April 10, 1956 J. G. TRUMP ET AL 2,741,704

IRRADIATION METHOD AND APPARATUS

Filed June 22, 1953 3 Sheets-Sheet 1

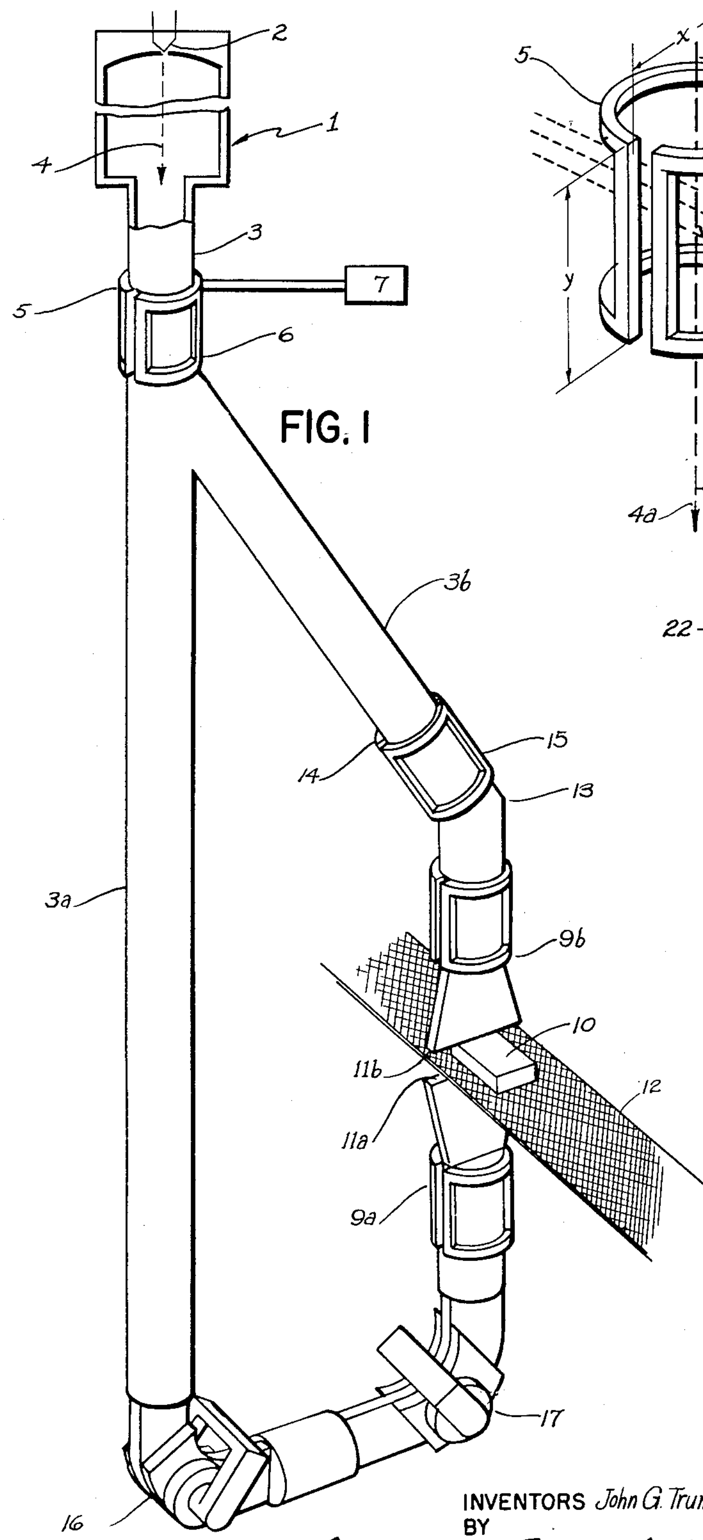

FIG. 1

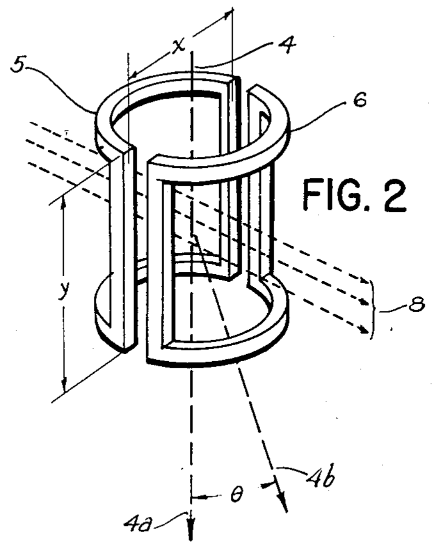

FIG. 2

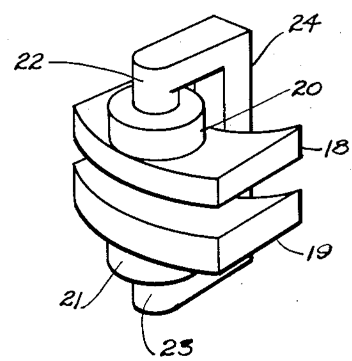

FIG. 3

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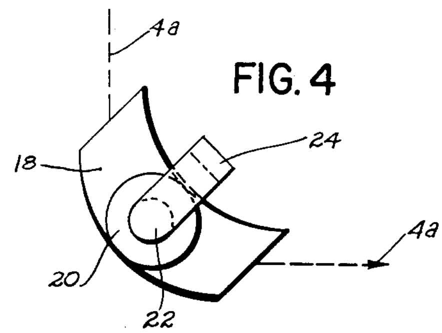

FIG. 4

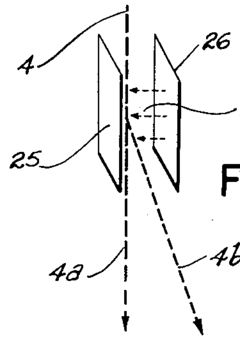

FIG. 5

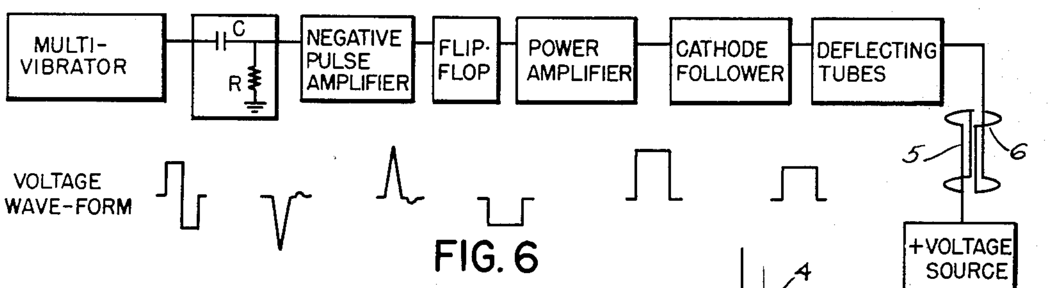

FIG. 6

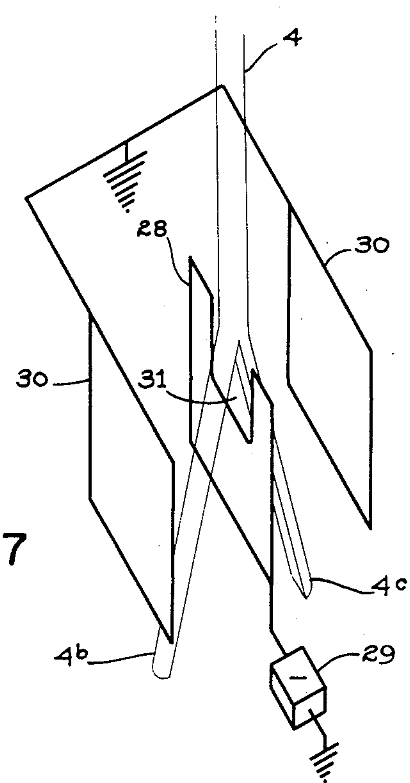

FIG. 7

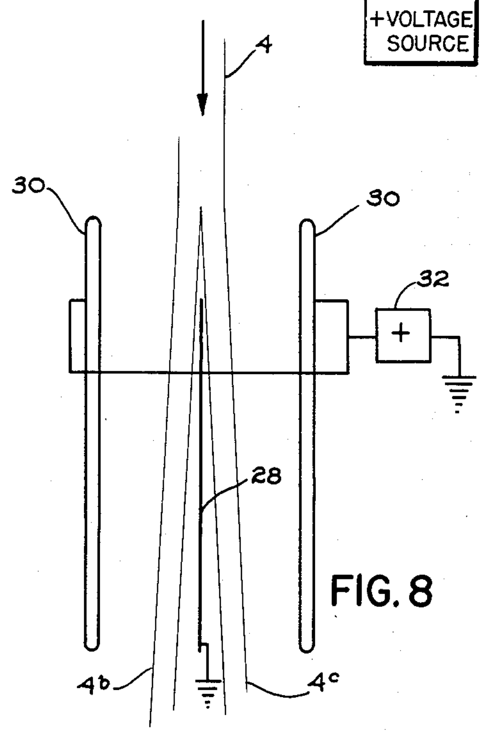

FIG. 8

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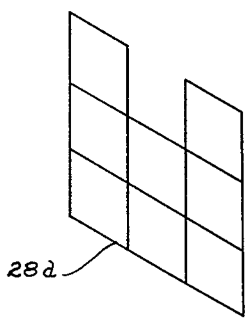

FIG. 9

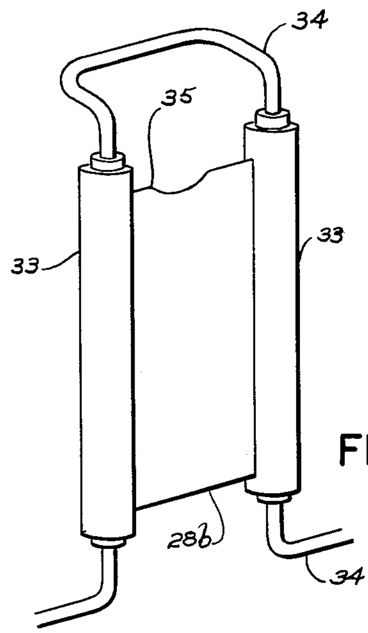

FIG. 10

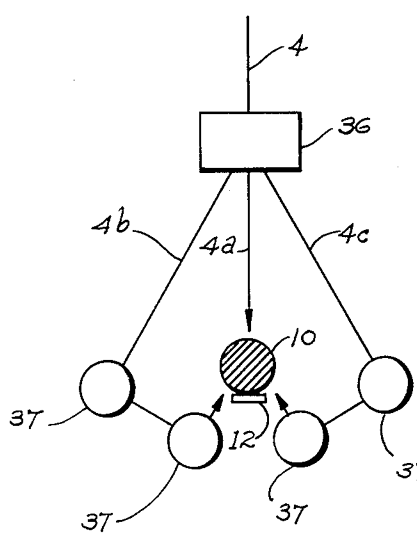

FIG. 11

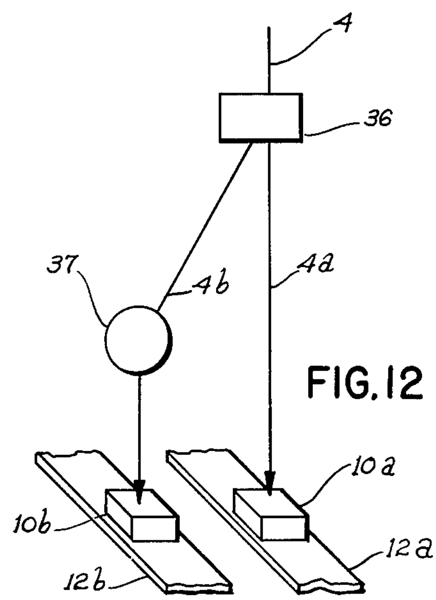

FIG. 12

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United States Patent Office

2,741,704

Patented Apr. 10, 1956

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2,741,704

IRRADIATION METHOD AND APPARATUS

John G. Trump, Winchester, and Robert J. Van de Graaff, Belmont, Mass., assignors to High Voltage Engineering Corporation, Cambridge, Mass., a corporation of Massachusetts

Application June 22, 1953, Serial No. 363,078

23 Claims. (Cl. 250—49.5)

This invention relates to the irradiation of materials or substances with high-energy charged particles and in particular to a method and apparatus for obtaining the more efficient use of the ionizing energy of a high-power beam of charged particles by splitting such beam into a plurality of discrete components.

The principal object of our invention is to multiply the effective depth of penetration of a single charged-particle source by splitting the beam of charged particles emanating therefrom and redirecting its several separated components from essentially opposing aspects toward a product, material or substance to be irradiated.

Another major object of our invention is to deflect and redirect such beam of charged particles so that such charged particles follow a plurality of discrete paths, in order to secure the more uniform distribution of ionizing energy in the irradiated product, material or substance.

Still another object of our invention is to apply a single charged-particle source to a multiplicity of production lines, where the power output of such source is too great to be applied safely or advantageously to a single production line.

Our invention may be practised to advantage with any beam of high-energy charged particles. Therefore, while our invention is herein described and illustrated with particular reference to beams of high-energy electrons, it is clearly to be understood that our invention is not limited in its application to electron beams, but also comprehends beams of protons, positive ions, and other charged particles.

In the drawings:

Fig. 1 is a view, mainly in perspective but partly in longitudinal section, of one preferred embodiment of apparatus for practising the method of our invention;

Fig. 2 is a diagram illustrating the deflecting action of a pair of beam-splitting coils upon a beam of high-energy electrons;

Fig. 3 is a diagrammatic view of a beam-bending electromagnet;

Fig. 4 is a top plan view of the beam-bending electromagnet represented in Fig. 3;

Fig. 5 is a diagram similar to Fig. 2 illustrating the deflecting action of a pair of beam-splitting electrodes upon a beam of high-energy electrons;

Fig. 6 is a diagram of a square-wave current generator for energizing the beam-splitting coils represented in Fig. 2;

Fig. 7 is a diagram illustrating the deflecting action of a thin conducting diaphragm, maintained at constant negative potential, upon a beam of high-energy electrons;

Fig. 8 is a diagram illustrating the apparatus of Fig. 7 in the lateral view, except that in the diagram of Fig. 8 the diaphragm is grounded and flanked on each side by electrodes maintained at constant positive potential;

Fig. 9 is a diagram illustrating a modified construction of the diaphragm of Fig. 7;

Fig. 10 is a diagram illustrating another modified construction of the diaphragm of Fig. 7 and showing means for cooling the diaphragm;

Fig. 11 is a diagram illustrating a modified arrangement of apparatus similar to that shown in Fig. 1; and

Fig. 12 is a diagram similar to Fig. 11 illustrating another modified arrangement of apparatus similar to that shown in Fig. 1.

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It is now becoming established that all types of living organisms are affected by gamma rays and high energy electrons and that lethal effects can be produced on unwanted organisms by doses which will raise the temperature of water only a few degrees centigrade. The growing availability of streams of high energy electrons makes possible the practical application of this knowledge to the sterilization of many important products, such as pharmaceuticals, surgical instruments, animal tissues for transplant purposes, as well as for the preservation of certain foods. Only high energy electron sources, as distinct from gamma ray sources, appear to possess enough total power output to handle economically the considerable amounts of material which may require sterilization or preservation.

Moreover, the possibility of using various forms of ionizing radiation to promote chemical reactions has recently been explored, including highly endothermic chemical reactions which require large quantities of energy in concentrated form and exothermic chemical reactions which are triggered by the initial application of concentrated energy. Among available sources of ionizing radiation, high energy electrons seem to be the best medium for delivering ionizing energy in an efficient and controlled manner to a substance or substances for the purpose of promoting chemical reactions,

Measurements of the properties of high energy electrons have disclosed that their range in typical materials is small compared to that of gamma rays. A 2-million-volt electron has a maximum range in water of 1 cm. Beyond this limiting distance there is no ionizing effect, while the maximum ionizing effect occurs at one-third this range. Although practical high energy electron sources may be constructed for many millions of volts, such higher energy apparatus becomes progressively more expensive and also often has a lower output electron current capacity.

A common method of, in effect, doubling the range of penetration of an available stream of electrons is to irradiate the object from both sides, as by reversing the object and irradiating again, or by irradiating the object simultaneously from two electron sources. However, the former is limited to the irradiation of material in rigid form, and the latter entails the additional expense and space requirements of a second electron source. Furthermore, an interruption or modulation of electron intensity would not affect both aspects simultaneously, unless the product is irradiated simultaneously from two electron sources with special electronic coupling being introduced between the two sources; consequently, it would be difficult to re-irradiate the partially irradiated material to bring its dose up to the proper level.

Referring more particularly to the drawings, one embodiment of apparatus for practising the method of our invention is shown in Fig. 1, wherein an acceleration tube for the acceleration of electrons to high energy is indicated at **1**. Although our invention is not limited to the use of any particular apparatus for creating streams of high energy electrons, we prefer to use an acceleration tube of the type disclosed in U. S. Patent No. 2,517,260 to Van de Graaff and Buechner. By using such an acceleration tube in conjunction with an electrostatic generator of the type disclosed in U. S. Patent No. 2,252,668 to Trump, a 4-milliampere beam of electrons having an energy of 3 million electron volts has been obtained, thus providing a power output of 12 kilowatts.

Electrons emitted at the cathode **2** are accelerated through the vacuum region of the acceleration tube **1** in a manner not necessary to explain herein in detail and enter a main tube extension **3** as a concentrated and continuous beam **4** of substantially monoenergetic electrons. Said main tube extension **3** passes between a pair of beam-splitting coils **5**, **6** which are preferably shaped as shown, in order to provide a substantially uniform magnetic field perpendicular to the direction of travel of the electrons in the beam **4**.

By means of a square-wave current generator, to be described in more detail hereinafter and therefore indicated merely diagrammatically at **7** in Fig. 1, a current of predetermined value is caused to flow intermittently through said coils **5**, **6**. The effect of the resultant magnetic field upon the electron beam **4** is illustrated in Fig. 2. When no current flows through the coils **5**, **6**, the electron beam **4** travels between the coils **5**, **6** in a straight line or path, as shown at *4a* in said Fig. 2. However, when current flows through said coils **5**, **6**, a magnetic field is impressed transversely across the direction of travel of the electrons in the beam **4**, the direction of such magnetic field being indicated by the arrows **8** in said Fig. 2. Such magnetic field deflects the electron beam **4** as shown at *4b*.

Referring again to Fig. 1, it will be apparent that the effect of the beam-splitting coils **5**, **6** is to cause the electron beam **4** to travel alternately through the lower tube extension **3*a*** and the upper tube extension **3*b***. Said lower and upper tube extensions **3*a*** and **3*b*** are bent, as shown in Fig. 1, and may terminate in beam-scanning devices **9*a*** and **9*b*** respectively, which serve to fan out the electron beams **4*a*** and **4*b*** in a manner which is fully set forth in U. S. Patent No. 2,602,751 to Robinson.

A product, material or substance **10** which is to be irradiated is positioned in the path of the opposed electron streams **4*a*** and **4*b***, which issue from the lower and upper tube extensions **3*a*** and **3*b*** through electron windows **11*a*** and **11*b*** respectively, by a support **12**, which may be movable or stationary, and which is shown in Fig. 1 as a traveling belt of wire mesh. Said support **12** must be so constructed as to minimize absorption of energy from the lower electron stream **4*a***.

In order that the electron beams **4*a*** and **4*b*** may travel axially through the lower and upper tube extensions **3*a*** and **3*b*** respectively, we provide a pair of beam-bending coils at each bend in the said tube extensions **3*a*** and **3*b***. For small angles of deflection, as at **13** in upper tube extension **3*b***, we may use a pair of coils **14**, **15** which are similar to beam-splitting coils **5**, **6** and through which a constant current is fed by conventional means, not shown. For large angles of deflection, such as 90 degrees at **16** and **17** in lower tube extension **3*a***, we prefer to use electromagnets of the type shown in detail in Figs. 3 and 4. The magnetic field traversed by the electrons is produced in the space between pole faces **18**, **19** by means of coils **20**, **21**, through which a constant current is fed by conventional means, not shown. The magnetic flux created by the coils **20**, **21** is confined by the pole faces **18**, **19**, pole pieces **22**, **23** and connecting bar **24**, all of which are composed of a magnetic alloy, so that the magnetic field between the pole faces **18**, **19** is substantially uniform and is confined to an area corresponding to that of the pole faces **18**, **19**, as shown in Fig. 4. Said area is such that substantially all the electrons in the beam **4*a*** spend the same amount of time in passing through the substantially uniform magnetic field, so that all such electrons are deflected by the same amount, herein illustratively shown as 90 degrees.

As an alternative to the beam-splitting coils **5**, **6**, which split the electron beam **4** in time by means of an intermittent magnetic field, we may create an intermittent electric field perpendicular to the direction of travel of the electrons in the beam **4** by providing a pair of electrodes **25**, **26** between which said beam **4** travels, as shown in Fig. 5. A square-wave voltage generator, not shown, creates an intermittent potential difference across the electrodes **25**, **26**, whereby an intermittent electric field is impressed transversely across the direction of travel of the electrons in the beam **4**, the direction of such electric field being indicated by the arrows **27** in said Fig. 5. The effect of such electric field upon the electron beam **4**, which is composed of negatively charged particles, is to deflect said beam as shown at *4b*, the undeflected beam being shown at *4a*.

Referring again to Figs. 1 and 2, the shape of the beam-splitting coils **5**, **6** is preferably as shown, so that the magnetic field produced thereby is substantially uniform and is confined to a cylindrical volume of diameter x cm. and length y cm. If the inductance of the coils is L henries, a current of I amperes flowing therethrough will produce a substantially uniform magnetic field the total energy in which will be $\frac{1}{2}LI^2$ henry-amperes².

With such a magnetic field, the total energy required to deflect an electron beam of E m. e. v. (million electron volts) through an angle θ is

$$\frac{10}{288}E(E+1.02)\ \sin^2\theta\frac{x^2}{y}\ \text{henry-amperes}^2$$

The total energy required may be minimized by proper choice of the dimensions θ, x and y. Suitable dimensions are, for example: $\theta=16°$, $x=10$ cm., $y=25$ cm. Then, for 2 m. e. v. electrons the total energy required in the deflecting magnetic field is .0637 henry-amperes²; and for 5 m. e. v. electrons the total energy required is .318 henry-amperes².

The necessary value of LI^2 may be obtained by equating the energy required to the energy produced. Thus, for 2 m. e. v. electrons $LI^2=.127$ henry-amperes²; and for 5 m. e. v. electrons $LI^2=.635$ henry-amperes².

If a voltage V is impressed across the beam-splitting coils **5**, **6**, the time required for the current therethrough to rise from zero to the desired value I will be proportional to LI/V. Similarly, the time required for the current to fall to zero when the voltage V is removed will also be proportional to LI/V. Consequently, the value of LI is determined by the time required to shift the beam from one position to the other and by the available voltage V. Since the value of LI^2 is fixed by the energy requirements, the values of L and I may thus be ascertained.

Since it is desired to split the electron beam into discrete, time-separated components, the time required to shift the beam from one position to another should be markedly less than those time intervals during which the beam is stationary. One possible arrangement is to have the electron beam undeflected for 2500 microseconds, deflected for 2500 microseconds, and to allow 250 microseconds to shift the beam from one position to the other. If the available voltage V is 400 volts, then for 2 m. e. v. electrons $L=.032$ henry and $I=2$ amps.; and for 5 m. e. v. electrons $L=.0063$ henry and $I=10$ amps.

A suitable square-wave current generator for energizing the beam-splitting coils **5**, **6** is indicated diagrammatically in Fig. 6. Since the circuitry of the various component parts of such a square-wave generator is well-known in the art, said component parts are referred to merely by name in said Fig. 6, the voltage wave-form which is fed from each component part to the next component part being indicated in the lower portion of said Fig. 6. Referring to said Fig. 6, a multivibrator generates a 200-cycle square wave, which is differentiated by a capacitance C and resistance R and then fed to a negative pulse amplifier. The resulting trigger fires a 2500-microsecond flip-flop circuit. The negative output from the flip-flop circuit feeds a power amplifier which is coupled to a cathode-follower. The cathode-follower drives a multiplicity of deflecting tubes connected in parallel, and the output from the deflecting tubes energizes the beam-splitting coils **5**, **6**.

Both the beam-splitting coils **5**, **6** of Figs. 1 and 2 and the beam-splitting electrodes **25**, **26** of Fig. 5 serve to split the beam 4 in time into time-separated components. Our invention also comprehends splitting the beam in space, and one embodiment of apparatus for dividing the beam into two spatially-separated components is shown in Fig. 7, wherein a thin diaphragm **28** of suitable conducting material, such as tungsten, is placed vertically in the path of the electron beam 4. Said diaphragm **28** is maintained at a suitable negative potential, such as 20 kilovolts, by a voltage source which is indicated merely diagrammatically at **29**. As electrons in the beam **4** travel alongside the diaphragm on both sides thereof, they are repelled by the electric field of said diaphragm **28** and separate into two components separated in space, as at **4*b*** and **4*c*** in said Fig. 7. The two spatially-separated components may then be redirected as desired by means of beam-bending devices, as hereinbefore described.

The diaphragm **28** is preferably flanked on each side by electrodes **30** at ground potential, in order to insure a strong split electric field at right angles to the beam **4**. The upper control portion of the diaphragm **28** has been cut out somewhat, as indicated at **31**, so that the electron beam **4** may be diverged by the electric field before striking the diaphragm **28**.

The apparatus shown in the diagram of Fig. 8 is identical to that of Fig. 7, except that in the arrangement of Fig. 8 the outer electrodes **30** are connected to a positive potential source **32**, and the diaphragm **28** is grounded. The arrangement of Fig. 8 is electrically identical to that of Fig. 7 and has the advantage that the potential source **32** would probably have to supply less power.

Various alternative constructions of the diaphragm **28** will be readily apparent to those skilled in the art. For example, the diaphragm may consist of one or more transverse wires, such as the grid structure indicated in Fig. 9.

By constructing the diaphragm or electrode **28*a*** of wires, as shown in Fig. 9, an electric field may be created such that the beam 4 separates before reaching any of the wires, so that the diaphragm **28*a*** is not subjected to substantial electron bombardment. However, in certain cases it may be desirable to provide for water-cooling of the central electrode **28**. An appropriate construction of the diaphragm **28** which provides for water cooling is indicated in Fig. 10, wherein the sides **33** of the diaphragm **28*b*** are thickened and hollowed out. The diaphragm **28*b*** is cooled by water which flows through the sides **33** via the water conduit **34**. The leading edge **35** of the diaphragm is very thin, in order to minimize the amount of electron energy impinging on the diaphragm **28*b***.

If the diaphragm **28*b*** is water-cooled, it is preferably maintained at ground potential, as indicated in the construction of Fig. 8.

While in general the most useful application of our invention is to multiply the effective depth of penetration of a single electron source by dividing the electron stream into two substantially equal intervals and redirecting the component streams onto the product from opposing aspects, the shape or composition of the product may be such that irradiation from more than two aspects will be more efficient. For example, irradiation of a bottle on its side may be accomplished by a down-directed stream and by two upward opposing oblique streams, as is indicated diagrammatically in Fig. 11.

The effect of such irradiation from essentially opposing aspects is not only to increase the effective depth of penetration of the electron stream, but also to secure the more uniform distribution of its ionizing energy. Thus, referring to Fig. 11, the ionization produced in the product **10** by any one beam component, such as 4*a*, is a maximum at a short distance below the surface of the product **10**, but decreases at greater depths. However, the decreased ionization produced by said beam component 4*a* at such greater depths is increasingly supplemented by the ionization produced by the two opposing beam components **4*b*** and **4*c***, so that the distribution of ionization in depth tends to be uniform.

Uniform distribution of the beam's ionizing energy throughout the product is especially desirable in cases where a minimum dose must be received throughout the product to produce the desired effect, but where excessive dose at any point in the product may produce undesired side effects. For example, uniform distribution of ionizing energy is important in the irradiation, by high-energy electrons, of food and drugs for the purpose of sterilizing or preserving the same.

Another important application of my invention is to apply a single electron source to a multiplicity of production lines. A single electron source has space-saving and economic advantages over a multiplicity of sources. However, its power output may be too great to be applied safely or advantageously to a single production line. Excessive power in a single beam can quickly cause fires and other difficulties if the production conveyor is stopped. Moreover, a single conveyor traveling through a high-power electron stream must move rapidly in order to avoid damage to the conveyor or to the material being irradiated. By dividing the high-power electron stream into several separated components and directing such components onto a number of parallel conveyors, it is possible to maintain the conveyor speed at a more convenient rate for product-handling and practical mechanical reasons. In Fig. 12 are diagrammatically indicated two parallel conveyors **12*a*** and **12*b*** which support the products **10*a*** and **10*b*** to be irradiated. The electron stream **4** is split by the beam-splitting device **36** into two component streams **4*a*** and **4*b***, which are then redirected onto the products **10*a*** and **10*b*** respectively.

Having thus disclosed the method of our invention and several illustrative embodiments of apparatus for practising the method, it is to be understood that although 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.

We claim:

1. That method of delivering the ionizing energy of a single beam of charged particles to substances or matter so as to secure the more advantageous distribution of such ionizing energy throughout such substances or matter, which method comprises creating and directing a beam of high-energy charged particles, splitting said beam into a plurality of discrete components, and directing each of said discrete components onto substances or matter to be irradiated.

2. That method of applying the ionizing energy of a single source of charged particles to a plurality of treatment areas in substances or matter to be irradiated, which method comprises creating and directing a beam of high-energy charged particles, splitting said beam into a plurality of discrete components, and directing each of said discrete components onto a different treatment area in substances or matter to be irradiated.

3. That method of applying the ionizing energy of a single source of charged particles to a plurality of treatment areas in substances or matter to be irradiated, which method comprises creating and directing a beam of high-energy charged particles, intermittently deflecting said beam, whereby said beam is divided into a plurality of discrete time-separated components, and directing each of said time-separated components onto a different treatment area in substances or matter to be irradiated.

4. That method of applying the ionizing energy of a single source of charged particles to a plurality of treatment areas in substances or matter to be irradiated, which method comprises creating and directing a beam of high-energy charged particles, deflecting said beam by the action of an electric field so that said beam is divided in space into a plurality of discrete, spatially separated components, and directing each of said spatially sepa-

rated components onto a different treatment area in substances or matter to be irradiated.

5. That method of increasing the effective depth of penetration, in an object to be irradiated, of charged particles from a single charged-particle source, which method comprises creating and directing a beam of high-energy charged particles, dividing said beam into a plurality of discrete components by the action of a deflecting field, and causing each of said discrete components to approach said object from a different aspect.

6. That method of increasing the effective range of an available stream of charged particles which comprises creating a beam of high-energy charged particles, directing said beam from one aspect onto an object to be irradiated, intermittently deflecting said beam, and directing the deflected beam onto said object from a different aspect.

7. That method of increasing the effective range of an available stream of charged particles which comprises creating and directing a beam of high-energy charged particles; causing said beam, by the deflecting action of an electric field, to split into two discrete components which follow divergent paths; and directing each of said components onto said object from a different aspect.

8. That method of increasing the effective depth of penetration, in an object to be irradiated, of electrons from a single electron source, which method comprises creating a single stream of high energy electrons, dividing said single stream into a plurality of streams by intermittently deflecting said single stream in a plurality of directions, and causing each of said streams to approach said object from a different aspect.

9. That method of irradiating an object with high energy electrons which comprises creating a stream of high energy electrons, directing said stream onto an object to be irradiated, and periodically deflecting and redirecting said stream onto said object from different aspects, so as to secure the more uniform distribution of its ionizing energy in said object.

10. That method of securing the more uniform distribution of the ionizing energy of an available stream of high energy electrons in an object irradiated by said stream, which method comprises creating and directing a beam of high energy electrons, splitting said electron beam in time, and redirecting the several time-separated components of said electron beam toward an object to be irradiated from different aspects.

11. That method of securing the more uniform distribution of the ionizing energy of an available stream of high energy electrons in an object irradiated by said stream, which method comprises creating and directing a beam of high energy electrons, splitting said electron beam in space, and redirecting the several space-separated components of said electron beam toward an object to be irradiated from different aspects.

12. That method of increasing the effective range of an available stream of electrons which comprises creating a beam of high energy electrons, directing said beam from one aspect onto an object to be irradiated, intermittently deflecting said beam, and directing the deflected beam onto said object from the opposite aspect.

13. A method in accordance with claim 12, wherein each of the time intervals during which said beam is deflected is substantially equal to each of the intervening time intervals during which said beam is undeflected.

14. A method in accordance with claim 13, wherein each of said time intervals is of very short duration.

15. That method of applying a single charged-particle source to a multiplicity of production lines of material to be irradiated, which method comprises creating and directing a high-power beam of high-energy charged particles, splitting said beam into at least as many discrete components as there are production lines, and redirecting at least one such component onto each production line of material to be irradiated.

16. Apparatus for irradiating substances or material with high energy charged particles, comprising in combination, means for creating and directing a beam of high energy charged particles, means for subjecting said beam to the intermittent action of a magnetic field extending transversely across said beam, whereby said beam is deflected intermittently, and means for directing the undeflected and the deflected portions of said beam onto substances or material to be irradiated.

17. Apparatus for irradiating substances or material with high energy charged particles, comprising in combination, means for creating and directing a beam of high energy charged particles, means for subjecting said beam to the intermittent action of an electric field extending transversely across said beam, whereby said beam is deflected intermittently, and means for directing the undeflected and the deflected portions of said beam onto substances or material to be irradiated.

18. Apparatus for irradiating substances or material with high energy charged particles, comprising in combination, means for creating and directing a beam of high energy charged particles, a plurality of coils adapted to impress a magnetic field transversely across the direction of travel of said charged particles, a square-wave current generator adapted to cause a current of predetermined value to flow intermittently through said coils, whereby said beam is deflected intermittently, and means for directing the undeflected and the deflected portions of said beam onto substances or material to be irradiated.

19. Apparatus for irradiating substances or material with high energy charged particles, comprising in combination, means for creating and directing a beam of high energy charged particles, a plurality of electrodes adapted to impress an electric field transversely across the direction of travel of said charged particles, a square-wave voltage generator adapted to impress a voltage of predetermined value intermittently across said electrodes, whereby said beam is deflected intermittently, and means for directing the undeflected and the deflected portions of said beam onto substances or material to be irradiated.

20. Apparatus for irradiating substances or material with high energy charged particles, comprising in combination means for creating and directing a beam of high energy charged particles, a thin diaphragm of conducting material supported in the path of said beam and parallel to the longitudinal axis of said beam, means for maintaining said diaphragm at a voltage which tends to repel said charged particles, whereby said beam is divided into two space-separated components, and means for directing said components onto substances or material to be irradiated.

21. Apparatus in accordance with claim 20, wherein said diaphragm comprises a plate of conducting material the upper central portion of which is cut out somewhat, whereby said beam of charged particles is caused to diverge by the electric field about said diaphragm before striking said diaphragm.

22. Apparatus in accordance with claim 20, wherein said diaphragm comprises at least one wire.

23. Apparatus in accordance with claim 20, wherein said diaphragm comprises a plate of conducting material the leading edge of which is of reduced thickness, whereby the electron energy, impinging upon said plate is minimized.

References Cited in the file of this patent

UNITED STATES PATENTS

2,372,422	Hillier	Mar. 27, 1945
2,437,912	Frondel	Mar. 16, 1948
2,447,260	Marton	Aug. 17, 1948

OTHER REFERENCES

Ser. No. 376,309, Von Ardenne (A. P. C.), published May 25, 1943.