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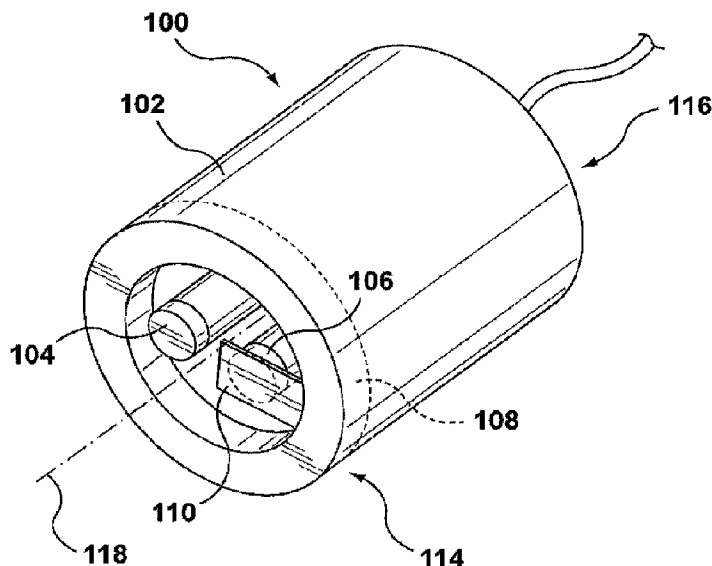
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(54) **Titre : APPAREIL DE DETECTION PORTATIF ET PROCEDE**
(54) **Title: PORTABLE DETECTION APPARATUS AND METHOD**



(57) **Abrégé/Abstract:**

A portable detection apparatus can include a housing, a first detector for detecting ionizing radiation from a first subject and a second detector within the housing for the detecting the background radiation. A shield within the housing can surround the first and second detectors and define a shield aperture around the first and second detectors for radiation from the subject to enter the housing. A radiation blocking member can substantially block at least a portion of the ionizing radiation from reaching the second detector, whereby radiation detected by the second detector comprises substantially only the background radiation. A processor module can be connected to the first and second detectors for determining the amount of ionizing radiation detected by the first detector attributable to secondary radiation.

ABSTRACT

A portable detection apparatus can include a housing, a first detector for detecting ionizing radiation from a first subject and a second detector within the housing for the detecting the background radiation. A shield within the housing can surround
5 the first and second detectors and define a shield aperture around the first and second detectors for radiation from the subject to enter the housing. A radiation blocking member can substantially block at least a portion of the ionizing radiation from reaching the second detector, whereby radiation detected by the second detector comprises substantially only the background radiation. A processor
10 module can be connected to the first and second detectors for determining the amount of ionizing radiation detected by the first detector attributable to secondary radiation.

TITLE: PORTABLE DETECTION APPARATUS AND METHOD

FIELD

[0001] The present subject matter relates generally to a portable radiation detection apparatus and method.

5 INTRODUCTION

[0002] US Patent Pub. No. 2011/0192981 relates to a radiation detection system that can include a scintillating member including a polymer matrix, a first scintillating material and a second scintillating material different from the first scintillating material and at least one photosensor coupled to the scintillating
10 member. The radiation detection system can be configured to receive particular radiation at the scintillating member, generate a first light from the first scintillating material and a second light from the second scintillating material in response to receiving the particular radiation, receive the first and second lights at the at least one photosensor, generate a signal at the photosensor, and determine a total
15 effective energy of the particular radiation based at least in part on the signal. Practical applications of the radiation detection system can include identifying a particular isotope present within an object, identifying a particular type of radiation emitted by the object, or locating a source of radiation within the object.

[0003] WO 2011/0877861 relates to a gamma-neutron detector based on
20 mixtures of thermal neutron absorbers that produce heavy-particle emission following thermal capture. The detector consists of one or more thin screens embedded in transparent hydrogenous light guides, which also serve as a neutron moderator. The emitted particles interact with the scintillator screen and produce a high light output, which is collected by the light guides into a photomultiplier tube
25 and produces a signal from which the neutrons are counted. Simultaneous gamma-ray detection is provided by replacing the light guide material with a

plastic scintillator. The plastic scintillator serves as the gamma-ray detector, moderator and light guide. The neutrons and gamma-ray events are separated employing Pulse-Shape Discrimination (PSD). The detector can be used in several scanning configurations including portal, drive-through, drive-by, handheld
5 and backpack, etc.

SUMMARY

[0004] This summary is intended to introduce the reader to the more detailed description that follows and not to limit or define any claimed or as yet unclaimed invention. One or more inventions may reside in any combination or
10 sub-combination of the elements or process steps disclosed in any part of this document including its claims and figures.

[0005] Following a radiological / nuclear (RN) emergency, such as release of radioactive substances in nuclear accidents at power plants or local contamination incidents involving in misuse of radioactive sources, and illicit
15 dispersion of radioactivity in a radiological dispersal device (RDD) by terrorists, the population may be internally exposed to radionuclides. It may be desirable to provide on-site testing to screen subjects that have been exposed to radionuclides to determine which subjects may require further medical care.

[0006] Radiological emergency sites may also include high levels of
20 background radiation. The presence of background radiation may make it difficult to accurately determine a subject's individual radiation exposure. It may be desirable to provide a detection apparatus that is portable (for example so that it can be transported to the site of a radiological emergency) and that is configured to measure a subject's radiation exposure. The detection apparatus may
25 optionally be configured to help distinguish radiation being emitted from a subject from the surrounding background radiation.

[0007] According to one broad aspect of the invention, a portable detection apparatus can include a housing and a first detector within the housing for detecting ionizing radiation comprising background radiation and secondary
30 radiation from a subject. The detection apparatus can also include a second detector within the housing for the detecting the background radiation. A shield

can be provided within the housing to surround the first and second detectors and define a shield aperture around the first and second detectors for radiation from the subject to enter the housing. The detection apparatus can also include a radiation blocking member substantially blocking at least a portion of the ionizing radiation entering the housing through the shield aperture from reaching the second detector. Radiation detected by the second detector can include substantially only the background radiation. The detection apparatus can also include a processor module connected to the first and second detectors for determining the amount of ionizing radiation detected by the first detector attributable to the secondary radiation.

[0008] The housing can define a detection apparatus axis and can be axially alignable with the subject. The first detector can include a first scintillator having an exposed first detection surface extending in a generally lateral direction and positionable opposite the subject. The second detector can include a second scintillator having an second detection surface extending in the generally lateral direction.

[0009] The radiation blocking member can cover substantially all of the second detection face. The secondary radiation can be substantially prevented from reaching the second detection face.

[0010] The shield apparatus can laterally surround the first scintillator and the second scintillator. The shield aperture can be registered with the first detection surface and the second detection surface.

[0011] The first scintillator can produce a first light when excited by the ionizing radiation and the second scintillator can produce a second light when excited by the ionizing radiation. The detection apparatus can also include a photosensor positioned adjacent the first and second scintillators to receive the first light and generate a corresponding first output signal, and to receive the second light and generate a corresponding second output signal.

[0012] The processor module can be operably linked to the photosensor and can be operable to determine the amount of ionizing radiation detected by the first

detector attributable to the secondary radiation by comparing the second output signal with the first output signal.

[0013] The processor module can be operable to determine a quantity of the radioactive material contained in the subject based on the amount of ionizing
5 radiation detected by the first detector attributable to the secondary radiation measured by the detection apparatus.

[0014] The processor module can be operable to compare at least one of the amount of ionizing radiation detected by the first detector attributable to the secondary radiation and the quantity of radioactive material contained in the
10 subject to a predetermined alarm threshold value and generate an alarm signal if the at least one of the amount of ionizing radiation detected by the first detector attributable to the secondary radiation and the quantity of radioactive material contained in the subject exceeds the alarm threshold value.

[0015] The photosensor can include a first photomultiplier tube to receive the first light and generate the first output signal and a second photomultiplier tube
15 to receive the second light and generate the second output signal.

[0016] The radiation blocking member can have a thickness between about 0.05mm and about 5mm.

[0017] The radiation blocking member can include a plate member.

20 [0018] The plate member can include at least one of copper, tin, and aluminum or a combination thereof.

[0019] The radiation blocking member may allow transmission of the background radiation there through, whereby the background radiation can reach the second detector.

25 The shield can include a first shielding layer formed from a first material, a second shielding layer formed from a second material and disposed laterally inboard of the first shielding layer, and a third shielding layer disposed laterally inboard of the second shielding layer.

[0020] The first shielding layer can have a first lateral width, the second
30 shielding layer can have a second lateral width and the third shielding layer can

have a third lateral width. The first lateral width can be greater than the both the second and third lateral widths.

[0021] The first shielding layer can be formed from lead or tungsten, and the first lateral width can be between about 2.5mm and 125mm.

- 5 [0022] The second shielding layer can be formed from tin, and the second lateral width can be between about 0.25mm and about 25mm.

[0023] The third shielding layer can be formed from copper, and the third lateral width can be between about 0.25mm and about 25mm.

- [0024] The first and second scintillators can include first and second
10 detection crystals, respectively.

[0025] The first scintillator can have an overall surface area and the first detection surface can have a detection surface area. The detection surface area can be between about 25% and about 45% of the overall surface area.

- [0026] The first scintillator can have a first thickness in the axial direction of
15 less than about 25mm.

[0027] The first and second detection crystals can include NaI(Tl) crystals.

[0028] The second scintillator can be generally identical to the first scintillator.

- [0029] The time elapsed between exposure of the detection apparatus to
20 the source of the secondary radiation and obtaining the resultant output signal defines a detection cycle time, and the detection cycle time can be less than about 10 minutes.

[0030] The detection cycle time can be less than about 2 minutes.

[0031] The detection apparatus can be a mountable on a vehicle.

- 25 [0032] Radioactive material within the subject can emit beta radiation and the secondary radiation can be bremsstrahlung radiation produced by an interaction between the beta radiation from the radioactive material and the subject.

[0033] The detection apparatus can be configured to measure photons having an energy that is less than about 500keV.

[0034] The detection apparatus can be configured to measure photons having an energy that is greater than about 30keV.

- 5 [0035] The detection apparatus can have an operating sensitivity capable of detecting an activity of at least about 460 Bq within the subject using a 5 minute scan.

[0036] According to another broad aspect of the invention, a portable radiation detection system can include a vehicle and a portable radiation detection
10 apparatus mounted on and transportable with the vehicle.

[0037] The vehicle can include a radiation shielded chamber, and the first and second detectors can be provided within the shielded chamber.

According to yet another broad aspect of the invention, a method of measuring the quantity of a beta-emitting radioactive material within a subject using a portable
15 detection apparatus can include the steps of a) positioning the portable detection apparatus adjacent the subject. The portable detection apparatus can include a first detector, configured to detect ionizing radiation comprising background radiation and secondary radiation, and a second detector configured to detect ionizing radiation. The method can also include the steps of b) detecting a
20 combination of the secondary radiation and the background radiation using the first detector and providing a corresponding a first output signal, c) simultaneously detecting the background radiation using the second detector and providing a corresponding second output signal; and d) automatically calculating a resultant output value based on at least the first output signal and the second output signal.

- 25 [0038] The method can include the step of comparing the resultant output value to a predetermined alarm threshold value, and generating an alarm output if the resultant output value exceeds the alarm threshold value.

[0039] Calculating the resultant output value can include comparing subtracting the second output signal from the first output signal to determine a first
30 quantity of secondary radiation received by the detection apparatus.

[0040] Calculating the resultant output value can also include determining a second quantity of radioactive material contained within the subject based on the first quantity of secondary radiation.

[0041] The resultant output value can include at least one of the first
5 quantity of secondary radiation and the second quantity of radioactive material.

[0042] The method can also include transporting the portable detection apparatus to a temporary testing location.

[0043] The method can also include positioning a radiation blocking member between the second detector and the subject to inhibit the secondary
10 radiation from reaching the second detector.

DRAWINGS

[0044] The drawings included herewith are for illustrating various examples of articles, methods, and apparatuses of the teaching of the present specification and are not intended to limit the scope of what is taught in any way.

15 [0045] In the drawings:

[0046] Figure 1 is a perspective view of a portable detection apparatus;

[0047] Figure 2 is an end view of the portable detection apparatus of Figure 1,

[0048] Figure 3 is a perspective view of a first scintillator useable with the
20 detection apparatus of Figure 1;

[0049] Figure 4 is a section view taken along line 4-4 in Figure 2;

[0050] Figure 5 is a perspective view of the portable detection apparatus of Figure 1 positioned adjacent a patient;

[0051] Figure 6 is an enlarged view of area 6 as shown on Figure 5, with a
25 portion of the detection apparatus housing cut-away;

[0052] Figure 7 is a schematic representation of a processor module useable with the detection apparatus of Figure 1;

[0053] Figure 8a is a perspective view of another example of a detection apparatus;

[0054] Figure 8b is a perspective view of yet another example of a detection apparatus;

5 [0055] Figure 9 is a partial cut-away view of a portable radiation detection system;

[0056] Figure 10 is a flow chart illustrating a method of using a portable detection apparatus;

[0057] Figure 11 is a graph illustrating detector response for a variety of
10 radioactive compounds;

[0058] Figure 12 is a graph illustrating a comparison between combined background and secondary radiation signals and background radiation signals for an unshielded detection apparatus;

[0059] Figure 13 is a graph illustrating a comparison between combined
15 background and secondary radiation signals and background radiation signals for a shielded detection apparatus;

[0060] Figure 14 is a graph illustrating detector efficiency as a function of scintillator thickness; and

[0061] Figure 15 is a graph illustrating photomultiplier tube signal variation
20 for different thickness of the aluminum scintillator housing.

[0062] Elements shown in the figures have not necessarily been drawn to scale. Further, where considered appropriate, reference numerals may be repeated among the figures to indicate corresponding or analogous elements.

DETAILED DESCRIPTION

25 [0063] Various apparatuses or processes will be described below to provide an example of an embodiment of each claimed invention. No embodiment described below limits any claimed invention and any claimed invention may cover processes or apparatuses that differ from those described below. The claimed inventions are not limited to apparatuses or processes having all of the features of

any one apparatus or process described below or to features common to multiple or all of the apparatuses described below. It is possible that an apparatus or process described below is not an embodiment of any claimed invention. Any invention disclosed in an apparatus or process described below that is not claimed
5 in this document may be the subject matter of another protective instrument, for example, a continuing patent application, and the applicants, inventors or owners do not intend to abandon, disclaim or dedicate to the public any such invention by its disclosure in this document.

[0064] Following a radiological / nuclear (RN) emergency, such as release
10 of radioactive substances in nuclear accidents at power plants or local contamination incidents involving in misuse of radioactive sources, and illicit dispersion of radioactivity in a radiological dispersal device (RDD) by terrorists, the population may be internally exposed to radionuclides. Rapid bioassay can be important to identify the contaminated individuals and to provide quick dose
15 information to the physicians for necessary medical treatment. As a bone-seeking element and a pure beta emitter with notable commercial uses, Strontium-90 (^{90}Sr) has been identified as one of the high-risk radionuclides or RDDs by the U.S. Department of Energy (DOE) and the U.S. Nuclear Regulatory Commission (NRC) interagency working group (the U.S. DOE/NRC 2003).

20 [0065] ^{90}Sr is a radioactive isotope of strontium, with a half-life of approximately 28 years and a maximum beta energy of 0.546 MeV distributed to an electron, an anti-neutrino and the yttrium isotope ^{90}Y (with a half-life of 64 hours and a maximum beta energy of 2.228 MeV). $^{90}\text{Sr/Y}$ is almost a pure beta source, and gamma emissions from the decay of $^{90}\text{Sr/Y}$ can be very weak.

25 [0066] Compared to substances that are strong gamma emitters, it may be relatively easier to shield the beta particles emitted by $^{90}\text{Sr/Y}$ (or other substantially pure high-energy beta-emitting sources, including, for example Phosphorous-32) from conventional detection techniques, for example by using shielding packing structures and materials. Beta sources are also more difficult to
30 detect than gamma sources. Thus, a RDD using ^{90}Sr source is more attractive to the terrorists as it would be easy to carry and difficult to monitor while in delivery

to the target location. In an emergency involving internal contamination of ^{90}Sr , large populations may need to be screened for early medical response.

[0067] For example, if exposed to air-borne $^{90}\text{Sr/Y}$ particles, a patient may inhale a quantity of $^{90}\text{Sr/Y}$, which can then become lodged in the patient's lungs.

- 5 The health risk posed to the patient can vary based on the quantity of $^{90}\text{Sr/Y}$ material present in the patient's lungs. To help facilitate diagnosis of patients exposed to $^{90}\text{Sr/Y}$ in this manner, it may be desirable to screen each patient to determine his/her exposure level.

- [0068] Traditional $^{90}\text{Sr/Y}$ screening apparatuses include large room-sized
10 test chambers (for example within a hospital or other facility) with extensive radiation shielding to filter out substantially all of the ambient/ background radiation. Background radiation can include radiation emitted from a variety of sources, including, for example, cosmic rays, natural radioactive background of surrounding materials (such as concrete, etc.).

- 15 [0069] Conventional radiation shielding can include thick layers of lead (or other suitable materials). A patient is then placed within the testing room and radiation emitted from the patient is monitored using a suitable detector. This type of screening can produce relatively accurate results, but typically takes approximately 20mins or longer to screen one patient. In instances of mass
20 exposure to $^{90}\text{Sr/Y}$, traditional screening methods may require a relatively long scan time per patient, which may limit the number of patients that can be screened in a given time period.

- [0070] Also, transporting a large number of patients to a suitable medical facility for screening may take a long time and may not be practical in some
25 situations. Further, transporting patients prior to screening for exposure to $^{90}\text{Sr/Y}$ may result in the transport of non-contaminated patients. Transporting non-contaminated patients to a secondary medical facility may be unnecessary and may consume resources that could otherwise be used to transport and treat contaminated patients.

- 30 [0071] To help facilitate the screening of patients on-site at a temporary testing location (i.e. generally at the scene of the $^{90}\text{Sr/Y}$ exposure) a relatively

rapid and mobile/ portable radiation detection apparatus (optionally useable to detect $^{90}\text{Sr/Y}$ and/or any other suitable radioactive material) and technique for $^{90}\text{Sr/Y}$ bioassay screening may be desirable. Preferably, the portable detection apparatus can be moved to, and operated effectively within, a $^{90}\text{Sr/Y}$ exposure site. In most instances, the portable $^{90}\text{Sr/Y}$ detection apparatus may operate without the benefit of the comprehensive radiation shielding that is used in conventional, room-based screening systems. In such instances, the patient, and the $^{90}\text{Sr/Y}$ detection apparatus, may not be substantially isolated from the surrounding background radiation.

10 [0072] Preferably, the portable $^{90}\text{Sr/Y}$ detection apparatus can be configured to be mounted on a truck, or other suitable vehicle, including, for example an airplane and a boat, and can be transported to a $^{90}\text{Sr/Y}$ exposure site.

[0073] Preferably, the portable $^{90}\text{Sr/Y}$ detection apparatus can be operable to screen patients at a faster rate than conventional screening systems. For example, the portable $^{90}\text{Sr/Y}$ detection apparatus can be configured to have a screening time that is less than 20mins per patient, and optionally can be less than 10mins per patient and can be between about 1min and about 2mins per patient, or less than 1min per patient.

20 [0074] Optionally, a portable $^{90}\text{Sr/Y}$ detection apparatus can be configured to directly monitor the beta radiation emitted by a $^{90}\text{Sr/Y}$ source. However, beta radiation emitted from a $^{90}\text{Sr/Y}$ source within a patient's lungs can be partially or completely blocked by the patient's lung tissue and other body parts. Such blockage of the beta radiation can make direct detection of the beta radiation more difficult.

25 [0075] Alternatively, instead of directly monitoring the primary beta radiation, a portable $^{90}\text{Sr/Y}$ detection apparatus can be configured to monitor a type of secondary radiation, which can then be correlated to an amount of beta radiation, and a related quantity of $^{90}\text{Sr/Y}$ material, present in the patient's lungs. One example of a measureable, secondary radiation is bremsstrahlung radiation.

30 Bremsstrahlung radiation (x-rays) is a type of secondary radiation that is produced as a result of the stopping or slowing of the primary radiation (in this case

electrons generated by the $^{90}\text{Sr/Y}$ beta radiation). The amount of bremsstrahlung radiation emitted can be correlated to the amount of incident beta radiation present. The amount of bremsstrahlung radiation produced can be dependent on the density of the material impacted with beta radiation, and can rise generally
5 with electron energy.

[0076] For example, a portable $^{90}\text{Sr/Y}$ detection apparatus can be configured to detect bremsstrahlung radiation present emitted by the patient, and to determine the amount of beta radiation and/or $^{90}\text{Sr/Y}$ material present based at least in part on the quantity of bremsstrahlung radiation detected.

10 [0077] Optionally, the portable $^{90}\text{Sr/Y}$ detection apparatus can also be configured to account for, and optionally filter out background radiation. Filtering out background radiation may help facilitate a more accurate reading of the secondary bremsstrahlung radiation levels present in the patient. For example, the detection apparatus can include a first detector that is configured to detect a
15 combination of secondary radiation and background radiation, and a second detector that is configured to simultaneously detect substantially only the background radiation. The amount of secondary target radiation detected can then be calculated by subtracting the second detector readings from the first detector readings.

20 [0078] A radiation blocking member can be used to prevent the secondary radiation from reaching the second detector. The blocking member can be any suitable material, and can be selected so that it is thick enough (for a given material) to block substantially all the secondary bremsstrahlung radiation. The background radiation can be higher energy than the secondary radiation, and can
25 pass through the blocking member to reach the second detector. Background radiation can come from all sides of the detection system (including, for example, natural radioactivity produced by common materials – K, U, Th). In contrast, the secondary bremsstrahlung radiation is emitted from the subject. Positioning the blocking member between the second detector and the subject may help prevent
30 the secondary radiation from reaching the second detector.

[0079] In addition to detecting $^{90}\text{Sr/Y}$, the teachings disclosed herein may also be useful for detecting other pure beta emitters, including, for example, P-32, Sr-89, Dy-165, Bi-210, Pd-109, Pr-143, Ho-166 and Pm-149. Some of all of these isotopes may have potential for use in nuclear medicine diagnostics and/or treatments. Measuring the relative concentrations of these materials according to the teachings disclosed herein may be advantageous, and may allow for more precise measurement, and/or measurement of relatively smaller quantities of such isotopes than is currently practical using known measurement techniques and/or apparatuses. The teachings disclosed herein may also reduce the time required to obtain a desired measurement, and may allow for portable or on-site measurements of suitable pure, or substantially pure beta emitters.

[0080] In addition to detecting/ measuring substantially pure beta emitters, the inventor believe that the teachings described herein may also be utilized to detect low energy gamma emitters, including, for example, Am-241, Ce-144, Ce-141 and U-235. For example, the use of a shielded, thin NaI detector (as explained in greater detail below) may allow for detection of low energy gamma emitters that might otherwise be obscured by background radiation using known, portable detectors. While the following example of a detection apparatus is illustrated with reference to detecting $^{90}\text{Sr/Y}$ for clarity, optionally the detection apparatus may also be configured for use with any other suitable material, including, for example, the isotopes set out above.

[0081] Referring to Figure 1, a portable $^{90}\text{Sr/Y}$ detection apparatus 100 includes a housing 102, a first detector 104 within the housing 102 for detecting ionizing radiation and a second detector 106 within the housing 102 for detecting ionizing radiation. The detection apparatus 100 also includes a radiation shield 108 (shown in dashed lines, see also Figure 4), a radiation blocking member 110 and a processor module 112 (Figure 4) connected to the first and second detectors 104, 106. The first and second detectors 104, 106 can be used simultaneously to measure the ionizing radiation. The blocking member 110 can be used to block at least a portion of the ionizing radiation from reaching the second detector 106, so that the radiation readings from the first and second detectors 104, 106 are different. The readings from the first and second detectors

104, 106 can then be compared by the processor module 112 to arrive at a resultant reading (for example the difference between the first detector reading and the second detector reading). The resultant reading can be provided to a system operator, and/or used to generate an alarm, a resultant output signal or
5 other output.

[0082] The detection apparatus 100 has a first end 114 (suitable for positioning adjacent a subject) and a second end 116 spaced apart from the first end. The detection apparatus defines a longitudinal axis 118 extending between the first and second ends.

10 [0083] The ionizing radiation detected by the first and second detectors 104, 106 can be any suitable type of secondary radiation (compatible with the detectors selected) and can include a combination of background radiation and secondary radiation from the subject. The secondary radiation can be any radiation, generally emitted from the subject that a system operator wishes to
15 measure. The background radiation can include radiation from a variety of sources, and can include radiation emitted from sources other than the subject. The processor module 112 is operable to determine the amount of ionizing radiation detected by the first detector that is attributable to secondary radiation, as opposed to the background radiation.

20 [0084] In some instances, the background radiation and secondary radiation may be similar forms of radiation, including, for example beta radiation, Bremsstrahlung radiation and x-ray radiation, and may have similar energy levels. Preferably, both the first and second detectors 104, 106 are capable of detecting the background radiation, and at least one of the detectors, for example the first
25 detector 104, is also capable of detecting the secondary radiation.

[0085] Referring To Figures 5 and 6, in the example illustrated, the subject is a human patient 120 that has been exposed to $^{90}\text{Sr/Y}$, and the detection apparatus 100 can be positioned adjacent the torso of the patient 120. Optionally, the detection apparatus can be positioned generally adjacent the lungs 122 of the
30 patient 120. This configuration may help facilitate detection of $^{90}\text{Sr/Y}$ radioactive material 124 (schematically represented as a single particle 124) that has been

inhaled by the patient 120, and has become lodged in the patient's lungs 122. In this example, the decay of $^{90}\text{Sr/Y}$ radioactive material 124 within the patient's lungs 122 may release ionizing beta radiation 126 (schematically represented as solid dots 126). This beta radiation 126 may interact with the bones, organs and
5 tissue of the patient's torso and may produce Bremsstrahlung radiation 128 (schematically represented as hollow dots 128). The Bremsstrahlung radiation 128 can then form at least a portion of the secondary radiation emitted from the patient's torso, and can be measured using the detection apparatus 100.

[0086] Referring to Figures 3 and 4, the first detector 104 includes a first
10 scintillator 130a having a first detection face 132a extending generally in the lateral direction (i.e. generally orthogonal to the longitudinal axis), and a first rear face 134a axially spaced apart from the first detection face 132a. A first sidewall 136a extends between the first detection face 132a and the first rear face 134a.

[0087] The second detector 106 includes a second scintillator 130b having
15 a second detection face 132b extending generally in the lateral direction, and a second rear face 134b axially spaced apart from the second detection face 132b. A second sidewall 136b extends between the second detection face 132b and the second rear face 134b. When the detection apparatus 100 is in use, the first
20 detection surface 132a and second detection surface 132b can be positioned facing the torso of the patient 120, and optionally can be placed in physical contact against the front or back of the torso of the patient 120.

[0088] In the illustrated example, both the first and second detectors 104,
106 are generally cylindrical in shape, and the first and second detection faces 132a, 132b are generally circular in cross-section. The scintillators 130a, 130b
25 have respective diameters 138 and lengths 140. In the example illustrated, the scintillator diameters 138a, 138b can be between about 25mm and about 125mm, and between about 50mm and about 100mm, and can be approximately 75mm. Optionally, the scintillator diameters 138a, 138b can be less than about 25mm or greater than about 125mm.

30 [0089] The scintillator lengths 140a, 140b can be between about 2.5mm and about 75mm, and can be between about 6.5mm and about 20mm, and

optionally can be about 12mm. Optionally, the scintillator lengths 140a, 140b can be less than 2.5mm and greater than about 75mm.

[0090] Optionally, the dimensions of the first and second detectors 104, 106 can be selected so that the surface area of the detection faces 132a, 132b is
5 between about 25% and about 45% of the total surface area of the first and second detectors 104, 106, respectively (e.g. the sum of the surface area of the first detection surface 132a, the first rear surface 134a and the first sidewall 136a).

[0091] The first and second detectors 104, 106 extend along respective detector axes 140a, 140b. The detector axes 140a, 140b can be generally
10 parallel to the axis 118. The first and second detectors 104, 106 are laterally separated from each other by a detector spacing distance 142 (Figure 4). The detector spacing distance 142 can be selected such that it is less than 1.5 times the lateral width, in this case the diameter 132a, of the first detector 104. Positioning the first and second detectors 104, 106 laterally close to each other
15 may help increase the likelihood that the first and second detectors 104, 106 are exposed to substantially the same ionizing radiation background. Alternatively, the detector spacing 142 can be greater than the 1.5 times first diameter 132a.

[0092] In the illustrated example, the first and second detectors 104, 106 can be generally identical. Alternatively, the first and second detectors can be
20 different.

[0093] The scintillators used to provide the first and second detectors 130a, 130b can be any suitable radiation detecting material. In the illustrated example, the first and second scintillators are sodium iodide crystals doped with thallium (NaI(Tl) crystals). The first and second scintillators 130a, 130b can each be
25 formed from a single NaI(Tl) crystal, or a plurality of crystals. Alternatively, the first and second scintillators 130a, 130b can be formed from another type of scintillator material, including, for example, organic crystals, organic liquids, plastic scintillators and inorganic crystals (including alkali metal halides, lanthanum halides, bismuth germanate and cadmium zinc telluride).

[0094] Alternatively, the first and second detectors 104, 106 can be any suitable type of detector or sensor, that can detect the secondary radiation, and need not be scintillators having the configuration described herein.

[0095] Referring to Figure 4, the radiation shield 108 is disposed within the housing 102 and surrounds the first and second detectors 104, 106. The radiation shield 108 can be any type of apparatus, and/or can be formed from any suitable material, that can at least partially shield the first and second detectors from incoming background radiation.

[0096] In the illustrated example, the shield 108 laterally surrounds the sidewalls 136a, 136b of the first and second detectors 104, 106, and includes a shield aperture 144 (see also Figures 1 and 2) located toward the first end 114 of the detection apparatus housing 102.

[0097] The shield aperture 144 includes at least one opening in the shield 108 to allow radiation to enter the housing 102 and contact the first and second detectors 104, 106. Preferably, the shield aperture 144 is provided in a plane 146 (Figure 4) that is generally perpendicular to the axis 118 and is laterally registered with the first and second detection faces 132a, 132b, so that the first and second 132a, 132b are at least partially overlapped by the aperture 144. This configuration may allow the first and second detection faces 132a, 132b to be exposed to a patient and may help reduce the exposure of the first and second detection faces 132a, 132b to radiation that is travelling in a generally non-axial direction.

[0098] Referring to Figures 5 and 6, when the detection apparatus 100 is positioned adjacent the torso of a patient 120, and aligned so that the longitudinal axis 118 intersects the torso of the patient 120, at least a portion of the secondary radiation 128 emitted from the patient 120 may travel through the shield aperture 144 to reach the first and second detectors 104, 106, while external background radiation 146 (illustrated by arrows 146) travelling in a non-axial direction may be at least partially blocked from reaching the first and second detection surfaces 132a, 132b.

[0099] The shield aperture 144 need not be a single, continuous opening that overlaps both the first and second detection surfaces 132a, 132b. Optionally, the blocking member 110 can be configured to cover substantially all of the shield aperture 144 and can include two or more discrete openings 144a, 144b (Figure 5 8a). For example the shield aperture can include a first opening 144a registered with the first detection face 132a, and a discrete second opening 144b registered with the second detection surface 132b. The blocking member 110 can be positioned to cover the opening 144b, to help prevent the secondary radiation from reaching the second detection surface 132b. Alternatively, referring to Figure 10 8b, the blocking member 110 can be configured to cover substantially all of the shield aperture 144, and can include a single opening 144a registered with the first detection surface 132a. The second detection face 132b can be covered by the shield member 110 (as illustrated using dashed lines in Figure 8b).

[00100] Referring to Figure 4, in the example illustrated, the shield 108 is a multi-layer apparatus, including a first shielding layer 148a formed from a first material, a second shielding layer 148b formed from a second material and disposed laterally inboard of the first shielding layer; and a third shielding layer 148c disposed laterally inboard of the second shielding layer. Each shielding layer 148a-c can be formed from any suitable material that can provide a desired degree of radiation shielding, including, for example, lead, copper, tin, tungsten, aluminium and other suitable materials. . Optionally, the shield layers 148a-c can be formed from different materials, or from the same material.

[00101] The first shielding layer 148a has a first lateral width 150a, the second shielding layer 148b has a second lateral width 150b and the third shielding layer 148c has a third lateral width 150c. Optionally, the first lateral width 148a can be greater than the both the second and third lateral widths 148b, 148c, and can be greater than the sum of the second and third lateral widths 148b, 148c.

[00102] In the illustrated example, the first shielding layer 148a is formed from lead, and the first lateral width 150a can be between about 2.5mm and 125mm, or more. The width of the first shield layer 148a can be selected based

on a variety of factors, including, for example, weight, safety and health considerations and radiation shielding characteristics. Reducing the weight of the shield 108 may be desirable and may help increase the portability of the detection apparatus. In some embodiments, selecting a shield thickness to reduce weight
5 may be more desirable than achieving a higher level of radiation shielding.

[00103] Some radiation shielding materials, effective at blocking certain types of radiation, can also emit radiation. In some instances, the radiation emitted by the shielding material can be generally similar to the secondary radiation. In such instances, it may be desirable to configure the inner shielding
10 layers (for example the second and third shielding layers 148b, 148c) to help block the radiation emitted by the first shielding layer 148a.

[00104] For example, lead may be generally effective at blocking gamma and beta radiation, but may emit low levels of x-ray radiation. X-ray radiation emitted by the lead shielding can be generally similar to the secondary
15 Bremsstrahlung radiation 128 emitted by the patient. To help facilitate accurate target radiation readings, it can be desirable to block the x-ray radiation emitted from the lead shielding from reaching the first and second detectors 104, 106. In the illustrated example, the second and third shielding layers 148b, 148c are formed from a material other than lead, and may help block x-rays emitted by the
20 first shielding layer from reaching the detectors. The second and third shielding layers 148b, 148c can be formed from any suitable material.

[00105] In the example illustrated, the second shielding layer 148b can be formed from tin and the third shielding layer 148c can be formed from copper. The second lateral width 150b and third lateral width 150c can be between about
25 0.25mm and about 25mm, and can be approximately 1mm. Optionally, the second and third lateral widths can be greater than about 25mm or less than about 0.25mm.

[00106] Referring to Figures 2 and 6, the radiation blocking member 110 is configured to substantially block at least a portion of the ionizing radiation entering
30 the housing through the shield aperture 144 from reaching the second detector 106 (shown in phantom in Figure 2). Preferably, the radiation blocking member

110 is configured so that when bombarded with ionizing radiation containing a mixture of background radiation 146 and secondary radiation 128, that substantially all of the secondary radiation 128 is blocked by the blocking member 110, and substantially all of the background radiation 146 can pass through the blocking member 110 and reach the second detector 106. In this configuration, the second detector 106 would detect substantially only the background radiation.

[00107] The blocking member 110 can be formed from any suitable material, having the desired radiation shielding properties, and can be any suitable size.

[00108] In the illustrated example, the blocking member 110 includes a plate member coupled to the housing 102 (or optionally integrally formed with the housing). The radiation blocking member 110 has an axial thickness 150 between about 0.25mm and about 7.5mm, and can be approximately 2mm thick. Optionally, the blocking member 110 can be formed from copper, tin, aluminium, any other suitable material or a combination thereof. In the illustrated example, the blocking member 110 is formed from copper.

[00109] Preferably, the blocking member 110 has a surface area that is generally equal to or greater than the surface area of the second detection face 132b, so that the plate can be positioned to cover all of the second detection face 132b (Figure 2).

[00110] Referring to Figure 4, the processor module 112 connected to the first and second detectors 104, 106 is used to determine the amount of ionizing radiation detected by the first detector 104 attributable to the secondary radiation 128. Referring also to Figure 7, the processor module 112 can include a central processing unit (CPU) 154, a memory module 156 an input module 158 and an output module 160. The processor module 112 may also include any other suitable modules. Any of the modules can be provided as hardware components, firmware components, software components and any combination thereof. A power source 162 can also be included within the housing 102 to provide power for the processor module 112 and/or detectors. Optionally, the power source 162 can be provided within the processor module 112. While illustrated as separate modules, optionally, some or all of the modules can be integral with each other.

[00111] The input module 158 can be any suitable module adapted to receive signals 164 from the detectors (optionally, via an intermediate connecting apparatus as explained below), including, for example, a single channel or multi-channel data acquisition apparatus, analogue-to-digital convertor, pre-amplifiers, amplifiers, FADCs, FPGAs, ASICs, etc.

[00112] The output module 160 can be any suitable module adapted to send output signals 166 from the processor module 112. The output signals 166 may include any type of signal, including electrical signals, data signals, printed or displayed dosage estimates, visual output signals (such as flashing lights, text on a display screen, etc.), auditory signals (such as warning sounds or sirens) and control output signals that can be used to control other pieces of equipment. Examples of suitable output modules 160 can include, for example, display screens, lights, audio transducers and command and control signals. The output module 160 can also include a transmitter, for example a wireless transmitter 168, for transmitting output signals 160 from the detection apparatus 100 to an external location.

[00113] The memory module 156 can be any suitable type of memory that can be read by the CPU 154. The memory module 156 can be configured to store alarm threshold data, look-up tables, databases, apparatus operation algorithms and any other suitable type of information. The memory can be selectively queried by the CPU 156.

[00114] Preferably, the processor module 112 can be contained within the housing 102. This configuration may help facilitate transportation of the detection apparatus 100. A self-contained detection apparatus 100 of this type may be more portable than a detection apparatus comprising a plurality of independent pieces. Alternatively, some or all of the processor module 112 can be independent from the housing 102 containing the first and second detectors 104, 106.

[00115] Referring to Figures 4 and 6, in the illustrated example, the first scintillator 130a produces a first light when excited by the ionizing radiation and the second scintillator 130b produces a second light when excited by the ionizing

radiation. Optionally, a photosensor 170 can be positioned adjacent the first and second scintillators 130a, 130b to receive the first light and generate a corresponding first output signal, and to receive the second light and generate a corresponding second output signal. The photosensor 170 can be positioned
5 between the first and second detectors 104, 106 and the processor module 112.

[00116] In the example illustrated, the photosensor 170 includes a first photomultiplier tube 172a positioned adjacent the first rear face 134a to receive the first light and generate a corresponding first electrical output signal, and a second photomultiplier tube 172b positioned adjacent the second rear face 134b
10 to receive the second light and generate a corresponding second electrical output signal. The strength of the first and second output signals can be proportional to the amount of ionizing radiation received by the first and second detectors 104, 106, respectively. The photomultiplier tubes (PMTs) 172a, 172b can be of any suitable configuration. Outputs from the PMTs 172a, 172b are sent to the input
15 module 158 in the processor unit 112.

[00117] Alternatively, any other suitable type of connecting apparatus can be used to link the detectors to the processor module. The type of connecting apparatus used may depend on the nature of the detectors and processor module used. Other examples of connecting apparatuses can include amplifiers and
20 analogue-to-digital convertors.

[00118] Referring to Figures 4 and 6, in the example illustrated the processor module 112 is operably linked to the photosensor 170 and is operable to determine the amount of ionizing radiation detected by the first detector 104 attributable to the secondary radiation 128 by comparing the second output signal
25 with the first output signal.

[00119] For example, the first output signal from the first PMT 172a may be proportional to the total amount of background radiation 146 and secondary radiation 128 received by the first detector 104, and the second output signal may be proportional to the total amount of background radiation received by the
30 second detector 106. Due to the presence of the blocking member 110 that can filter out the secondary radiation 128, the total amount of radiation received by the

second detector 106 can be substantially equal to background radiation 146. The amount the ionizing radiation detected by the first detector 104 that is attributable to the secondary radiation 128 can be determined by subtracting the second output signal from the first output signal. The resultant signal is proportional to the amount of secondary radiation 128 detected. This operation can be performed by the processor module 112.

[00120] Optionally, the processor module 112 can be configured to calculate the quantity of secondary radiation 128 emitted from the subject 120, based on the resultant signal. In the illustrated example, the processor module 112 may be operable to calculate the amount of Bremsstrahlung radiation 128 emitted from the patient 120, based on the difference between the signals from the first and second detectors.

[00121] Further, the processor module 112 may also be configured to calculate the quantity of radioactive material 124 contained within the subject 120. In the example illustrated, the processor module 112 may be configured to calculate the amount of beta radiation 126 that is present within the patient 120 to produce the measured level of Bremsstrahlung radiation 128, and then calculate the quantity of $^{90}\text{Sr/Y}$ 124 present within the subject based on the calculated beta radiation levels.

[00122] Optionally, the processor module 112 can be operable to compare at least one of the amount of ionizing radiation detected by the first detector 106 attributable to the secondary radiation (for example the quantity of Bremsstrahlung radiation 128 measured) and the quantity of radioactive material contained in the subject (for example the quantity of $^{90}\text{Sr/Y}$ 124 in the patient) to one or more predetermined alarm threshold values stored in the memory module 156. The processor module 112 can then generate a warning output signal or an alarm output signal 166 if the at least one of the amount of ionizing radiation detected by the first detector 104 attributable to the secondary radiation 128 and the quantity of radioactive material 124 contained in the subject 120 exceeds its corresponding alarm threshold value. The warning and alarm output signals can be any suitable output signal, as described above.

[00123] When the detection apparatus 100 is in use, the time elapsed between exposure of the detection apparatus 100 to the source of the secondary radiation 128 (e.g. the patient 120) and obtaining the resultant output signal can define a detection cycle time. When measuring Bremsstrahlung radiation 128, the precision or resolution of the measurement may increase with longer detection cycle time. For example, a conventional scan performed in a heavily shielded room (for example within a hospital) may produce relatively precise radiation readings, but may have a detection cycle time of approximately 20 minutes, or more. The length of the scan can be based on the desired accuracy of the results.

[00124] However, if the detection apparatus 100 is used as an on-site emergency scanner, providing relatively precise radiation readings may be relatively less important. Instead, providing a more coarse radiation reading while providing relatively short detection cycle times may be advantageous, as it may allow multiple patients 120 to be scanned in a relatively short time period. For example, in an emergency bioassay or triage type situation, it may be sufficient to simply determine if the amount of $^{90}\text{Sr/Y}$ a patient has received is above or below a certain threshold. In such instances, it may not be necessary in the field to determine precisely how much $^{90}\text{Sr/Y}$ a patient has inhaled, but rather whether the patient's exposure is high enough to warrant further medical care. A more precise scan may then be performed at a hospital or other care facility if warranted.

[00125] When used on-site, the detection apparatus 100 can be configured to have a cycle time that is less than the cycle time of conventional, room-based scanners. Optionally, the detection apparatus 100 can be configured to reduce cycle time to help facilitate the relatively rapid scanning of multiple patients, even if such reduced cycle times are achieved by sacrificing the precision of the radiation readings. Configuring the detection apparatus 100 can include modifying the programming of the processor module 112 to limit scan times and/or limit the acquisition threshold or energy spectrum detection range.

[00126] Optionally, the detection apparatus can be configured so that the detection cycle time is less than about 10 minutes, and can about 5 minutes and can be less than about 2 minutes.

[00127] Optionally, the detection apparatus can be configured to measure
5 photons having an energy that is between about 0keV and about 700keV, between about 30keV and about 600keV and preferably between about 120keV and about 500keV, and filter out energy signals outside of this range. Limiting the energy spectrum detection range may help reduce detection cycle time.

[00128] Optionally, the detection apparatus can be configured to have an
10 operating sensitivity capable of detecting an activity of at least about 460 Bq within the subject using a 5 minute scan. The detection apparatus and method may be a viable technique for detecting ^{90}Sr with a minimum detectable activity (MDA) of 1.1×10^4 Bq for a realistic dual shielded detector system in a $0.25 \mu\text{Gy h}^{-1}$ background field for a 100 s scan. This MDA is below the action level of 8.2×10^4
15 Bq for ^{90}Sr intake in the lungs.

[00129] Optionally, the detection apparatus 100 can be part of a larger mobile radiation detection system and can be mountable on a vehicle to help facilitate transportation of the detection apparatus to a radiological emergency site. While an example of a truck is illustrated, the detection apparatus can be
20 mountable on a variety of vehicles (including planes and ships), and/or in a plurality of portable labs or other structures (including trailers and modular building components that can be transported to emergency sites).

[00130] Referring to Figure 9 a portable radiation detection system 900 can include a vehicle, for example truck 902, and a portable radiation detection
25 apparatus 1000 mounted on the vehicle. The portable detection apparatus 1000 can be any suitable apparatus, and can include any of the features of detection apparatus 100 described above.

[00131] Optionally, the vehicle 902 can include a radiation shielded chamber 904 and the portable detection apparatus 1000 can be provided within the
30 shielded chamber. In the example illustrated, the radiation shielded chamber 904 is provided inside the cargo area of the truck 902, which is illustrated in a partially

cut-away view. The walls 906 of the cargo area can be shielded with any suitable material. The quantity of shielding 908 may be relatively limited to help ensure that the weight of the shielding material 908 does not prevent operation of the truck 902. The quantity of shielding 908 provided on the truck 902 is generally
5 less than the quantity of shielding that can be provided around a stationary scanning room.

[00132] Referring to Figure 10 a method 1200 of using a portable detection apparatus to measure the quantity of a beta-emitting radioactive material, for example $^{90}\text{Sr/Y}$, disposed within a subject is illustrated.

10 [00133] Optionally, the method 1200 can include the step 1202 of transporting the detection apparatus to a temporary testing location. The temporary testing location can be any location where on-site radiation detection is desired for a relatively short time period, and then the radiation detection equipment is removed from the location (for example an emergency scene). The
15 method can also include calibration steps to calibrate the detector to the local environment.

[00134] Step 1204 includes positioning the portable detection apparatus adjacent the torso of the subject.

[00135] The portable detection apparatus can be any type of portable
20 detection apparatus including those examples described herein. Optionally the detection apparatus can include a first detector, configured to detect a combination of background radiation and a secondary radiation, and a second detector, configured to detect the background radiation.

[00136] The method can also include the step 1206 of detecting a
25 combination of the secondary radiation (for example Bremsstrahlung radiation) and the background radiation using the first detector and providing a corresponding a first output signal. At step 1208, the method 1200 includes simultaneously detecting the background radiation using the second detector and providing a corresponding second output signal. Optionally, steps 1206 and 1208
30 can be conducted simultaneously. Alternatively, they can be conducted in series.

[00137] Step 1210 includes automatically calculating a resultant output value based on the first output signal and the second output signal. Step 1212 includes comparing the resultant output value to a predetermined alarm threshold value, and optionally generating an alarm output if the resultant output value exceeds the
5 alarm threshold value at step 1214.

[00138] The method can include calculating the resultant output value by subtracting the second output signal from the first output signal to determine a first quantity of secondary radiation (e.g. Bremsstrahlung radiation) received by the detection apparatus.

10 [00139] Calculating the resultant output value further can include determining the quantity of radioactive material, for example $^{90}\text{Sr/Y}$, contained within the patient based on the first quantity of Bremsstrahlung radiation.

[00140] Optionally, the resultant output value can include at least one of the quantity of Bremsstrahlung radiation and the quantity of $^{90}\text{Sr/Y}$ material. For
15 example, the portable detection apparatus can be configured to generate an alarm signal based on the calculated quantity of $^{90}\text{Sr/Y}$ disposed within a patient's lungs, or optionally based directly on the measured Bremsstrahlung radiation levels, without requiring the subsequent calculation of the $^{90}\text{Sr/Y}$ quantities or beta emission levels.

20 [00141] An experiment was conducted to study various aspects of the apparatuses and methods disclosed herein.

[00142] The study was directed to developing a portable ^{90}Sr detector suitable for rapid bioassay in emergency situations. A method to detect beta-emitters ^{90}Sr and its daughter ^{90}Y inside the human lung via bremsstrahlung
25 radiation was also investigated using a 3"x3" NaI(Tl) crystal detector and a polyethylene encapsulated source to emulate human lung tissue.

[00143] The results illustrate that this method may be a viable technique for detecting ^{90}Sr with a minimum detectable activity (MDA) of 1.1×10^4 Bq for a realistic dual shielded detector system in a $0.25 \mu\text{Gy h}^{-1}$ background field for a 100
30 s scan shielded with 5 cm of lead. These results are well below the recognized

action level (i.e. a threshold over which further medical treatment may be required) of 8.2×10^4 Bq for ^{90}Sr intake in the lungs. The experimental data was verified using Monte Carlo calculations (see for example Figures 14 and 15), including an estimate for internal bremsstrahlung, and an optimization of the
5 detector geometry was performed.

[00144] The study included the preparation of a ^{90}Sr source. As explained above, within a human lung, the beta particles emitted by the ^{90}Sr – ^{90}Y decay and interact with the surrounding tissue to generate x-rays through bremsstrahlung. These x-rays will then transport out of the body, where they may be detected. This
10 detection indicates the presence of the beta-emitter within the lung. In order to experimentally replicate this effect, a bremsstrahlung radiation source was devised and constructed.

[00145] The sensitivity requirement for in vivo lung counting technique for assessing internal contamination following an RN emergency was first derived to
15 guide the experimental design for source preparation. A dose threshold of 0.1 Sv CED (committed effective dose) was chosen to calculate the sensitivity required for the ^{90}Sr lung counting techniques using a dose calculation software GenmodPC. Similar same input parameters for ^{90}Sr were used for calculation, including the most commonly available chemical form (titanate), ICRP default
20 particle solubility type (fast), f_r (0.01) and inhalation dose coefficients (1.6×10^{-7} Sv Bq^{-1}) for the public (adults). This led to a daily lung burden of 8.5×10^4 – 7.9×10^4 Bq of ^{90}Sr within the first 5 days after an inhalation exposure of 0.1 Sv CED, with a lung burden of 8.2×10^4 Bq in the third day after exposure.

[00146] The experimental bremsstrahlung radiation source was made by
25 evaporating a ^{90}Sr standard solution (purchased from the National Institute of Standard and Technology, US) within a recess inside a 2" diameter and 2 cm thick cylindrical polyethylene container. This was then covered with another 2" diameter and 2 cm cylindrical polyethylene slab and sealed. This source geometry was designed to emulate a practical ^{90}Sr inhalation scenario. Polyethylene was
30 selected as a suitable tissue equivalent material that substantially mimics human tissue (for example in both Z-value and material density). Polyethylene gives a

similar bremsstrahlung production probability compared to human tissue. The beta source activity was determined to be 112.1 kBq, excluding the contribution of ^{90}Y .

[00147] An experimental ^{90}Sr detection apparatus was also constructed for test purposes. The detection apparatus included a Bicron 3M3/3-X, which is a
5 standard 3"x3" NaI(Tl) crystal optically coupled with a 3" PMT. The crystal and PMT were hermetically sealed within an aluminium case. This PMT was mounted with a Saint-Gobain P-14 PMT base and operated with a high voltage of +780 V. The output signal was then put through a charge-sensitive preamplifier and the resulting pulse height, which corresponds to detected particle energy, was
10 recorded by the acquisition system.

[00148] Detection of the ^{90}Sr – ^{90}Y source was achieved through the detection of bremsstrahlung radiation. When configured as a portable detector, it may be advantageous to keep the overall size of the detection apparatus to a minimum while still retaining the capability to measure x-ray emission from large surface
15 areas (i.e. the torso of a patient). These specifications made a NaI(Tl) crystal a suitable candidate for testing as it is a dense, high-Z material capable of being produced as a relatively large single crystal, which may be preferred for gamma or x-ray detection. The final design of this detector may be small enough and light enough to fit within an emergency mobile detection unit, such as a truck or van, or
20 may be hand-held or carryable by one or more operators.

[00149] Initial calibration of the experimental detector was performed using weak sources of ^{60}Co (γ : 1.17 and 1.33 MeV), ^{137}Cs (γ : 662 keV), and ^{133}Ba (γ : 303 keV and 356 keV). As expected, the detected gamma energy scaled linearly with the PMT signal voltage. Recorded spectra are shown in Figure 11. The
25 FWHM of the signal peaks corresponding to these gamma lines are approximately 60 keV for ^{60}Co , 40 keV for ^{137}Cs , and 30 keV for ^{133}Ba .

[00150] Measurements were made with this detector setup for background and source or secondary radiation for 2 hours each. Additional measurements were later made for 30 minutes each, but with the inclusion of a 5 cm thick
30 surrounding layer of Pb to reduce the ambient background. Monte Carlo calculations of the detector geometry were then compared to the experimental

data. These simulations helped in optimizing the detector geometry and identifying factors in the ^{90}Sr detection method discussed. The calculation was done using Geant4, a simulation toolkit based in the C++ programming language.

[00151] The inventors discovered that the region of interest (ROI) for these
5 experiments was from about 0keV to about 500 keV. This region was selected based on the inventor's discovery that there is little statistical difference between the experimental source signal and the experimental background signal beyond about 500 keV as the bremsstrahlung energy spectrum has a relatively low energy (similar to that of the background radiation). See for example the spectra shown in
10 Figure 12.

[00152] For example, the measured spectra with and without the source can be seen in Figure 12. A difference is noticeable between the combined secondary and background signal and the pure background signal, an integrated total difference within the ROI was calculated to be about $98,161 \pm 1,297$. This error
15 was calculated by summing the statistical counting errors of the source and background scans. This difference may be significant when compared to the background count total of approximately 361,000 in the ROI. This may help confirm the capability of this technique to monitor inhaled ^{90}Sr even without conventional, bulky radiation shields.

20 [00153] The measured radiation intensity begins to drop off sharply below 120 keV as this was the threshold of detection for the data acquisition system used in this experiment. Since the bremsstrahlung process mainly generates lower energy x-rays, the counting statistics may not be optimal as a result of the high threshold.

25 [00154] A Monte Carlo simulation was constructed with a simplified geometry. The simulation modelled the beta minus decay of the ^{90}Sr and ^{90}Y nuclei, the bremsstrahlung radiation subsequently generated within the polyethylene source container, and the crystal scintillation as a result of the photon energy loss in the crystal. The simulations were run with a total of
30 6.726×10^6 histories in order to simulate the approximate number of disintegrations in the 112.1 kBq source in the time span of 1 minute.

[00155] This simulation did not include the internal bremsstrahlung spectrum, which is the direct production of x-rays accompanying the beta decay. This phenomenon has a low energy x-ray spectrum similar to that of external bremsstrahlung. The KUB theory describes the probability of internal
5 bremsstrahlung interaction with a first-order approximation of $\frac{\alpha}{w}$, where α is the fine structure constant ($\sim 1/137$) and w is the emitted photon energy in units of electron rest mass energy. This probability is about $\sim 1\%$ for 100 keV photons and decreases for higher energies. This is in the same range as the probability of interaction for external bremsstrahlung in the polyethylene container.

10 [00156] The experimental results of the unshielded experiment were compared against the simulation results. This comparison showed good agreement beyond 130 keV. A sharp drop-off shown in the measured data below 120 keV was the result of the acquisition system threshold being defined at 120 keV, meaning sampled pulse heights lower than those corresponding to 120 keV
15 x-rays were not recorded by the acquisition system.

[00157] To improve the source signal detection rate, a 5 cm thick layer of lead blocks were placed around the detector and source apparatus to reduce the acquisition time required for a scan. This structure simulates the shield described above. Measurements were made with this modified detector setup for
20 background and source for 30 minutes each.

[00158] Referring to Figure 13 with the presence of the shield, the background signal was attenuated significantly, providing a more prominent bremsstrahlung spectrum with an integrated total difference within the ROI of $79,079 \pm 442$. In the illustrated example, the background total count recorded in
25 the ROI for this trial is approximately 17,300. As with the previous set of experimental data, the differential spectrum was compared to the simulation results, which showed good agreement with the experimental results combined with better statistics on the differential spectrum due to background reduction.

[00159] With the simulation verified against experimental data, it was found
30 through further simulations that there are factors in the detector setup which can be optimized.

[00160] One such factor is the NaI(Tl) crystal thickness. Since the source detection rate is dependent on the effective detector surface area and the background rate is dependent on the detector volume, the inventors discovered that it may be desirable for a detector to be as thin as possible to help reduce the background signal. However, providing too thin a crystal may allow some x-rays to escape the detector volume without being detected. The simulation was run multiple times with different crystal thicknesses, each with 2×10^6 histories (number of Sr/Y decays) for good statistics.

[00161] The efficiency was defined as:

10 [00162]
$$\epsilon = \frac{n_{\text{detected}}}{N_{\text{histories}}} \quad (1)$$

[00163] Referring to Figure 14, a simulated efficiency curve shows little significant efficiency gains for crystal thicknesses greater than 1" and it was determined that a 1/2" crystal could be used for the detection of x-rays at the energies associated with this detection method.

15 [00164] Another factor found to affect the signal statistics was the thickness of the aluminium housing surrounding the detector crystal. Since the energy region of interest lies in the low energy range, the inventors discovered that a thin layer of aluminum may be capable of attenuating the secondary radiation. Referring to Figure 15, a simulation of the signal below 50 keV appears to be attenuated as the aluminium housing thickness increases. Based on these results, the inventors believe that a 17.4% gain in the integrated signal above 30 keV may be achieved from thinning the aluminum layer from 1.0 mm to 0.01 mm. The experimental detector geometry has an aluminium housing thickness of 0.5 mm. This layer also shifts the peak detectable x-ray energy. As shown in Figure 20 25 15, the peak detection occurs at approximately 40 keV for an aluminium thickness of 0.01 mm, but this moves closer to 60 keV at a thickness of 1.0 mm.

[00165] For the characterisation of a portable detector, both the lower limit of detection (LLD) and the minimum detectable activity (MDA) may be relatively significant factors for the detection apparatus. It was determined that a 5 minute scan may be one acceptable detection cycle time for a rapid bio-assay technique

30

(i.e. on-site testing), and all the experimental calculations were performed for an equivalent scan of 5 minutes. Additionally, the background count rates were corrected for the detector dead time previously calculated and all of the following calculations use a calculated detector efficiency of 0.4%, which was calculated to be the total efficiency for an 3"x3" NaI(Tl) crystal in this arrangement.

[00166] The LLD can be calculated as:

$$[00167] \quad LLD = \frac{1.645 \sqrt{R_b/t_b}}{\epsilon(A/100 \text{ cm}^2)} \quad (2)$$

[00168] where R_b is the background count rate (dead time corrected), t_b is the acquisition time of the background count, ϵ is the efficiency of the detector, and A is the effective area of the detector. For the unshielded and shielded detector geometries, the LLD was determined to be 401 Bq and 167 Bq, respectively. The MDA of this detector can be calculated as:

$$[00169] \quad MDA = \frac{(2.71/t) + 4.65 \sqrt{R_b/t}}{\epsilon(A/100 \text{ cm}^2)} \quad (3)$$

[00170] where t is the time of the scans. For the unshielded and shielded detectors, the MDA was calculated to be 1,132 Bq and 471 Bq, respectively. These results are well below the action level of 0.1 Sv CED for ^{90}Sr inhalation.

[00171] Based on the experiments described above, the inventors have found that the bremsstrahlung x-ray emission from beta emitters ^{90}Sr – ^{90}Y inside the lung may be successfully measured by an external NaI(Tl) detector arrangement. The experiment also shows that one example of a suitable detector geometry includes a 3"x½" NaI crystal, with a relatively thin layer of aluminium surrounding the crystal. Also, the bremsstrahlung count rate (background subtracted) for the unshielded detector was found to be 10 counts s^{-1} for a 112.1 kBq source, with a background count rate of 70 counts s^{-1} . The MDA for a 5 minute scan with this setup was determined to be a source with an activity of 1,132. A Pb layer of 5 cm surrounding the detector was found to help improve the bremsstrahlung net count rate to 40 counts s^{-1} for the same source, with a background count rate of 25 counts s^{-1} .

[00172] The non-limiting illustrative examples herein illustrate one or more embodiments of a portable radiation detection apparatus and method suitable for detecting $^{90}\text{Sr/Y}$. Other embodiments of a portable radiation detection apparatus/method can be configured to be suitable for detecting other radioactive materials, including, for example, beta-emitting radioactive materials.

5 [00173] While the subject is illustrated as a human patient 120, the portable detection apparatus 100 can also be used to detect radiation in other types of subjects, including animals and plants that may have received internal exposure to beta-emitting radioactive materials.

10 [00174] What has been described above has been intended to be illustrative of the invention and non-limiting and it will be understood by persons skilled in the art that other variants and modifications may be made without departing from the scope of the invention as defined in the claims appended hereto.

CLAIMS:

1. A portable detection apparatus, comprising:
 - a) a housing;
 - b) a first detector within the housing for detecting ionizing radiation comprising background radiation and secondary radiation from a subject;
 - c) a second detector within the housing for the detecting the background radiation;
 - d) a shield within the housing surrounding the first and second detectors and defining a shield aperture around the first and second detectors for radiation from the subject to enter the housing;
 - e) a radiation blocking member substantially blocking at least a portion of the ionizing radiation entering the housing through the shield aperture from reaching the second detector and allowing transmission of the background radiation there through, whereby the background radiation can reach the second detector so that radiation detected by the second detector comprises substantially only the background radiation; and
 - f) a processor module connected to the first and second detectors for determining the amount of ionizing radiation detected by the first detector attributable to the secondary radiation.
2. The apparatus of claim 1, wherein the housing defines a detection apparatus axis and being axially alignable with the subject, and the first detector comprises a first scintillator having an exposed first detection surface extending in a generally lateral direction and positionable opposite the subject, and the second detector comprising a second scintillator having a second detection surface extending in the generally lateral direction.
3. The apparatus of any one of claims 1 to 2, wherein the radiation blocking member covers substantially all of the second detection face, whereby the secondary radiation is substantially prevented from reaching the second detection face.

4. The apparatus of claim 2, wherein the shield laterally surrounds the first scintillator and the second scintillator and the shield aperture is registered with the first detection surface and the second detection surface.
5. The apparatus of claim 4, wherein the first scintillator produces a first light when excited by the ionizing radiation and the second scintillator produces a second light when excited by the ionizing radiation and further comprising a photosensor positioned adjacent the first and second scintillators to receive the first light and generate a corresponding first output signal, and to receive the second light and generate a corresponding second output signal.
6. The apparatus of claim 5, wherein the processor module is operably linked to the photosensor and is operable to determine the amount of ionizing radiation detected by the first detector attributable to the secondary radiation by comparing the second output signal with the first output signal.
7. A portable detection apparatus, comprising:
- a) a housing;
 - b) a first detector within the housing for detecting ionizing radiation comprising background radiation and secondary radiation from a subject, the first detector comprising a first scintillator having an exposed first detection surface extending in a generally lateral direction and positionable opposite the subject and operable to produce a first light when excited by the ionizing radiation;
 - c) a second detector within the housing for the detecting the background radiation and comprising a second scintillator having a second detection surface extending in the generally lateral direction and operable to produce a second light when excited by the ionizing radiation;
 - d) a shield within the housing and laterally surrounding the first scintillator and the second scintillator and defining a shield aperture registered with the first detection surface and the second detection surface for radiation from the subject to enter the housing;
 - e) a radiation blocking member substantially blocking at least a portion of the ionizing radiation entering the housing through the shield aperture

from reaching the second detector whereby radiation detected by the second detector comprises substantially only the background radiation;

5 f) a photosensor positioned adjacent the first and second scintillators to receive the first light and generate a corresponding first output signal and to receive the second light and generate a corresponding second output signal; and

10 g) a processor module operably linked to the photosensor and operable to determine the amount of ionizing radiation detected by the first detector attributable to the secondary radiation by comparing the second output signal with the first output signal.

8. The apparatus of claim 6 or 7, wherein the processor module is operable to determine a quantity of the radioactive material contained in the subject based on the amount of ionizing radiation detected by the first detector attributable to the secondary radiation measured by the detection apparatus.

15 9. The apparatus of claim 8, wherein the processor module is operable to compare at least one of the amount of ionizing radiation detected by the first detector attributable to the secondary radiation and the quantity of radioactive material contained in the subject to a predetermined alarm threshold value and generate an alarm signal if the at least one of the amount of ionizing radiation
20 detected by the first detector attributable to the secondary radiation and the quantity of radioactive material contained in the subject exceeds the alarm threshold value.

25 10. The apparatus of any one of claims 6 to 8, wherein the photosensor comprise a first photomultiplier tube to receive the first light and generate the first output signal and a second photomultiplier tube to receive the second light and generate the second output signal.

11. The apparatus of any one of claims 1 to 10, wherein the radiation blocking member has a thickness between about 0.05mm and about 5mm.

12. The apparatus of any one of claims 1 to 11, wherein the radiation blocking member comprises a plate member.
13. The apparatus of claim 12, wherein the plate member comprises at least one of copper, tin, and aluminum or a combination thereof.
- 5 14. The apparatus of any one of claims 1 to 13, wherein the shield comprises
- a) a first shielding layer formed from a first material,
 - b) a second shielding layer formed from a second material and disposed laterally inboard of the first shielding layer; and
 - c) a third shielding layer disposed laterally inboard of the second
- 10 shielding layer.
15. The apparatus of claim 14, wherein the first shielding layer has a first lateral width, the second shielding layer has a second lateral width and the third shielding layer has a third lateral width, the first lateral width being greater than the both the second and third lateral widths.
- 15 16. The apparatus of claim 15, wherein the first shielding layer is formed from lead or tungsten, and the first lateral width is between about 2.5mm and 125mm.
17. The apparatus of any one of claims 14 to 16, wherein the second shielding layer is formed from tin, and the second lateral width is between about 0.25mm and about 25mm.
- 20 18. The apparatus of any one of claims 14 to 17, wherein the third shielding layer is formed from copper, and the third lateral width is between about 0.25mm and about 25mm.
19. The apparatus of claim 2 or 7, wherein the first scintillator has an overall surface area and the first detection surface has a detection surface area, and the
- 25 detection surface area is between about 25% and about 45% of the overall surface area.

20. The apparatus of any one of claims 2, 7 or 19, wherein the first scintillator has a first thickness in the axial direction of less than about 25mm.
21. The apparatus of any one of claims 2, 7, 19 or 20, wherein the first and second detection crystals comprise NaI(Tl) crystals.
- 5 22. The apparatus of any one of claims 2, 7, or 19 to 21, wherein the second scintillator is generally identical to the first scintillator.
23. A portable detection apparatus, comprising:
- a) a housing;
 - b) a first detector within the housing for detecting ionizing radiation
 - 10 comprising background radiation and secondary radiation from a subject;
 - c) a second detector within the housing for detecting the background radiation;
 - d) a shield within the housing surrounding the first and second detectors and defining a shield aperture around the first and second detectors for
 - 15 radiation from the subject to enter the housing;
 - e) a radiation blocking member substantially blocking at least a portion of the ionizing radiation entering the housing through the shield aperture from reaching the second detector whereby radiation detected by the second detector comprises substantially only the background radiation; and
 - 20 f) a processor module connected to the first and second detectors for determining the amount of ionizing radiation detected by the first detector attributable to the secondary radiation and configured to generate a corresponding resultant output signal;
- wherein time elapsed between exposure of the detection apparatus
- 25 to the source of the secondary radiation and obtaining the resultant output signal defines a detection cycle time, and the detection cycle time is less than about 10 minutes.

24. The apparatus of claim 23, wherein the detection cycle time is less than about 2 minutes.

25. The apparatus of any one of claims 1 to 24, wherein the detection apparatus is a mountable on a vehicle.
26. The apparatus of any one of claims 1 to 23, wherein radioactive material within the subject emits beta radiation and the secondary radiation is bremsstrahlung radiation produced by an interaction between the beta radiation from the radioactive material and the subject.
27. The apparatus of any one of claims 1 to 26, wherein the detection apparatus is configured to measure photons having an energy that is less than about 500keV.
28. The apparatus of any one of claims 1 to 27, wherein the detection apparatus is configured to measure photons having an energy that is greater than about 30keV.
29. A portable detection apparatus, comprising:
- a) a housing;
 - b) a first detector within the housing for detecting ionizing radiation comprising background radiation and secondary radiation from a subject;
 - c) a second detector within the housing for the detecting the background radiation;
 - d) a shield within the housing surrounding the first and second detectors and defining a shield aperture around the first and second detectors for radiation from the subject to enter the housing;
 - e) a radiation blocking member substantially blocking at least a portion of the ionizing radiation entering the housing through the shield aperture from reaching the second detector, whereby radiation detected by the second detector comprises substantially only the background radiation; and
 - f) a processor module connected to the first and second detectors for determining the amount of ionizing radiation detected by the first detector attributable to the secondary radiation

wherein the detection apparatus has an operating sensitivity capable of detecting an activity of at least about 460 Bq within the subject using a 5 minute scan.

30. A portable radiation detection system comprising:

- 5 a) a vehicle; and
 b) a portable radiation detection apparatus according to any one of claims 1 to 29 mounted on and transportable with the vehicle.

31. The portable radiation detection system of claim 30, wherein the vehicle comprises a radiation shielded chamber, and the first and second detectors are
10 provided within the shielded chamber.

32. A method of indirectly measuring a quantity of a beta-emitting radioactive material within a subject using a portable detection apparatus, the method comprising:

- a) positioning the portable detection apparatus adjacent the subject,
15 the portable detection apparatus comprising a first detector, configured to detect ionizing radiation comprising background radiation and secondary radiation, and a second detector configured to detect ionizing radiation, wherein the secondary radiation is emitted by the subject and is produced by an interaction between beta radiation emitted by the radioactive material and the subject;
20 b) detecting a combination of the secondary radiation and the background radiation using the first detector and providing a corresponding a first output signal;
 c) simultaneously detecting the background radiation using the second detector and providing a corresponding second output signal; and
25 d) automatically calculating a resultant output value based on at least the first output signal and the second output signal by subtracting the second output signal from the first output signal to determine a first quantity of secondary radiation received by the detection apparatus.

33. The method of claim 32, further comprising comparing the resultant output value to a predetermined alarm threshold value, and generating an alarm output if the resultant output value exceeds the alarm threshold value.

5 34. The method of claim 33, wherein calculating the resultant output value further comprises determining a second quantity of radioactive material contained within the subject based on the first quantity of secondary radiation.

35. The method of claim 34, wherein the resultant output value comprises at least one of the first quantity of secondary radiation and the second quantity of
10 radioactive material.

36. The method of any one of claims 32 to 35, further comprising transporting the portable detection apparatus to a temporary testing location.

37. The method of any one of claims 32 to 36, further comprising positioning a radiation blocking member between the second detector and the subject to inhibit
15 the secondary radiation from reaching the second detector.

38. A portable detection apparatus, comprising:

 a) a housing;

 b) a first detector within the housing for detecting ionizing radiation comprising background radiation and secondary radiation;

20 c) a second detector within the housing for the detecting the background radiation;

 d) a shield within the housing and surrounding the first and second detectors, the shield defining a shield aperture around the first and second detectors for the ionizing radiation to enter the housing;

e) a radiation blocking member positioned between the shield aperture and the second detector so that a first portion of the ionizing radiation entering the housing through the shield aperture reaches the first detector without passing through the radiation blocking member and a second portion of the ionizing radiation entering the housing through the shield aperture passes through the radiation blocking member before reaching the second detector, whereby radiation detected by the second detector comprises substantially only the background radiation; and

f) a processor module connected to the first and second detectors for determining the amount of ionizing radiation detected by the first detector attributable to the secondary radiation.

39. The apparatus of claim 38, wherein the housing defines a detection apparatus axis and being axially alignable with the subject, and the first detector comprises a first scintillator having an exposed first detection surface extending in a generally lateral direction and positionable opposite the subject, and the second detector comprising a second scintillator having a second detection surface extending in the generally lateral direction.

40. The apparatus of claim 39, wherein the radiation blocking member covers substantially all of the second detection face, whereby the secondary radiation is substantially prevented from reaching the second detection face.

41. The apparatus of claim 39, wherein the first scintillator produces a first light when excited by the ionizing radiation and the second scintillator produces a second light when excited by the ionizing radiation and further comprising a photosensor positioned adjacent the first and second scintillators to receive the first light and generate a corresponding first output signal, and to receive the second light and generate a corresponding second output signal.

42. The apparatus of claim 41, wherein the processor module is operably linked to the photosensor and is operable to determine the amount of ionizing radiation

detected by the first detector attributable to the secondary radiation by comparing the second output signal with the first output signal.

43. The apparatus of claim 41, wherein the photosensor comprise a first photomultiplier tube to receive the first light and generate the first output signal
5 and a second photomultiplier tube to receive the second light and generate the second output signal.

44. The apparatus of claim 39, wherein the first and second scintillators comprise first and second detection crystals, respectively.

45. The apparatus of claim 44, wherein the first scintillator has an overall surface
10 area and the first detection surface has a detection surface area, and the detection surface area is between about 25% and about 45% of the overall surface area.

46. The apparatus of claim 44, wherein the first scintillator has a first thickness in the axial direction of less than about 25 mm.

15 47. The apparatus of claim 44, wherein the first and second detection crystals comprise NaI(Tl) crystals.

48. The apparatus of claim 44, wherein the second scintillator is generally identical to the first scintillator.

49. The apparatus of claim 39, wherein the shield laterally surrounds the first
20 scintillator and the second scintillator and the shield aperture is registered with the first detection surface and the second detection surface.

50. The apparatus of claim 38, wherein the radiation blocking member has a thickness between about 0.05 mm and about 5 mm.

51. The apparatus of claim 38, wherein the shield comprises
25 a) a first shielding layer formed from a first material;

b) a second shielding layer formed from a second material and disposed laterally inboard of the first shielding layer; and

c) a third shielding layer disposed laterally inboard of the second shielding layer;

- 5 and wherein the first shielding layer has a first lateral width, the second shielding layer has a second lateral width and the third shielding layer has a third lateral width, the first lateral width being greater than the both the second and third lateral widths.

10 52. The apparatus of claim 51, wherein the first shielding layer is formed from lead or tungsten, and the first lateral width is between about 2.5 mm and 125 mm.

53. The apparatus of claim 51, wherein the second shielding layer is formed from tin, and the second lateral width is between about 0.25 mm and about 25 mm.

54. The apparatus of claim 51, wherein the third shielding layer is formed from copper, and the third lateral width is between about 0.25 mm and about 25 mm.

15 55. The apparatus of claim 38, wherein the detection apparatus is a mountable on a vehicle.

56. The apparatus of claim 38, wherein radioactive material within the subject emits beta radiation and the secondary radiation is bremsstrahlung radiation produced by an interaction between the beta radiation from the radioactive
20 material and the subject.

57. The apparatus of claim 38, wherein the detection apparatus is configured to measure photons having an energy that is less than about 500 keV.

58. The apparatus of claim 57, wherein the detection apparatus is configured to measure photons having an energy that is greater than about 30 keV.

25 59. The apparatus of claim 38, wherein the processor module is operable to determine a quantity of a radioactive material contained in the subject based on

the amount of ionizing radiation detected by the first detector attributable to the secondary radiation measured by the detection apparatus.

60. The apparatus of claim 59, wherein the processor module is operable to compare at least one of the amount of ionizing radiation detected by the first detector attributable to the secondary radiation and the quantity of the radioactive material contained in the subject to a predetermined alarm threshold value and generate an alarm signal if the at least one of the amount of ionizing radiation detected by the first detector attributable to the secondary radiation and the quantity of the radioactive material contained in the subject exceeds the alarm threshold value.

61. The apparatus of claim 38, wherein the radiation blocking member comprises a plate member.

62. The apparatus of claim 61, wherein the plate member comprises at least one of copper, tin, and aluminum or a combination thereof.

63. The apparatus of claim 38, wherein the radiation blocking member allows transmission of the background radiation there through, whereby the background radiation can reach the second detector.

64. A portable radiation detection apparatus comprising:

a) a housing having a first end positionable adjacent a subject and a second end spaced from the first end in an axial direction;

b) a first detector within the housing and, when the first end of the housing is positioned adjacent the subject the first detector is configured to receive both background radiation and secondary radiation that is produced by an interaction between a primary radiation and the subject and is emitted by the subject and to generate a first output signal;

c) a second detector and, when the first end of the housing is positioned adjacent the subject the second detector is configured to receive substantially only the background radiation and to generate a second output signal; and

5 d) a processor communicably linked to the first and second detectors to receive the first and second outputs and configured to determine an amount of secondary radiation detected by the first detector by comparing the first and second output signals and to generate a corresponding result output signal.

65. The apparatus of claim 64, further comprising a radiation shield positioned within the housing and at least laterally surrounding the first detector and second
10 detector to prevent at least a portion of the background radiation from reaching the first and second detectors, the radiation shield being configured so that when the first end of the housing is positioned adjacent the subject radiation emitted by the subject and at least a portion of the background radiation travelling in the axial direction reaches the first detector without passing through the radiation shield.

15 66. The apparatus of claim 65, wherein the radiation shield comprises at least one shield aperture proximate the first end of the housing through which the background radiation travelling in the axial direction and the secondary radiation can travel to reach the first detector without passing through the radiation shield.

67. The apparatus of claim 65, wherein the radiation shield comprises

20 a) a first shielding layer formed from a first material that comprises at least one of lead and tungsten and having a first lateral width that is between about 2.5 mm and 125 mm,

b) a second shielding layer formed from a second material that is different than the first material, having a second lateral width that is between about 0.25
25 mm and about 25 mm, and being disposed laterally inboard of the first shielding layer; and

c) a third shielding layer formed from a third material that is different than the first and second materials, having third lateral width is between about 0.25 mm and about 25 mm and being disposed laterally inboard of the second shielding layer.

5 68. The apparatus of claim 65, further comprising a radiation blocking member at least partially overlying the second detector in a lateral direction that is orthogonal to the axial direction and configured to block the secondary radiation and allow the background radiation to travel therethrough, the radiation blocking member positioned such that when the first end of the housing is adjacent the subject at
10 least a portion of secondary radiation emitted by the subject is blocked from reaching the second detector by the radiation blocking member, whereby the second detector receives substantially only background radiation.

69. The apparatus of claim 68, wherein the first detector comprises a first scintillator having a first detection surface extending in the lateral direction and the
15 second detector comprises a second detection surface extending in the lateral direction, and wherein the radiation blocking member covers substantially all of the second detection face.

70. The apparatus of claim 68, wherein the radiation blocking member has a thickness in the axial direction of between about 0.05 mm and about 5 mm and
20 comprises at least one of copper, tin and aluminum.

71. The apparatus of claim 68, wherein the radiation blocking member is configured to block the transmission of Bremsstrahlung radiation.

72. The apparatus of claim 64, wherein time elapsed between positioning the first end of the housing adjacent the subject and obtaining the resultant output signal
25 defines a detection cycle time, and the detection cycle time is less than about 10 minutes.

73. The apparatus of claim 72, wherein the detection cycle time is less than 2 minutes.

74. The apparatus of claim 64, wherein the first and second detectors are configured to detect photons having an energy that is between about 30 keV and about 500 keV.

75. A portable radiation detection system comprising:

- 5 a) a vehicle that is movable to a monitoring location; and
- b) a portable radiation detection apparatus according to claim 64 mounted to vehicle.

76. The portable radiation detection system of claim 75, wherein the vehicle comprises a radiation-shielded measurement chamber that is configured to
10 receive a human subject, and wherein the portable radiation detection apparatus is disposed within the measurement chamber.

77. A portable radiation detection apparatus comprising:

- a) a housing having a first end positionable adjacent a subject and a second end spaced from the first end in an axial direction;
- 15 b) a first detector within the housing and having a first detection surface extending in a lateral direction that is orthogonal to the axial direction, wherein when the first end of the housing is positioned adjacent the subject the first detection surface is configured to receive both background radiation and secondary radiation that is produced by an interaction between primary radiation
20 and the subject and is emitted by the subject and the first detector is operable to generate a first output signal;
- c) a second detector having a second detection surface extending in a lateral direction and laterally spaced from the first detection surface, wherein when the first end of the housing is positioned adjacent the subject the second detection
25 surface is configured to receive substantially only the background radiation and the second detector is operable to generate a second output signal;

d) a radiation shield operable to block the background radiation and the secondary radiation and positioned within the housing to laterally surround the first detector and second detector, cover the second end of the housing and having at least one opening aligned within the first end of the housing to permit radiation to enter the housing when the first end of the housing is positioned adjacent the subject;

e) a radiation blocking member configured to block the travel of the secondary radiation and allow the background radiation to travel therethrough, the radiation blocking member positioned between the second detection surface and the at least one opening of the radiation shield, whereby when the first end of the housing is adjacent the subject at least a portion of secondary radiation emitted by the subject is blocked from reaching the second detector by the radiation blocking member and the second detector receives substantially only background radiation; and

f) a processor communicably linked to the first and second detectors to receive the first and second outputs and configured to determine an amount of secondary radiation detected by the first detector by comparing the first and second outputs and to generate a corresponding result output signal indicative of a quantity of the secondary radiation detected.

78. The apparatus of claim 77, wherein the radiation shield comprises:

a) a first shielding layer formed from a first material that comprises at least one of lead and tungsten and having a first lateral width that is between about 2.5 mm and 125 mm,

b) a second shielding layer formed from a second material that is different than the first material, having a second lateral width that is between about 0.25 mm and about 25 mm, and being disposed laterally inboard of the first shielding layer; and

c) a third shielding layer formed from a third material that is different than the first and second materials, having third lateral width is between about 0.25 mm and about 25 mm and being disposed laterally inboard of the second shielding layer.

5 79. The apparatus of claim 77, wherein the radiation blocking member has a thickness in the axial direction of between about 0.05 mm and about 5 mm and comprises at least one of copper, tin and aluminum.

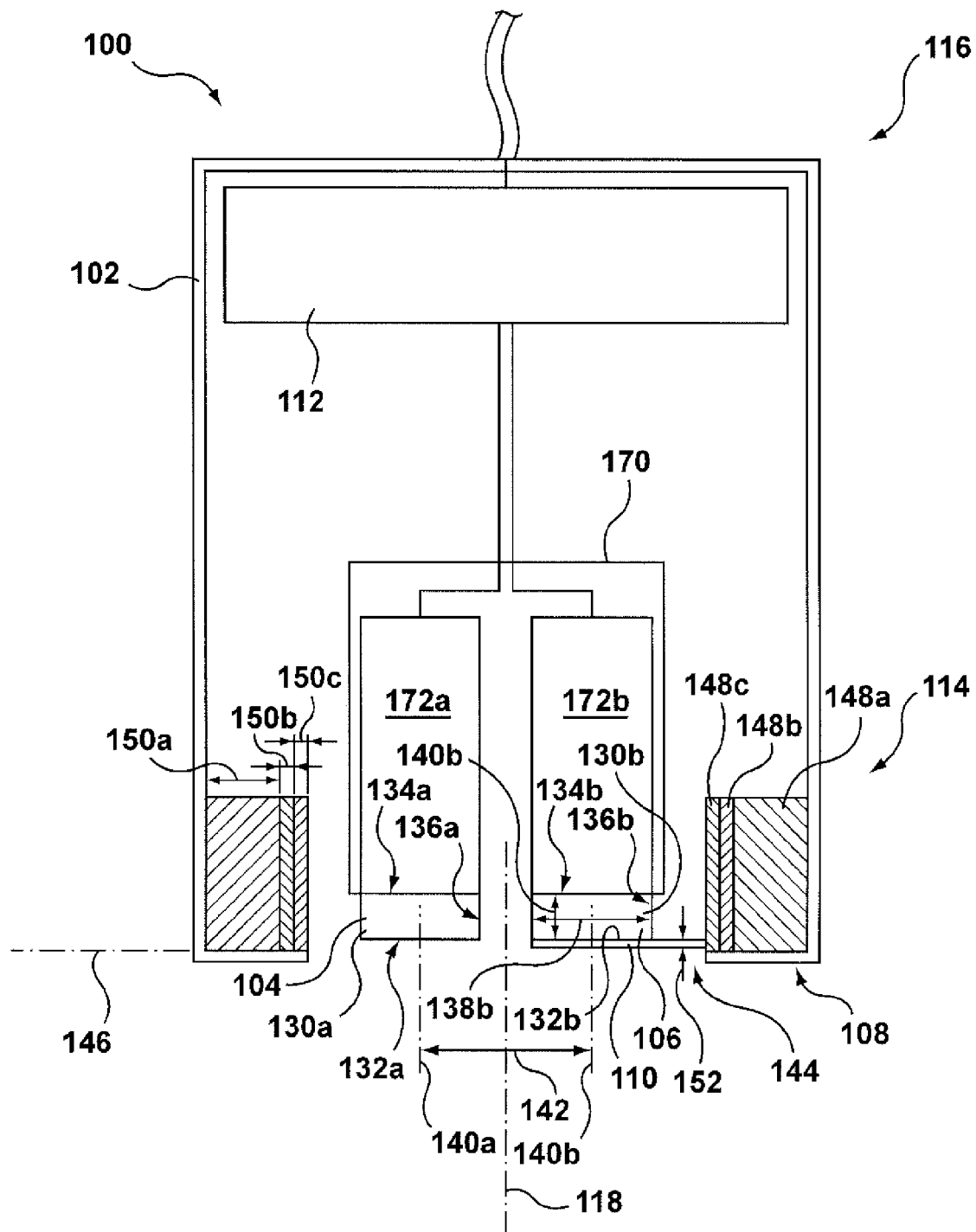
80. The apparatus of claim 77, wherein time elapsed between positioning the first end of the housing adjacent the subject and obtaining the resultant output signal
10 defines a detection cycle time, and the detection cycle time is less than about 10 minutes.

81. The apparatus of claim 80, wherein the detection cycle time is less than 2 minutes.

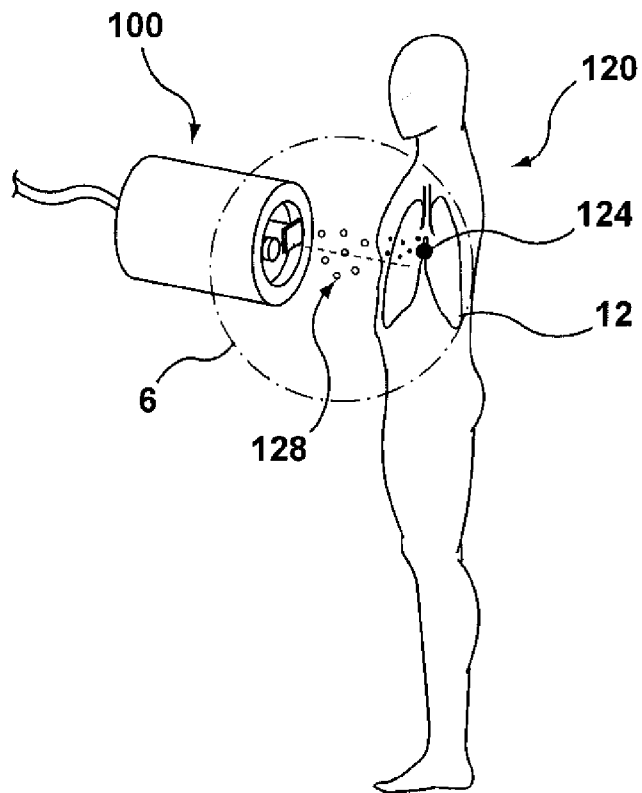
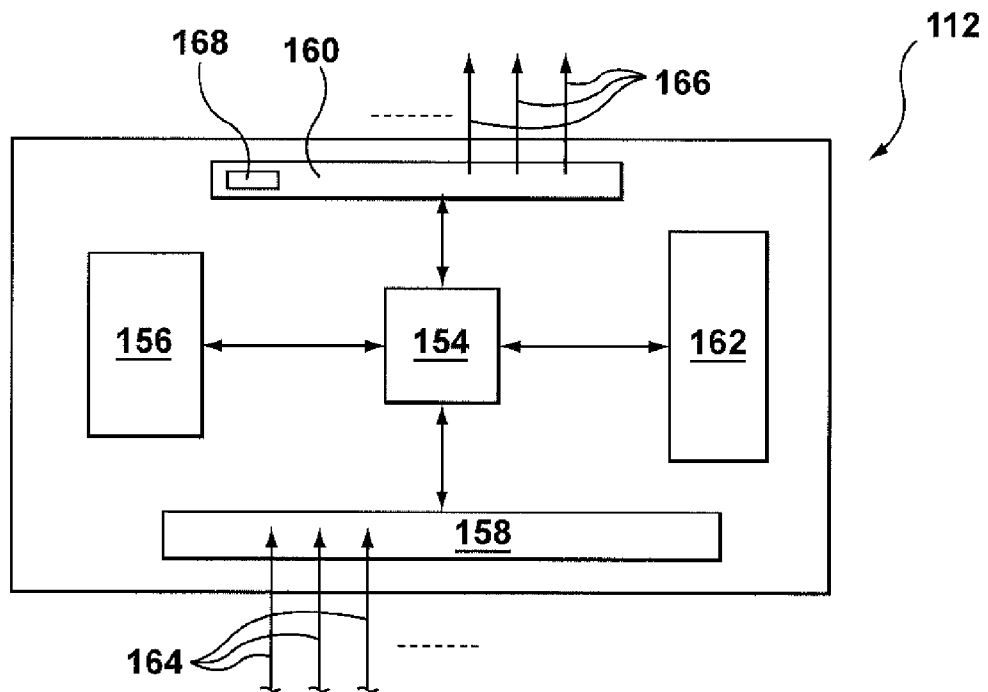
82. The apparatus of claim 77, wherein the detection apparatus the first and
15 second detectors are configured to detect photons having an energy that is between about 30 keV and about 500 keV.

83. The apparatus of claim 77, wherein the radiation blocking member is configured to block the transmission of Bremsstrahlung radiation.

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**FIG. 4**

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**FIG. 5****FIG. 7**

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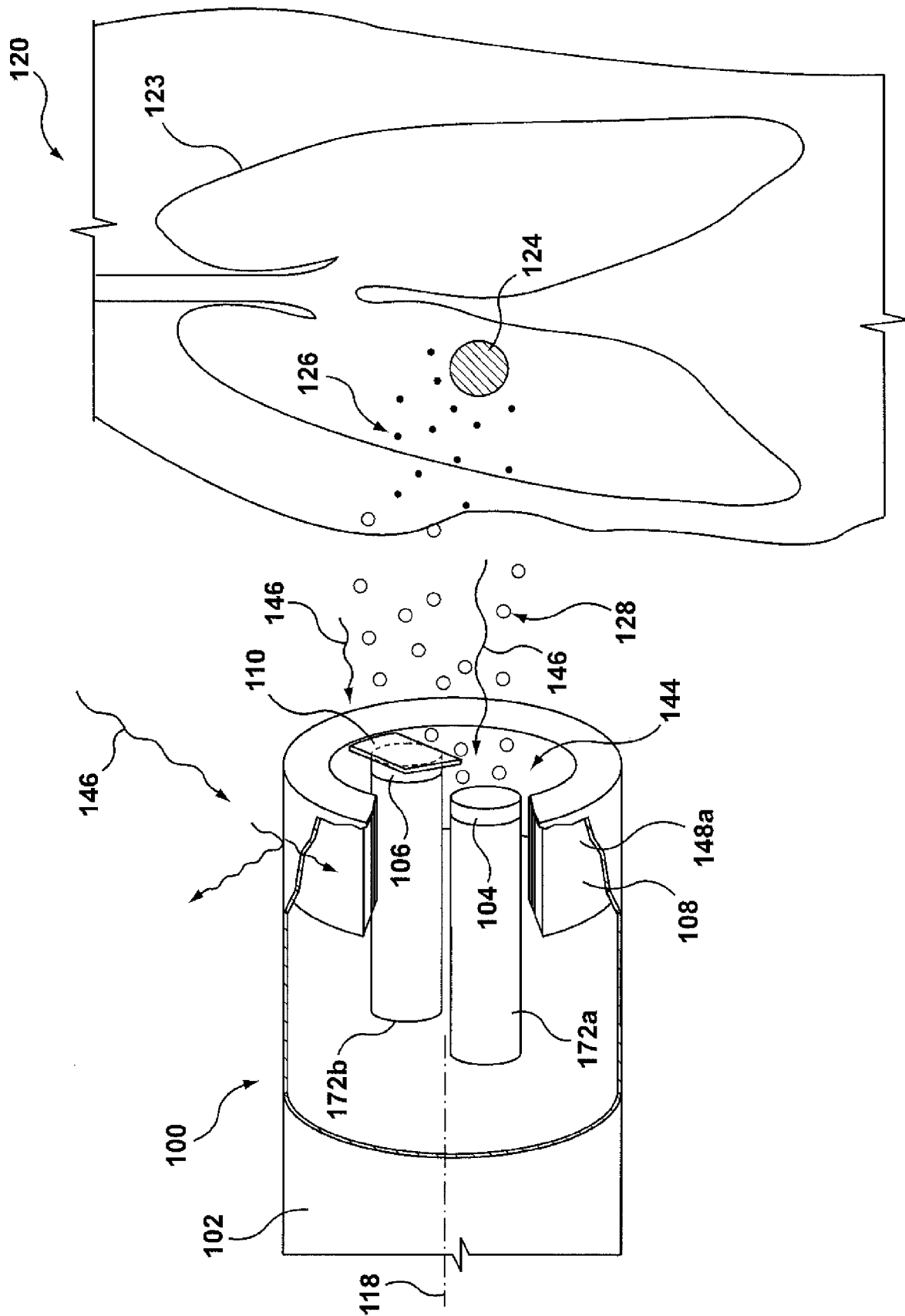
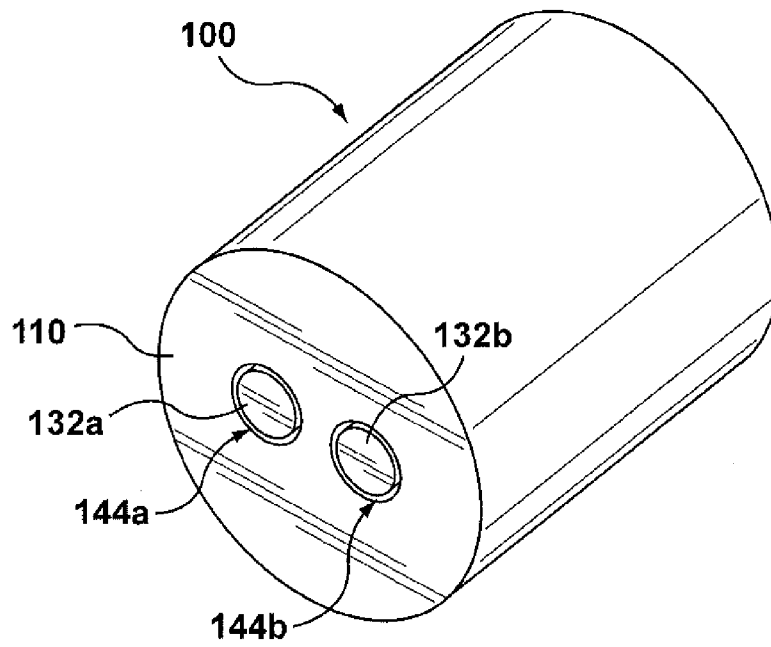
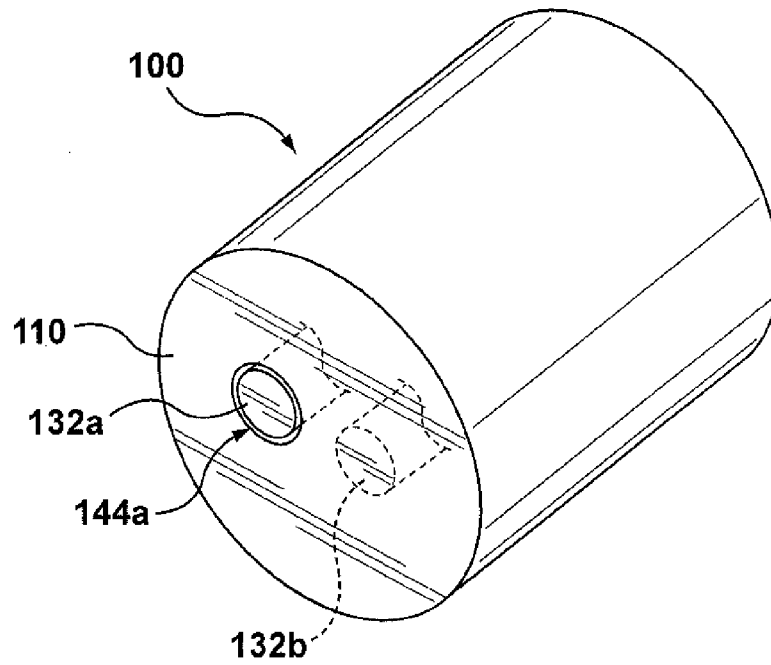
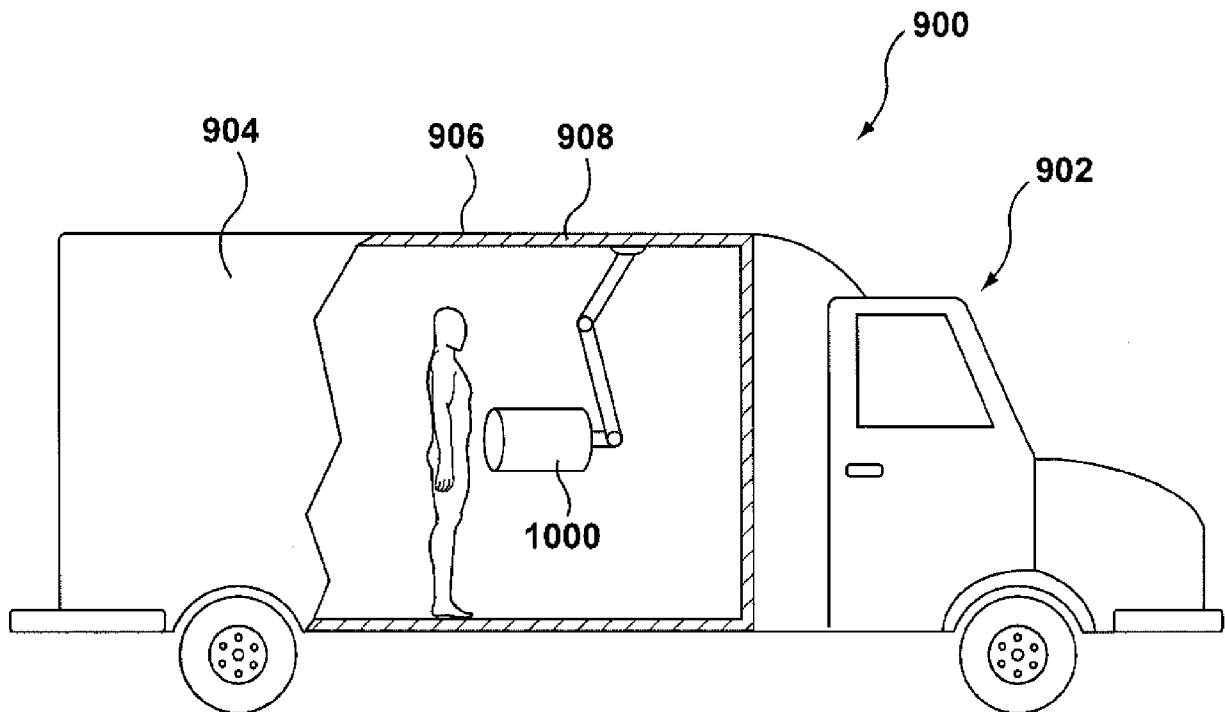


FIG. 6

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**FIG. 8a****FIG. 8b**

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**FIG. 9**

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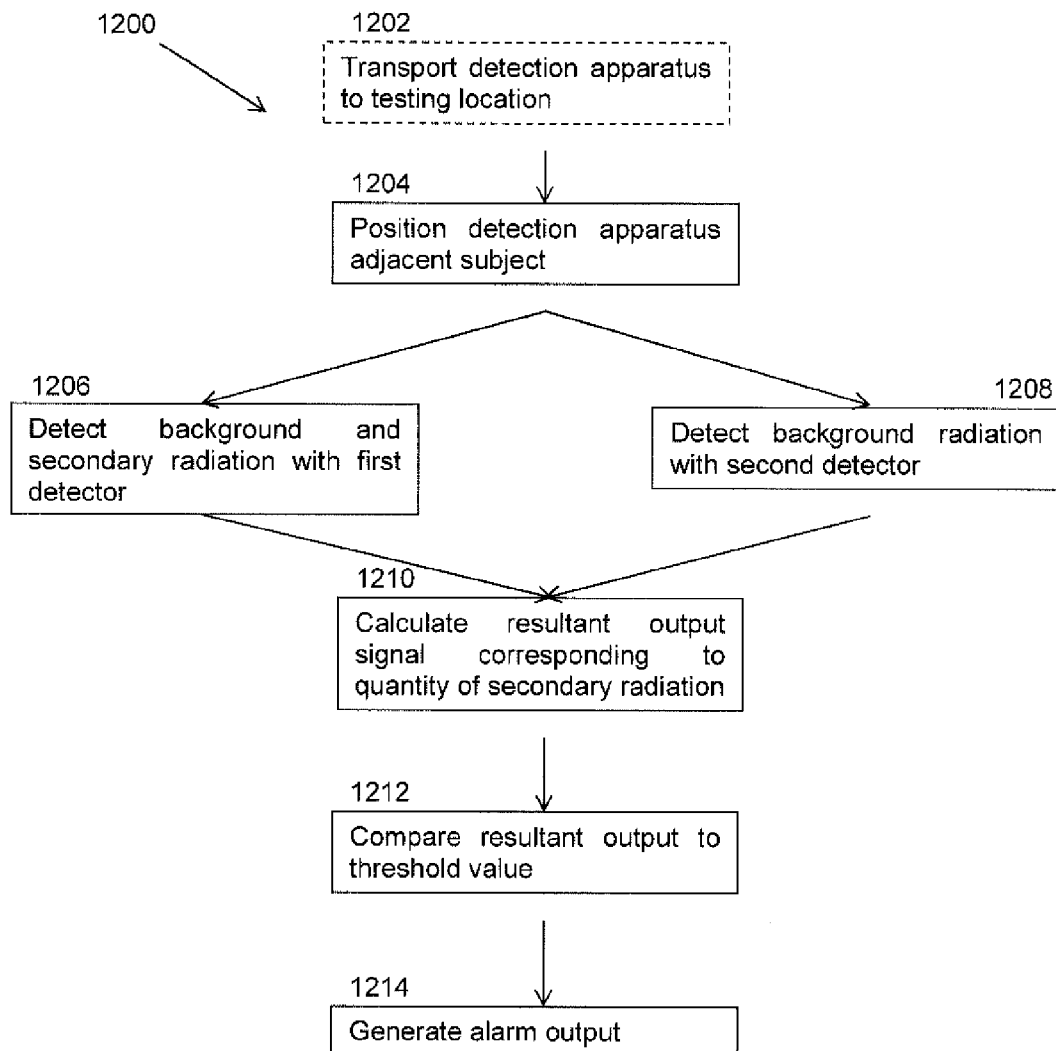


Fig. 10

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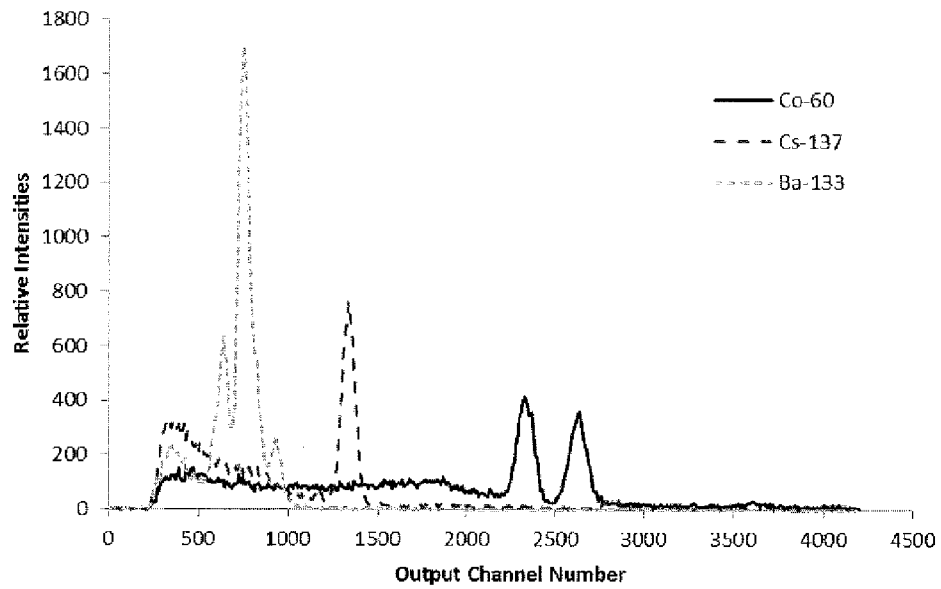


Figure 11

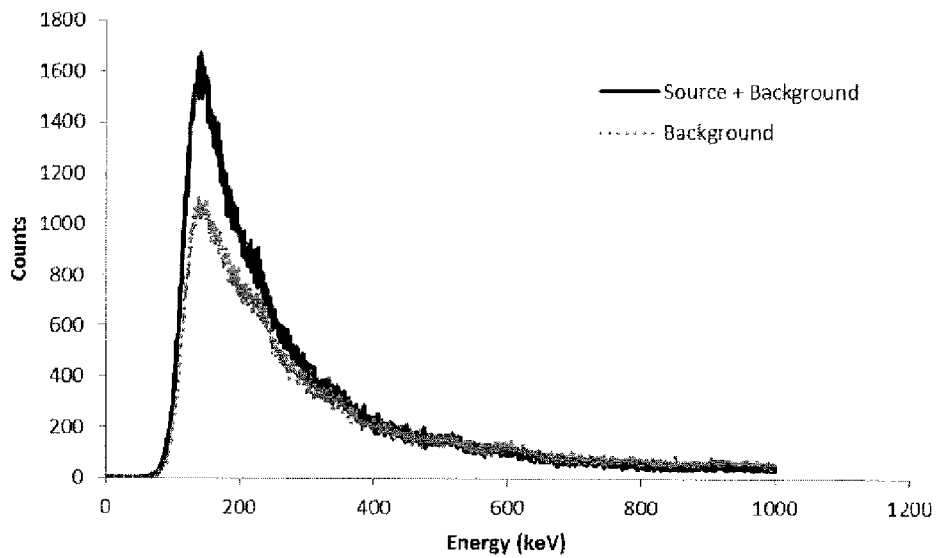


Figure 12

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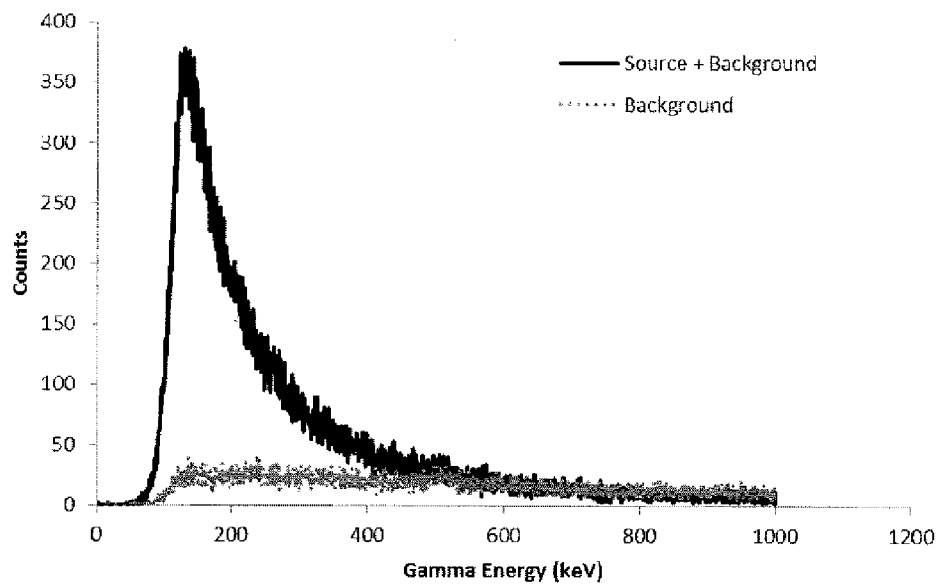


Figure 13

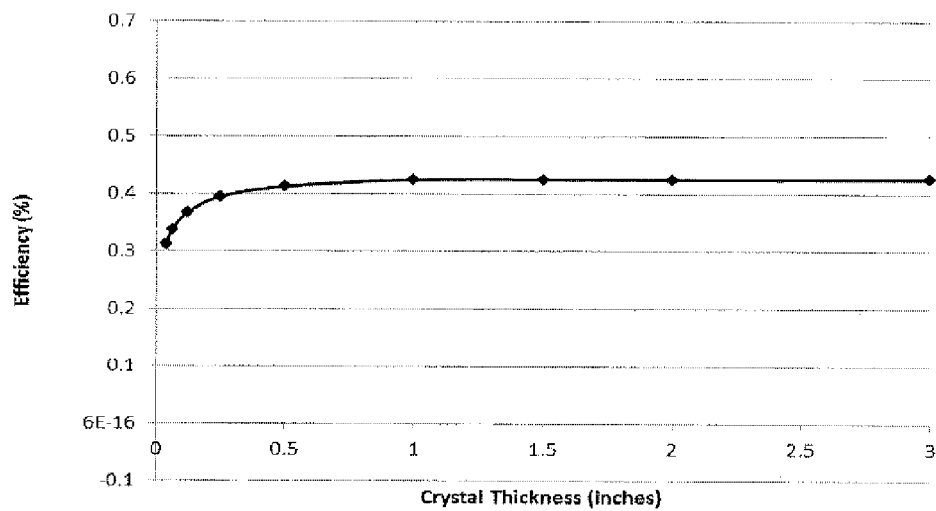


Figure 14

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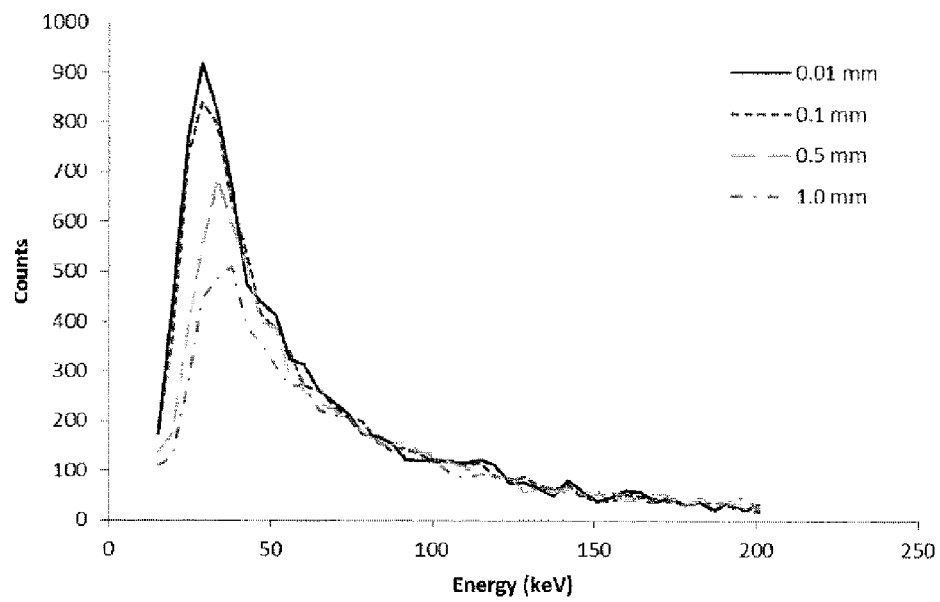


Figure 15

