

Jan. 2, 1968

J. V. KANE
SPATIALLY ALTERNATING GRADIENT VOLTAGE SYSTEM
FOR A VAN DE GRAAFF ACCELERATOR

3,361,980

Filed Oct. 19, 1965

3 Sheets-Sheet 1

FIG. 1

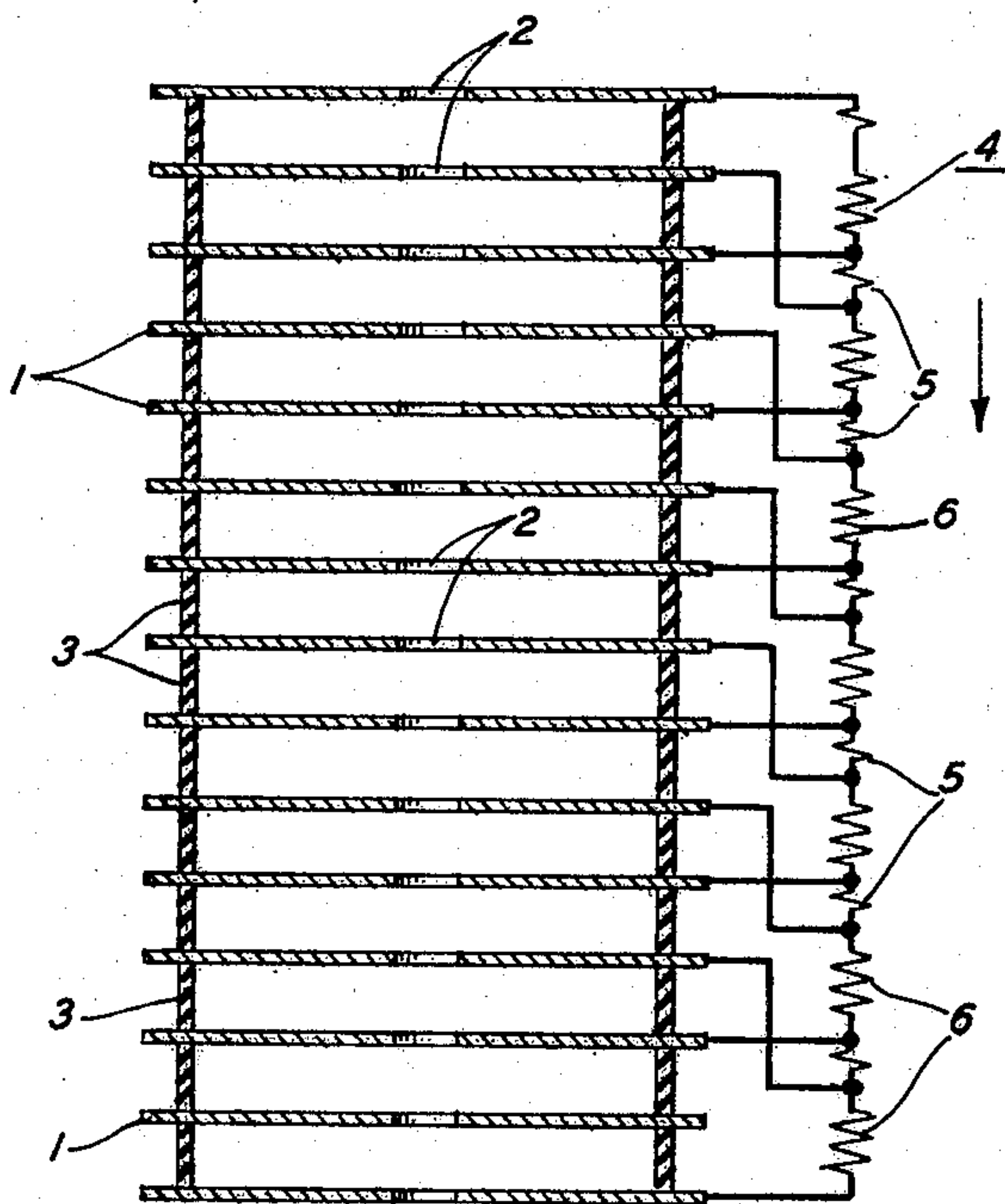
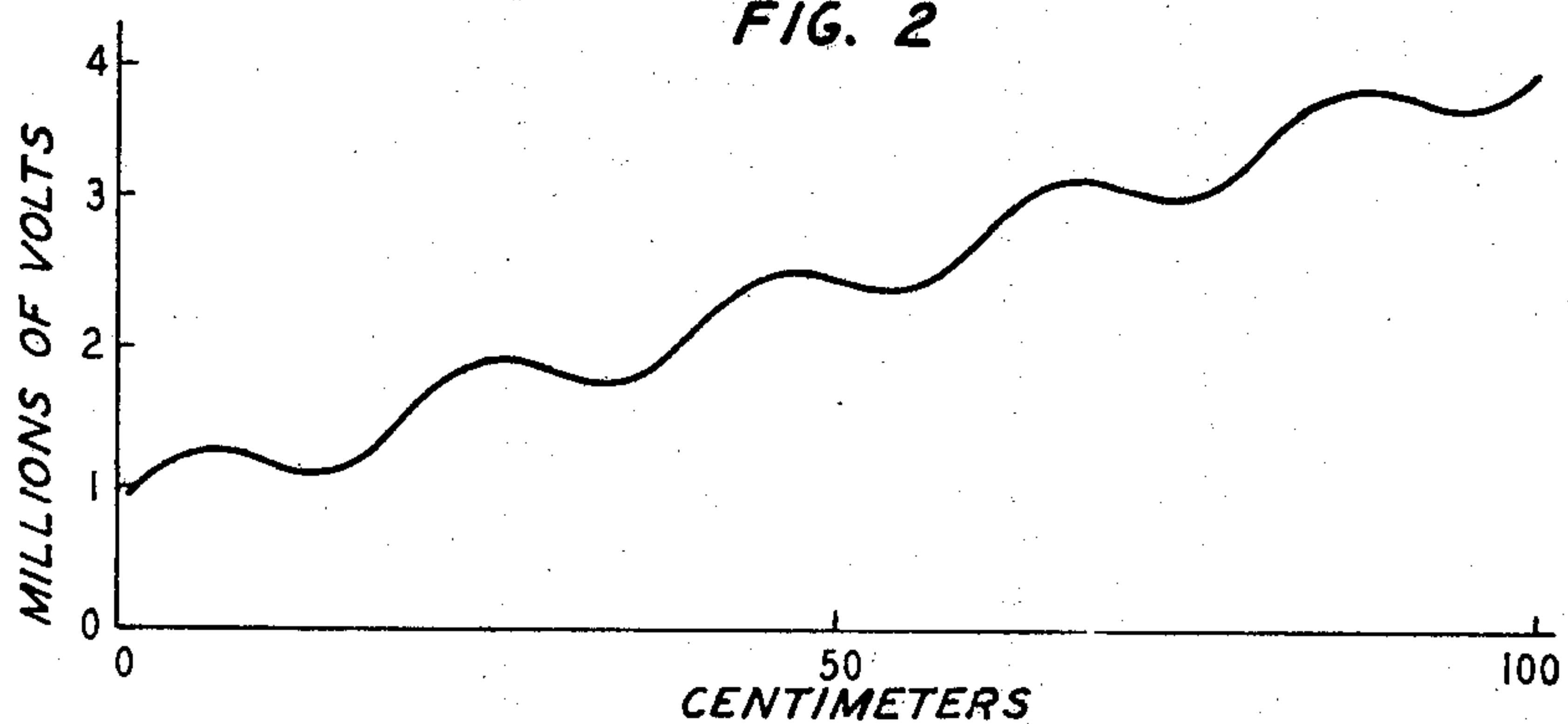


FIG. 2



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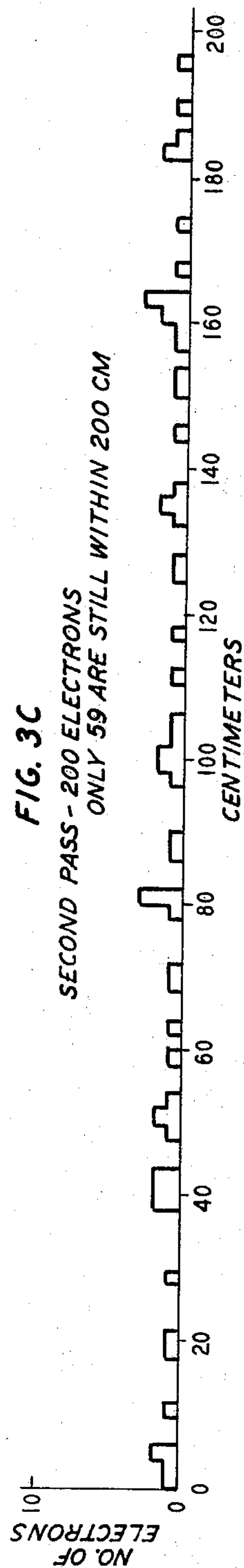
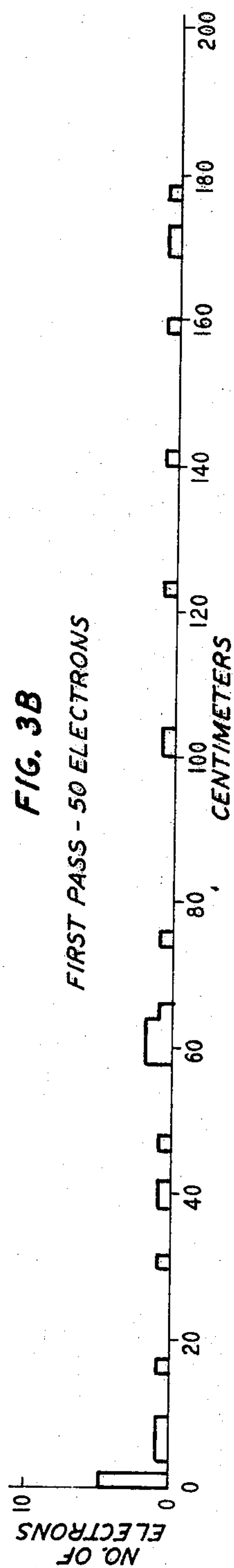
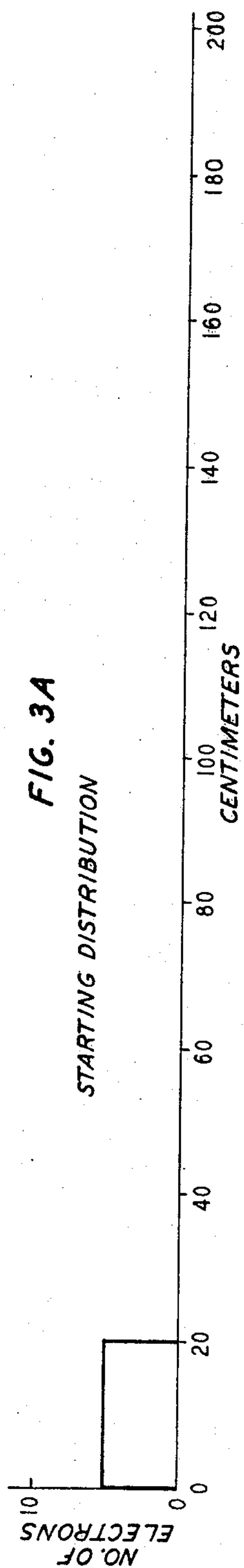
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FIG. 4A

STARTING DISTRIBUTION

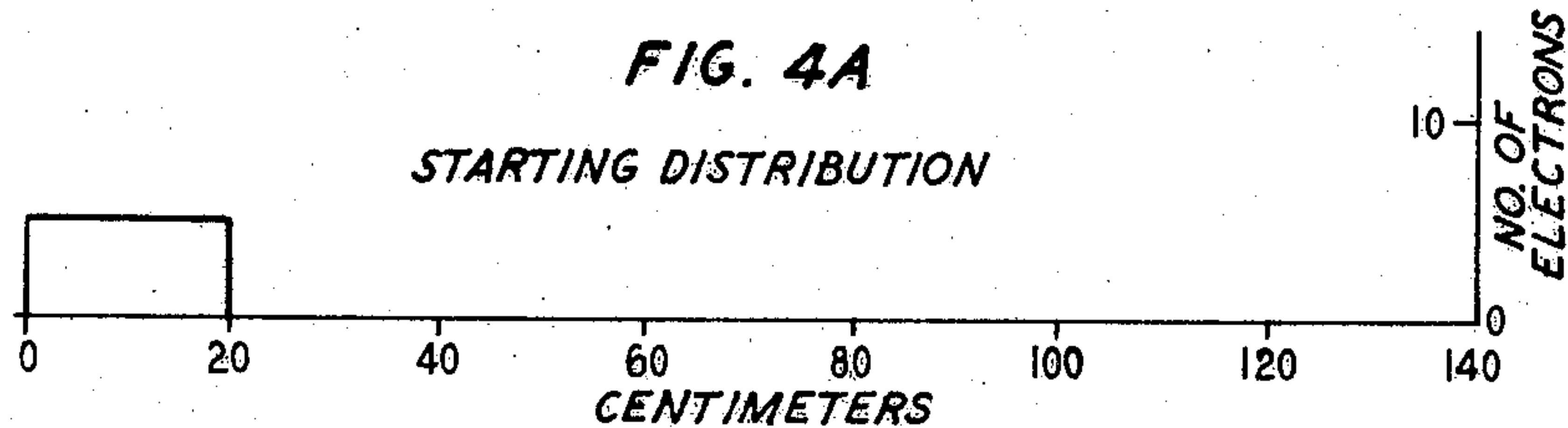


FIG. 4B

*FIRST PASS - 50 ELECTRONS
3 ESCAPE END AT 500 CM*

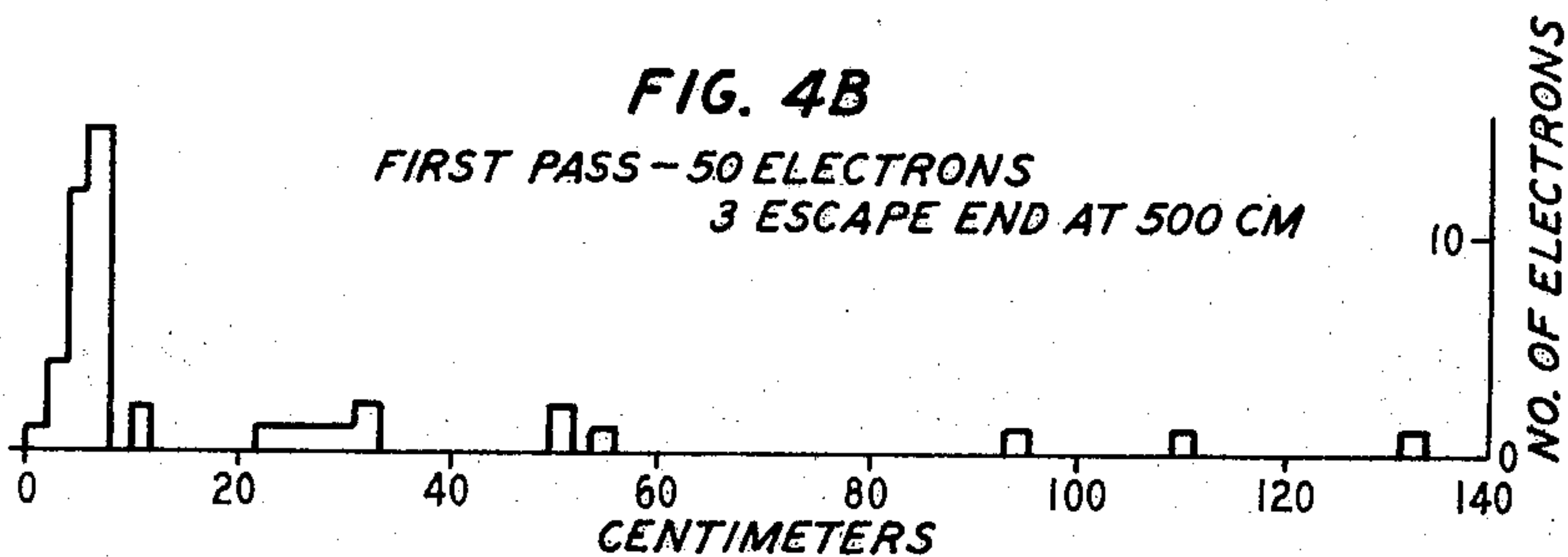


FIG. 4C

*SECOND PASS - 185 ELECTRONS
0 ESCAPE END*

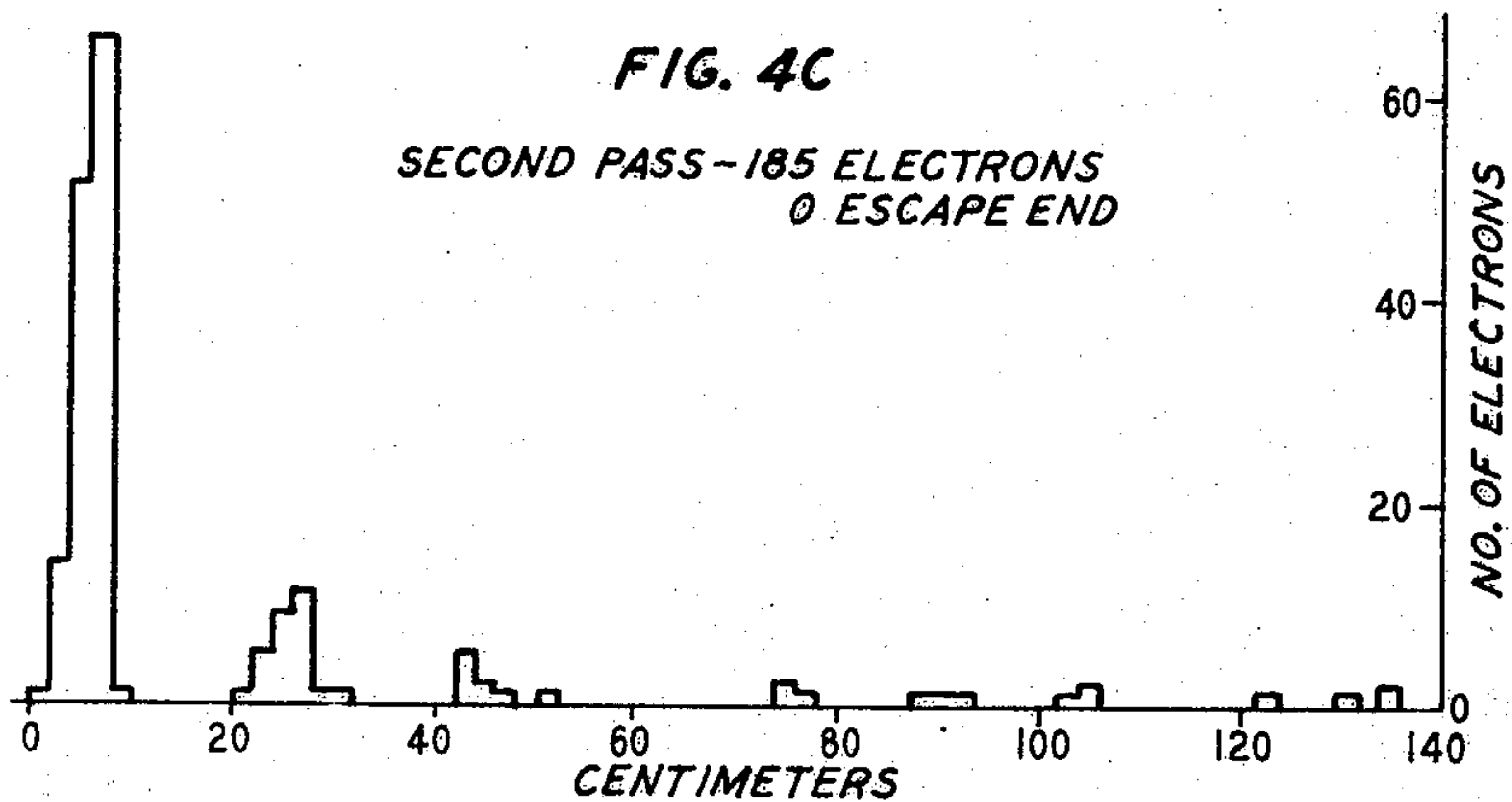
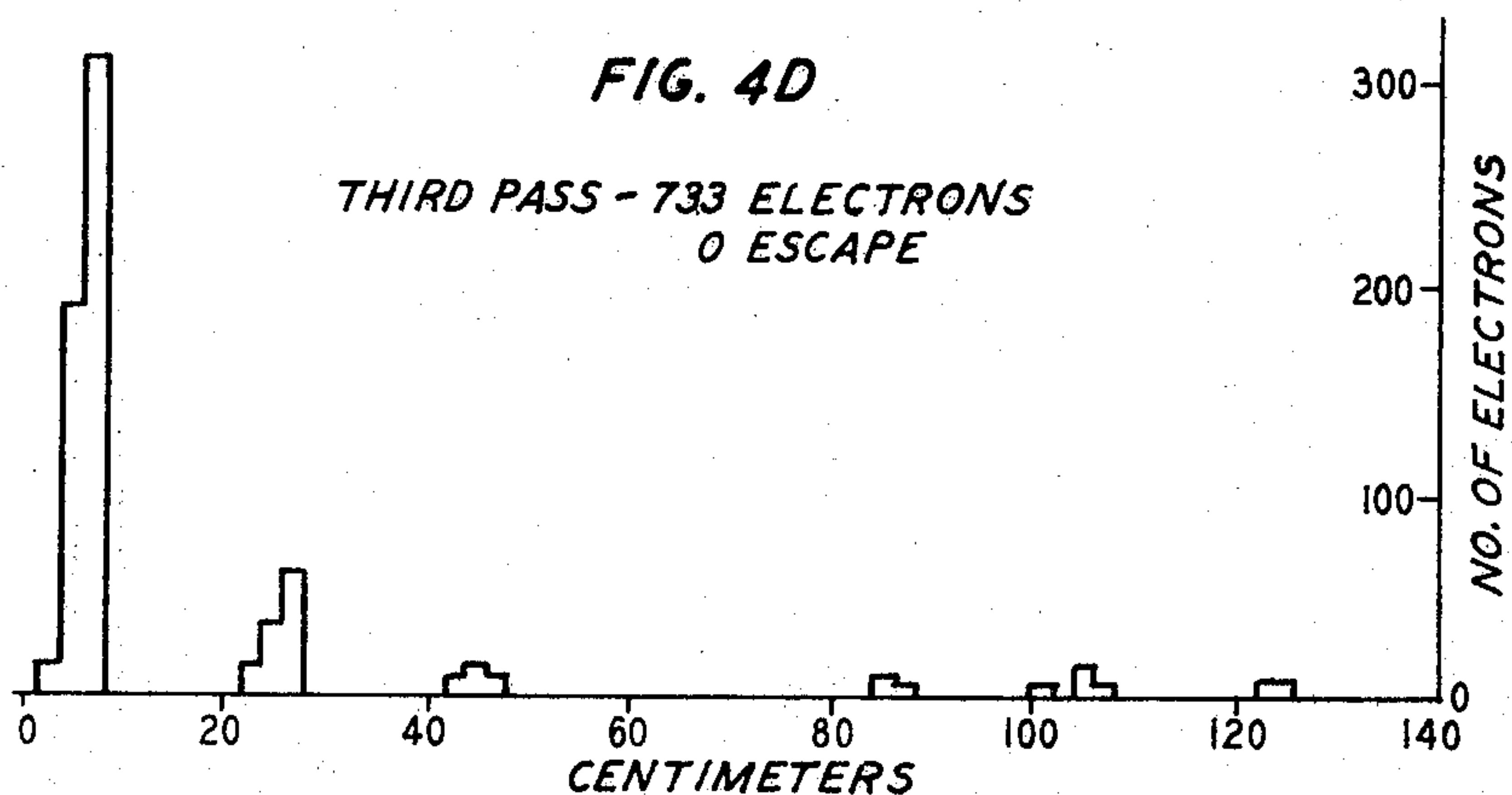


FIG. 4D

*THIRD PASS - 733 ELECTRONS
0 ESCAPE*



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SPATIALLY ALTERNATING GRADIENT VOLTAGE SYSTEM FOR A VAN DE GRAEFF ACCELERATOR

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4 Claims. (Cl. 328—233)

ABSTRACT OF THE DISCLOSURE

A Van de Graeff accelerator capable of producing higher energy particles for a given length and configuration results in the superimposition of a spatially alternating component of the overall electrostatic voltage gradient.

This invention relates to particle accelerators operating on the Van de Graeff principle.

It is unnecessary to comment on the scientific significance of the Van de Graeff particle accelerator. The principle of operation, first reported in 1931, is simple in conception and application and today permits the attainment of particle energies in the range of several mev. in thousands of laboratories, both industrial and academic, concerned with the many aspects of nuclear physics.

Due to this widespread interest, the apparatus has undergone many design modifications. The substitution of high pressure gas insulation for the early use of atmospheric air, the availability of better vacuum pumps, and improvements in general design parameters such as aperture size, plate spacing, interplate insulation, etc. have permitted attainment of energies of the order of 8 mev. as compared with the approximately 1 mev. achieved by early apparatus. Still, results continue to be disappointing because of the apparent inability to attain theoretical voltage expectations.

The reason difficulties are encountered when high voltages are applied to accelerating tubes is that they display a phenomenon called "loading." This phenomenon is a condition in which large currents are observed to flow between the plates of the accelerating tube. These currents may occur as a steady D-C current flow which increases rapidly as the voltage along the tube is increased, or they may occur as discharges with slow or rapid onset and in this latter form are often called "kicks" or "spikes" and seem to display many of the properties of an avalanche breakdown process.

These loading phenomena contain large electron currents and are maintained in operation by processes which occur when electrons are accelerated and strike plates, insulators or gas molecules. An energetic electron which strikes matter can produce multiple secondary electrons, free charged ions, and uncharged particles such as photons or X-rays (often called bremsstrahlung).

A recent attempt to minimize this electron "loading" phenomenon has taken the form of the inclined field tube, 28 Nuc. Inst. and Meth., 10 (1964), which utilizes inclined field electrodes, resulting in small fields transverse to beam direction. These transverse fields tend to sweep the angularly traveling electrons out of the beam. The method has permitted attainment of higher particle energies and is considered to be a valuable contribution to the art. Unfortunately, the superimposed transverse field do affect beam direction so that particles of different mass do not travel uniaxially. Further, it is difficult to calculate the electric field due to the inclined electrodes, and the effect can only be estimated or investigated experimentally.

In accordance with this invention, it has been discov-

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ered that superimposition of a spatially alternating field gradient in the direction of the over-all gradient responsible for acceleration permits attainment of higher particle energies. This alternating field, which results in at least one local reversal of direction of gradient, and preferably two or more reversals, with respect to the accelerating field, brings this result about by particle trapping. It is postulated that this local reversal imposes a limitation on the maximum travel distance of any locally produced, and therefore low velocity, particle, so limiting the maximum energy that it can attain. This, in turn, imposes a limit on the maximum permissible multiplication. The result is to minimize the electron loading or other unwanted particle current considered to have prevented realization of higher particle energies.

It has been mentioned that considerable attention has been paid to various design parameters. The advantages and disadvantages of large and small apertures, of greater and smaller plate spacing, of increased tube length, and the like are, in large part, understood. It is possible that accepted accelerator design will be modified by work related to this invention and by other experimentation now being carried out. It is an important advantage of this invention that the inventive principles may be adapted to any existing or future accelerator design working on the Van de Graeff principle. It is possible that since the alternating field principle herein in a sense accomplishes some of the advantages gained by the use of a small aperture (that is, since both reduce mean free path), the need for smaller apertures may be lessened.

It has been generally stated that a locally reversed gradient is required in accordance with this invention. The strength of this reversal and the periodicity of its occurrence are design parameters interrelated with those considered in the design of any accelerator. Since it is the function of the reversed gradient to trap particles, its strength must be sufficient to overcome the energy of any particle to be encountered. This, in turn, is a function of the periodicity of the alternation, greater and greater reverse strength being indicated by greater intervals. Similarly, greater reverse gradient strength, or increased periodicity, is indicated by larger apertures, since larger aperture means greater mean free path and, consequently, greater energy. For most purposes, it is considered desirable to have a reverse gradient which, at the surface of the apertures, has a maximum reverse strength at least one-third that of the maximum strength in the direction of the over-all gradient and also that the periodicity be such that there is less than one reversal in the distance equal to the aperture diameter. Accordingly, a preferred embodiment of this invention incorporates such minimum reverse field strength and such minimum periodicity.

Discussion of the invention is expedited by reference to the drawings, in which:

FIG. 1 is a schematic representation of an accelerator tube in accordance with this invention;

FIG. 2, on coordinates of mv. (millions of volts) and centimeters, is a curve representing an illustrative gradient herein;

FIGS. 3A, 3B, and 3C, on coordinates of number of electrons and length of the accelerating tube in centimeters, illustrate the distribution of impacts with the wall for an assumed initial number of random electrons. Of these figures, 3A shows the starting distribution; 3B, the distribution after the first pass; and 3C, the distribution after the second pass; and

FIGS. 4A, 4B, 4C, and 4D, on the same coordinates of number of electrons and length of the accelerating tube in centimeters, assume the same number of random starting electrons initially (4A), after the first pass (4B), after the second pass (4C), and, finally, after the third pass (4D).

Referring again to FIG. 1, the tube illustrated includes metallic plates 1, each provided with an aperture 2. Wall 3, constructed of an electrically insulating medium through which metallic plates 1 extend, is cylindrical in configuration, and defines an enclosure within which a vacuum is maintained by a means not shown. A voltage gradient produced by a source such as a Van de Graaf generator, not shown, is maintained across the initial and final of plates 1. An alternating perturbation along the over-all unidirectional gradient is imposed by means of the resistor network 4. In accordance with this illustrative arrangement, alternate plates are connected by a series pair of resistors 5 and 6, with the resistance value of resistor 6 being appreciably greater, perhaps twice that of resistor 5. Assuming, for discussion, a negative particle accelerator, so that there is an over-all positive gradient in the direction of the arrow, intermediate plates 1 are maintained at a potential slightly higher than that of the succeeding plate in this direction. For the arrangement shown, the potential level of such intermediate plates is at a higher potential by an amount approximately equal to one-third that of the drop across the series pair. In operation, charge particles are injected, by means not shown, into the straight section defined by apertures 2 at the upper most plate position. This is a schematic representation, and no attempt has been made to show the practical refinements generally incorporated in such apparatus.

The reversal field length, strength and interval of FIG. 1 are illustrative of but one acceptable embodiment. Length need not correspond with a single plate spacing but may extend over many; strength may vary so long as the inventive requirements are met; and intervals for reversal fields may be different from those of forward fields.

In FIG. 2, there is depicted a field gradient such as occurs in the apparatus of FIG. 1. The particular apparatus for which the plot is made has a depicted tube length of 100 cm., along which length there is maintained a gradient of 4 mv. Over this length there are five field reversal positions in which the maximum gradient is of the order of 0.03 mv./cm., which, in turn, is about one-third the value of the maximum forward potential of 0.1 mv./cm.

FIGS. 3A through 3C and 4A through 4D are graphical representations resulting from trajectory random calculations for assumed uniform starting conditions in a standard Van de Graaf accelerator (FIGS. 3) and an alternating gradient accelerator in accordance with this invention (FIGS. 4). For the purpose of the calculations resulting in this data, a uniform distribution of starting electrons having random initial velocities and direction was chosen. It was assumed that all electrons originated at the accelerator tube wall, although the apparatus does have the ability to trap electrons which start in the center of the tube unless they are collimated along the axis. The initial kinetic energy was assumed to be a random value between zero and a maximum of 10 kev. The trajectories of these electrons were then followed until they hit the wall. It was assumed that each electron produced about four secondary electrons. These were then followed and distributions of collisions with the walls were found up through two multiplications in FIG. 3 and three multiplications in FIG. 4. The potential gradient of the tube calculated was 15 mv. in sixteen feet.

In the figures, fifty random electrons are released from a starting distribution distributed over a 20 cm. period (FIGS. 3A and 4A). The accelerating force is to the right. The distribution of impacts with the wall is shown in the box labeled "first pass" (FIGS. 3B and 4B). Each of these electrons then releases four secondaries, whose impact distribution is shown as the "second pass" (FIGS. 3C and 4C). For the case of the alternating gradient device, the next generation of secondaries is again

followed (FIG. 4D). After only two multiplications for the conventional accelerator (FIG. 3C), 141 out of 200 electrons have already traveled more than two meters beyond the region of calculation. The buildup of a large number of secondaries having large energies and the simultaneous release of X-rays proceed rapidly.

The contrast to this situation in the case of the alternating gradient tube is quite dramatic. Out of the original fifty uniformly distributed electrons, only three managed to go a full 500 cm., and those remaining produced 125 secondary electrons whose distribution of impacts is shown in the "second pass" of FIG. 4C. These electrons show a strong tendency to collect in trapping regions at 0-10 cm., 20-30 cm., and 30-40 cm. By the third multiplication (FIG. 4D), 500 out of a total of 733 electrons were trapped within 10 cm. of the starting distribution, and all the others were trapped within a few trapping periods. No further gain in energy can be realized by the avalanche, and its buildup is effectively halted.

The invention has been discussed in terms of a limited number of embodiments. The inventive principle of superimposing a spatially alternating gradient such as to result in at least one region of reversed gradient in the beam travel direction of a Van de Graaf accelerator is considered to be generally applicable. The proposed trapping method gives electron suppression for all of the avalanche and loading mechanisms which have been proposed as limiting the maximum energy in such an accelerator. It has been found that the parameters of the tube, such as aperture, plate spacing, and gradient periodicity, are not critical, in consequence of which the alternating field principle can be adapted to existing Van de Graaf accelerators.

While the invention is discussed in terms of accelerators per se, it is apparent the principles of this invention are applicable to apparatus in which the accelerating tube is only a part. Such embodiments may take the form of klystron amplifiers and oscillators as well as traveling wave tube amplifiers and oscillators in which a high velocity particle beam is used. Other uses include X-ray generators, particle beam welding equipment, food sterilizers, chemical processors in which particle beams or ionizing radiation is used to catalyze reactions, etc.

What is claimed is:

1. Van de Graaf accelerator apparatus defining a path over which particles are accelerated, with means including a series of plates each having an aperture which together define the beam path for providing a substantially fixed electrostatic voltage gradient along such path, said gradient having an over-all value and also having a spatially alternating component sufficient to produce a reversal in field direction in at least one position along said path during particle traversal.
2. Apparatus of claim 1 in which the maximum strength of the field in the said position is at least one-third that of the maximum strength of the over-all gradient.
3. Apparatus of claim 1 in which there are at least two said positions separated by a distance greater than the said aperture diameter.
4. Apparatus of claim 1 in which the said means includes a resistor network.

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