CLAIMS

The embodiments of the invention in which an exclusive property or right is claimed are defined as follows. Having thus described the invention what is claimed is:

1. A monitoring system comprising

a cosmic ray-produced charged particle tracker having a plurality of charged particle detectors, said charged particle detectors comprising drift cells configured both to enable tracking of incoming and outgoing charged particles passing through a volume to be scanned and detection of gamma rays and, wherein, in use, said system can both selectively detect any materials or devices occupying said volume from multiple scattering of said charged particles and detect any radioactive sources occupying said volume from gamma rays emitted therefrom.

2. The system of claim 1, wherein said drift cells comprise drift tubes of circular or non-circular cross-section, or non-tube shaped cells.

3. The system of claim 1, wherein said drift cells comprise sealed drift cells.

4. The system of claim 1, wherein an operating gas of said drift cells comprises a non-flammable gas.

5. The system of claim 1, wherein said drift cells comprise a set of drift tubes located above said volume and another set of drift tubes located below said volume, each set of drift tubes having at least three drift tubes configured in a first direction and another at least three drift tubes configured in a second direction.

6. The system of claim 5, wherein said first direction is substantially orthogonal to said second direction.

7. The system of claim 6, wherein said charged particles comprise muons.

8. The system of claim 1, wherein said drift cells are arranged to allow at least three charged particle positional measurements in a first direction and at least three charged particle positional measurements in a second direction different from said first direction.

9. The system of claim 1, further comprising a gamma ray or neutron source arranged within said system to thereby enable active interrogation of material occupying said volume.

10. A monitoring system comprising

a cosmic ray-produced muon tomography system having a plurality of muon detectors, said muon detectors comprising drift cells arranged at least above and below a volume to be scanned both to enable tracking of incoming and outgoing muons and counting of gamma rays and, wherein, in use, said system can both selectively detect any high density shielding occupying said volume from multiple scattering of said muons passing through said volume and detect any radioactive material occupying said volume from gamma rays emitted therefrom.

11. The system of claim 10, wherein said drift cells comprise aluminum drift cells or carbon composite drift cells having internal conductive coatings and wherein said drift cells comprise drift tubes of circular or non-circular cross-section, or non-tube shaped cells.

12. The system of claim 11, wherein said operating gas of said drift tube comprises a non-flammable gas.

13. The system of claim 11, wherein said operating gas comprises a mixture of argon and at least one gas selected from the group consisting of carbon dioxide, isobutane, tetrafluoromethane and ethane.

14. The system of claim 11, wherein said drift tubes are arranged in separate

planes in two orthogonal coordinates or wherein said drift tubes are arranged in non-orthogonal planes.

15. The system of claim 10, wherein said volume is of sufficient size to enable a vehicle or cargo container to occupy said volume.

16. A method of monitoring comprising

arranging a plurality drift cells on opposite sides of a volume to be scanned;

detecting with said drift cells incoming and outgoing cosmic ray-produced charged particles and any gamma rays;

selectively detecting any material occupying said volume from multiple scattering of said charged particles passing through said volume; and

detecting any radioactive sources occupying said volume from detection of said gamma rays.

17. The method of claim 16, wherein said drift cells comprise comprise drift tubes of circular or non-circular cross-section, or non-tube shaped cells.

18. The method of claim 17, wherein said drift cells comprise sealed drift tubes.

19. The method of claim 17, wherein arranging said plurality of drift cells comprises arranging a set of at least three planes of drift tubes above said volume and arranging a set of at least three planes of drift tubes below said volume.

20. The method of claim 16, wherein arranging said plurality of drift cells further comprises arranging said drift tubes in separate planes in two orthogonal coordinates or arranging said drift tubes in non-orthogonal planes.

21. A particle detection system, comprising:

a first set of position sensitive charged particle detectors located on a first

side of an object holding area to measure positions and directions of incident charged particles towards the object holding area;

a second set of position sensitive charged particle detectors located on a second side of the object holding area opposite to the first side to measure positions and directions of outgoing charged particles exiting the object holding area; and

a signal processing unit to receive data of measured signals of the incoming charged particles from the first set of position sensitive charged particle detectors and measured signals of the outgoing charged particles from the second set of position sensitive charged particle detectors, wherein the signal processing unit is configured to analyze scattering of the charged particles in the materials within the object holding area based on the measured incoming and outgoing positions and directions of charged particles to obtain a tomographic profile or the spatial distribution of scattering centers within the object holding area.

22. The system as in claim 21, wherein the drift cells are arranged to allow at least three charged particle positional measurements in a first direction and at least three charged particle positional measurements in a second direction different from the first direction.

23. The system as in claim 21, wherein the drift cells are adapted and arranged on surrounding sides of the object holding area to form a box or four sided structure.

24. The system as in claim 21, wherein the signal processing unit is configured to reconstruct a trajectory of a charged particle through the object holding area, measure a momentum of an incoming charged based on signals from the first set of position sensitive charged particle detectors , measure a momentum of an outgoing charged particle based on signals from the second set of position sensitive charged particle detectors, and obtain a spatial distribution of a scattering density of the object holding area.

CLAIMS

1. A monitoring system comprising:

a cosmic ray-produced charged particle tracker having a plurality of charged particle detectors, said charged particle detectors comprising drift tubes or cells configured both to enable tracking of incoming and outgoing charged particles passing through a volume to be scanned and detection of gamma rays and, wherein, in use, said system can both selectively detect any materials or devices occupying said volume from multiple scattering of said charged particles and detect any radioactive sources occupying said volume from gamma rays emitted therefrom.

2. The system of claim 1, wherein said drift tubes include drift tubes of circular or non-circular cross-section, and said drift cells include non-tube shaped cells.

3. The system of claim 1, further comprising a signal processing unit to receive (1) signals from the drift tubes or cells caused by the incoming charged particles and (2) signals from the drift tubes or cells caused by outgoing charged particles, wherein the signal processing unit is configured to analyze scattering of the charged particles in the materials or devices within said volume based on the measured incoming and outgoing positions and directions of charged particles to obtain a tomographic profile or the spatial distribution of scattering centers within said volume.

4. The system of claim 3, wherein the signal processing unit is configured to reconstruct a trajectory of a charged particle through said volume, measure a momentum of an incoming charged particle based on signals from the set of drift tubes or cells above said volume, measure a momentum of an outgoing charged particle based on signals from the other set of drift tubes or cells below said volume, and obtain a spatial distribution of a scattering density of said volume.

5. The system as in claim 4, wherein the signal processing unit includes a mechanism to determine spatial distribution of the scattering density of said volume to obtain predetermined charged particle tomography data corresponding to scattering angles and estimated momentum of charged particles passing through said volume; to provide a probability distribution of charged particle scattering for use in an expectation maximization algorithm based on a statistical multiple scattering model; and to determine a substantially maximum likelihood estimate of the scattering density of said volume using the expectation maximization algorithm.

6. The system as in claim 3, wherein the signal processing unit includes a mechanism to use the tomographic profile or the spatial distribution of scattering centers within said volume to identify either or both of presence and type of an object in said volume.

7. The system as in claim 3, wherein each set of the drift tubes above said volume and the drift tubes below said volume includes a plurality of layers of drift tubes where at least two layers of drift tubes have different orientations.

8. The system of claim 1, wherein an operating gas of said drift cells comprises a non-flammable gas.

9. The system of claim 1, wherein said drift tubes comprise a set of drift tubes located above said volume and another set of drift tubes located below said volume, each set of drift tubes having at least three drift tubes configured in a first direction and another at least three drift tubes configured in a second direction.

10. The system of claim 9, wherein said first direction is substantially orthogonal to said second direction.

11. The system of claim 10, wherein said charged particles comprise muons.

12. The system of claim 1, wherein said drift tubes or cells are arranged to allow at least three charged particle positional measurements in a first direction and at least three charged particle positional measurements in a second direction different from said first direction.

13. The system of claim 1, further comprising a gamma ray or neutron source arranged within said system to thereby enable active interrogation of material occupying said volume.

14. A monitoring system comprising

a cosmic ray-produced muon tomography system having a plurality of muon detectors, said muon detectors comprising drift tubes or cells arranged at least above and below a volume to be scanned both to enable tracking of incoming and outgoing muons and counting of gamma rays and, wherein, in use, said system can both selectively detect any high density shielding occupying said volume from multiple scattering of said muons passing through said volume and detect any radioactive material occupying said volume from gamma rays emitted therefrom.

15. The system of claim 14, wherein said drift tubes or cells comprise aluminum drift tubes or cells or carbon composite drift tubes or cells having internal conductive coatings and wherein said drift tubes comprise drift tubes of circular or non-circular cross-section, said drift cells include non-tube shaped cells.

16. The system of claim 15, wherein said operating gas of said drift tube comprises a non-flammable gas.

17. The system of claim 15, wherein said operating gas comprises a mixture of argon and at least one gas selected from the group consisting of carbon dioxide, isobutane, tetrafluoromethane and ethane.

18. The system of claim 15, wherein said drift tubes are arranged in separate planes in two orthogonal coordinates or wherein said drift tubes are arranged in non-orthogonal planes.

19. The system of claim 14, wherein said volume is of sufficient size to enable a vehicle or cargo container to occupy said volume.

20. The system of claim 14, further comprising a signal processing unit to receive (1) signals from the drift tubes or cells caused by the incoming muons and (2) signals from the drift tubes or cells caused by outgoing muons, wherein the signal processing unit is configured to analyze scattering of the muons in the materials or devices within said volume based on the measured incoming and outgoing positions and directions of muons to obtain a tomographic profile or the spatial distribution of scattering centers within said volume.

21. The system of claim 20, wherein the signal processing unit is configured to reconstruct a trajectory of a muon through said volume, measure a momentum of an incoming muon based on signals from the set of drift tubes or cells above said volume, measure a momentum of an outgoing muon based on signals from the other set of drift tubes or cells below said volume, and obtain a spatial distribution of a scattering density of said volume.

22. The system as in claim 21, wherein the signal processing unit includes a mechanism to determine spatial distribution of the scattering density of said volume to obtain predetermined muon tomography data corresponding to scattering angles and estimated momentum of muons passing through said volume; to provide a probability distribution of muon scattering for use in an expectation maximization algorithm based on a statistical multiple scattering model; and to determine a substantially maximum likelihood estimate of the scattering density of said volume using the expectation maximization algorithm.

23. The system as in claim 20, wherein the signal processing unit includes a mechanism to use the tomographic profile or the spatial distribution of scattering centers within said volume to identify either or both of presence and type of an object in said volume.

24. The system as in claim 20, wherein each set of the drift tubes above said volume and below said volume includes a plurality of layers of drift tubes where at least two layers of drift tubes have different orientations.

25. A method of monitoring comprising

arranging a plurality drift tubes or cells on opposite sides of a volume to be scanned;

detecting with said drift tubes or cells incoming and outgoing cosmic ray-produced charged particles and any gamma rays;

selectively detecting any material occupying said volume from multiple scattering of said charged particles passing through said volume; and

detecting any radioactive sources occupying said volume from detection of said gamma rays.

26. The method of claim 25, wherein said drift tubes comprise drift tubes of circular or non-circular cross-section, and said drift cells include non-tube shaped cells.

27. The method of claim 26, further comprising:
receiving (1) signals from the drift tubes or cells caused by the incoming charged particles and (2) signals from the drift tubes or cells caused by outgoing charged particles;
processing the received signals to obtain measured incoming and outgoing positions and directions of charged particles; and
processing the measured incoming and outgoing positions and directions of charged particles to obtain a tomographic profile or the spatial distribution of scattering centers within said volume.

28. The method of claim 27, wherein the processing includes:
reconstructing a trajectory of a charged particle through said volume;
determining a momentum of an incoming charged particle based on signals from the set of drift tubes or cells above said volume;
determining a momentum of an outgoing charged particle based on signals from the other set of drift tubes or cells below said volume;
obtaining a spatial distribution of a scattering density of said volume.

29. The method as in claim 28, wherein the processing further includes:
using the spatial distribution of the scattering density of said volume to obtain predetermined charged particle tomography data corresponding to scattering angles and estimated momentum of charged particles passing through said volume;
providing a probability distribution of charged particle scattering for use in an expectation maximization algorithm based on a statistical multiple scattering model; and
determining a substantially maximum likelihood estimate of the scattering density of said volume using the expectation maximization algorithm.

30. The method as in claim 27, wherein the processing further includes using the tomographic profile or the spatial distribution of scattering centers within said volume to identify either or both of presence and type of an object in said volume.

31. The method of claim 26, wherein arranging said plurality of drift tubes or cells comprises arranging a set of at least three planes of drift tubes above said volume and arranging a set of at least three planes of drift tubes below said volume.

32. The method of claim 25, wherein arranging said plurality of drift tubes ~~cells~~ further comprises arranging said drift tubes in separate planes in two orthogonal coordinates or arranging said drift tubes in non-orthogonal planes.

33. A particle detection system, comprising:

a first set of position sensitive charged particle detectors located on a first side of an object holding area to measure positions and directions of incident charged particles towards the object holding area;

a second set of position sensitive charged particle detectors located on a second side of the object holding area opposite to the first side to measure positions and directions of outgoing charged particles exiting the object holding area; and

a signal processing unit to receive data of measured signals of the incoming charged particles from the first set of position sensitive charged particle detectors and measured signals of the outgoing charged particles from the second set of position sensitive charged particle detectors, wherein the signal processing unit is configured to analyze scattering of the charged particles in the materials within the object holding area based on the measured incoming and outgoing positions and directions of charged particles to obtain a tomographic profile or the spatial distribution of scattering centers within the object holding area, and

wherein the position sensitive charged particle detectors are arranged to allow at least three charged particle positional measurements in a first direction and at least three charged particle positional measurements in a second direction different from the first direction.

34. The system as in claim 33, wherein the drift cells are adapted and arranged on surrounding sides of the object holding area to form a box or four sided structure.

35. The system as in claim 33, wherein the signal processing unit is configured to reconstruct a trajectory of a charged particle through the object holding area, measure a momentum of an incoming charged based on signals from the first set of position sensitive charged particle detectors, measure a momentum of an outgoing charged particle based on signals from the second set of position sensitive charged particle detectors, and obtain a spatial distribution of a scattering density of the object holding area.

36. The system as in claim 35, wherein the signal processing unit includes a mechanism to determine spatial distribution of the scattering density of the object holding area to obtain predetermined charged particle tomography data corresponding to scattering angles and estimated momentum of charged particles passing through the object holding area; to provide a probability distribution of charged particle scattering for use in an expectation maximization algorithm based on a statistical multiple scattering model; and to determine a substantially maximum likelihood estimate of the scattering density of the object holding area using the expectation maximization algorithm.

37. The system as in claim 35, wherein the signal processing unit includes a mechanism to use the tomographic profile or the spatial distribution of scattering centers within the object holding area to identify either or both of presence and type of an object in the object holding area.

38. The system as in claim 35, wherein each set of the first and second sets of position sensitive charged particle detectors includes a plurality of layers of drift tubes where at least two layers of drift tubes have different orientations.

39. The system as in claim 33, wherein each position sensitive charged particle detector is structured to detect both cosmic ray-produced muons and gamma rays.

40. The system as in claim 33, wherein each drift tube is filled with a gaseous medium.

41. A method for sensing a presence or absence of a material in a target object, comprising:

exposing the target object to incident charged particles;

using a first set of position sensitive charged particle detectors located on a first side of the target object to measure positions and directions of incident charged particles towards the target object before reaching the target object;

using a second set of position sensitive charged particle detectors located on a second side of the target object opposite to the first side to measure positions and directions of outgoing charged particles exiting the target object;

obtaining first detector signals from the first set of position sensitive charged particle detectors containing information of the incoming charged particles and second detector signals from the second set of position sensitive charged particle detectors containing information of the outgoing charged particles;

analyzing scattering of the charged particles in the target object based on the positions and directions of the incoming and outgoing charged particles to obtain a tomographic profile or the spatial distribution of scattering centers within the target object; and

processing the tomographic profile or the spatial distribution of scattering centers to determine a presence or absence of a material in the target object,

wherein the analyzing scattering of the charged particles in the target object includes obtaining angle and momentum information of each charged particle passing through the target object to provide a probability distribution of charged particle scattering;

wherein the first set of position sensitive charged particle detectors includes a first double-layer of drift tubes arranged in an X direction and a second double-layer of drift tubes arranged in a Y direction.

42. The method as in claim 41, wherein the exposing the target object to incident charged particles includes exposing the target object to muons in cosmic rays and the outgoing charged particles include scattered muons.

43. The method as in claim 42, wherein the outgoing charged particles include the scattered muons and gamma rays coming out of the target object, and the second set of position sensitive detectors are responsive to both scattered muons and gamma rays from the target object.

44. The method as in claim 41, comprising:

after a material is determined to be present in the target object, determining a type of the material present in the target object.

45. The method as in claim 44, wherein the type is determined based on atomic numbers of materials.

46. The method of claim 41, further comprising arranging the drift tubes in the first double-layer and the second double-layer in two rows, offset by half a tube diameter from each other.

47. A particle detection system, comprising:

a first set of position sensitive charged particle detectors located on a first side of an object holding area to measure positions and directions of incident charged particles towards the object holding area;

a second set of position sensitive charged particle detectors located on a second side of the object holding area opposite to the first side to measure positions and directions of outgoing charged particles exiting the object holding area;

means for processing scattering of the charged particles in the materials within the object holding area based on the measured incoming and outgoing positions and directions of charged particles to obtain a tomographic profile or the spatial distribution of scattering centers within the object holding area;

means for reconstructing a trajectory of a charged particle through the object holding area;

means for measuring a momentum of an incoming charged particle based on signals from the first set of position sensitive charged particle detectors;

means for measuring a momentum of an outgoing charged particle based on signals from the second set of position sensitive charged particle detectors;

means for obtaining a spatial distribution of a scattering density of the object holding area, means for determining spatial distribution of the scattering density of the object holding area to obtain predetermined charged particle tomography data corresponding to scattering angles and estimated momentum of charged particles passing through the object holding area;

means for producing a probability distribution of charged particle scattering for use in an expectation maximization algorithm based on a statistical multiple scattering model; and

means for determining a substantially maximum likelihood estimate of the scattering density of the object holding area using the expectation maximization algorithm,

wherein the first set of position sensitive charged particle detectors includes a first double-layer of drift tubes arranged in an X direction and a second double-layer of drift tubes arranged in a Y direction.

48. The system as in claim 47, wherein the drift tubes are arranged to allow at least three charged particle positional measurements in a first direction and at least three charged particle positional measurements in a second direction different from the first direction.

49. The system as in claim 47, wherein the drift tubes are adapted and arranged on surrounding sides of the object holding area to form a box or four sided structure.

50. The system as in claim 47, further comprising means for using the scattering density to identify either or both of presence and type of an object in the object holding area.

51. The system as in claim 47, wherein each position sensitive charged particle detector is structured to detect both cosmic ray-produced muons and gamma rays.

52. The system as in claim 47, wherein each position sensitive charged particle detector includes one or more drift tubes filled with a gaseous medium.

53. The system as in claim 52, wherein the second set of position sensitive charged particle detectors includes a plurality of layers of drift tubes where at least two layers of drift tubes have different orientations.

54. The system as in claim 52, wherein the drift tubes in the first double-layer and the second double-layer are arranged in two rows, offset by half a tube diameter from each other.

55. The system as in claim 52, wherein the drift tubes are arranged to allow at least three charged particle positional measurements in a first direction and at least three charged particle positional measurements in a second direction different from the first direction.