Example Provisional Patent Application

#4 Neutron Fluorescence with Synchronized Gamma Detector

This Provisional Patent Application was eventually re-written and filed as a utility (non-provisional) patent application in the U.S. Patent Office. The patent was eventually granted as US Patent No. 8,410,451

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Minimizing Detector Noise in Thermal, Epithermal, and Cold Neutron Fluorescence Processes Using Neutron Flux Modulation and Gamma ray Detector Pulse Gating Synchronized to Neutron Time of Flight

FIELD OF THE INVENTION

[0001] The present disclosure relates generally to the use of flux modulation or "pulsing" of a thermal, epithermal, or cold neutron beam, synchronized to the time of flight of a packet or cloud of neutrons, as well as time-gating of the gamma ray detector, as a means to minimize noise in that gamma ray detector when employed to detect a substance of interest.

BACKGROUND

[0002] The use of beams of neutrons to identify substances at a distance is an emerging technology.

[0003] The device described in US Publication No. 2008/0017806 uses a neutron beam, consisting of either thermal, epithermal, or cold neutrons, for such identifications. The entire disclosure of US Publication No. 2008/0017806 is hereby incorporated by reference and relied upon.

[0004] All neutron sources produce gamma rays as byproducts. Such gamma rays are frequently known as "fratricidal" gamma rays, since they degrade the mission of the device from which they emanate. This use of the term "fratricidal" mirrors the use of that term in military parlance.

[0005] Gamma ray detectors used as part of the substance identification device cannot be completely shielded from gamma rays produced by the neutron source that is also a part of the identification device.

[0006] Gamma rays produced as a result of neutron production thus constitute a noise or nuisance signal for the gamma ray detectors. This nuisance signal degrades the ability of the gamma ray detector to detect and identify genuine signals of interest.

[0007] Gamma rays are also produced by the interaction of the neutron beam with atmospheric nitrogen as the beam travels toward the substance of interest. Such gamma rays are referred to as “atmospheric backshine gammas” or “atmospheric sparkle gamma rays”. These gamma rays also constitute noise or nuisance signals.

SUMMARY OF THE INVENTION

[0008] The present invention improves upon prior art by pulsing the neutron beam and by exploiting only the data from the gamma ray detector that occurs during times when fratricidal and backshine gammas are at minimum flux, a process referred to as “pulse gating” or “time gating” the gamma ray data . The effect of these two techniques is to release a “cloud” of thermal neutrons in the direction of the substance of interest, after which the neutron source either turns off or greatly reduces flux, reducing the gamma rays it produces to a very low value or zero. While the neutron source is operating at either zero or low neutron beam flux, the amount of nuisance, or “fratricidal”, gamma rays is reduced either to zero or to a low value. In addition, the gamma ray detector is either switched off, or else its data is ignored, during this period.

[0009] The cloud travels toward the substance of interest at speeds distributed according to a nominally Maxwellian distribution. The mode of this distribution and its width vary with the equilibrium temperature of the neutrons in the cloud. At thermal neutron speeds, the modal speed is approximately 2,200 meters per second, or approximately 0.455 milliseconds per meter. The cloud also spreads out slightly as it travels.

[0010] Although the cloud of neutrons spreads out as it moves, due to the distribution of speeds of the neutrons, the preponderance of the neutrons arrive in a short time, of the same order of magnitude as the time width of the original cloud.

[0011] During the time of flight of the neutrons toward the substance of interest, the neutron cloud or pulse creates backshine gamma rays from atmospheric nitrogen. These gamma rays are disregarded by the gamma ray detector, or else the gamma ray detector is physically switched off during their generation.

[0012] As the cloud of neutrons penetrates and illuminates the substance of interest, it causes that substance to begin to emit gamma rays. A target range detector computes the time when the neutrons begin to arrive in large numbers and passes that information to a control mechanism. As that time occurs, the control mechanism switches the gamma ray detector on [or directs it to begin exploiting the signal it is receiving], allowing the gamma rays from the substance of interest to be recognized and counted.

[0013] During the time the gamma rays are being produced by the substance of interest, the neutron source itself is producing either no gamma rays at all, or else a very low gamma ray flux, since it is / was switched off.

[0014] In addition to avoiding fratricidal gamma rays from the neutron source due to its being switched off, the gamma ray detector also is subjected to the minimum amount of atmospheric backshine possible, since gamma rays occurring prior to the arrival of the cloud of neutrons at the substance of interest are either disregarded or not detected.

[0015] This reduction of gamma ray flux from the neutron source and from atmospheric backshine greatly reduces the noise signal seen by the gamma ray detectors while they are being illuminated by gamma rays from the substance of interest.

[0016] After all gamma rays from the substance of interest have been received by the gamma ray detector, the neutron source is pulsed again, repeating the process just described.

[0017] The time constants involved, 0.455 milliseconds per meter, the distances involved, up to 20 meters, and the pulsing rate, of the order of 100 hertz, are all reasonable and achievable for problems of interest.

[0018] In other disciplines, such as radar and sonar, the synchronization of a detector with modulations in the strength of an interrogation signal is referred to as "pulse gating". That terminology is borrowed from other disciplines and applied to the case of neutron analysis to underscore analytical and theoretical similarities with other detection modalities.

[0019] The present invention is directed to an apparatus and method for using pulses of thermal, epithermal, or cold neutrons to illuminate a substance of interest for the purpose of stimulating it to produce gamma rays that can be used to identify it, and additionally for gating the gamma ray detector so as to minimize the amount of atmospheric backshine gamma rays it detects. The reason for using pulsing is that the neutron generator itself produces gamma rays that constitute a “noise” or “nuisance” gamma ray signal that can partially obscure the gamma signal from the substance of interest. Between pulses, when the neutron generator is either switched off or set to a very low neutron flux value, the flux of noise gammas is either much less than it would be during the pulse or actually zero, both of which phenomena have the effect of greatly reducing the noise caused by the detector. The reason for using detector time gating is that atmospheric backshine gamma rays produced at times when the substance of interest is not being illuminated by neutrons are excluded from exploitation.

[0020] This invention is possible because the time of flight of such a neutron beam to a typical substance of interest is of the order of several milliseconds, a time constant during which available neutron generators can be switched on and off.

[0021] Briefly, the disclosed invention consists of a device and method for pulsing a thermal, epithermal, or cold neutron beam and either a) synchronizing a gamma ray detector with the neutron beam flux so as to detect gamma rays only when the gamma rays produced by the neutron source are at a low enough flux to minimize their effects as a noise signal and the neutrons are actually illuminating the substance of interest, or b) causing the gamma ray detector’s signal processing apparatus to achieve nominally the same effect as a).

[0022] Thermal neutrons, with mean energy of 4.05×10^{-21} Joules = 0.026 eV, have velocities distributed according to a Maxwell-Boltzman distribution, with mean velocity of 2,200 meters per second, corresponding to a momentum of 3.68×10^{-24} kg-m/sec.

[0023] Embodiments of the present invention include systems in which the neutron source is pulsed, systems in which the gamma ray detector is optionally time gated so as to literally not respond to gamma rays while the neutron flux is too high or the substance of interest is not being illuminated, and systems in which the gamma ray detector is instructed to ignore the nuisance signals, despite the fact that it is physically sensing them.

BRIEF DESCRIPTION OF THE DRAWINGS

[0024] FIGURE 1 (basic science) shows the population of thermal neutrons arriving at a gamma ray detector as a function of time, for a substance of interest located 10 meters from the neutron source, and for a 5 millisecond thermal neutron pulse. Note that epithermal neutrons would arrive more quickly, and cold ones more slowly.

[0025] FIGURE 2 (basic science) shows the phenomenon of atmospheric nitrogen gamma ray "backshine" or "sparkle".

[0026] FIGURE 3 (applied science) shows a schematic of a neutron pulse or "cloud" as it leaves a neutron source headed for a substance of interest. The lightest shades of gray indicate the fastest neutrons, and the darkest indicate the slowest. Three steps are shown: (a) In the first step, the neutron pulse or cloud is leaving the neutron source, and the source itself is making nuisance gamma rays. The gamma ray detector is not sensing these gamma rays; (b) In the second step, the neutrons are in flight toward the substance of interest; (c) In the third step, the neutrons are producing gamma rays by colliding with the substance of interest. The gamma ray detector detects them. They travel at the speed of light. The neutron source is not producing nuisance gamma rays, reducing the problem of noise in the gamma ray detectors.

[0027] Figure 4 shows a functional description [see below].

DETAILED DESCRIPTION

[0028] References in this document to "one embodiment", "an embodiment", "some embodiments", or similar linguistic formulations means that a particular feature, structure, operation, or characteristic described in connection with those embodiments is included in at least one embodiment of the present invention. Thus, the appearances of such phrases or linguistic formulations in this document do not necessarily refer to the same embodiment. Further, various particular features, structures, operations, or characteristics may be combined in any suitable manner in one or more embodiments.

[0029] FIGURE 4 illustrates graphically an apparatus for minimizing nuisance or noise signal due to gamma rays used in the detection of substances of interest by the mechanism of neutron irradiation that are produced by the neutron generator itself or by atmospheric backshine, in accordance with one embodiment of the present invention. (Conventional elements, such as housings, mountings, supports, electrical power supplies, external radiation shielding, etc. are omitted of ease of illustration.) The apparatus has four main components: a neutron source 100; a gamma ray detector 200; a control mechanism 300; and a target range detector 400.

[0030] The neutron source 100 emits a neutron cloud 150 toward the target. The neutron source produces fratricidal gamma rays 120, which are a nuisance signal. The neutron cloud produces backshine gamma rays 130 as a result of interactions with atoms of atmospheric nitrogen-14 it encounters on its path, which are also a nuisance signal. Upon encountering the substance of interest 160, the cloud of neutrons interacts to produce gamma rays of interest 160. The gamma ray detector 200 is switched on [in some embodiments] or told to stop disregarding the gamma rays [in other embodiments] by the control mechanism 300 at the moment the bulk of the neutrons arrive at the substance of interest, based on time of flight of the neutron cloud, which is determined from the range to the substance of interest 160 determined by the target range detector 400. The gamma ray detector continues to sense the gamma rays of interest for the entire time the substance of interest is being illuminated by substantial numbers of neutrons. During this time, the gamma rays of interest 170, which travel at the speed of light, are arriving at the gamma ray detector 200, while the nuisance signals consisting of the fratricidal gamma rays 120 and the backshine gamma rays 130 are minimized in their effect. [For clarity, neutrons and gamma rays not involved in the described processes, as well as other sensors that are a part of the primary constituents, are not shown. Connections between the control mechanism 300 and the neutron source 100, the gamma ray detector 200, and the target range detector 400 are shown as broken lines, but are not labeled in the interest of keeping the drawing simple]. These four main components are first broadly described by their sub-components, and then each sub-component is described in detail.

[0031] A main component of the apparatus is neutron source 100, which emits thermal, epithermal, or cold neutrons. For this invention, the neutron source emits neutrons in pulses, resulting in a cloud of neutrons 150, rather than a steady stream of neutrons. The flux of neutrons is controlled by commands from a control mechanism

300. The connection between the neutron source 100 and the control mechanism 300 may be either unidirectional, in which commands pass from the control mechanism 300 to the neutron source 100, or bidirectional, in which control and / or status commands pass in both directions between the two components. Between pulses, the neutron source is either switched off [in some embodiments] or else switched to a very low value [in other embodiments.] When operating, the neutron source may also emit fratricidal gamma rays 120, which are a nuisance signal. When the neutron source is either switched off or switched to a very low neutron flux, the fratricidal gamma rays 120 either cease entirely or drop to a very low flux.

[0032] A second main component of the apparatus is the gamma ray detector 200. This detector is designed to sense gamma rays of interest 170. It also detects nuisance gamma rays 120 and 130, since it is impossible in principle to design a detector that will reject 100% of nuisance gamma rays. The detector can be switched on and off [in some embodiments] or told to regard or disregard gamma rays [in other embodiments] by a control mechanism 300. The connection between the gamma ray detector 200 and the control mechanism 300 may be either unidirectional, in which commands pass from the control mechanism 300 to the gamma ray detector 200, or bidirectional, in which control and / or status commands pass in both directions between the two components.

[0033] A third main component of the apparatus is the control mechanism 300. This mechanism sends commands to both the neutron source 100 and the gamma ray detector 200. In the case of the neutron source 100, these commands specify the neutron flux emitted. In the case of the gamma ray detector, these commands specify the state of that component regarding either its on / off state [in some embodiments] or its regarding or disregarding of gamma rays [in other embodiments]. In addition to the commands just specified, other commands may be issued, such as system commands, self-test, diagnostic, etc. In addition to commands being sent by the control mechanism 300, optionally, status information may be sent from either the neutron source 100 or the gamma ray detector 200, or both. If sent, such status information may either be sent upon request of the control mechanism 300 or autonomously by either or both of the neutron source 100 or the gamma ray detector 200.

[0034] A fourth main component of the apparatus is the target range detector 400. This mechanism measures the distance between the neutron source 100 and the substance of interest 160 and makes it available to the control mechanism 300 either upon query by the control mechanism 300, on a schedule determined by the target range detector's operating parameters, or continuously.

[0035] While the present invention has been described in terms of the above-described embodiments and apparatuses, those skilled in the art will recognize that the invention is not limited to the embodiments described. The present invention may be practiced with various modifications and alterations within the spirit of the appended claims.

EXEMPLARY CLAIMS

What is claimed is:

1. Apparatus for minimizing detector noise in thermal, epithermal, and cold neutron fluorescence processes using neutron flux modulation and gamma ray detector pulse gating synchronized to neutron time of flight, comprising:

a source of thermal, epithermal, or cold neutrons, optionally switched between flux or power settings in various embodiments;

a gamma ray detector or detection system;

a control mechanism; and

a target range detector.

2. The apparatus of Claim 1, in which the neutron source is capable of being switched between multiple neutron flux settings.

3. The apparatus of Claim 1, in which the neutron source is capable of being switched between OFF and ON, where these terms refer to "Full or nearly full neutron flux" and "zero or nearly zero neutron flux", respectively.

4. The apparatus of Claim 1 in which the neutron source switching is triggered by any signal emanating from any source whatsoever.

5. The apparatus of Claim 1 in which the gamma ray detector or gamma ray detection system can be switched on and off by any signal emanating from any source whatsoever.

6. The apparatus of Claim 1 in which the gamma ray detector or gamma ray detection system can be told to regard or disregard gamma rays by any signal emanating from any source whatsoever.

7. The apparatus of Claim 1 in which the gamma ray detector's or gamma ray detection system's signal processing apparatus can be programmed to achieve nominally the same effect as physically switching the detector off and on.

8. The apparatus of Claim 1 in which the control mechanism sends control commands to the neutron source by any means whatsoever.

9. The apparatus of Claim 1 in which the control mechanism sends control commands to the gamma ray detector or gamma ray detection system by any means whatsoever.

10. The apparatus of Claim 1 in which the control mechanism receives information of any type from the neutron source by any means whatsoever.

11. The apparatus of Claim 1 in which the control mechanism receives information of any type from the gamma ray detector or gamma ray detection system by any means whatsoever.

12. The apparatus of Claim 1 in which the target range detector sends target range data to the control mechanism by any means whatsoever under any protocol whatsoever.

13. The apparatus of Claim 1 in which the target range detector uses microwave or radar techniques to determine range.

14. The apparatus of Claim 1 in which the target range detector uses either passive or active acoustic techniques to determine range.

15. The apparatus of Claim 1 in which the target range detector uses optical techniques to determine range.

16. The apparatus of Claim 1 in which the target range detector uses invisible light techniques, such as infrared, terahertz, or millimeter wave techniques to determine range.

17. The apparatus of Claim 1 in which the target range detector uses multiple sensor modalities or techniques to determine range.

18. The apparatus of Claim 1 in which the target range detector uses multiple sensor modalities or techniques combined with sensor fusion techniques to determine range.

19. An apparatus for minimizing detector noise in thermal, epithermal, and cold neutron fluorescence processes using neutron flux modulation and gamma ray detector pulse gating synchronized to neutron time of flight, substantially as shown and described herein.

20. A method for minimizing detector noise in thermal, epithermal, and cold neutron fluorescence processes using neutron flux modulation and gamma ray detector pulse gating synchronized to neutron time of flight, substantially as shown and described herein.

ABSTRACT

Apparatus for minimizing detector noise in thermal, epithermal, and cold neutron fluorescence processes using neutron flux modulation and gamma ray detector pulse gating synchronized to neutron time of flight. The apparatus includes a source of thermal, epithermal, or cold neutrons, optionally switched between flux or power settings in various embodiments, a gamma ray detector or detection system capable of either being turned on and off, in some embodiments, or else being told to regard or disregard gamma ray signals in other embodiments, a control mechanism; and a target range detector.

An example of a possible embodiment includes a source of thermal neutrons produced by a modulated electronic neutron source, accompanied by a time-gated gamma ray detector, an optical range detection system, and a computer with appropriate control software. Other embodiments are possible.

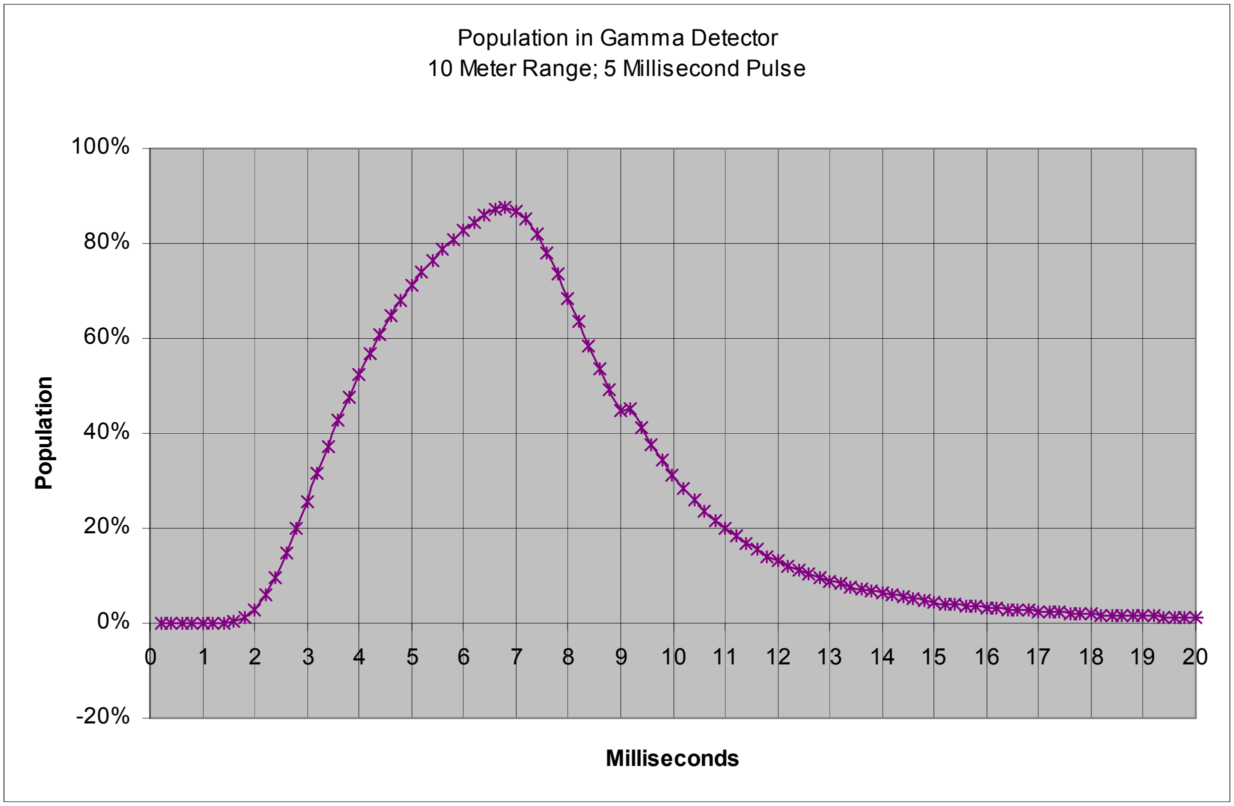

Figure 1. Population of Gamma Rays in a Detector Following a Neutron Pulse.

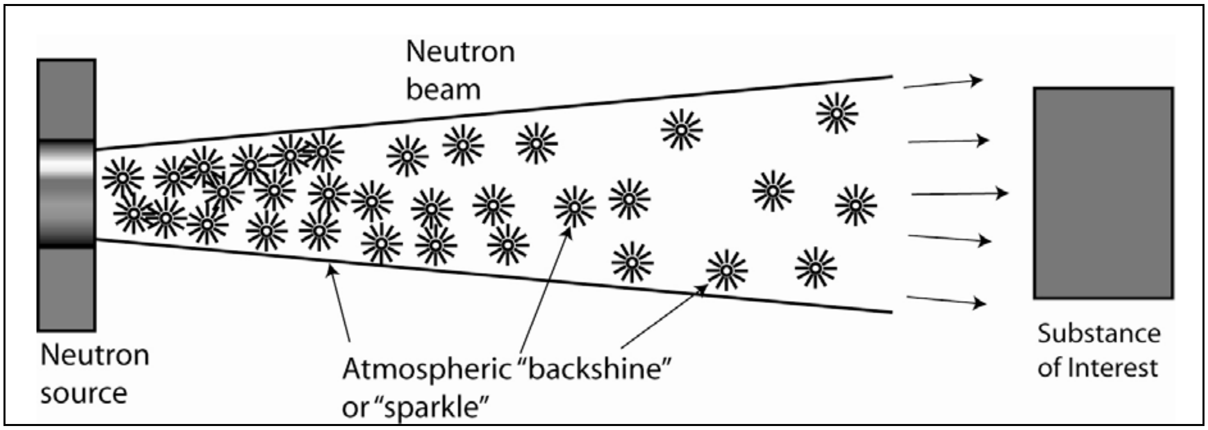

Figure 2. Atmospheric "backshine" or "sparkle"

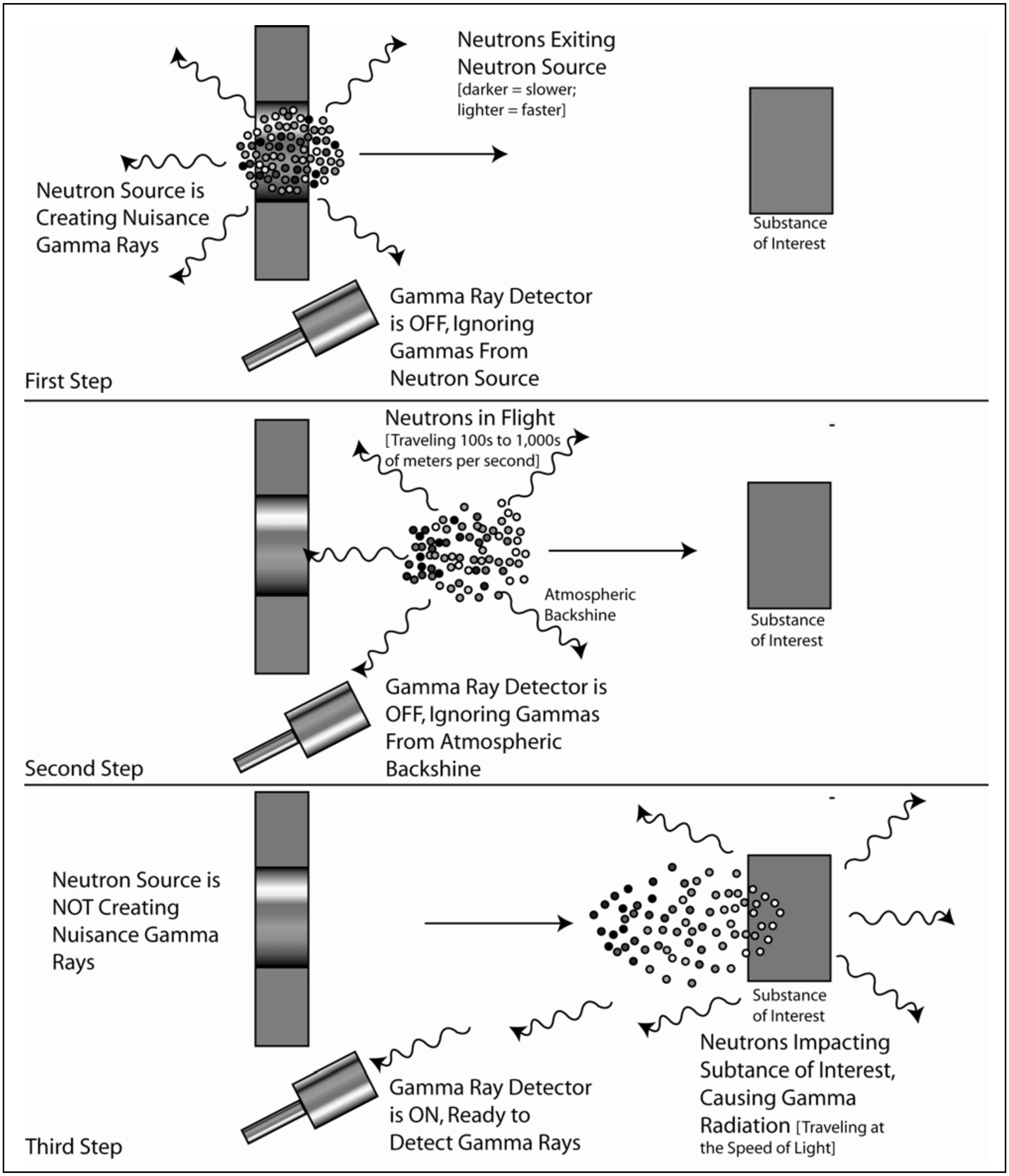

Figure 3. Neutrons exiting the source in a pulse or “cloud” and traveling to the substance of interest. Note that gammas are only sensed as the substance of interest is illuminated. Noise or nuisance gammas from the source are not detected.

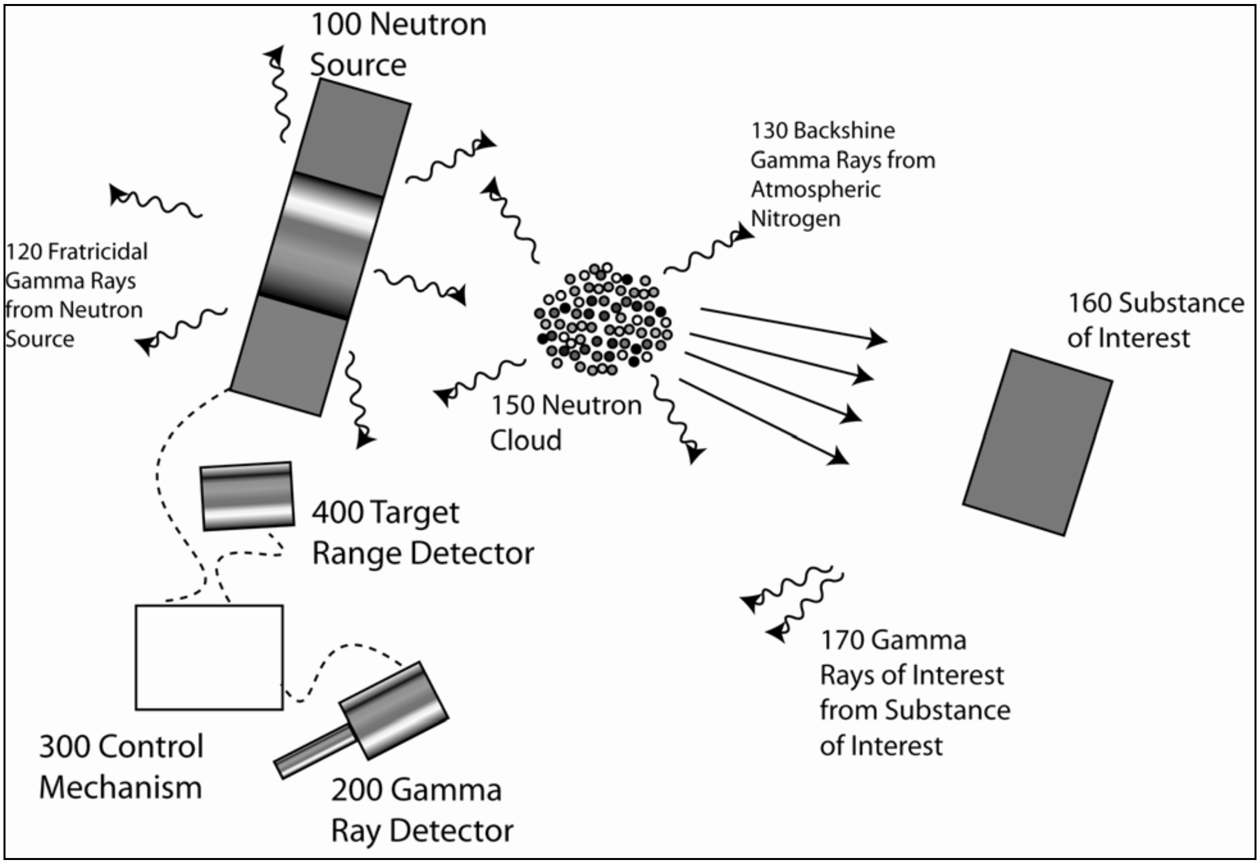

Figure 4. Schematic diagram showing the components of the invention.