June 8, 1954 E. A. BURRILL 2,680,815

METHOD OF AND APPARATUS FOR TREATING SUBSTANCES WITH HIGH ENERGY ELECTRONS

Filed Dec. 28, 1950

3 Sheets-Sheet 1

FIG. 1

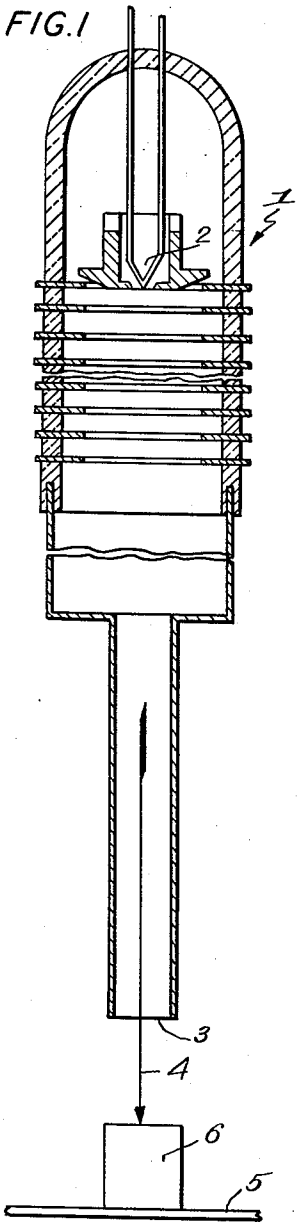


FIG. 1A

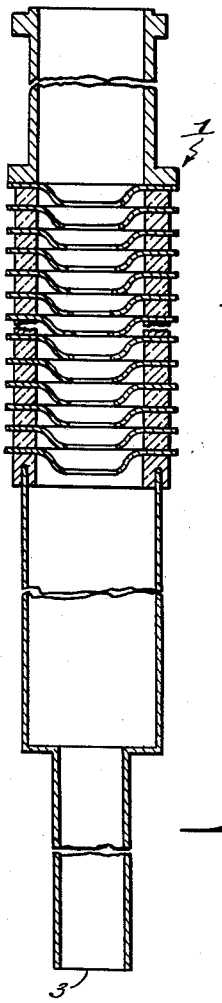


FIG. 2

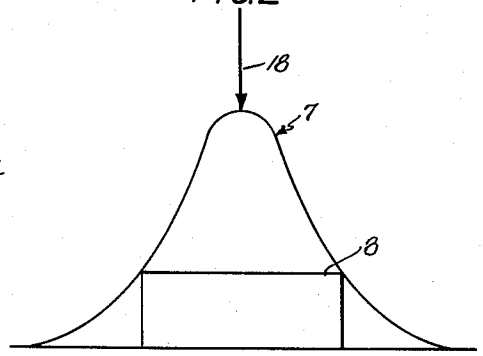


FIG. 4

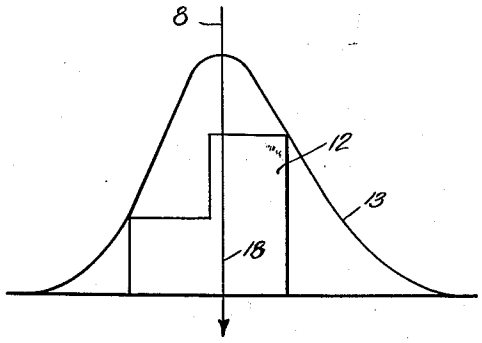
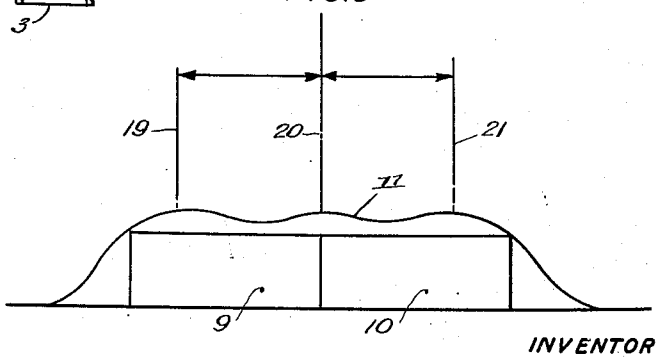


FIG. 3



INVENTOR
ERNEST A. BURRILL

BY Emery, Booth, Townsend, Miller and Laidlaw ATT'Y.

June 8, 1954 E. A. BURRILL 2,680,815

METHOD OF AND APPARATUS FOR TREATING SUBSTANCES WITH HIGH ENERGY ELECTRONS

Filed Dec. 28, 1950 3 Sheets-Sheet 2

FIG.5

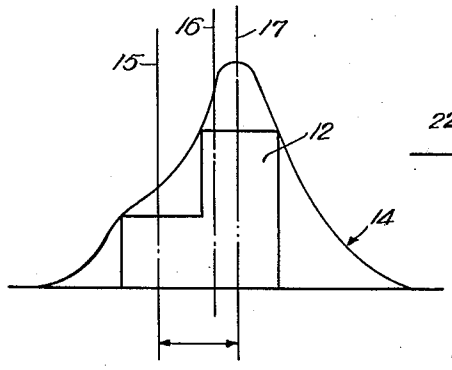


FIG.6

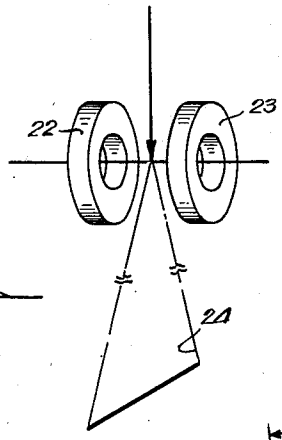


FIG.7

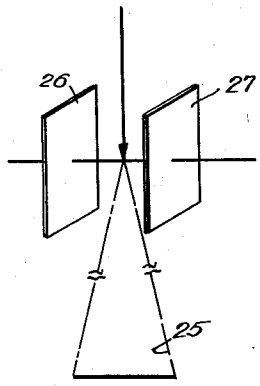


FIG.8

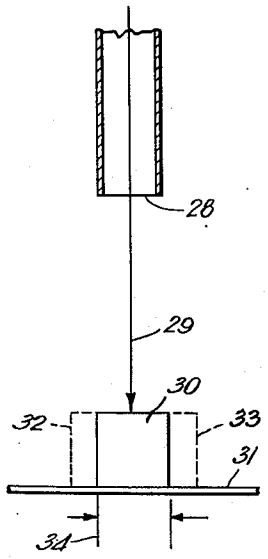
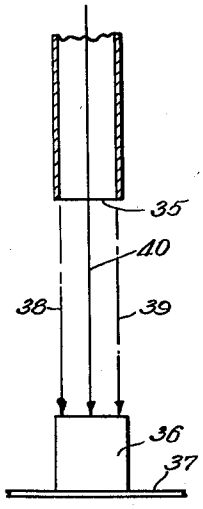


FIG.8A



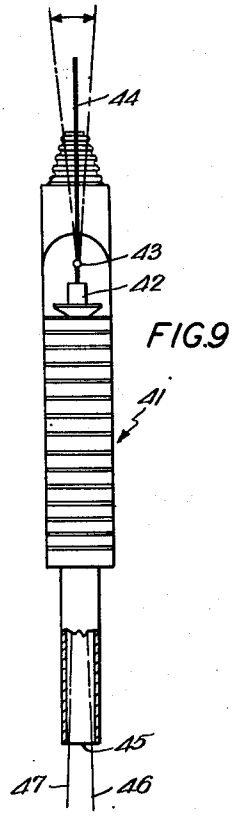
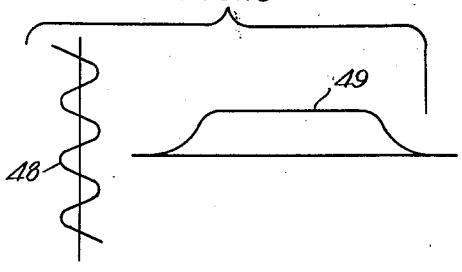


FIG.9

FIG.10



INVENTOR
ERNEST A. BURRILL
BY Emery, Booth, Townsend, Miller and Laucheimer. ATT'YS.

June 8, 1954 E. A. BURRILL 2,680,815

METHOD OF AND APPARATUS FOR TREATING SUBSTANCES WITH HIGH ENERGY ELECTRONS

Filed Dec. 28, 1950 3 Sheets-Sheet 3

FIG.11

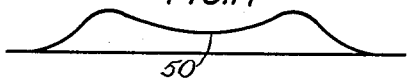


FIG.12

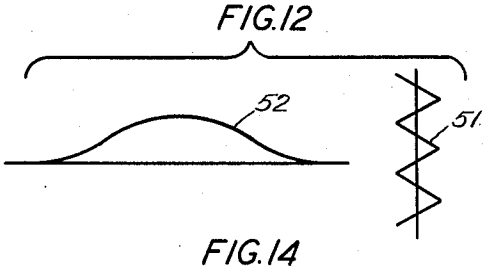


FIG.13

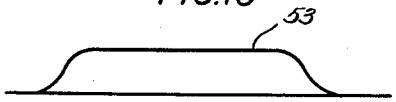


FIG.14

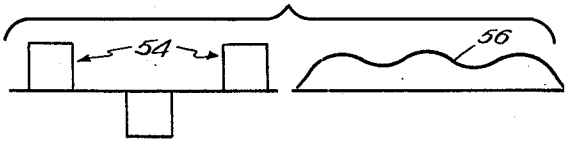


FIG.15

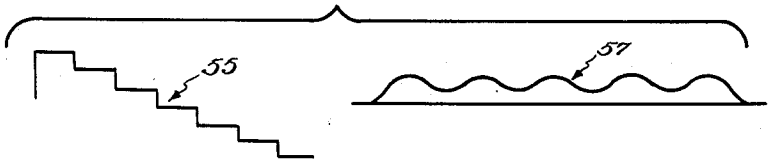


FIG.16

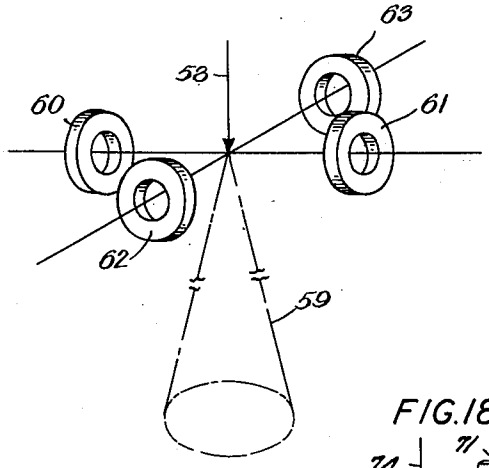


FIG.17

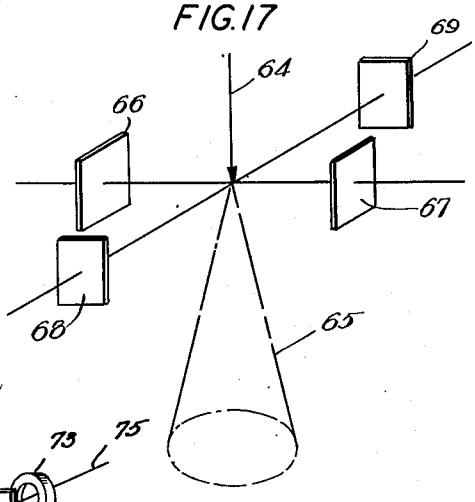
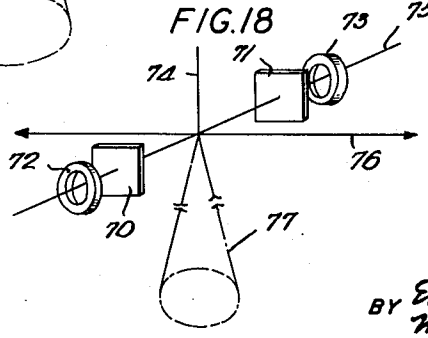


FIG.18



INVENTOR
ERNEST A. BURRILL
BY Emery Booth, Townsend, Miller and Weidner. ATT'YS.

Patented June 8, 1954

2,680,815

UNITED STATES PATENT OFFICE

2,680,815

METHOD OF AND APPARATUS FOR TREATING SUBSTANCES WITH HIGH ENERGY ELECTRONS

Ernest A. Burrill, Natick, Mass., assignor to High Voltage Engineering Corporation, Cambridge, Mass., a corporation of Massachusetts

Application December 28, 1950, Serial No. 203,172

6 Claims. (Cl. 250—49.5)

1

This invention relates to magnetic, electrostatic and other methods, and to different types of apparatus practicing methods for distributing the intensity of a high-energy electron beam, thereby to obtain a more efficient utilization of the total energy of such electron beam in the sterilization of foods, drugs, packaging material and other substances, materials, or matters, which provide for adapting the high-energy electron beam to the size of the particular product or other matter to be sterilized and which provide for obtaining a preferential distribution of the intensity of the electron beam in the sterilization of products or substances of varying thickness or density.

In order that the principle of the invention may be readily understood, I have disclosed several embodiments thereof in the accompanying drawings, wherein—

Fig. 1 is a vertical sectional view, partly broken away, of one embodiment only of an acceleration tube used in a high-voltage electrostatic generator, here shown, without limitation thereto, as for the creation and maintenance of a beam of high-energy electrons, which acceleration tube is provided with a cathode, an accelerating region and an electron or cathode-ray window of any suitable character and through which the beam of high-energy electrons may pass for sterilizing action upon the mass of the substance, material or matter that is positioned and supported beneath said window at a suitable distance therefrom, as upon a conveyor, table or other support, and in such manner that the beam may be varied by deflecting, shaping, spreading, oscillating or otherwise modifying it (or/and the substance or matter may be moved during the sterilizing action) so that the action of the beam may be accordingly modified for the purpose of increasing the percentage or proportion of equalization of the sterilizing action of said beam of high-energy electrons upon all parts of such mass;

Fig. 1A is a view very similar to Fig. 1, but showing the adaptation to my invention of the most recent form of Van de Graaff acceleration tube;

Fig. 2 is a diagram representing the uneven sterilizing action of the beam upon a product package prior to my invention;

Fig. 3 is a diagram illustrating the sterilizing action of a beam in accordance with my invention, wherein the beam is modified by a spreading or other action, or the product is moved during sterilization, or both actions occur;

Fig. 4 is a diagram showing the uneven sterilizing action prior to my invention of a beam of high-energy electrons upon a product package of irregular or uneven shape;

2

Fig. 5 is a diagram representing the more even sterilizing action of a beam of high-energy electrons when, in accordance with my invention, the beam is modified as by a spreading action, or the product is moved during sterilization, or both actions are employed;

Fig. 6 is a diagram illustrating the modification of a beam of high-energy electrons in accordance with my invention, such beam being spread by the action of alternating currents solenoid magnets;

Fig. 7 is a similar diagram illustrating the modification of a beam of high-energy electrons in accordance with my invention, the beam being spread by the action of parallel plates having alternating current high-voltage impressed across them;

Fig. 8 is a diagram representing the lower end of an acceleration tube through the cathode-ray window whereof the unmodified electron beam emerges and thence into a product that is laterally vibrated or otherwise displaced during the sterilizing action;

Fig. 8*a* is a diagram similar to Fig. 8, but wherein the axis of the beam of high-energy electrons is vibrated or otherwise moved to and fro, but the product package remains stationary during sterilization;

Fig. 9 is a diagrammatic representation of an acceleration tube of any desired or suitable type, wherein the cathode thereof is rocked or oscillated to and fro during the emission of the beam of high-energy electrons, so as to modify the said beam with respect to the position of the product package positioned beneath said acceleration tube;

Fig. 10 is a diagram indicating a sinusoidal oscillation of the beam of high-energy electrons, and at one side thereof is indicated the intensity distribution of said beam with small sinusoidal oscillations;

Fig. 11 is a diagram indicating the intensity distribution for or incident to large sinusoidal oscillations of the electron beam;

Fig. 12 is a view simular to Fig. 10, but representing a saw-toothed oscillation of the electron beam and also indicating the intensity distribution for small saw-toothed oscillations;

Fig. 13 is a diagram similar to Fig. 11, but representing the intensity distribution for large saw-toothed oscillations;

Figs. 14 and 15 are diagrams showing the effect

of square wave oscillations, both large and small;

Fig. 16 is a diagram showing the modification or displacement of the electron beam axis through the action of an alternating current magnetic field axis employing two sets of alternating current magnetic coils mutually at right angles to each other;

Fig. 17 is a diagrammatic view similar to Fig. 16, but representing the displacement or modification of the electron beam axis through the action of two sets of parallel plates providing two alternating current signals of independent frequency and magnitude; and

Fig. 18 schematically represents a combination of electrostatic and electromagnetic deflecting fields so oriented that the respective deflecting forces are mutually perpendicular.

Referring first and specifically to Figs. 1 and 1A, I have therein diagrammatically indicated at 1 an acceleration tube, partly broken away, which may be of any type, but there shown as the Van de Graaff type, Fig. 1A showing the most recent form thereof, as built by High Voltage Engineering Corporation, of Cambridge, Massachusetts, the assignee of this application and invention. The cathode from and by which the beam of high-energy electrons is emitted is indicated at 2. The cathode-ray window at the lower end of the acceleration tube is indicated at 3. Such window may be of any suitable character, as, for example, a very thin foil. The electron beam is indicated at 4, and at a suitable distance therebelow, as, for example, fifteen to forty centimeters, is positioned a conveyor support 5, movable or stationary, upon which is positioned, as an example only, a package or mass 6 of the substance to be sterilized. For example, the support may be a conveyor or a table. The distance between the cathode-ray window and the supported package or mass may be suitably varied within the scope of the invention. The substance being treated by sterilization may indeed be in virtual contact with the window, but on the other hand, it should not be unduly separated therefrom. It may be placed between such limits. The penetrating distance into the substance to be sterilized is approximately proportional to energy in the range above .1 m. e. v. It is to be understood that in all cases the conveyor, table or other support may itself be moved during the sterilizing action of the beam of high-energy electrons, or such conveyor, table or other support may remain stationary. That is to say, in accordance with my invention, I may modify, as hereinafter described or otherwise, the position of the axis of the electron beam, or I may during sterilization move the conveyor, table or other support, or I may both modify the axis of the beam and at the same time may move the conveyor, belt or other support, and I may suitably vary the distance between the window and the substance being sterilized.

The conveyor or other support is of material impervious to electron bombardment, such as metal, or I may provide means to protect the conveyor or other support in the vicinity of intense electron beam action as, for example, a plate which momentarily separates the product from the conveyor or other support. If, for example, the support is a driven conveyor, such as a belt, I may (and preferably do) during the travel of the belt, very rapidly deflect, vary, oscillate or otherwise change the position of the axis of the beam of high-energy electrons with respect to the position on the belt of the matter or substance that is to be subjected to the sterilizing action of such beam of high-energy electrons. This I may do, for example, by oscillating the said beam of high-energy electrons with great rapidity across the entire width of the traveling belt whereon the matter or substance is supported, and the speed of travel of the belt or other conveyor relative to the width of the said beam in a direction of travel of the belt or other conveyor is so arranged that each particle of the matter or substance obtains one or more successive irradiations by the said beam of high-energy electrons.

In the sterilization of foods, drugs, medical supplies, packaging material and other products, substances and materials, by means of high-energy electrons or cathode rays, the normal transverse distribution of electrons is represented by a curve as shown at 7 in Fig. 2. Although the shape of the curve may be different depending upon the energy of the electron beam and depending upon the type of cathode-ray window or scattering agent interposed between the window and the product to be sterlized, the distribution is characterized by a central region of relatively high intensity which attenuates gradually as the distance from the axis of the electron beam is increased by said curve, as indicated in said Fig. 2. A product, such as indicated at 8, being sterilized by such a beam of electrons receives more intensity than is required in its central regions and barely enough at its outer edges. As shown in Fig. 2, the portion of the curve 7 that is shaded represents electron power that is not used or which is used inefficiently. An important improvement in the efficiency of this electron beam can be obtained by spreading the intensity laterally, as is done in the practice of my invention, thus broadening the region of maximum intensity and reducing the attenuated portions. Fig. 3 shows schematically the type of improvement that would be obtained. Therein two packages are indicated at 9 and 10. Although the intensity is reduced in the central portions, the resultant beam is now broad enough so that a plurality of products (herein shown as two) can be treated at the same time. A net increase in the rate of treatment is thus obtained even though individual units of the product remain under the beam for a longer period of time. In Fig. 3 the curve is shown at 11, and the character thereof as compared with that shown in Fig. 2 is marked.

From the foregoing considerations it will be evident that my herein disclosed method is also adapted to the sterilization of products, materials, etc. whose lateral dimensions are large as compared to the natural or normal size of the beam of high-energy electrons. Products of irregular dimensions or of vary density are also treated inefficiently with the use of the normal electron beam. I obtain an improvement in efficiency by causing a preferential distribution of intensity of the beam of high-energy electrons over the surface of the product to be sterilized. This application is shown schematically in Fig. 4, which shows the inefficient utilization of electron beams prior to my invention, and Fig. 5 shows a more efficient utilization of the beam for the particular product indicated in Fig. 4. In both of said figures, the irregularly shaped package or product is indicated at 12. In Fig. 4 the curve 13 represents the sterilizing action of the beam prior to my invention, and in Fig. 5 the curve 14 repre-

sents the sterilizing action of the beam in accordance with my invention.

In both Figs. 4 and 5, the irregularly shaped package 12 is shown as of stepped form, but it is to be understood that my invention may be employed in sterilizing the contents of a package of any iregular shape or of regular shape, or of unpackaged material. In Fig. 5, the deflection of the axis of the beam distribution, in accordance with the shape of the product, is indicated by the vertical lines 15 and 17, and the axis of the undeflected beam distribution is indicated by the vertical line 16. In Fig. 4, which represents the procedure employed prior to my invention, the axis of the beam of high-energy electrons is indicated at 18. It is to be noted that in Fig. 2 the axis of the electron beam, according to the procedure of my invention, is also indicated at 18, and that in Fig. 3 the extent of beam axis displacement by any suitable means is indicated by the vertical lines 19 and 21, and the undeflected beam axis is indicated by the vertical line 20.

In former practices, as indicated in Fig. 2, the electron beam intensity varies with the distance from the beam axis. In Fig. 3, the spread electron beam intensity varies as the distance from the beam axis. The curves (Figs. 2 and 3) are plots of the electron beam intensity as a function of distance from the undeflected beam axis, and the areas under both curves are equal, representing equal total electron intensities. Fig. 3 indicates that with the same total beam intensity as in Fig. 2, two products can be treated instead of one, as in Fig. 2.

Sources of high-energy electrons.—The invention herein disclosed can be used without limitation on any electron accelerator producing electrons of energy exceeding 100,000 electron volts. Among electron accelerators which I may use are the electrostatic or Van de Graaff accelerator, resonance transformers, transformer-rectifiers in any of their modifications, impulse or Marx generators or capacitrons, microwave wave-guide linear accelerators, betatrons and synchrotrons. The electron beams from certain of them are more easily adaptable for spreading than others. The Van de Graaff-type generator, resonance transformers and transformer-rectifiers represent examples of this type. The other accelerators referred to yield electron beams in pulses rather than in a continuous stream. The adaptation of an electron beam-spreader to accelerate beams of the pulse type are discussed subsequently. My method may be practiced without limitation by many different types of electron accelerators and includes a number of different methods for modifying by a spreading or other action a high-energy electron beam, for carrying out the object thereof, and also includes markedly different apparatus for carrying out such methods. Several types of apparatus for the purpose will now be described without, however, limiting my invention thereof.

Methods of spreading a beam of high-energy electrons

A. *Magnetic deflection of electron beams.*—After electrons are accelerated to the terminal energy established by the particular accelerator used, they travel in a straight line in the vacuum region unless acted upon by some external agency. A magnetic field directed at right angles to the direction of propagation of the beam will cause the beam deflection in a direction at right angles to either of the said directions.

If the magnetic field is created by an alternating current passing through a solenoid coil, the electron beam will oscillate about its beam position with a frequency of the oscillating current and with an amplitude of oscillation depending upon the strength of the magnetic field. Fig. 6 shows diagrammatically the location of the solenoid coils 22, 23 to give the desired deflection of the electron beam, indicated at 24. A small angular beam displacement in the vicinity of the magnetic field will cause a lateral movement of the electron beam center, the magnitude of which depends upon the strength of the magnetic field and on the distance of the products therefrom. One or more solenoid coils may be used for the purpose. My invention is not restricted to the character of the apparatus producing the alternating current magnetic field required.

B. *Electrostatic deflection.*—The electron beam, indicated at 25 in Fig. 7, can be similarly deflected by an alternating electrostatic field at right angles to the direction of propagation of the electron beam. Fig. 7 shows schematically a pair of parallel conducting plates 26, 27 well insulated from each other, on which an alternating high voltage is impressed. As in the case of the magnetic deflection method and apparatus, indicated in Fig. 6, the magnitude of the displacement of the electron beam center depends upon the magnitude of the alternating high voltage and on the distance of the product from the electrostatic field.

Summarizing, Fig. 6 indicates diagrammatically the spread of the electron beam axis in the case of the application of an alternating current magnetic field, and Fig. 7 indicates the spread of the electron beam through the action of parallel plates with alternating-current high-voltage impressed across them. In accordance with my invention, the deflection of the electron beam may be effected either by an all-electromagnetic system or an all-electrostatic system, or by a combination of such two systems as hereinafter described.

In Figs. 8 and 8A are diagrammatically represented two alternative procedures constituting two different embodiments of the apparatus of my invention. In Fig. 8 the cathode-ray window of the acceleration tube is indicated at 28, the axis of the electron beam is indicated at 29, and a package of the product is indicated at 30 as supported upon a conveyor belt 31 or other suitable support. In this construction the electron beam axis is not moved or otherwise modified, but the support 31 for the product is moved, vibrated or otherwise shifted to and fro as indicated by the dotted lines 32, 33. The vibration amplitude of the product is indicated at 34.

In Fig. 8A the cathode-ray window is indicated at 35 and the beam of high-energy electrons is modified in any suitable manner while the product, indicated at 36, and the support 37 therefor remain stationary. The vibration amplitude of the acceleration tube is indicated by the vertical lines 38, 39, the axis of said beam being indicated by the vertical line 40.

It is to be understood that the beam may be vibrated or otherwise modified in any manner and that if desired I may vibrate or otherwise modify the electron beam, as indicated in Fig. 8A, and at the same time I may also vibrate or otherwise suitably move the product as indicated in Fig. 8. That is to say, I may vibrate or otherwise modify the electron beam or vibrate or otherwise modify the position of the product, or I may at the same

time both vibrate the beam and also vibrate or otherwise move the product.

C. *Mechanical oscillation of the cathode of the electron accelerator.*—I may obtain a certain amount of displacement of the center line of the electron beam with respect to the center line of the accelerating tube by mechanically displacing the cathode with respect to the acceleration tube axis. Fig. 9 shows schematically the results which can be thereby obtained. There are, however, certain limitations attendant upon a mechanical oscillation of the cathode, as follows:

The initial beam of electrons can be displaced no further than the internal diameter of the acceleration tube. This method of spreading the electron beam I do not at present consider entirely suitable for such accelerators, as the betatron or the synchrotron which do not involve high voltages but which accelerate electrons by other means. Such method and means therefor are, however, within the scope of my invention.

The cathode of an acceleration tube can be oscillated by one of several methods or types of apparatus including the following:

I establish an insulating mechanical linkage between the cathode and the grounded end of the electron accelerator, by means of which the necessary oscillation can be obtained. This manner of operation is limited to the transmittal of a relatively simple type of motion, and I do not consider it to be adaptable to some of the more complex modes of oscillation hereinafter referred to. I may oscillate the cathode by means of an arrangement which obtains its power from the same source as does the cathode filament itself. I may also employ a remote control arrangement to permit the selection of the proper mode of oscillation for the particular type of product being sterilized.

In Fig. 9 the acceleration tube is diagrammatically indicated at 41 and the cathode thereof at 42, the latter being mounted on a suitable pivot indicated at 43. By any suitable mechanical linkage, diagrammatically indicated at 44, the cathode 42 may be oscillated upon its pivot 43 to the extent indicated or described. In this figure the cathode-ray window is indicated at 45, the axis of the electron beam being indicated at 46 and the extent of the shift of the axis of the electron beam is indicated by the said line 46 and the adjacent substantially vertical line 47.

D. *Mutual oscillation of the product and the electron accelerator.*—As already stated and depending upon which is the more convenient, the product on its conveying belt or table or other support, or the electron beam issuing through the electron accelerator, or the acceleration tube itself, may be displaced, or both the electron beam and the product may at the same time be displaced in such manner that the electron beam effectively sweeps across the surface of the product. Within the scope of my invention the accelerator tube itself may be vibrated or moved slightly to and fro, thereby causing the vibration of the electron beam because of the vibration of the acceleration tube, even though the electron beam itself is not oscillated or otherwise modified with respect to the acceleration tube itself, which latter is in the instance referred to the thing that is vibrated or otherwise moved.

In the referred to manner of operation (that is, the vibration or movement of the conveying belt or table, or the vibration or movement of the electron accelerator itself, or the simultaneous movement both of the conveying belt or table and of the electron accelerator) the actual means for effecting oscillation or movement is quite simple with respect to the mechanical problems involved. Figs. 8, 8*a* and 9, as above stated, show diagrammatically how any and all of these ways of effecting oscillation or movement of one or the other, or both the elements involved, may be practiced.

Modes of oscillation of electron beams.—Depending upon the extent to which the electron beam is to spread and also upon the shape and size of the product to be sterilized, I employ various types and modes of oscillation or movement. The simplest oscillation is sinusoidal, as indicated at 48 in Fig. 10. If the displacement of the center line of the electron beam is small in comparison to the normal spread of the beam, the resultant distribution in intensity, the time being averaged, resembles that shown at 49, at the right in Fig. 10. If the deflection of the beam center line is large as compared with the normal beam diameter, the time-averaged intensity pattern would resemble that shown at 50 in Fig. 11.

A saw-toothed mode of oscillation, indicated at 51 in Fig. 12, yields the distribution shown at 52 in Fig. 12, if the beam deflection is small in comparison with the beam diameter, and is shown at 53 in Fig. 13 if the deflection is large in comparison with the beam diameter.

Figs. 14 and 15 show the effect on intensity distribution if a square-wave mode of oscillation 54 or 55 is used, for the cases of small and large deflection respectively, as indicated at 56 and 57 therein. In the case of the Van de Graaff-type of accelerator an oscillation frequency of sixty cycles per second is adequate because of the direct-current nature of the electron beam. For a transformer-rectifier set operating from sixty cycle power, an oscillation frequency for the electron beam of sixty cycles per second I consider to be adequate, but a higher frequency may be preferable to avoid the effect of interference between the normal frequency of the electron beam and the deflection frequency. The resonance transformer type of electron accelerator may operate with frequencies higher than 60 cycles per second as, for example, 180 cycles per second. For this type of accelerator, a deflection or oscillation frequency greater than the normal accelerating frequency is to be preferred.

In the case of the accelerators whose electron beam output is of a pulsed nature rather than of a continuous nature, the deflection frequency must be very high to permit using this technique. For example, the oscillation frequency for the impulse generator or capacitron must be in the megacycle range because of the fact that the pulse duration is of the order of a microsecond. The same conditions apply to the oscillation of a pulsed beam from the linear accelerator, betatron or synchrotron.

My invention as to both method and apparatus may be practiced with or by any of such types of apparatus, the adaptation of any or all of which, for practicing my invention, is within the scope of my invention.

Preliminary beam-focusing before oscillation.—The use of a direct-current annular magnet surrounding the accelerated electron beam permits varying the natural or normal diameter of the beam as it emerges from the acceleration tube. Depending upon the product to be sterilized, I consider it to be efficient either to reduce or to increase the natural or normal size of the beam

by focusing or defocusing with an annular magnet. Depending upon the magnitude of the direct-current sent through the magnet, the beam size is progressively brought to a focused and thence to an overfocused condition.

An annular electric magnet for the purpose of focusing an electron beam of swift particles is shown at 14 in Fig. 1 of the United States patent to Van de Graaff and Buechner, No. 2,517,260, dated August 1, 1950, in connection with the acceleration hereinbefore referred to. I may employ such a magnet for my said purpose.

Varying the shape of the emerging electron beam in more than one dimension.—By utilizing two sets of alternating magnet coils mutually at right angles to each other, or two sets of parallel plates, two alternating current signals of independent frequency and magnitude are applied for the purpose of producing an electron beam shape of any desired pattern such as an ellipse or a rectangle, or other geometric figure. The principle involved in this technique is well illustrated by the operation of a cathode-ray oscilloscope. Figs. 16 and 17 show schematically the effects of adding these improvements.

In Fig. 16 the electron beam axis is indicated at 58 and the spread thereof is indicated at 59. The two sets of alternating magnet coils mutually at right angles to each other, are indicated at 60, 61 and 62, 63.

In Fig. 17 the electron beam axis is indicated at 64 and the spread thereof at 65. The two sets of parallel plates are indicated at 66, 67 and 68, 69.

I have at a preceding point stated that the deflection of the electron beam may be effected by a combination of an electromagnetic system. Such a combined system is represented in Fig. 18, wherein I have represented a pair of parallel conducting plates 70, 71, and a pair of magnet coils or magnets 72, 73. The axis of the electron beam is indicated at 74, the electric field axis at 75, the magnetic field deflection force at 76, and the resulting pattern locus at the electron beam axis at 77.

It is clearly to be understood that I employ my method herein disclosed not only for products such as foods, drugs, etc., whether packaged or non-packaged, but also for the sterilization of packaging material.

Regarding the sterilization of packaging material, the state of the art is rather undeveloped at this time. There is a very evident need in commerce for sterilizing plastic foil, metal foil, cardboard, glass and plastic containers, and other substances of a similar nature. It is important in some cases that the packaging material itself be sterile in addition to the produce which is contained therein. In other cases, it is sufficient to sterilize the package material only. In any event, such packaging material would be sterilized after the articles are placed therein because, otherwise, contamination would result in the wrapping of the articles. Among packaging material that I sterilize by the method herein disclosed, I mention plastic foil, metal foil, cardboard, glass and plastic containers and other substances of a similar nature.

It is to be clearly understood from the foregoing that many different mechanisms or apparatus differing greatly from each other and independent of each other can be used to carry out the method or methods herein disclosed, and their uses for my purposes are within the scope of my invention.

The purpose of this invention is to distribute the intensity of a high energy electron beam, so as thereby to obtain a more efficient utilization of the total energy of such an electron beam. While for this purpose I have herein disclosed that I may rapidly deflect, vary, oscillate or otherwise change the position of the axis of the beam of high energy electrons, that is done for the purpose just stated.

The normal transverse distribution of electrons of a high energy electron beam is characterized by a central region of relatively high intensity which attenuates gradually as the distance increases from the axis of the electron beam, and my invention is for the purpose of remedying that condition.

This application is referred to in the specification of the patent to Denis M. Robinson, No. 2,602,751, dated July 8, 1952, between line 59 of column 1 and line 15 of column 2 of said patent. It is there correctly pointed out that this present application provides means for varying the normal relation of the axis of the beam of high energy electrons with respect to the position of the mass of the substance or material subjected to the action of such beam of high energy electrons for the purpose of more nearly equalizing the sterilizing action of such beam of high energy electrons, or, in other words, of increasing the percentage or portion of the sterilizing action of said beam upon all parts of the substance or material, while the same is being subjected to such sterilizing action.

The said patent to Robinson, No. 2,602,751, is distinguished from the present invention in that it discloses a method and means for irradiating with a continuous electron beam of high energy electrons, materials wherein it is desired to deliver the required total dosage with maximum ionization density, which method comprises rapidly scanning or sweeping such materials with such electron beam.

Therefore, this present application does not present a disclosure or anticipation of the subject matter of said Robinson Patent 2,602,751, neither does that patent present a disclosure of the subject matter of this application.

Having thus described several methods and several types of apparatus for practicing the same, 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.

I claim:

1. The method of increasing the uniformity of distribution of the intensity of a high-energy electron beam, comprising the following steps: creating a beam of high-energy electrons in an evacuated region; directing said beam of high-energy electrons out of said evacuated region and onto the surface of the mass of the substance to be irradiated by said high-energy electrons; and distributing during the irradiation the intensity of the action of the high-energy electrons on the mass of the substance being irradiated by subjecting said beam to the action of an electron-deflecting field; causing said field to vary cyclically in time, whereby the path of the intersection of said beam and the incident surface of the mass of the substance being irradiated repeatedly describes a linear pattern; and, in so varying said field, causing said field to vary in such a manner as to render substantially uniform over said linear pattern the electron current, impinging on said

surface, per unit length of the path described by the intersection of said beam and said surface.

2. A method in accordance with claim 1, wherein the electron-deflecting field is a magnetic field.

3. The method of delivering the ionizing energy of a beam of high-energy electrons to substances to be irradiated, with maximum energy efficiency and minimum side effects due to excess dosage, which method comprises the following steps: creating a beam of high-energy electrons in an evacuated region; directing said beam of high-energy electrons out of said evacuated region and onto the surface of the mass of the substance to be irradiated by said high-energy electrons; and distributing during the irradiation the intensity of the action of the high-energy electrons on the mass of the substance being irradiated by subjecting said beam to the action of an electron-deflecting field; causing said field to vary cyclically in time in such a manner that the path of intersection of said beam and the incident surface of the mass of the substance being irradiated repeatedly describes an elongated, substantially rectilinear pattern; and, in so varying said field, causing said field to vary in such a manner that the velocity with which said beam moves along said pattern from one extremity thereof to the opposite extremity thereof is substantially constant.

4. Apparatus for delivering the ionizing energy of a beam of high-energy electrons to substances to be irradiated, with maximum energy efficiency and minimum side effects due to excess dosage, comprising in combination: means for creating a beam of high-energy electrons in an evacuated region; means for directing said beam out of said evacuated region and onto substances to be irradiated by said high-energy electrons; means for creating an electron-deflecting field in the path of said beam; means for varying said field cyclically in time, whereby the path of the intersection of said beam and the incident surface of the substance being irradiated repeatedly describes a linear pattern; and means for controlling the variation of said field so as to render substantially uniform over said linear pattern the electron current, impinging on said surface, per unit length of the path described by the intersection of said beam and said surface.

5. Apparatus for delivering the ionizing energy of a beam of high-energy electrons to substances to be irradiated, with maximum energy efficiency and minimum side effects due to excess dosage, comprising in combination: means for creating a beam of high-energy electrons in an evacuated region; means for directing said beam out of said evacuated region and onto substances to be irradiated by said high-energy electrons; means for creating an electron-deflecting field in the path of said beam; means for causing the intensity of said field to oscillate, whereby the path of the intersection of said beam and the incident surface of the substance being irradiated repeatedly describes a substantially rectilinear pattern, the amplitude of said oscillation being sufficient so that the length of said substantially rectilinear pattern is large relative to the width thereof; and means for controlling the rate at which the intensity of said field varies during said oscillation so that the velocity with which said beam moves along said pattern from one extremity thereof to the opposite extremity thereof is substantially constant.

6. Apparatus for delivering the ionizing energy of a beam of high-energy electrons to substances to be irradiated, with maximum energy efficiency and minimum side effects due to excess dosage, comprising in combination: an evacuated acceleration tube for creating a beam of high-energy electrons, said evacuated acceleration tube having an electron permeable window to prevent impairment of the necessary vacuum in said acceleration tube while permitting said beam to issue therefrom; means for directing said beam out of said acceleration tube through said electron permeable window and onto substances to be irradiated by said high-energy electrons; means for creating an electron-deflecting field in the path of said beam; means for varying said field cyclically in time, whereby the path of the intersection of said beam and the incident surface of the substance being irradiated repeatedly describes a linear pattern; and means for controlling the variation of said field so as to render substantially uniform over said linear pattern the electron current, impinging on said surface, per unit length of the path described by the intersection of said beam and said surface.

References Cited in the file of this patent

UNITED STATES PATENTS

Number	Name	Date
1,870,975	Uirey	Aug. 9, 1932
1,877,382	Bills	Sept. 13, 1932
2,004,453	Watanabe	June 11, 1935
2,241,432	Von Ardenne et al.	May 13, 1941
2,333,842	Cascio et al.	Nov. 9, 1943
2,429,217	Brasch	Oct. 21, 1947
2,456,909	Brasch	Dec. 21, 1948
2,511,853	Kaiser	June 20, 1950
2,517,260	Van de Graaff et al.	Aug. 1, 1950
2,602,751	Robinson	July 8, 1952