properties, but the dominant effect is the atomic number, Z, of nuclei. The trajectories are more strongly affected by materials that make good gamma ray shielding (such as lead and tungsten for example) and by special nuclear material (SNM), that is, uranium and plutonium, than by materials that make up more ordinary objects such as water, plastic, aluminum and steel. Each muon carries information about the objects that it has penetrated, and measurements of the scattering of multiple muons can be used to probe the properties of these objects. For example, a material with a high atomic number Z and a high density can be detected and identified when the material is located, inside low-Z and medium-Z matter.

SUMMARY

[0005] Techniques and systems for using cosmic ray-produced muons to inspect objects based on an initial scanning of all objects and an additional scanning of objects that are determined by the initial scanning to potentially include one or more suspect regions. In one implementation, a system can include a primary scanner for performing the initial or primary scanning and a smaller secondary scanner for the additional or secondary scanning to provide efficient and accurate inspection of objects while maintaining a desired throughput of the inspection. In another implementation, a single scanner can be used to perform both the initial scanning and the additional scanning while maintaining a sufficient throughput of a line of objects under inspection.

[0005a] In an aspect, a method for inspecting objects based on muon tomography using cosmic ray-produced muons, comprising: operating a first muon tomography scanner that includes position sensitive charged particle detectors to perform an imaging scan of an object under inspection for a first imaging duration to obtain a first muon tomography image of the entire object; processing the first muon tomography image of the entire object to obtain information inside the object; generating a clearance signal when the processing of the first muon tomography image reveals no suspect region inside the object to set the first muon tomography scanner ready for receiving a next object for inspection; when the processing of the first muon tomography image reveals one or more suspect regions inside the object, removing the object from the first muon tomography scanner to place the object in a second, separate muon tomography scanner to perform an imaging scan of the object for a second imaging duration longer than the first imaging duration to obtain a second muon tomography image of only each

suspect region of the object without imaging the entire object, wherein the second muon tomography scanner is configured to have a smaller imaging area covered by the position sensitive charged particle detectors to obtain an image of only a portion of the object; and while the second muon tomography scanner is being operated to further inspect the object with the one or more suspect regions, operating the first muon tomography scanner to receive a next object to inspect.

[0005b] In another aspect, a method for inspecting objects based on tomography using cosmic ray-produced muons, comprising: operating a muon tomography scanner that includes position sensitive charged particle detectors to perform an imaging scan of an object in a line of objects under inspection for an imaging duration to obtain a muon tomography image of the entire object; processing the muon tomography image of the entire object to obtain information on one or more suspect regions inside the object; generating a clearance signal when the processing of the muon tomography image reveals no suspect region inside the object to set the muon tomography scanner ready for receiving a next object for inspection; and when the processing of the muon tomography image reveals one or more suspect regions inside the object, operating the muon tomography scanner to scan the object for an additional scan time that is sufficiently long to make an affirmative decision on whether or not the one or more suspect regions inside the object constitute a threat.

[0005c] In yet another aspect, a system for inspecting objects based on muon tomography using cosmic ray-produced muons, comprising: a main inspection traffic path along which objects under inspection are lined up in sequence to move in a common direction; a first muon tomography scanner located in the main inspection traffic path to inspect the objects in sequence, the first muon tomography scanner configured to include position sensitive charged particle detectors to perform an imaging scan of an object under inspection for a first imaging duration to obtain a first muon tomography image of the object, and the first muon tomography scanner further configured to have a sufficiently large imaging area covered by the position sensitive charged particle detectors to obtain a full image of the entire object; a second, separate muon tomography scanner that includes position sensitive charged particle detectors to perform an imaging scan of the object for a second imaging duration longer than the first imaging duration to obtain a second muon tomography image of only each suspect region of the object without imaging the entire object, wherein the second muon tomography scanner is configured to have a

smaller imaging area covered by the position sensitive charged particle detectors to obtain an image of only a portion of the object, and the second muon tomography scanner is located at a second location off the main inspection traffic path without interfering movement of the objects in the main inspection traffic path; and an inspection control mechanism that processes the first muon tomography image of the object, generates a clearance signal when the processing of the first muon tomography image reveals no suspect region inside the object to set the first muon tomography scanner ready for receiving a next object for inspection, and issues an instruction for removing the object from the first muon tomography scanner to place the object in the second muon tomography scanner for further inspection if the first muon tomography image reveals one or more suspect regions inside the object, while operating the first muon tomography scanner to receive a next object to inspect.

BRIEF DESCRIPTION OF THE DRAWINGS

[0006] FIG. 1A illustrates an example of a muon tomography scanner system for portal monitoring and other inspection applications utilizing cosmic ray-produced muons to obtain images of an object.

[0007] FIG. 1B illustrates a side view of a muon tomography scanner system utilizing cosmic ray-produced muons to detect an object.

[0008] FIG. 2 illustrates a detailed perspective view of a muon tomography scanner system.

[0009] FIG. 3 shows an example of a vehicle inspection system based on a primary muon tomography scanner for an initial scan and for maintaining a flow of vehicles under inspection

spatial distribution of scattering centers within the object holding area.

17. The system as in claim 11, wherein:

the inspection control mechanism is configured to obtain information on a traffic flow of objects to be inspected in the main inspection traffic path and, based on the obtained information on the traffic flow, to determine whether to hold the object at the first muon tomography scanner to perform a further scanning of the object in the first muon tomography scanner if the first muon tomography image reveals one or more suspect regions inside the object.

18. The system as in claim 17, wherein:

when the obtained information on the traffic flow indicates a low traffic, the inspection control mechanism is configured to hold the object at the first muon tomography scanner to perform a further scanning of the object in the first muon tomography scanner if the first muon tomography image reveals one or more suspect regions inside the object; and

when the obtained information on the traffic flow indicates a high traffic, the inspection control mechanism is configured to issue the instruction for removing the object from the first muon tomography scanner to place the object in the second muon tomography scanner for further inspection if the first muon tomography image reveals one or more suspect regions inside the object, while operating the first muon tomography scanner to receive a next object to inspect.

19. The system as in claims 11 ~~through 18~~, wherein

each of the first and second muon tomography scanners is configured to:

reconstruct a trajectory of a muon through the object based on signals from the position sensitive charged particle detectors;

measure an incoming momentum and an outgoing momentum of a muon based on signals from the position sensitive charged particle detectors;

determine a spatial distribution of a scattering density within the object; and

using information of the trajectory, momentum and spatial distribution of the scattering density in the object to construct a tomographic profile inside the object.

20. The system as in claim 11, wherein: