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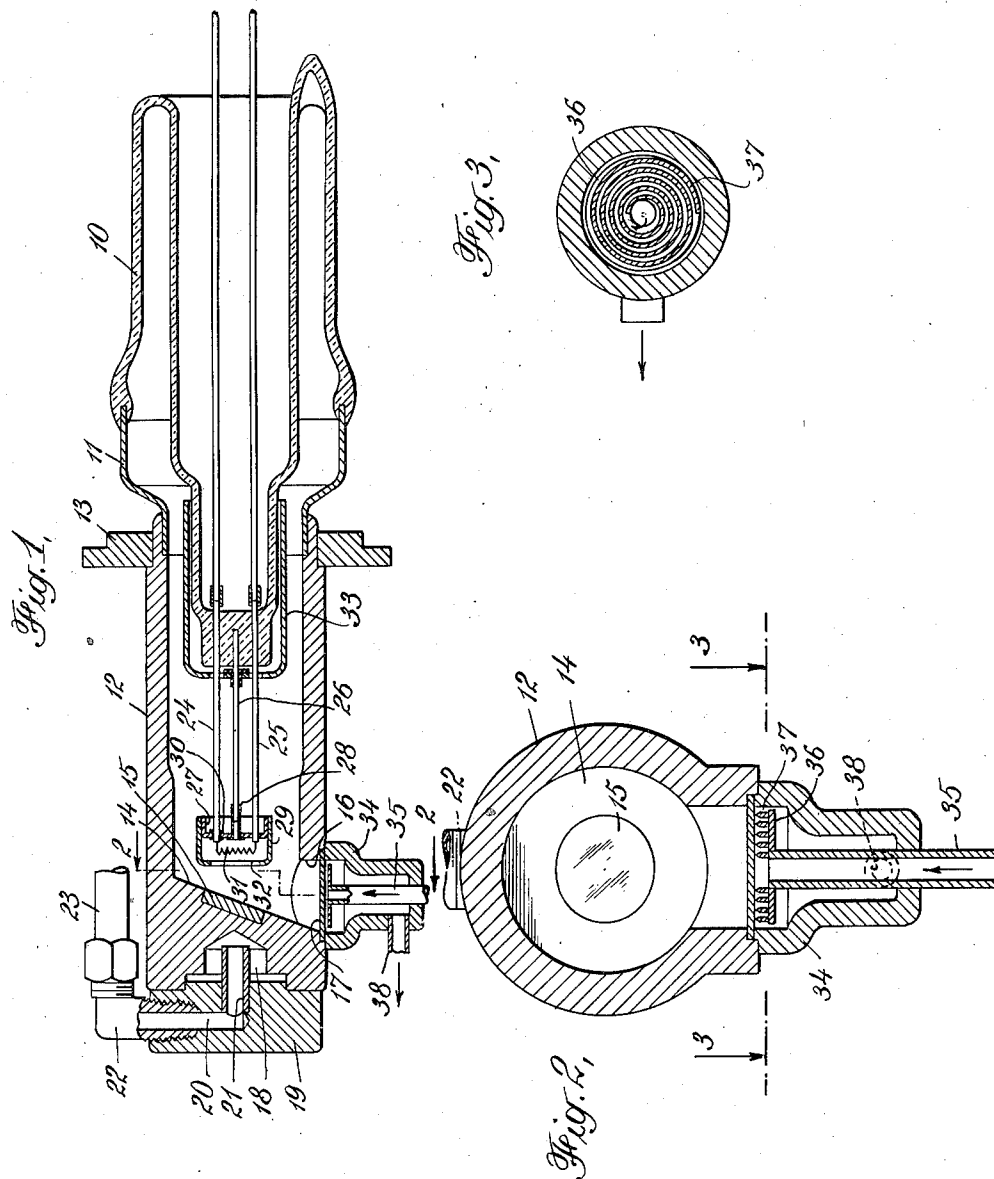
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2,480,198

ELECTRICAL DISCHARGE TUBE

Filed Nov. 26, 1945

2 Sheets-Sheet 1



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2 Sheets-Sheet 2

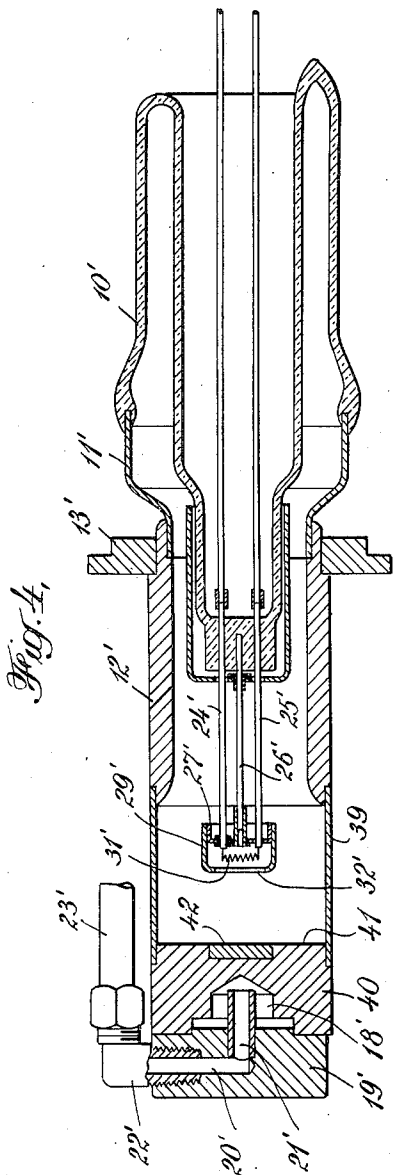


Fig. 6.

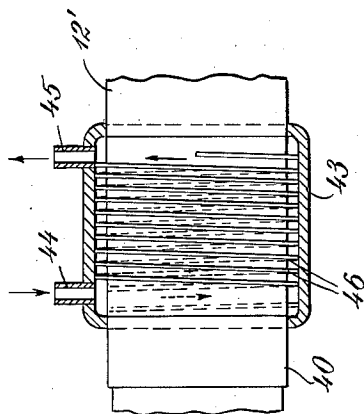
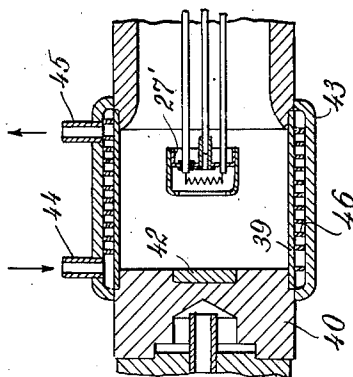


Fig. 5,



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ELECTRICAL DISCHARGE TUBE

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This invention relates to the use of X-rays in the treatment of materials for effecting changes therein, as, for example, the killing of bacteria, the production of photochemical reactions, etc. More specifically, the invention resides in a novel method by the use of which materials of various kinds may be effectively irradiated with X-rays for the purpose mentioned, and in a new X-ray tube, which may be advantageously employed in the practice of that method.

At the present time, X-rays are widely used in medicine for two main purposes, namely, diagnosis and therapy, and in these applications, the rays are employed in directly opposite manners. In diagnosis, differential absorption of the rays caused by differences in opacity in the physiological objects being examined provides the desired information, so that the useful results are obtained by reason of the modification of the beam by the object. In therapy, the X-ray beam causes modification of the object irradiated by producing ionization therein, and benefits are derived from such action, when the rays are used under properly controlled conditions. X-rays are ordinarily used in industry to provide data from which the internal structure of the specimen being examined may be determined, and, as in diagnostic use, the modification of the beam, as by differential absorption or diffraction of the rays into patterns, is utilized to provide the information sought.

Up to the present, there have been practically no industrial applications of X-rays in a manner corresponding to its use in therapy, that is, to produce changes in the material being treated, although investigations in this field have indicated that X-rays may be advantageously employed for such purposes, as, for example, for the destruction of bacteria in the sterilization of food products, and also for photochemical changes. The reason why X-rays have not been employed in industry in the applications referred to seems to be that the investigators found that, for useful results, large dosages of the rays are required and, heretofore, no tubes capable of producing X-radiation of the necessary intensity and constructed to permit effective irradiation of materials in quantity have been available.

The present invention is directed to the provision of a novel method, by the use of which materials may be rapidly and effectively treated with high intensity X-rays in order to produce changes in the materials, and of a new X-ray tube, by which that method may be conveniently practiced. The new tube is so constructed that

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it meets all the requirements for practical production of high intensity X-rays and, by its use in accordance with the method, all parts of the material undergoing treatment may be uniformly irradiated with high dosages not provided by prior tubes.

The principal factors which affect the intensity of an X-ray beam issuing from a tube are the target material, the anode voltage, the anode current, and absorption of the rays by the tube window. Other factors affecting the intensity of the beam at the point of application are the distance from the focal spot of the tube to that point, and absorption of the rays in the space between the window and that point.

The manner in which the intensity of radiation emitted from a tube varies with the target material, the anode voltage, and the anode current is given by a well-known formula, from which it is apparent that the intensity varies directly with the atomic number of the target material. From the formula, it can also be deduced that, for a constant amount of cathode-ray energy, the X-ray intensity is proportional to the anode voltage. The voltage to be used in a tube intended for high intensity X-ray production will be determined by a number of considerations, including the complexity of the apparatus, the desired wave length characteristics of the beam, etc. Also, the photoelectron production of the radiation, on which its photochemical effect depends, diminishes rapidly with an increase in the anode voltage above 70 kv., so that the anode voltage is preferably kept below that value. The intensity of the radiation is proportional to the anode current, all other factors remaining unchanged, and a tube for high intensity radiation should, accordingly, permit the use of as high an anode current as possible. The new tube includes a target of tungsten, which is of high atomic number, and, in one form, the tube has a normal continuous rating of 50 ma. at 50 kv. Such a tube provides radiation of an intensity several hundred times those employed in prior photochemical or sterilization work.

The inherent filtration of an X-ray tube, that is, the absorption of the X-ray energy by the material forming the tube wall at the point of egress of the beam, depends both on that material and on the wave length distribution of the energy in the beam. As the components of different wave length are absorbed to different extents, the inherent filtration both reduces the total energy and also changes the wave length distribution. As changes, such as the photo-

chemical effect, in a material undergoing irradiation depend upon the amount of energy absorbed, which, in turn, is dependent upon the wave length, it will be apparent that the material used for the window of a high intensity X-ray tube is of great importance.

X-ray tubes are commonly constructed with an envelope of glass of the kind known commercially as "Pyrex," and the window of such a tube may be a section of the glass wall having a thickness of the order of 1 mm. Beryllium has also been employed for X-ray tube windows, because it is the least absorptive of materials suitable for the purpose, and some use has been made of aluminum. Investigation has developed that the use of a beryllium window not only greatly broadens the wave length distribution in the beam but also gives a much greater total intensity than either "Pyrex" glass or aluminum. Thus, the total intensity values, expressed in terms of roentgens per minute, for glass and aluminum windows of 1 mm. thickness are, respectively, only 7.9% and 4.9% of that of a beryllium window of the same thickness, when the tube is operated with an anode voltage of 50 kv.

The intensity of an X-ray beam at the point of application varies inversely as the square of the distance between that point and the focal spot. It is, therefore, important that a tube for the production of high intensity X-rays for the treatment of material should have a window lying as close as possible to the focal spot and that the material should be brought as close as possible to the window. Beryllium is of such good electrical and heat conductivity that a window of that metal may be placed very close to the focal spot without becoming overheated or charged, and it is mechanically strong and resistant to chemical action, so that a wide variety of materials may be brought into direct contact with it without danger of the window being mechanically injured or corroded.

X-ray tubes with beryllium windows have been used heretofore for special purposes, such as X-ray diffraction work, for example, in which the low absorption factor of the beryllium and the possibility of placing the window close to the focal spot in order to provide a maximum intensity of characteristic radiation from a special target material are of prime importance. Such tubes, however, have commonly been provided with windows of small area, through which there is emitted only a narrow pencil of radiation, which is, however, entirely suitable for diffraction analysis. For photochemical or other similar purposes, it is desirable to irradiate as large an area as possible to increase the volume of reaction achieved and, for such uses, the prior tubes are wholly inadequate. The area over which irradiation is effected is proportional to the square of the solid angle included by the cone of radiation, and at anode voltages of the order of 50 kv. or less, the radiation issues from the target with substantially uniform intensity throughout the 180° solid angle subtended by the target face. With the prior tubes having small windows, only a small fraction of the total radiation has been utilized.

Another important factor in the treatment of materials by X-radiation is the absorption by the material itself. It will be apparent that, when a film of the material is irradiated, the layers of the film remote from the window of the tube will receive less intense treatment than the layers nearer the window, because of absorption by the nearer layers. The optimum thickness of the

film depends upon the coefficient of absorption of the material and the necessary degree of uniformity of treatment of the entire body of material. If the required degree of uniformity is high, it can be attained by using a very thin film, but, in that case, a large percentage of the radiation is wasted. Thus, if the intensity at the outermost layer is 80% of that at the layer nearest the source, 80% of the radiation is not absorbed and utilized. If, on the other hand, the film is sufficiently thick to absorb 80% of the radiation, some parts of the material may receive only a fraction of the treatment given others.

The new tube includes a beryllium window lying close to the focal spot and is provided with means by which the material to be treated may be caused to pass over the outer surface of the window in direct contact therewith and, preferably, along a prolonged path. In one form of the new tube, the material is confined in the form of a film of a thickness such that all parts of the material are treated within the degree of uniformity required, while, in another construction, provision is made for subjecting a thicker layer of the material to the action of the rays and, at the same time, creating turbulence in the material, so that there can be no shielding of some of the material by the remainder and uniform treatment is obtained. The tube window is of relatively large area in all forms of the new tube, so that a large volume of the material can be treated at a time, and, in one construction, the window is of cylindrical form, so that about half of the total radiation emanating from the target is utilized, which is a much larger proportion than is usefully employed with prior tubes.

For a better understanding of the invention, reference may be made to the accompanying drawings, in which:

Fig. 1 is a longitudinal sectional view through one form of the new tube;

Fig. 2 is a sectional view on the line 2—2 of Fig. 1;

Fig. 3 is a sectional view on the line 3—3 of Fig. 2;

Fig. 4 is a longitudinal sectional view through another form of the new tube, with parts omitted;

Fig. 5 is a longitudinal sectional view through parts of the complete tube of Fig. 4; and

Fig. 6 is a view in side elevation of the tube shown in Fig. 5, with parts broken away.

The form of the new tube shown in Figs. 1-3, inclusive, includes an evacuated envelope comprising a reentrant end section 10 which may be made of glass and is connected by a metal sleeve 11 to a hollow anode section 12, which may conveniently be made of copper. Section 12 is provided with a circumferential flange 13, by which the tube may be mounted on any suitable support and within a shock-proof and ray-proof housing, if desired. Section 12 has an inclined end wall 14, within which is embedded a tungsten disc 15 forming the target and, at the outer end of wall 14, a window opening 16 is formed through the side wall of section 12. The window opening is closed by a disc or window 17 of beryllium or of the beryllium alloy of Claussen Patent 2,306,592, issued December 29, 1942. The window is preferably about 1 mm. thick.

The solid end of the anode section has a cavity 18, which extends inwardly to terminate a short distance from the back of the target, and the outer end of the cavity is closed by a block 19, which has a radial passage 20 through it to a cen-

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tral tube 21 projecting into the cavity. A fitting 22 is threaded into the block at the end of the passage, and a cooling fluid is supplied through a line 23 leading to the fitting. The fluid issues from tube 21 into the cavity and flows over the inner end wall of the cavity to escape by another passage (not shown) in block 19, which leads from the cavity to a discharge fitting and a line similar to fitting 22 and line 23. The coolant prevents overheating of the target during tube operation and the target is grounded through the cooling system.

A pair of conductors 24, 25 are sealed through the end wall of the re-entrant portion of section 10 of the envelope and a supporting rod 26 is seated at one end in the wall between the conductors. At its inner end, the rod carries a cathode comprising a metal cup 27, seated on a metallic bushing 28 on the end of the rod, and an outer metallic focusing cup 29 telescoped over cup 27. The conductor 24 extends through an insulating bushing 30 seated in an opening in the bottom of cup 27 and conductor 25 extends through another opening in the bottom of the cup and in electrical contact with the cup. A helical filament 31 lies between the bottoms of cups 27 and 29 and its ends are connected to the conductors 24, 25. The bottom of cup 29, which faces the target, is formed with a slot 32 aligned with the filament. The usual shield 33 for protecting the glass-metal seals between conductors 24, 25 and the end wall of section 10 is mounted on a bushing on rod 26.

A casing 34 is secured to the outer wall of anode section 12 to enclose the outer face of the window 17 and a tube 35 extends into the casing free of the walls thereof and terminates close to the window. The tube carries a flange 36 on its inner end which is approximately the same shape and size as the window and lies parallel thereto. As shown in Figs. 2 and 3, a spiral partition 37 may be mounted on the flange 36 to engage the opposed surfaces of the window and define a prolonged passage from the end of tube 35 to the edge of flange 36. The casing is provided with an outlet near its outer end from which leads a tube 38.

The tube is constructed to operate continuously at a high rate of power input, such as 50 kv. and 50 ma., with a focal spot approximately 5 mm. wide. The outer surface of the window may be about 2 cm. from the center of the focal spot and the window may be of such dimensions that the cone of radiation passing therethrough includes a 40° solid angle. When the tube is operated at the rating referred to, the intensity of the radiation at the outer surface of the window is of the order of 2,330,000 roentgens per minute.

In the practice of the new method, the material to be irradiated is caused to pass over the outer surface of the window of the tube in the form of a thin film while the tube is producing high intensity radiation. The material may be liquid or gaseous or it may be in the form of solid particles of fine size suspended in a liquid or a gas. The fluid discharged against the outer surface of the window from the tube 35 flows across the window surface into the main body of casing 34, from which it issues through the outlet into tube 38. When no means, such as the spiral partition 37 are employed to guide the fluid and prolong its path of travel, it tends to flow radially from the discharge end of tube 35 across the window surface, and in that case, it is important that the flange 36 lie close to the window, so that the film of fluid being treated will be thin. The thickness

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of the film depends upon the degree of uniformity of treatment that is desired, since the material in that part of the film lying close to the window will absorb some of the radiation and thus reduce the energy available for acting on the material more remote from the window. By varying the distance between flange 36 and the window and thus controlling the thickness of the film, the variation of the treatment given the material in different parts of the film may be kept within desired limits.

In order that the material may be properly treated at an increased rate, means, such as the spiral partition 37, may be employed. Such means serve to prolong the path of the material over the surface of the window and also to create turbulence in the material, so that there is no stratification therein and all parts of the material come into direct contact with the window surface during their travel across it. Such turbulence may be increased by the use of baffles attached to the walls of the partition or any other suitable means in the path of the material.

The tube shown in Figs. 4 to 6, inc., is of the same general construction as that above described but differs therefrom with respect to the window. The second form of tube includes an envelope made up of a glass section 10', a metal anode section 12', and a sleeve 11' connecting the two sections. A cylindrical portion of the anode section is replaced by a cylindrical window 39, which is of beryllium or of the beryllium alloy of the Claussen patent above identified. Beyond the window, section 12' is provided with an end wall 40 having a flat surface 41 extending transverse to the axis of the envelope. A target disc 42 of tungsten is embedded in wall 41. The wall has a cavity 18' closed by a block 19', in which is formed a passage 20' leading to a tube 21' entering the cavity and terminating close to the inner end wall thereof. Cooling fluid is supplied to the passage 20' through a fitting 22' and a line 23' connected thereto and the fluid escapes from the cavity through another passage (not shown) which leads to a fitting and a discharge line. Within the envelope is a cathode, which includes the cups 27' and 29' telescoped together and a helical filament 31' mounted between the cups in line with a slot 32' in cup 29'. The filament is connected to conductors 24', 25' sealed through the bottom end wall of the re-entrant portion of section 10' and the cathode is supported on a rod 26' seated in the end wall referred to.

A casing 43 encloses the window to form a liquid-tight chamber defined in part by the outer surface of the window. This chamber is provided with an inlet 44 and an outlet 45 at opposite ends, so that material to be treated travels the length of the window between the inlet and the outlet. Means may be provided within the chamber for prolonging the path of the material flowing through the chamber between the inlet and outlet and, in the construction shown, such means take the form of a helical partition 46 which co-operates with the outer surface of the window and the inner surface of the casing to define a helical passage having a considerable number of convolutions. By the use of the partition, the material flowing through the treating chamber is caused to have prolonged exposure to the radiation and, in addition, the material is made turbulent. The layer of material may, therefore, be thicker than would otherwise be permissible in order to obtain a desired degree of uniformity of

treatment. If desired, baffles may be mounted on the partition to increase the turbulence.

The tube shown in Fig. 4 is operated at a high rating, such as 50 kv. and 50 ma. with a 5 mm. focal spot, and the distance from the center of the focal spot to the outer surface of the window may be approximately 2 cm. Under the conditions of operation described, the radiation issues from the target with substantially uniform intensity through the 180° solid angle or hemisphere subtended by the target face and all the radiation, except that eclipsed by the cathode and its supporting structure, passes out through the window. About one-half the total radiation is thus available for use.

With the tube constructions described, it is possible to subject material to radiation of an intensity of a wholly different order of magnitude from that previously available, and, at the same time, to treat the material rapidly and in a uniform manner. The use of a tungsten target and a beryllium window lying close to the focal spot fulfills certain of the conditions for high intensity X-ray production and, by causing the material to flow in direct contact with the outer surface of the window over a prolonged path and in the form of a thin film or with turbulent flow, the radiation is employed to best advantage in the treatment of the material.

I claim:

1. An X-ray tube for treating material which comprises an evacuated envelope having a cylindrical window, anode and cathode means within the envelope, the anode and window being coaxial, a cylindrical sleeve enclosing the envelope at the window and with the latter defining a thin chamber, an inlet for introducing the material into the chamber, a discharge opening through which the material may leave the chamber, and means within the chamber for guiding the material from the inlet to the discharge opening along a path longer than the direct route through the chamber between the inlet and discharge opening, said means causing turbulent flow of the material.

2. An X-ray tube for treating material, which comprises an evacuated envelope having a cylindrical beryllium window, anode and cathode means within the envelope, the anode and window being coaxial, a cylindrical sleeve enclosing the envelope at the window and with the latter defining a thin chamber, an inlet for introducing the material into the chamber, a discharge opening through which the material may leave the chamber, and means within the chamber forming a tortuous passage between the inlet and the outlet, one wall of the passage being formed by the outer surface of the window, said means causing turbulent flow of the material through said passage.

3. An X-ray tube for treating material, which comprises an evacuated envelope having a cylindrical beryllium window, anode and cathode means within the envelope, the anode and window being coaxial, a cylindrical sleeve enclosing the envelope at the window and with the latter defining a thin chamber, an inlet near one end of the window for introducing material into the chamber, an outlet near the other end of the window for escape of the material from the chamber, and means for defining a helical passage encircling the window and leading from the inlet to the outlet, one wall of the passage being formed by the outer surface of the window.

4. An X-ray device for irradiating a fluid,

which comprises an evacuated envelope having a window for emission of X-rays, an anode within the envelope having a target, a cathode within the envelope for directing an electron beam against the target, means outside the envelope cooperating with the window to define a passage for the fluid, the passage having an inlet and an outlet and containing a stream of the fluid of such thickness as to absorb a substantial part of the X-rays passing therethrough, and means in contact with the fluid in the passage for causing turbulent flow of the fluid through the passage, the thickness of the passage being such in relation to its length that, in the turbulent flow of the fluid, all parts thereof absorb substantially the same quantity of radiation.

5. An X-ray device for irradiating a fluid, which comprises an evacuated envelope having a beryllium window for emission of X-rays, an anode within the envelope having a target, a cathode within the envelope for directing an electron beam against the target, means outside the envelope and spaced from the window to define a passage for the fluid, the window forming one wall of the passage, the passage having an inlet and an outlet and being of such dimension in the direction of travel of the X-rays that fluid in the passage will absorb a substantial part of the X-rays passing through it, and means in contact with fluid in the passage for causing turbulent flow of the fluid through the passage, the dimension of the passage in the direction of travel of the X-rays being such in relation to the length of the passage that, in the turbulent flow of the fluid through the passage, all parts of the fluid absorb substantially the same quantity of radiation.

6. An X-ray tube for treating material which comprises an evacuated envelope having a window, anode and cathode means within the envelope, means cooperating with said window to define a chamber in part bounded by the window for the passage of material to be treated, whereby material passing through said chamber is brought into direct contact with the window, an inlet through which material to be treated may be introduced into said chamber, a discharge opening through which treated material may leave said chamber, and means within the chamber for guiding material from the inlet to the discharge opening along a path longer than the direct route through the chamber between the inlet and discharge opening, said means causing turbulent flow of the material.

7. An X-ray tube for treating material which comprises an evacuated envelope having a beryllium window, anode and cathode means within the envelope, means cooperating with said window to define a chamber in part bounded by the window for the passage of material to be treated, whereby material passing through said chamber is brought into direct contact with the window, an inlet through which material to be treated may be introduced into said chamber, a discharge opening through which treated material may leave said chamber, and means within the chamber for guiding material from the inlet to the discharge opening along a path longer than the direct route through the chamber between the inlet and discharge opening, said means causing turbulent flow of the material, the dimension of the chamber outwardly from the window being such that X-rays passing through material filling said chamber will be attenuated to an appreciable extent by progressive absorption in the

layers of material successively more remote from the window.

8. The method of treating a material with large dosages of X-radiation in a short period of time which comprises passing the material over and in direct contact with a window of an X-ray producing device while operating the device to produce X-rays issuing through the window, the thickness of the moving material being sufficient to attenuate the intensity of the X-rays directed into it by an appreciable percentage by progressive absorption of the X-rays in the layers successively more remote from the window, and replacing the layers of the material next to the window with material from the outer layers thereof to obtain a uniform treatment of the material.

9. The method of treating a material with large dosages of X-radiation in a short period of time which comprises passing the material in a stream in direct contact with a window of an X-ray producing device while operating the device to produce X-rays issuing through the window, the thickness of the stream passing in contact with the window being sufficient to attenuate the intensity of the X-rays directed into it by an appreciable percentage by progressive absorption of the X-rays in the layers successively more remote from the window, and creating turbulence in the flowing stream while it is being subjected to the X-rays to replace the material in direct contact with the window with material from the outer layers of the flowing stream to obtain uniform treatment of the material.

10. The method of treating a material with large dosages of X-radiation in a short period of time which comprises passing the material over

and in direct contact with a window of an X-ray producing machine which will transmit the longer wave length components generated at the target while operating the device to produce X-rays issuing through the window, the thickness of the moving material being sufficient to attenuate the intensity of the X-rays directed into it by an appreciable percentage by progressive absorption of the X-rays in the layers successively more remote from the window, and replacing the layers of the material next to the window with material from the outer layers thereof to obtain a uniform treatment of the material.

11. The method of treating a material with X-radiation as set forth in claim 8 in which the material is guided while passing in contact with the window to cause it to travel a path longer than the direct route over the window.

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