THE DEVELOPMENT OF HIGH VOLTAGE FOR THE PRODUCTION OF NEUTRONS AND ARTIFICIAL RADIOACTIVITY

E. U. CONDON, Ph.D.,
Associate Director, Westinghouse Research Laboratories,
East Pittsburgh, Pa.

Eight years ago neutrons and the phenomenon of artificial radioactivity were discovered, following closely on the first work on artificial transmutation of the elements. In the years that have followed there has been a tremendous advance in our knowledge of fundamental physics of the atom as a result of these discoveries, a big development of equipment for producing and measuring the new radiations, and a wide recognition of their great potentialities for medicine. I understand it to be the function of our symposium this morning to make a rapid survey of this field from the particular standpoint of the cancer problem. In opening the discussion, I shall undertake only to present the physical side of the subject, properly leaving to my associates a discussion of the biological and medical phases.

Let us start by recalling that we now know that the atoms of matter are made of a central nucleus, composed of protons and neutrons and hence charged electrically positive, surrounded by enough electrons to make the atom as a whole electrically neutral. All the development of atomic physics from 1912 to 1930 was concerned with the study of the outer electronic structure—the decade from 1930 to 1940 has seen the interest shift almost entirely to the internal structure of the nucleus.

In solid bodies the atoms are packed in about one hundred million to the inch and the nucleus itself is about ten thousand times smaller in diameter. The atomic nucleus is the smallest thing whose structure is studied by man. The principal means of study has been by observation of what happens when atomic nuclei are struck by ions of hydrogen or helium which have been artificially accelerated to high speeds by means of high voltages. The bombarding ions need the high speed because they are charged positively and so are repelled by the nuclei, hence unless they have very high speeds they do not get close enough to produce any effect.

In the latter 1920's when physicists began to turn their attention to the nucleus, it was thought that several million volts at least would be needed to give the particles enough energy to effect nuclear transmutation. And at that time there was no known way that appeared practicable for getting more than one million volts. Cascaded transformers had been used up to one million volts or so. Electronic rectifiers in combination with transformers had been developed up to several hundred kilovolts. But then two developments occurred which opened up the subject. In the first place, theoretical applications of wave mechanics showed that the voltages needed were not nearly so high as at first thought. This theoretical prediction led to discovery that light elements could be transmuted with relatively low voltages—several hundred thousand—although at such voltages the yield is very low and rises exponentially with the voltage.

The other important development was the introduction of two means of getting particles of extremely high energy. These are the cyclotron of Professor E. O. Lawrence of Berkeley and the belt-type electrostatic generator of Professor R. J. Van de Graaff of the Massachusetts Institute of Technology. These made possible the production of high energy beams of positive ions for production of neutrons, artificial radio-active materials, and nuclear research in general. The principle of operation of each of these is well-known to this audience. In the cyclotron there are no extremely high voltages on different parts of the apparatus. Instead the ions are caused by a magnetic field to move in a spiral path while gaining energy from an alternating electric field. In the belt generator the high voltage is obtained by carrying charge to an electrode with an endless cloth belt. The maximum attained voltage depends on the breakdown strength of the dielectric around this high voltage design. This requirement leads at once to very large sizes and special means of insulation. Both types of equipment, when built on a scale sufficient to provide several millions of volts, are quite expensive—somewhere in the neighborhood of $100,000 being the amount needed.

The cyclotron started in 1930 with a very small model built by Lawrence, then a working instrument built by Lawrence and Livingston which gave 1 million electron volts (Mev.) protons. This was followed by another with a magnet having pole-pieces 37 inches in diameter which attained about 6 Mev. and last year by completion of another having 60 inch pole pieces which gives 16 Mev. deuterons and 32 Mev. alpha particles. Now Lawrence is busy with the details of a huge project involving a cyclotron with pole pieces 184 inches in diameter, the magnet of which will weigh close to 5000 tons, which will produce deuterons of some 150 Mev. energy. The project is estimated to cost in the neighborhood of $1,500,000 of which some two-thirds has been provided by the Rockefeller Foundation. In the same period there has been a very widespread recognition of the importance of this research tool as evidenced by the fact that there are some thirty cyclotrons in the world, either built or building, mostly in the United States, and mostly financed in the expectation that they will prove valuable research tools in medicine.

Going along with this story of steadily increasing voltage, the "cyclotroneers" have made an enviable record in improving the total beam current, the latest being a total of 300 microamperes of deuterons at 16 Mev. on the 60-inch cyclotron. This means practically 5 kilowatts of power in a form available for intense nuclear disintegrations. Just a few years ago we heard of currents of 0.1 microampere. Now currents well above 10 are commonplace and many cyclotrons are getting close to 100 microamperes of beam current.

The first large belt generator is the one built by Van de Graaff at Round Hill, Massachusetts. This attained very great voltages, around ten million, but the great difficulties associated with building a large vacuum tube in which to accelerate the ions with this generator were never successfully overcome. The tube was designed for horizontal operation, which introduced great difficulties of support. The first successful application of the belt generator principle to the study of nuclear physics is due to Tuve and Hafstad of the Carnegie Institution of Washington. Their generator with a two-meter sphere worked successfully to about 1200 kilovolts, and they usually have had available about 1 microampere of analyzed beam current. Later the Round Hill outfit was moved to the campus of the Massachusetts Institute of Technology and sat up in a different way to permit the installation of a vertical discharge tube. In this form it gets about 2500 kilovolts. This laboratory has principally applied the outfit to studies on the ultra hard X-rays produced when electrons of this voltage strike a metal target. Most X-ray physics and all radiological experience hitherto has stopped at 1000 kv., so we may hope for many interesting results from Cambridge.

About five years ago, Herb at Madison, Wisconsin, made the first really successful application of the use of compressed air as an insulating medium to improve the attainable voltage with a belt generator. Working with a pressure tank about 6 feet in diameter and 14 feet long, he built a machine which gives 2.5 million volts. The great gain in compactness which compressed air insulation gives is apparent when we realize that Herb's outfit in a small basement laboratory room gives essentially the same voltage as the large M.I.T. outfit which requires a good-sized building to house it.

With this experience to go on, the decision was made to build a large pressure insulated belt generator at the Westinghouse laboratories. This has been in operation about a year, as has also another similar one at the Carnegie Institution in Washington. Our machine is operated successfully at 4000 kilovolts with proton beam currents of about 1 microampere. The Washington machine has shown a similar performance. Two more pressure insulated belt generator outfits of intermediate size are now nearing completion, at the University of Minnesota and at the University of Pennsylvania.

I am sure that people who are closely interested in this subject would like me to say something about the relative merits of the two means of obtaining high energy particles. This is a quite complicated subject—and there seems to be no one who has had close working experience with both types. The Washington group soon will be in this position, for they are now building a large cyclotron like Lawrence's present large one to supplement the work of their large belt generator.

Since yields of neutrons or of radio-active materials go up roughly exponentially with voltage and directly with current, there is no question but that a cyclotron is at present superior to the belt generator as a strong producer of radio-active materials or of neutrons. And it does not seem likely that the belt type generator will catch up in total voltage and current for some time to come, so as a production instrument the cyclotron seems quite superior. In the belt generator the generator itself is capable of providing much greater currents—the crux of the problem is in the ion source at the high voltage end of the vacuum tube.

The main advantages of the belt generator seem to be as a scientific instrument and as a means of studying ultra-hard X-rays. The cyclotron cannot accelerate electrons owing to their light mass and high relativistic variation of mass. Moreover, the different particles in a cyclotron beam do not appear to be nearly so homogeneous in energy as the particles in the beam in a steady belt generator. In our outfit at Westinghouse, we feel the variation is scarcely more than ± one-tenth per cent, whereas I think all cyclotron beams show a range of about ± 10 per cent, although it is hard to get definite information on this point. This makes the belt outfit an ideal instrument for precision measurements of resonance levels in nuclei and for onset thresholds of certain endoergic reactions.

It appears, therefore, that the two machines are more complementary than competitive, and that each is destined to play an important part in the continuing development of nuclear physics.