



- (51) International Patent Classification:
G01T 1/00 (2006.01)
- (21) International Application Number:
PCT/US2014/038212
- (22) International Filing Date:
15 May 2014 (15.05.2014)
- (25) Filing Language: English
- (26) Publication Language: English
- (30) Priority Data:
13/895,159 15 May 2013 (15.05.2013) US
- (71) Applicant (for CA only): **SCHLUMBERGER CANADA LIMITED** [CA/CA]; 125 - 9 Avenue SE, Calgary, Alberta T2G 0P6 (CA).
- (71) Applicant (for FR only): **SERVICES PETROLIERS SCHLUMBERGER** [FR/FR]; 42 rue Saint Dominique, 75007 Paris (FR).
- (71) Applicant (for GB, JP, NL only): **SCHLUMBERGER HOLDINGS LIMITED**; P.O. Box 71, Craigmuir Chambers, Road Town, 1110 Tortola, Virgin Islands, British (VG).
- (71) Applicant (for all designated States except AE, AO, BH, CA, CN, FR, GB, GH, IN, JP, LY, MA, MZ, NA, NG, NL, PH, SD, SY, US, VN): **SCHLUMBERGER TECHNOLOGY B.V.** [NL/NL]; Parkstraat 83-89, NL-2514 JG The Hague (NL).
- (71) Applicant (for AE, AO, BF, BH, BJ, CF, CG, CI, CM, CN, GA, GH, GN, GQ, GW, IN, KM, LY, MA, ML, MR, MZ, NA, NE, NG, PH, SD, SN, SY, TD, TG, VN only): **PRAD RESEARCH AND DEVELOPMENT LIMITED**; P.O. Box 71, Craigmuir Chambers, Road Town, 1110 Tortola, Virgin Island, British (VG).
- (71) Applicant (for US only): **SCHLUMBERGER TECHNOLOGY CORPORATION** [US/US]; 300 Schlumberger Drive, Sugar Land, TX 77478 (US).
- (72) Inventors: **STEPHENSON, Kenneth, E.**; 4107 Fox Run Drive, Plainsboro, NJ 08536 (US). **ZIEGLER, Wolfgang**; 122 Orchard Ave., Hightstown, NJ 08520 (US).

[Continued on next page]

(54) Title: SCINTILLATION DETECTOR PACKAGE HAVING RADIOACTIVE REFLECTIVE MATERIAL THEREIN

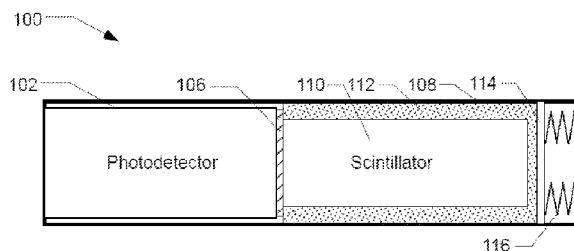


FIG. 1a

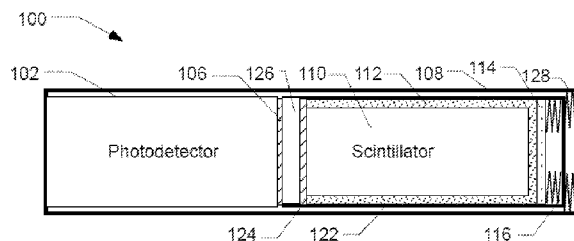


FIG. 1b

(57) Abstract: A scintillator detector package includes a housing, with a scintillator in the housing. There is a radioactive reflective material between at least a portion of the scintillator and the housing. The radioactive reflective material may be a naturally occurring material, such as Lu_2O_3 , and may be in powdered form. A photodetector may be optically coupled to the scintillator package, and gain stabilization circuitry may perform gain stabilization based upon detecting scintillations of the scintillator caused by radiation emitted by the radioactive reflective material striking the scintillator.



(74) **Agents:** BERMAN, Jeremy et al.; 10001 Richmond Avenue, IP Administration Center of Excellence, Room 4720, Houston, TX 77042 (US).

(81) **Designated States** (*unless otherwise indicated, for every kind of national protection available*): AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IR, IS, JP, KE, KG, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LT, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) **Designated States** (*unless otherwise indicated, for every kind of regional protection available*): ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

Published:

— with international search report (Art. 21(3))

SCINTILLATION DETECTOR PACKAGE HAVING RADIOACTIVE REFLECTIVE MATERIAL THEREIN

Cross-reference to related applications

[0001] This application claims priority to US Patent Application 13/895159, filed May 15, 2013 and entitled “Scintillation Detector Package Having Radioactive Reflective Material Therein”, which is incorporated herein in its entirety.

Field of the Disclosure

[0002] This disclosure related to the field of scintillators, and, more particularly, to scintillators that may be used in well logging or other applications.

Background

[0003] Radiation detectors, such as gamma-ray or x-ray detectors, for example, often use a scintillator material which converts energy deposited by a given type of radiation (e.g., gamma-rays or x-rays) into light. The light is directed to a photodetector, which converts the light generated by the scintillator into an electrical signal, which may be used to measure the amount of radiation which is deposited in the crystal.

[0004] In the case of well-logging tools for hydrocarbon wells (e.g., gas and oil wells), a borehole radiation detector may be incorporated into the tool string to measure radiation from the geological formation surrounding the borehole to determine information about the geological formation, including the location of gas and oil. The measured radiation may be naturally occurring radiation emanating from the materials in and around the hydrocarbon well, or may be radiation emanating from the materials in and around the hydrocarbon well as a result of interactions with radiation (e.g. neutrons, gamma-rays, or x-rays) radiated into the hydrocarbon well by the well-logging tool.

[0005] In some applications, it may be useful to gain stabilize a radiation detector. As such, new developments in the area of radiation detectors and ways to gain stabilize them are desirable.

Summary

- [0006] This summary is provided to introduce a selection of concepts that are further described below in the detailed description. This summary is not intended to identify key or essential features of the claimed subject matter, nor is it intended to be used as an aid in limiting the scope of the claimed subject matter.
- [0007] A scintillation detection package may have a housing, with a scintillator in the housing. In addition, there may be a radioactive reflective material between at least a portion of the scintillator and the housing.
- [0008] A further application is directed to a radiation detection system. The radiation detection system may include a scintillator package with a housing, and a scintillator in the housing to scintillate when struck by radiation. There may be a naturally occurring radioactive reflective material between at least a portion of the scintillator and the housing, and a window sealing an end of the housing to permit light emitted during a scintillation to exit the housing. There may be a photodetector optically coupled to the scintillator package, and gain stabilization circuitry coupled to the photodetector. The gain stabilization circuitry may be configured to perform gain stabilization based upon scintillations of the scintillator caused by radiation emitted by the naturally occurring radioactive reflective material striking the scintillator.
- [0009] A method aspect is directed to a method of logging a formation having a borehole therein. The method may include lowering a well logging instrument into the borehole, and detecting incoming radiation from the formation using a radiation detector carried by the well logging instrument, the radiation detector comprising a scintillator housing with a scintillator therein. The method may further include gain stabilizing the radiation detector based upon detecting scintillations of the scintillator caused by radiation emitted by a radioactive reflective material between at least a portion of the scintillator and the scintillator housing striking the scintillator, using gain stabilization circuitry.

Brief Description of the Drawings

- [0010] FIG. 1A is a schematic block diagram of a radiation detector in accordance with the present disclosure including a radioactive reflective material, wherein the scintillator and photodetector share a common housing.
- [0011] FIG. 1B is a schematic block diagram of a radiation detector in accordance with the present disclosure including a radioactive reflective material, wherein the scintillator has its own housing.
- [0012] FIG. 2 is a schematic block diagram of a radiation detector in accordance with the present disclosure wherein the radioactive reflective material is at an end of the housing of the radiation detector.
- [0013] FIG. 3 is a schematic block diagram of radiation detector in accordance with the present disclosure including both a radioactive reflective material and a non-radioactive reflective material.
- [0014] FIG. 4 is a schematic block diagram of radiation detector in accordance with the present disclosure wherein the radioactive reflective material is at least partially embedded in a sleeve surrounding the scintillator.
- [0015] FIG. 5 is a schematic block diagram of radiation detector in accordance with the present disclosure with a non-radioactive reflective material at least partially surrounding the radioactive reflective material.
- [0016] FIG. 6 is a schematic block diagram of radiation detector in accordance with the present disclosure wherein an absorptive layer is between the scintillator and radioactive reflective material.
- [0017] FIG. 7 is a schematic block diagram of a radiation detector in accordance with the present disclosure wherein a naturally occurring radioactive material is between the housing and a reflective material that is adjacent the scintillator.
- [0018] FIG. 8 is a schematic block diagram of a well-logging tool in which the radiation detectors disclosed herein may be used.

Detailed Description

[0019] The present description is made with reference to the accompanying drawings, in which example embodiments are shown. However, many different embodiments may be used, and thus the description should not be construed as limited to the embodiments set forth herein. Rather, these embodiments are provided so that this disclosure will be thorough and complete. Like numbers separated by century refer to like elements throughout, with the exception of those elements shown in FIG. 7.

[0020] Referring initially to FIG. 1A, a radiation detector 100 is now described. The radiation detector 100 includes a scintillator 110 coupled to a photodetector 102 through an optical coupler 106 (e.g. a silicon pad, optical grease, etc.). The detector housing 108 in the illustrated example is cylindrical, such as typical for use in a well-logging tool, as will be described further below. The detector housing 108 may comprise a metal (e.g. aluminum, magnesium etc.), or a ceramic, which allows radiation such as gamma rays, x-rays or neutrons to pass through. Alternatively, the housing 108 could be made of a non-metallic material such as a high strength carbon-fiber reinforced polymer. The scintillator 110 is pushed against the photodetector using a spring 116. An optional base plate 114 may be between the scintillator 110 and the spring 116. The photodetector 102 may include a photocathode and a photomultiplier tube, the entrance window (not shown) of which is coupled to the scintillation crystal with the optical coupler 106. It should be noted that other suitable photodetector 102 configurations may be used in some applications, such as an avalanche photodiode (APD) configuration, or silicon photomultiplier configuration, for example.

[0021] The detector housing 108, base plate 114, spring 116, or any combination thereof may be constructed at least partly from a naturally occurring radioactive material. For example, they may be constructed entirely from the naturally occurring radioactive material, or may be constructed from a non-radioactive substrate with the naturally occurring radioactive material therein or thereon, or may be constructed from a ceramic with the naturally occurring radioactive material integrated therein. The radioactivity of the naturally occurring radioactive material can be used to gain stabilize the radiation detector 100, as will be explained below in detail.

[0022] Alternatively, the scintillator itself may be enclosed in its own housing as shown in FIG. 1B. This is to protect scintillators like NaI(Tl), LaBr₃, etc. from deteriorating in the presence of humidity. Here, the scintillator may be hermetically sealed in its housing 122. At one end of the housing 122 the scintillator 110 is coupled to an exit window 126 with an optical coupler 124. On the other end a spring 116 pushes the scintillator 110 against the exit window 126. In turn, the scintillator housing is pushed against the photodetector by a spring 128. There may be an optional base plate between the spring 116 and the scintillator 110.

[0023] Similarly to that described above, the housing 122, base plate, spring 116, or any combination thereof may be constructed from a naturally occurring radioactive material. The naturally occurring radioactive material may be lutetium, potassium, thorium, lanthanum or any combinations thereof, with or without other non-radioactive materials included. The naturally occurring radioactive material may be an oxide of the materials listed above, for example Lu₂O₃ or La₂O₃. In fact, the naturally occurring radioactive material may include any of the materials listed above as well as oxides thereof.

[0024] In addition, the naturally occurring radioactive material may be a metallic substance in solid form, such as one of the listed materials, or a combination thereof. Additionally, the naturally occurring radioactive material may be one or more of the previous listed materials in metallic form alloyed with a non-radioactive metal.

[0025] The scintillator 110 may be a plastic scintillator or crystal scintillator, for example. Indeed, various types of scintillator materials may be used for the scintillator 110 depending upon the given application. Example scintillator materials may include: gadolinium oxyorthosilicate (GSO), YAlO₃ (YAP), LuYAP, LaCl₃(Ce) (lanthanum chloride doped with Cerium), LaBr₃(Ce) (Cerium-doped lanthanum bromide), bismuth germanate (BGO), NaI(Tl), LuAG, YAG, LuAP, SrI₂, GAGG/GYGaGG, CeBr₃, GdI₂, LuI₂, ceramic scintillators, GPS, LPS, BaBrI, LuAG ceramic, LiCaF, CLYC, CLLB, CLLC, etc.

[0026] As noted above, scintillators are widely used in radiation detectors 100 in several research and industrial fields, including the oil industry. The scintillator emits light when struck by ionizing radiation. In a radiation detector 100 configuration, the scintillation

light is to be directed towards the photodetector 102, whose function is to convert the light signal into an electrical signal. The electrical signal may be amplified by an amplifier(s), which may provide an amplified signal to a signal processor or processing circuitry. The signal processor may include a general or special-purpose processor, such as a microprocessor or field programmable gate array, and associated memory, and may perform a spectroscopic analysis of the electrical signal, for example.

[0027] There is a radioactive reflective material 112 between at least a portion of the detector housing (108) or the scintillator package housing 122 and the scintillator 110. The reflective properties of the radioactive reflective material 112 helps improve light transport and direct light emitted by the scintillator into the photodetector 102. The radioactivity of the radioactive reflective material 112 can be used to gain stabilize the radiation detector 100, as will be explained below in detail.

[0028] In addition, the exit window 126 may be constructed from a non-scintillating, radioactive material, and may also be used to gain stabilize the radiation detector. This non-scintillating, radioactive material may be naturally occurring, and may comprise lutetium, for example. Indeed, the non-scintillating, radioactive material may be undoped LuAP or undoped LuAG, such as LuAP that is not doped with cerium and LuAG that is not doped with cerium. The exit window could also be made of Lu_2O_3 ceramic or could be a glass containing potassium, for example. The radioactive reflective material 112 may be in powdered form, and may be a naturally occurring material. It should be noted that the radioactive reflective 112 material may be mixed with a non-radioactive reflective metallic powder, such as aluminum, silver, or a non-metallic powder such as Al_2O_3 , or TiO_2 . This may be done to reduce the radioactivity of the radioactive reflective powder and/or its ability to absorb incoming radiation from a formation.

[0029] The radioactive reflective material 112 may be any suitable material. Suitable materials are chemically compatible with typical scintillator materials (e.g. not cause degradation of optical parameters during extended periods at high temperature), chemically stable at borehole temperatures, emit radiation such as gamma-rays that form scintillation lines separate from the ones of interest in the measurement (usable for gain stabilization, as will be explained below), and emit sufficient amounts of radiation such

that the statistical precision is adequate for gain stabilization but not so much that the material becomes a radiation hazard.

[0030] In accordance with this, the radioactive reflective material 112 may comprise (i.e. be partially constituted from) lutetium, potassium, lanthanum, or thorium, and for example may be Lu_2O_3 , KCl, ThO_2 , LaO, or any mix thereof. Having the radioactive reflective material 112 be a naturally occurring material, as opposed to a material created in a reactor or particle accelerator, can be useful in that the resulting radiation detector 100 may be subject to fewer government regulations. Thus, it should be understood that a naturally occurring material means a material not created in a reactor or particle accelerator, and a material that has not been enriched to increase the fraction of radioactive isotopes therein. Thus, a naturally occurring material is one with its naturally occurring isotopic distribution.

[0031] The radioactive reflective material 112 may be adjacent portions of the scintillator 110, or may surround the scintillator as in FIG. 1. Indeed, the radioactive reflective material 112 may be described as circumscribing the scintillator 110 along a longitudinal axis thereof, and as well as an end of the scintillator.

[0032] In some applications, as shown in FIG. 2, the radioactive reflective material 212 is adjacent an end of the scintillator 210 without partially or fully circumscribing the longitudinal axis of the scintillator. In other applications, as shown in FIG. 3, the radioactive reflective material 312 may be adjacent a portion or portions of the scintillator 310, while a non-radioactive reflective material 318 may be adjacent another portion or portions of the scintillator. This may be done to form a “window” to help allow certain energies and types of external incoming radiation to more easily reach the scintillator 310. The radiation detector 310 can be oriented in a well logging instrument such that the “window” faces a direction from which incoming radiation from a formation into which the well logging instrument is inserted is likely to be received. In some such applications, it would be particularly useful if the non-radioactive reflective material 318 has a same reflectance as the radioactive reflective material 312, but attenuates radiation such as gamma rays less than the radioactive reflective material. As another approach, it could also be useful if the non-radioactive reflective material 318 is

less dense than the radioactive reflective material 312, so as to help enhance the directionality of the radiation sensitivity of the radiation detector 310.

[0033] To help restrict the radioactive reflective material 412 from moving within the scintillator package housing 408, the radioactive reflective material 412 may be completely or incompletely embedded in an elastomer, as shown in FIG. 4.

[0034] To help further improve light transport, in some cases, a non-radioactive reflective material 522, such as a reflective elastomer or Teflon, may partially or fully surround the radioactive reflective material 512, as shown in FIG. 5.

[0035] As will now be explained with reference to FIG. 6, when the radioactive reflective material 612 emits radiation, that radiation may be in the form of alpha, beta, or gamma radiation. To shield the scintillator 610 from undesirable forms of radiation, typically the alpha and beta radiation, there may be an absorptive layer 620 between the radioactive reflective material 612 and the scintillator to absorb the alpha radiation and/or beta radiation. This absorptive layer 620 is optically transparent, and may helpfully have a low index of refraction.

[0036] In a typical density measurement using a radiation generator, such as an electronic radiation generator or a radioisotopic source, the radiation generated by the radiation generator and directed into a formation scatters many times before the byproducts of those scattering interactions reach the radiation detector 600. Thus, the radiation incoming to the radiation detector 600 from the formation may have an energy of less than 300 keV. To gain stabilize the detector 600, a “check” source of radiation that produces radiation having an energy greater than that of the radiation incoming to the radiation detector, but not too much greater, is useful. The radioactive reflective material 612 serves this purpose. When radiation from the radioactive reflective material 612 strikes the scintillator 610, scintillation lines separate from those of interest in making the density measurement are detected. These detected scintillation lines can be used by gain stabilization circuitry 630 to gain stabilize the radiation detector 600.

[0037] In an application shown in FIG. 7, there is a non-radioactive reflective material 713 at least partially surrounding the scintillator 710. A naturally occurring radioactive material 723, such as a sleeve, at least partially surrounds the non-radioactive reflective

material 713 to urge the non-radioactive reflective material into the scintillator 710. This configuration works for situations where the scintillator 710 has its own housing, as well as for situations where the scintillator and photodetector 702 are in a common housing.

[0038] It should be noted that the scintillator packages and radiation detection systems disclosed herein are suitable for uses outside of oilfield applications, for example in the medical, mining, materials inspection, and security fields.

[0039] Turning now to FIG. 8, an example of a well-logging tool in which one or more radiation detectors 30 (similar to those described above) may be used. The detectors 30 are positioned within a sonde housing 918 along with a radiation generator 936 (e.g., neutron generator, x-ray generator, etc.) and associated high voltage electrical components (e.g., power supply). In some applications, the detectors 30 and radiation generator 936 could be in a pad rather than a sonde. Supporting control circuitry 914 for the radiation generator 936 (e.g., low voltage control components) and other components, such as downhole telemetry circuitry 912, may also be carried in the sonde housing 918.

[0040] The sonde housing 918 is to be moved through a borehole 920. In the illustrated example, the borehole 920 is lined with a steel casing 922 and a surrounding cement annulus 924, although the sonde housing and radiation generator 936 may be used with other borehole configurations (e.g., open holes). By way of example, the sonde housing 918 may be suspended in the borehole 920 by a cable 926, although a coiled tubing, etc., may also be used. Furthermore, other modes of conveyance of the sonde housing 918 within the borehole 920 may be used, such as wireline, slickline, Tough Logging Conditions (TLC) systems, and logging while drilling (LWD), for example. The sonde housing 918 may also be deployed for extended or permanent monitoring in some applications.

[0041] A multi-conductor power supply cable 930 may be carried by the cable 926 to provide electrical power from the surface (from power supply circuitry 932) downhole to the sonde housing 918 and the electrical components therein (i.e., the downhole telemetry circuitry 912, low-voltage radiation generator support circuitry 914, and one or more of the above-described radiation detectors 30). However, in other configurations power may be supplied by batteries and/or a downhole power generator, for example.

[0042] The radiation generator 936 is operated to emit x-rays or other radiation to irradiate the geological formation adjacent the sonde housing 918. X-rays or other radiation that returns from the formation are detected by the radiation detectors 30. The outputs of the radiation detectors 30 are communicated to the surface via the downhole telemetry circuitry 912 and the surface telemetry circuitry 932 and may be analyzed by a signal analyzer 934 to obtain information regarding the geological formation. By way of example, the signal analyzer 934 may be implemented by a computer system executing signal analysis software for obtaining information regarding the formation. More particularly, oil, gas, water and other elements of the geological formation have distinctive radiation signatures that permit identification of these elements. Signal analysis can also be carried out downhole within the sonde housing 918 in some embodiments.

[0043] Many modifications and other embodiments will come to the mind of one skilled in the art having the benefit of the teachings presented in the foregoing descriptions and the associated drawings. Therefore, it is understood that various modifications and embodiments are intended to be included within the scope of the appended claims.

Claims

1. A scintillation detector package comprising:
a housing;
a scintillator in the housing; and
a radioactive reflective material between at least a portion of the scintillator and the housing.
2. The scintillation detector package of claim 1, wherein the radioactive reflective material is a naturally occurring material.
3. The scintillation detector package of claim 1, wherein the radioactive reflective material is powdered.
4. The scintillation detector package of claim 1, wherein the radioactive reflective material comprises lutetium and/or potassium and/or thorium and/or lanthanum or combinations thereof.
5. The scintillation detector package of claim 1, wherein the radioactive reflective material comprises Lu_2O_3 , and/or KCl and/or ThO_2 and/or LaO , or combinations thereof.
6. The scintillation detector package of claim 1, wherein the radioactive reflective material is mixed with a non-radioactive reflective powder.
7. The scintillation detector package of claim 1, further comprising a non-radioactive reflective material at least partially surrounding the radioactive reflective material.
8. The scintillation detector package of claim 1, further comprising a sleeve between the housing and scintillator into which the radioactive reflective material is partially embedded.
9. The scintillation detector package of claim 1, wherein the radioactive reflective material circumscribes the scintillator along a longitudinal axis thereof.
10. The scintillation detector package of claim 1, wherein the scintillator comprises a plastic scintillator or a crystal scintillator.
11. The scintillation detector package of claim 1, wherein the scintillator comprises a first end, a second end, and a medial portion therebetween; and wherein the radioactive reflective material is adjacent the first end or the second end of the scintillator.

12. The scintillation detector package of claim 1, wherein the scintillator comprises first and second portions; further comprising a non-radioactive reflective material between the first portion of the scintillator and the housing; and wherein the radioactive reflective material is between the second portion of the scintillator and the housing.
13. The scintillation detector package of claim 12, wherein the non-radioactive reflective material has a same reflectance as the radioactive reflective material, but attenuates gamma rays less than the radioactive reflective material.
14. The scintillation detector package of claim 1, further comprising an absorptive layer between the radioactive reflective material and the scintillator to absorb alpha radiation and/or beta radiation.
15. A radiation detection system comprising:
a scintillator package comprising
 - a housing,
 - a scintillator in the housing to scintillate when struck by radiation, a
 - a naturally occurring radioactive reflective material between at least a portion of the scintillator and the housing, and
 - a window sealing an end of the housing to permit light emitted during a scintillation to exit the housing;
a photodetector optically coupled to the scintillator package; and
gain stabilization circuitry coupled to the photodetector and configured to perform gain stabilization based upon scintillations of the scintillator caused by radiation emitted by the naturally occurring radioactive reflective material striking the scintillator.
16. The radiation detection system of claim 15, further comprising an absorptive layer between the naturally occurring radioactive reflective material and the scintillator to absorb alpha radiation and/or beta radiation.
17. The radiation detection system of claim 15, wherein the scintillator comprises first and second portions; further comprising a non-radioactive reflective material between the first portion of the scintillator and the housing; and wherein the naturally occurring

radioactive reflective material is between the second portion of the scintillator and the housing.

18. The radiation detection system of claim 17, wherein the non-radioactive reflective material has a same reflectance as the naturally occurring radioactive reflective material, but attenuates gamma rays less than the naturally occurring radioactive reflective material.

19. A method of logging a formation having a borehole therein comprising:

lowering a well logging instrument into the borehole;

detecting incoming radiation from the formation using a radiation detector carried by the well logging instrument, the radiation detector comprising a detector housing with a scintillator therein;

gain stabilizing the radiation detector based upon detecting scintillations of the scintillator caused by radiation emitted by a radioactive reflective material between at least a portion of the scintillator and the scintillator housing striking the scintillator, using gain stabilization circuitry, the radioactive reflective material comprising lutetium and/or potassium and/or thorium.

20. The method of claim 19, wherein the incoming radiation from the formation is generated based upon interactions between x-rays emitted into the formation and constituents of the formation, the x-rays being emitted into the formation using an x-ray generator of the well logging instrument.

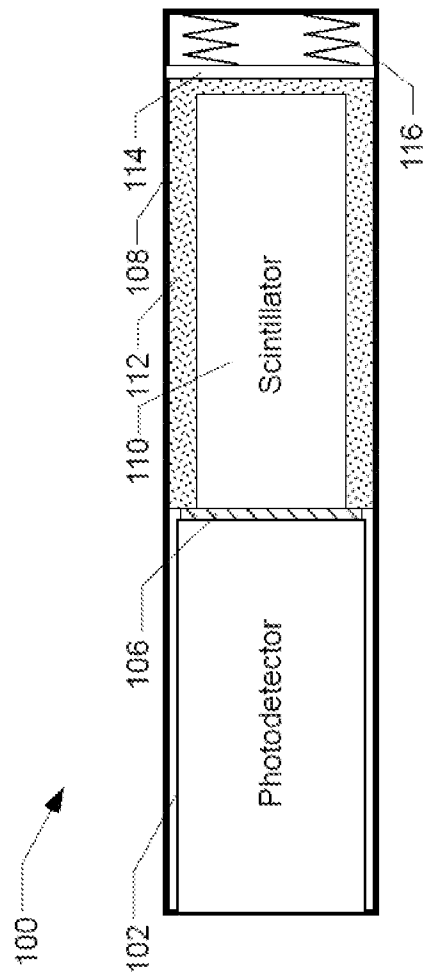


FIG. 1a

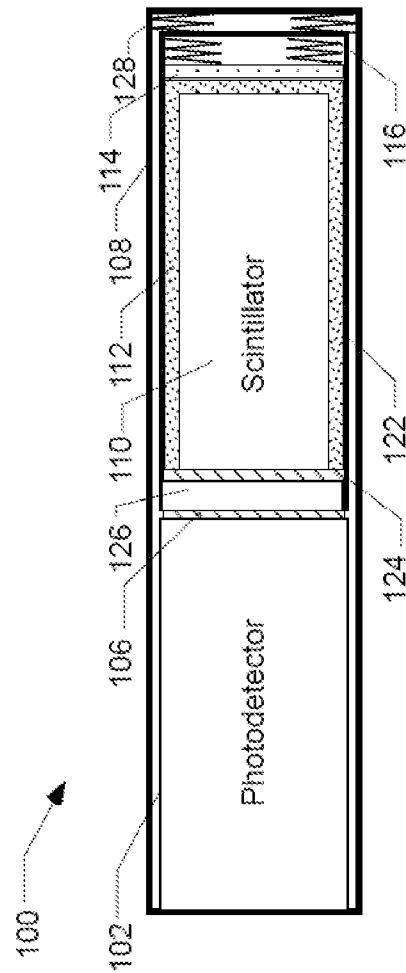


FIG. 1b

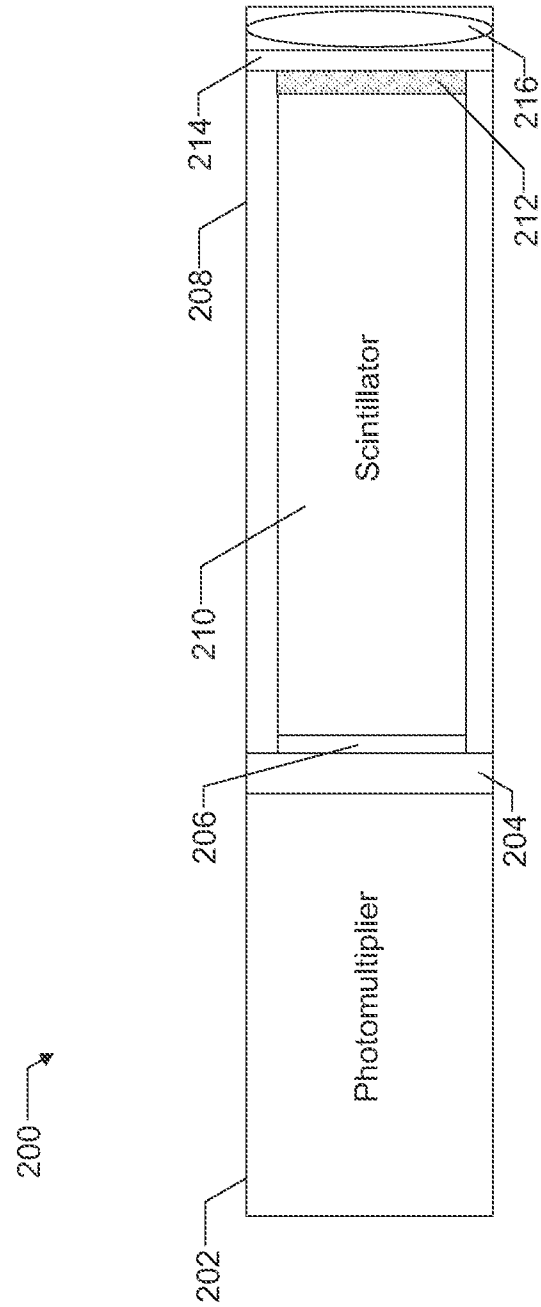


FIG. 2

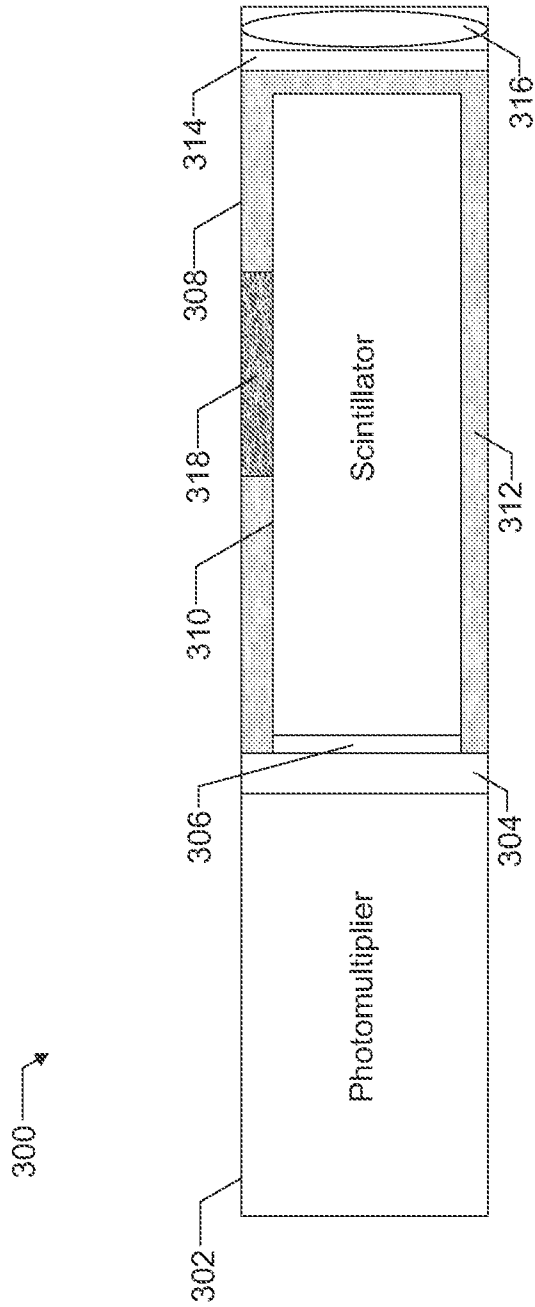


FIG. 3

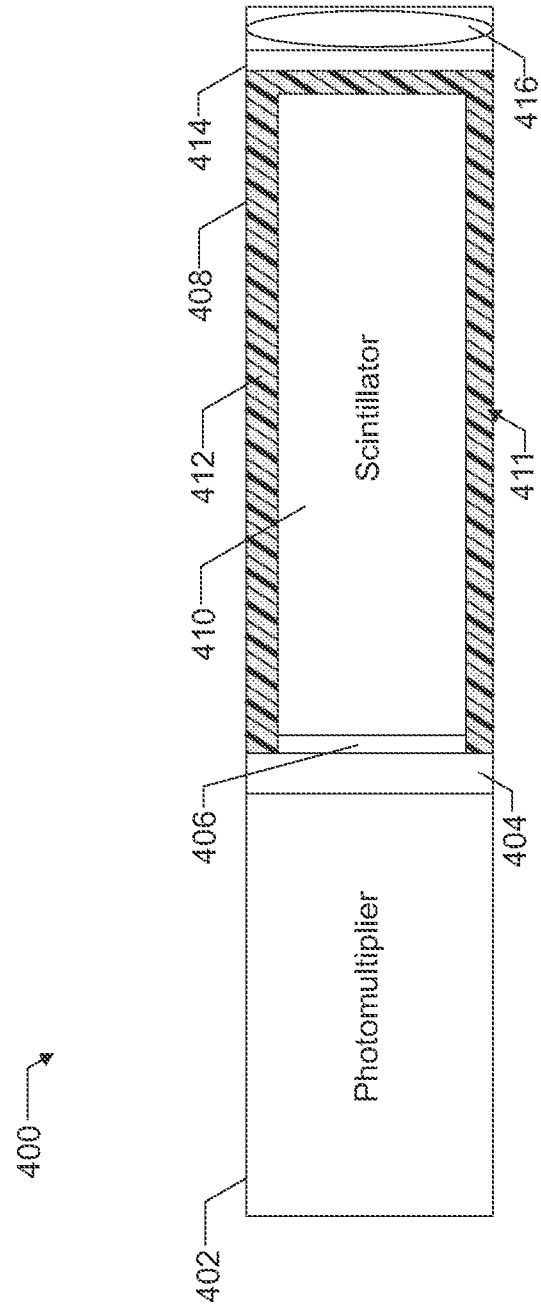


FIG. 4

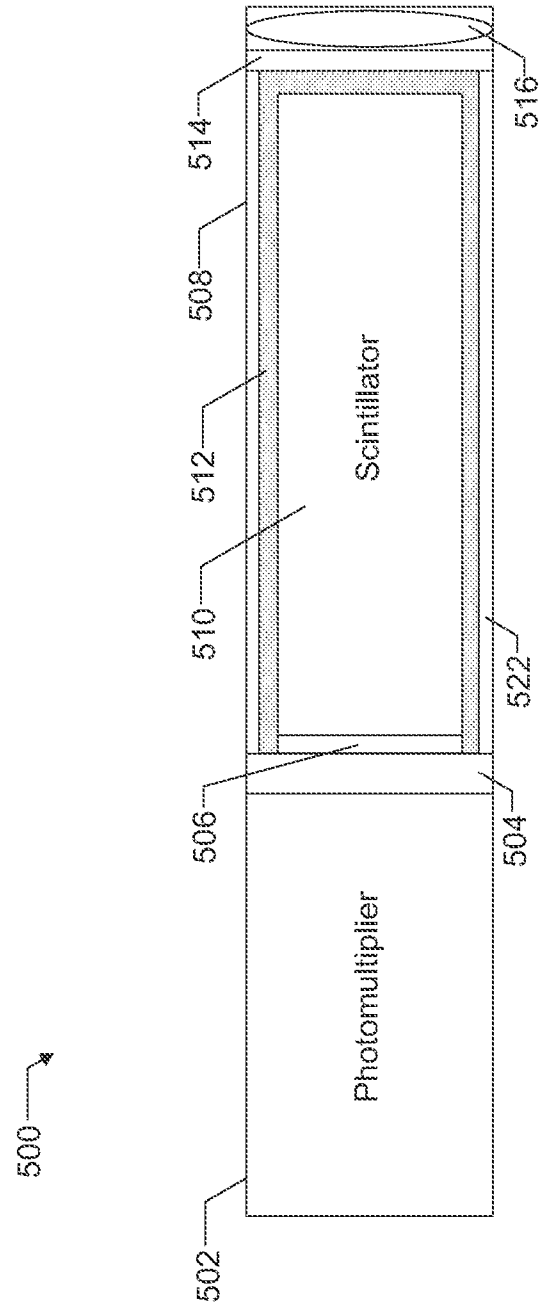


FIG. 5

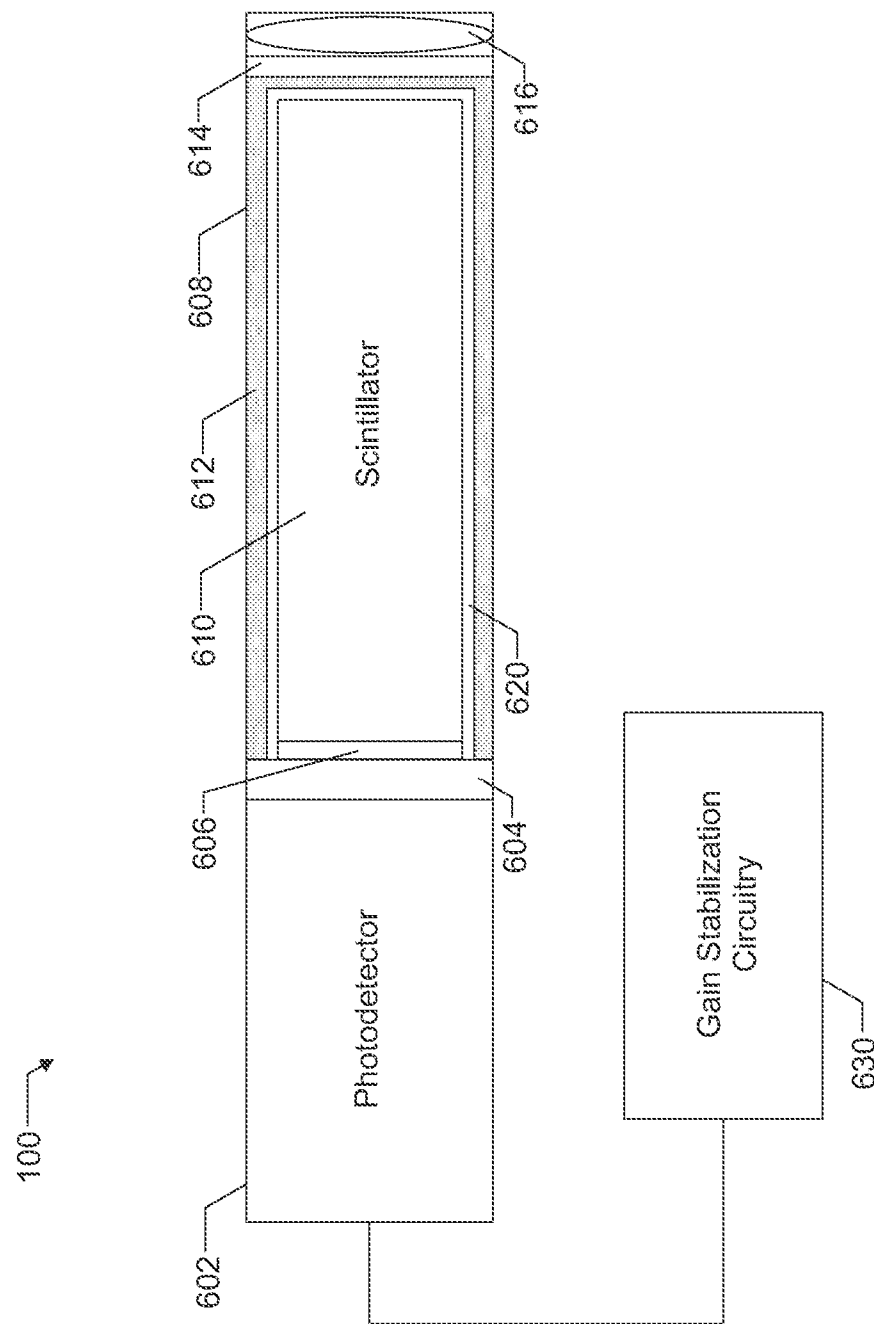


FIG. 6

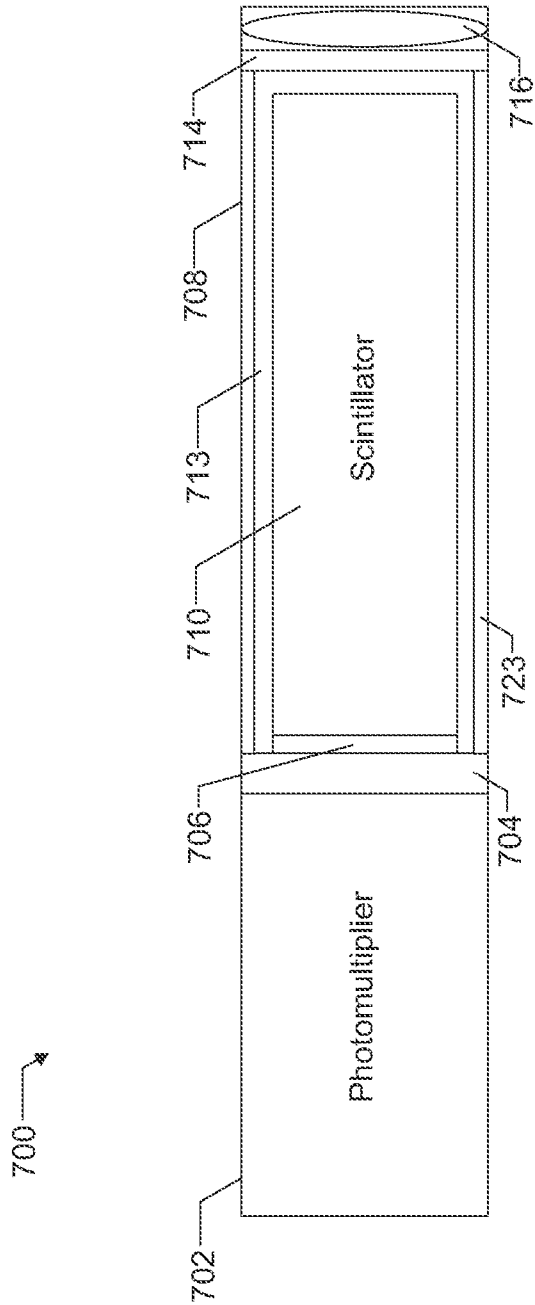


FIG. 7

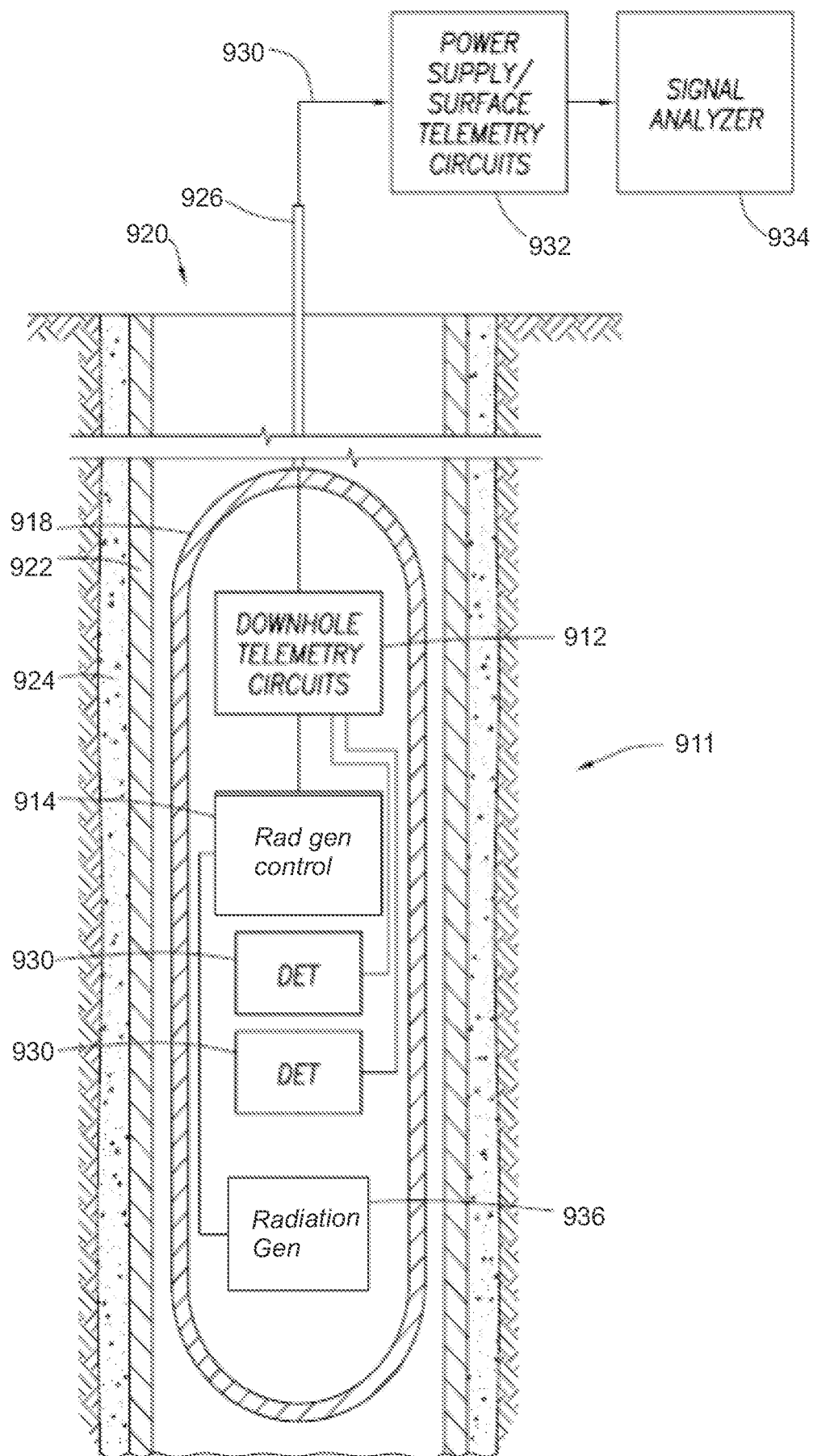


FIG. 8

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2014/038212

A. CLASSIFICATION OF SUBJECT MATTER
INV. G01T1
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
G01T G01V

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 2008/088386 A2 (THERMO ELECTRON CORP [US]; IWATSCHENKO-BORHO MICHAEL [DE]) 24 July 2008 (2008-07-24)	1-18
Y	abstract; figures 1-3,5,7-11 page 6, line 29 - page 7, lines 1, 20-34 page 8, lines 1-2, 15-27 page 9, lines 8-20,25 - page 10, lines 2, 13-19, 21-25 page 12, lines 9-24 page 17, lines 1-4,9-11,20-24,31-34 page 18, lines 21-27 page 21, lines 10-13	19,20
X	----- US 3 030 509 A (CARLSON ROLAND W) 17 April 1962 (1962-04-17) column 3, lines 6-11,65-71; figures 1,3 column 4, line 52 - column 5, line 10 column 5, line 32 - column 6, line 20 ----- -/-	1,2,10, 15



Further documents are listed in the continuation of Box C.



See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search

17 July 2014

Date of mailing of the international search report

29/07/2014

Name and mailing address of the ISA/

European Patent Office, P.B. 5818 Patentlaan 2
NL - 2280 HV Rijswijk
Tel. (+31-70) 340-2040,
Fax: (+31-70) 340-3016

Authorized officer

Van Ouytsel, Krist'1

INTERNATIONAL SEARCH REPORT

International application No

PCT/US2014/038212

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	WO 2010/053818 A2 (SCHLUMBERGER CA LTD [CA]; SCHLUMBERGER TECHNOLOGY BV [NL]; PRAD RES &) 14 May 2010 (2010-05-14)	19
A	abstract; figure 2 paragraphs [0001], [0005], [0019], [0024], [0028], [0046] -----	1,15,20
Y	US 7 960 687 B1 (SIMON MATTHIEU [US] ET AL) 14 June 2011 (2011-06-14)	20
A	abstract; figures 1,8 -----	1,15,19
A	US 4 450 354 A (SMITH JR HARRY D [US] ET AL) 22 May 1984 (1984-05-22) figures 1,5 column 7, line 32 - column 8, line 36 -----	1,2,4,5, 10,11, 15,19
A	EP 0 189 645 A1 (FILTRON CORP [US]) 6 August 1986 (1986-08-06) page 2, lines 20-34; figures 1-3 page 6, line 27 - page 7, line 33 page 8, line 4 - page 9, line 26 page 11, lines 32-35 page 12, lines 11-13 -----	1,2,4,5, 10,11,15

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/US2014/038212

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
WO 2008088386 A2	24-07-2008	CN 101535835 A EP 2062070 A2 US 2009127449 A1 WO 2008088386 A2	16-09-2009 27-05-2009 21-05-2009 24-07-2008
US 3030509 A	17-04-1962	GB 968188 A US 3030509 A	26-08-1964 17-04-1962
WO 2010053818 A2	14-05-2010	CA 2742840 A1 EP 2350702 A2 RU 2011123640 A US 2010116978 A1 WO 2010053818 A2	14-05-2010 03-08-2011 20-12-2012 13-05-2010 14-05-2010
US 7960687 B1	14-06-2011	GB 2499132 A US 7960687 B1 WO 2012050725 A2	07-08-2013 14-06-2011 19-04-2012
US 4450354 A	22-05-1984	AU 2604984 A CA 1217881 A1 DE 3464662 D1 EP 0125024 A1 US 4450354 A	11-10-1984 07-02-1987 13-08-1987 14-11-1984 22-05-1984
EP 0189645 A1	06-08-1986	EP 0189645 A1 JP S61164178 A US 4772792 A	06-08-1986 24-07-1986 20-09-1988