

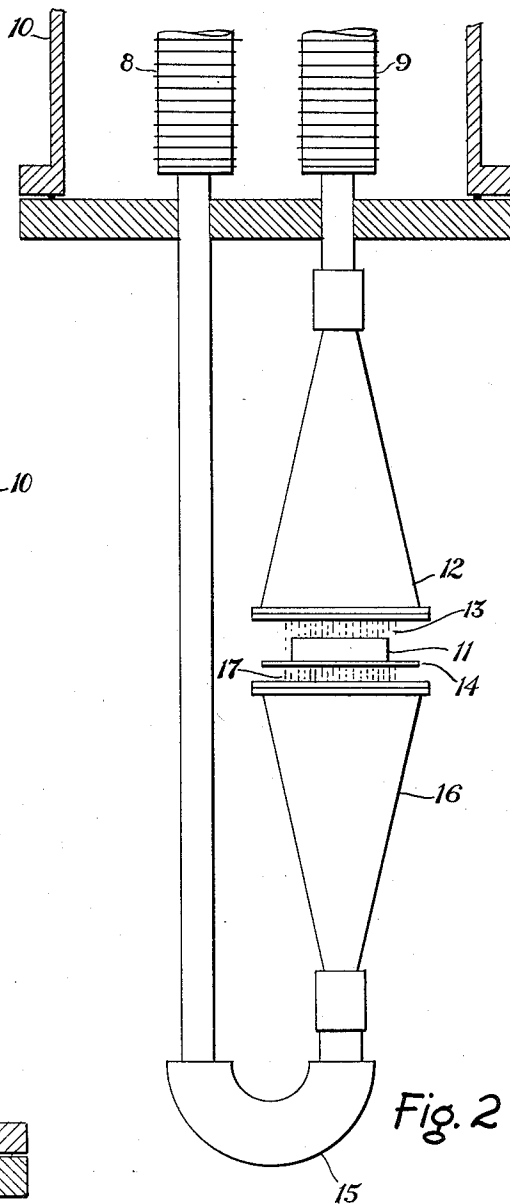
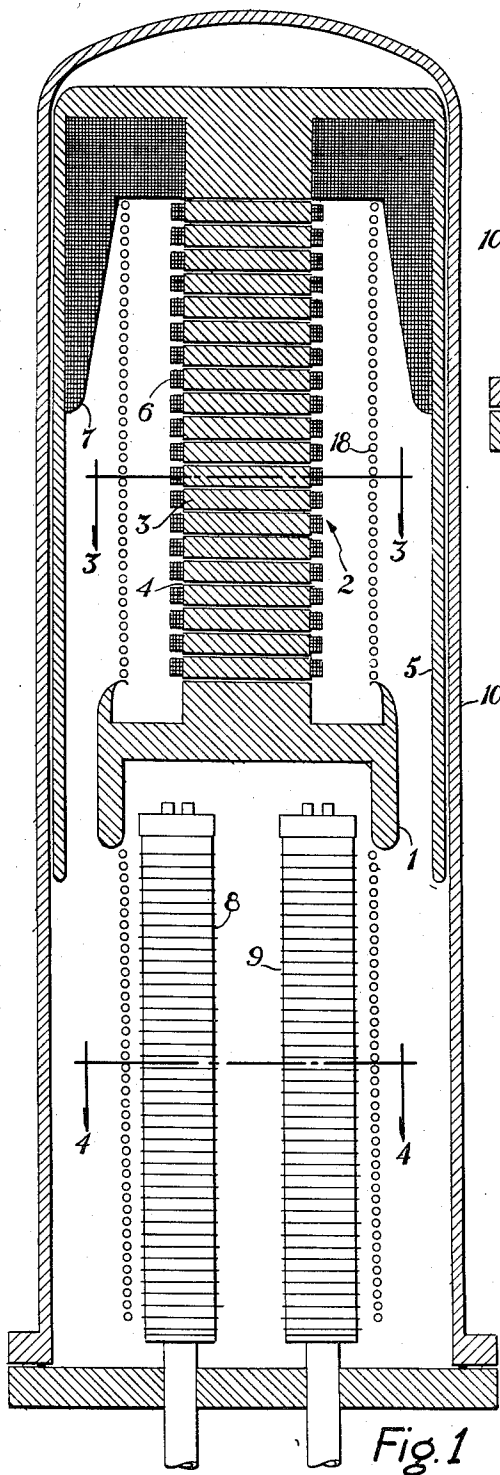
April 5, 1960

R. J. VAN DE GRAAFF ET AL
ACCELERATION AND APPLICATION OF HIGH INTENSITY
ELECTRON BEAMS FOR RADIATION PROCESSING

2,931,903

Filed June 17, 1957

2 Sheets-Sheet 1



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2 Sheets-Sheet 2

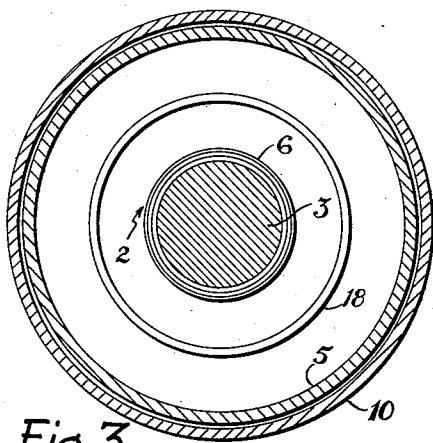


Fig. 3

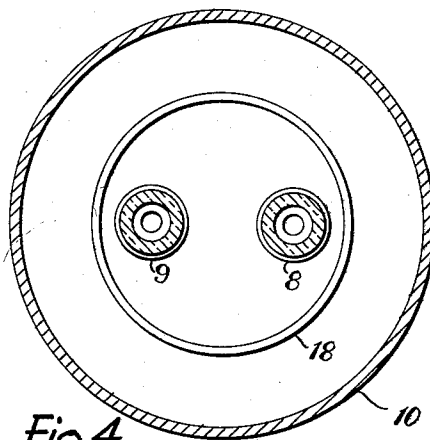


Fig. 4

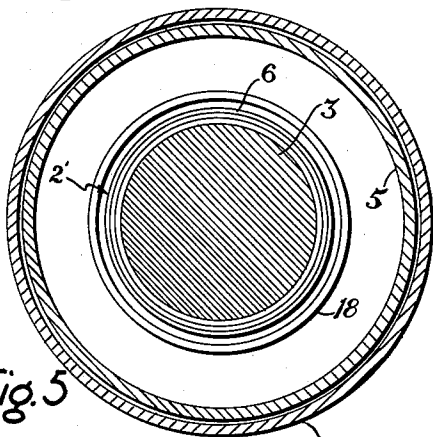


Fig. 5

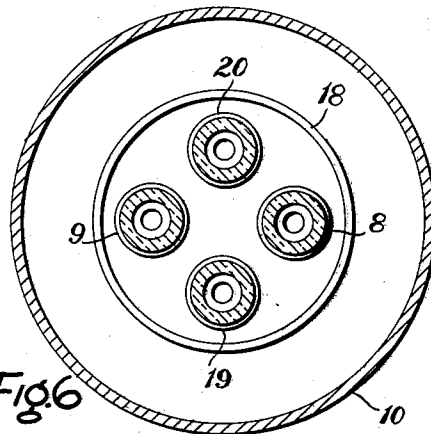


Fig. 6

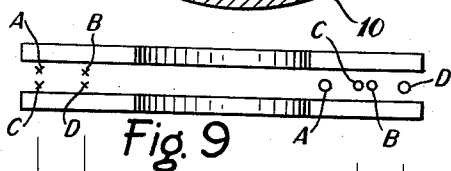


Fig. 9

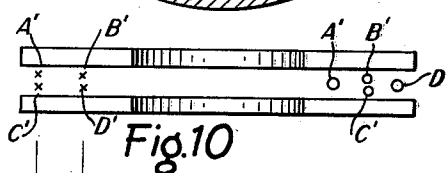


Fig. 10

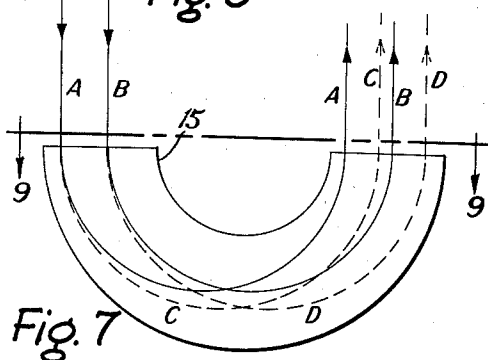


Fig. 7

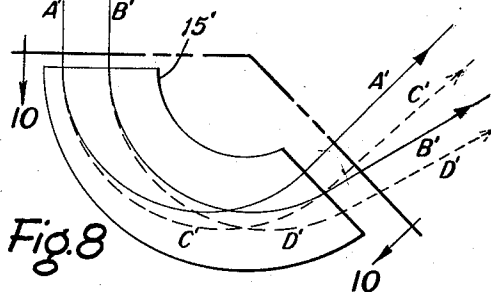


Fig. 8

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2,931,903

ACCELERATION AND APPLICATION OF HIGH INTENSITY ELECTRON BEAMS FOR RADIATION PROCESSING

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Application June 17, 1957, Serial No. 666,161

10 Claims. (Cl. 250—49.5)

This invention relates to the production of high-energy electron beams for radiation processing and in particular to a method of and apparatus for converting the power output of a high-power high-voltage D.C. generator into electron beams which are then applied in radiation processing in a highly efficient manner. Briefly stated the invention comprehends, in combination with a high-power high-voltage D.C. generator, at least two acceleration tubes in which electrons are accelerated to high energy, the electron beam from one tube being directed from one aspect onto the product to be irradiated, and the electron beam from the other tube being reflected by a magnetic mirror and directed onto the product from an opposing aspect.

Assuming the availability of a high-power high-voltage D.C. generator, the problem of converting this power into electron radiation efficiently becomes a real one. As high powers are attained, the efficiency tends to become more important. Present-day high-voltage electron acceleration tubes are not able to operate at very high powers. Not only does the tube itself encounter breakdown difficulties at high powers, but the cathode filament and the electron window have limited life at high electron currents under high-voltage conditions. In accordance with the invention, the use of two tubes reduces in half the power-handling requirement of each tube with its associated cathode and window. Moreover, the outputs of the two tubes bombard the product from opposing aspects, thereby gaining the increased range and better uniformity and efficiency which result from double bombardment techniques. By using two tubes, one is able to take full advantage of the special electron optical properties of a magnetic mirror. Even in the case of energy variations, the reflected beam is directed parallel to the incident beam, and any lateral displacement of the reflected beam caused by an energy variation is relatively small. Various devices, in which more than one beam is produced after accelerating a single electron beam, are not able in this simple manner to take advantage of the magnetic mirror. The apparatus of the invention uses a magnetic mirror in such a way that the reflected beam is, identical to the direct beam, so that a standard scanner may be used on both beams in a standard way.

The invention may best be understood from the following detailed description thereof, having reference to the accompanying drawings in which:

Fig. 1 is a longitudinal central section taken through the electron-accelerating portion of one embodiment of the invention;

Fig. 2 is a longitudinal central section of the beam-deflecting apparatus associated with the device of Fig. 1;

Fig. 3 is a section along the line 3—3 of Fig. 1;

Fig. 4 is a section along the line 4—4 of Fig. 1;

Fig. 5 is a view similar to that of Fig. 3, but showing a modification adapted to provide additional power;

Fig. 6 is a view similar to that of Fig. 4, but showing a modification in which four acceleration tubes are employed;

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Fig. 7 is a diagram illustrating the trajectories of four electrons through a magnetic mirror;

Fig. 8 is a diagram similar to Fig. 7 but showing the trajectories of four electrons through a magnetic deflection device which does not have the properties of a magnetic mirror;

Fig. 9 is a diagrammatic view along the line 9—9 of Fig. 7; and

Fig. 10 is a diagrammatic view along the line 10—10 of Fig. 8.

Referring to the drawings, and first to Figs. 1—4 thereof, high voltage is generated at a high-voltage terminal 1 by a somewhat modified version of the high-voltage generator described and claimed in a co-pending application, Serial No. 647,915, filed March 22, 1957, and assigned to the assignee of the present invention. The high voltage terminal 1 forms part of a magnetic circuit which also includes a core 2, comprising a series of magnetic elements 3 spaced by thin layers 4 of insulating material. The magnetic circuit is completed by a magnetic lining 5 and by the gap between the high voltage terminal 1 and the magnetic lining 5. The high voltage terminal 1 is electrically connected to ground through a series of secondary coils 6 in which an electromotive force is generated by the changing magnetic flux in the core 2 which is produced by a primary coil 7. The high voltage thus generated is used to accelerate electrons in a pair of acceleration tubes 8, 9. The entire voltage-generating and electron-accelerating apparatus is enclosed within a grounded tank 10 which is filled with a suitable insulating gas such as sulphur hexafluoride at high pressure. The acceleration tubes might be placed alongside the core 2 or else centrally within a transformer core which has been made hollow in order to receive the tube. However, in the former event the acceleration tubes must be provided with a magnetic shield. In the latter event, while the use of such a hollow transformer core in effect shields the electrons from the magnetic field, edge effects are produced at the inside edge of the insulating layers 4 which are undesirable. In the apparatus shown in Figs. 1—4 the accelerator tubes 8, 9 are placed outside the magnetic circuit. This leaves more room for the transformer part of the apparatus and also eliminates the need for much magnetic shielding without producing the undesirable edge effects resulting from a hollow core. Moreover, the arrangement shown in Figs. 1—4 renders the power unit independent of the acceleration tubes. That is to say, if it should be decided to use the power unit for other purposes it may be so used and the tube may be removed without affecting the operation of the power unit.

In order to improve operation of the device as a D.C. machine, a series of rectifiers (not shown) such as silicon diodes may be provided. These rectifiers must be alongside the core 2 but other control apparatus, such as the control rods (not shown) for adjusting the filament current, may be placed alongside the acceleration tubes 8, 9 thereby again increasing the space available for the magnetic circuit. The beam from one acceleration tube 8 is directed onto the product 11 to be irradiated in the conventional manner; for example, this beam may be scanned by a suitable scanning device 12 so as to emerge into the atmosphere as a sheet-like stream of electrons 13. The product 11 to be irradiated is conveyed through the sheet 13 transversely thereto. For solid products a belt conveyor 14 of wire mesh may be used.

The beam from the other acceleration tube 9 is directed into an electron-optical arrangement which is herein referred to as a magnetic mirror 15. This comprises a magnet whose pole pieces flank the electron beam and which produces a uniform magnetic field perpendicular to the plane of the drawing. The edges of the

pole pieces are so arranged that the incident beam enters the field normal to its edge and emerges from the field after being deflected through 180° . The emergent beam is then scanned by a scanning device 16 and directed onto the product 11 as a sheet-like electron stream 17 from a direction opposite to that of the first beam 13 in the conventional manner. By using the magnetic mirror 15, which has special properties, and by maintaining both beams in vacuo until just before they strike the product 11, the invention provides very accurate electron optics.

The power output of an electron accelerator such as that shown in Figs. 1 through 4 may be increased by increasing the diameter of the magnetic core 2. Referring now to Figs. 5 and 6 therein is shown an electron accelerator which is identical to that shown in Figs. 1 through 4 except that the diameter of the core 21 has been increased as much as possible and still lie within the equipotential rings 18 whose diameter is limited by the dielectric strength of the insulating gas. If the resultant additional power is too much for two tubes to handle, an additional pair of tubes 19, 20 may be provided as shown in Fig. 6. Summarizing somewhat, the removal of the first pair of acceleration tubes 8, 9 from a position along side the core 2 to that shown in Figs. 1 to 4 provides additional space for the transformer core 2 so that the voltage generator can then be modified as shown in Fig. 5 by increasing the diameter of the core 2' so as to give additional power. Then this additional power can in turn be handled by adding a second pair of tubes 19, 20 as shown in Fig. 6. If four tubes are used, two of the tubes would bombard the product with adjacent electron streams from one aspect and the other two would be reflected by two magnetic mirrors and bombard the product with two adjacent electron streams from an opposing aspect. Each pair of adjacent electron streams can easily be aligned. Alternatively only one pair of tubes could be used at any one time with the second pair held in reserve to provide increased reliability of operation of the accelerator.

Many of the advantages of the invention result from the ability to use a magnetic mirror with the resultant favorable electron optics. As previously noted, the percentage lateral displacement of the reflected beam is only one-half the percentage energy variation of the incident beam, and the reflected beam always has the same direction despite energy variations in the incident beam.

Referring to Figs. 7 and 9, the two trajectories illustrated by solid lines A and B, respectively, represent two electrons having the same energy both entering the magnetic field normal to the edge of the field but mutually laterally displaced. The magnetic field is, of course, perpendicular to the plane of the drawing in Fig. 7 and parallel thereto in Fig. 9. For example, these two trajectories may be taken as indicating the boundaries of an electron stream. The trajectories illustrated by the broken lines C and D respectively represent the paths which the adjacent two electrons would have taken if their energy were increased. It will be observed that despite energy variations the beam is neither magnified nor is its direction altered. Referring now to Figs. 8 and 10, therein is shown an electron beam deflector comprising a uniform magnetic field perpendicular to the plane of the drawing in Fig. 8 and parallel thereto in Fig. 10 but not adapted to the properties of the magnetic mirror. The unbroken lines A' and B' and broken lines C' and D' have the same significance as those in Figs. 7 and 9, and it will be observed that the electrons in the beam do not emerge in parallel paths but diverge and that energy variations product not only a lateral displacement of the beam but also a change in the direction of each beam and a change in the angle of divergence of the two beams.

Since electrons are being deflected by the magnetic mirror, the magnetic field required is not great and so the magnetic material need not be saturated. This per-

mits greater contrast between the magnetic material and the surrounding air of vacuum so that leakage and fringing effects are minimized. Moreover, since the electrons are deflected in vacuo, there is no scatter either from a gas or from an electron window so that the gap between the pole faces of the magnet may be made very small which further minimizes edge effects. The incident beam should be normal to the edge of the magnetic field, but this is not a critical condition, and small angular deviations are not serious. It will now be apparent that the magnetic mirror has unusual electron optical properties and one of the advantages of the invention is the fact that it permits such a device to be used.

The advantages of the invention may be seen from the following considerations. There are three steps involved in radiation processing. The first step is generating the high voltage. The second step is using the high voltage to accelerate electrons so as to produce the radiation. The third step is applying the radiation to the product in the most efficient manner. All three of these steps are essential, so that a saving in any one of them means a corresponding improvement in the whole accelerator. The invention provides a saving not only in the second step but also in the third step.

The saving in the second step results from the fact that by providing two tubes, development problems connected with increasing the power output of acceleration tubes are reduced, since if two tubes are used the development need only be pushed half as far as if the whole output were required from one tube. This is important, because at the present time the development of high-power high-voltage sources is advancing to the point where the acceleration tube as well as the high-voltage generator is limiting power output.

The invention provides a saving in the third step by virtue of the fact that it provides better and simpler electron optics, which in turn leads to better dose distribution. Increasing uniformity of dosage leads to many advantages, including, for example, the attainment of reliable and complete sterility in electron sterilization with less power. At the same time, increasing uniformity of dosage leads to the reduction of unnecessary, undesirable side effects due to non-uniformity of dosage throughout the volume of the material. It is evident that unreliability in the attainment of sterility, which results from non-uniformity, greatly impairs the usefulness of an accelerator for practical sterilization applications. Moreover, the reduction of unnecessary, extra side effects due to non-uniformity is also a very real problem at the present time. And, finally, increasing uniformity of dosage results in increased efficiency, which is of real economic importance, since energy in the form of radiation is expensive.

Other systems have been proposed for obtaining the advantages of double-bombardment techniques from a single high-voltage generator. However, in such systems it is not easy to get good electron optics. There are various disadvantages resulting from unsatisfactory electron optics, one of which is the directional effect. For example, traveling in an unnecessary air path causes scattering and loss of energy which produce a change in the characteristics of the electron beam, and this change is generally undesirable. In accordance with the invention, there are no unnecessary energy losses in the air path, and the amplification of angular deviations which would result from multiple deflections is avoided. While the principle of using double bombardment to increase uniformity of dosage is not new, the provision of the advantages of double bombardment from a single voltage generator while preserving optimum electron optics is believed to be novel and is an important feature of the invention.

Having thus described the method of the invention, together with a preferred embodiment of apparatus for carrying out the method, it is to be understood that al-

though specific terms are employed, they are used in a generic and descriptive sense and not for purposes of limitation, the scope of the invention being set forth in the following claims. In particular while the principal applications of the invention will be in the field of electron processing and while the invention has therefore been described with particular reference to electron accelerators, the invention also includes irradiation with other charged particles such as positive ions.

We claim:

1. A method of irradiating an object using high-energy electrons which method comprises the following steps: generating high-power high voltage, transforming said high-voltage power into electron radiation by accelerating at least two electron beams by means of said high voltage, directing one of said beams onto the product to be irradiated, reflecting the other beam by a magnetic mirror, and directing said reflected beam onto said product from an opposing aspect.

2. In electron irradiation a method of delivering a high-power substantially uniform dosage to the object being irradiated which method comprises the following steps: generating high voltage at high power, converting said high voltage power into electron radiation by accelerating in vacuo at least two electron beams by means of said high voltage, directing one of said beams in vacuo onto an electron window and thence onto the product to be irradiated, reflecting the other beam in vacuo by a magnetic mirror, and directing said reflected beam in vacuo onto an electron window and thence onto said product from an opposing aspect.

3. A method of generating simultaneously two beams of charged particles which are equivalent in all respects and which converge from opposing aspects, which method comprises: generating high voltage power, transforming said high voltage power into corpuscular radiation by accelerating two beams of charged particles by means of said high voltage power, and reflecting one of said beams in vacuo by a magnetic mirror.

4. A method of generating simultaneously two electron beams which are equivalent in all respects and which converge from opposing aspects, which method comprises: generating high voltage power, transforming said high voltage power into electron radiation by accelerating two electron beams by means of said high voltage power, and reflecting one of said beams in vacuo by a magnetic mirror.

5. Electron radiation apparatus comprising, in combination with a high-power high-voltage generator: at least two evacuated electron acceleration tubes each adapted to accelerate electrons by means of said high voltage, each having its own electron emitter and each having its own electron window, said electron windows facing each other and being adapted to receive the product to be irradiated therebetween, at least one of said acceleration tubes having an evacuated tube extension; and a magnetic mirror adapted to create a uniform magnetic field within said tube extension for the purpose of reflecting electrons in said tube extension through approximately 180°.

6. Electron radiation apparatus comprising in combination: a high-power high-voltage D.C. generator, which has at least two evacuated electron acceleration tubes each adapted to accelerate electrons by means of said high voltage, each having its own electron emitter and each having an evacuated tube extension terminating in an electron window, said electron windows facing each other and being adapted to receive the product to be irradiated therebetween, and a magnetic mirror adapted to create a uniform magnetic field within one of said tube extensions for the purpose of reflecting electrons in said tube extension through approximately 180°.

7. Apparatus for irradiating an object using high-energy electrons comprising in combination: means for generating high-power high voltage, means for transforming said high-voltage power into electron radiation by accelerating at least two electron beams by means of said high voltage, means for directing one of said beams onto the product to be irradiated, magnetic mirror means for reflecting the other beam, and means for directing said reflected beam onto said product from an opposing aspect.

8. In electron irradiation apparatus for delivering a high-power substantially uniform dosage to the object being irradiated comprising in combination: means for generating high voltage at high power, means for converting said high voltage power into electron radiation by accelerating in vacuo at least two electron beams by means of said high voltage, means for directing one of said beams in vacuo onto an electron window and thence onto the product to be irradiated, magnetic mirror means for reflecting the other beam in vacuo, and means for directing said reflected beam in vacuo onto an electron window and thence onto said product from an opposing aspect.

9. Apparatus for generating simultaneously two beams of charged particles which are equivalent in all respects and which converge from opposing aspects, comprising in combination: means for generating high voltage power, means for transforming said high voltage power into corpuscular radiation by accelerating two beams of charged particles by means of said high voltage power, and magnetic mirror means for reflecting one of said beams in vacuo.

10. Apparatus for generating simultaneously two electron beams which are equivalent in all respects and which converge from opposing aspects, comprising in combination: means for generating high voltage power, means for transforming said high voltage power into electron radiation by accelerating two electron beams by means of said high voltage power, and magnetic mirror means for reflecting one of said beams in vacuo.

References Cited in the file of this patent

UNITED STATES PATENTS

55	2,702,863	Koch	Feb. 22, 1955
	2,724,059	Gale	Nov. 15, 1955
	2,741,704	Trump et al.	Apr. 10, 1956
	2,777,958	Le Poole	Jan. 15, 1957
	2,796,545	Brasch et al.	June 18, 1957
60	2,824,969	Crowley-Milling	Feb. 25, 1958