



- (51) International Patent Classification:
G01T 1/20 (2006.01) *G01V 5/04* (2006.01)
- (21) International Application Number:
PCT/US2014/018223
- (22) International Filing Date:
25 February 2014 (25.02.2014)
- (25) Filing Language: English
- (26) Publication Language: English
- (30) Priority Data:
13/829,818 14 March 2013 (14.03.2013) 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, F-75007 Paris (FR).
- (71) Applicant (for GB, JP, NL only): **SCHLUMBERGER HOLDINGS LIMITED**; P.O. Box 71, Craigmuir Chambers, Road Town, 1110 Tortola (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 (VG).
- (71) Applicant (for US only): **SCHLUMBERGER TECHNOLOGY CORPORATION** [US/US]; 300 Schlumberger Drive, Sugar Land, Texas 77478 (US).
- (72) Inventor: **STOLLER, Christian**; 42 Warwick Road, Princeton Junction, New Jersey 08550 (US).
- (74) Agents: **BERMAN, Jeremy** et al.; 10001 Richmond Avenue, IP Administration Center of Excellence, Room 4720, Houston, Texas 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,

[Continued on next page]

- (54) Title: RADIATION DETECTOR FOR WELL-LOGGING TOOL

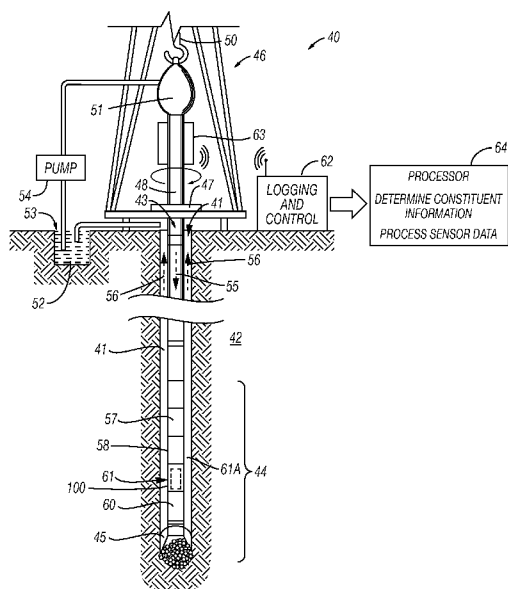


FIG. 1

(57) Abstract: A radiation detector is used in a well-logging tool for positioning in a wellbore of a geologic formation. The radiation detector includes a photomultiplier housing and a scintillator housing. A housing coupler joins together opposing ends of the photomultiplier housing and scintillator housing. A photomultiplier is contained within the photomultiplier housing and a scintillator body is contained within the scintillator housing. A scintillator window is secured to the housing coupler.



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.

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).

(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,

Published:

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

RADIATION DETECTOR FOR WELL-LOGGING TOOL

Background

[0001] Some well-logging tools include a radiation detector having a scintillator coupled to a photomultiplier, which converts photons emitted from the scintillator into an electrical current for amplification. A scintillator window is positioned between the scintillator and photomultiplier. Because the scintillator and photomultiplier may be exposed to high temperatures, harsh downhole environments and excessive shock during well-logging, the scintillator and photomultiplier are contained in at least one protective housing to provide shock resistance, provide a temperature resistant seal, and accommodate differential expansion during temperature changes among the scintillator, photomultiplier, the housing and scintillator window. Also, the scintillator and photomultiplier are coupled together in a manner to maximize a diameter of the scintillator compared to the total diameter of the housing. In some cases, instead of a single housing supporting the scintillator and photomultiplier, a scintillator housing and photomultiplier housing contain the respective scintillator and photomultiplier to facilitate assembly and functional operation. The scintillator is used in well-logging tools for gamma ray measurements, natural gamma ray spectroscopy, gamma-gamma density measurement, neutron induced gamma ray spectroscopy and scintillator-based neutron detection. In well-logging, the scintillator may detect naturally occurring radioactive materials such as thorium, uranium and potassium and their radioactive decay products.

Summary

[0002] 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.

[0003] A radiation detector includes a photomultiplier housing and a scintillator housing. A housing coupler joins opposing ends of the photomultiplier housing and scintillator housing

together. A photomultiplier is contained within the photomultiplier housing and a scintillator body is contained within the scintillator housing. A scintillator window is secured to the housing coupler.

[0004] A well-logging tool for positioning in a wellbore of a geologic formation includes a well-logging housing and a radiation detector contained in the well-logging housing. The radiation detector includes a photomultiplier housing and a scintillator housing. A housing coupler joins opposing ends of the photomultiplier housing and scintillator housing together. A photomultiplier is within the photomultiplier housing. A scintillator body is within the scintillator housing. A scintillator window is within the scintillator housing. A brazed joint secures the scintillator window and the housing coupler. The scintillator window includes a first material having a first CTE. The housing coupler includes a second material having a second CTE that is within $\pm 20\%$ of the first CTE.

[0005] A method for making a radiation detector includes securing a scintillator window and a housing coupler together. The method further includes joining opposing ends of a photomultiplier housing and scintillator housing together using the housing coupler, and with a photomultiplier within the photomultiplier housing and the scintillator body within the scintillator housing.

Brief Description of the Drawings

[0006] FIG. 1 is a schematic diagram of a well-logging system in accordance with an example embodiment.

[0007] FIG. 2 is a sectional view of a radiation detector used in a well-logging tool that includes a scintillator window and a scintillator housing joined to a photomultiplier housing in accordance with a non-limiting example.

[0008] FIG. 3 is a sectional view of another embodiment of the radiation detector showing the scintillator window secured within the scintillator housing and the photomultiplier housing joined to the scintillator housing using an overlapping joint in accordance with a non-limiting example.

[0009] FIG. 4 is a sectional view of another embodiment of the radiation detector showing another overlapping joint between the scintillator housing and photomultiplier housing in accordance with a non-limiting example.

[0010] FIG. 5 is a partial, enlarged sectional view of the radiation detector showing another overlapping joint between the photomultiplier housing and scintillator housing in accordance with a non-limiting example.

[0011] FIG. 6 is a partial, enlarged sectional view of the radiation detector showing a housing coupler joining opposing ends of the photomultiplier housing and scintillator housing together in accordance with a non-limiting example.

Detailed Description

[0012] Different embodiments will now be described more fully hereinafter with reference to the accompanying drawings, in which preferred embodiments are shown. Many different forms can be set forth and described embodiments 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 to those skilled in the art.

[0013] A radiation detector includes a photomultiplier housing and a scintillator housing. A housing coupler joins opposing ends of the photomultiplier housing and scintillator housing together. A photomultiplier is contained within the photomultiplier housing and a scintillator body is contained within the scintillator housing. A scintillator window is secured to the housing coupler.

[0014] In well-logging applications, it has been found desirable to couple the scintillator directly to a faceplate of the photomultiplier with an optical window such as a scintillator window mounted to the housing and positioned between the scintillator and photomultiplier. In this type of design, the scintillator window is secured to the housing, for example, by brazing or other fastening technique that may require high heat of up to 700°C to 800°C.

[0015] In one example, a brazed joint secures the scintillator window and the housing coupler together. In another example, the housing coupler defines an enlarged inner diameter relative to

the scintillator housing. The scintillator window has a larger area than an adjacent portion of the scintillator body. The scintillator window may be formed from a first material having a first Coefficient of Thermal Expansion (CTE) and the housing coupler may be formed from a second material having a second CTE that is within ± 20 percent of the first CTE. The first material may be formed from sapphire and the second material may be formed from Kovar.

[0016] In another example, the photomultiplier housing is formed from a third material having a third CTE. The scintillator housing may be formed from a fourth material having a fourth CTE lower than the first CTE. The third material may be formed from stainless steel and the fourth material may be formed as titanium. In another example, the housing coupler defines respective overlapping joints with the photomultiplier housing and the scintillator housing. In another example, a photomultiplier window is within the photomultiplier housing. The photomultiplier housing may have a vent opening and at least one plug associated to plug the vent opening

[0017] FIG. 1 illustrates a well site system **40** in which various embodiments of the radiation detector **100** that may be used in well-logging and described below may be implemented. In the illustrated example, the well site **40** is a land-based site, but the techniques described herein may also be used with a water or offshore-based well site as well. In this example system, a borehole **41** is formed in a subsurface or geological formation **42** by rotary drilling, for example. Some embodiments may also use directional drilling.

[0018] Although this description proceeds with the description of a Drilling and Measurement (D&M) system that includes a drill string, it should be understood that a wireline drilling and logging system may be used. Also, slickline, coiled tube conveyed or drill pipe conveyed logging may be used. The radiation detector as described below may be used with either system.

[0019] A drill string **43** is suspended within the borehole **41** and has a bottom hole assembly (“BHA”) **44** which includes a drill bit **45** at its lower end. The system **40** further includes a platform and derrick assembly **46** positioned over the borehole **41**. The assembly **46** illustratively includes a rotary table **47**, kelly **48**, hook **50** and rotary swivel **51**. The drill string **43** in this example may be rotated by the rotary table **47**, which engages the kelly **48** at the upper end of the drill string. The drill string **43** is illustratively suspended from the hook **50**, which is attached to a

traveling block (not shown). The kelly **48** and the rotary swivel **51** permits rotation of the drill string relative to the hook. A top drive system (not shown) may also be used to rotate and axially move the drill string **43**, for example.

[0020] In the present example, the system **40** may further include drilling fluid or mud **52** stored in a pit **53** formed at the well site (or a tank) for such purpose. A pump **54** delivers the drilling fluid **52** to the interior of the drill string **43** via a port in the swivel **51**, causing the drilling fluid to flow downwardly through the drill string as indicated by the directional arrow **55**. The drilling fluid exits the drill string **43** via ports or nozzles (not shown) in the drill bit **45**, and then circulates upwardly through an annular space (“annulus”) between the outside of the drill string and the wall of the borehole, as indicated by the directional arrows **56**. The drilling fluid lubricates the drill bit **45** and carries formation cuttings up to the surface as it is cleaned and returned to the pit **53** for recirculation.

[0021] The BHA **44** of the illustrated embodiment may include a logging-while-drilling (“LWD”) module **57**, a measuring-while-drilling (“MWD”) module **58**, a rotary steerable directional drilling system and motor **60**, and the drill bit **45**. These modules are part of downhole tubulars formed from respective housings as illustrated. It should be understood that the mode of conveyance is not limited to a BHA **44** for a MWD or LWD or wireline. Other modes of conveyance include slickline, coiled tubing conveyed or drill pipe conveyed logging.

[0022] The LWD module **57** may be housed in a special type of drill collar, as is known in the art, and may include one or more types of well-logging instruments, including the example radiation detectors **100**. It will also be understood that optional LWD and/or MWD modules **61** may also be used in some embodiments that include the radiation detector **100** having a scintillator and photomultiplier as described below. (References, throughout, to a module at the position of **57** may mean a module at the position of **61** as well). The module **61** has a pressure housing as a well-logging housing **61a** containing the radiation detector **100** shown in dashed lines and other down hole tool components to form a well-logging tool. The LWD module **57** may include capabilities for measuring, processing, and storing information, as well as for communicating the information with the surface equipment, e.g., to a logging and control unit

62, which may include a computer and/or other processors for decoding information transmitted from the MWD and LWD modules **57**, **58** and recording and calculating parameters therefrom. The information provided by the MWD and LWD modules **57**, **58** may be provided to a processor **64** (which may be off site, or in some embodiments may be on-site as part of the logging and control unit **62**, etc.) for determining volumetric and other information regarding constituents within the geological formation **42** and process sensor data collected from sensors located in different modules.

[0023] A wireline cable may be used instead that includes a standard cable head connected at its lower end to a logging tool with a wireline cable extending to the surface of the borehole. During a logging operation, data may be transmitted from the logging tool to the wireline cable through the cable head and into the logging and control system **62** such as shown in FIG. 1. The downhole tubular may include one or more pressure bulkheads that enclose a protected area as an enclosure for a module and contain the electronic devices such as the radiation detector, including sensors for downhole logging and processors and other electronics. The bulkhead may form a pressure housing as part of the downhole tubular.

[0024] FIG. 2 is a sectional view of the radiation detector **100** as a detector module that may be within the well-logging tool in accordance with a non-limiting example and showing a scintillator window **102** secured within a scintillator housing **104**. A photomultiplier housing **106** is secured to the scintillator housing **104** by a weld joint **109** in this example. A brazed joint **110** secures the scintillator window **102** to the scintillator housing **104** in this non-limiting example. A photomultiplier **112** is secured within the photomultiplier housing **106**. The end of the scintillator housing **104** extends past the scintillator window **102** and butts against the end of the photomultiplier housing **106** to which it is welded. The photomultiplier **112** within the photomultiplier housing **106** extends to the scintillator window **102**. The scintillator body **114** is received within the scintillator housing **104**. The photomultiplier housing **106** butts against the scintillator housing **104** at a distance of 0.5 inches in this non-limiting example from the scintillator window **102**, thus assuring that the welded process does not heat the scintillator window or the scintillator body **114** inside the scintillator housing **104** if it is present during the

well process and damage the scintillator window **102** or an optical coupling outside the scintillator window or the components of the scintillator body.

[0025] The photomultiplier **112** may include a high voltage supply **120** and a preamplifier and high voltage control circuit **124**. Other ancillary electronics may be included around the photomultiplier **112** but not inside, including a pulse height analyzer, multi-channel scaler (MCS), a battery and a memory device to allow autonomous recording of ionizing radiation. The photomultiplier **112** includes a vacuum envelope that contains normal components of the photomultiplier. A feedthrough connector is shown at **125**. The photomultiplier housing **106** and scintillator housing **104** may serve as the outer housings of the radiation detector without requiring an additional pressure housing. Usually, there will be a pressure housing such as shown in FIG. 1, which may contain additional components of a downhole tool. Together, these two housings **104**, **106** may be used in wireline or slickline applications and in LWD and MWD or coiled tubing or drill pipe conveyed logging where the well-logging tool formed from the scintillator housing **104** and photomultiplier housing **106** may be mounted on the outside of a drill collar or as part of a mandrel inside a mud channel without requiring pressure protection. Different types of photomultipliers **112** may be incorporated within the photomultiplier housing **106**, but one example is the Venetian blind type of photomultiplier that withstands harsh environmental conditions associated with well-logging. The scintillator window **102** is brazed to the scintillator housing **104** in this example, but an adhesive may also be used in some examples, and in another example, a glue or glass frit may be used to form a seal.

[0026] The scintillator body **114** is formed as a hygroscopic scintillator in this non-limiting example, but may be formed as a non-hygroscopic scintillator in another example. An example scintillator is made from a hygroscopic material such as NaI(Tl), SrI₂(Eu), LaBr₃:Ce, LaCl₃:Ce, CeBr₃, CsI(Na), CsI(Tl), and mixed La-halides. Non-hygroscopic materials may be used to form a non-hygroscopic scintillator, including BGO, GSO:Ce, LSO:Ce, YAP:Ce, LuAP:Ce, YAG:Pr, LuAG:Pr and many others. The method of construction is not limited to gamma ray detectors but applies also to scintillators suited for neutron detection such as Li-glass or newer materials such as Elpasolites.

[0027] The radiation detector **100** in the example of FIG. 2 may be formed by initially securing the scintillator window **102** and scintillator housing **104** together. The brazed joint **110** secures together the scintillator window **102** to the scintillator housing **104** in the example. Because brazing may use heating to as high as 700°C to 800°C, the scintillator window **102** is first brazed within the scintillator housing **104** since the high heat from brazing may damage the scintillation crystal contained in the scintillator body **114**. Other components include an optical coupling with the scintillator window **102**, reflecting material an optional shock absorbing material, and an electric element positioning the scintillator body **114** against the scintillator window such as a spring. In the example of FIG. 2, after securing the scintillator window **102** to the scintillator housing **104** by brazing, the opposing ends of the photomultiplier housing **106** and scintillator housing **104** may be secured by welding the two housings together with or without the scintillator body **114** and photomultiplier **112** inserted therein.

[0028] In one example, after the scintillator window **102** is brazed to the scintillator housing **104**, the photomultiplier housing **106** is joined to the scintillator housing **104**. The scintillator body **114** may next be positioned within the scintillator housing **104** and the photomultiplier **112** positioned within the photomultiplier housing **106**. This sequence of assembly steps may vary, however. For example, the scintillator body **114** may be positioned within the scintillator housing **104** prior to joining opposing ends of the photomultiplier housing **106** and scintillator housing **104** together. In another example, the scintillator body **114** may be positioned within the scintillator housing **104** after joining opposing ends of the photomultiplier housing **106** and scintillator housing **104** together. The photomultiplier **112** may be positioned within the photomultiplier housing **106** prior to joining opposing ends of the photomultiplier housing **106** and scintillator housing **104** together. In yet another example, the photomultiplier **112** may be positioned within the photomultiplier housing **106** after joining opposing ends of the photomultiplier housing **106** and scintillator housing **104** together.

[0029] In the example shown in FIG. 2, the photomultiplier housing **106** has at least one vent opening **130**, which allows air to escape as the photomultiplier **112** is inserted within the photomultiplier housing **106** and pressed against the scintillator window **102**. This facilitates

insertion of the photomultiplier **112**. The vent opening **130** may be plugged using a plug **131** although the plug in some instances may not be used. The plug **131** may or may not provide a hermetic seal after positioning the photomultiplier **112** within the photomultiplier housing **106** depending on design. After the scintillator body **114** is positioned within the scintillator housing **104**, an end cap **134** is received on the end of the scintillator housing **114** to hold the scintillator body **114** within the scintillator housing **104**. A spring or other biasing member **136** may be inserted between the end cap **134** and the scintillator body **114** to bias the scintillator body **114** forward against the scintillator window **102** as illustrated in FIG. 2. An end cap **138** may be placed at the end of the photomultiplier housing **106** to hold the photomultiplier **112** within the housing. An intervening optical coupling material such as a pad or optical shock absorbing material or both may be made between a photomultiplier window and the scintillator window **102**. This assures enhanced light transmission to a photocathode on the inside of the photomultiplier window.

[0030] An example material for the scintillator housing **104** may be titanium or other similar material for better gamma ray transmission and compatible with the scintillator window material **102** to allow a stable hermetic seal that will not break with temperature changes. Other materials may include a material with a low atomic number *Z* and a low density. Example materials may include beryllium and may include carbon fiber structures. The photomultiplier housing **106** may be formed from a structural material such as stainless steel. It is possible to make the parts of the photomultiplier **112** from a material of high magnetic permeability such as AD-MU-80 or AD-MU-48 material from AD-Vance Magnetics, Inc. of Rochester, Indiana to shield the photomultiplier **112** against magnetic fields.

[0031] FIG. 3 is another embodiment of the radiation detector **100'** similar to the embodiment shown in FIG. 2, but using an overlapping joint instead of a butt weld joint to secure the scintillator housing **104'** to the photomultiplier housing **106'**. As illustrated, the ends of the photomultiplier housing **106'** and the scintillator housing **104'** form at least one overlapping joint indicated generally at **140'** and shown by the circled portion to highlight the area of the overlapping joint **140'**. In this example, the photomultiplier housing **106'** has a thinner end

portion **150'** that extends past the scintillator window **102'** and overlaps a thinner end portion **152'** of the scintillator housing **104'**. The two thinner end portions **150'**, **152'** are secured to each other preferably by welding as a non-limiting example although it is possible to use an adhesive and other fastening techniques.

[0032] FIG. 4 is an example of the radiation detector **100''** similar to FIG. 3 that also includes at the illustrated oval an overlap joint generally at **174''**, but showing a beveled scintillator window **176''** and an internal bevel **178''** on the scintillator housing **104''**. The end portion of the scintillator housing **104''** is thickened to accommodate the bevel. The thickened portion that forms the bevel **178''** may have threads to allow the photomultiplier housing **106''** to be screwed onto the scintillator housing **104''**. Welding at the weld joint **179''** at the overlap joint **174''** forms a better hermetic seal. In this example, the internal bevel **178''** begins at the vertical line (l) extending through the scintillator housing **104''**.

[0033] It should be understood that it is possible for the scintillator housing **104'''** to have an extended thinner section that extends past the scintillator window **102'''** and overlaps a portion of the photomultiplier housing **106'''** as shown in the enlarged sectional view in FIG. 5 where an overlap joint **142'''** is formed. The scintillator housing **104'''** may include an enlarged inner diameter section **160'''** formed by the overlap joint **142'''** relative to adjacent sections receiving the scintillator window **102'''** such that the scintillator window **102'''** has a larger area than an adjacent portion of the scintillator body **114'''** to allow more light to be collected and passed into the photomultiplier **112'''**. The scintillator housing **104'''** may be secured to the photomultiplier housing **106'''** by a weld joint **172'''** at the overlap seal **142'''** in this example to form a hermetic seal.

[0034] FIG. 6 is an enlarged sectional view of another embodiment of the radiation detector **100''''** that includes a housing coupler **180''''** that joins the ends of the photomultiplier housing **106''''** and scintillator housing **104''''** together. In this example, the scintillator window **102''''** is secured to the housing coupler **180''''** such as using a brazed joint **110''''**. As illustrated, the housing coupler **180''''** defines an enlarged inner diameter **160''''** relative to the scintillator housing **104''''**. The scintillator window **102''''** has a larger area than an adjacent portion of the

scintillator body **114'''** to allow more light to pass and be collected at the photomultiplier **112'''**. In one example, the scintillator window **102'''** is formed from a first material having a first Coefficient of Thermal Expansion (CTE) and the housing coupler **180'''** is formed from a second material having a second CTE that is within ± 20 percent of the first CTE.

[0035] In another example, the first material forming the scintillator window **102'''** is sapphire and the second material forming the housing coupler **180'''** is Kovar. The expansion characteristics of Kovar match sapphire, borosilicate and Pyrex glass and other materials used for scintillator windows so that the materials may shrink and expand in a similar manner as environmental conditions change during assembly and well-logging without causing the scintillator window **102'''** to come apart from the housing coupler **180'''** or expand into the coupler and shatter. In another example, the photomultiplier housing **106''** is formed from a third material having a third CTE and the scintillator housing **104'''** is formed from a fourth material having a fourth CTE lower than the first CTE. For example, the third material forming the photomultiplier **112'''** could be a stainless steel and the fourth material forming the scintillator housing **104'''** could be titanium as discussed above. The housing coupler **180'''** has an overlapping joint **190'''** with the photomultiplier housing **106'''** and another overlapping joint **192'''** and the scintillator housing **104'''** as shown in FIG. 6. The photomultiplier housing **106'''** in this example also includes at least one vent opening (not shown) and a plug associated therewith to facilitate insertion of the photomultiplier **112'''** into the photomultiplier housing **106'''** as described before.

[0036] It is possible to include a stud **190'** on one side of the scintillator housing **104'** such as shown in dashed lines of FIG. 3 to permit direct mounting of the scintillator housing **104'** on another part. It is also possible to include extensions **192''** on both the photomultiplier housing **108''** and scintillator housing **104''** for external attachments as shown in the dashed lines of FIG. 4.

[0037] This application is related to copending patent application entitled, “**METHOD OF MAKING A WELL-LOGGING RADIATION DETECTOR,**” which is filed on the same

date and by the same assignee and inventors, the disclosure which is hereby incorporated by reference.

[0038] Many modifications and other embodiments of the invention 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 invention 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 radiation detector comprising:
 - a photomultiplier housing;
 - a scintillator housing;
 - a housing coupler joining opposing ends of said photomultiplier housing and scintillator housing together;
 - a photomultiplier within said photomultiplier housing;
 - a scintillator body within said scintillator housing; and
 - a scintillator window secured to said housing coupler.
2. The radiation detector according to Claim 1 further comprising a brazed joint securing said scintillator window and said housing coupler together.
3. The radiation detector according to Claim 1 wherein said housing coupler defines an enlarged inner diameter relative to said scintillator housing; and wherein said scintillator window has a larger area than an adjacent portion of said scintillator body.
4. The radiation detector according to Claim 1 wherein said scintillator window comprises a first material having a first CTE; and wherein said housing coupler comprises a second material having a second CTE that is within ± 20 percent of the first CTE.
5. The radiation detector according to Claim 4 wherein said first material comprises sapphire, and said second material comprises Kovar.
6. The radiation detector according to Claim 1 wherein said photomultiplier comprises a third material having a third CTE; and wherein said scintillator housing comprises a fourth material having a fourth CTE lower than the third CTE.

7. The radiation detector according to Claim 6 wherein said third material comprises stainless steel, and said fourth material comprises titanium.

8. The radiation detector according to Claim 1 wherein said housing coupler defines respective overlapping joints with said photomultiplier housing and said scintillator housing.

9. The radiation detector according to Claim 1 wherein said photomultiplier housing has at least one vent opening therein and at least one plug associated with the at least one vent opening.

10. A well-logging tool for positioning in a wellbore of a geologic formation comprising:

a well-logging housing and;

a radiation detector within the well-logging housing comprising,

a photomultiplier housing;

a scintillator housing;

a housing coupler joining opposing ends of said photomultiplier housing and scintillator housing together;

a photomultiplier within said photomultiplier housing;

a scintillator body within said scintillator housing;

a scintillator window within said scintillator housing; and

a brazed joint securing said scintillator window and said housing coupler together;

said scintillator window comprising a first material having a first CTE;

said housing coupler comprising a second material having a second CTE that is within ± 20 percent of the first CTE.

11. The well-logging tool according to Claim 10 wherein said housing coupler defines an enlarged inner diameter relative to said scintillator housing; and wherein said scintillator window has a larger area than an adjacent portion of said scintillator body.

12. The well-logging tool according to Claim 10 wherein said first material comprises sapphire, and said second material comprises Kovar.

13. The well-logging tool according to Claim 10 wherein said photomultiplier housing comprises a third material having a third coefficient of thermal expansion (CTE); and wherein said scintillator housing comprises a fourth material having a fourth CTE lower than the first CTE.

14. The well-logging tool according to Claim 13 wherein said third material comprises stainless steel, and said fourth material comprises titanium.

15. The well-logging tool according to Claim 10 wherein said housing coupler defines respective overlapping joints with said photomultiplier housing and said scintillator housing.

16. A method for making a radiation detector for a well-logging tool, the method comprising:

securing a scintillator window and a housing coupler together; and

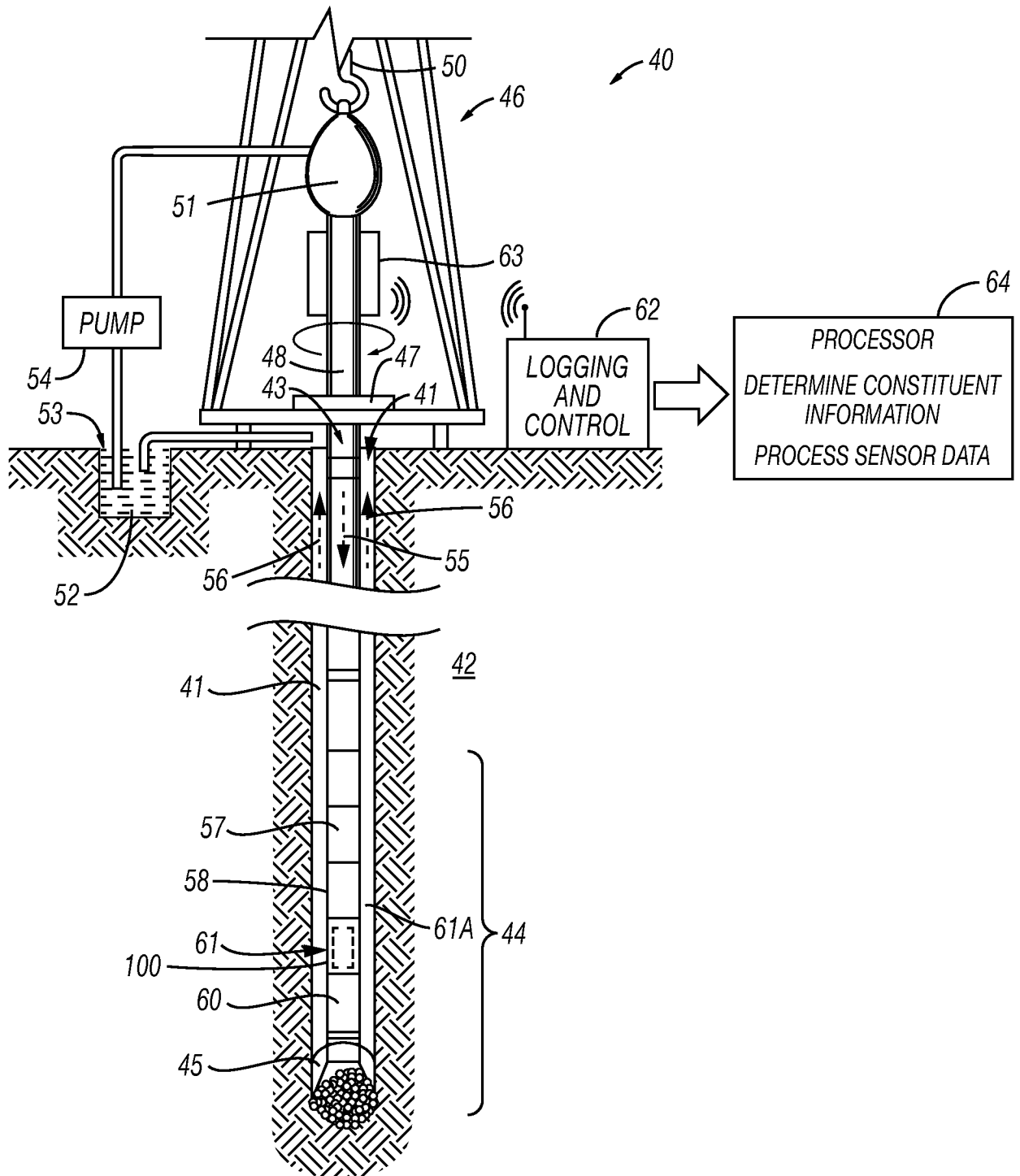
joining opposing ends of a photomultiplier housing and scintillator housing together using the housing coupler, and with a photomultiplier within the photomultiplier housing, and a scintillator body within the scintillator housing.

17. The method according to Claim 16 wherein securing the scintillator window comprises forming a brazed joint to secure the scintillator window and the housing coupler together.

18. The method according to Claim 16 wherein the housing coupler defines an enlarged inner diameter relative to the scintillator housing; and wherein the scintillator window has a larger area than an adjacent portion of the scintillator body.

19. The method according to Claim 16 wherein the scintillator window comprises a first material having a first CTE; and wherein the housing coupler comprises a second material having a second CTE that is within ± 20 percent of the first CTE.

20. The method according to Claim 16 wherein the photomultiplier housing comprises a third material having a third CTE; and wherein the scintillator housing comprises a fourth material having a fourth CTE lower than the third CTE.

**FIG. 1**

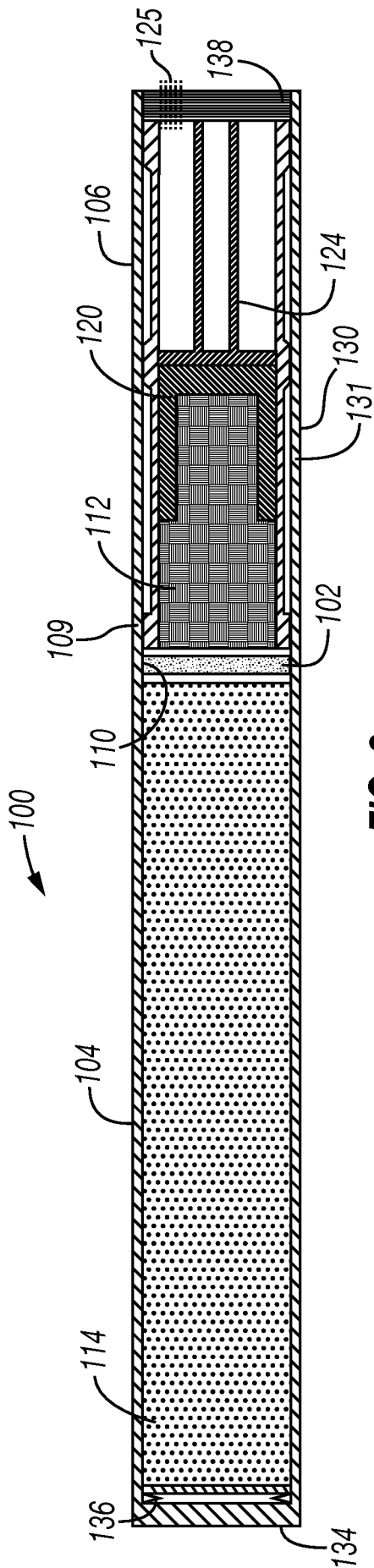


FIG. 2

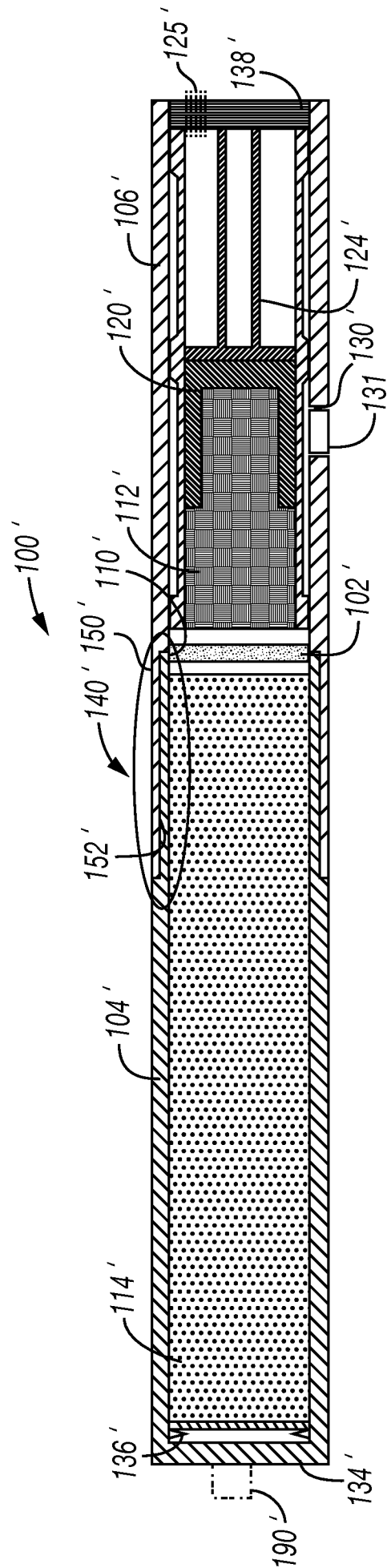


FIG. 3

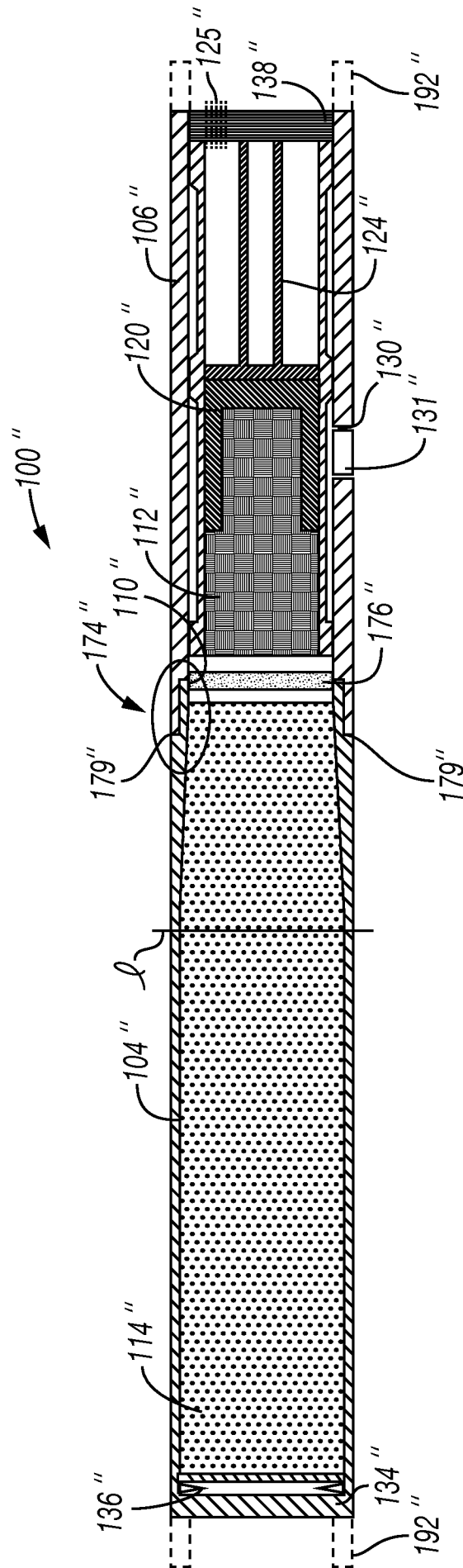
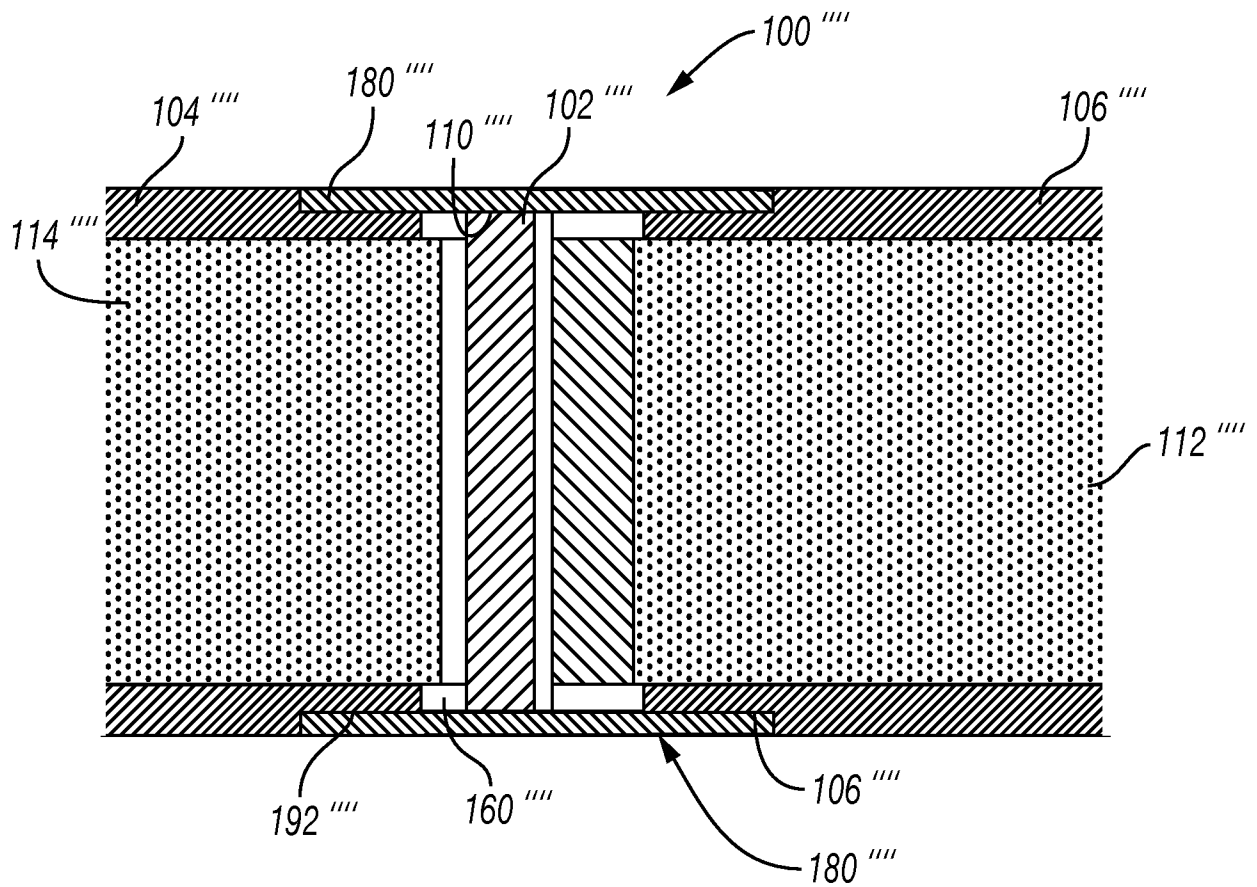
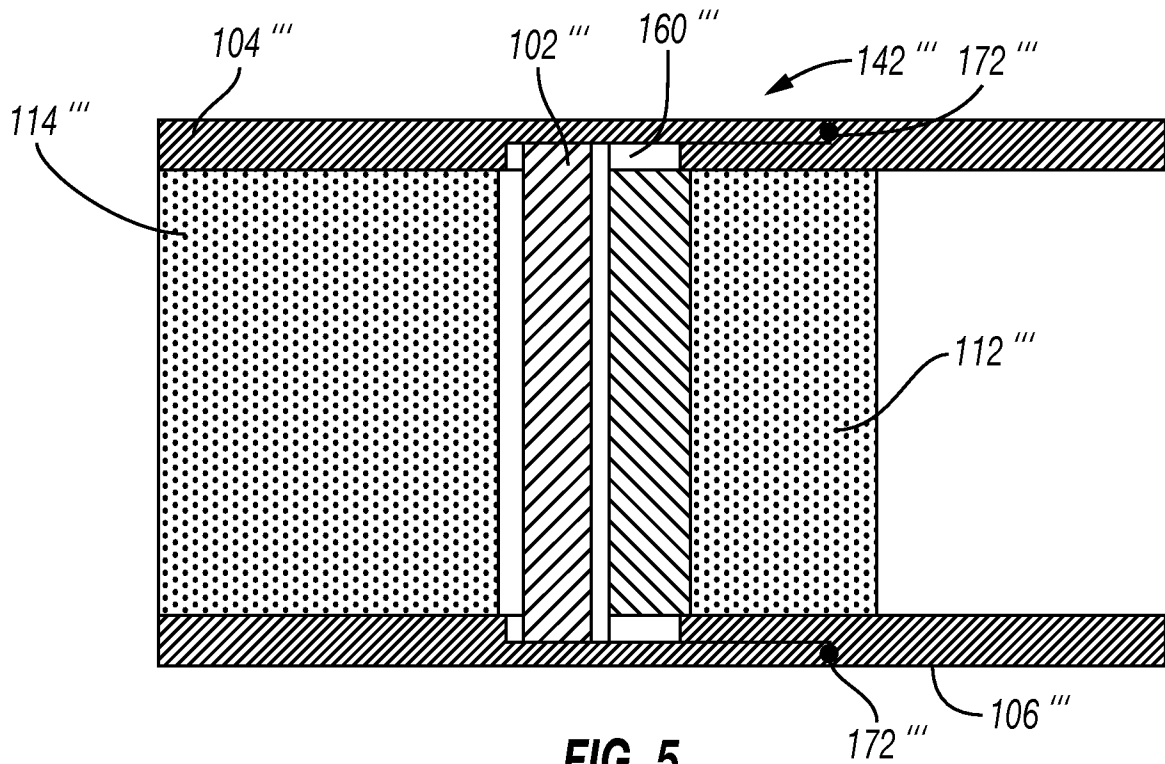


FIG. 4



INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2014/018223**A. CLASSIFICATION OF SUBJECT MATTER****G01T 1/20(2006.01)i, G01V 5/04(2006.01)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)

G01T 1/20; G01T 1/202; G01T 7/00; G01V 5/04; H01G 9/155; G21F 3/00

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: well-logging, radiation detector, photomultiplier, scintillator, housing, braze joint, and wellbore

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 2012-058569 A2 (SCHLUMBERGER CANADA LIMITED) 03 May 2012 See abstract; pages 3-10 and figures 1-15.	1-8, 10-20
Y		9
Y	WO 2010-135303 A2 (SCHLUMBERGER CANADA LIMITED) 25 November 2010 See abstract; pages 6-11 and figures 1-4.	9
A	WO 2013-016145 A1 (FASTCAP SYSTEMS CORPORATION) 31 January 2013 See abstract; paragraphs 133-144 and figures 5-9.	1-20
A	US 4360733 A (NOVAK et al.) 23 November 1982 See abstract; column 2, line 29 - column 5, line 58 and figures 1,2.	1-20
A	US 4649276 A (SUZUKI, ARATA) 10 March 1987 See abstract; column 3, line 40 - column 6, line 4 and figures 1-6.	1-20



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

24 June 2014 (24.06.2014)

Date of mailing of the international search report

24 June 2014 (24.06.2014)

Name and mailing address of the ISA/KR

International Application Division
Korean Intellectual Property Office
189 Cheongsu-ro, Seo-gu, Daejeon Metropolitan City, 302-701,
Republic of Korea

Facsimile No. +82-42-472-7140

Authorized officer

AHN, Jae Yul

Telephone No. +82-42-481-8525



INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.

PCT/US2014/018223

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
WO 2012-058569 A2	03/05/2012	WO 2012-058569 A3	02/08/2012
WO 2010-135303 A2	25/11/2010	EP 2433154 A2	28/03/2012
		GB 201121174 D0	18/01/2012
		GB 2483400 A	07/03/2012
		GB 2483400 B	08/01/2014
		JP 2012-527620 A	08/11/2012
		US 2012-0228472 A1	13/09/2012
		WO 2010-135303 A3	03/03/2011
WO 2013-016145 A1	31/01/2013	CA 2838557 A1	13/12/2012
		US 2013-0026978 A1	31/01/2013
		WO 2012-170749 A2	13/12/2012
		WO 2012-170749 A3	31/01/2013
		WO 2013-009720 A2	17/01/2013
		WO 2013-009720 A3	14/03/2013
		WO 2013-126915 A1	29/08/2013
US 04360733 A	23/11/1982	None	
US 04649276 A	10/03/1987	CA 1236937 A1	17/05/1988
		DE 3671540 D1	28/06/1990
		DK 113686 A	14/09/1986
		DK 113686 D0	12/03/1986
		DK 174065 B1	21/05/2002
		EP 0199434 A1	29/10/1986
		EP 0199434 B1	23/05/1990
		IL 77952 A	31/10/1989
		JP 1891452 C	07/12/1994
		JP 6016098 B2	02/03/1994
		JP 61-262675 A	20/11/1986