L. REIFFEL

2,797,333

X-RAY SOURCE

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Fig. 1

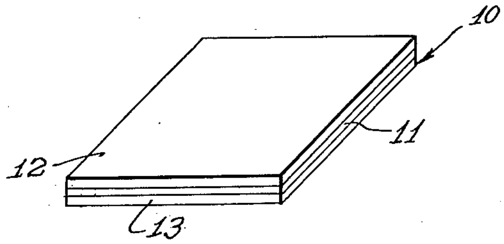


Fig. 2

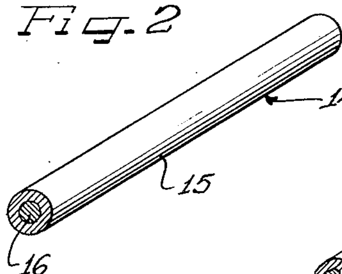


Fig. 3

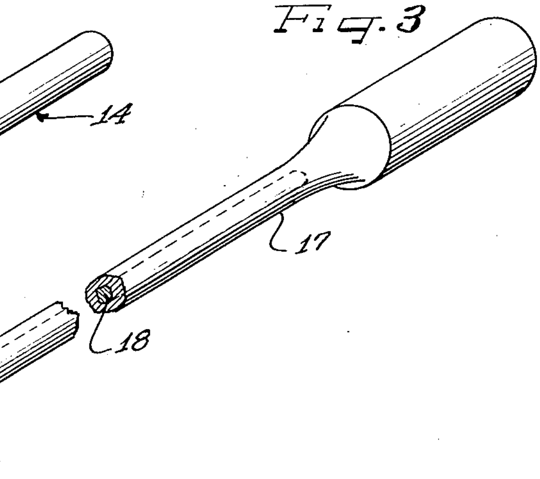


Fig. 4

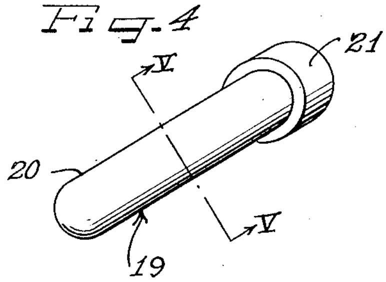
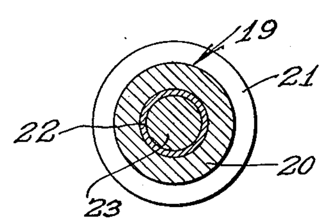


Fig. 5



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X-RAY SOURCE

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12 Claims. (Cl. 250—84)

This invention relates to a source of X-rays and, more particularly, to a source of X-rays including a source of beta particle emitting radioactive material and a target in conjunction therewith.

X-rays have heretofore been produced by X-ray tubes in which electrons are accelerated by use of a source of high potential and impinged on a target. The apparatus required is very bulky, complex and expensive to manufacture and maintain and the high potentials utilized are very dangerous.

This invention utilizes Bremsstrahlung which is radiation generated when high energy beta particles (electrons) are decelerated in the region of target nuclei. The theory underlying this effect has been known for many years but no practical use has ever been made of it. In fact, it has constituted mainly a nuisance and has been considered in practice only to the extent that shields and the like have been provided to prevent such radiation.

According to this invention, the Bremsstrahlung effect is utilized in an X-ray source which may preferably comprise beta particle emitting radioactive material in conjunction with a target.

It will be readily appreciated that this source may be very compact and yet efficient, safe, reliable and inexpensive. In addition, the intensity spectrum of the radiation produced is approximately flat from zero up to the energy of the incident beta particles so that a continuous spectrum of X-rays is produced which is desirable in many applications. Further, the invention makes possible the use of X-rays in applications where they have never before been utilized or where they have been utilized only to a very restricted extent, due to the limitations on the X-ray generating equipment previously used.

Any kind of beta particle emitting radioactive material is suitable. In most applications, the maximum energy of the beta particles should be at least 150,000 electron volts. The material may, or may not, emit alpha particles as well, since such slow moving particles will normally be readily absorbed by the target material. The radioactive material may, or may not, emit gamma rays. However, if the material does emit gamma rays, then the energy of the X-rays derived from impingement of the beta particles on the target should be at least one percent and, preferably, considerably more than 10 percent of the energy derived from the gamma rays.

The target may be of any desired material, gaseous, liquid or solid. However, in most applications, a target material having a relatively high atomic number will be preferred, since the efficiency of X-ray production is greater the higher the atomic number. Lead, tungsten and other heavy metals are particularly suitable.

According to another feature of the invention, the target is in surrounding relation to the radioactive material so that, in addition to acting to produce X-rays, it also acts as a shield preventing radiation of undesirable rays into the surrounding space. If desired, the target may be thicker on one side than another so as to prevent any radiation from the one side and to direct X-ray radiation from the other side.

According to a further important feature of the invention, the target is of such a form that it has oppositely facing boundaries. For example, it may take the form of a plate having parallel boundary surfaces or a tube having inner and outer boundary surfaces. Means are provided for impinging beta particles against one of the boundaries which means may preferably comprise beta particle emitting radioactive material but might comprise a vacuum or gaseous conduction tube or the like.

It has been discovered that for maximum efficiency, the beta particles should have sufficient energy to penetrate to the region of the other of the boundaries from which the X-rays are emitted.

Accordingly, the spacing between the boundaries should be so related to the characteristics of the target and the energy of the beta particles that the range of the particles is to the vicinity of the aforesaid other boundary.

It might be here noted that with the conventional X-ray generator tubes, the X-ray radiation is from the same side of the target as that on which the electrons are impinged, while by this invention, the X-ray radiation is from a surface or boundary of the target opposite to that on which the beta particles are impinged.

With any particular type of target material and with any maximum given beta particle energy, there will, of course, be a particular penetration range which can be determined from known tables and formula or by preliminary tests made according to well-known test procedure, as will readily be understood by those skilled in the art.

If the beta particles penetrate appreciably farther than the boundary of the target, then they may penetrate appreciable distances into the surrounding space and may likely cause harmful effects. If the beta particles do not penetrate to the region of the boundary, then there will be appreciable absorption of the X-rays and decreased efficiency. Also, the process of producing the X-rays from impingement of beta particles on the target material is, by nature, reversible. Hence, X-rays produced may act on the target material beyond the range of penetration of the beta particles and cause a "secondary" emission of beta particles from the target which, of course, would be highly undesirable.

According to a specific feature of the invention, the X-ray source may take the form of a "sandwich" in which the radioactive material is placed between two sheets of target material of a thickness depending upon the range of beta particle radiation emitted.

According to another specific feature of the invention, the X-ray source may take the form of an intimate mixture of the beta particle emitting radioactive material and the target material as liquids or as powders.

According to a further specific feature of the invention, the X-ray source may comprise a target in the form of a tube with the beta particle emitting radioactive material therewithin. The thickness of the walls of the tube is, of course, dependent upon the range of the beta particles.

According to still another specific feature of the invention, the X-ray source may comprise a capsule of very thin plastic containing the beta particle emitting radioactive material and surrounded by a removable target. This X-ray source could be "turned off" by replacing the target with a beta radiation shield of considerable thickness.

According to a still further specific feature of the invention, the X-ray source may comprise a target in the form of a hollow needle in which the beta particle emitting radioactive material is disposed. This source might, for example, be imbedded in a cancerous growth. The range of radiation and the long useful life obtainable from such a source make it particularly desirable for such a purpose.

It will, accordingly, be apparent that this invention provides a source of X-rays which is extremely compact, portable, readily used, inexpensive, safe and highly efficient.

An object of this invention, accordingly, is to provide an improved source of X-rays.

Another object of this invention is to provide an improved source of X-rays using radioactive material.

A further object of this invention is to provide an improved source of X-rays utilizing a beta particle emitting radioactive material surrounded by a target.

Still another object of this invention is to provide an improved X-ray source comprising a target having oppositely facing boundaries with means for impinging beta particles against one of the boundaries with sufficient energy to penetrate to the region of the other of the boundaries.

Other objects of the invention reside in the particular and highly advantageous arrangements of beta particle emitting radioactive material and targets.

This invention contemplates other objects, features and advantages which will become more fully apparent from the following detailed description taken in conjunction with the accompanying drawing which illustrates preferred embodiments and in which:

Figures 1, 2, 3 and 4 illustrated preferred embodiments of X-ray sources constructed according to the principles of this invention; and

Figure 5 is a sectional view through the embodiment of Figure 4, taken substantially along the line V—V.

In Figure 1, reference numeral **10** designates one preferred form of X-ray source constructed according to the principles of this invention. The source **10** is in the form of a "sandwich" in which beta particle emitting radioactive material **11** is placed between two sheets **12** and **13** of target material.

The thickness of the sheets **12** and **13** will be determined by the maximum energy of the beta particles emitted by the material **11** and the type of material used for the target sheets **12** and **13**. This thickness should preferably be such that the beta particles will penetrate to the outer surfaces of the sheets **12** and **13**. This thickness can be determined by known tables and formula or by preliminary tests made according to well-known test procedures.

As examples, the radioactive material **11** might be strontium 90 and the sheets **12** and **13** might be lead plates approximately 0.040 inch thick or platinum plates approximately 0.018 inch thick.

It will be understood that thinner plates might be used if beta particle emission is permissible or desirable while somewhat thicker plates might be used if it is desired to reduce the total energy of the X-rays or change the frequency spectrum of the X-rays emitted.

The radioactive material **11** must, of course, emit beta particles and the maximum energy of the beta particles emitted should preferably be at least 150,000 electron volts to obtain efficient production of the X-rays. The material may, or may not, emit alpha particles as well since such slow moving particles will normally be readily absorbed by the target.

The radioactive material **11** may or may not emit gamma rays. However, if it does emit gamma rays, then the energy of the X-rays derived from impingement of the beta particles on the target plates **12** and **13** should be at least one percent and preferably much more than 10 percent of the energy derived from the gamma rays.

It may be noted that the plates **12** and **13** are in generally surrounding relation to the radioactive material **11** so as to act as a shield in preventing undesirable radiations. If desired, the peripheries of the plates **12** and **13** might be joined so as to completely enclose the radioactive material.

In Figure 2, reference numeral **14** designates another preferred form of X-ray source according to the principles of this invention. The source **14** comprises a target **15** in the form of a tube with radioactive material **16** disposed inside the tube **15**. The considerations involved in selecting the type of radioactive material **16** and the thickness of the walls of the tube **15** are generally the same as those involved in selecting the radioactive material **11** and the thickness of the plates **12** and **13** in the embodiment of Figure 1 as described above.

As an example, the tube **15** may be of platinum approximately 0.1 inch in diameter and 0.3 inch long with a wall thickness of 0.018 inch filled with one-half curie of strontium 90 and might be used in interstitial treatment of extensive malignancies. This would be appropriate for high level dosage, for extremely long times.

Another example would be the same tube filled with phosphorus 32 which could be used for shorter lived irradiation with approximately the same X-ray characteristics.

As a further example, silver **111** might be used in the same configuration.

Still another example would be calcium **45** which could be used for extremely low energy radiation for fairly long times of a year or so. With both silver **111** and calcium **45**, the wall thickness of the tube **15** might be appreciably thinner than 0.018 inch, perhaps 0.005 inch.

The ends of the tube **15** might preferably be closed as to prevent radiation directly from the radioactive material **16**. If desired, the general form of Figure 2 might take the form of a needle **17** as illustrated in Figure 3 with the needle forming the target and being hollow with radioactive material **18** disposed therewithin. With this form, the treatment of many types of malignancies could be readily effected.

In Figure 4, reference numeral **19** designates another preferred X-ray source according to the principles of this invention. The source **19** comprises a target having a hollow body portion **20** and a cap **21** removable disposed on one end of the body portion **20**. Disposed within the body portion **20** is a capsule **22** of thin plasic material, or the like, which is filled with radioactive material **23**. The walls of the capsule must, of course, be thin enough to readily pass the beta particles emitted by the radioactive material **23**.

To "turn off" the source **19**, the capsule **22** might be removed from the target and the target replaced with a shield of similar physical construction but having low atomic number and considerable thickness so as to effectively eliminate radiation.

Another preferred form of the invention, not illustrated, is an intimate combination of beta particle emitting radioactive material with target material, either as powders, gases, liquids, mixtures, alloys or compounds, or any combination thereof.

It will be understood that while certain preferred structural forms and certain preferred types and dimensions of materials have been set forth above, the invention is not limited thereto and various other physical embodiments, dimensions, and characteristics will be suggested by the teachings above.

It will further be apparent that this invention provides an X-ray source having extremely wide application which is extremely compact, portable, readily used, inexpensive, safe and highly efficient.

It will still further be understood that various modifications and variations may be effected without departing from the spirit and scope of the novel concepts of this invention.

I claim as my invention:

1. An X-ray generator, comprising: a target, and beta particle emitting radioactive material so disposed relative

to said target that the beta particles bombard target atoms to produce X-rays, the compositions and relative geometry of the radioactive and target materials being such that usable quantities of X-rays are radiated from the generator and comprise at least one percent of the total radiation from the generator.

2. An X-ray generator, comprising: a target, and beta particle emitting radioactive material so disposed relative to said target that the beta particles bombard target atoms to produce X-rays, the compositions and relative geometry of the radioactive and target materials being such that the energy radiated from the generator is predominantly in the form of X-ray radiation.

3. In an X-ray generator, beta particle emitting radioactive material, and target material in the path of the beta particles emitted by said radioactive material to substantially absorb said beta particles and generate X-rays through the bombardment of target atoms by the beta particles, the compositions and relative geometry of the radioactive and target materials being such that usable quantities of X-rays are radiated from the generator and comprise at least one percent of the total radiation from the generator.

4. In an X-ray generator, beta particle emitting radioactive material, and target material in the path of the beta particles emitted by said radioactive material to substantially absorb said beta particles and generate X-rays through the bombardment of target atoms by the beta particles, the compositions and relative geometry of the radioactive and target materials being such that the energy radiated from the generator is predominantly in the form of X-ray radiation.

5. An X-ray generator, comprising: a target having oppositely facing boundaries, and radioactive material for impinging beta particles against one of said boundaries with sufficient energy to penetrate to the region of the other said boundaries so that the beta particles bombard target atoms to cause emission of X-rays from said other of said boundaries, the compositions and relative geometry of the radioactive and target materials being such that usable quantities of X-rays are radiated from the generator and comprise at least one percent of the total radiation from the generator.

6. An X-ray generator comprising: an intimate combination of beta particle emitting radioactive material and target material such that the beta particles bombard target atoms to produce X-rays, the compositions and relative geometry of the radioactive and target materials being such that usable quantities of X-rays are radiated from the generator and comprise at least one percent of the total radiation from the generator.

7. An X-ray generator, comprising: a pair of sheets of target material, and beta particle emitting radioactive material arranged between said sheets so that the beta particles bombard target atoms to produce X-rays, the compositions and relative geometry of the radioactive and materials being such that usable quantities of X-rays are radiated from the generator and comprise at least one percent of the total radiation from the generator.

8. An X-ray generator, comprising a capsule of target material having beta particle emitting radioactive material therewithin so that the beta particles bombard target atoms to produce X-rays, the compositions and relative geometry of the radioactive and target materials being such that usable quantities of X-rays are radiated from the generator and comprise at least one percent of the total radiation from the generator.

9. An X-ray generator, comprising: a capsule containing beta particles emitting radioactive material and having walls thin enough to readily pass the beta particles, and a target removably surrounding said capsule so that the beta particles bombard target atoms to produce X-rays, the composition and relative geometry of the radioactive and target materials being such that usable quantities of X-rays are radiated from the generator and comprise at least one percent of the total radiation from the generator.

10. An X-ray generator, comprising: a needle of target material, and beta particle emitting radioactive material within said needle so that the beta particles bombard target atoms to produce X-rays, the compositions and relative geometry of the radioactive and target materials being such that usable quantities of X-rays are radiated from the generator and comprise at least one percent of the total radiation from the generator.

11. An X-ray generator, comprising: a capsule containing beta particles emitting radioactive material and having walls thin enough to readily pass the beta particles, and a target removably surrounding said capsule so that the beta particles bombard target atoms to produce X-rays, the compositions and relative geometry of the radioactive and target materials being such that usable quantities of X-rays are radiated from the generator and comprise at least one percent of the total radiation from the generator, said target being replaceable with a shield having a lower atomic number and considerably greater thickness so as to effectively eliminate radiation.

12. An X-ray generator comprising: a target, and beta particle emitting radioactive material so disposed relative to said target that the beta particles bombard target atoms to produce X-rays, the compositions and relative geometry of the radioactive and target materials being such that usable quantities of X-rays are radiated from the generator and comprise at least one percent of the total radiation from the generator, the beta particles emitted from said radioactive material having a maximum energy of at least 150,000 electron volts.

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