Aug. 12, 1958 J. W. CLARK 2,847,581

NUCLEONIC X-RAY APPARATUS

Filed May 5, 1955 2 Sheets-Sheet 1

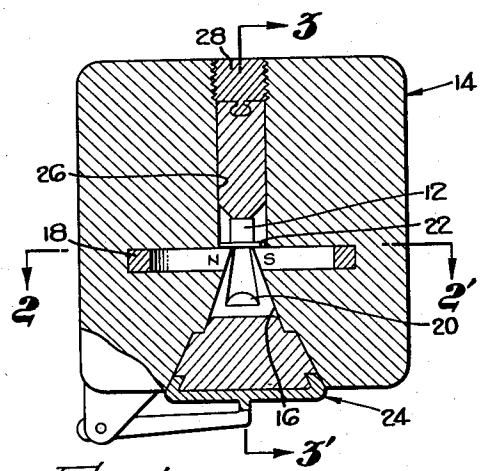


FIG. 1.

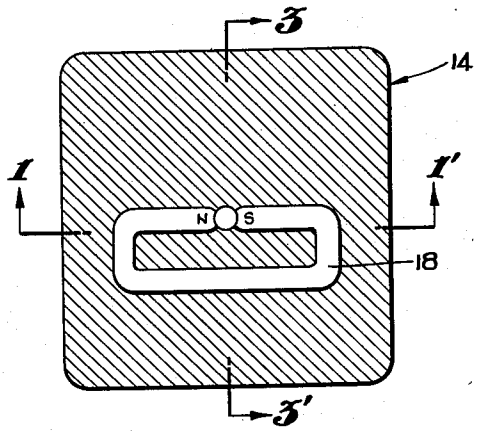


FIG. 2.

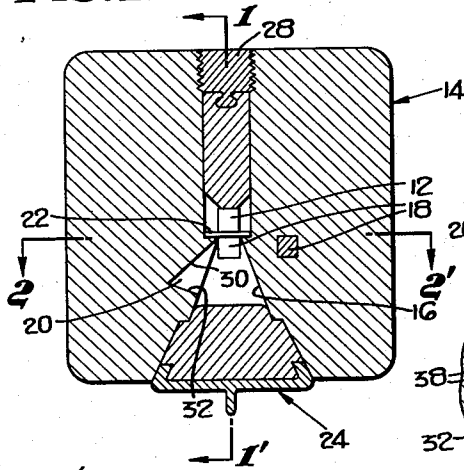


FIG. 3.

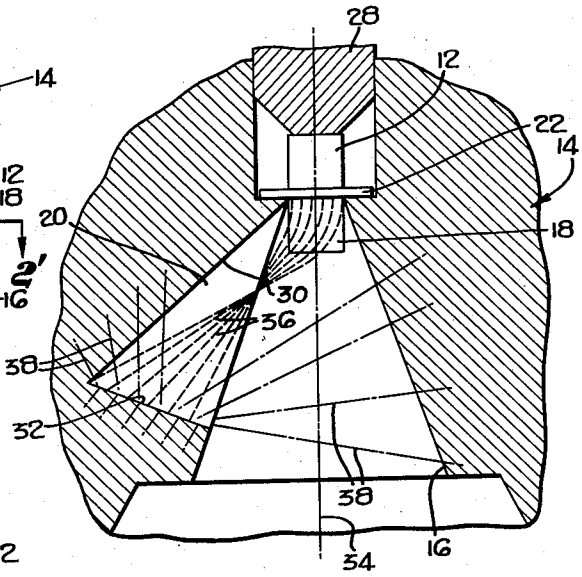


FIG. 4.

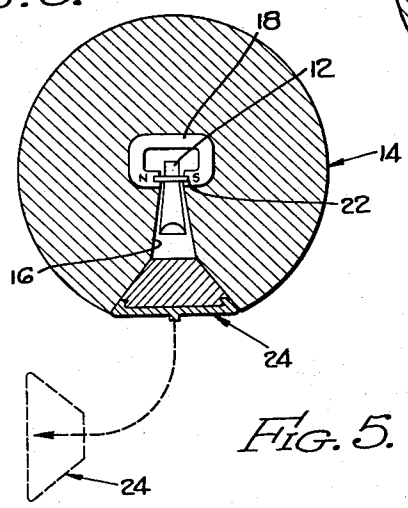


FIG. 5.

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NUCLEONIC X-RAY APPARATUS

Filed May 5, 1955 2 Sheets-Sheet 2

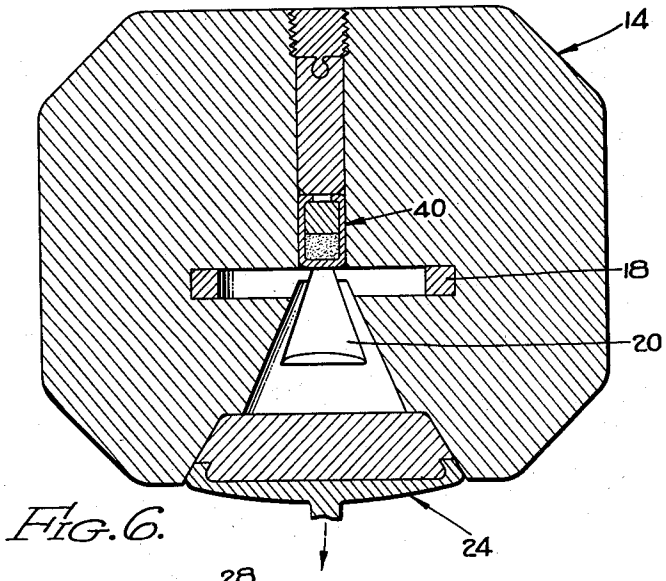


FIG. 6.

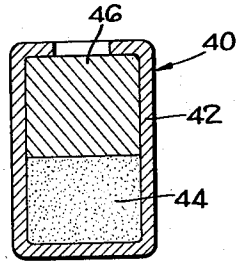


FIG. 7.

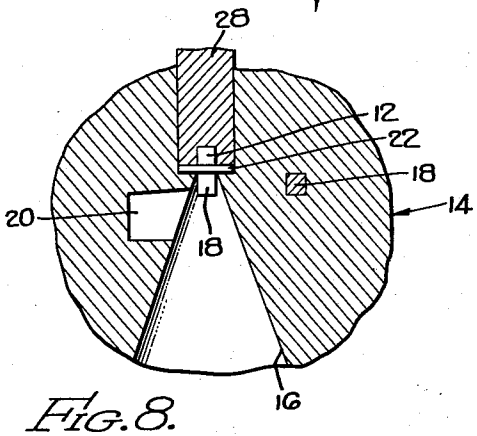


FIG. 8.

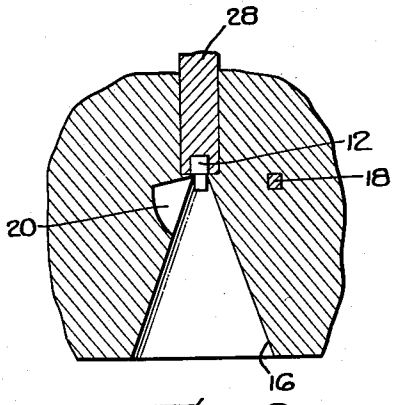


FIG. 9.

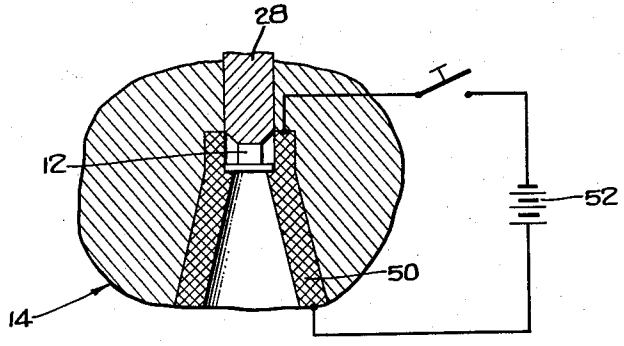


FIG. 10.

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2,847,581

NUCLEONIC X-RAY APPARATUS

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Application May 5, 1955, Serial No. 506,225

12 Claims. (Cl. 250—108)

This invention relates to nucleonic X-ray apparatus, and more particularly to a diagnostic X-ray apparatus which employs a radioactive source for generating a diagnostic X-ray or gamma ray beam and in which a magnetic field is utilized to control beta radiation to thereby produce radiographic images having improved contrast.

The term "diagnostic X-ray apparatus," as herein employed, is utilized to distinguish the X-ray apparatus of the invention from therapeutic and high energy industrial X-ray apparatus. In general, therapeutic X-ray machines and their industrial counterparts may be classified as high energy apparatus in that they produce relatively hard gamma rays, or in other words, radiation of extremely short wave length. Stated differently, the energy of radiation produced by therapeutic apparatus is of the order of one hundred thousand electron volts or higher. Conversely, diagnostic X-ray apparatus typically embodies an X-ray source whose radiation energy is of the order of one hundred thousand electron volts or less, and which consequently produces radiation of longer wave length.

The utilization of relatively low energy X-ray sources for X-ray diagnosis is of course dictated by the fact that all portions of the human body are substantially equally transparent to high energy radiation such as the relatively hard gamma rays produced by therapeutic X-ray apparatus, whereas there is a marked distinction between the transparency of the various elements and organs of the body to lower energy radiation. Consequently, X-ray or fluoroscopic pictures projected by a relatively low energy diagnostic X-ray source exhibit marked contrast between the various elements and organs of the body, the contrast exhibited depending upon the degree to which the incident radiation has been absorbed in different areas.

In the prior art essentially all X-ray diagnosis has been carried out by utilizing electronic X-ray apparatus, the use of nucleonic or radioactive X-ray sources having been restricted to therapeutic and industrial applications. The conventional diagnostic X-ray apparatus of the prior art usually employs an X-ray tube such as a Coolidge tube, for example, and is operative at approximately seventy five kilovolts, the radiation emanating from the tube customarily being filtered by an aluminum or copper plate which functions as a high pass filter and absorbs substantially all of the X-rays below a predetermined wave length. The radiation which passes through the filter is then utilized for irradiating a patient to obtain an X-ray picture or fluoroscopic image, this radiation consisting essentially of relatively hard X-rays or relatively soft gamma rays. It will be recognized, of course, that the gamma ray spectrum is merely a continuation of the X-ray spectrum, and that hard X-rays may also be termed soft gamma rays.

Although the diagnostic X-ray apparatus of the prior art has performed satisfactorily for most purposes, it still has several inherent disadvantages. For example, the electronic units of the prior art are relatively bulky

and expensive, and are almost invariably part of a fixed or stationary installation. In addition, a source of electrical power is required to operate the devices, thereby further restricting their portability and their usefulness under many circumstances.

In order to overcome these disadvantages of the prior art diagnostic X-ray apparatus, considerable effort has been expended to develop relatively light weight, inexpensive and portable diagnostic X-ray apparatus. These efforts have culminated in the construction of a new class of X-ray units which employ as an X-ray source a radioactive isotope capable of generating relatively soft or low energy gamma rays. Among the isotopes which meet this requirement are europium 155, terbium 160, osmium 191–3, indium 114 and thulium 170, for example; in particular thulium 170 has been found to be especially useful owing to the fact that it has a reasonably long half life of approximately 130 days, that it is relatively easy to produce, and that its gamma radiation is at 84.1 kilovolts, or in other words, very nearly that of conventional electronic diagnostic X-ray apparatus.

Although portable nucleonic X-ray units of the above type have been successfully constructed, there is one serious disadvantage attendant their use, namely, that the radioactive isotopes employed as the X-ray sources emit relatively high energy electrons which are termed beta rays, the beta rays in turn functioning to produce very high energy secondary radiation when they strike an object in their path of travel. This secondary radiation is termed "bremsstrahlung" in the field of radiography, and consists primarily of relatively hard gamma rays which are detrimental to X-ray picture quality. More specifically, the gamma rays of secondary radiation tend to destroy contrast in X-ray pictures and thereby complicate the already delicate problem of X-ray picture interpretation.

In order to reduce secondary radiation caused by beta radiation it has been proposed to encapsulate the radioactive source in a plastic cartridge and to place a plastic sheet approximately one half of an inch thick in radiation intercepting relationship with the X-ray beam to filter out beta rays produced by the source. One structure which embodies these concepts is disclosed in U. S. Patent #2,675,479 issued April 13, 1954 to P. J. Steward, et al. for "Method and Apparatus for Radiography." While it is true that relatively low density materials, such as plastic, for example, do not generate as much secondary radiation when struck by beta rays as do higher density conventional filtering materials such as aluminum, nevertheless the amount of "bremsstrahlung" produced by a relatively thick sheet of plastic is sufficient to markedly degrade X-ray picture contrast. In addition, the utilization of a relatively thick plastic sheet as a beta ray filter is of limited value since the sheet must be placed outside the shielded housing member which houses the source cartridge; consequently, the beta radiation which passes through the source cartridge may still strike the walls of the aperture in the shielded housing member and produce a relatively large amount of high energy secondary radiation which the plastic sheet, of course, is incapable of stopping.

The present invention, on the other hand, provides nucleonic X-ray apparatus which is applicable to X-ray diagnosis and which substantially eliminates the adverse effects of bremsstrahlung or secondary radiation, thereby providing diagnostic X-ray pictures with greatly improved contrast. According to the basic concept of the invention, a magnetic field is established adjacent the X-ray source and is employed to direct the beta rays so that they either produce substantially no secondary radiation or so that any secondary radiation they might produce

is precluded from adversely affecting X-ray picture contrast.

In accordance with several embodiments of the invention the magnetic field is established adjacent the X-ray source and transverse to the direction of the projected X-ray beam for deflecting beta rays which emerge from the source into a trap so located that any secondary radiation produced by the deflected beta radiation cannot strike the X-ray film holder or cassette. In accordance with another embodiment of the invention the magnetic field is established adjacent the X-ray source and concentric with the projected X-ray beam, the beta rays which emerge from the X-ray source thereby being channeled down the center of the aperture in the shielded housing member which houses the X-ray source. Owing to the fact that beta rays are in reality only high energy electrons and can propagate only a few centimeters in air before being absorbed or captured, the channeled beta rays are precluded from striking any relatively dense material, such as the sides of the housing aperture, before they are absorbed. Consequently, the only secondary radiation which is produced by the beta rays which emerge from the X-ray source is the extremely small amount which results from the collision of the high energy electrons with the gas molecules of air.

As will be more clearly understood from the description set forth hereinbelow, the magnetic field employed to control the directivity of the beta rays in the various embodiments of the invention may be provided either by an electromagnet or by one or more permanent magnets. It will also be shown that the radioactive source material may be in the form of a metallic specimen or in the form of a powder contained within an associated cartridge. In each of the various embodiments of the invention the amount of bremsstrahlung or secondary radiation which emerges from the X-ray apparatus is appreciably reduced; consequently the contrast in the X-ray pictures produced with the X-ray apparatus of the invention is greatly improved.

It is, therefore, an object of the invention to provide nucleonic X-ray apparatus in which beta radiation is controlled by a magnetic field to improve X-ray picture contrast.

It is another object of the invention to provide nucleonic diagnostic X-ray apparatus in which a magnetic field is employed to eliminate substantially all of the secondary radiation from the X-ray beam through the control of beta rays produced by the X-ray source.

A further object of the invention is to provide nucleonic X-ray apparatus in which a magnetic field is established adjacent the X-ray source and transverse to the axis of the X-ray beam generated thereby for deflecting beta rays emitted from the source to substantially remove secondary radiation from the X-ray beam.

Another object of the invention is to provide a nucleonic diagnostic X-ray apparatus wherein a transverse magnetic field is employed for deflecting into a trap beta rays emitted from the X-ray source, thereby to materially improve the contrast of X-ray pictures taken with the apparatus.

It is also an object of the invention to provide nucleonic X-ray apparatus wherein a magnetic field is established adjacent the X-ray source and substantially concentric with the X-ray beam therefrom for channeling into a beam beta rays emitted from the source to preclude the beta rays from striking any relatively dense material before they are absorbed.

The novel features which are believed to be characteristic of the invention, both as to its organization and method of operation, together with further objects and advantages thereof, will be better understood from the following description considered in connection with the accompanying drawings in which several embodiments of the invention are illustrated by way of example. It is to be expressly understood, however, that the drawings

are for the purpose of illustration and description only, and are not intended as a definition of the limits of the invention.

Fig. 1 is a side elevation, partly in section, of one form of nucleonic X-ray apparatus, according to the invention;

Fig. 2 is a sectional plan view of the apparatus shown in Fig. 1 taken perpendicular to plane **2—2'**, and illustrates one manner in which a magnetic field may be established adjacent the X-ray source;

Fig. 3 is a sectional front elevation of the apparatus shown in Figs. 1 and 2 taken perpendicular to plane **3—3'**, and illustrates one form of trap which may be utilized for trapping beta radiation emitted from the X-ray source;

Fig. 4 is an expanded view of a portion of the apparatus as shown in Fig. 3 and is utilized to illustrate how the X-ray apparatus of Figs. 1, 2 and 3 functions to reduce the effects of secondary radiation on X-ray picture quality;

Fig. 5 is a side elevation of another embodiment of a nucleonic X-ray apparatus according to the invention;

Fig. 6 is a side elevation of still another embodiment of a nucleonic X-ray apparatus, according to the invention;

Fig. 7 is a sectional view of an X-ray source capsule of the type utilized in the apparatus of Fig. 6;

Figs. 8 and 9 are sectional views of portions of X-ray apparatus which employ modified forms of beta ray traps; and

Fig. 10 is a sectional view of another form of nucleonic X-ray apparatus, according to the invention, which employs an alternate form of magnetic circuit for controlling the beta radiation from the X-ray source.

Referring now to the drawings, wherein like or corresponding parts are designated by the same reference characters throughout the several views, there is shown in Fig. 1 a nucleonic X-ray apparatus, according to the invention, which is operative to produce an X-ray beam in which high energy secondary radiation is greatly reduced. Basically the apparatus comprises a nucleonic source **12** of X-rays, a shielded housing member generally designated **14** for enclosing source **12** and including a normally shuttered beam forming aperture **16** for channeling an X-ray beam from source **12**, a magnetic field generating element, such as permanent magnet **18**, positioned adjacent source **12** for deflecting from their normal path beta rays which are projected into aperture **16** from the source, and a trap or cavity **20** formed in the side of aperture **16** adjacent magnet **18** for receiving beta radiation deflected by magnet **18**.

In the particular embodiment of the invention shown in Fig. 1 nucleonic source **12** comprises a metallic specimen which may be composed of any radioactive isotope capable of generating diagnostic X-rays at the desired wavelength. As pointed out hereinabove, thulium 170 has been found to be especially suitable owing to the fact that it has a reasonably long half life, is commercially available in considerable quantity, and has a radiation spectrum closely approximating that of conventional electronic diagnostic X-ray machines. It is to be expressly understood, however, that the invention is to be in no manner restricted by the selection of a particular radioactive isotope for the source material.

As shown in Fig. 1, source **12** is mounted on a relatively thin sheet **22** of a relatively low density material by a suitable adhesive or bonding agent, not shown. The function of sheet **22** is to centrally position source **12** with respect to the axis of aperture **16** in the housing member, and to make the X-ray apparatus as "fail safe" as possible by separating the source from aperture **16** so that no radioactive material can fall from the machine.

The construction of sheet **22** from light weight material is dictated by the fact that the beta rays produced by radioactive materials produce a certain amount of

high energy secondary radiation upon striking any substance, the amount of secondary radiation produced being roughly proportional to the density of the substance. Since it is this secondary radiation which must be reduced to improve X-ray picture contrast, and inasmuch as source **12** is contiguous to sheet **22**, the sheet is also made as thin as practical so that most of the beta rays which strike the sheet are transmitted therethrough and into the magnetic field of magnet **18**. Thus sheet **22** may comprise a strip of Lucite, for example, about ten thousandths of an inch thick.

Shielded housing member **14** is constructed from a relatively dense material, such as lead, which is capable of readily absorbing X-ray and gamma rays, and includes a shutter mechanism, generally designated **24**, for selectively blocking or unblocking the lower end of aperture **16**, as viewed in the drawings. It should be understood, of course, that any suitable form of shutter mechanism and actuating unit therefor may be employed with the X-ray apparatus of the invention, and that the particular shutter shown in Fig. 1 is not intended to limit the invention.

As shown in Fig. 1 the shielded housing member also includes a tubular loading cavity **26** for placing the radioactive source material within the housing member, cavity **26** being sealed by a threaded plug **28** whose lower end is composed of lead. The plug thus serves as a radiation shield and a supporting element for the radioactive source. In addition, it should be pointed out that plug **28** may be equipped with a suitable safety seal, not shown, to make the apparatus tamper proof after the radioactive source has been sealed therein.

In the particular embodiment of the invention shown in Fig. 1, permanent magnet **18** is sealed within housing member **14** so that sheet **22** is normally supported thereon, the magnet configuration and the position of its pole pieces relative to aperture **16** being shown in more detail in Fig. 2. It will be recognized that magnet **18** is thus positioned contiguous to X-ray source **12** and generates a magnetic field transverse to the axis of the aperture in the housing member, or in other words, perpendicular to the axis of the X-ray beam which is radiated from the apparatus when shutter mechanism **24** is actuated to unblock aperture **16**.

With reference now to Fig. 3, which is a sectional view of the same embodiment of the invention shown in Figs. 1 and 2 taken perpendicular to reference plane **3—3'**, the configuration of trap **20** and its relation to aperture **16** is shown in more detail. As shown in Fig. 3, trap **20** includes a side portion **30** which extends away from the smaller end of aperture **16**, and a bottom portion **32** which is so located that a plane taken therethrough intercepts the lead shield of housing member **14** in all directions. It will also be noted that the common plane of symmetry through aperture **16** and trap **20** is substantially perpendicular to the magnetic field generated by magnet **18**, of which only the end of one pole piece is visible in Fig. 3.

The manner in which magnet **18** and trap **20** cooperate to curtail high energy secondary radiation or bremsstrahlung will now be described with reference to Fig. 4, which is an enlarged view of the pertinent portions of Fig. 3. Assuming that the shutter mechanism is withdrawn from aperture **16**, source **12** functions to emit primary X-rays or gamma rays which are radiated through aperture **16** as a beam concentric with axis **34**. Concomitant with the generation of this useful radiation, however, source **12** also emits high energy electrons or beta rays, the amount of beta radiation produced relative to the amount of useful gamma radiation produced being primarily a function of the material of which the radioactive source is composed. For thulium 170, for example, the ratio of beta radiation to gamma or X-ray radiation is of the order of nine to one.

Consider now the action of the magnetic field provided by magnet **18** on beta rays emitted toward aperture **16**. A certain amount of the beta radiation will be absorbed by sheet **22** and functions to produce secondary radiation which is radiated out through the aperture along with the primary radiation from the X-ray source. However, if sheet **22** is composed of a relatively thin sheet of a light material such as plastic, as set forth hereinabove, most of the beta rays will pass through sheet **22** into aperture **16**. As the beta rays are passing through sheet **22** and after they emerge therefrom into aperture **16** they are acted upon by the magnetic field from magnet **18** which bends the rays in a direction normal to the magnetic field vector in accordance with the well known right hand rule. With reference once more to Fig. 4, the electrons or beta rays which emerge from sheet **22** are illustratively designated by the dotted lines **36**. Assuming the direction of the magnetic field to be into the plane of the paper, the beta rays are deflected to the left into trap **20** and strike bottom surface **32** of the trap. Accordingly, a relatively large amount of secondary radiation will be produced at surface **32**, this secondary radiation propagating in all directions, as indicated by the dashed lines **38**. However, owing to the fact that the plane of surface **32** intercepts housing member **14** in all directions and that secondary radiation is readily absorbed by lead, substantially all of the secondary radiation generated is dissipated within the housing member and cannot radiate from aperture **16**; consequently X-ray images projected by the beam which is emitted from the X-ray apparatus have greatly improved contrast.

It will be recognized by those familiar with electron ballistics that magnet **18** should be designed to provide a magnetic field whose strength and area are sufficient to insure that the beta radiation is deflected to strike surface **32**. Among the factors that control the determination of the field strength required are the geometry of aperture **16** and trap **20**, and the velocity of the electrons which constitute the beta rays, these factors in turn depending upon the form of the housing member utilized and upon the particular radioactive isotope utilized as the X-ray source. In general it has been found that field strengths of the order of several thousand gauss are sufficient to provide the desired deflection.

It will be appreciated that the magnetic field required in the diagnostic X-ray apparatus of the invention may also be provided by utilizing an electromagnet or permanent magnets having configurations different from that shown in Figs. 1 and 2. With reference to Fig. 5, for example, there is shown an embodiment of the invention wherein the plane of magnet **18** is parallel to the axis of aperture **16** and wherein mounting sheet **22** is positioned within a pair of slots machined in the pole faces of the magnet. It is clear that if this structural embodiment of the invention is to be utilized, a lateral loading entrance should be provided in housing member **14** for inserting source **12** to its operating position.

In each of the foregoing embodiments of the invention it has been assumed that source **12** consists of a metellic specimen of radioactive material. It should be understood, however, that the invention is equally applicable to nucleonic X-ray apparatus which employ powdered radioactive material as an X-ray source. As shown in Fig. 6, for example, a cartridge **40** containing a radioactive powder such as thulium oxide may be positioned adjacent magnet **18**, the magnet again functioning in the manner previously described to deflect into a trap **20** beta radiation which emerges from cartridge **40**.

It will be recognized that the utilization of a cartridge for containing the source material eliminates any need for a platform such as was provided by sheet **22** in the embodiments of the invention heretofore described. However, it is still desirable that the cartridge be composed of a relatively thin and light weight substance, such as plastic or aluminum, in order to permit most of the beta radiation generated by the source to escape from the car-

tridge without generating secondary radiation. One form of cartridge which has been found satisfactory is shown in Fig. 7 and includes a thin aluminum can **42** in which a radioactive powder **44** is contained, the can being sealed by a plug **46** which is press fitted into the top of the can and over which the open end of the can has been spun.

It is clear of course that still other modifications in the basic concept of the invention will occur to those skilled in the art. As illustrated in Figs. 8 and 9, for example, the configuration of trap **20** may be varied widely so long as secondary radiation generated therein is precluded from striking the X-ray film employed in cooperation with the X-ray apparatus. With refernce to Fig. 9 in particular it will be noted that the form of the secondary radiation trap may be such as to permit secondary radiation to emerge from aperture **16** when its shutter is open, so long as this radiation does not impinge upon the associated sensitized film utilized in conjunction with the appartus of the invention.

Figs. 8 and 9 are also illustrative of alternative methods for mounting source **12** within housing member **14**. In the embodiment of Fig. 8, for example, source **12** and sheet **22** are both affixed to the end of plug member **28**, whereas in the embodiment of Fig. 9, source **12** is embedded in the end of plug member **28** and no mounting plate or sheet is interposed between the source and aperture **16**.

In all of the embodiments of the invention disclosed hereinabove it has been assumed that the direction of the magnetic field utilized to control beta radiation has been transverse to the axis of the output aperture in the shielded housing member. It should be expressly understood, however, that the fundamental concept of the present invention pertains broadly to the use of a magnetic field to materially decrease or substantially eliminate secondary radiation, and that this basic object of the invention may be accomplished by utilizing other than a transverse magnetic field.

Referring now to Fig. 10 there is shown a sectional view of a portion of a modified form of nucleonic X-ray apparatus, according to the invention, wherein a longitudinal magnetic field is established concentric with aperture **16** by an electromagnet winding **50**, the winding being energizable from an associated source, such as battery **52**, for focusing or channeling down the center of aperture **16** beta rays generated by source **12**. Owing to the fact that the beta rays are thereby constrained and cannot impinge upon the adjacent walls of housing member **14**, and furthermore, since the mean free path of beta radiation in air is limited to distances of the order of several centimeters, a substantial reduction may be realized in the amount of secondary radiation produced as opposed to the amount of secondary radiation normally produced in the absence of a magnetic field.

It should be clear that numerous other alterations and modifications may be made in the nucleonic X-ray apparatus herein disclosed without departing from the spirit and scope of the invention. For example it is obvious that a number of permanent magnets could be employed to perform the same function performed by winding **50** in the embodiment of the invention shown in Fig. 10. It should also be pointed out that although the invention has been described with particular reference to diagnostic X-ray machines, it is also clearly applicable to relatively low energy nucleonic X-ray apparatus for industrial applications. Accordingly, it is to be expressly understood that the invention is to be limited only by the spirit and scope of the appended claims.

What is claimed as new is:

1. A nucleonic diagnostic X-ray apparatus for generating an X-ray beam in which secondary radiation normally produced by beta rays is materially reduced, said apparatus comprising: an X-ray source consisting essentially of a radio-active isotope; a shielded housing member surrounding said source, said housing member having an aperture therein communicating between said source and the exterior of said housing member for forming the X-ray beam; and magnetic means positioned adjacent said X-ray source for generating a magnetic field in the aperture adjacent said source, said magnetic field being operative to deflect beta rays emitted from said source in such a manner as to reduce the amount of secondary radiation in the X-ray beam.

2. A nucleonic diagnostic X-ray apparatus for generating an X-ray beam in which secondary radiation normally produced by beta rays is materially reduced, said apparatus comprising: an X-ray source consisting essentially of a radioactive isotope for generating X-rays; a shielded housing member surrounding said source, said housing member having an aperture therein extending between said source and the exterior of said housing member for forming the X-ray beam from X-rays generated by said source; and magnetic means positioned adjacent said X-ray source for generating a magnetic field in the aperture adjacent said source, said magnetic field being operative to deflect beta rays emitted from said source to prevent the beta rays from striking the sides of the aperture adjacent said source whereby the amount of secondary radiation in the X-ray beam is materially reduced.

3. The nucleonic X-ray apparatus defined in claim 2 which further includes a shutter mechanism for selectively blocking or unblocking said aperture at its external end.

4. The nucleonic X-ray apparatus defined in claim 2 wherein said magnetic means comprises a permanent magnet having first and second pole faces positioned adjacent said source and contiguous with said aperture, said magnet generating a magnetic field transverse to the X-ray beam formed by said aperture.

5. The nucleonic X-ray apparatus defined in claim 4 wherein said aperture has a cavity trap formed in its side, said trap being located at the end of said aperture adjacent said X-ray source, said trap being substantially bisected by a reference plane taken perpendicular to said transverse magnetic field and equidistant from said first and second pole faces.

6. The nucleonic X-ray apparatus defined in claim 5 wherein the plane of said magnet is substantially perpendicular to the axis of said aperture.

7. The nucleonic X-ray apparatus defined in claim 5 wherein the plane of said magnet is substantially parallel to the axis of said aperture.

8. The nucleonic X-ray apparatus defined in claim 2 wherein said magnetic means comprises an electromagnet winding positioned adjacent said source and concentric with said aperture, said winding being energizable for generating a magnetic field concentric with said aperture to channel beta rays emitted from said source down the center of said aperture whereby the beta rays are precluded from striking the sides of said aperture.

9. The nucleonic X-ray apparatus defined in claim 2 wherein sad X-ray source is a metallic specimen of a radioactive isotope.

10. The nucleonic X-ray apparatus defined in claim 8 wherein said metallic specimen is composed of thulium 170.

11. The nucleonic X-ray apparatus defined in claim 2 wherein said X-ray source is composed of a radioactive powder and wherein said apparatus also includes a relatively thin shelled cartridge for containing said powder.

12. A diagnostic X-ray apparatus for generating an X-ray beam in which secondary radiation normally produced by beta rays is materially reduced, said apparatus comprising: an X-ray source consisting essentially of a radioactive isotope; a shielded housing member surrounding said source, said housing member having an aperture extending between said source and the exterior of said housing member for forming the X-ray beam; a perma-

nent magnet positioned adjacent said X-ray source for generating a transverse magnetic field in the aperture adjacent said source, said aperture having a radiation trap formed in the side thereof adjacent said source, said magnetic field being operative to deflect into said trap beta rays emitted from said source into said aperture whereby the amount of secondary radiation in the X-ray beam is reduced.

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