of the completely assembled and by then operating accelerator, taken, facing SE, early in 1937. Standing in the background is George Collins. Next to him is the rotating voltmeter. At the time there was one belt, running to the lower left in the picture, and there was just one corona ring to each drift tube.

Figure 4 shows the accelerator as it looked early in 1937. A double row of windows faced on Dorr Road (until another building intervened a few years ago), a rather busy campus thoroughfare. The terminal would have been visible in its entirety. There were very few lights in the room, just a few bulbs on the wall, enough for a passerby at night to be able to make out this huge copper sphere sitting up on its spindly legs. Remember that corona was a normal way of life for this machine, and it is said that the corona glow would at times fill the entire room. What a sight it must have been on a winter evening to see this monstrous machine bathed in a purple glow.

Experimentation began in earnest upon the return of dry weather in the fall of 1937, and continued thereafter except for the summer months, which were devoted mostly to machine development. The picture on the mugs, and on the cover of the program, is from 1939 and shows several changes. There was a second charging belt, running to the opposite corner of the room. Its purpose was simply to provide more charging current, since the terminal voltage was limited by corona current.

The total charging current by then was typically 500 microamperes, allowing 1.8 MV to be reached quite regularly. There were also twice as many (39) corona rings, with ball gaps between them, to give further protection to the tube.

Because electrons were accelerated, the Earth's magnetic field was always a problem. At first, small permanent magnets had been placed empirically along the tube to compensate for this, but later Helmholz coils, 10 m in diameter, were constructed on the walls, floor and ceiling. Parts of the floor coil and one of the wall coils are visible in the 1939 photograph. Another major improvement was the addition of strings from the disintegration room to the terminal, for control and communication, so that it was not always necessary to have an operator in the terminal at start-up.

A booster pump was added to the vacuum system, which for the first time made the mean free path greater than the length of the tube, greatly improving the quality of the beam. The total cost of the completed accelerator was estimated at $3000. This of course does not include any of the labor.

Routine operation continued until 1942. By that time most of the personnel had left for war-related work, and our second accelerator was already in operation, itself engaged in wartime research.

A lot of good research was done with the first accelerator. Some of the highlights are, the first experimental confirmation of Cerenkov radiation, the first electrodisintegration of a nucleus, the first pair production by electrons, the experimental investigation of Mott scattering, and an investigation of the tip of the Bremsstrahlung spectrum.

Electrodynamics was of great interest in those days, and there was close collaboration between our accelerator people and the one other strong group in our department, the theorists.

Thanks to the success of our first accelerator, the University funded the construction of the second, a horizontal pressurized machine that has its own long and interesting history. And thanks to the success of the second, we have today the Physics Department's third and fourth accelerators operating productively. Number three itself has already passed its thirtieth anniversary. We also have the Radiation Laboratory, in a sense an offshoot of the second accelerator, that has its own electron accelerators, and we have the strong nuclear group in Physics who have made this continuation of the accelerators possible.