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Williams

[11] **3,767,931**

[45] **Oct. 23, 1973**

[54] **ADJUSTABLE X-RAY BEAM COLLIMATOR WITH SHUTTER FOR ILLUMINATION OF THE RADIATION PATTERN**

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[51] **Int. Cl.** **G21f 5/04,** H01j 35/16

[58] **Field of Search** 250/452, 496, 497, 250/498, 503, 505, 506, 511, 512, 513

[56] **References Cited**

UNITED STATES PATENTS

2,844,736	7/1958	Johns et al.	250/512
2,959,680	11/1960	Green	250/513
3,304,427	2/1967	Peyser	250/512
3,539,813	11/1970	Resnick	250/513 X

Primary Examiner—William F. Lindquist
Attorney—Stanley Z. Cole et al.

[57] **ABSTRACT**

A shutter is provided to admit visible light into the region defined by the adjustable beam-defining components of the collimator of an X-ray apparatus. The light so admitted is reflected so as to appear to emanate from a virtual source located at the origin of the X-ray beam. The shutter is mechanically biased to remain closed, and can be opened to admit light only when no X-ray beam is being produced. Thus, the radiation pattern formed by the adjustable collimator can be simulated by visible light without the light source being located in the path of the X-ray beam. Furthermore, simulation of the radiation pattern is obtained without the shutter being open when X-ray radiation is being produced, so that radiation leakage through an open shutter is precluded.

15 Claims, 4 Drawing Figures

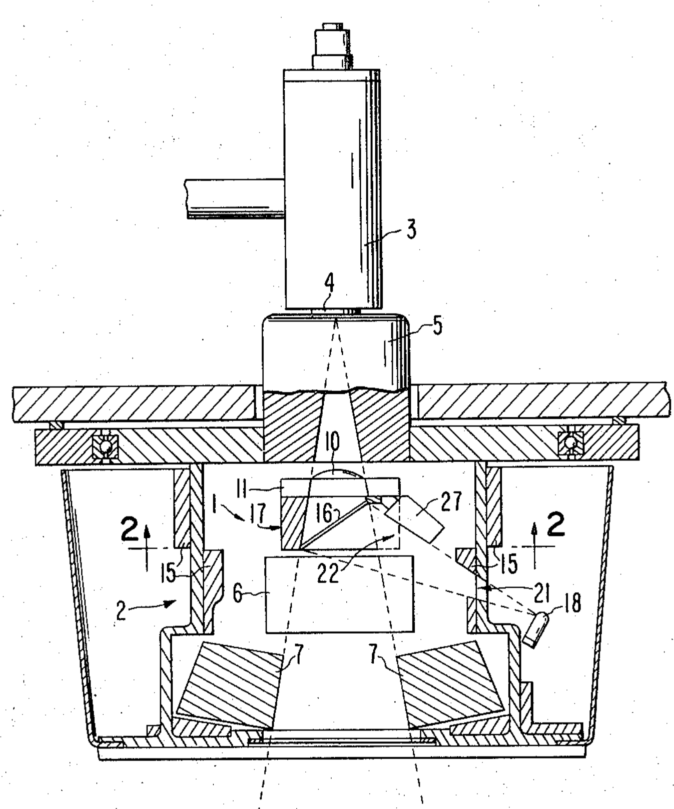

FIG.1

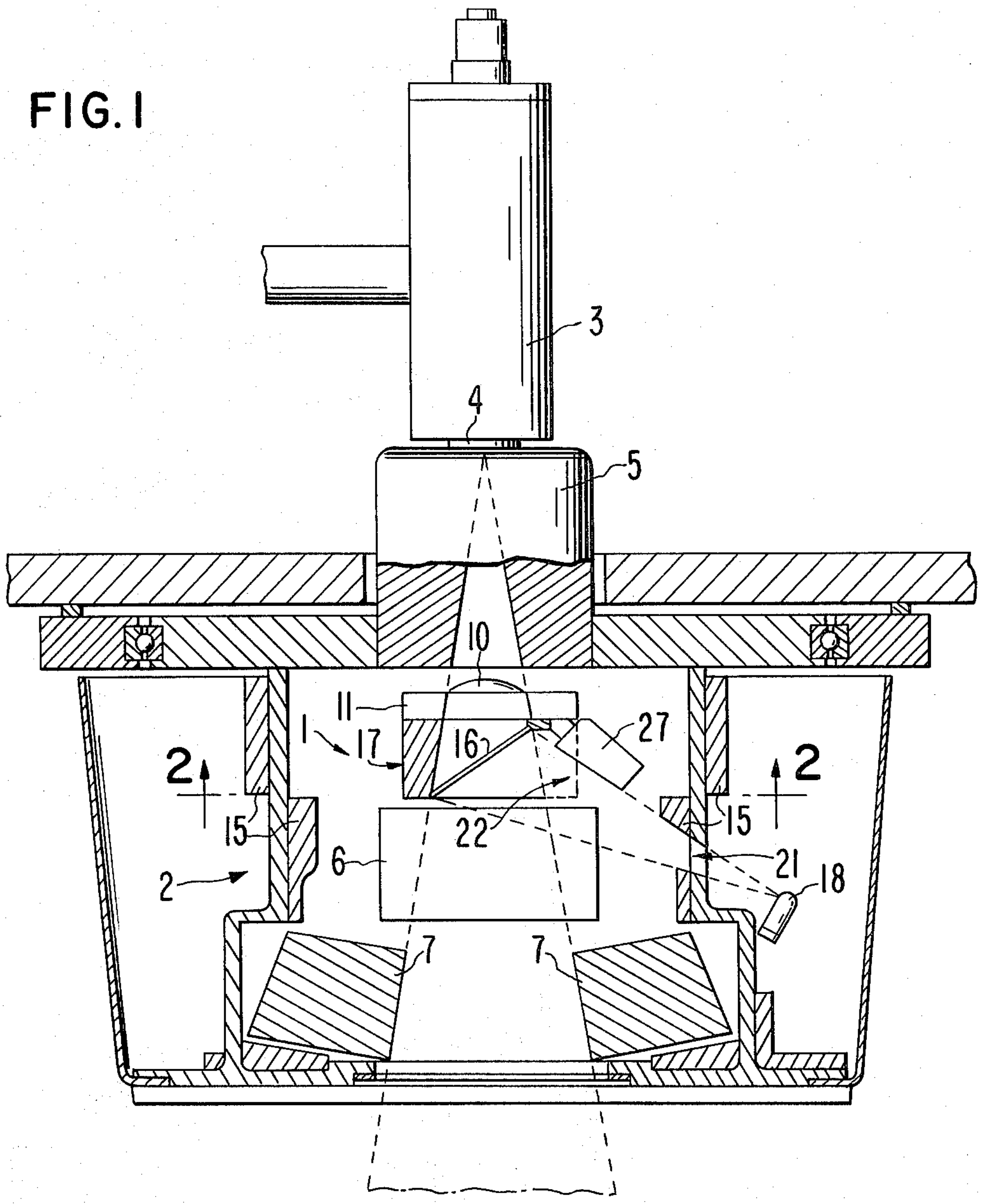
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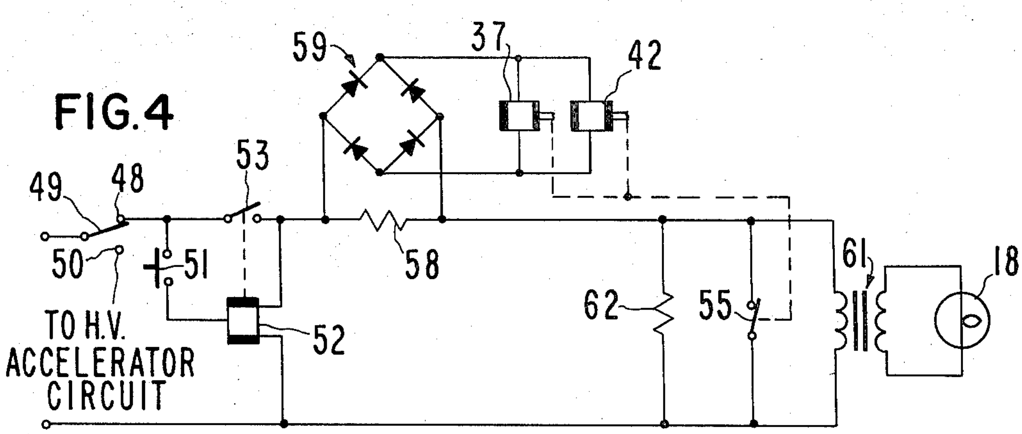
FIG.4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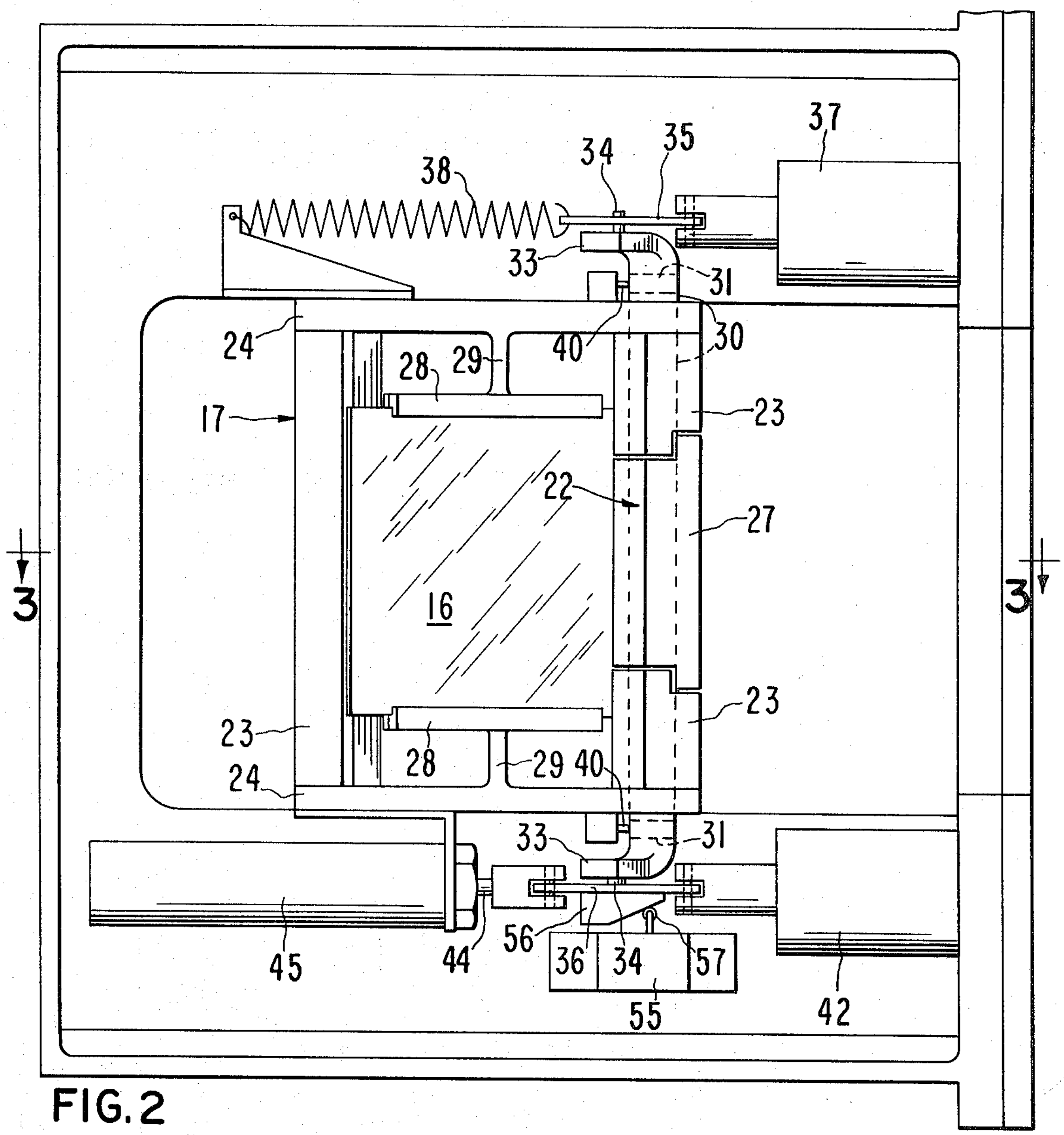
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FIG.2

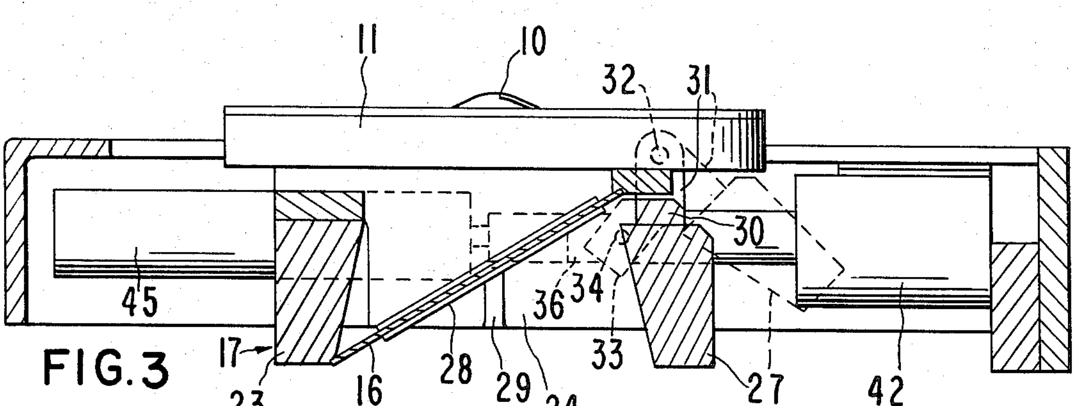
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FIG.3

ADJUSTABLE X-RAY BEAM COLLIMATOR WITH SHUTTER FOR ILLUMINATION OF THE RADIATION PATTERN

BACKGROUND OF THE INVENTION

1. Field of the Invention:

This invention is a further development in the art of visually simulating the radiation pattern formed by an X-ray beam collimator.

2. Description of the Prior Art:

It is desirable to be able to simulate the radiation pattern by a visible light pattern. In order to achieve effective simulation, however, it is necessary that the source of visible light be virtually imaged at the origin of the X-ray beam. This virtual imaging has been achieved in the prior art by use of an X-ray transparent mirror suitably disposed in the X-ray beam to reflect light from a visible light source so that the light appears to emanate precisely from the origin of the X-ray beam. The location of the visible light source, however, has presented an awkward design problem prior to this invention.

A collimator for defining the beam of an X-ray apparatus is dislosed in U.S. Pat. No. 3,539,813, issued Nov. 10, 1970 to Larry Resnick and assigned to the assignee of the present invention. The upper and lower jaws of the Resnick invention allow adjustable collimation of the X-ray beam, with each adjustment of either jaw causing a change in the X-ray radiation pattern. The Resnick apparatus provides shielding suitably disposed to confine the primary X-ray beam and also to absorb secondary radiation emanating from those components located in the path of the X-ray beam such as, for example, the field flattener provided to promote a uniform beam intensity throughout the beam cross section. In the Resnick apparatus, or in any X-ray apparatus having a beam collimator, a visible light source for simulation of the X-ray radiation pattern could be located either directly in the primary X-ray beam path or outside the beam path but within the shielding disposed to absorb secondary radiation. However, the prior art has experienced a number of disadvantages in connection with the placement of the light source in either of these locations. When the light source and its attendant electric circuitry are directly in the X-ray beam path, a radiation shadow of the light source and circuitry is formed on the object being irradiated. Furthermore, repeated irradiation of the light source and its attendant circuitry by the primary X-ray beam results in radiation damage to the light source and circuitry, and consequently results in the need for more frequent repairs than would be necessary if the light source were placed outside the X-ray beam path. Placement of the light source outside the X-ray beam path but within the shielding disposed to absorb secondary radiation would still subject the light source and its attendant circuitry to damage from secondary radiation. Furthermore, the light source with its circuitry would then become an additional source of secondary radiation, consequently requiring that the mass of surrounding shielding material be increased to accommodate this additional source of secondary radiation.

In order to avoid the aforementioned disadvantages, attempts have been made to locate the visible light source outside the secondary radiation shielding. In such attempts, the integrity of the shielding has been breached to permit entry of visible light into the region of the X-ray beam for virtual imaging of the light source at the origin of the X-ray beam. Various mechanical and optical systems have been tried in an attempt to accommodate a light source external to the shielding without seriously compromising the effectiveness of the secondary radiation shielding. For example, an optical periscope technique has been tried to transmit visible light in a tortuous path through shielding elements that have been disposed to absorb line-of-sight X-ray radiation. Such a technique, however, requires a greater mass of shielding material than would be necessary if the radiation shield were unapertured. It is highly desirable in an X-ray apparatus, particularly in an apparatus that is controllably movable to a variety of orientations, that the weight of the shielding material be minimized; yet it is essential especially in a therapy apparatus that shielding protection from secondary radiation be maximized. In certain applications where radiation protection requirements are minimal, the prior art has used a visible-light transparent material as a portion of the shielding wall. This technique can accommodate a visible light source external to the shielding, but it seriously compromises the effectiveness of the shielding. For example, multiple thicknesses of glass plate interspersed with visible-light transmissive fluid have been used. However, the shielding effectiveness of such materials is not adequate in applications where the weight and bulkiness of the shielding material must be minimized, as for example in the case of an X-ray therapy machine that is controllably movable to a variety of orientations. In addition, fluid shielding materials have a tendency to leak and frequently become turbid upon repeated exposure to X-ray radiation, which reduces their effectiveness in transmitting visible light. Glass with a high lead content is commonly used for shielding purposes. However, high-lead glass is a relatively poor transmitter of visible light and furthermore tends to darken upon exposure to X-ray radiation.

Until the present invention, the optimum shielding design had not been achieved for an adjustable X-ray beam collimator which allows simulation by visible light of the X-ray radiation pattern produced by any particular adjustment of the collimator.

SUMMARY OF THE INVENTION

The present invention optimizes the shielding design of an X-ray beam collimator adapted to allow simulation by visible light of the X-ray radiation pattern produced upon an object being irradiated for any distance of the collimator from said object and for any adjustment of the beam-defining components of the collimator. An aperture is provided in the secondary radiation shielding surrounding the collimator, whereby light from a visible source located outside the shielding can enter the region inside the shielding for reflection from a mirror disposed in the X-ray beam path at such an angle with respect to the external light source that the light source is virtually imaged at the origin of the X-ray beam. The mirror is supported in the X-ray beam on a cylindrical frame, which in the preferred embodiment forms a generally rectangular passageway for the X-ray beam with the central axis of the cylinder coincident with the central axis of the X-ray beam. The walls of the cylindrical frame form a shielding structure to absorb secondary radiation produced by the X-ray beam. A shutter is provided in one wall of the frame whereby visible light from the external light source can

impinge upon the aforementioned mirror when the shutter is open. When the shutter is closed, the shielding structure of the cylindrical frame presents an integral unapertured shield for absorbing secondary radiation. The shutter is mechanically spring-biased to remain closed, and can be opened by energizing solenoids to oppose the spring bias. The solenoids can be energized only when the electron accelerator is not energized, i.e., only when no X-ray beam is being produced. When the shutter is opened, the radiation pattern characteristic of the particular distance of the collimator from the object being irradiated and the particular adjustment of the beam-defining components of the collimator is simulated by visible light reflected from the mirror as if from a virtual source located at the origin of the X-ray beam. This visible-light simulation of the X-ray radiation pattern occurs only when no X-ray beam is being produced, so that the danger of secondary radiation leakage through the aperture is eliminated. The mechanical bias of the spring is fail-safe, so that the shutter cannot be opened when the X-ray beam is being produced. If the X-ray beam should accidentally be produced the mechanical bias of the spring will close the shutter to prevent radiation leakage through the aperture.

It is an object of this invention to provide an X-ray beam collimator having a shutter to allow illumination of the radiation field, whereby the radiation pattern can be simulated by visible light. Light simulation of the radiation pattern occurs only when no X-ray beam is being produced, so that the danger of secondary radiation leakage through an open shutter is eliminated. The mechanical bias of the shutter is fail-safe, so that the shutter cannot be opened when the X-ray beam is being produced.

It is a further object of this invention to locate the source of visible light outside the X-ray beam, whereby a radiation shadow upon the object being irradiated can be prevented and radiation damage to the light source and its attendant electric circuitry can be avoided.

It is likewise an object of this invention to locate the shutter in the wall of a shielding structure disposed immediately adjacent the primary X-ray beam, whereby the amount of secondary radiation and hence the mass of shielding material necessary to absorb secondary radiation can be minimized.

It is also an object of this invention to permit light from an external source to enter the region of the X-ray beam by direct line-of-sight transmission and at the same time avoid X-ray leakage, whereby the need for a complex optical system for transmission of the light is avoided.

Another object of this invention is to provide a spring-biased shutter, whereby the mechanical bias of the shutter to remain closed is unaffected by the orientation of the X-ray beam collimator.

A further object of this invention is to accomplish the preceding objectives in an adjustable collimating system.

Other features of this invention will be apparent from a perusal of the accompanying drawings and description of the preferred embodiment.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a sectional partly schematic view of an adjustable X-ray beam collimator with a shutter that embodies the features of this invention;

FIG. **2** is a sectional view through line **2—2** of FIG. **1**;

FIG. **3** is a sectional view through line **3—3** of FIG. **2**; and

FIG. **4** is a schematic diagram of an electric circuit that provides for fail-safe operation of the shutter of this invention.

DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring to FIG. **1**, the preferred embodiment comprises an X-ray beam confining structure which includes an adjustable X-ray beam collimator **1** and an additional radiation confining portion **2** surrounding the various components of collimator **1** which serves to contain stray radiation that may escape from the collimator. A charged particle accelerator **3** generates an electron beam that bombards a target **4** to produce an X-ray beam. The X-ray beam is directed through a conically shaped aperture in fixed component **5** of the collimator. Fixed component **5** is an annular structure having a tapered central passageway, which together with the adjustable upper jaws **6** and lower jaws **7** serves to collimate the X-ray beam. Typically, fixed component **5** and jaws **6** and **7** are made of depleted uranium. In FIG. **1**, only one jaw of the pair comprising upper jaws **6** is shown, and the pair of lower jaws **7** is positioned in 90° rotation about the axis of the X-ray beam with respect to the pair of upper jaws **6**. The jaws are preferably adjustable as described in U.S. Pat. No. 3,539,813.

Field flattener **10** is disposed in the X-ray beam to promote a uniform beam intensity throughout the beam cross section. Ionization chamber **11** is positioned adjacent field flattener **10** for measuring total radiation intensity. Bombardment of field flattener **10** by the primary X-ray beam causes secondary X-rays to emanate therefrom. Thus, additional shielding must be provided to absorb secondary radiation emanating from the field flattener and other sources. Such additional shielding is provided by the confining portion **2** which includes a generally rectangular shielding structure comprising plates **15** disposed around the various components of the primary beam collimator to absorb the secondary radiation. Plates **15** are of a material substantially opaque to X-rays. A mirror **16** is mounted on a frame **17** coaxial with the primary X-ray beam. Mirror **16** would ideally be completely X-ray transparent, but in practice attenuates the X-ray beam. However, the attenuation is uniform throughout the cross section of the beam, which precludes formation of a radiation shadow on the object being irradiated. Frame **17** supports mirror **16** at the proper orientation so that light from a source **18** located externally of the X-ray beam confining structure will pass through an appropriately located passageway to the mirror for reflection therefrom onto the object to be irradiated in such a way that a virtual image of light source **18** will be formed at the origin of the X-ray beam at target **4**. The passageway for light transmission from source **18** is provided by aperture **21** (see FIG. **1**) in the confining portion **2** of the X-ray beam confining structure, and by aperture **22** in a side wall 23 of frame 17 (see FIG. 2) as will be discussed more fully below.

Frame 17 comprises side wall pairs 23 and 24 (see FIG. 2) which enclose a rectangular internal passageway, the central axis of which is coincident with the axis of the X-ray beam. The wall of frame 17 that contains aperture 22 is provided with a shutter 27 for closing said aperture 22. The shutter 27 and the walls of frame 17 are made of material which is substantially opaque to X-rays. When shutter 27 is closed, it prevents X-rays from passing out through aperture 22 and thence through aperture 21. Also, when shutter 27 is closed, visible light from source 18 cannot penetrate into the region within frame 17 to fully illuminate mirror 16. When shutter 27 is open, however, light enters the region within frame 17 for reflection from mirror 16 onto the surface of the object to be irradiated. The light so reflected onto the surface of the object to be irradiated simulates precisely the X-ray radiation pattern that would be produced for the particular adjustment of the collimator. If shutter 27 were open when the X-ray beam is present, radiation would escape through aperture 22 and thence through aperture 21. Thus, shutter 27 is mechanically biased to remain closed, as will be discussed more fully below, and can be opened only when no X-ray beam is being produced.

FIG. 2 shows a sectional view of frame 17 along line 2—2 of FIG. 1. Mirror 16 is supported within frame 17 by support brackets 28 connected to ribs 29 on walls 24 of frame 17. Light from external source 18 will impinge upon mirror 16 when shutter 27 is open, as shown by dashed lines in FIG. 1. It will be noted in FIG. 2 that aperture 22 and the adjacent walls of shutter 27 are step-shaped to prevent escape of X-ray radiation through the necessary clearance between the shutter and the wall 23 which receives it. It is a feature of this invention that shutter 27 can be opened for visual simulation of the radiation pattern while the collimator is being adjusted to provide the most desirable radiation pattern. Once the desired radiation pattern is obtained by visual simulation, shutter 27 is closed and the X-ray beam may be produced. Shutter 27 cannot be opened while the X-ray beam is being produced so that there can be no radiation leakage through aperture 22.

Shutter 27 is rigidly affixed to a support bar 30 which is positioned above that side of frame 17 which lies closest to light source 18. Movement of shutter 27 is therefore controlled by the movement of bar 30. Each end of bar 30 has an upwardly projecting ear 31 which is pivotably supported on frame 17 by pivot pins 32 shown by dashed lines in FIG. 3. Bar 30 extends in each direction beyond the shielding walls 24 of frame 17, and is bent at each end to provide downwardly extending arms 33. Pins 34, one of which is rigidly fixed to each arm 33 at either end of bar 30, are pivotally received in apertures in connecting strips 35 and 36. One end of strip 35 is connected to the armature of a solenoid 37, while the other end of strip 35 is connected to spring 38. The natural bias of spring 38 pulls strip 35 toward spring 38, thereby pulling the armature of solenoid 37 to its outwardly extended position. This pulling of strip 35 causes bar 30 to pivot about pivot pins 32 to the closed position, whereupon ears 31 compressively abut against abutment members 40. Concurrently with the outward extension of the armature of solenoid 37, the armature of a coacting solenoid 42 is also extended to its outward position because of the connection of the armature of solenoid 42 to connecting strip 36 which is connected to bar 30 by the other of the pins 34. Strip 36 is also connected to plunger 44 of a double-acting dashpot 45, so that movement of shutter 27 will be cushioned by the action of the dashpot. The dashpot feature of this embodiment prevents slamming of the shutter, and thus inhibits the formation of mechanical stresses that would otherwise occur with repeated opening and closing of the shutter. It has been found that an air-filled dashpot works very satisfactorily and obviates the disadvantage of possible leakage inherent in a liquid-filled dashpot.

Referring now to FIG. 4, the circuit for overcoming the mechanical bias which causes the shutter 27 to remain shut is shown. Relay 49 is the relay for energizing accelerator 3 to produce the X-ray beam. Relay contact 48 is the "beam off " contact, and is normally closed. When the X-ray beam is to be produced, contact 48 is opened so that contact 50, the "beam on" contact, can be closed. Even if contact 48 is closed (i.e., in the "beam off" situation), solenoids 37 and 42 remain unenergized and shutter 27 remains closed because of the mechanical bias of spring 38. When simulation of the X-ray radiation pattern that would be produced for a given adjustment of the collimator is desired, the operator presses (i.e., closes) push-button switch 51, which is normally open. It will be noted that closing of switch 51 will have an effect only when relay contact 48 is closed. When push-button switch 51 is closed momentarily by the action of the operator, time-delay-off relay 52 is activated to close switch 53. Relay 52 causes switch 53 to remain closed for approximately 3 minutes, which has been found to be sufficient time for a skilled X-ray machine operator to position an object properly in the simulated radiation pattern or alternatively to adjust the radiation pattern in accordance with the configuration of the object to be irradiated. With contact 48 and switch 53 closed, the shutter-opening circuit of FIG. 4 is energized. After 3 minutes, the circuit is deenergized unless the operator chooses to close switch 51 again. In this way, the circuit for overcoming the mechanical bias which causes shutter 27 to remain shut can be energized for no more than 3 minutes without the affirmative action of the X-ray machine operator.

Returning now to FIG. 2, cam 56 is shown attached to connecting strip 36. The switch 55, shown in FIG. 2 and FIG. 4, is operated by cam follower 57 which forms part of the switch mechanism. When shutter 27 is shut, i.e., when connecting strip 36 is in the position whereby the armature of solenoid 42 is in its outwardly extended position, cam follower 57 projects outwardly to its fullest extent from switch 55. This outward extension of cam follower 57 causes switch 55 to be closed. Referring to FIG. 4, it will be noted that switch 55 is closed when switch 51 is initially closed. Thus, when the shutter-opening circuit of FIG. 4 is first energized, the greater part of the voltage drop of the line voltage (which is typically about 120 volts) will be across resistor 58, because of the low resistance across closed switch 55 and the high resistance of resistor 62 inserted in parallel with switch 55. Diode bridge rectifier 59 in parallel with resistor 58 provides a direct current to activate solenoids 37 and 42. As the solenoids are activated, connecting strips 35 and 36 are pulled toward the solenoids 37 and 42, whereby cam 56 causes cam follower 57 to be depressed and thus to open switch 55.

When switch **55** is opened, transformer **61** is effectively inserted into the circuit in series with resistor **58** because of the high resistance of resistor **62.** A suitable value for resistor **62** would be 500 ohms when the value of resistor **58** is 75 ohms. The value of resistor **58** is chosen so that when the primary impedance of transformer **61** is in series with resistor **58,** the current through the solenoids will be only enough to hold the solenoids "home" in the shutter-open position. In a particular embodiment of this invention, transformer **61** has a step-down voltage ratio of 120:24 whereby lamp **18,** which is a 150-watt projection lamp, can be operated at about 16 volts for long life. If lamp **18** burns out, the impedance of the primary winding of transformer **61** will become extremely large. A value of 500 ohms for resistor **62** will still be low enough to short-circuit the primary winding of the transformer, so that resistor **58** will draw sufficient current to allow solenoids **37** and **42** to pull "home" rather than oscillate about the "make point" of switch **57.** For the values of the circuit components as given above, a voltage drop of about 80 volts appears across the primary winding of transformer **65** and a current of about 0.7 amperes is drawn by each solenoid. This optimization of the current drawn by the solenoids will minimize the generation of heat in the solenoids while preventing the mechanical stresses that might otherwise develop in frame **17** if the shutter were allowed to "chatter" whenever lamp **18** burns out.

Lamp **18** remains lighted for about 3 minutes, after which time switch **53** will open to deenergize solenoids **37** and **42** thereby causing shutter **27** to close. The closing of shutter **27** causes switch **55** to close so that lamp **18** will be shunted out of the circuit. Switch **53** cannot be closed when push-button switch **51** is closed unless relay contact **48** is likewise closed. But contact **48** must necessarily be open when X-rays are being produced. Thus, the mechanical bias of spring **38** will cause shutter **27** to close when contact **48** opens so that the integrity of the secondary radiation shielding cannot be breached when X-rays are being produced.

If the operator needs additional time to prepare the object to be irradiated, he can gain a further 3 minutes of illumination for simulating the radiation pattern by pressing the push-button switch **51** again. If the operator is ready to produce X-rays at a time when lamp **18** is lighted and shutter **27** is open, he may safely do so by closing the "beam on" contact **50** of relay **49,** which energizes the accelerator **3.** The act of energizing the accelerator to produce X-rays causes contact **48** to open, thereby deenergizing solenoids **37** and **42** so that spring **38** will pull shutter **27** closed.

This embodiment has been described in terms of visible-light simulation of the X-ray radiation pattern. It is also envisioned that the surface of the object to be irradiated could be painted with material that fluoresces under ultra-violet light, and the visible light source could be replaced by an ultra-violet source. It is also envisioned that the collimator apparatus of this invention could be used with a gamma-ray beam instead of an X-ray beam, so that a radioactive material such as cobalt 60 could replace the accelerator **3** and target **4** of FIG. **1.** Also, the shutter **27** could be located at aperture **21** instead of aperture **22.** However, location of shutter **27** at aperture **22** is preferred because at this location the shutter confines the primary X-ray beam and lessens the creation of secondary X-rays which would require the use of thicker shield plates **15.** Since many changes could be made in the particular details of the embodiment of this invention without departing from the scope thereof, it is intended that the above description and accompanying drawings be interpreted as illustrative only and not as limiting.

What is claimed is:

1. In an apparatus for irradiating an object with a beam of penetrating radiation from a source of such radiation, means for collimating said beam for impingement upon the object to be irradiated, and means for simulating the irradiation pattern of said penetrating radiation on the surface of the object to be irradiated by illumination of said surface; said collimating means comprising walls substantially opaque to said penetrating radiation and a shutter substantially opaque to said penetrating radiation disposed in a passageway through said walls; said simulation means comprising a source of illuminating radiation located externally of said walls, means disposed within said collimating means to form a virtual image of said illuminating radiation source at the location of the source of said penetrating radiation when said shutter is open, and means for opening and closing said shutter.

2. The apparatus of claim **1** wherein said source of penetrating radiation comprises a charged particle accelerator and an X-ray generating target disposed in the path of said charged particles.

3. The apparatus of claim **1** wherein said source of penetrating radiation comprises a radioactive material.

4. The apparatus of claim **1** wherein said source of illuminating radiation comprises a source of visible light.

5. The apparatus of claim **1** wherein said source of illuminating radiation comprises a source of ultra-violet radiation.

6. The apparatus of claim **1** wherein said collimating means further comprises an adjustable jaw mechanism for precisely defining the irradiation pattern of said penetrating radiation.

7. The apparatus of claim **1** wherein said shutter has a step-shaped surface corresponding to a similarly shaped aperture in said walls for receiving said shutter when closed.

8. The apparatus of claim **1** wherein said shutter is mechanically biased to remain closed and wherein said means for opening said shutter must oppose said mechanical bias.

9. The apparatus of claim **8** wherein said mechanical bias is provided by a spring.

10. The apparatus of claim **1** wherein said virtual image forming means is an illuminating-radiation reflective member substantially transparent to said penetrating radiation.

11. The apparatus of claim **1** wherein said means for opening and closing said shutter comprises means to prevent the opening of said shutter when said beam of penetrating radiation is being generated.

12. The apparatus of claim **11** wherein said means for opening said shutter comprises solenoid means.

13. The apparatus of claim **11** wherein said means for opening and closing said shutter further comprises means to prevent said shutter from remaining open for longer than a selected time interval.

14. The apparatus of claim **2** wherein said means for opening and closing said shutter comprises means to cause said shutter to be closed whenever said source of illuminating radiation fails.

15. The apparatus of claim 1 further comprising electrical means for generating said beam of penetrating radiation, and wherein said means for opening said shutter comprises an electric circuit electrically connectable to said means for generating said beam, said circuit further comprising a time-delay relay, a first resistor, a rectifier in parallel with said first resistor, a solenoid activatable by said rectifier, a second resistor in series with said first resistor and having a higher resistance than said first resistor, a switch in parallel with said second resistor, said switch being operated by said solenoid, a primary transformer winding in parallel with said switch, a secondary transformer winding adjacent said primary winding, and said source of illuminating radiation being an electric light in series with said secondary winding.

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