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(54) Title: WELL-LOGGING TOOL WITH FIRST AND SECOND AZIMUTHAL RADIATION DETECTORS AND RELATED METHODS

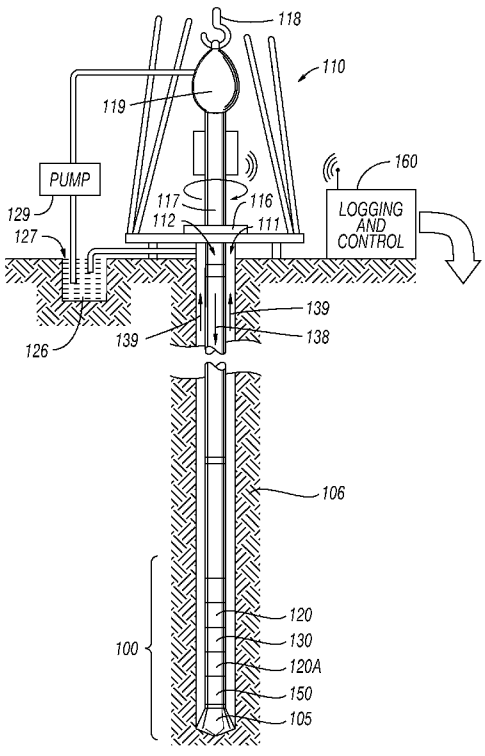


FIG. 1

(57) Abstract: A well-logging tool may be positioned within a borehole of a subterranean formation. The well-logging tool may include a housing having an interior defining a dual-detector receiving chamber extending longitudinally, and having first and second portions, and a first azimuthal radiation detector carried by the first portion of the dual-detector receiving chamber. The first azimuthal radiation detector may include a first gamma-ray detector and a first photodetector associated with the first gamma-ray detector. The well-logging tool may include a second azimuthal radiation detector carried by the second portion of the dual-detector receiving chamber. The second azimuthal radiation detector may include a second gamma-ray detector and a second photodetector associated with the second gamma-ray detector.

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WELL-LOGGING TOOL WITH FIRST AND SECOND AZIMUTHAL RADIATION DETECTORS AND RELATED METHODS

Background

[0001] Radiation detectors, such as gamma-ray detectors, for example, often use a scintillator material which converts energy deposited by a given type of radiation (e.g. gamma-rays) into light. The light is directed to a photodetector, which converts the light generated by the scintillator into an electrical signal. The electrical signal may be used to measure the amount of radiation which is deposited in the crystal.

[0002] In the case of well-logging tools for hydrocarbon wells (e.g. gas and oil wells), a borehole gamma-ray detector may be incorporated into the drill 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. Given the harsh operating conditions and space constraints associated with borehole operation, providing scintillator structures which are able to withstand relatively high stress levels and also provide desired operating characteristics may be difficult in some applications.

Summary

[0003] 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.

[0004] Generally speaking, a well-logging tool may be positioned within a borehole of a subterranean formation. The well-logging tool may include a housing having an interior defining a dual-detector receiving chamber extending longitudinally, and having first and second portions, and a first azimuthal radiation detector carried by the first portion of the dual-detector receiving chamber. The first azimuthal radiation detector may include a first gamma-ray detector and a first photodetector associated with the first gamma-ray detector. The well-logging tool may include a second azimuthal radiation detector carried by the second portion of the dual-detector receiving chamber.

The second azimuthal radiation detector may include a second gamma-ray detector and a second photodetector associated with the second gamma-ray detector.

Brief Description of the Drawings

[0005] Embodiments of well-logging tool are described with reference to the following figures. The same numbers are used throughout the figures to reference like features and components.

[0006] FIG. 1 is a schematic diagram of a well site system which may be used for implementation of an example embodiment.

[0007] FIG. 2 is a schematic diagram of an embodiment of a well-logging system, according to the present disclosure.

[0008] FIG. 3 is a schematic diagram of an embodiment of a well-logging system, according to the present disclosure.

[0009] FIG. 4 is a perspective view of a radiation detector in the well-logging tool of FIG. 3.

[0010] FIG. 5 is a cross-sectional view of the radiation detector of FIG. 4 along line 4-4.

[0011] FIG. 6 is a perspective view of another embodiment of an azimuthal radiation detector, according to the present disclosure.

[0012] FIG. 7 is a cross-sectional view of the radiation detector of FIG. 6 along line 6-6.

[0013] FIGS. 8A-8B are cross-sectional views of the radiation detectors of FIGS. 4 and 6, respectively, and along lines 7A-7A and 7B-7B, respectively.

[0014] FIGS. 9A-9C are schematic partial cross-sectional views of several embodiments of the well-logging tool, according to the present disclosure.

Detailed Description of the Preferred Embodiments

[0015] The present embodiments will now be described more fully hereinafter with reference to the accompanying drawings, in which preferred embodiments of the disclosure are shown. This present embodiments may, however, be embodied in many different forms and 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, and will fully convey the scope of the present embodiments to those skilled in the art. Like numbers refer to like elements throughout, and prime and multiple prime notations are used to indicate similar elements in alternative embodiments.

[0016] Referring initially to FIG. 1, a well site system which may be used for implementation of the example embodiments set forth herein is first described. The well site may be onshore or offshore. In this exemplary system, a borehole **111** is formed in subsurface formations **106** by rotary drilling. Embodiments of the disclosure may also use directional drilling, for example.

[0017] A drill string **112** is suspended within the borehole **111** and has a bottom hole assembly **100** which includes a drill bit **105** at its lower end. The surface system includes a platform and derrick assembly **110** positioned over the borehole **111**, the assembly **110** including a rotary table **116**, Kelly **117**, hook **118** and rotary swivel **119**. The drill string **112** is rotated by the rotary table **116**, which engages the Kelly **117** at the upper end of the drill string. The drill string **112** is suspended from a hook **118**, attached to a traveling block (not shown), through the Kelly **117** and a rotary swivel **119** which permits rotation of the drill string relative to the hook. A top drive system may also be used in some embodiments.

[0018] In the illustrated embodiment, the surface system further includes drilling fluid or mud **126** stored in a pit **127** formed at the well site. A pump **129** delivers the drilling fluid **126** to the interior of the drill string **112** via a port in the swivel **119**, causing the drilling fluid to flow downwardly through the drill string **112** as indicated by the directional arrow **138**. The drilling fluid exits the drill string **112** via ports in the drill bit **105**, and then circulates upwardly through the annulus region between the outside of the drill string and the wall of the borehole **111**, as indicated by the directional arrows **139**. The drilling fluid lubricates the drill bit **105** and carries formation **106** cuttings up to the surface as it is returned to the pit **127** for recirculation.

[0019] In various embodiments, the systems and methods disclosed herein may be used with other conveyance approaches known to those of ordinary skill in the art. For example, the systems and methods disclosed herein may be used with tools or other

electronics conveyed by wireline, slickline, drill pipe conveyance, coiled tubing drilling, and/or a while-drilling conveyance interface. For the purpose of an example only, FIG. 1 shows a while-drilling interface. However, systems and methods disclosed herein could apply equally to wireline or other suitable conveyance platforms. The bottom hole assembly **100** of the illustrated embodiment includes a logging-while-drilling (LWD) module **120**, a measuring-while-drilling (MWD) module **130**, a rotary-steerable system and motor, and drill bit **105**.

[0020] The LWD module **120** is housed in a drill collar and may include one or a more types of logging tools. It will also be understood that more than one LWD and/or MWD module may be used, e.g. as represented at **120A, 150**. (References, throughout, to a module at the position of **120** may alternatively mean a module at the position of **120A** as well.) The LWD module may include capabilities for measuring, processing, and storing information, as well as for communicating with the surface equipment, such as the illustrated logging and control station **160**. By way of example, the LWD module may include one or more of an electromagnetic device, acoustic device, nuclear magnetic resonance device, nuclear measurement device (e.g. gamma ray, density, photoelectric factor, sigma thermal neutron capture cross-section, neutron porosity), etc., although other measurement devices may also be used.

[0021] The MWD module **130** is also housed in a drill collar and may include one or more devices for measuring characteristics of the drill string and drill bit. The MWD tool may further include an apparatus for generating electrical power to the downhole system (not shown). This may include a mud turbine generator powered by the flow of the drilling fluid, it being understood that other power and/or battery systems may be employed. The MWD module may also include one or more of the following types of measuring devices: a weight-on-bit measuring device, a torque measuring device, a shock and vibration measuring device, a temperature measuring device, a pressure measuring device, a rotations-per-minute measuring device, a mud flow rate measuring device, a direction measuring device, and an inclination measuring device.

[0022] The above-described borehole tools may be used for collecting measurements of the geological formation adjacent the borehole **111** to determine one or more characteristics of the fluids being displaced within the geological formation **106**

in accordance with example embodiments. The system **110** may include a processor **170** for determining such characteristics. The processor **170** may be implemented using a combination of hardware (e.g., microprocessor, etc.) and a non-transitory medium having computer-executable instructions for performing the various operations described herein. It should be noted that the processor **170** may be located at the well site, or it may be remotely located.

[0023] By way of background, one of the objectives of formation evaluation (FE) is formation volumetrics, i.e., the quantification of the percentage volumetric fraction of each constituent present in a given sample of formation under study. At the heart of formation volumetrics is the identification of the constituents present, and the corresponding geological model. The constituents are assigned a signature on different log measurements, and log measurements selected are typically optimized to ensure a unique signature per the constituents present. In general, practical considerations such as technology, operating conditions (well geometry, hole size, mud-type, open vs. cased hole, temperature, etc.,), HSE aspects, and economics may restrict the log measurements contemplated. Moreover, homogeneous medium mixing laws are selected based on the intrinsic physics of measurements selected, and three-dimensional geometrical response functions are selected based on the specific tool type and design carrying out the measurement. The individual constituents forward model responses have to be calibrated before the log measurements may be converted into elemental volumetric fractions.

[0024] In particular, the operations of identifying and assigning a log signature to the different constituents present (at in-situ conditions) may be a challenge, especially when working with wireline logs with relatively shallow depth of investigation, in the presence of relatively deep depth of invasion (in the case of conventional over-balance drilling). However, whereas identifying the different constituents present may be remedied to some extent through various operations, assigning a unique signature to the different constituents present does not always have an easy solution. This may be due to several factors.

[0025] For example, the analysis of rock cuttings brought back to the surface during the drilling process and/or mud logging operations may generally provide geologists and

petrophysicists with significant and early clues ("ground truth") as to the identity of the different constituents present, with certain exceptions (depending on mud type). Optional coring operations (which may potentially be costly and impractical) go a step further, to cut and retrieve many feet of formation whole core for further detailed analysis on surface. Downhole advanced elemental spectroscopy logging techniques (e.g., thermal neutron capture spectroscopy logs, fast neutron inelastic scattering spectroscopy logs, elemental neutron activation spectroscopy logs, etc.) may all help account for the matrix constituents, and reduce the formation volumetrics challenge down to just fluid elemental volumetric fractions.

[0026] Furthermore, optional formation testing operations (e.g., pressure gradients, downhole fluid analysis, fluid sampling, etc.), despite the limited availability of such station data at discrete depth points, may be considered to test the producible fluid constituents of the formation. Recently introduced advanced multi-dimensional NMR logging techniques may help tell different fluid constituents apart from each other. Another factor may be that logging while drilling (LWD) measurements may be acquired prior to invasion having already progressed too deep inside the formation. Still another factor may be under-balance drilling.

[0027] Referring initially to FIGS. 2-5, a well-logging system **10** according to the present disclosure is now described. The well-logging system **10** is illustratively positioned within a borehole **12** of a subterranean formation **11**. The well-logging system **10** illustratively includes a well-logging tool **43**, a collar **30** surrounding the well-logging tool **43**, and a drilling device (not shown) coupled to the collar.

[0028] In the illustrated embodiment, the well-logging tool **43** is a LWD device. In other embodiments, the well-logging tool **43** may be a stand alone tool used after the drilling, such as a WL type device. But in other embodiments, other configurations may be used.

[0029] The well-logging tool **43** illustratively includes a housing **25** having an interior defining a dual-detector receiving chamber **42** extending longitudinally, and having first **41a** and second **41b** portions. In some embodiments, the housing **25** may be tubular in shape. In the illustrated embodiment, the housing **25** is cylindrical in shape, but it may comprise other shapes, such as a polygonal shaped tube. In some embodiments, the

housing **25** may comprise a pressure housing, which may provide added protection to the well-logging tool **43**.

[0030] The well-logging tool **43** illustratively includes a first radiation detector **13a** carried by the first portion **41a** of the dual-detector receiving chamber **42**. The first radiation detector **13a** comprises a first gamma-ray detector **18a** and a first photodetector **15a** (e.g. photomultiplier tube) associated therewith. For example, the first gamma-ray detector **18a** may comprise at least one of a scintillator crystal and an inorganic scintillator crystal, such as a sodium iodide thallium NaI(Ti) crystal. In other embodiments, the first gamma-ray detector **18a** may comprise other materials, such as CsI(Tl), CsI(Na), CsI(pure), CsF, KI(Tl), LiI(Eu). The size of the crystal may be, for example, ¾ inches x 6 inches (centered azimuthal gamma-ray detectors (FIGS. 4-5 & 8A)), 1 ¾ inches x 6 inches (spectral gamma-ray detectors), and ¾ inches x 4 inches (offset azimuthal gamma-ray detectors (FIGS. 6-7 & 8B)).

[0031] The well-logging tool **43** illustratively includes a second radiation detector **13b** carried by the second portion **41b** of the dual-detector receiving chamber **42**. The second radiation detector **13b** comprises a second gamma-ray detector **18b** and a second photodetector **15b** (e.g. photomultiplier tube) associated therewith. In some embodiments, the first and second gamma-ray detectors **18a-18b** may be arranged in end-to-end relation. The first and second radiation detectors **13a-13b** may detect natural gamma-ray emissions from the subterranean formation **11**. Moreover, although the illustrated embodiment includes the first and second radiation detectors **13a-13b**, other embodiments may include more spectral and/or azimuthal radiation detectors

[0032] Advantageously, by using first and second radiation detectors **13a-13b** inside the housing, the well-logging tool **43** and its housing **25** can be readily modified to fit collars of varying sizes. In these embodiments, the well-logging tool **43** includes a plurality of spacers between the housing **25** and the collar **30** (i.e. to fit the outer diameter of the housing to the inner diameter of the collar).

[0033] The first and second radiation detectors **13a-13b** may be specially tailored to varying logging application. In particular, one or both of the first and second radiation detectors **13a-13b** may comprise a spectral gamma-ray detector. Also, one or both of the first and second radiation detectors **13a-13b** may comprise an azimuthal gamma-

ray detector. In some embodiments, the first and second radiation detectors **13a-13b** may be readily removable from the housing **25a**, thereby providing a plug-and-play capability to the well-logging tool **43**.

[0034] In the field, the housing **25a** would be configured with first and second radiation detectors **13a-13b** to provide the desired measurements for the intended application. For instance, if the best possible spectral gamma measurement is desired, only spectral gamma detectors would be installed. If a spectral as well as azimuthal gamma measurement is needed, both a spectral and an azimuthal detector would be installed.

[0035] Advantageously, with the versatility of the well-logging tool **43**, each radiation detector may be optimized for its purpose, i.e. whether it is intended to determine azimuthal or spectral radiation characteristics. Also, by combining spectral and azimuthal gamma-ray detectors, a detector arrangement can be optimized for the intended logging application. In other words, the operator of well-logging tool **43** may customize the device for the specific application.

[0036] The first radiation detector **13a** illustratively includes a controller **14, 14a** (i.e. control circuitry) coupled to the photodetector **15a** for determining characteristics of the subterranean formation **11** and producing a signal therefor. The controller **14, 14a** may comprise processing circuitry for determining the characteristics of the subterranean formation **11**. In other embodiments, the well-logging data may be transmitted to the surface for such processing. In the embodiment of FIG. 2, the controllers **14, 14a-14b** are illustratively coupled to the respective ones of the first and second photodetectors **15a-15b**.

[0037] In other embodiments, there may be single controller for both first and second photodetectors **15a-15b**, for example being adjacent the first photodetector. In this embodiment, a wire from the second radiation detector **13b** past the first radiation detector **13a** may be employed.

[0038] Also, in some embodiments, the first and second radiation detectors **13a-13b** can be oriented in opposite longitudinal directions. In these embodiments, the controllers **14, 14a-14b** can be situated in between the first and second radiation detectors **13a-13b** (i.e. there may be a single controller rather than multiple controllers).

Moreover, the order of components shown in FIG. 3 is just one embodiment. The order could be serial, i.e. the first photodetector **15a**, first scintillator **18a**, second photodetector **15b**, and second scintillator **18b**.

[0039] The first radiation detector **13a** illustratively includes adapter plates **17a, 21a, 22a** for securing the internal components to the housing **25a**. Additionally, the first radiation detector **13a** illustratively includes a connector mounting block **24a** for carrying the controller **14, 14a**, and a first shield **16a** partially surrounding the first gamma-ray detector **18a**. In some embodiments, the shield **16a** may comprise a tungsten material or an alloy thereof. In other embodiments, other materials can be used, so long as they at least attenuate or block gamma-ray radiation.

[0040] In the illustrated embodiment, the first radiation detector **13a** is an azimuthal gamma-ray detector, i.e. the first shield **16a** provides a known directionality to the radiation received from the subterranean formation **11**. Also, the first radiation detector **13a** illustratively includes a compressed spring **23a** between the adapter plate **22a** and the connector mounting block **24a.** The compressed spring **23a** may provide a longitudinal directed biasing for the connector mounting block **24a**. Although only the first radiation detector **13a** is illustrated in detail, it should be appreciated that the second radiation detector **13b** is similarly constituted.

[0041] Referring now additionally to FIG. 8A, the first gamma-ray detector **18a** illustratively includes a first scintillator crystal aligned along an axis of the housing **25a**. In particular, the first scintillator crystal is illustratively aligned along a center axis of the housing **25a**. In other embodiments, the first scintillator crystal may be aligned differently, such as offset (FIGS. 6-7 & 8B).

[0042] Another aspect is directed to a method of making a logging tool **43** comprising forming a housing **25** having an interior defining a dual-detector receiving chamber **42** extending longitudinally, and having first and second portions **41a-41b**. The method also includes coupling a first radiation detector **13a** to be carried by the first portion **41a** of the dual-detector receiving chamber **42**, the first radiation detector comprising a first gamma-ray detector **18a** and a first photodetector **15a** associated therewith, and coupling a second radiation detector **13b** to be carried by the second portion **41b** of the

dual-detector receiving chamber, the second radiation detector comprising a second gamma-ray detector **18b** and a second photodetector **15b** associated therewith.

[0043] In some embodiments the first and second radiation detectors **13a-13b** are both spectral or azimuthal gamma-ray detectors, the first radiation detector may have different capabilities than the second radiation detector. For example, the first radiation detector **13a** (large detector) may have worse spatial resolution but better precision than the second radiation detector **13b** (smaller detector having better spatial resolution but worse precision, as compared to the first radiation detector). In other embodiments, the first radiation detector **13a** may have a high azimuthal resolution, and the second radiation detector **13b** may have a high vertical resolution.

[0044] Also, in some embodiments, the first and second radiation detectors **13a-13b** may each comprise a modular unit, making it easy to switch out individual radiation detectors depending on the application. In particular, each of the first and second radiation detectors **13a-13b** is a complete independent electronic unit having a digital input and output for communicating with external components.

[0045] Referring now additionally to FIGS. 6-7 & 8B, another embodiment of the first radiation detector **13a'** is now described. In this embodiment of the first radiation detector **13a'**, those elements already discussed above with respect to FIGS. 2-5 are given prime notation and most require no further discussion herein. This embodiment differs from the previous embodiment in that this first radiation detector **13a'** has the first scintillator crystal aligned in an offset relation to an axis (i.e. the center axis) of the housing **25a'**. In some embodiments with offset axis arrangement, high and low azimuthal resolution could be achieved by using the low azimuthal sensitivity but high precision of the larger detector (spectral detector) and the high azimuthal sensitivity of the azimuthal sensor to obtain an enhanced precision image.

[0046] Referring now additionally to FIG. 9A, another embodiment of the well-logging tool **43''** is now described. In this embodiment of the well-logging tool **43''**, those elements already discussed above with respect to FIGS. 2-5 are given double prime notation and most require no further discussion herein. This well-logging tool **43''** illustratively includes the first radiation detector **13a''** comprising a spectral gamma-ray detector. The second radiation detector **13b''** comprises an azimuthal gamma-ray

detector, and associated shield **16b''**. In this illustrated embodiment, the scintillator of the spectral first radiation detector **18a''** is physically larger than the scintillator of the azimuthal second radiation detector **18b''**. The size of the scintillator of the spectral first radiation detector **13a''** provides for increasing the likelihood that high energy gamma rays will be detected and their energy deposited. Advantageously, this embodiment of the well-logging tool **43''** provides a hybrid approach to well-logging, offering both spectral and azimuthal logging data from separate radiation detectors. Also, the dual-detector receiving chamber **42''** provides adequate spacing to receive both the spectral first radiation detector **13a''** and the azimuthal second gamma-ray detector, and associated shield **16b''**.

[0047] Referring now additionally to FIG. 9B, another embodiment of the well-logging tool **43'''** is now described. In this embodiment of the well-logging tool **43'''**, those elements already discussed above with respect to FIGS. 2-5 are given triple prime notation and most require no further discussion herein. This well-logging tool **43'''** illustratively includes both the first and second radiation detectors **13a'''-13b'''** each comprising a spectral gamma-ray detector. Advantageously, for applications where azimuthal readings are not desired, the gamma-ray count rates can be doubled and measurement precision can be improved by using two spectral gamma-ray detectors.

[0048] Referring now additionally to FIG. 9C, another embodiment of the well-logging tool **43''''** is now described. In this embodiment of the well-logging tool **43''''**, those elements already discussed above with respect to FIGS. 2-5 are given quadruple prime notation and most require no further discussion herein. This well-logging tool **43''''** illustratively includes both the first and second radiation detectors **13a''''-13b''''** each comprising azimuthal gamma-ray detectors directed in opposite directions, and associated shields **16a''''-16b''''**.

[0049] Advantageously, the combination of the azimuthal gamma-ray detectors facing in opposite directions, the gamma-ray readings from both directions can be obtained without a controlled spinning of the well-logging tool **43''''**. For example, this may be helpful when the well-logging tool **43''''** is slid down a horizontal borehole **12** along with the drill string in LWD embodiments, i.e. enabling the well-logging tool to look in opposite directions. This is in contrast to other approaches where the well-logging

tool rotates so that azimuthal gamma-ray detectors may receive a full picture of the subterranean formation **11**.

[0050] Of course, in other embodiments, first and second radiation detectors **13a""-13b""** can be pointed in any arbitrary direction. For example, in some embodiments having four azimuthal radiation detectors, the radiation detectors may be spaced apart 90 degrees. Moreover, in some embodiments, each of the azimuthal radiation detectors could be collimated differently to provide different azimuthal sensitivity. Additionally, enhanced statistical precision could be obtained through alpha-processing or other methods of combining an accurate and a precise measurement.

[0051] Many modifications and other embodiments of the present disclosure 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 the present embodiments is not to be limited to the specific embodiments disclosed, and that modifications and embodiments are intended to be included within the scope of the appended claims.

THAT WHICH IS CLAIMED IS:

1. A well-logging tool to be positioned within a borehole of a subterranean formation, the well-logging tool comprising:

a housing having an interior defining a dual-detector receiving chamber extending longitudinally, and having first and second portions;

a first azimuthal radiation detector carried by the first portion of the dual-detector receiving chamber, said first azimuthal radiation detector comprising a first gamma-ray detector and a first photodetector associated therewith; and

a second azimuthal radiation detector carried by the second portion of the dual-detector receiving chamber, said second azimuthal radiation detector comprising a second gamma-ray detector and a second photodetector associated therewith.

2. The well-logging tool of claim 1 wherein said first and second gamma-ray detectors are in end-to-end relation.

3. The well-logging tool of claim 1 wherein said first azimuthal radiation detector comprises a first shield partially surrounding said first gamma-ray detector.

4. The well-logging tool of claim 3 wherein said second azimuthal radiation detector comprises a second shield partially surrounding said second gamma-ray detector.

5. The well-logging tool of claim 1 wherein said first gamma-ray detector comprises a first scintillator crystal aligned along an axis of said housing.

6. The well-logging tool of claim 1 wherein said first gamma-ray detector comprises a first scintillator crystal aligned in an offset relation to an axis of said housing.

7. The well-logging tool of claim 1 wherein said first and second azimuthal radiation detectors are directed in opposite directions.

8. A method of making a logging tool comprising:

forming a housing having an interior defining a dual-detector receiving chamber extending longitudinally, and having first and second portions;

coupling a first azimuthal radiation detector within the first portion of the dual-detector receiving chamber, the first azimuthal radiation detector comprising a first gamma-ray detector and a first photodetector associated therewith; and

coupling a second azimuthal radiation detector within the second portion of the dual-detector receiving chamber, the second azimuthal radiation detector comprising a second gamma-ray detector and a second photodetector associated therewith.

9. The method of claim 8 further comprising coupling the first and second gamma-ray detectors in end-to-end relation.

10. The method of claim 8 wherein the first azimuthal radiation detector comprises a first shield partially surrounding the first gamma-ray detector.

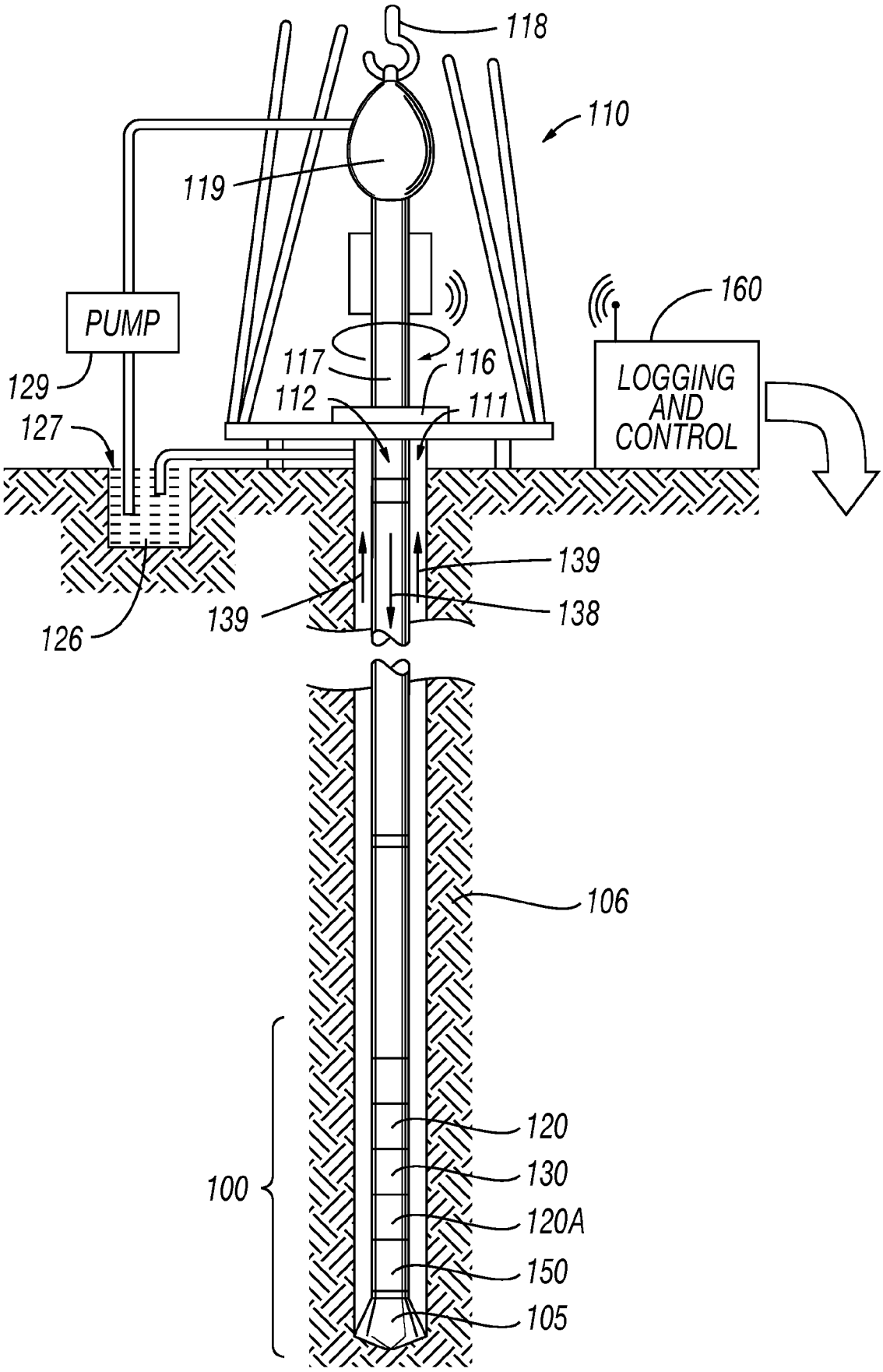

118
110
119
PUMP
160
LOGGING AND CONTROL
129
127
117
116
112
111
139
138
126
139
106
100
120
130
120A
150
105

FIG. 1

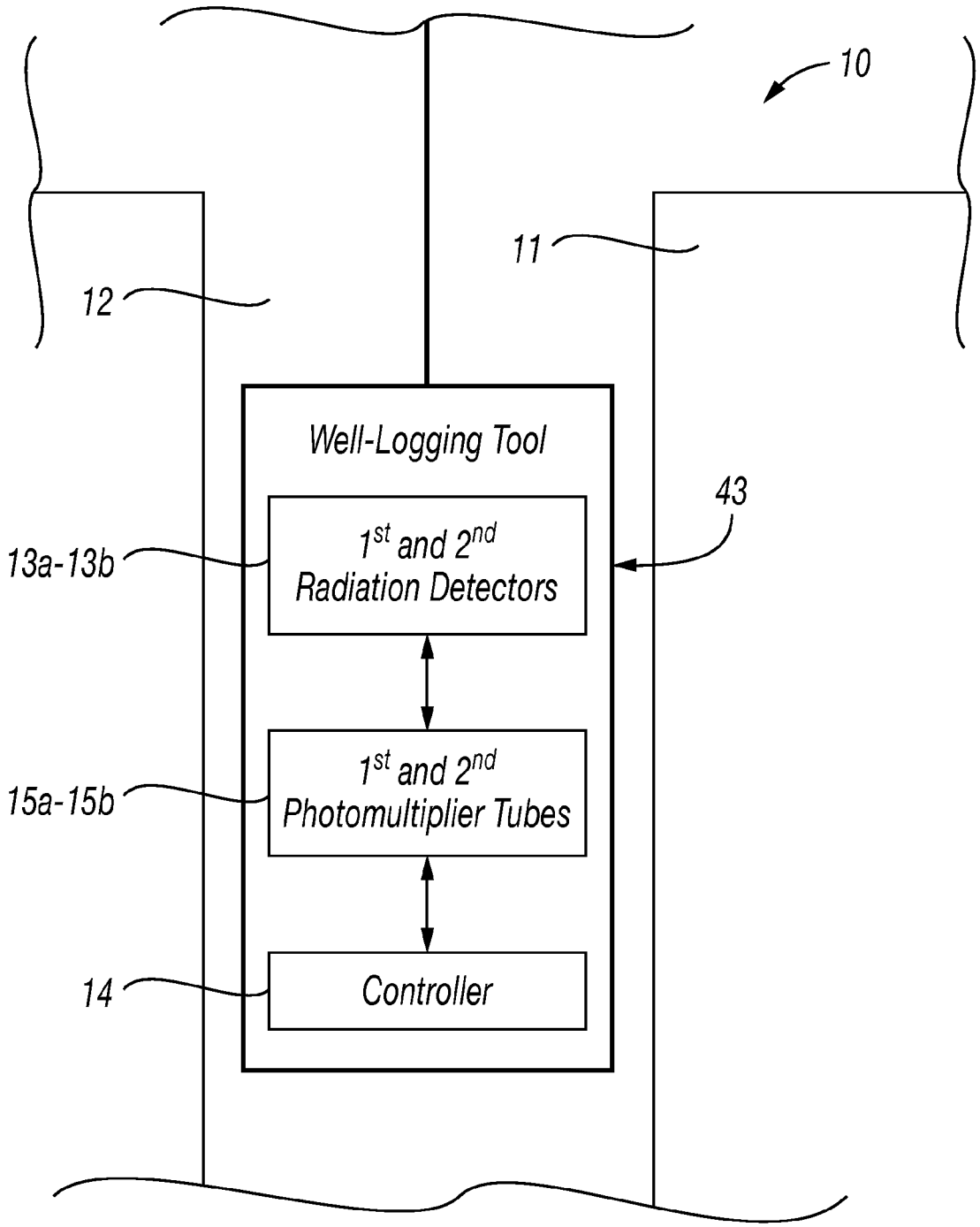

10
11
12
Well-Logging Tool
43
13a-13b
1st and 2nd Radiation Detectors
15a-15b
1st and 2nd Photomultiplier Tubes
14
Controller

FIG. 2

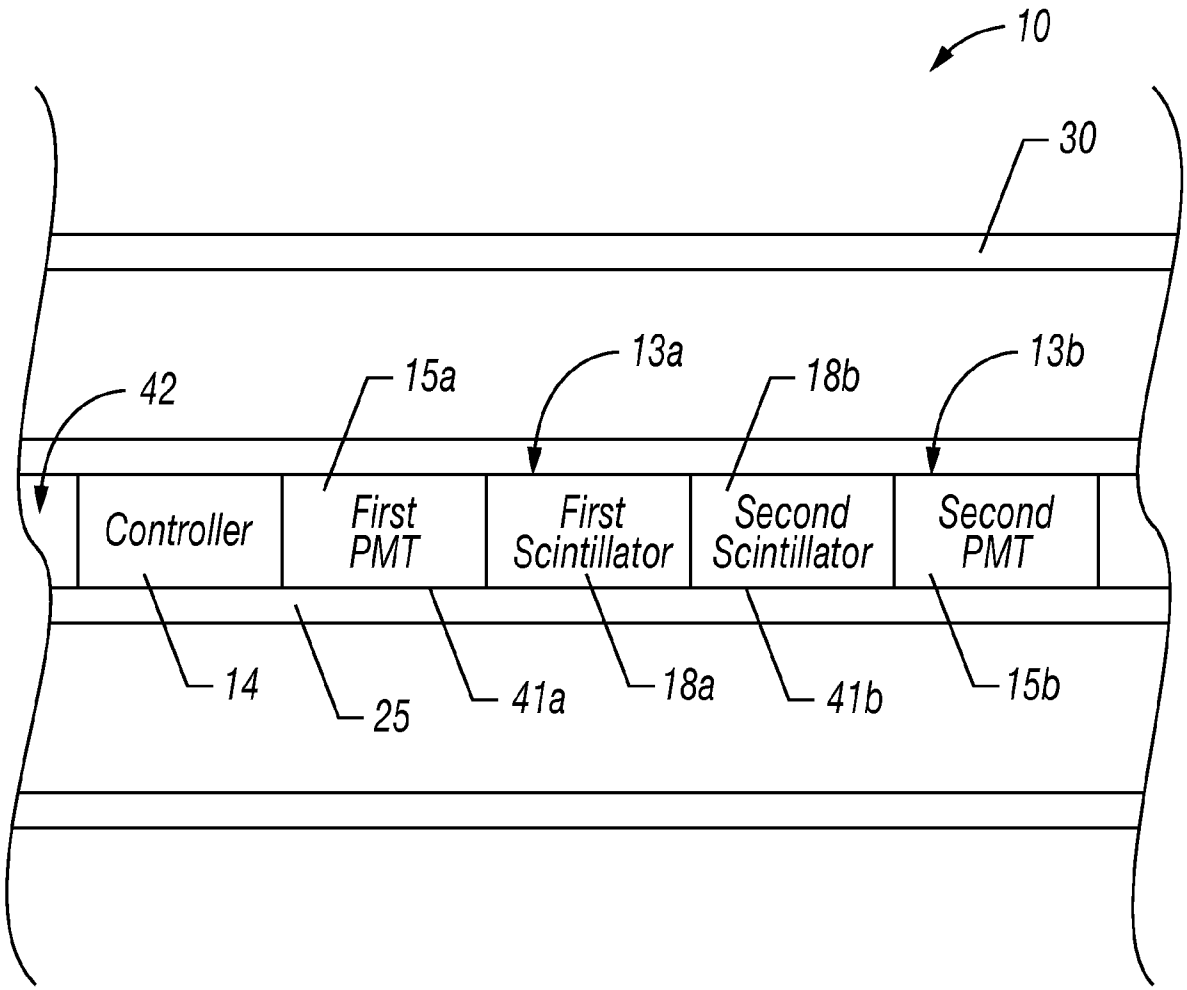

10
30
42
15a
13a
18b
13b
Controller
First PMT
First Scintillator
Second Scintillator
Second PMT
14
25
41a
18a
41b
15b

FIG. 3

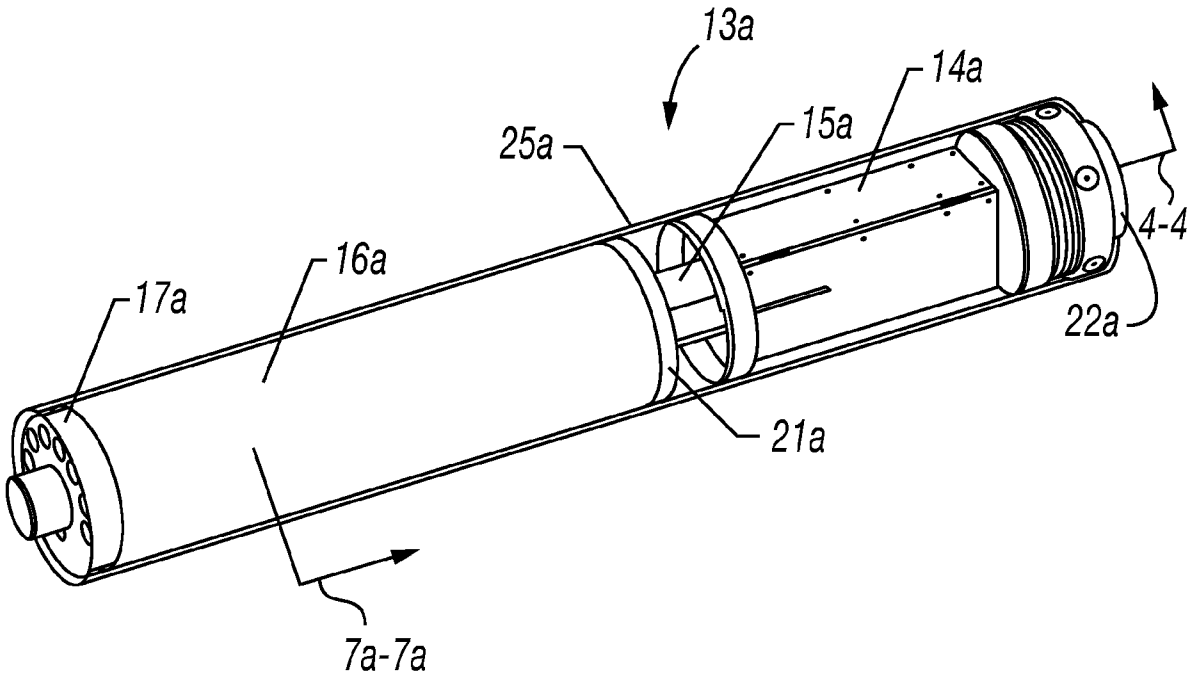

13a
14a
15a
25a
4-4
16a
17a
22a
21a
7a-7a

FIG. 4

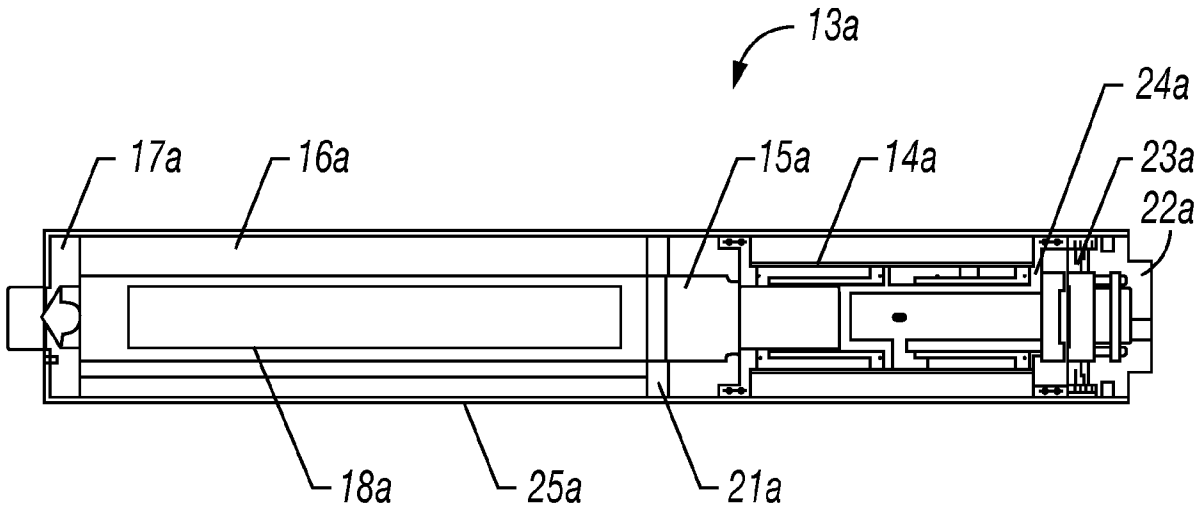

13a
24a
17a
16a
15a
14a
23a
22a
18a
25a
21a

FIG. 5

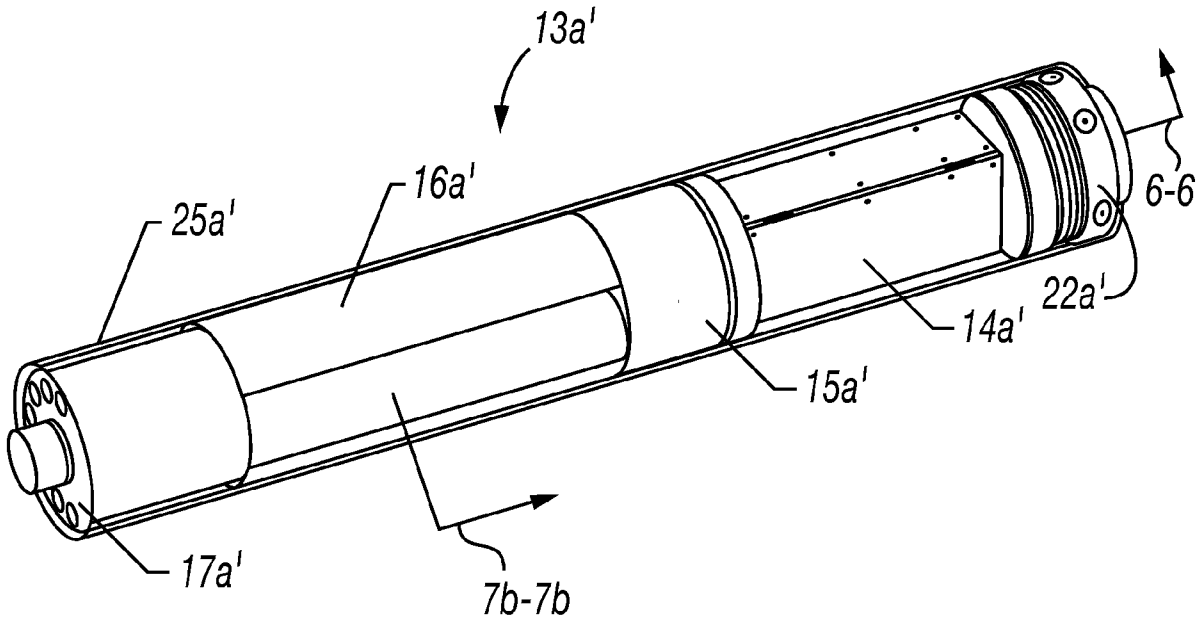

13a'
16a'
25a'
6-6
22a'
14a'
15a'
17a'
7b-7b

FIG. 6

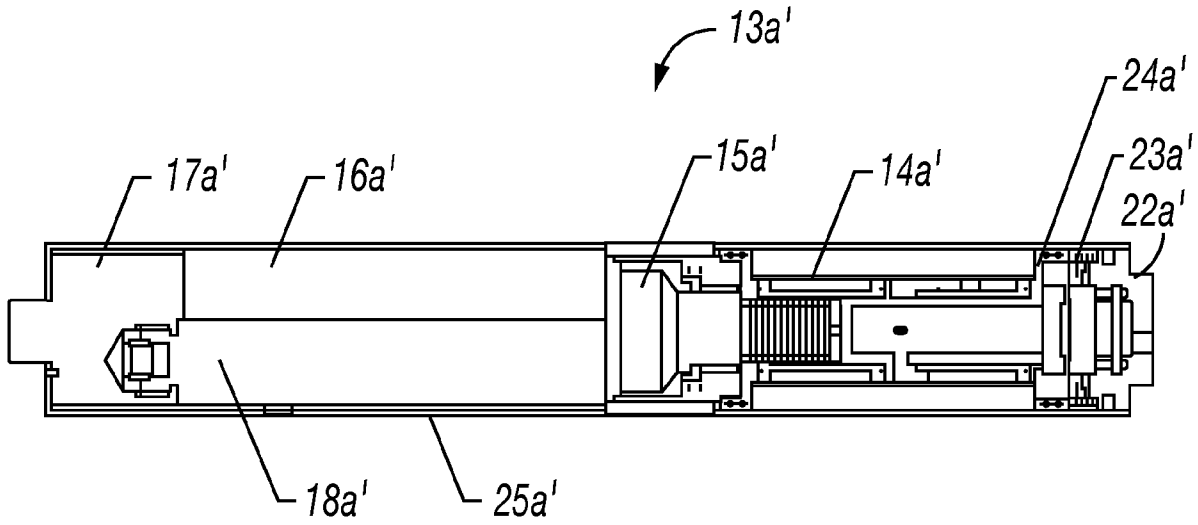
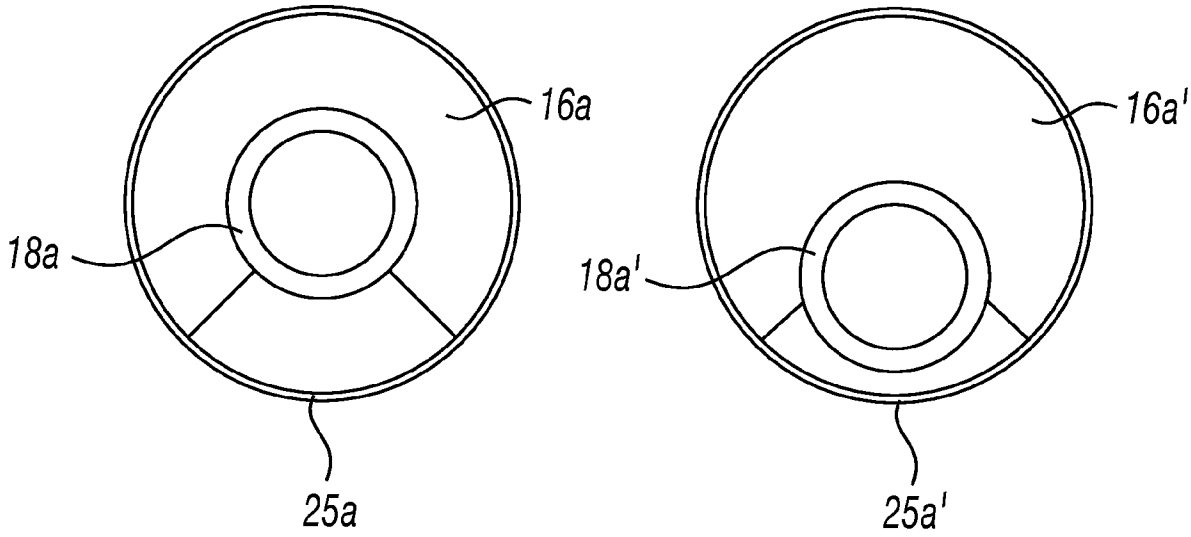

13a'
24a'
17a'
16a'
15a'
14a'
23a'
22a'
18a'
25a'

FIG. 7



FIGS. 8A-8B

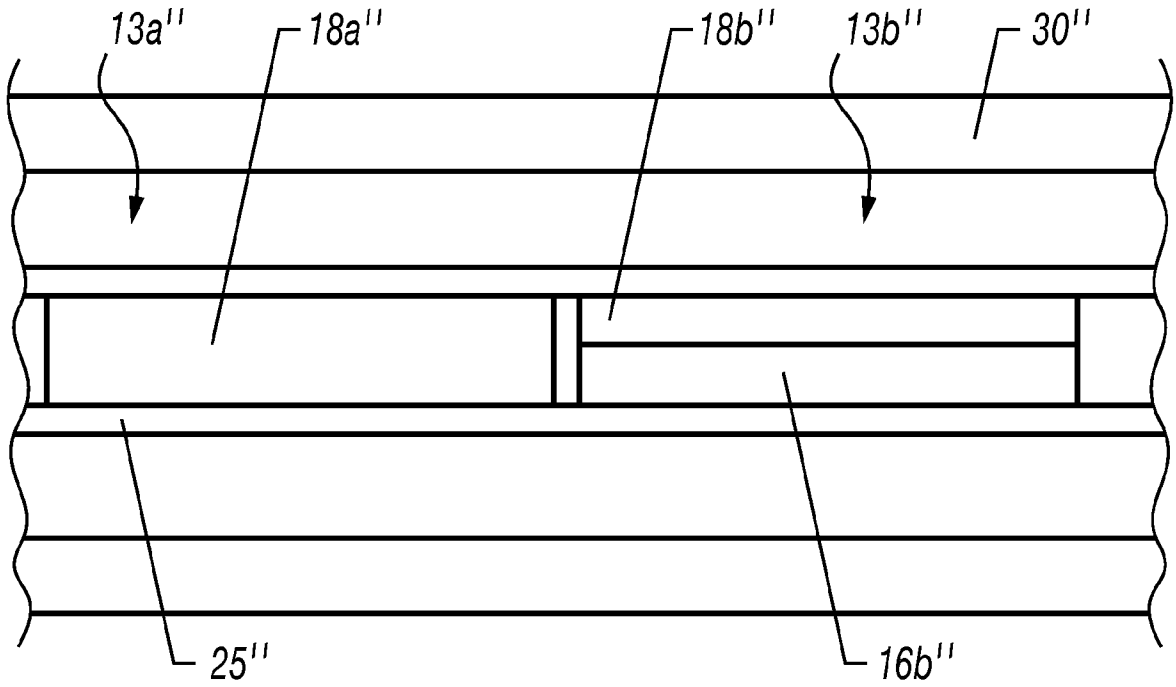


FIG. 9A

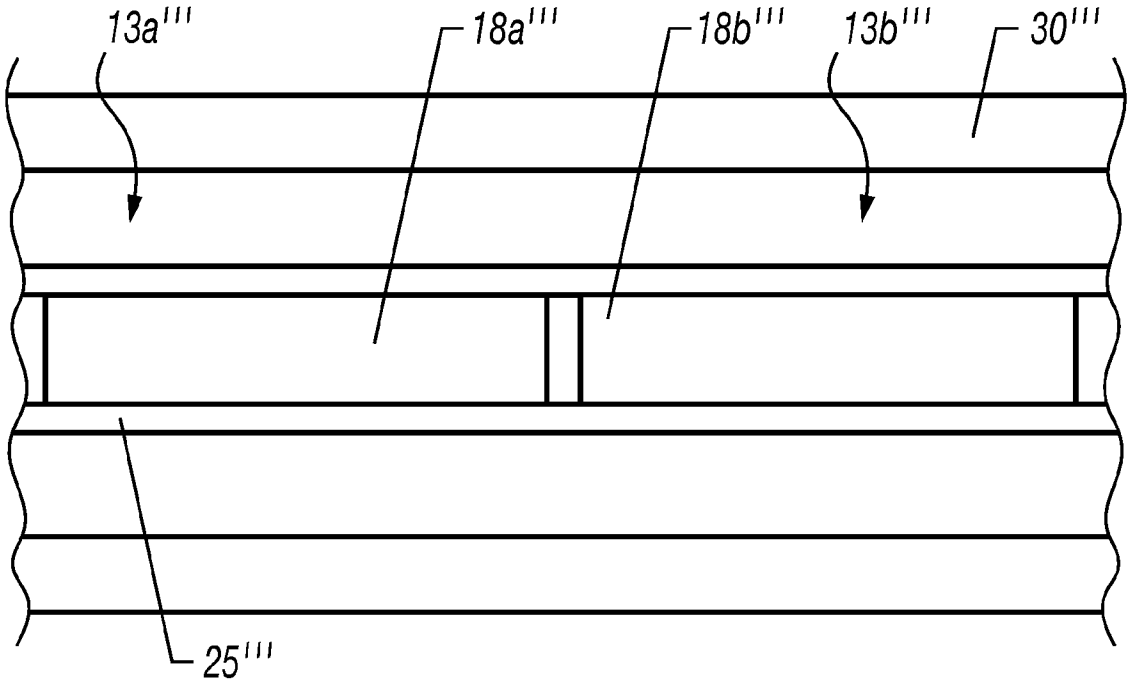


FIG. 9B

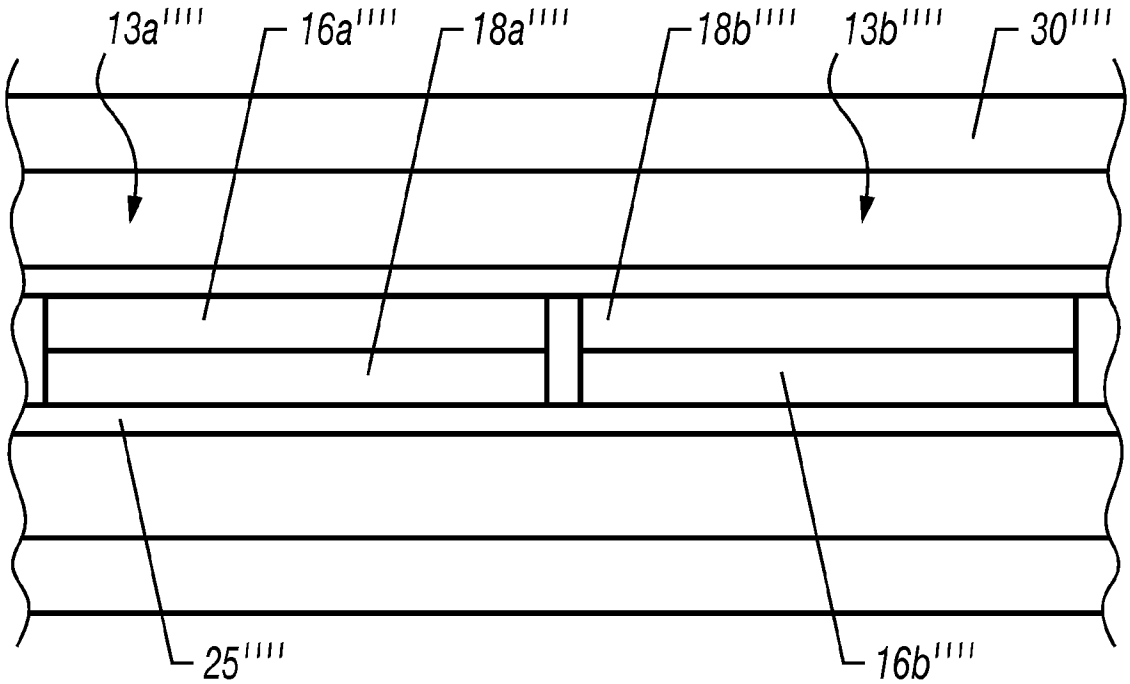


FIG. 9C

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2014/039317

A. CLASSIFICATION OF SUBJECT MATTER

E21B 47/00(2006.01)i, G01V 5/04(2006.01)i, E21B 47/26(2012.01)i

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)
E21B 47/00; G01T 3/00; G01N 23/20; G01V 5/12; G01V 5/00; G01T 1/20; G01V 5/04; E21B 47/26

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
Korean utility models and applications for utility models
Japanese utility models and applications for utility models

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
eKOMPASS(KIPO internal) & Keywords: wellbore, logging, gamma, detector, scintillator, crystal and azimuthal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 6300624 B1 (YOO et al.) 09 October 2001 See abstract, column 4,lines 19-34, column 5,lines 29-40 and figures 2-4.	1-10
A	WO 2007-146405 A2 (BAKER HUGHES INCORPORATED) 21 December 2007 See abstract, paragraphs [0015]-[0017] and figures 1-3.	1-10
A	WO 2012-012101 A2 (SCHLUMBERGER CANADA LIMITED et al.) 26 January 2012 See abstract, paragraph [0028] and figure 4.	1-10
A	US 2005-0199794 A1 (MICKAEL, MEDHAT) 15 September 2005 See abstract, paragraphs [0042],[0043] and figures 2-3b.	1-10
A	EP 0860715 A1 (SCHLUMBERGER LIMITED et al.) 26 August 1998 See abstract, column 8,lines 1-47 and figure 7.	1-10

☐ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

* Special categories of cited documents:
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"O" document referring to an oral disclosure, use, exhibition or other means
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"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	Date of mailing of the international search report
23 September 2014 (23.09.2014)	**23 September 2014 (23.09.2014)**

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.
PCT/US2014/039317

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PCT/US2014/039317

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