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(54) **SYSTEM AND METHOD FOR INSPECTING AN OBJECT USING SPATIALLY AND SPECTRALLY DISTINGUISHED BEAMS**

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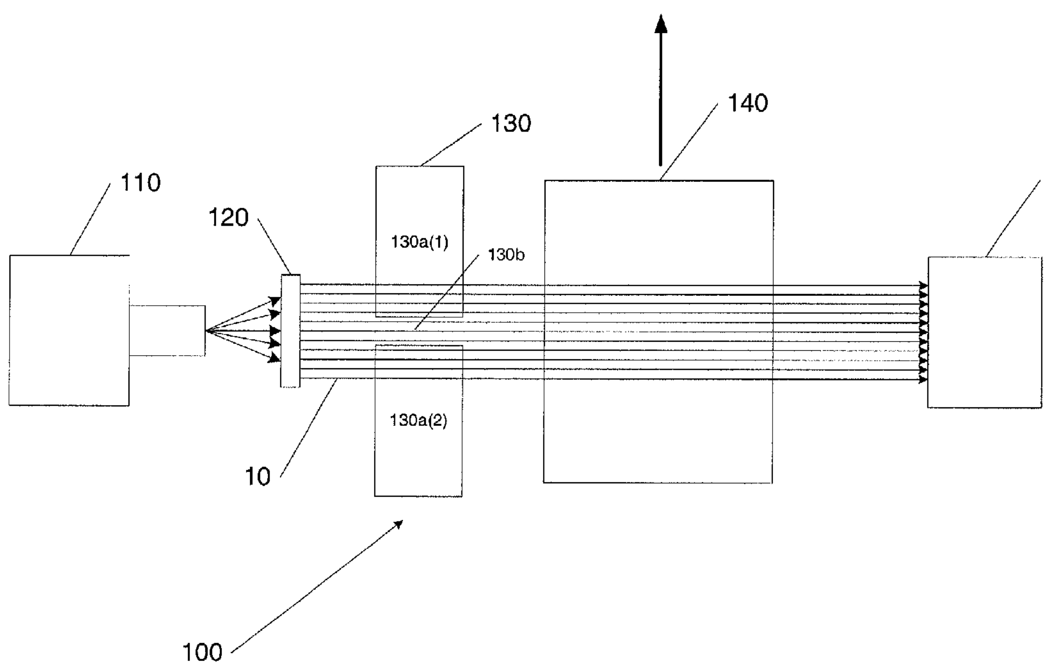
(57) **ABSTRACT**

A system and method for inspecting an object, the system and method comprising a source for generating a penetrating radiation beam for irradiating the object, the beam having, for each instant of time, an instantaneous energy spectrum of intensity, a shaper for modulating the generated beam, thereby creating a shaped beam, the shaper comprising at least a first section and a second section, the first section attenuating the intensity of a portion of the generated beam by a first attenuation factor and the second section attenuating the intensity of another portion of the generated beam by a second attenuation factor, and at least one detector for detecting the shaped beam after the shaped beam interacts with the object.



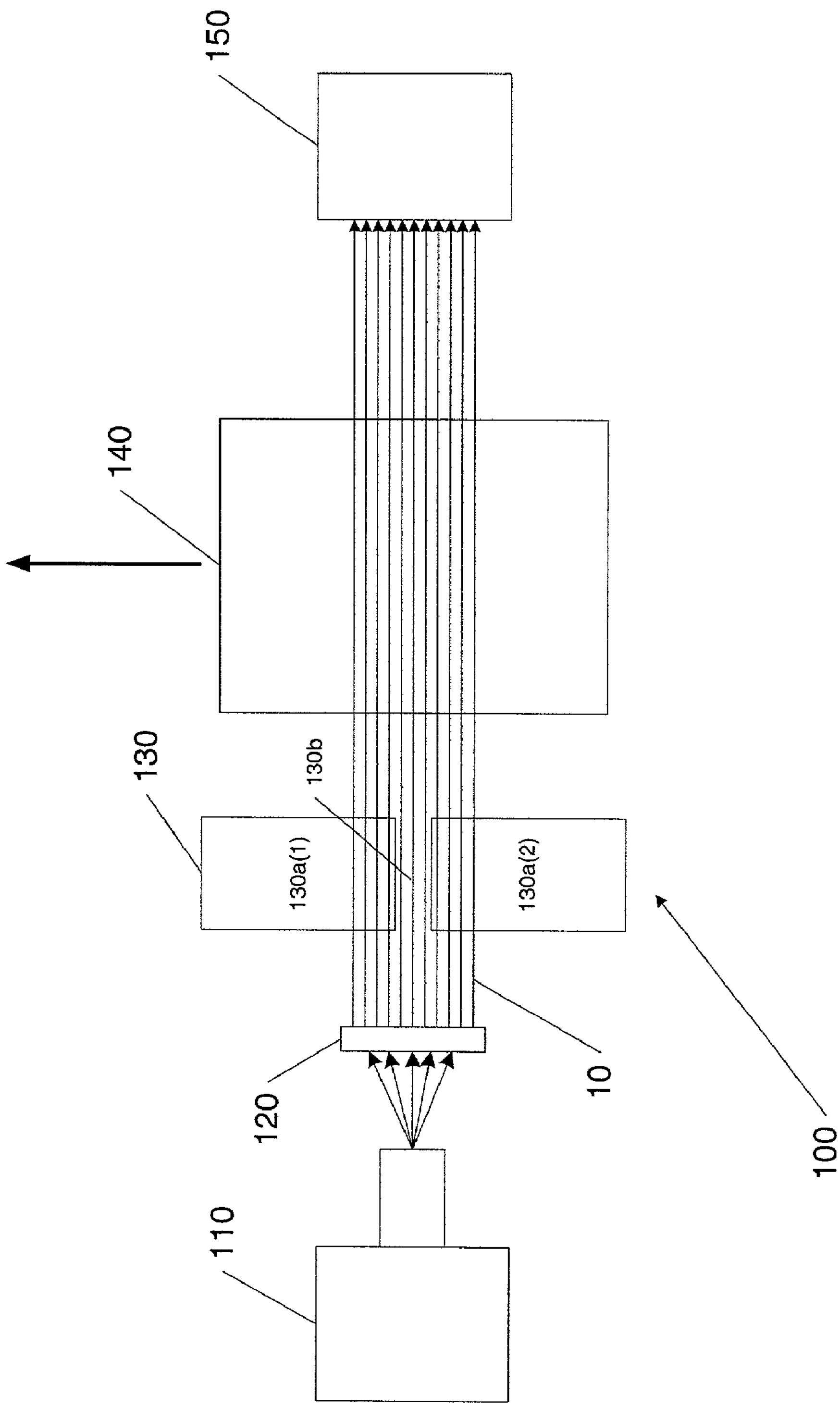


Figure 1

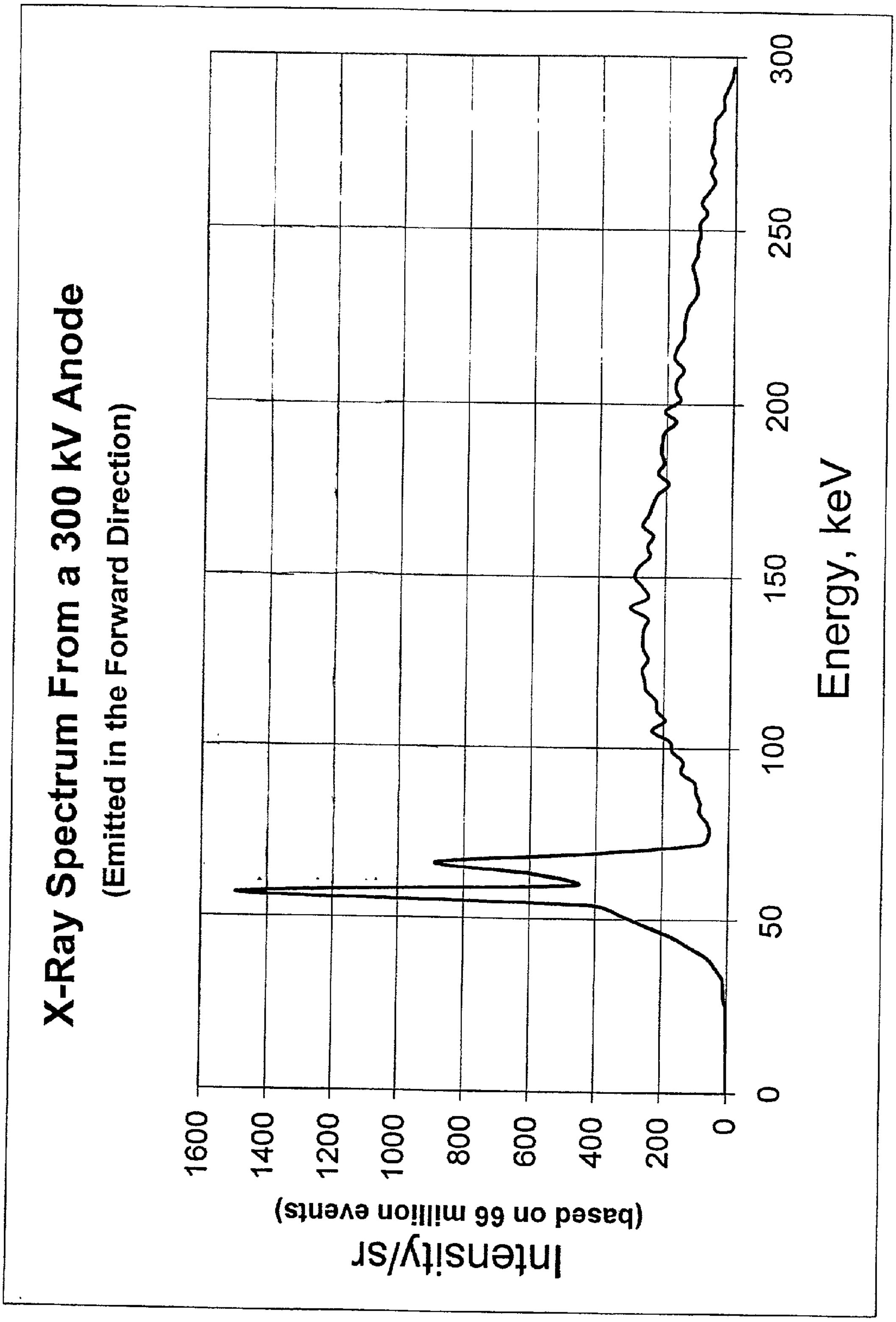

X-Ray Spectrum From a 300 kV Anode
(Emitted in the Forward Direction)
Intensity/sr
(based on 66 million events)
1600
1400
1200
1000
800
600
400
200
0
0
50
100
150
200
250
300
Energy, keV

Figure 2a

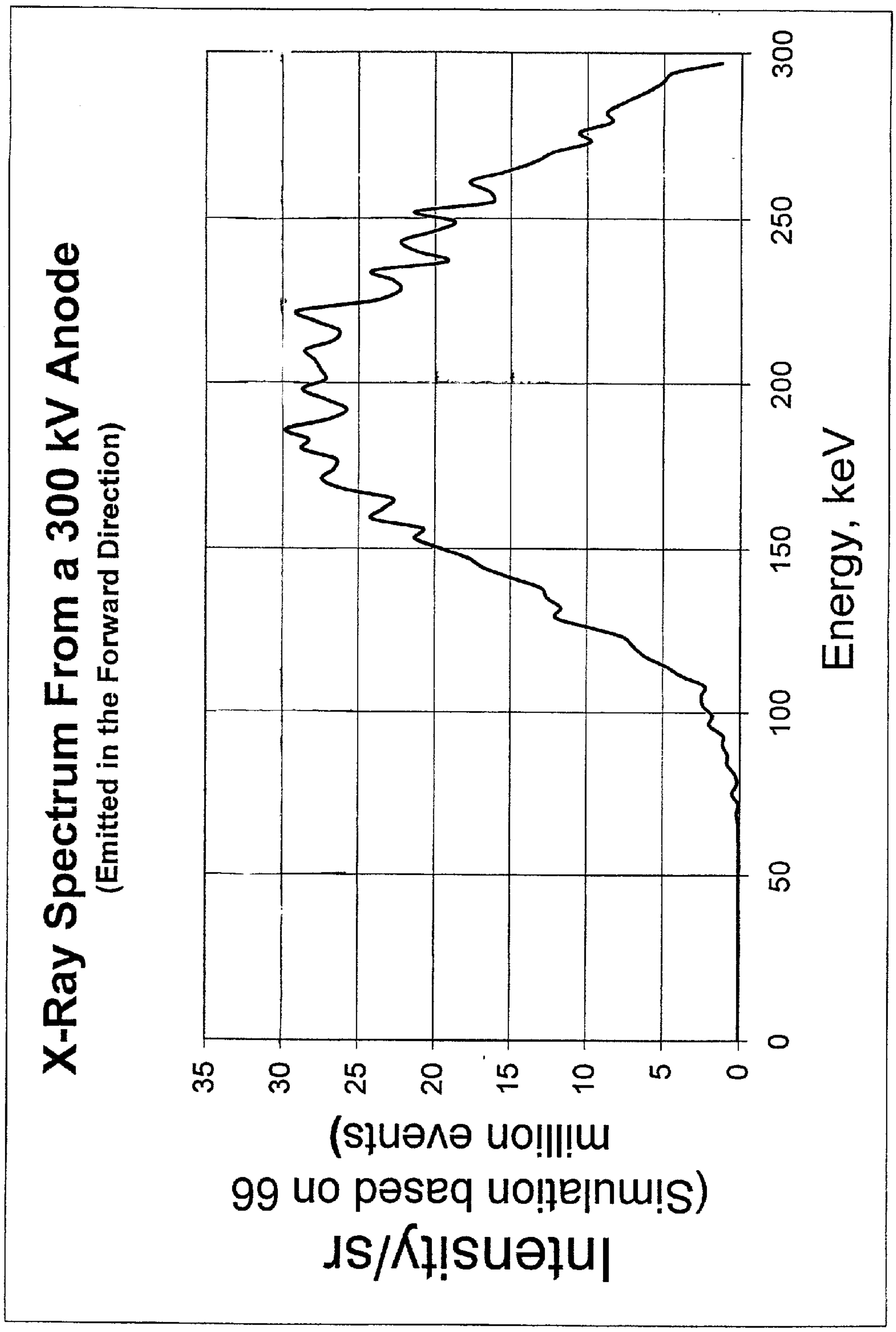

X-Ray Spectrum From a 300 kV Anode
(Emitted in the Forward Direction)
Intensity/sr
(Simulation based on 66
million events)
Energy, keV
0
5
10
15
20
25
30
35
0
50
100
150
200
250
300

Figure 2b

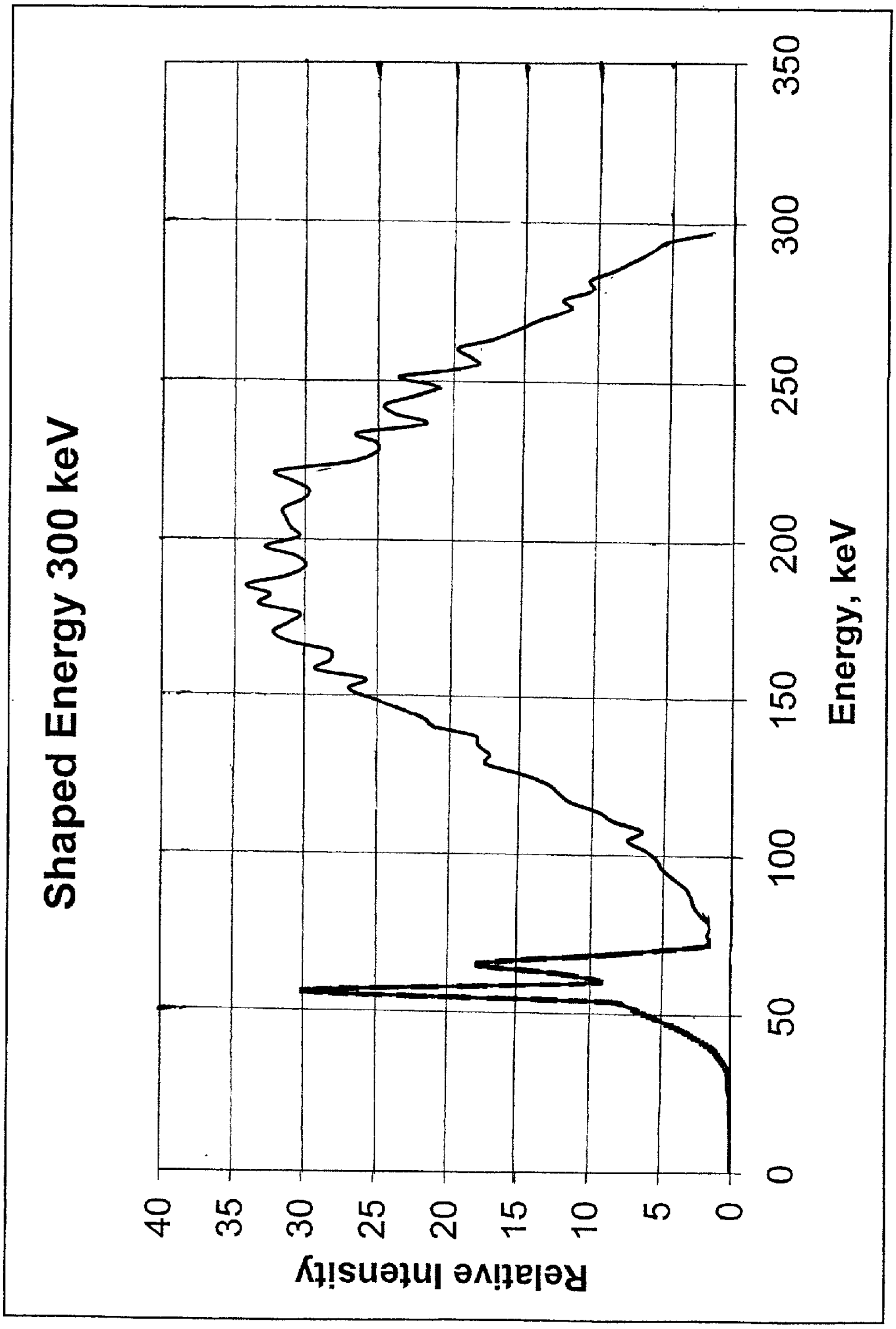

Shaped Energy 300 keV
Relative Intensity
0
5
10
15
20
25
30
35
40
Energy, keV
0
50
100
150
200
250
300
350

Figure 2c

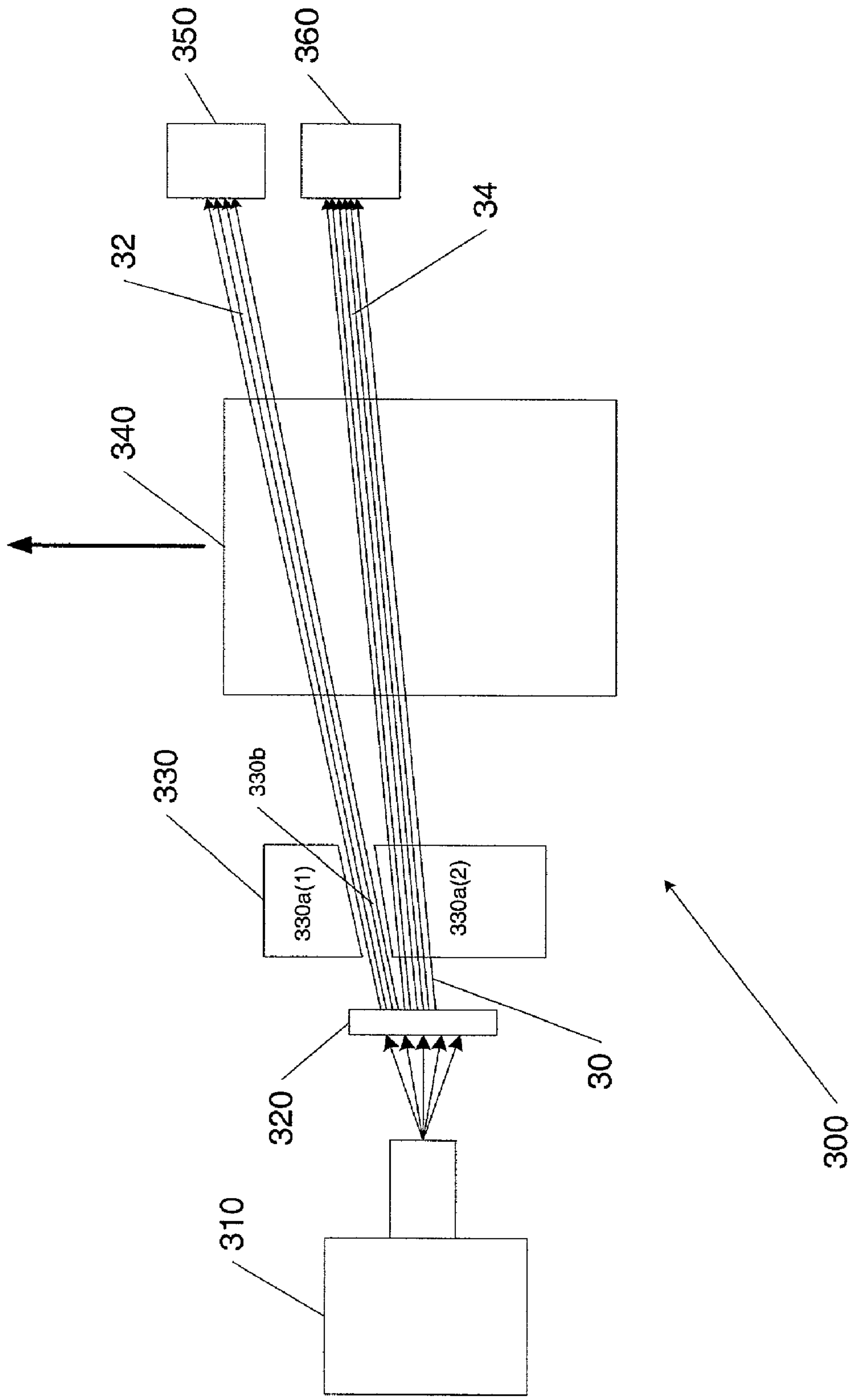


Figure 3

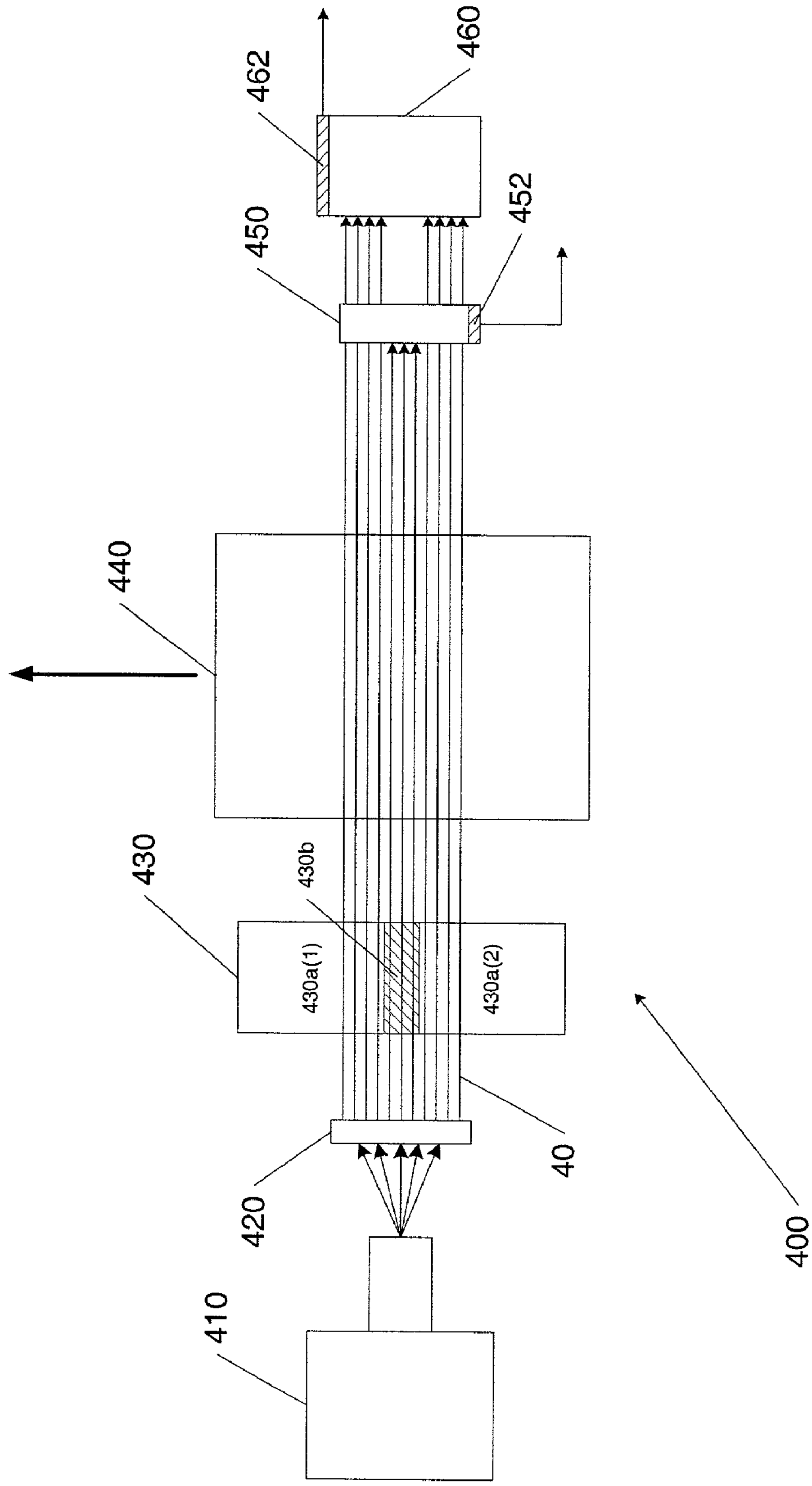


Figure 4

SYSTEM AND METHOD FOR INSPECTING AN OBJECT USING SPATIALLY AND SPECTRALLY DISTINGUISHED BEAMS

CROSS REFERENCE TO RELATED APPLICATIONS

[0001] This application is a combination-in-part of U.S. patent application Ser. No. 09/502,093, filed Feb. 10, 2000, entitled SPECTRALLY SHAPED X-RAY INSPECTION SYSTEM and bearing attorney docket number 1945/A09, the disclosure of which is incorporated herein, in its entirety, by reference.

TECHNICAL FIELD AND BACKGROUND ART

[0002] The invention relates to systems and methods for inspecting objects and, more particularly, the invention relates to systems and methods for inspecting objects a plurality of radiation beams characterized by distinctive energy spectra.

[0003] As discussed in U.S. patent application Ser. No. 09/502,093, the design of an x-ray inspection system to examine heterogeneous cargo requires joint consideration of conflicting requirements for penetration, radiation dosage, and sensitivity. For example, the high-energy x-ray components of a radiation beam from a 3 MeV x-ray accelerator penetrate approximately 3 times farther through iron than do the high-energy x-ray components of a radiation beam from a 450 keV x-ray accelerator. However, radiation dosage, that is, the integrated radiated energy, increases as the electron energy from an x-ray accelerator is raised. For example, the radiation dose from a 3 MeV x-ray accelerator is almost 40 times greater than the radiation dose from a 450 keV x-ray accelerator. In addition, the high-energy x-ray components of a radiation beam are not as "sensitive" for distinguishing among materials as the low-energy x-ray components of a radiation beam.

[0004] The ability of a x-ray inspection system to detect "contraband" is measured by determining the minimum thickness of material that can be detected. In determining that minimum thickness, consider a mono-energetic beam of photons penetrating an object having thickness T. The object has a linear absorption co-efficient $\lambda(E,Z)$, which is a function of the material and the energy of the photons that penetrate the object. If $N_o(E)$ is the number of x-ray photons incident on the object, then N(E), the number of x-ray photons emerging from the object, is given by:

$$N(E)=N_o(E)e^{-\lambda T} \quad (1)$$

[0005] To determine the minimum thickness, AT, that can be detected, we differentiate Equation #1:

$$\frac{\Delta N}{\Delta T} = -N_o \lambda e^{-\lambda T} \quad \text{(Equation \#2)}$$

[0006] The relative change in count rate per thickness is:

$$\frac{\Delta N}{N \Delta T} = -\lambda \quad \text{(Equation \#3)}$$

[0007] The minimal detectable signal is taken, by convention, to be 3 times the standard deviation of the signal:

$$\Delta N=3\sqrt{N} \quad (4)$$

[0008] Substituting Equation #4 into Equation #3 gives the minimum thickness that can be detected for a given number of detected counts:

$$|\Delta T| = \frac{3}{\lambda\sqrt{N}} \quad \text{(Equation \#5)}$$

[0009] Thus, the minimum detectable thickness varies inversely with the square root of the counts in the detector and inversely with the linear attenuation coefficient λ.

[0010] The linear attenuation coefficient for iron is 8.8 cm^{-1} at 60 keV, the energy of the strong, characteristic x-ray beams from a tungsten anode. As the energy of the photon increases, $\lambda(F_e)$ drops rapidly, for example, at 200 keV, λ(Fe) is 1.1 cm^{-1} and at 1 MeV, λ(Fe) is 0.47 cm^{-1}. Thus, for the same counts in the detector, a 60 keV photon beam can detect 1/20 th the thickness that can be detected by a 1 MeV photon.

[0011] It follows that a lightly-loaded container is typically better inspected by the low-energy x-ray components of a radiation beam because X is greater at lower energies. But, a heavily-loaded container must be better inspected by the high-energy x-ray components of a radiation beam. However, the high-energy x-ray components, in turn, increase the ambient radiation dose-the dose of scattered radiation in the surrounding environment.

SUMMARY OF THE INVENTION

[0012] In accordance with one aspect of the invention, a system and method for inspecting an object comprises a source for generating a penetrating radiation beam for irradiating the object, the beam having, for each instant of time, an instantaneous energy spectrum of intensity, a shaper for modulating the generated beam, thereby creating a shaped beam, the shaper comprising at least a first section and a second section, the first section attenuating the intensity of a portion of the generated beam by a first attenuation factor and the second section attenuating the intensity of another portion of the generated beam by a second attenuation factor, and at least one detector for detecting the shaped beam after the shaped beam interacts with the object.

[0013] In further embodiments of this aspect of the invention, the at least one detector may detect photons of energies exceeding a first fiducial energy and may detect photons of energies exceeding a second fiducial energy. In addition, the at least one detector may operate in an energy-dispersive mode or in a current mode.

[0014] In one alternate embodiment of this aspect of the invention, the shaper spatially separates the shaped beam into a first beam and a second beam, the first beam including the portion of the generated beam attenuated in the first section of the shaper and the second beam including the portion of the generated beam attenuated in the second section of the shaper. In a further embodiment of this alternate embodiment, the at least one detector detects the first beam after the first beam interacts with the object and a second detector detects the second beam after the second beam interacts with the object. In a still further embodiment of this alternate embodiment, the at least one detector further detects photons of energies in the first beam exceeding a first fiducial energy and the second detector further detects the photons of energies in the second beam exceeding a second fiducial energy.

[**0015**] In accordance with a second aspect of the invention, a system and method for inspecting an object comprises a source for generating a penetrating radiation beam for irradiating the object, the beam having, for each instant of time, an instantaneous energy spectrum of intensity, a shaper for modulating the generated beam, thereby creating a shaped beam, the shaper comprising at least a first section and a second section, the first section attenuating the intensity of a portion of the generated beam by a first attenuation factor and the second section attenuating the intensity of another portion of the generated beam by a second attenuation factor, a first detector for detecting the shaped beam attenuated by the first attenuation factor after the shaped beam interacts with the object, and a second detector for detecting the shaped beam attenuated by the second attenuation factor after the shaped beam interacts with the object.

[**0016**] In one alternate embodiment of this aspect of the invention, the first detector and second detector are arranged in tandem. In this embodiment of the invention, the first detector may further detect photons of energies exceeding a first fiducial energy and the second detector may further detects photons of energies exceeding a second fiducial energy.

[**0017**] In a further embodiment of both aspects of the invention, the first attenuation factor is 1, that is, no attenuation. In another further embodiment of both aspects of the invention, the shaper is configured in such a manner as to reduce ambient radiation dose. In still another further embodiment of both aspects of the invention, at least the first section of the shaper is composed of an element having an atomic number greater than 23.

BRIEF DESCRIPTION OF THE DRAWINGS

[**0018**] The foregoing features of the invention will be more readily understood by reference to the following detailed description, taken with reference to the accompanying drawings, in which:

[**0019**] **FIG. 1** is a schematic top view of an exemplary embodiment of an inspection system in accordance with the invention using a shaper to attenuate portions of a radiation beam using different attenuation factors and a detector to detect the shaped beam.

[**0020**] **FIGS. 2***a***-2***c* show the exemplary energy spectra of a radiation beam that is substantially unattenuated (**FIG. 2***a*), substantially attenuated (**FIG. 2***b*), and shaped in accordance with an exemplary embodiment of the invention (**FIG. 2***c*).

[**0021**] **FIG. 3** is a schematic top view of an exemplary embodiment of an inspection system in accordance with the invention using a shaper to attenuate portions of a radiation beam using different attenuation factors, as well as separate the radiation beam, and two detectors to detect the separate, shaped beams.

[**0022**] **FIG. 4** is a schematic top view of an exemplary embodiment of an inspection system in accordance with the invention using a shaper to attenuate portions of a radiation beam using different attenuation factors and two detectors to detect the various photon energies of the shaped beam.

DETAILED DESCRIPTION OF SPECIFIC EMBODIMENTS

[**0023**] In accordance with an embodiment of the invention, the energy distribution of an x-ray beam is filtered to simultaneously optimize the penetration of the x-ray beam through a high-density object, as well as the sensitivity of the x-ray beam to a low-density object, while minimizing the ambient radiation dose. The term 'x-ray' is used herein to encompass penetrating radiation generally and, for example, gamma rays are within the scope of the invention.

[**0024**] **FIG. 1** is a schematic top view of an exemplary embodiment of an inspection system in accordance with the invention. The system, referenced as system **100**, includes generator **110** and collimator **120**. Generator **110** generates penetrating radiation and may include, for example, an x-ray tube or a linear accelerator ("LINAC"). The generated x-ray beam typically includes x-ray energies from below approximately 200 keV to above approximately 9 MeV. Collimator **120** forms the generated radiation into a beam **10** of specified cross-section, as appropriate to differing inspection scenarios.

[**0025**] In addition, system **100** includes shaper **130**, which shapes the spectrum of beam **10** via section **130***a***(1)**, section **130***a***(2)** and section **130***b*, through which pass distinct spatial segments of beam **10**. The term "shaping" as used herein refers to spectral filtering that may be applied differentially with respect to different segments of the beam. Typically, both sections of section **130***a*, as well as section **130***b*, attenuate the intensity of the portion of beam **10** that passes through the respective section with specified spectral selectivity. For example, in system **100**, section **130***b* is shown as an opening between section **130***a***(1)** and section **130***a***(2)**. Thus, section **130***b* attenuates the portion of beam **10** that passes through section **130***b* by a factor of 1. For purposes of discussion herein, an attenuation factor of 1 is the same as no attenuation.

[**0026**] Section **130***a***(1)** and section **130***a***(2)** also attenuate the portion of the beam that passes through each respective section. Typically, section **130***a***(1)** and section **130***a***(2)** are composed of the same material of the same thickness. For example, section **130***a***(1)** and section **130***a***(2)** may be composed of a "heavy" element, for example, an element having an atomic number greater than **23**, such as iron, chromium, or lead. However, depending upon the particular application of use for beam **10**, section **130***a***(1)** and section **130***a***(2)** may be composed of: (1) the same material, but of different thicknesses; (2) different material, but of the same thickness; or (3) different material of different thicknesses.

[**0027**] In addition, depending upon the particular application of use for beam **30**, the configuration of section **130***b* may be modified. For example, section **130***b* may be circular in shape. Or, section **130***b* may be triangular in shape.

[**0028**] System **100** further includes detector **150**, which detects shaped beam **10** after shaped beam **10** has passed through object **140**. In **FIG. 1**, object **140** is moving in a direction away from the bottom of the page and toward the top of the page. Detector **150** may be a single detector that efficiently detects both the low-energy x-ray components of shaped beam **10** and the high-energy x-ray components of shaped beam **10**. In this embodiment, if the count rate of detector **150** is low enough for pulse counting, then the low-energy and high-energy x-ray components of beam **10** can be distinguished by their pulse heights, a method known in the art. However, if the count rate in detector **150** is too high for pulse counting, the gain in sensitivity for lightly-loaded objects will be less than the gain in sensitivity when more than one detector is used (discussed below). In regard to sensitivity to thickness change in a heavily-loaded object, the sensitivity is the same for one detector as for more than one detector.

[**0029**] When object **140** is a "high-density" object, for example, $-\lambda>1$ at low energies, then the x-ray components that penetrate to detector **150** are substantially the high-energy x-ray components. In turn, when object **140** is a "low-density" object, for example, object **140** is lightly-loaded, then the x-ray components that penetrate to detector **150** are substantially all of the x-ray components of shaped beam **10**.

[**0030**] **FIGS. 2***a*-**2***c* show the exemplary energy spectra of a radiation beam that is substantially unattenuated (**FIG. 2***a*), substantially attenuated (**FIG. 2***b*), and shaped in accordance with an exemplary embodiment of the invention (**FIG. 2***c*). In particular, **FIG. 2***a* is an exemplary energy spectrum of a substantially unattenuated 300 keV x-ray beam. As shown, the "bulk" of the integrated intensity of the energy spectrum is between approximately 60 keV and approximately 75 keV. In contrast, **FIG. 2***b* is an exemplary energy spectrum of a 300 keV x-ray beam that has passed through 2 cm of copper. As shown, the "bulk" of the integrated intensity is between approximately 150 keV and approximately 250 keV. In other words, the 2 cm thick copper has attenuated the intensity of the 300 keV x-ray beam by an attenuation factor, specifically, the 2 cm thick copper has reduced the low-energy x-ray components of the 300 keV x-ray beam by more than a factor of 10,000, and has reduced the high-energy x-ray components of the 300 keV x-ray beam by approximately a factor of 10.

[**0031**] While the reductions differ for the different x-ray energies of the beam, for purposes of discussion herein, these reductions are referred to simply as an energy-dependent attenuation factor. In other words, the use herein of the phrase "attenuation factor" may mean that a particular material reduces different x-ray energies by different factors. Additionally, as used herein and in any appended claims, "modulate" means "to modify a characteristic of," whether such modulation is a function of space, energy, or time.

[**0032**] **FIG. 2***c* is an exemplary energy spectrum of a radiation beam shaped in accordance with an exemplary embodiment of the invention, in particular, with reference to the exemplary embodiment shown in **FIG. 1**. Specifically, **FIG. 2***c* shows the spectrum of a 300 keV x-ray beam, generated by generator **110**, that has passed through shaper **130**, in which section **130***a*(**1**) and section **130***a*(**2**) of shaper **130** are composed of copper that is 2 cm in thickness, and section **130***b* of shaper **130** allows an areal fraction of approximately 2% of the 300 keV x-ray beam to pass through section **130***b* without attenuation. As shown, the "bulk" of the intensity of the energy spectrum is between approximately 60 keV and approximately 75 keV and between approximately 150 keV and approximately 250 keV. In other words, the shaped energy spectrum is the sum of approximately 2% of the energy spectrum shown in **FIG. 2***a* and approximately 100% of the energy spectrum shown in **FIG. 2***b*. Accordingly, the shaped energy spectrum contains sufficient low-energy x-ray components to inspect a low-density object **140**, for example, object **140** has an absorption equivalent to 1 cm of iron, and sufficient high-energy x-ray components to inspect a high-density object **140**, for example, object **140** has an absorption equivalent to 10 cm of iron, while substantially reducing the ambient radiation dose.

[**0033**] **FIG. 3** is a schematic top view of another exemplary embodiment of an inspection system in accordance with the invention. As in the exemplary embodiment shown in **FIG. 1**, the system, referenced as system **300**, includes a generator **310** and a collimator **320**. In this exemplary embodiment, however, the shaper **330**, modulates beam **30** by both attenuating the intensity of at least a portion of the beam, beam **30**, and separating beam **30** into a first beam **32** and a second beam **34**. In particular, section **330***a*(**1**), section **330***a*(**2**), and section **330***b* attenuate the intensity of the portion of beam **30** that passes through the respective sections. Thus, the first beam **32**, which passes through section **330***b*, is attenuated in accordance with a first attenuation factor (which, for this exemplary embodiment, equals 1), and the second beam **34**, which passes through section **330***a*(**2**), is attenuated in accordance with a second attenuation factor.

[**0034**] Depending upon the particular application of use for beam **30**, beam **30** may pass through section **330***a*(**1**) and section **330***b*, rather than section **330***a*(**2**) and section **330***b*. Or, in the alternative, beam **30** may pass through all three sections of shaper **330**. In addition, as discussed above, the configuration of section **330***b* may be modified. Moreover, as discussed above, section **330***a*(**1**) and section **330***a*(**2**) may be composed of: (1) the same material of the same thickness; (2) the same material, but of different thicknesses; (3) different material, but of the same thickness; or (4) different material of different thicknesses. Of course, description of the system in terms of three attenuating sections is for the purpose of example only and any number of attenuating sections may be employed within the scope of the invention.

[**0035**] System **300** further includes two or more detectors, shown as detector **350** and detector **360**. Detector **350** detects the first beam **32** of shaped beam **30** after the first beam has passed through object **340**. As with object **140** in **FIG. 1**, object **340** is moving in a direction away from the bottom of the page and toward the top of the page. Detector **360** detects the second beam of shaped beam **30** after the second beam has passed through object **340**. In one exemplary embodiment, the first beam of beam **30** may include, for example, the low-energy x-ray components of beam **30**. In this embodiment, detector **350** might be designed to be primarily sensitive to the low-energy x-ray components of beam **30**. Similarly, the second beam may include, for example, the high-energy x-ray components of beam **30**. In this embodiment, detector **360** might be designed to be primarily sensitive to the high-energy x-ray components of beam **30**.

[0036] **FIG. 4** is a schematic top view of still another exemplary embodiment of an inspection system in accordance with the invention. As in the exemplary embodiment shown in **FIG. 3**, the system, referenced as system **400**, includes a generator **410**, a collimator **420**, and two detector **450** and **460**. In this exemplary embodiment, however, detector **450** and detector **460** are in tandem. In addition, the shaper, shaper **430**, modulates the beam, beam **40**, by attenuating the intensity of beam **40**, but not by separating beam **40** into a first beam and a second beam. Rather, as with shaper **130** of **FIG. 1**, shaper **430** attenuates the intensity of an areal portion of beam **40** in accordance with a first attenuation factor, and attenuates the intensity of the remaining portion of beam **40** in accordance with a second attenuation factor.

[0037] Moreover, in this exemplary embodiment, section **430***b* of shaper **430** is composed of some material of some thickness. Thus, unlike section **130***b* and section **330***b*, section **430***b* attenuates the portion of beam **40** in accordance with an attenuation factor that is not equal to 1. Section **430***b* may be composed of the same material, but of a different thickness, than section **430***a*(**1**) or section **430***a*(**2**). Or, section **430***b* may be composed of a different material, but of the same thickness, as section **430***a*(**1**) or section **430***a*(**2**). Or, section **430***b* may be composed of a different material of different thickness than section **430***a*(**1**) or section **430**(*a*)(**2**). In turn, as discussed above, section **430***a*(**1**) and section **430***a*(**2**) may be composed of: (1) the same material of the same thickness; (2) the same material, but of different thicknesses; (3) different material, but of the same thickness; or (4) different material of different thicknesses. Moreover, as discussed above, the configuration of section **430***b* may be modified.

[0038] As discussed, detector **450** and detector **460** are in tandem. Typically, detector **450** is optically isolated from detector **460**, to stop scintillation from detector **460** being detected in detector **450**. This may be achieved, for example, by painting the back side of detector **450** (the side facing detector **460**) with black paint. In one exemplary embodiment, detector **450** might be designed to be primarily sensitive to the low x-ray energy components of beam **40** and detector **460** might be designed to be primarily sensitive to the high-energy components of beam **40**. For example, detector **450** may be a 0.6 mm thick detector of CsI scintillator and detector **460** may be a 1 cm thick detector of CsI scintillator. In this embodiment, detector **450** has photodiode **452** to detect the photons generated in its scintillator, and detector **460** has photo-diode **462** to detect the photons generated in its scintillator. The signal current from photodiode **452** measures the low-energy x-ray components of shaped beam **40**, and the signal current from photo-diode **462** measures the high-energy x-ray components of shaped beam **40**.

[0039] In another exemplary embodiment with detector **350** and detector **360** arranged in tandem, detector **350** might be designed to be efficient for detecting the low-energy x-ray components of beam **30** and inefficient for stopping the high-energy x-ray components of beam **30**. In turn, detector **360** might be designed to be highly efficient for stopping all energy components of beam **30** but, because detector **350** absorbs the low-energy x-ray components of beam **30**, detector **360** need only detect the high-energy x-ray components of beam **30**.

[0040] Although various exemplary embodiments of the invention have been disclosed, it should be apparent to those skilled in the art that various changes and modifications can be made which will achieve some of the advantages of the invention without departing from the true scope of the invention. These and other obvious modifications are intended to be covered by the appended claims.

What is claimed is:

1. A system for inspecting an object, the system comprising:

a. a source for generating a penetrating radiation beam for irradiating the object, the beam having, at each instant of time, an instantaneous energy spectrum of intensity;

b. a shaper for modulating the generated beam, thereby creating a shaped beam, the shaper comprising at least a first section and a second section, the first section attenuating the intensity of a portion of the generated beam by a first attenuation factor and the second section attenuating the intensity of another portion of the generated beam by a second attenuation factor; and

c. at least one detector for detecting the shaped beam after the shaped beam interacts with the object.

2. The inspection system according to claim 1 wherein the first attenuation factor is 1.

3. The inspection system according to claim 1 wherein the at least one detector detects photons of energies exceeding a first fiducial energy and detects photons of energies exceeding a second fiducial energy.

4. The inspection system according to claim 1 wherein the at least one detector operates in an energy-dispersive mode.

5. The inspection system according to claim 1 wherein the at least one detector operates in a current mode.

6. The inspection system according to claim 1 wherein the shaper spatially separates the shaped beam into a first beam and a second beam, the first beam including the portion of the generated beam attenuated in the first section of the shaper and the second beam including the portion of the generated beam attenuated in the second section of the shaper.

7. The inspection system according to claim 6 wherein the at least one detector detects the first beam after the first beam interacts with the object, further comprising a second detector for detecting the second beam after the second beam interacts with the object.

8. The inspection system according to claim 7 wherein the at least one detector further detects photons of energies in the first beam exceeding a first fiducial energy and wherein the second detector further detects photons of energies in the second beam exceeding a second fiducial energy.

9. The inspection system according to claim 1 wherein the shaper is configured in such a manner as to reduce ambient radiation dose.

10. The inspection system according to claim 1 wherein at least the first section of the shaper is composed of a element having an atomic number greater than 23.

11. A system for inspecting an object, the system comprising:

a. a source for generating a penetrating radiation beam for irradiating the object, the beam having, for each instant of time, an instantaneous energy spectrum of intensity;

b. a shaper for modulating the generated beam, thereby creating a shaped beam, the shaper comprising at least a first section and a second section, the first section attenuating the intensity of a portion of the generated beam by a first attenuation factor and the second section attenuating the intensity of another portion of the generated beam by a second attenuation factor;

c. a first detector for detecting the shaped beam attenuated by the first attenuation factor after the shaped beam interacts with the object; and

d. a second detector for detecting the shaped beam attenuated by the second attenuation factor after the shaped beam interacts with the object.

12. The inspection system according to claim 11 wherein the first attenuation factor is 1.

13. The inspection system according to claim 11 wherein the first detector further detects photons of energies exceeding a first fiducial energy and the second detector further detects photons of energies exceeding a second fiducial energy.

14. The inspection system according to claim 11 wherein the shaper is configured in such a manner as to reduce ambient radiation dose.

15. The inspection system according to claim 11 wherein the first detector and second detector are arranged in tandem.

16. A method for inspecting an object, the method comprising:

a. generating a penetrating radiation beam for irradiating the object, the beam having, for each instant of time, an instantaneous energy spectrum of intensity;

b. creating an attenuated beam by:

(1) attenuating the intensity of a first portion of the generated beam by a first attenuation factor;

(2) attenuating the intensity of another portion of the generated beam by a second attenuation factor; and

c. detecting the attenuated beam after the attenuated beam interacts with the object.

17. The method according to claim 16 wherein the first attenuation factor is 1.

18. A method for inspecting an object, the method comprising:

a. generating a penetrating radiation beam for irradiating the object, the beam having, for each instant of time, an instantaneous energy spectrum of intensity;

b. attenuating the intensity of a portion of the generated beam by a first attenuation factor;

c. attenuating the intensity of the remaining portion of the generated beam by a second attenuation factor;

d. detecting the beam attenuated by the first attenuation factor after the attenuated beam interacts with the object; and

e. detecting the beam attenuated by the second attenuation factor after the attenutated beam interacts with the object.

19. The method according to claim 18 wherein the first attenuation factor is 1.

* * * * *