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(54) Title: LATERAL WELL RUGGEDIZED BUOYANT DATA MODULE DEPLOYMENT

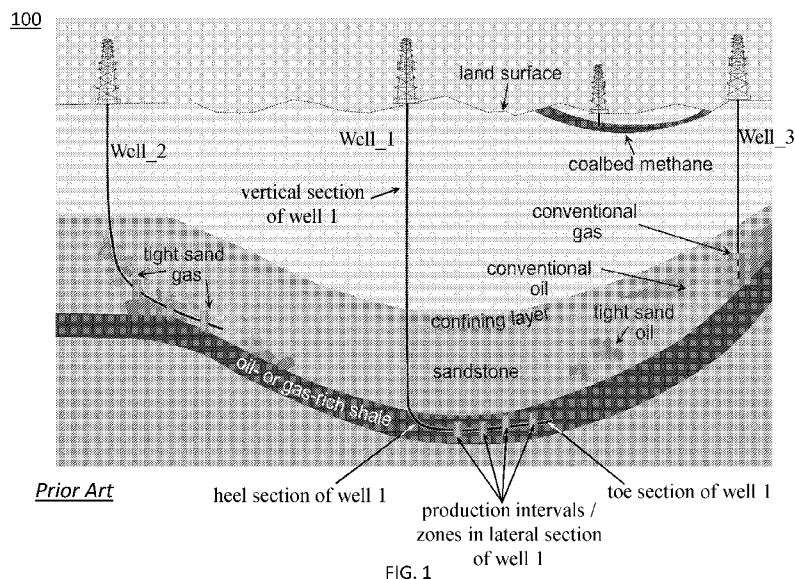


FIG. 1

(57) Abstract: Systems and methods for delivering detailed information about physical properties, including inflow data across production zones or intervals, in a downhole of a well to the surface without the need of providing cabling to the downhole are presented. Such information can be based on data captured by sensors (542, 545, 560, 570) placed within memory of ruggedized buoyant data modules (RBDMs, 220, 420) that are physically injected into the fluid flow of the well. The RBDMs use the flow of the fluid inside of the well, as well as optional mobility (780, 782, 785) and/or buoyancy control features (790, 7901, 7902, 7903, 7906, 790a, 7908) to robustly deliver the data to a location where the data can be extracted. The RBDMs can be stored either at a base station (430) located at the toe of a lateral section of the well or in a mobile robot (450, 1010). Data captured by and stored in the RBDMs can be extracted either directly from the RBDMs or remotely (1110).

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LATERAL WELL RUGGEDIZED BUOYANT DATA MODULE DEPLOYMENT

CROSS REFERENCE TO RELATED APPLICATIONS

[0001] The present application claims priority to US provisional patent application Serial No. 62/825,583 entitled “Lateral Well Ruggedized Buoyant Data Module Deployment, (Attorney Docket No. P2344-USP), filed on March 28, 2019, and may be related to the pending International patent application Serial No. PCT/US18/55565 entitled “Ruggedized Buoyant Memory Modules for Data Logging and Delivery System Using Fluid Flow in Oil and Gas Wells” (Attorney Docket No. P2300-PCT), filed on October 12, 2018, which in turn claims priority to and the benefit of co-pending US provisional patent application Serial No. 62/572,309 entitled “Ruggedized Buoyant Memory Modules for Data Logging and Delivery System Using Fluid Flow in Oil Wells (RBMM)”, filed on October 13, 2017, the disclosures of which are incorporated herein by reference in their entirety.

STATEMENT OF GOVERNMENT GRANT

[0002] This invention was made with government support under Contract No. NNN12AA01C awarded by the National Aeronautics and Space Administration. The government has certain rights in the invention.

TECHNICAL FIELD

[0003] The present disclosure generally relates to systems and methods for measuring and delivering of data from a downhole of a well during production. In particular, it relates to buoyant ruggedized memory modules for data logging and delivering systems using fluid flow in lateral oil/gas wells with varying- to low-fluid flow conditions.

BACKGROUND

[0004] Detailed information about physical properties (e.g., reservoir inflow) in the downhole of an oil-gas producing well, is important to help optimize production and field development. Inflow data points such as oil-gas-water flow rates, pressure, and temperature, for example, are key to

understanding the nature of the reservoir properties and the effect of well drilling and completion methods. Although useful, the inflow data are not often measured along the lateral section of the well due to technical or cost-prohibitive challenges. Instead, surface well-head production data (total flow rates, pressure, temperature, etc.) are measured for well performance diagnostics and for reporting purposes.

[0005] Attempts to instrument the well with continuous electrical or fiber optic cables for powering sensors to measure and deliver physical properties in the downhole of a well have not been successful and/or have not been cost effective. This is particularly true for modern wells that have, for example, long laterals and multiple perforation entry points of their casing pipe (to contact the rock formation) which then undergo high-pressure hydraulic fracturing to increase hydrocarbon inflows from oil-bearing rock formations. Such harsh activities can easily damage power and data cables in the downhole of a well.

[0006] Unconventional tight rock geologic formations may require a large number of oil/gas wells (holes) drilled in close proximity to each other to effectively extract the hydrocarbon contained in a field. As shown in FIG. 1, horizontally-drilled wells may be used in these applications since the hydrocarbon-bearing rock formations tend to exist in stratified layers aligned perpendicular to the gravity vector. The typical vertical section of these wells can be 1-3 km below the surface and can extend laterally (i.e., in a horizontal direction) for distances of, for example, 2-3 km or even more. Oil, natural gas, and water may enter the well at many locations (production intervals/zones open to perforations and fracturing) formed along a lateral distance (e.g., 2-3 km or more) of the well with local flow rates and composition (e.g. oil/water fractions) varying due to inherent geology and the accuracy with which the well intersects (e.g., at the production intervals or sections) the oil-bearing rock formations. In general, information about the performance or hydrocarbon delivery and capacity of a well, such as, for example, flow rate, pressure, and composition, can practically be measured at the surface of the well as-combined values and with little or no knowledge of individual contributions from each of the production intervals or zones. Lack of local information of the inflow details of the well, at, for example, the production intervals or zones, can be a barrier to improving the efficiency of oil-gas extraction from the overall field.

[0007] A person skilled in the art readily knows that better knowledge of local interval inflow data across each or multiple entry points (e.g. physical properties such as flow rates, pressure, temperature, etc.) at the downhole of a well (e.g., along the horizontal/lateral section of the well) may help in making better decisions about placement of subsequent perforation/completion intervals for production in a well and/or subsequent drilling of other wells in the field, such as that shown in FIG. 1.

[0008] For example, as shown in FIG. 1, an oil production field may have a variety of drilled wells, including an unconventional horizontal oil well that extracts oil from shale and tight formation through a plurality of production intervals or zones (shown as rectangles). In order to develop the field, producing the hydrocarbon-bearing rock formations, a number of wells (i.e., holes) may be drilled and spaced, for example, in the order of 500 feet apart from each other. These wells are drilled and completed serially so that information may be gathered from a downhole of a first well, for example, and can aid in determining where to perforate the casing and to apply hydraulic fracturing at selected intervals of the formation in a second and following well.

[0009] The above referenced International patent application PCT/US18/55565, the disclosure of which is incorporated herein by reference in its entirety, provides a solution to the above problems associated with cabling of a downhole of a well while providing detailed information about local physical properties in a downhole, including inflow data, which can be used for optimizing the design of drilling, completion and production of subsequent wells (e.g. drilling order, completion spacing, timing to install artificial lift methods). According to such patent application, data related to information about local physical properties of the downhole can be captured by sensors placed within a lateral section of the downhole of the well, and subsequently stored into memory of ruggedized buoyant memory modules (RBMM) that are physically injected into the stream of fluid that flows in the lateral section of the well. Such memory modules use the flow of the fluid inside the well to deliver the data to a location where the data can be extracted. Data stored in the memory modules can be extracted either directly from the memory modules or remotely via, for example, a wireless interface (e.g., Wifi, Bluetooth, etc.). In order to allow the memory modules to flow with the fluid, the memory modules, as well as the sensors, are placed in regions of the well where fluid flow is sufficient to carry injected memory modules towards the surface or heel of the well.

This means that the memory modules are placed away from the toe of the well where there is substantially no flow (dead flow zone) and in a region of the well close to a production zone where inflow from the production zone can generate enough flow to carry the injected memory modules. However, due to varying flow rates and undulations of the flow in the lateral sections of the well, the memory modules may get stuck to walls of the horizontal section of a well and therefore may not be able to be carried towards the heel of the well and to the surface.

[0010] Teachings according to the present disclosure solve the above problems by providing methods and structures that allow memory modules stored in regions of the lateral well with low and/or varying flow rates to be deployed and carried to the surface/heel of the well without getting stuck to the walls of the horizontal section of the well due to undulations in the flow and/or the varying or low flow rates. Furthermore, different from the above referenced PCT/US18/55565, the memory modules according to the present disclosure may be fitted with sensors to allow such modules to capture/sense downhole data while being carried by the fluid flow along the lateral section of the well.

SUMMARY

[0011] The present disclosure describes systems and methods for delivering detailed information about physical properties, including inflow data, in a lateral section of a well to the surface without the need of providing cabling between the surface of the well and the downhole. Such information can be based on data captured by sensors placed in memory modules that are stored in the toe of a lateral well or other regions of the lateral well with low or varying flow conditions. In order to facilitate flow of the memory modules in regions of the well having the low or varying (fluid) flow conditions, including in regions where the flow includes undulations of the fluid, the memory modules of the present disclosure are designed to include features such as buoyancy control and mobility control to provide for a more robust delivery of the data to the surface of the well. According to some embodiments of the present disclosure, injection of such memory modules into the flow of the lateral well can be performed via a deployment system (LWRBDMD later described) that may include a delivery module (e.g., a mobile robot) to carry the memory modules to regions of the well having sufficient flow before injecting the memory modules into the flow. While carried by the flow, sensors of the memory modules according to the present disclosure may

gather (i.e. measure and record) data related to the physical properties of the well. Various degrees of complexity can be provided to the deployment system according to the present disclosure, with basic features such as, for example, storing of the memory modules, optionally carrying (via the delivery module) of the memory modules to regions of the well with sufficient flow rate, and injecting of the memory modules into the flow. The delivery module according to the present disclosure may be a specialized mobile robot (e.g., FIGs. 10A-10E later described) that is provided with additional and more complex features, such as, for example, autonomous power via, for example, flow energy harvesting, freedom of travel in the lateral section of the well, high quality sensors for data capture, and transfer of captured data to the memory modules prior to injection. According to some exemplary embodiments of the present disclosure, depending on availability of sensors within the delivery module (e.g., mobile robot), the memory modules may be simple memory modules without sensors (e.g., RBMMs per above reference) or memory modules with sensors (e.g., RBDMs later described). Once injected into the flow, the memory modules according to the present disclosure can use the flow of the fluid inside of the well to deliver the data to a location where the data can be extracted. Data stored in the memory modules can be extracted either directly from the memory modules or remotely via, for example, a wireless interface.

[0012] Although the present systems and methods are described with reference to wells used in the oil industry, such systems and methods may equally apply to other industries, such as, for example, deep sea exploration to send data from underwater robotic vehicles without the need of said vehicles to surface and transmit the data, or for through-ice exploration to get data gathered from melt probes by floating the memory modules up through a melt probe hole while the melt probe hole remains open, or by tying the memory modules to respective radioactive heating units (RHUs) to melt their way up from under the ice while the melt probe hole is closed.

[0013] According to one embodiment the present disclosure, a system for delivering information about physical properties in a lateral section of a well is presented, the system comprising: an autonomous deployment system arranged at a toe section of the well away from a production zone, the deployment system comprising: a plurality of ruggedized buoyant data modules (RBDMs), each RBDM comprising one or more sensors configured to sense, when injected into a fluid of the well, the physical properties along the lateral section of the well and store data corresponding to

sensed physical properties into a memory of said RBDM; and a delivery module configured to carry an RBDM of the plurality of RBDMs from the toe section to a region of the lateral section of the well close to the production zone, and inject the RBDM into the fluid, wherein when injected into the fluid, adjustable buoyancy features of the RBDM in combination with a flow of the fluid cause the RBDM to travel along the lateral section of the well to a location of the well for readout of the data.

[0014] According to a second embodiment of the present disclosure, a system for delivering information about physical properties in a lateral section of a well is presented, the system comprising: an autonomous mobile robot comprising a plurality of ruggedized buoyant memory modules (RBMMs), the autonomous mobile robot comprising one or more sensors configured to sense the physical properties along the lateral section of the well and store data corresponding to sensed physical properties into a memory of at least one RBMM of the plurality of RBMMs, wherein the autonomous mobile robot travels from a toe section to a heel section of the well and injects the at least one RBMM into a fluid of the well for conduction of the RBMM by a flow of the fluid to a location of the well for readout of the data.

[0015] Further aspects of the disclosure are shown in the specification, drawings and claims of the present application.

BRIEF DESCRIPTION OF DRAWINGS

[0016] The accompanying drawings, which are incorporated into and constitute a part of this specification, illustrate one or more embodiments of the present disclosure and, together with the description of example embodiments, serve to explain the principles and implementations of the disclosure.

[0017] FIG. 1 illustrates a cross sectional view of an exemplary known oil production field, comprising one or more drilled wells for production of oil and/or gas.

[0018] FIG. 2A shows an exemplary embodiment according to the present disclosure of a lateral well ruggedized buoyant data module deployment (LWRBDMD) system that is positioned in a lateral section of a well of the oil production field shown in FIG. 1 between a production zone and

a heel section of the well. As can be seen in FIG. 2A, the LWRBDMD system is positioned in an annular region of the lateral section of the well.

[0019] FIG. 2B shows an alternative exemplary embodiment according to the present disclosure of the (LWRBDMD) system of FIG. 2A, wherein the LWRBDMD system is positioned in a shallow region of the lateral section of the well.

[0020] FIG. 3 shows an exemplary embodiment according to the present disclosure of a lateral well ruggedized buoyant data module deployment (LWRBDMD) system that is positioned in a toe section of a well of the oil production field shown in FIG. 1.

[0021] FIG. 4A shows an exemplary embodiment according to the present disclosure of a lateral well ruggedized buoyant data module deployment (LWRBDMD) system comprising a delivery module that loads ruggedized buoyant data modules (RBDMs) stored in the toe region of a well of the oil production field shown in FIG. 1 from a base station, and positions the loaded RBDMs into a region of a production zone (e.g., between the production zone and heel section of the well) for injection into the fluid flow.

[0022] FIG. 4B shows an alternative exemplary embodiment according to the present disclosure of the (LWRBDMD) system of FIG. 4A, wherein the delivery module stores all of the RBDMs to be injected and positions the RBDMs into a region of the production zone for injection into the fluid flow.

[0023] FIG. 4C shows an alternative exemplary embodiment according to the present disclosure of the (LWRBDMD) system of FIG. 4A, wherein the delivery module stores all of the ruggedized buoyant data modules (RBDMs) to be injected and positions the RBDMs into a heel region of the well for injection into the fluid flow.

[0024] FIG. 5 shows an exploded view of a ruggedized buoyant data module (RBDM) according to an embodiment of the present disclosure.

[0025] FIG. 6A shows a picture of an exemplary embodiment of an actual RBDM according to the present disclosure having a substantially spherical enclosure, wherein the enclosure top of the RBDM is removed.

[0026] FIG. 6B shows a picture of the RBDM of FIG. 6A in a closed state wherein the enclosure top and bottom are mated.

[0027] FIG. 7A shows a ruggedized buoyant data module (RBDM) according to an exemplary embodiment of the present disclosure comprising passive and active mobility and buoyancy control features. In particular, FIG. 7A shows details of mobility control features including flagella.

[0028] FIG. 7B shows a ruggedized buoyant data module (RBDM) according to another exemplary embodiment of the present disclosure comprising passive and active mobility and buoyancy control features. In particular, FIG. 7B shows details of mobility control features including flagella and hair.

[0029] FIG. 7C shows a ruggedized buoyant data module (RBDM) according to yet another exemplary embodiment of the present disclosure comprising passive and active mobility and buoyancy control features. In particular, FIG. 7C shows details of mobility control features including drag skirts.

[0030] FIG. 8A shows details of an exemplary embodiment according to the present disclosure of buoyancy control features of the RBDM according to the present teachings.

[0031] FIG. 8B shows details of another exemplary embodiment according to the present disclosure of buoyancy control features of the RBDM according to the present teachings.

[0032] FIG. 8C shows details of yet another exemplary embodiment according to the present disclosure of buoyancy control features of the RBDM according to the present teachings.

[0033] FIG. 9 shows details of an exemplary embodiment according to the present disclosure of an adaptive buoyancy control feature of the RBDM according to the present teachings.

[0034] FIG. 10A shows various views of a mobile robot according to an embodiment of the present disclosure with further details shown in FIGs. 10B, 10C, 10D and 10E.

[0035] FIG. 10B shows a view of a clearance space to avoid debris and sand build up in the pipe provided by a position of the mobile robot of FIG. 10A.

[0036] FIG. 10C shows a docking station with wireless (inductive) charging according to an embodiment of the present disclosure that can include a power source to recharge batteries of the mobile robot of FIG. 10A.

[0037] FIG. 10D and FIG. 10E show respective views of expanded and retracted flow diverters of the mobile robot of FIG. 10A used to constrict fluid flow past the mobile robot.

[0038] FIG. 11A shows a diagram of an exemplary embodiment according to the present disclosure, wherein data of an RBDM injected into the flow is read at the surface of the well.

[0039] FIG. 11B shows a diagram of an exemplary embodiment according to the present disclosure, wherein data of an RBDM injected into the flow is read at a location of the well and transferred though wire to the surface of the well.

[0040] FIG. 11C shows a diagram of an exemplary embodiment according to the present disclosure, wherein data of an RBDM injected into the flow is read at a location of the well and transferred to a relay memory module that is read at the surface of the well.

[0041] FIG. 11D shows a diagram of an exemplary embodiment according to the present disclosure, wherein a rest station in a heel section of the well is used to provide a wired connection to a mobile robot in the lateral section of the well.

[0042] FIG. 11E shows a diagram of an exemplary embodiment according to the present disclosure, wherein data from a mobile robot is wirelessly read at a location of the well and transferred to a relay memory module that is read at the surface of the well.

DEFINITIONS

[0043] As used herein the term “ruggedized” may refer to a device or system that is specifically designed to reliably operate in harsh environments and conditions, such as, for example, corrosive and/or erosive environments with high temperatures, pressures and vibrations that may be present in a downhole of a well, either during drilling or production of the well. As known in the art, generally, ruggedization of a device may include provision of a case of the device that is specifically designed in view of the harsh environments and conditions to protect components and/or systems internal to the case. Furthermore, such components and/or systems may be designed with increased tolerance to the harsh environments and conditions.

[0044] As used herein the term “buoyant” may refer to the property of an object to float when immersed in a fluid. In other words, an upward force exerted by the fluid on the object opposes the weight of the immersed object.

[0045] As used herein, an object is said to have a “neutral buoyancy” if the buoyancy of the object is such that the object will neither sink nor rise in an immersed fluid. In other words, the object's average density is equal to the density of the fluid in which it is immersed, resulting in the buoyant force balancing the force of gravity that would otherwise cause the object to sink (if the body's density is greater than the density of the fluid in which it is immersed) or rise (if it's less).

[0046] As used herein the expression “memory module” may refer to a device that comprises a memory for data storage and retrieval. One such memory module is a ruggedized buoyant memory module (RBMM) as described in the above referenced International patent application PCT/US18/55565, the disclosure of which is incorporated herein by reference in its entirety.

[0047] As used herein the expression “data module” may refer to a memory module that comprises sensors to derive data corresponding to sensed information. The present disclosure describes with reference to, for example, FIGs. 5-9, data modules, referred to as buoyant data memory modules (RBDMs), that are ruggedized and buoyant with respect to a fluid that flows in a lateral section of a well (e.g., FIG. 1).

[0048] As used herein the term “autonomous” may refer to a device or system that is self-sufficient in performing tasks for which it was designed. Accordingly, such autonomous device or system may include a local power source.

DETAILED DESCRIPTION

[0049] FIG. 1 illustrates a cross sectional view of an exemplary oil production field 100, comprising one or more drilled wells (Well_1, Well_2, ...) for production and extraction of oil and/or gas from various regions of the field. A person skilled in the art is well aware of items of the production field 100 indicated in FIG. 1, the description of which is beyond the scope of the present disclosure. In particular, as can be seen in FIG. 1, a vertical section of the Well_1 may be drilled to reach and penetrate an oil- or gas-rich shale (e.g., rock formation), and a lateral (e.g., horizontal) section of the Well_1, which, in the exemplary case of FIG. 1 is substantially horizontal, may be drilled along the shale, starting from a heel section of the Well_1, and ending at a toe section of the Well_1. A person skilled in the art would know that the vertical section of the Well_1 may extend 1 to 3 km below the surface and the lateral section of the Well_1 may extend for distances of, for example, 2-3 km or more.

[0050] With continued reference to FIG. 1, as it is well known by a person skilled in the art, fluids, including oil, water, and natural gas, may enter the Well_1, for example, through open-hole or a casing of the Well_1, at production perforated intervals / zones that may be formed in the lateral section of the Well_1. Each of such production intervals / zones may include holes and/or openings that extract the fluid from the shale and route into the casing of the Well_1. As shown in FIG. 1, the perforated intervals / production zones may be separated by distances of, for example, about 100 meters (i.e., about 300 feet), and between each of the intervals (or stages) there are several clusters of perforations with closer spacing in order to cover a lengthy lateral and extract more hydrocarbon from shale/tight formations. Since there are many production zones, the inflow contribution for each of the intervals (or zones or clusters), such as, for example, local pressure, temperature, flow rates, and composition, may vary due to inherent geology and the accuracy with which the lateral section of the Well_1 intersects the oil-bearing rock formations at the production zones.

[0051] As described above, collecting data at regions of the Well_1, for example close to each of the production zones, can help evaluate effectiveness of inflow contribution for each of the production zones and further help in optimizing production (e.g. by altering the perforation / completion design). Systems and methods according to the present disclosure collect data from battery powered sensors that are placed inside of a well, including data related to, for example, pressure, temperature, flow rates and composition (e.g., fraction of oil, gas, water).

[0052] According to one embodiment of the present disclosure, sensors may be included in ruggedized buoyant data modules (RBDMs) to allow each such module to sense downhole information as the module is carried along, with the fluid flow, through the lateral section of the well and past one or more production zones. A deployment system may be used to store and inject the modules into the flow. Optionally, the deployment system may include a delivery module (e.g., a mobile robot) that loads each RBDM from a stored location in the downhole (e.g., toe of the well) and carries the RBDM to a region of the well where the flow is sufficient to carry the RBDM towards the heel or surface of the well.

[0053] According to another embodiment of the present disclosure, sensors may be included in a delivery module that stores the memory/data modules. Such delivery module, effectively a specialized mobile robot (e.g., FIGs. 10A-10E later described), may travel through the lateral section of the well, sense the downhole information, and save corresponding data to the RBDMs or ruggedized buoyant memory modules (RBMMs) before ejection of the modules into a region of the well where the fluid flow can carry the modules.

[0054] Data collected by the sensors can be logged, for example, as a function of time, and saved to the ruggedized buoyant memory/data module (RBMM/RBDM) according to the present disclosure. In turn, each of such modules may be injected into the flow of the fluid and extracted at the top of the well (e.g., Well_1 of FIG. 1), or at a location close to the heel of the well, for reading by an operator or a computer.

[0055] According to an embodiment of the present disclosure, timing between the injection of each of the modules can be adjusted according to any desired scheme. For example, it may be desirable to provide more data updates, and therefore higher frequency of injection of the modules,

in an early stage of a production zone where a change in local physical properties, such as, for example, flow, pressure, etc., may be high, and to provide fewer data updates, therefore lower frequency of injection, in later stages of the production zone.

[0056] The systems and methods according to the present disclosure solve problems related to cabling in the downhole of a well by using the flow of fluid inside of the well to physically deliver the data. Furthermore, systems and methods according to the present disclosure solve problems related to low fluid flow in the lateral section of the well by carrying the memory/data modules to regions of the lateral well where the flow is sufficient, or by providing the modules with active mobility features (e.g., motorized modules) that allow the modules to navigate through a low flow. Finally, systems and methods according to the present disclosure provide for further active and/or passive mobility and buoyancy control features that solve the problem of travel of the modules through undulations of the fluid which may trap the modules in the lateral section of the well.

[0057] FIG. 2A shows an exemplary embodiment according to the present disclosure of a lateral well ruggedized buoyant data module deployment (LWRBDMD) system (210) that is positioned in a lateral section of a well of the oil production field shown in FIG. 1 between a production zone and a heel section of the well. As can be seen in FIG. 2A, according to an exemplary embodiment of the present disclosure, the LWRBDMD system (210) may be positioned in an annular region of the lateral section of the well. The LWRBDMD may carry a plurality of ruggedized buoyant data modules (RBDMs, 220) which can be individually injected into the flow of the fluid for subsequent sensing (via built-in sensors of the RBDMs) of downhole information and storage of corresponding sensed data (via built-in memory) for delivery of the sensed data to the surface of the well.

[0058] With continued reference to FIG. 2A, since the LWRBDMD system (210) is positioned after (e.g., downstream from) the production zone, inflow from the production zone can generate enough flow to carry an injected RBDM (220a) towards the surface or heel of the well. In particular, the injected RBDM (220a) may be subjected to a velocity vector of the fluid, V_{fluid} , and a gravity vector, g . Since the lateral section of the well may not be perfectly flat and may include undulations, the velocity vector, V_{fluid} , may follow the undulations such that the flow of the fluid may go up and down with respect to the gravity vector, g . It follows that according to various embodiments of the present disclosure, as described in the following paragraphs, drag/friction

conditions of the module (e.g. RBDM, RBMM) may be controlled via passive and/or active features to assure the module is dragged along with the flow of the fluid and does not get stuck/trapped on/against walls of the lateral section of the well.

[0059] Active mobility features provided to the RBDMs (220) according to the present disclosure may include one or more of: a) motorized movement of structure (e.g., propeller, flagella, fin etc.), b) gas and/or fluid jet, c) deployable and/or retractable sail and/or drag, d) adjustment of the buoyancy via bellows, balloons or other, and e) in situ fluid flow energy harvesting (piezoelectric flagella) and/or power motor. According to further embodiments of the present disclosure, the passive mobility features provided to the RBDMs (220) according to the present disclosure may include features, such as, for example, flagella, hair, parachute and drag skirts. In some cases, the active and passive mobility features may complement one another for robust delivery of the modules to the surface and/or heel of the well.

[0060] It should be noted that methods and devices for placement of components inside of the downhole, including in the lateral section of the well, are well known by a person skilled in the art and not the subject of the present disclosure when referred to a LWRBDMD placement. One or more LWRBDMD (210) may be placed at various locations of the downhole from which local information may be desired. Such locations may include production zones formed inside the well from which oil, gas, and/or water may enter the well. Furthermore, it should be noted that systems and methods according to the present teachings may apply to any downhole containing fluids, whether a conventional vertical downhole, or unconventional horizontal (lateral) downhole (e.g., as known in fluid extraction via hydraulic fracturing), and irrespective of presence of a casing within the downhole.

[0061] The LWRBDMD (210) according to the present disclosure is an autonomous device that is powered by a battery module (not shown). The battery module may provide powering to various elements of the LWRBDMD (210). The battery module may have enough charge to power the LWRBDMD (210) through the life of the LWRBDMD (210) when positioned in the downhole.

[0062] With further reference to FIG. 2A, the RBDMs (220) according to the present disclosure may include one or more sensors for gathering data. Once injected into the fluid flow, such sensors

may be exposed (e.g., in contact) with the inside region of the well, inclusive of the fluid, so to sense relevant local physical properties of the well, such as, for example, flow rate, composition, temperature, and pressure. Such sensors may be encased within ruggedized enclosures of the RBDMs (220) that protect the sensors as well as other internal components of the RBDMs (220) from a harsh local downhole environment while providing adequate exposure of the sensors to the environment. According to an exemplary embodiment of the present disclosure, the sensors of the RBDMs (220) may be lower quality sensors to allow for a reduced cost of the deployment system (210). In such configuration, the lower quality sensors may be pre-calibrated, or initialized, prior to injection into the flow via higher quality sensors (225) integrated within the deployment system (210) and designed to sense variations of downhole information with respect to the pre-calibrated or initialized data.

[0063] The LWRBDMD system (210) of FIG. 2A may include a power source (e.g., rechargeable battery) and central processing unit CPU module (not shown) to control operation of the LWRBDMD system (210), including, but not limited to, data write/initialization to the RBDMs (220) and injection of the RBDMs (220) into the fluid flow. Similarly, each of the RBDMs (220) may include a power source (e.g., rechargeable battery) and a central processing unit (not shown) for control of the sensors, data read from the sensors, storage and manipulation of data read from the sensors, date and time (e.g., clock) generation, data write to local memory, and data transfer to readers at the surface/heel of the well. A person skilled in the art would know of many different design and implementations of such CPUs which are beyond the scope of the present application. It should be noted, however, that such CPUs may be based on readily available off-the-shelf devices and/or proprietary designs using well known in the art methods and tools, which in combination allow implementation of a cost-effective solution for gathering of downhole information. Other features of the LWRBDMD system (210) related to, for example, storage, stacking and ejection of the RBMMs (220) can be found, for example, in the above referenced International patent application PCT/US18/55565, the disclosure of which is incorporated herein by reference in its entirety.

[0064] With continued reference to FIG. 2A, the LWRBDMD system (210) may include a plurality of RBDMs (220) which can be injected into the fluid flow periodically. The frequency of

injection of the RBDMs (220) into the fluid flow may be pre-programmed into a memory of the LWRBDMD system (e.g., within the CPU) according to a lookup table or a formula that is a function of one or more parameters, including time, date, and optionally on any sensed local physical property of the well. A person skilled in the art is well aware that during production, information from the downhole of the well may be desired at a higher frequency during a beginning phase of the production, and lower frequency during latter phases of the production. Accordingly, any desired frequency of injection of the RBDMs (220) may be pre-programmed into the memory of the LWRBDMD system (210). A number of the RBDM modules (220) included in the LWRBDMD system (210) may be adjusted, prior to placement in the downhole, according to the desired frequency of injection and life of the system (210). According to some exemplary embodiments, tens to hundreds of such RBDMs (220) may be included in each LWRBDMD system (210).

[0065] As shown in FIG. 2A, once injected, and in view of the buoyancy of the (injected) RBDM (220a), the injected RBDM (220a) is conducted by the fluid flow through the well and in a same direction as the fluid flow, to a location of the well where the injected RBDM (220a) can be read, collected, or further manipulated. Such location may be the surface of the well, or, for example, a heel of the well. Due to the harsh environment within the downhole of the well, the RBDM (220) is designed to withstand temperatures above 85 °C, and up to, for example, 125 °C. As described above, active and/or passive mobility and buoyancy control features of the RBDMs (220) according to the present disclosure allow conduction of the modules in spite of undulations and/or varying flow rates of the fluid. In particular, the buoyancy control features may provide a neutral buoyancy of the RBDMs (220) so to allow floating of the RBDMs (220) in the fluid without sinking to the bottom of the lateral section of the well or rising and getting trapped by wall of the lateral section of the well.

[0066] FIG. 2B shows an alternative exemplary embodiment according to the present disclosure of the (LWRBDMD) system (220) of FIG. 2A, wherein the LWRBDMD system (210) is positioned in a shallow region of the lateral section of the well downstream from the production zone. A person skilled in the art is well aware of methods and systems to form such shallow region

and place the system (220) in such shallow region. Principle of operation of the system is similar to one described above with respect to FIG. 2A.

[0067] The LWRBDMD (210) systems of FIG. 2A and FIG. 2B are placed downstream from the production zone so that an injected RBDM (220a) is subjected to a fluid flow that is sufficient to carry it along the lateral section of the well to the surface or heel of the well. In some cases, it may be desired to place the LWRBDMD system farther away from the heel of the well and from the production zone toward a toe section of the well, as shown in FIG. 3. In particular, FIG. 3 shows an exemplary embodiment according to the present disclosure of a lateral well ruggedized buoyant data module deployment (LWRBDMD) system (310) that is positioned in the toe section of a well of the oil production field shown in FIG. 1. A person skilled in the art is well aware that the toe section of the well may include very low or zero flow rate and therefore, an injected RBDM (320a) from the LWRBDMD system (310) may not be subjected to enough flow to carry it past the production zone where a higher fluid flow exists. It follows that according to various embodiments of the present disclosure, the RBDMs (320) stored in the LWRBDMD system (310) may be fitted with active mobility features to move the RBDMs (320) once injected into the fluid at the toe section of the well. As will be described later in the present disclosure, such active mobility features may include one or more of: a) motorized movement of structure (e.g., propeller, flagella, fin etc.), b) gas and/or fluid jet, c) deployable and/or retractable sail and/or drag, d) adjustment of the buoyancy via bellows, balloons or other, and e) in situ energy harvesting (piezoelectric flagella) and/or power motor. According to further embodiments of the present disclosure, the active mobility features may be complemented with passive mobility features, such as, for example, flagella, hair, parachute, and drag skirts provided to the RBDMs (320).

[0068] In some cases, it may be desirable to provide modules with low complexity for a reduced cost of the modules, while placing/storing the modules in the toe region of the well. According to an embodiment of the present disclosure, complexity related to some of the active mobility features of the modules may be removed by including a delivery module that positions the modules (RBDMs) into a region of the well with sufficient flow rate, as shown in FIG. 4A.

[0069] FIG. 4A shows an exemplary embodiment according to the present disclosure of a lateral well ruggedized buoyant data module deployment (LWRBDMD) system (410A) comprising a

delivery module (450) and a (stationary) base station (430). As can be seen in FIG. 4A, the base station (430) is placed in the toe section of the well and stores a plurality of ruggedized buoyant data modules (RBDMs, 420). The delivery module (450) is first positioned at the toe section of the well for loading of at least one RBDM (420') from the base station (430). Then, the delivery module (450) is positioned into a region close to (e.g., downstream from) the production zone for injection of the loaded RBDM (420') into the fluid having a sufficient flow to carry the module to the surface or heel of the well. The delivery module (450) then injects the loaded RBDM (420') so that the injected RBDM (420a) can be carried along the lateral section of the well via the fluid flow. The sequence of positioning of the delivery module (450) to the toe section, loading of at least one RBDM (420) into the delivery module (450), positioning the delivery module (450) to a vicinity of the production zone where sufficient fluid flow exists, and injection of the loaded RBDM (420') into the fluid can be repeated for each of the RBDMs (420) stored in the base station (430).

[0070] With further reference to FIG. 4A, according to an exemplary embodiment of the present disclosure, the delivery module (450) can be tethered via a cord/cable to the base station. Such tethering may provide power and/or motion (push and pull) to the delivery module (450). According to another exemplary embodiment, the delivery module (450) may be autonomous, and include, for example, a rechargeable battery and means for motion. Such means for motion may include, for example, motors, actuators, springs, or any other means known in the art. Loading of the RBDMs (420) into the delivery module (450) may be provided by any means known in the art. According to some embodiments of the present disclosure, the base station (420) may include a power source, such as, for example, a rechargeable battery or cabled power source from the surface of the well.

[0071] FIG. 4B shows an alternative exemplary embodiment according to the present disclosure of a LWRBDMD system (410B), wherein the delivery module (450) stores all of the RBDMs (420) to be injected. Similar to the embodiment described above with reference to FIG. 4A, the delivery module (450) of FIG. 4B is positioned into a region close to (e.g., downstream from) the production zone for injection of a RBDM (420) into the fluid flow. According to some embodiments, the delivery module (450) can include a load and ejection mechanism (425) that

first loads one RBDM (420) from a storage location within the delivery module (450), and then ejects the loaded RBDM (420') into the fluid flow. Some exemplary loading and ejection mechanisms are described, for example, in the above referenced International patent application PCT/US18/55565, the disclosure of which is incorporated herein by reference in its entirety.

[0072] FIG. 4C shows an alternative exemplary embodiment according to the present disclosure of an LWRBDMD system (410C), wherein the delivery module (450) stores all of the RBDMs (420) to be injected. Different from the embodiments described above with reference to FIG. 4A and FIG. 4B, the delivery module (450) of FIG. 4C is positioned into (e.g., travels to) a region past the production zone and close to the heel of the well for injection of a RBDM (420) into the fluid flow. In some exemplary embodiments of the present disclosure, the delivery module (450) may be a specialized mobile robot (e.g., FIGs. 10A-10E later described) that includes sensors to sense downhole information and store corresponding data into the modules (420) prior to ejection of the modules into the fluid at the heel of the well. More information on sensing, storing and writing data into the memory of the modules (420) can be found, for example, in the above referenced International patent application PCT/US18/55565, the disclosure of which is incorporated herein by reference in its entirety.

[0073] The configuration depicted in FIG. 4C can allow usage of simple memory modules (RBMMs) without requirement to include sensors, CPUs, batteries, or complex buoyancy and motion control since a) the memory modules are not required to sense information and b) the memory modules are injected at the heel of the well where the vertical flow of the fluid can easily carry the modules along the vertical section of the well and towards the surface of the well. According to one exemplary embodiment of the present disclosure, the delivery module (450) shown in FIG. 4C (and FIG. 4B) may be autonomous, with a local/integrated power source capable for sustaining operation of the delivery module (450) through a predetermined time. In such configuration, the base station (430) may not be needed.

[0074] FIG. 5 shows an exploded view of a ruggedized buoyant data module RBDM (220) according to an embodiment of the present disclosure. As shown in FIG. 5, the RBDM (220) according to the present disclosure comprises an enclosure top (510) that is mated with an enclosure bottom (515) to encapsulate, in a ruggedized fashion, at least one memory device (520).

A (micro) CPU (540) may be used to control various activities of the RBDM (220), such as, for example, i) write and/or read data to/from the memory device (520) via, for example, a contact interface (550) or a wireless interface based on an antenna (560), ii) controlling local sensors (e.g., 542, 545, 560, 570) to sense downhole information and writing sensed data to the memory device (520), iii) readout of the sensed data from the memory device (520), and iv) controlling mobility/buoyancy features (if present, as shown for example in FIGs. 7-9 later described) of the RBDM (220), in view, for example, of some of the sensed information. An optional battery (530) may be provided to power the RBDM (220), such as, for example, to allow autonomous operation of the RBDM (220) per above activities. An optional indicator (570), such as for example, a light-emitting diode (LED), may be used to help in locating the RBDM (220) once at the surface of the well.

[0075] With continued reference to FIG. 5, according to an exemplary embodiment of the present disclosure, the RBDM (220) may include one or more sensors (e.g., 542, 545, 560, 570) for measuring local downhole data such as, for example, flow rate, water and salt content, temperature, pressure, composition, magnetic response of pipe joints, etc. As shown in FIG. 5, such sensors may include a) an inertial measurement sensor (IMU, 542) that can measure/sense a flow rate of the RBDM (220) based on a (known) drag coefficient of the RBDM (220), wherein a velocity of the RBDM (220) can be obtained by integration of the flow rate, b) a conductivity sensor/probe (e.g., 560) that can measure water and salt content, c) an array of pressure sensors (e.g., 560) that can perform differential measurement of local pressure which can also allow to derive local changes in flow, d) a resistance thermometer (e.g., 570), also known as an RTD sensor, that can measure local temperatures, e) an optical camera (e.g., 545) that, when combined with light from an LED, can be used to determine, for example, a composition of material at the downhole, including oil, water, gas and sand, and f) magnetic sensors (e.g., 560), such as, for example, Hall effect sensors, that can be used to determine small changes in magnetic response due to pipe joints in the lateral section of the well, and thereby allow to determine a position of the RBDM (220) based on such magnetic response, in combination with time stamps and flow rates. It should be noted that such sensors do not represent a complete list of possible sensors fitted within the RBDM (220) according to the present teachings, as a person skilled in the art would clearly use the present teachings to include other type of sensors as deemed necessary.

[0076] According to a further embodiment of the present disclosure, the RBDM (220) shown in FIG. 5 may be fitted with a passive radio frequency identification (RFID) tag for identification and localization of the RBDM (220). In turn, a reader may use such passive RFID to locate/identify the RBDM (220) at a surface or heel of the well prior to reading the data from the RBDM (220). According to other exemplary embodiments of the present disclosure, the RBDM (220) may be configured for inductive coupling of data and/or power via methods and devices that are well known in the art.

[0077] With further reference to the RBDM of FIG. 5, the enclosure top (510) and bottom (515) may be made of any material known in the art that may protect (shield) the memory device (520) and other elements (CPU, sensors, etc.) encased within the enclosure in view of known downhole conditions (e.g., temperature, pressure, flow rate, composition), while providing sufficient buoyancy for a small volume of the RBDM. Various metals, such as stainless steel and titanium, and various polymers may fit such requirements.

[0078] According to an embodiment of the present disclosure, the enclosure top (510) and bottom (515) provide for a spherical shape of the RBDM (or RBMM) that can withstand a downhole pressure of up to 5500 psi and thereby safely protect internal elements of the module. According to a first preferred embodiment, the spherical shape of the module provided by the enclosure top (510) and the enclosure bottom (515) has a diameter of 24 mm (i.e., 2.4 cm) with the enclosure top (510) and bottom (515) made of grade 5 titanium at a thickness of 0.53 mm or of grade 9 titanium at a thickness of 1.0 mm. According to a second preferred embodiment, the spherical shape of the module provided by the enclosure top (510) and the enclosure bottom (515) has a diameter of 10 mm (i.e., 1.0 cm) with the enclosure top (510) and bottom (515) made of grade 5 titanium at a thickness of 0.22 mm. Both such preferred embodiments allow for a module that can withstand a downhole pressure of up to 5500 psi.

[0079] According to an exemplary embodiment of the present disclosure, a shape of the RBDM (220) shown in FIG. 5, as dictated by a shape of the enclosure top (510) and bottom (515) when mated, can be substantially spherical (per in FIG. 5), or substantially bullet shaped. Other three-dimensional shapes, including shapes with either rounded or squared edges, may also be envisioned. It should be noted that a shape of the RBDM (220) may be also a function of any

active/passive mobility and/or buoyancy control features of the RBDM (220), some of which are shown in FIGs. 7-9 later described.

[0080] Data stored in the RBDM (220) can be extracted by any means known in the art. According to an exemplary embodiment of the present disclosure, such data can be extracted via manual means, wherein the RBDM (220) is first located and then physically handled (e.g., human or robotic arms) to combine an element of the RBDM (220), such as for example, the memory device (520) (e.g., a solid-state memory device), into a reading station that extracts (reads) the data stored into the memory device (520).

[0081] According to another exemplary embodiment of the present disclosure, the data stored in the RBDM (220) can be extracted via autonomous means, wherein the RBDM (220) is first located and then physically handled (e.g., human or robotic arms) to read the data directly from the RBDM (220) via, for example, an integrated interface/reader of the CPU (540). An optional integrated indicator, such as the LED (570) may help in localizing the RBDM (220), or alternatively, localization and identification of the RBDM (220) may be provided via passive RFID tagging as described above. The RBDM (220) may be provided via a small battery (530) integrated within the RBDM (220). Such battery (530) may be a rechargeable battery that is charged prior to data storage into the RBDM (220) and injection of the RBDM (220) into the fluid flow. A person skilled in the art is well aware of other means for provision of power to the RBDM (220), such as, for example, radiated power that may be used to charge power storage cells (e.g., capacitor banks) within the RBDM (220) prior to either writing or reading data into the memory device (530) (e.g., solid-state memory).

[0082] According to yet another exemplary embodiment of the present disclosure, the data stored in the RBDM (220) can be extracted via remote/wireless means. In such embodiment, data from the RBDM (220) can be read wirelessly, for example through the integrated antenna (not shown in FIG. 5), without the need to (precisely) locate and physically handle the RBDM (220). To this end, the micro CPU (540) shown in FIG. 5 may be Wifi and/or Bluetooth enabled. Power for remote/wireless transmission of the data stored in the RBDM (220) may be provided via a small battery (530) integrated in the RBDM (220).

[0083] FIG. 6A shows a picture of an exemplary embodiment of an actual RBDM (220) having a substantially spherical enclosure, wherein the enclosure top (510) of the RBDM (220) is removed. In the exemplary embodiment depicted in FIG. 6A, the RBDM (220) comprises the memory device (520), the battery (530), the CPU (540), and sensors (e.g., 542, 545, 560, 570) described above with reference to FIG. 5, encapsulated within the enclosure top (510) and the enclosure bottom (515) that may be sealed via a seal (e.g., gasket, rubber washer) (605). As can be seen in FIG. 6A, according to an exemplary embodiment of the present disclosure, the various internal elements of the RBDM (220) are fitted within slots formed in the enclosure bottom (515). A person skilled in the art would know of many methods for fabricating the enclosure bottom (515) and top (510), including for example, molding methods. As described above, a diameter of the RBDM (220) in a closed state, shown in FIG. 6B, may be 2.5 centimeters or less. Such small size can advantageously allow storage of a large quantity (e.g., hundreds) of RBDMs in a relatively small volume. A person skilled in the art would realize that the RBDM (220) according to the present teachings is not limited to a specific size, as a desired buoyancy (e.g., neutral buoyancy) of the RBDM (220) may be achieved for any size of the RBDM (220).

[0084] In addition to the sensing and communications functions, the RBDM (220) according to the present disclosure may include passive and/or active mobility features as shown in Table 1 below and depicted in FIGs. 7-9. As described above, such mobility features can enable movement of the RBDM (220) along the lateral section of the well in spite of undulations of the fluid and/or lack of sufficient drag from the flow of the fluid that may trap the RBDM (220) at high points (of the undulations) along walls of the lateral section.

[0085] Table 1 shows a list of active and passive mobility features of the RBDM (220) according to the present disclosure.

Active mobility features	Passive mobility features
a1) Motorized movement of a structure, such as propeller, flagella, fin, etc. (e.g., FIGs., 7-9)	a2) Flagella (e.g., FIGs. 7A, 7B)

b1) Gas/fluid jet (e.g., FIG. 8A)	b2) Hair (e.g., FIG. 7B)
c1) Deployable/retractable sail/drag skirts (e.g., FIG. 7C)	c2) Parachute
d1) In situ energy harvesting, via for example of piezoelectric flagella, for providing power to motor (e.g., FIGs. 7A, 7B)	d2) Drag skirts (e.g., FIG. 7C)

Table 1

[0086] With reference to the passive features shown in Table 1 above, such features are configured to provide an increase in drag coefficient of the RBDM (220) to ensure that the RBDM (220) flows along with the fluid and does not get trapped. Alternatively, or in addition, the active features shown in Table 1 can be deployed to provide an increased robustness to the movement of the RBDM (220) along the lateral section of the well. As can be seen in Table 1, some of the active features are designed to activate/deploy the passive features, such as, for example, motors to activate/deploy the flagella of FIGs. 7A and 7B or the drag skirts of FIG. 7C.

[0087] According to one exemplary embodiment of the present disclosure, the active features can be deployed in a case where it is sensed that the RBDM (220) is trapped (e.g., due to low flow variation and/or being stuck to wall of well due to, for example, undulations of the flow). Such sensing may be, for example, based on an acceleration of the RBDM (220) sensed by the IMU (542 of FIG. 5) integrated within the RBDM (220). For example, if the IMU (542) senses no net acceleration over a specific time period, then the RBDM (220) may be assumed trapped by the micro CPU (540 of FIG. 5) of the RBDM (220) which may prompt said CPU to control the active features for deployment.

[0088] FIG. 7A shows a ruggedized buoyant data module (RBDM, 220A) according to an exemplary embodiment of the present disclosure comprising passive and active mobility (780, 785) and buoyancy (790) control features. As previously described, active mobility and buoyancy control features of the RBDM according to the present disclosure may be controlled based on information sensed by the RBDM via local sensors of the RBDM, such as, for example, in view of a flow rate of the RBDM as measured by a local IMU sensor (e.g., 542 of FIG. 5). In particular,

as can be seen in FIG. 7A, mobility control of the RBDM (220A) includes flagella (780) that protrude the surface of an outer shell of the RBDM (220A) defined by the enclosures top and bottom (510, 515). A person skilled in the art is well aware of various usages of such flagella (780), which can be in the form of helically shaped structures, in controlling drag and/or motion of a moving body. According to an exemplary embodiment of the present disclosure, such flagella (780) can be passive elements controlling drag of the RBDM (220A) and include a coupling to the outer shell of the RBDM (220A) that allows for rotation of the flagella (780) in a clockwise and/or anti-clockwise direction. According to another exemplary embodiment of the present disclosure, the flagella (780) may be implemented as active elements via couplings to actuators (785) that can control motion (e.g., rotation) of the flagella (780), and thereby actively control mobility of the RBDM (220A). A person skilled in the art would know of many possible implementations of the actuator (785), including, for example, using piezoelectric elements or electroactive polymers (EAPs).

[0089] With continued reference to FIG. 7A, the RBDM (220A) may include in addition, or alternative, active mobility features per features a1) and b1) of Table 1. According to one embodiment of the present disclosure, piezoelectric elements coupled to, for example, the flagella (780), may be used for in situ energy harvesting and thereby providing power to various electronics/actuators of the RBDM (220A).

[0090] FIG. 7B shows a variation (220B) of the RBDM (220A) described above with reference to FIG. 7A, wherein in addition, or as an alternative, to the flagella (780), hair elements (782) can be used as a passive mobility feature to control drag of the RBDM (220B). As can be seen in FIG. 7B, the outer shell of the RBDM (220B), defined by the enclosures top and bottom (510, 515), can include hair elements (782) protruding from the surface of the outer shell, and therefore increase drag of the RBDM (220B). A person skilled in the art is well aware that by increasing drag, the RBDM (220B) may be able to move along the lateral section of the well in view of a lower flow (velocity of the fluid).

[0091] FIG. 7C shows a ruggedized buoyant data module (RBDM, 220C) according to yet another exemplary embodiment of the present disclosure comprising passive and active mobility (785, 788) and buoyancy (790) control features. In particular, as can be seen in FIG. 7C, mobility control

of the RBDM (220C) includes drag skirts (or sails) (785) that protrude, or are connected to, the surface of an outer shell of the RBDM (220C) defined by the enclosures top and bottom (510, 515). A person skilled in the art is well aware of various usages of such drag skirts (785), which can be in the form of flat structures having surfaces oriented in a manner to provide increased drag of the RBDM (220C). As can be seen in FIG. 7C, the drag skirts (788) can be of different shapes (surfaces) and connected, for example, symmetrically around the outer shell of the RBDM (220C). According to an exemplary embodiment of the present disclosure, the drag skirts (785) can be passive elements having fixed orientation (e.g., always deployed). According to another exemplary embodiment of the present disclosure, the drag skirts (785) may be implemented as active elements via couplings to actuators (788) that can control position (e.g., rotation, angular position) of the drag skirts (785), and thereby actively control mobility of the RBDM (220C). A person skilled in the art would know of many possible implementations of the actuator (788), including, for example, using piezoelectric elements or electroactive polymers (EAPs). It should be noted that similar to the drag skirts (785), sails or parachutes may also be considered as features to control drag of the RBDM in a manner known to a person skilled in the art. Furthermore, it should be noted that the passive/active mobility features described above in reference to FIGs. 7A, 7B and 7C may be included as standalone or combined mobility features.

[0092] FIG. 8A shows details of an exemplary embodiment according to the present disclosure of the buoyancy control feature (790) shown in FIGs. 7A, 7B and 7C. In case of undulations of the fluid in the lateral section of the well, movement of the RBDM (e.g., 220) in the lateral section of the well becomes dependent on the buoyancy of the RBDM. In other words, in case of undulations in the lateral section of the well, too high of a buoyancy may cause the RBDM to get stuck to a top wall of the lateral section of the well, and too low of a buoyancy may cause the RBDM to get stuck to a bottom wall of the lateral section of the well. The buoyancy control feature (790) according to the present teachings mitigate such effect by allowing control of the buoyancy of the RBDM in view of known undulations in the lateral section of the well. In particular, the buoyancy control feature (790) may provide a neutral buoyancy of the RBDM (e.g., 220) so to allow, in spite of the undulations in the lateral section of the well, floating of the RBDM in the fluid without sinking to the bottom of the lateral section of the well or rising and getting trapped by wall of the lateral section of the well.

[0093] According to an exemplary embodiment of the present disclosure, the buoyancy control feature of the RBDM shown in FIG. 8A may include an inflatable element such as a bladder, balloon, or bellows element (7901), a mechanical actuator (7902) and a compressed gas container or pump (7903). According to an exemplary embodiment of the present disclosure, the bellows (7901) may be driven mechanically or with a gas from a small compressed gas container or a phase changing reaction or by moving a fluid (e.g. mineral oil) across the pressure interface to inflate a bellows. According to another exemplary embodiment of the present disclosure, the bladder (7901) may be driven mechanically or with a gas from a small compressed gas container or a phase changing reaction or by moving a fluid (e.g. mineral oil) across the pressure interface to inflate the bladder (7901). In other words, in one embodiment, the mechanical actuator (7902) extends to increase a volume of the bellows (7901), and therefore increases a volume of the RBDM. In turn, the increase in volume displaces more fluid surrounding the immersed RBDM and increases the buoyancy force exerted onto the RBDM. In another embodiment, compressed gas (7903) is released into the bladder (7901) to increase a volume of the bladder (7901), and therefore increases a volume of the RBDM. In turn, the increase in volume displaces more fluid surrounding the immersed RBDM and increases the buoyancy force exerted onto the RBDM. As described above, the buoyancy control according to the present teachings can provide for a neutral buoyancy of the RBDM (or RBMM) so to allow floating of the RBDM in the fluid without sinking to the bottom of the lateral section of the well or rising and getting trapped by wall of the lateral section of the well.

[0094] FIG. 8B shows details of an exemplary embodiment according to the present disclosure of the buoyancy control feature (790) of the RBDM shown in FIGs. 7A, 7B and 7C. The buoyancy control feature shown in FIG. 8B is provided via a variable gap (7908) that controls an interior volume of the RBDM, and therefore the buoyancy of the RBDM. In particular, as can be seen in FIG. 8B, a set (e.g., two or more) of threaded screws (7907) are used to variably compress an O-ring seal (7906) fitted between the enclosure top (510) and the enclosure bottom (515), thereby providing the variable gap (7908) between the enclosure top (510) and bottom (515). A person skilled in the art would clearly realize that a more compressed O-ring seal (7906) results in a smaller variable gap (7908), which results in a smaller interior volume of the RBDM, and therefore a lower buoyancy of the RBDM. Accordingly, high and low values of the buoyancy are

respectively a function of least compressed and most compressed states of the O-ring seal (7906). As can be seen in FIG. 8B, the heads of the screws are coupled to the enclosure top (510) via rubber sealing washers (7905) and threaded into screw threads (7907) formed in the enclosure bottom (515).

[0095] FIG. 8C shows details of an exemplary embodiment according to the present disclosure of the buoyancy control feature (790) of the RBDM shown in FIGs. 7A, 7B and 7C. The buoyancy control feature shown in FIG. 8C is provided via a mechanical displacement (7909) which displaces an amount of fluid (e.g., oil from the well) within a cavity (790a) formed in the RBDM. In one exemplary embodiment, as shown in FIG. 8C, the mechanical displacement (7909) may be a set screw, and the cavity (790a) may be a threaded drill hole. The movement of the screw outward of the module increases the volume of the module in the fluid while maintaining the same mass. This increase in volume displaces more fluid thereby increasing the buoyancy force. Moving the screw inward of the module decreases the fluid displaced and thereby decreases the buoyancy force. Accordingly, a relative position of the mechanical displacement (e.g., set screw that is solid or partially hollow) (7909) within the cavity (e.g., threaded drill hole) (790a) may be adjustable, and therefore an amount of fluid entrapped within a closed space defined by the position of the mechanical displacement (e.g., set screw) (7909) along the cavity (e.g., threaded drill hole) (790a) can be controlled to increase or decrease buoyancy of the RBDM. According to an exemplary embodiment, a length of the mechanical displacement (7909) may be smaller than a length (depth) of the cavity (790a) so to allow the mechanical displacement (7909) be fully contained within the cavity (790a) for a reduced effect on a drag of the RBDM.

[0096] According to various embodiments of the present disclosure, the buoyancy of the RBDM may be controlled based on information sensed by sensors of the RBDM. For example, the location of the RBDM may provide feedback on whether the buoyancy needs to be increased or decreased. Position of the RBDM may be detected, for example, via integrated magnetic sensors (560), and used in combination with an a priori known spatial profile (e.g., undulations) of the lateral section of the well stored in memory (520) of the RBDM to actively control/adjust (increase or decrease) buoyancy of the RBDM. In another example, the IMU sensor (542) may sense no net acceleration

of the RBDM over a specific time period and accordingly control actuators of the RBDM to adjust buoyancy of the RBDM via the buoyancy control feature (790) described above.

[0097] It should be noted that the control of the buoyancy may be important at low flow levels where the drag force is smaller. At high flow rates the drag force may be larger than the frictional forces and therefore the RBDMs may get swept along with the flow. As described above, in addition to buoyancy control features, mobility control features may be used to help robust delivery of the RBDMs along the lateral section of the well to the surface/heel of the well for readout. In a same manner as described above with respect to the buoyancy control features, feedback from sensors integrated within the RBDMs can be used to control/adjust mobility of the RBDMs.

[0098] As noted above with reference to, for example, FIG. 4B and FIG. 4C, the delivery module (450) may be a specialized mobile robot that includes sensors to sense downhole information and store corresponding data into the modules (420), RBDMs or RBMMs, prior to ejection of the modules into the fluid at the heel of the well. FIG. 10A shows various views of one exemplary embodiment according to the present disclosure of such specialized module, with further details shown in FIGs. 10B-10E.

[0099] With reference to FIGs. 10A-10B, according to an exemplary embodiment of the present disclosure, the mobile robot (1010) may be a torpedo-shaped device with a longitudinal length of about 2.1 meter (e.g., ~7 ft), that rides on wheels (1020) in contact with a wall of the lateral portion of the well. According to the non-limiting exemplary embodiment depicted in FIGs. 10A-10B, the mobile robot (1010) may include three wheels (1020a, 1020b) that may be arranged (radially) around a circumference of the robot. Small electric actuators (not shown in the figures) may be used to turn the wheels (1020) and push the mobile robot (1010) along the lateral portion of the well at a speed of, for example, 3 cm/s or higher.

[00100] As shown in FIG. 10B, a position of the mobile robot (1010) is biased towards the top of the lateral section of the well so that a clearance space is provided at the bottom for any sand and/or proppant particulates, or any other wellbore debris, that might accumulate at the bottom of the lateral section of the well. According to an exemplary embodiment of the present disclosure, such clearance may be provided by a position of two wheels (1020a) at a bottom side of the mobile

robot (1010) in contact with the well wall at positions defining a horizontal clearance plane, $H_{\text{clearance}}$, of the well. As shown in FIG. 10B, the horizontal clearance plane, $H_{\text{clearance}}$, is at a distance from a bottom of the well according to the clearance space, as shown in FIG. 10B. As can be seen in FIG. 10B, the two bottom wheels (1020a) are arranged symmetrically with respect to a central vertical plane of the well, and a third wheel (1020b) is arranged on a top side of the mobile robot (1010) at a position passing thorough the central vertical plane of the well. Accordingly, the position of the mobile robot (1010) is biased is biased towards the top of the lateral section of the well, or in other words, biased above the central horizontal plane of the well as shown in FIG. 10B.

[00101] With continued reference to FIGs. 10A-10B, according to an exemplary embodiment of the present disclosure, the mobile robot (1010) is designed to block less than about half the flow area in the lateral section of the well, therefore allowing for a near-normal production flow while the robot is deployed. Higher quality sensors, as shown for example in FIG. 10A, may be integrated/arranged in the mobile robot (1010) as required to sense the desired downhole information and store corresponding data measurements. Such measurements may subsequently be transferred to the modules (420), RBDMs or RBMMs, stored within the mobile robot (1010) prior to injection of the modules (420) into the flow as described above with reference to FIGs. 4B and 4C.

[00102] As shown in FIG. 10A, one or more rechargeable batteries (1001) may power the mobile robot (1010) during each back and forth traverse of the lateral section of the well from its docking position. According to an exemplary embodiment of the present disclosure, as shown in FIG. 10C, a docking station (1005) may include a power source that can be used to recharge batteries of the mobile robot (1010) when the robot is docked. Such docking station (1005) may be, for example, the base station (430), or part of the base station (430), described above with reference to, for example, FIG. 4C. According to an exemplary embodiment of the present disclosure, inductive coils (1015) arranged in the docking station (1005) and in the mobile robot (1010), may be inductively coupled when the mobile robot (1010) is docked to the docking station (1005) so to recharge the batteries of the mobile robot (1010). According to an alternative embodiment of the

present disclosure, the mobile robot (1010) may be coupled/docked to the docking station (1005) via well-known in the art wet mate, wiping contacts.

[00103] Alternatively, or additionally, the mobile robot (1010) may recharge its batteries by first stopping at a location of the lateral section of the well where there exists sufficient flow of fluid, and then recharging its batteries by harvesting flow energy from the fluid. For example, after sensing/capturing data along the lateral section of the well, the mobile robot (1010) may stop at the heel section of the well to, for example, inject a module (420) as described above with reference to FIG. 4C, but in addition, the mobile robot may wait at the stopped position to recharge its batteries. Harvesting of the flow energy may be provided via a turbine (1030) as shown in FIGs. 10D-10E.

[00104] With further reference to FIGs. 10D-10E, according to an exemplary embodiment of the present disclosure, the mobile robot (1010) comprises a turbine (1030) that can be used to harvest flow energy from the fluid (e.g., oil and/or water) moving past the mobile robot (1010) and recharge the batteries of the mobile robot (1010) over a period of time (e.g., one or more hours). According to an exemplary embodiment of the present disclosure, the mobile robot (1010) includes expandable (or retractable) one or more flow diverters (1040) that can constrict the flow past the mobile robot (1010) to generate locally higher speed flow and thereby increase efficiency of the flow energy harvesting.

[00105] As shown in FIG. 10D, when the flow diverters (1040) are expanded, the flow is diverted to constricting channels (1050) leading to the turbine (1030), and accordingly a constricted flow having a higher speed (i.e., velocity of flow) is forced to move through the turbine (1030). As shown in FIG. 10E, when the batteries of the mobile robot (1010) are recharged, the flow diverters (1040) are retracted for normal flow of the fluid past the mobile robot (1010). In this case the mobile robot is ready to move out on another survey of the lateral section of the well.

[00106] FIG. 11A shows a diagram of an exemplary embodiment according to the present disclosure, wherein an injected RBDM (1120) (e.g., 220a, 320a, 420a, etc.) floats to the surface of the well where an RBDM reader (1110) can extract data stored in the RBDM (1120). As described

above, such data may be extracted (read) by any of a manual, autonomous, or remote/wireless means.

[00107] With continued reference to the diagram of FIG. 11A, as described above, floating of the injected RBDM (1120) to the surface of the well is provided by a flow of the fluid within the well and a buoyancy of the injected RBDM (1120) in view of known characteristics of the fluid. A person skilled in the art would clearly understand that the flow of the fluid within the well may change as a function of a production phase of the well. For example, in early production stages the flow may be significantly higher than in later production stages. Accordingly, as it is well known in the art, artificial means may be added to the well for extraction (lift) of the fluid (e.g., oil, gas, water) within the well. The exemplary embodiment depicted in FIG. 11A may equally apply during any of the production phases wherein (physical) floating of the injected RBDM (1120) to the surface of the well is not impeded. This includes a production phase where a gas is injected in the downhole (e.g., gas lift) to artificially increase fluid flow.

[00108] In some cases, the artificial means for lifting of the fluid within the well may require introduction of a screen (e.g., filter) in a vertical region of the well near the heel of the well, which screen may impede progression/flow of the injected RBDM (1120) to the surface of the well. Two such exemplary cases are shown in FIG. 11B and FIG. 11C, where a screen (1155) positioned at a region of the vertical section of the well near the heel of the well impedes progression of injected RBDMs (1120) towards the surface of the well. The screen may filter larger particles in the fluid to protect a pump that is used to artificially lift the (filtered) fluid. As noted in FIG. 11B, according to an exemplary embodiment, the pump may be an electrical pump (1150) that is powered via an electrical connection (1145) guided through the vertical section of the well. As noted in FIG. 11C, according to an exemplary embodiment, the pump may be a sucker rod pump (1160) that is (mechanically) powered via a rod connection (1165) guided through the vertical section of the well.

[00109] As shown in FIGs. 11B and 11C, the screen (1155) may impede progression of the injected RBDMs (1120). It follows that according to an embodiment of the present disclosure, extraction of the data from the injected RBDMs (1120) may be performed in a location in the

vertical section of the well that is at the vicinity of the screen (1155) positioned near the heel of the well.

[00110] With further reference to FIG. 11B, a diagram of an embodiment according to present disclosure is shown, wherein an RBDM reader (1110) is placed in the downhole of the well on a side of the screen (1155) away from the injected (and entrapped) RBDMs (1120). The reader (1110) may remotely/wirelessly read data from the injected RBDMs (1120), which are positioned at close proximity of the reader (1110) and transfer the read data to the surface of well via wires of the electrical connection (1145). Such exemplary embodiment according to present disclosure may be used in cases where the screen (1155) impedes progression of the injected RBDMs (1120) towards the surface of the well and where presence of the RBDMs (1120) between the pump (1150) and the surface of the well may interfere with production requirements. Accordingly, no RBDM may flow at the surface of the well.

[00111] With further reference to FIG. 11C, a diagram of an embodiment according to present disclosure is shown, wherein an RBDM relay center (1115) is placed in the downhole of the well on a side of the screen (1155) away from the injected (and entrapped) RBDMs (1120). The RBDM relay center (1115) may remotely/wirelessly read data from the injected (and entrapped) RBDMs (1120), which are positioned at close proximity of the RBDM relay center (1115) and transfer the read data to the surface of well via (simple/basic) relay memory module (525) (e.g., RBMMs per the reference application PCT/US18/55565 discussed above) that float to the surface of the well. In turn, a reader (1110) at the surface of the well reads the data from the relay RBMMs (1125) in a fashion similar to one described with reference to FIG. 11A. Such exemplary embodiment according to present disclosure may be used in cases where a screen (1155) impedes progression of the injected RBDMs (1120) and where presence of the RBDMs/RBMMs between the pump (1150) and the surface of the well may not interfere with production requirements. Accordingly, an injected relay RBMM (1125) may flow at the surface of the well. Further details of the RBDM relay center (1115) may be found, for example, in the above referenced International patent application PCT/US18/55565, the disclosure of which is incorporated herein by reference in its entirety.

[00112] FIG. 11D shows an exemplary embodiment according to the present disclosure, wherein a rest station (1185) may be arranged in the heel section of the well to provide a wired connection from a surface of the well to the mobile robot (e.g., 1010 of FIGs. 10A-10E). Such configuration based on the configurations of FIGs. 11B, 11C, may be used, for example, to provide wired power to recharge the mobile robot (1010), and/or to read data sensed from the lateral section of the well directly from the mobile robot (1010). It should be noted that such configuration may coexist with the configurations described above with reference to FIGs. 11B and 11C. Furthermore, it should be noted that the rest station (1185) may be arranged in any location at the heel of the well, including in a lateral location of the well as shown in FIG. 11D, or in a central location of the well.

[00113] FIG. 11E shows an exemplary embodiment according to the present disclosure, wherein data from a mobile robot (e.g., 1010 of FIGs. 10A-10E) is wirelessly read at a location of the well, such as, for example, the heel of the well, by the RBDM relay center (1115) described above with reference to FIG. 11C. In such configuration, the mobile robot is fitted with a wireless transmitter that is configured to communicate with a wireless receiver of the RBDM relay center (1115) for transfer of data sensed/captured by the mobile robot during its travel in the lateral section of the well along one or more production zones. Once read, the RBDM relay center (1115) may transfer the data to one or more memory modules, e.g., RBMMs, and inject those in the vertical section of the well for readout at the surface of the well. Furthermore, the RBDM relay center (1115) may be configured to communicate with the mobile robot to load the mobile robot with updates related to the operation of the mobile robot.

[00114] A number of embodiments of the disclosure have been described. Nevertheless, it will be understood that various modifications may be made without departing from the spirit and scope of the present disclosure. Accordingly, other embodiments are within the scope of the following claims. For example, although the present disclosure focuses on the RBDM/RBMM modules and robot for sensing and reporting of physical properties in a lateral well, the concept and design according to the present disclosure can also be used for sensing and reporting of physical properties in vertical well.

[00115] The examples set forth above are provided to those of ordinary skill in the art as a complete disclosure and description of how to make and use the embodiments of the disclosure and are not intended to limit the scope of what the inventor/inventors regard as their disclosure.

[00116] Modifications of the above-described modes for carrying out the methods and systems herein disclosed that are obvious to persons of skill in the art are intended to be within the scope of the following claims. All patents and publications mentioned in the specification are indicative of the levels of skill of those skilled in the art to which the disclosure pertains. All references cited in this disclosure are incorporated by reference to the same extent as if each reference had been incorporated by reference in its entirety individually.

[00117] It is to be understood that the disclosure is not limited to particular methods or systems, which can, of course, vary. It is also to be understood that the terminology used herein is for the purpose of describing particular embodiments only and is not intended to be limiting. As used in this specification and the appended claims, the singular forms "a," "an," and "the" include plural referents unless the content clearly dictates otherwise. The term "plurality" includes two or more referents unless the content clearly dictates otherwise. Unless defined otherwise, all technical and scientific terms used herein have the same meaning as commonly understood by one of ordinary skill in the art to which the disclosure pertains.

CLAIMS

1. A system for delivering information about physical properties in a lateral section of a well, the system comprising:
 - an autonomous deployment system arranged at a toe section of the well away from a production zone, the deployment system comprising:
 - a plurality of ruggedized buoyant data modules (RBDMs), each RBDM comprising one or more sensors configured to sense, when injected into a fluid of the well, the physical properties along the lateral section of the well and store data corresponding to sensed physical properties into a memory of said RBDM; and
 - a delivery module configured to carry an RBDM of the plurality of RBDMs from the toe section to a region of the lateral section of the well close to the production zone, and inject the RBDM into the fluid,
 - wherein when injected into the fluid, adjustable buoyancy features of the RBDM in combination with a flow of the fluid cause the RBDM to travel along the lateral section of the well to a location of the well for readout of the data.
2. The system according to claim 1, wherein:
 - the autonomous deployment system further comprises a stationary base station for storage of the plurality of RBDMs, and
 - the delivery module loads an RBDM from the plurality of RBDMs from the stationary base station for carrying of said RBDM close to the production zone.
3. The system according to claim 1, wherein the delivery module stores the plurality of RBDMs.
4. The system according to any one of claims 1-3, wherein the adjustable buoyancy features are controlled during the travel along the lateral section of the well based on the sensed physical properties.

5. The system according to claim 4, wherein the adjustable buoyancy features are controlled to provide a neutral buoyancy of the RBDM.
6. The system according to claim 5, wherein the adjustable buoyancy features comprise an inflatable element and an actuator configured to control a volume of the inflatable element.
7. The system according to claim 6, wherein the inflatable element is a bladder, a balloon, or a bellows, and wherein the actuator is a mechanical actuator or a pump.
8. The system according to claim 6, wherein the one or more sensors of the RBDM comprise an inertial measurement sensor configured to measure a flow rate of the RBDM when injected into the fluid, and wherein the flow rate of the RBDM is used to control the adjustable buoyancy features.
9. The system according to any one of claims 1-3, wherein the adjustable buoyancy features comprise a variable gap provided by a compressible O-ring seal arranged between a top side and a bottom side of an enclosure of the RBDM.
10. The system according to claim 9, wherein a set of threaded screws variably compress the compressible O-ring seal to provide the variable gap.
11. The system according to any one of claims 1-3, wherein the adjustable buoyancy features comprise an adjustable mechanical displacement that displaces an amount of fluid within a cavity.
12. The system according to claim 11, wherein the adjustable mechanical displacement is a set screw whose relative position in the cavity is adjusted via threads in the cavity.

13. The system according to claim 4, wherein the RBDM further comprises mobility features to allow the RBDM to travel along regions of the lateral section of the well with low flow of the fluid.
14. The system according to claim 13, wherein the mobility features include active mobility features comprising one or more of: a) a motorized movement of a structure, b) a gas or fluid jet, and c) a deployable or retractable sail or drag skirt.
15. The system according to claim 14, wherein the RBDM further comprises in situ energy harvesting to provide power for the active mobility features.
16. The system according to claim 13 or claim 14, wherein the mobility features include passive mobility features comprising one or more of: a) flagella, b) hair, c) a parachute, and d) a drag skirt.
17. The system according to any one of claims 1-3, wherein the plurality of RBDMs include one hundred or more RBDMs.
18. The system according to claim 17, wherein each RBDM of the plurality of RBDMs comprises a substantially spherical enclosure with a diameter that is smaller than 2.5 centimeters.
19. The system according to any one of claims 1-3, wherein each RBDM of the plurality of RBDMs is configured to withstand a pressure of at least 5500 psi.
20. The system according to claim 19,
 wherein said RBDM comprises a substantially spherical enclosure with a diameter of 2.4 centimeters, and
 wherein the enclosure is made from grade 5 titanium with a thickness of 0.53 mm.
21. The system according to claim 19,

wherein said RBDM comprises a substantially spherical enclosure with a diameter of 2.4 centimeters, and

wherein the enclosure is made from grade 9 titanium with a thickness of 1.0 mm.

22. The system according to claim 19,

wherein said RBDM comprises a substantially spherical enclosure with a diameter of 1.0 centimeters, and

wherein the enclosure is made from grade 5 titanium with a thickness of 0.22 mm.

23. The system according to any one of claims 1-3, wherein said RBDM travels across a plurality of production zones formed along the lateral section of well.

24. A system for delivering information about physical properties in a lateral section of a well, the system comprising:

an autonomous mobile robot comprising a plurality of ruggedized buoyant memory modules (RBMMs), the autonomous mobile robot comprising one or more sensors configured to sense the physical properties along the lateral section of the well and store data corresponding to sensed physical properties into a memory of at least one RBMM of the plurality of RBMMs,

wherein the autonomous mobile robot travels from a toe section to a heel section of the well and injects the at least one RBMM into a fluid of the well for conduction of the RBMM by a flow of the fluid to a location of the well for readout of the data.

25. The system according to claim 24, wherein the autonomous mobile robot comprises a plurality of wheels arranged radially around a circumference of the autonomous mobile robot so that:

a position of said robot is biased towards a top of the lateral section of the well, and

a clearance space is provided that clears particulates accumulated at the bottom of the lateral section of the well while said robot travels along the lateral section of the well.

26. The system according to claim 25, wherein the clearance is provided via position of two bottom wheels of the plurality of wheels that are arranged in a horizontal plane of the lateral section of the plane, said plane being at a distance from the bottom of the lateral section of the well corresponding to the clearance space.
27. The system according to claim 26, wherein the plurality of wheels consists of the two bottom wheels arranged symmetrically with respect to a central vertical plane of the lateral section of the well, and one top wheel arranged within said central vertical plane.
28. The system according to any one of claims 24-27, wherein the autonomous mobile robot comprises an in situ energy harvesting system comprising:
- one or more flow diverters;
 - one or more constricting channels; and
 - a turbine,
- wherein the one or more flow diverters selectively divert the flow of the fluid around the autonomous mobile robot to the turbine through the one or more constricting channels that increase a velocity of the flow.
29. The system according to claim 28, wherein the one or more flow diverters divert the flow of the fluid when the autonomous mobile robot is at rest at the heel region of the well after injecting the at least one RBMM.
30. The system according to any one of claims 24-27, further comprising a docking station arranged at a toe section of the well, the docking station comprising a power source and one or more inductive coils,
- wherein the autonomous mobile robot comprises a rechargeable battery and one or more inductive coils, and
 - wherein, when docked to the docking station, the power source recharges the rechargeable battery via inductive coupling of the one or more inductive coils.

31. The system according to any one of claims 24-27, further comprising a docking station arranged at a toe section of the well, the docking station comprising a power source and wet mate, wiping contacts for docking of the autonomous mobile robot and recharging a rechargeable battery of the autonomous mobile robot via the power source.
32. The system according to any one of claims 24-27, wherein the plurality of RBMMs include one hundred or more RBMMs.
33. The system according to claim 32, wherein each RBMM of the plurality of RBMMs comprises a substantially spherical enclosure with a diameter that is smaller than 2.5 centimeters.
34. The system according to any one of claims 24-27, wherein each RBMM of the plurality of RBMMs is configured to withstand a pressure of at least 5500 psi.
35. The system according to claim 34,
wherein said RBMM comprises a substantially spherical enclosure with a diameter of 2.4 centimeters, and
wherein the enclosure is made from grade 5 titanium with a thickness of 0.53 mm.
36. The system according to claim 34,
wherein said RBMM comprises a substantially spherical enclosure with a diameter of 2.4 centimeters, and
wherein the enclosure is made from grade 9 titanium with a thickness of 1.0 mm.
37. The system according to claim 34,
wherein said RBMM comprises a substantially spherical enclosure with a diameter of 1.0 centimeters, and
wherein the enclosure is made from grade 5 titanium with a thickness of 0.22 mm.

38. The system according to any one of claims 24-27, wherein the autonomous mobile robot travels across a plurality of production zones formed along the lateral section of well.

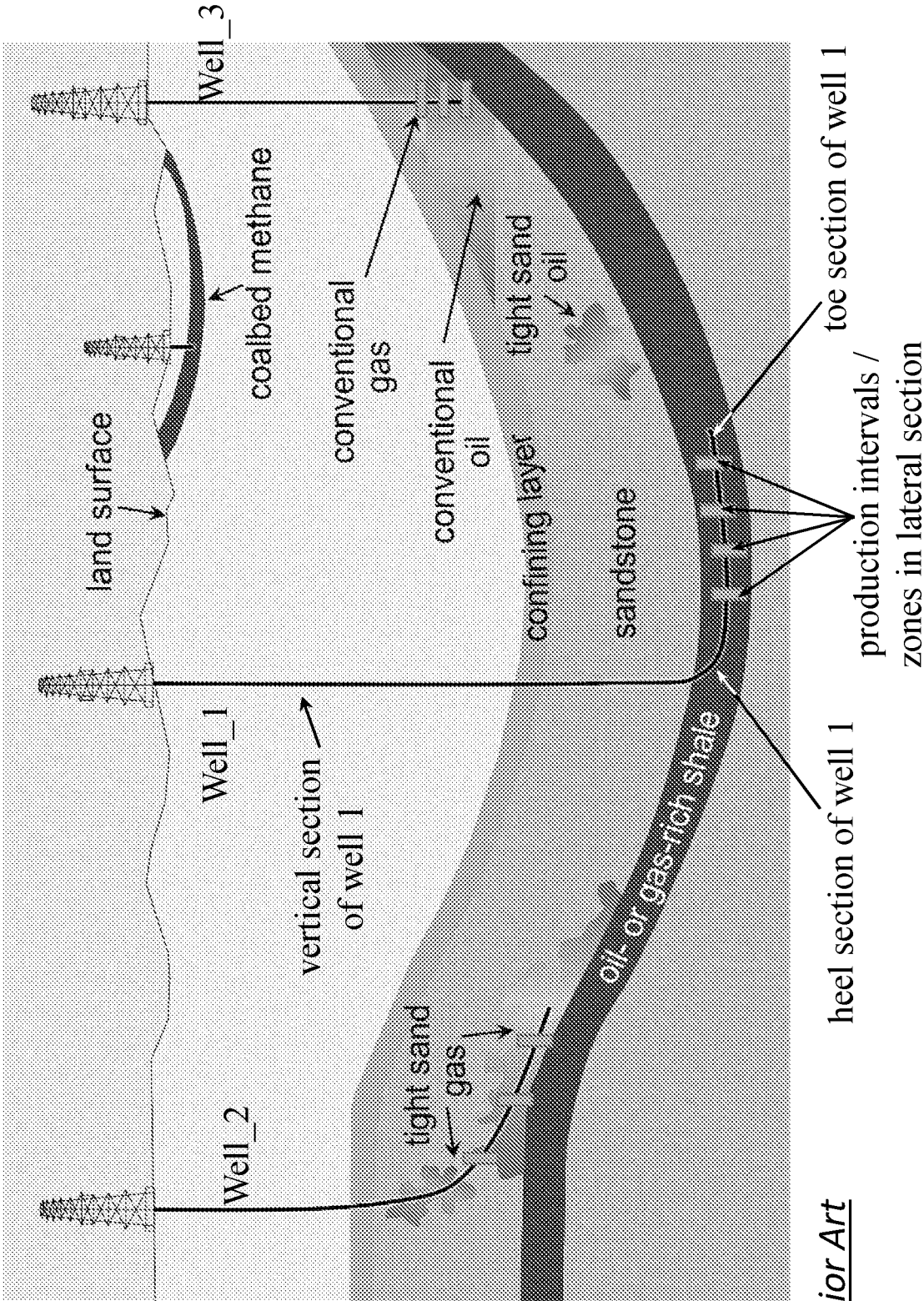


FIG. 1
of well 1

Prior Art

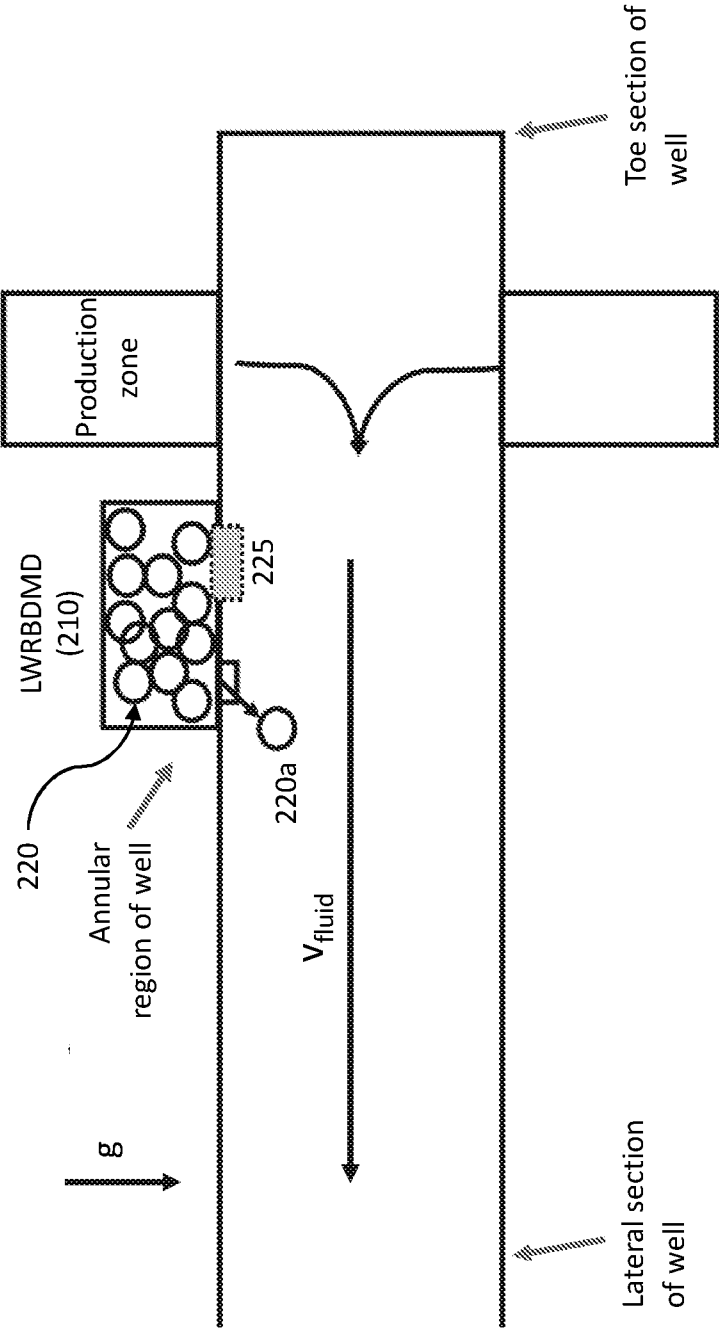


FIG. 2A

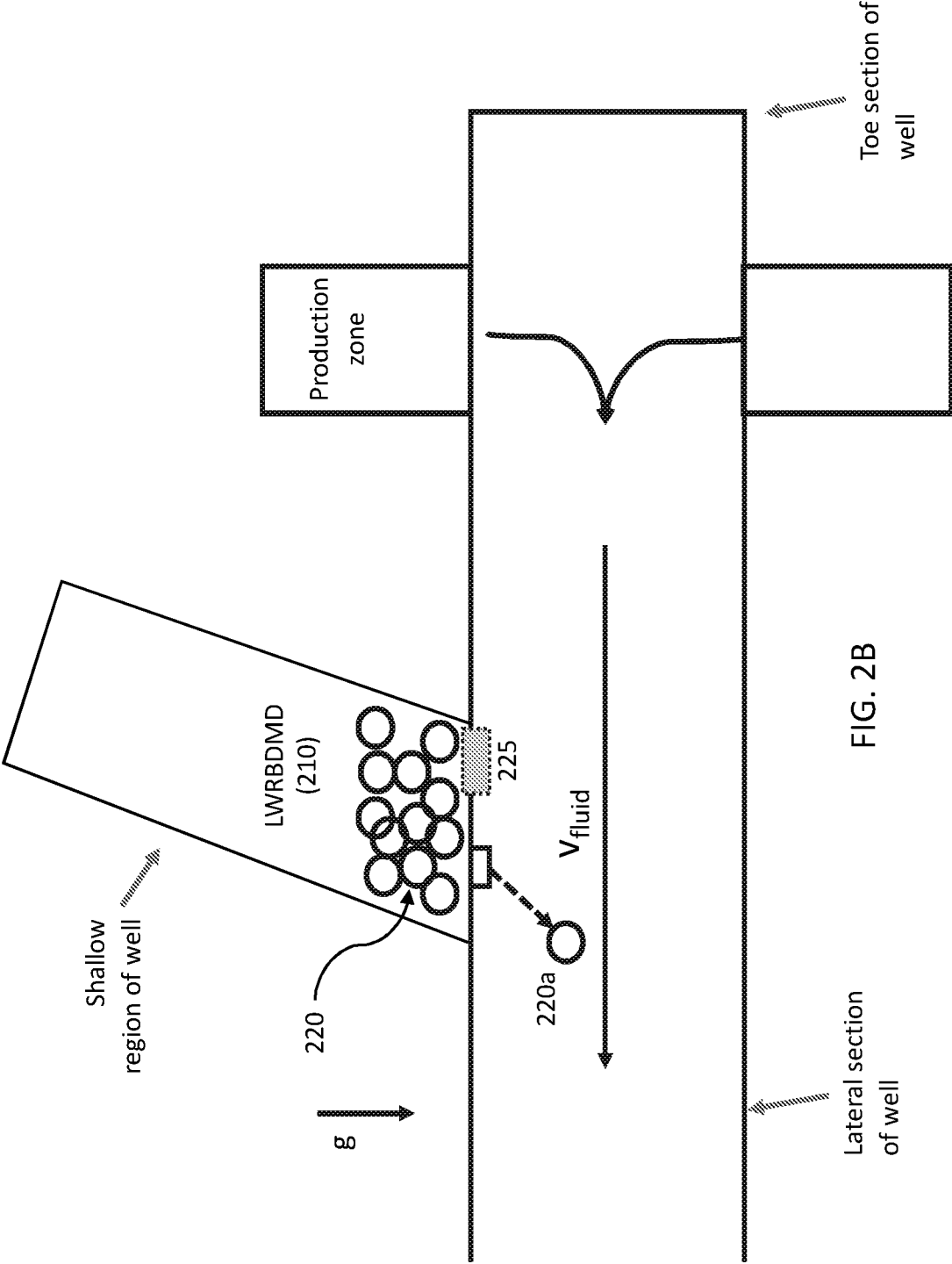


FIG. 2B

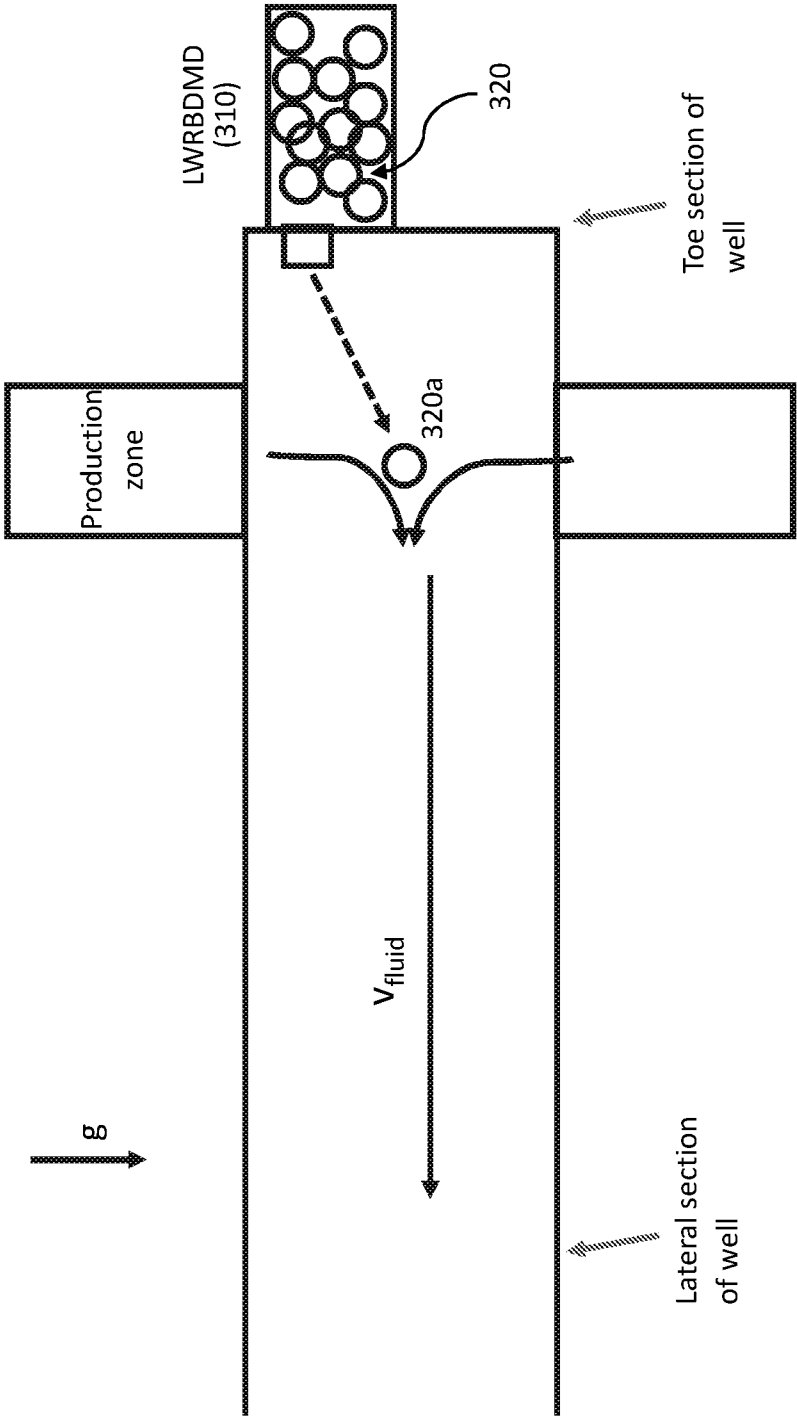


FIG. 3

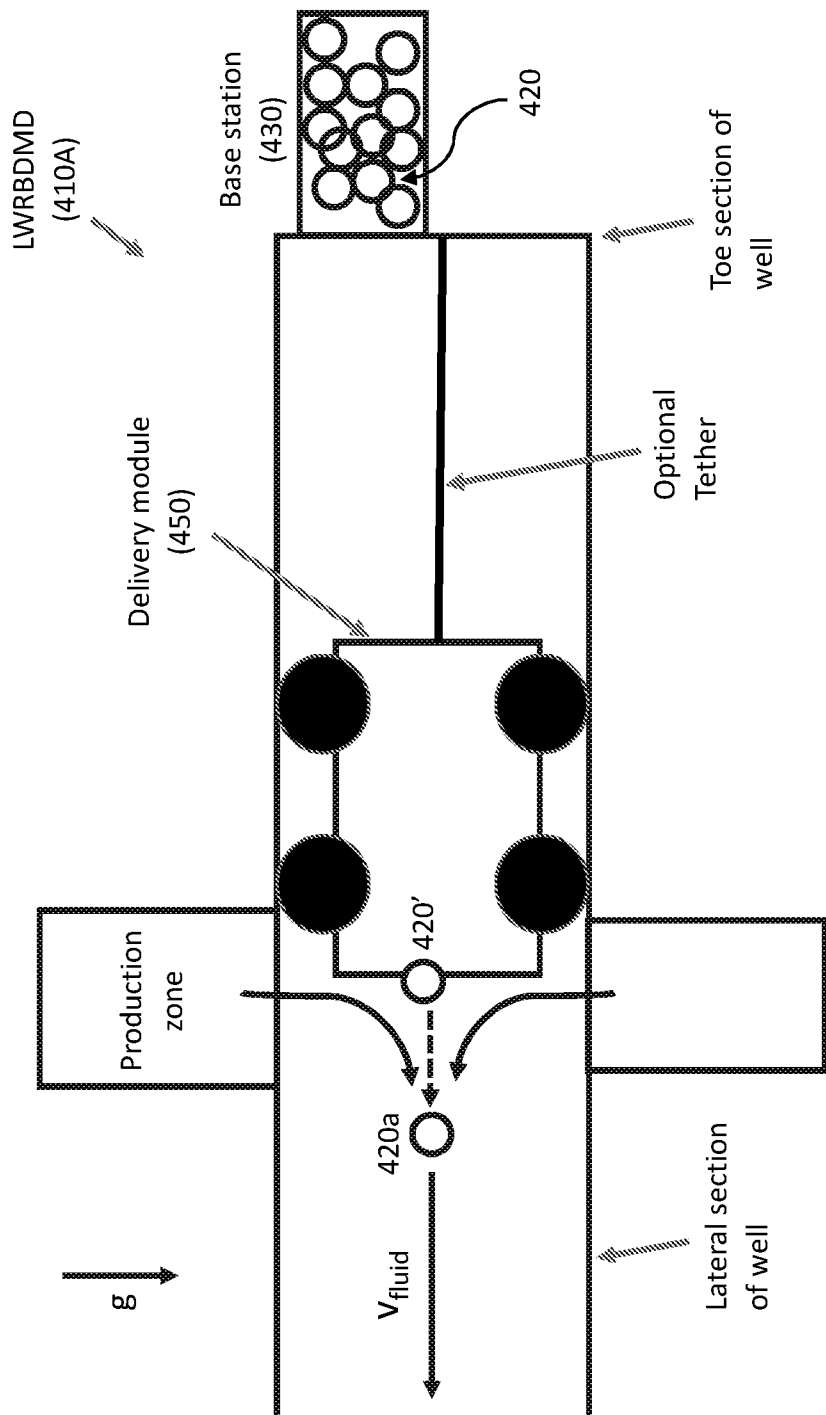


FIG. 4A

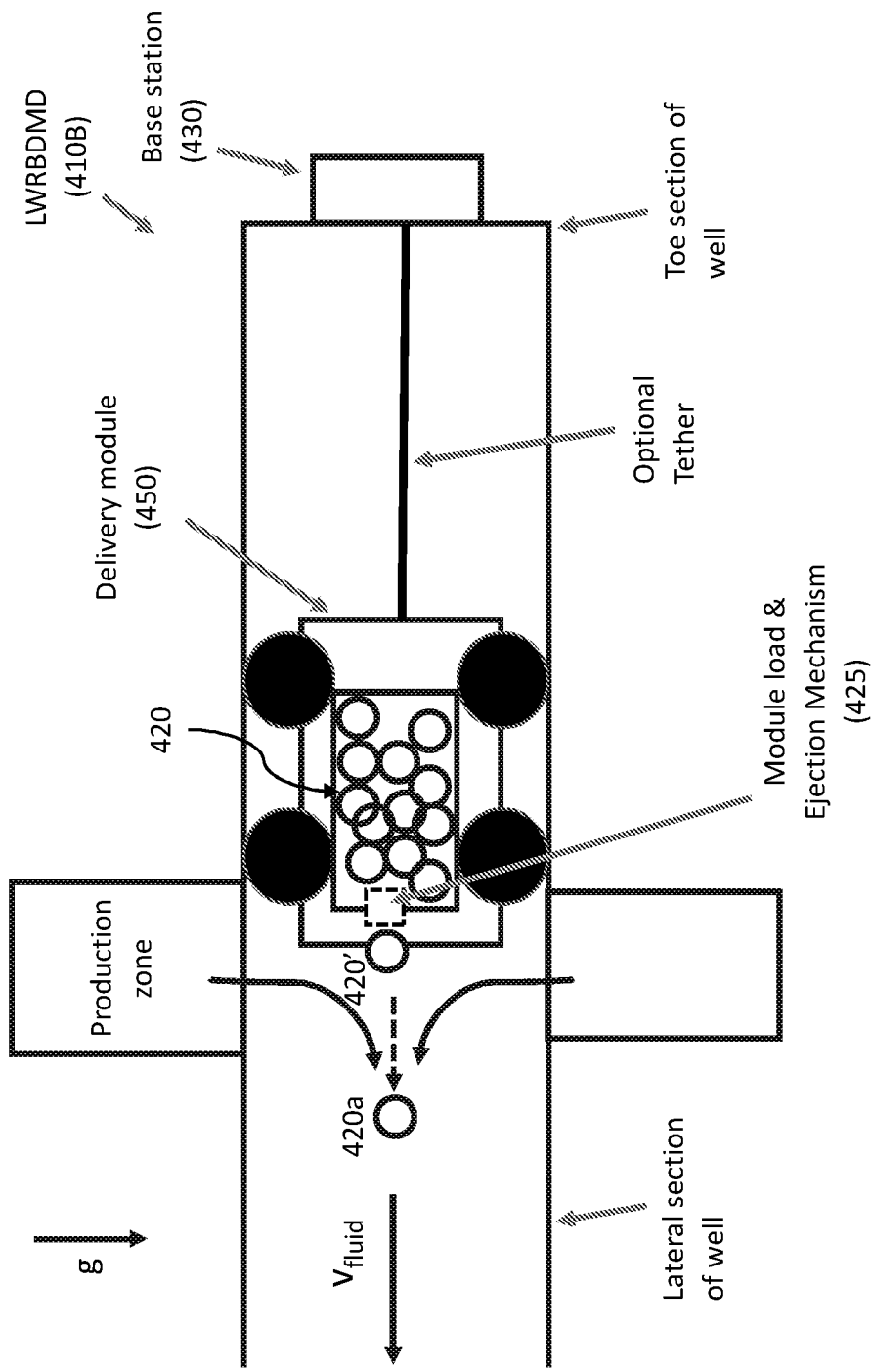


FIG. 4B

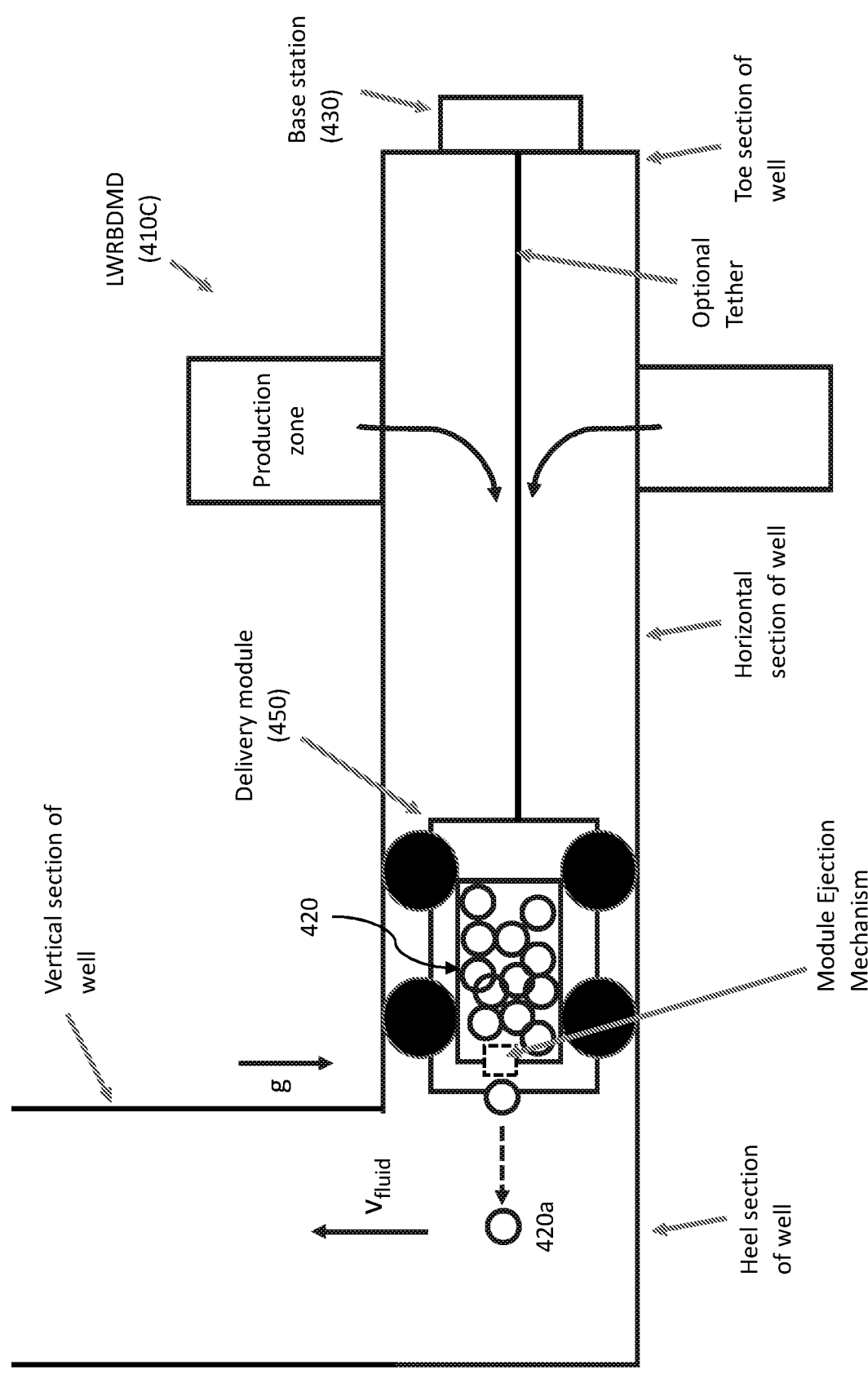
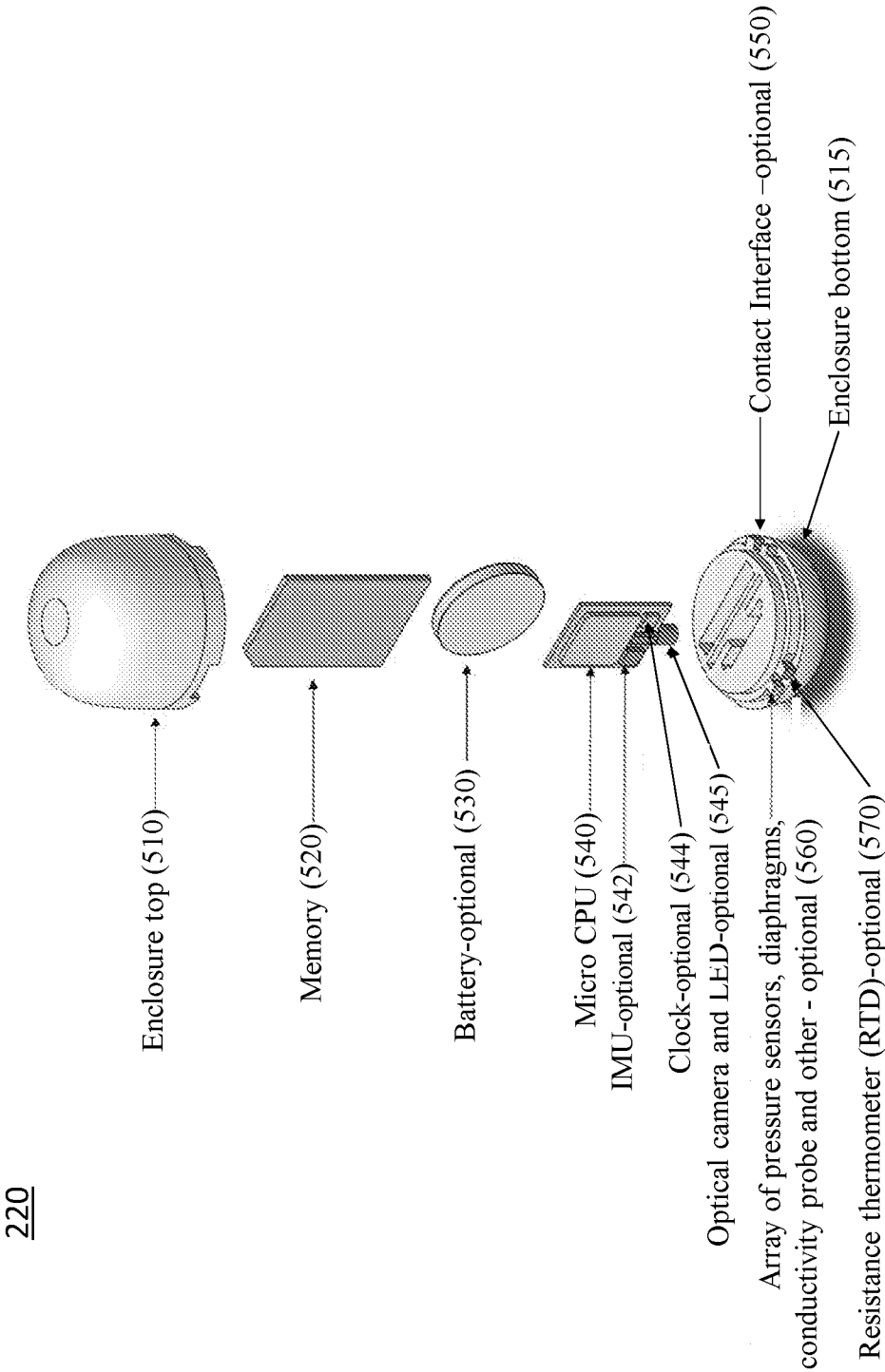


FIG. 4C



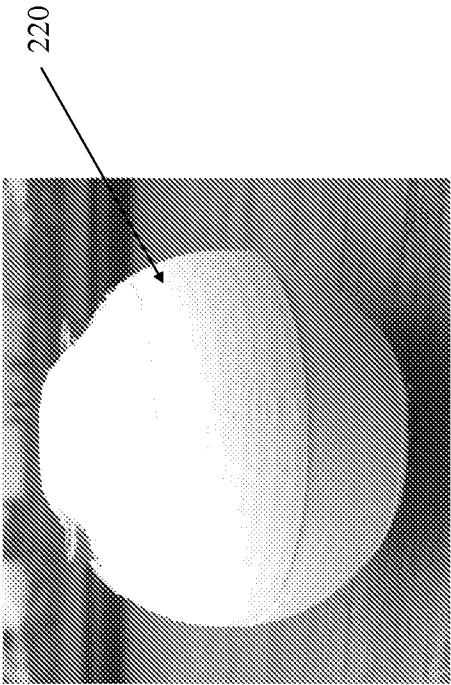
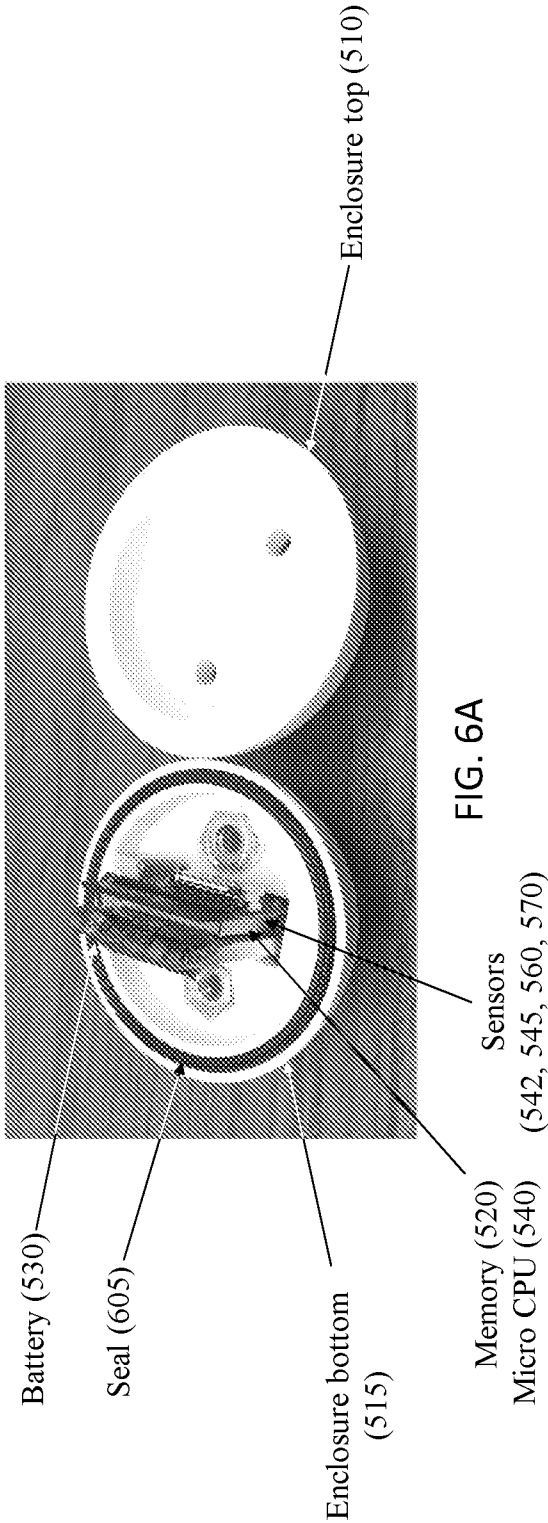


FIG. 6B

220A

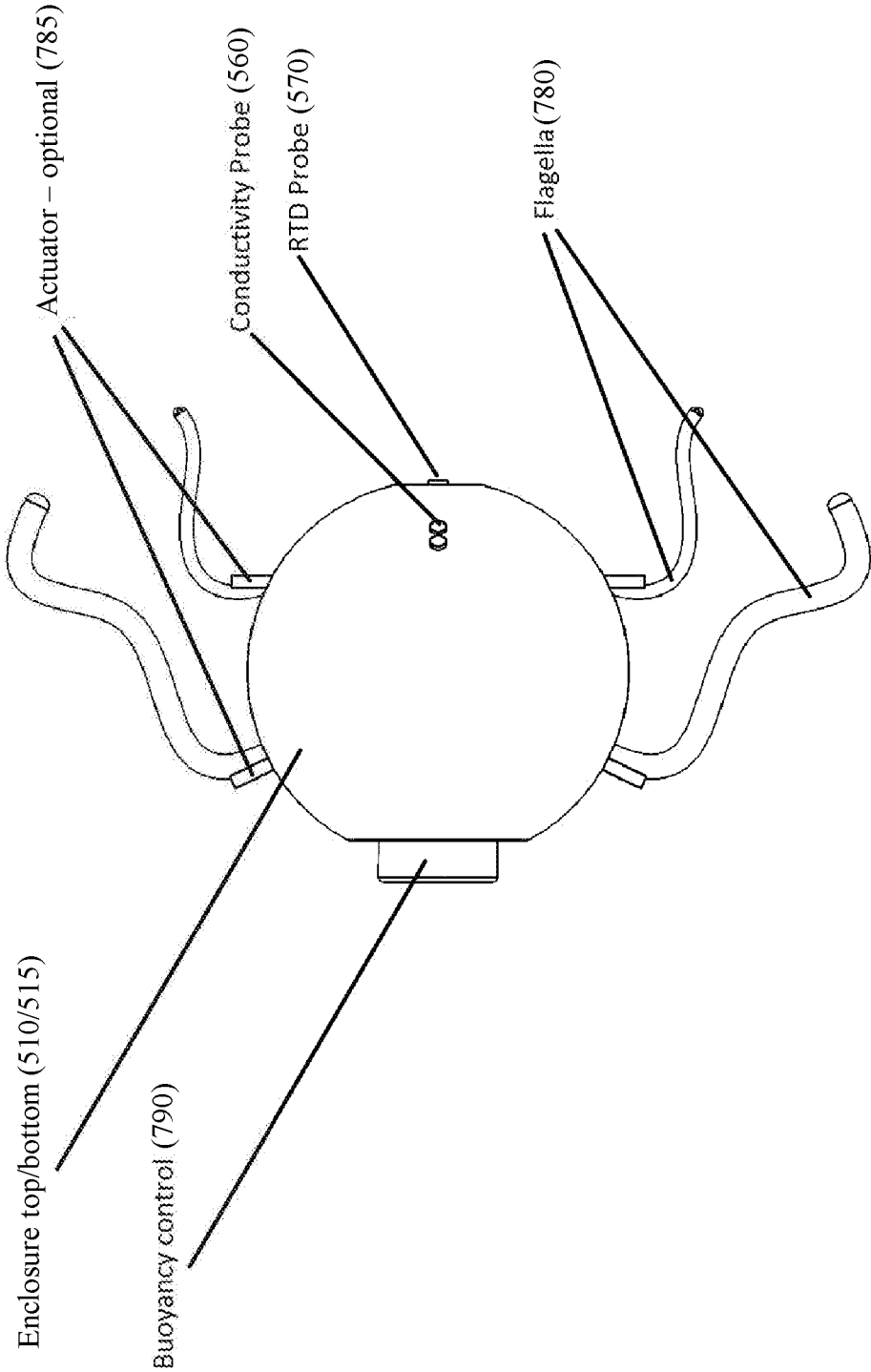


FIG. 7A

220B

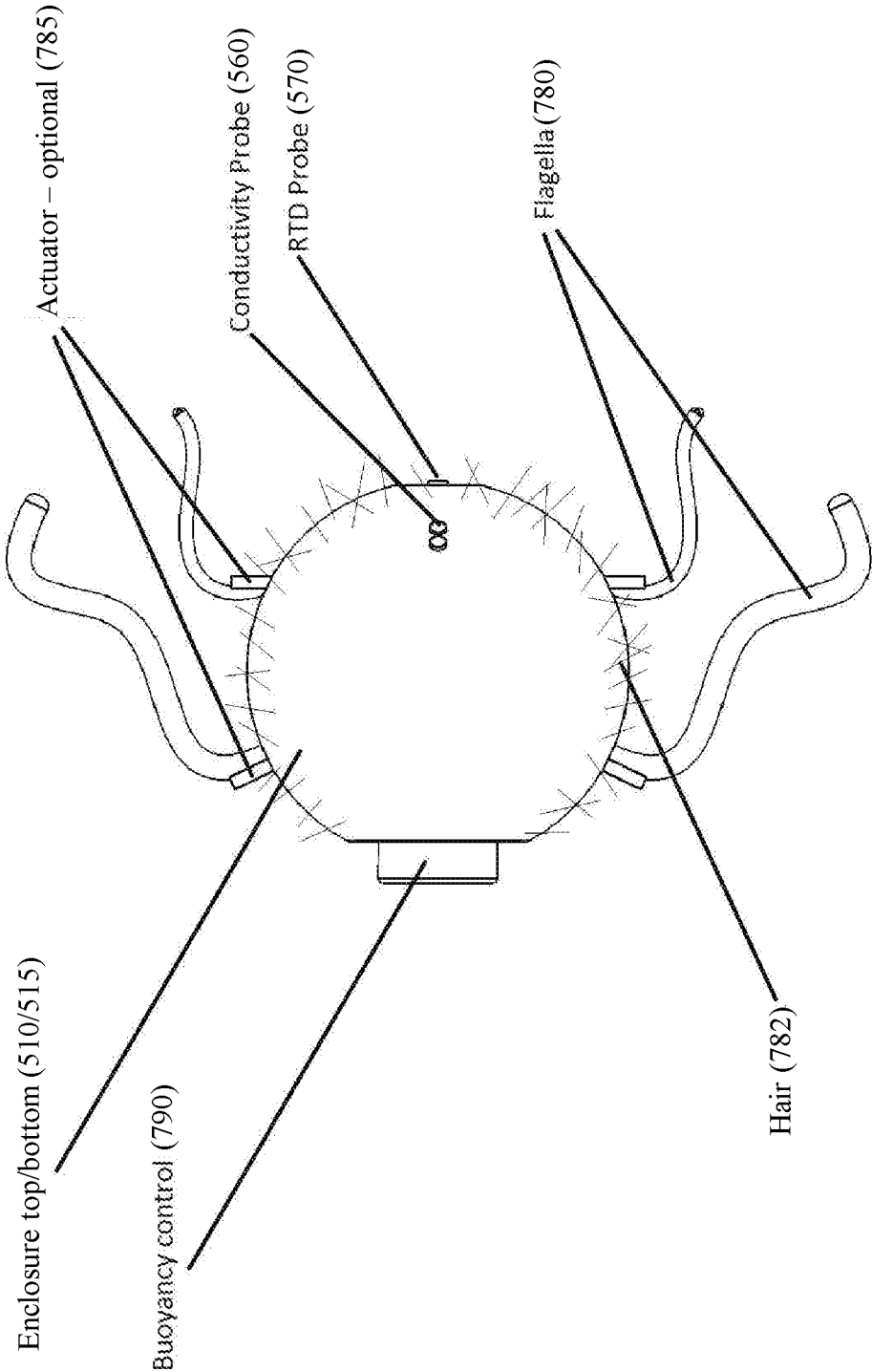


FIG. 7B

220C

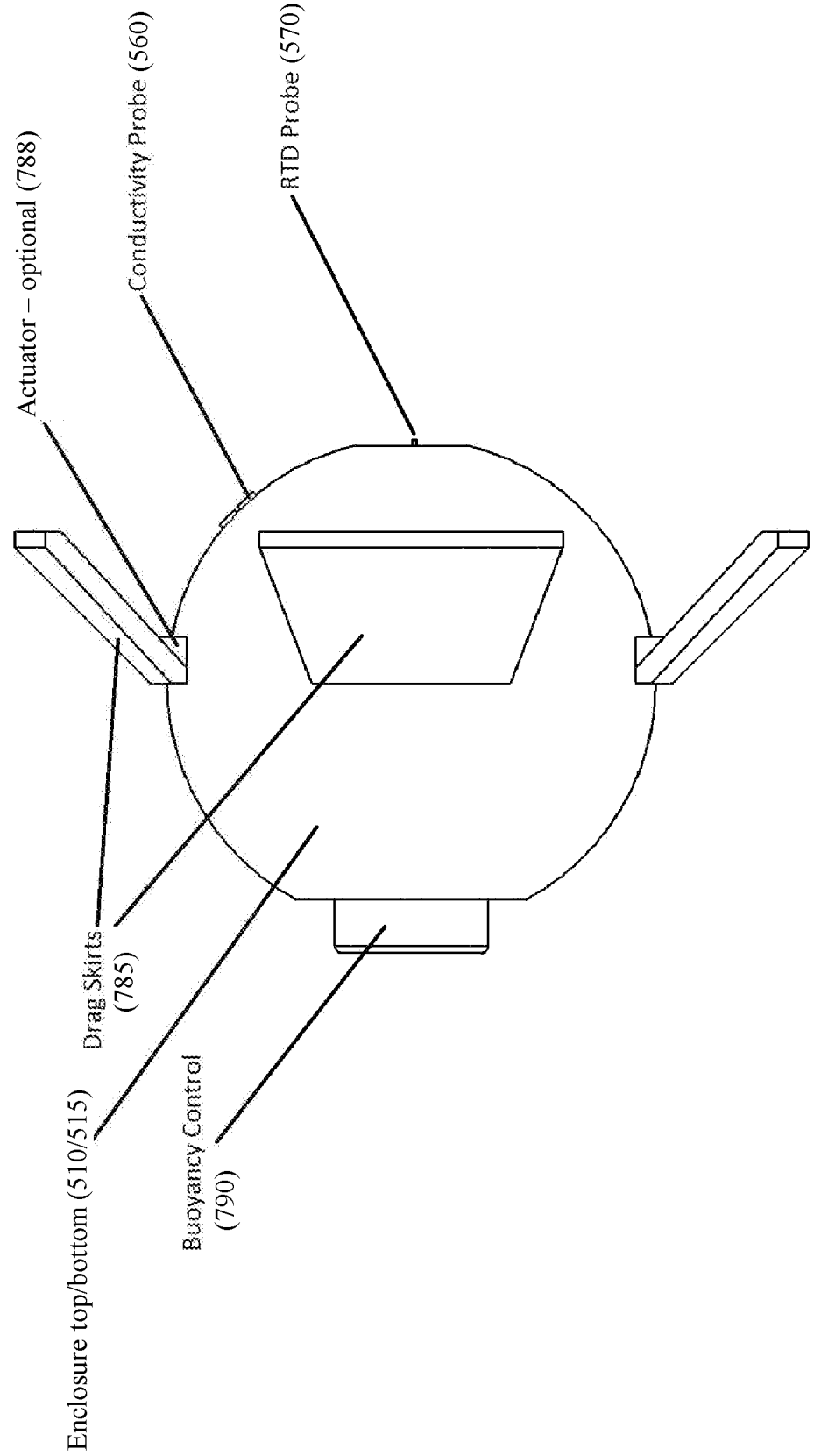


FIG. 7C

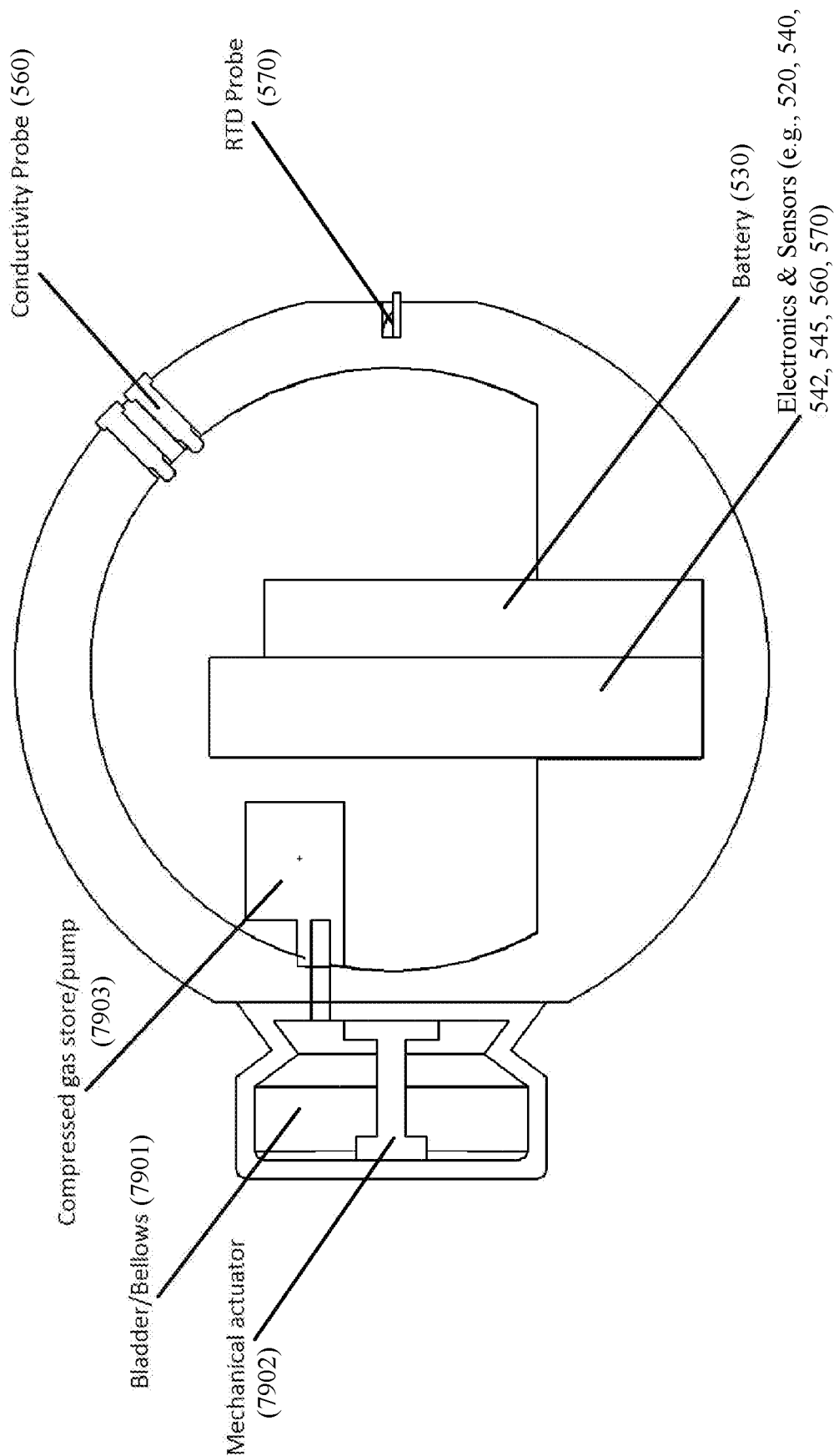


FIG. 8A

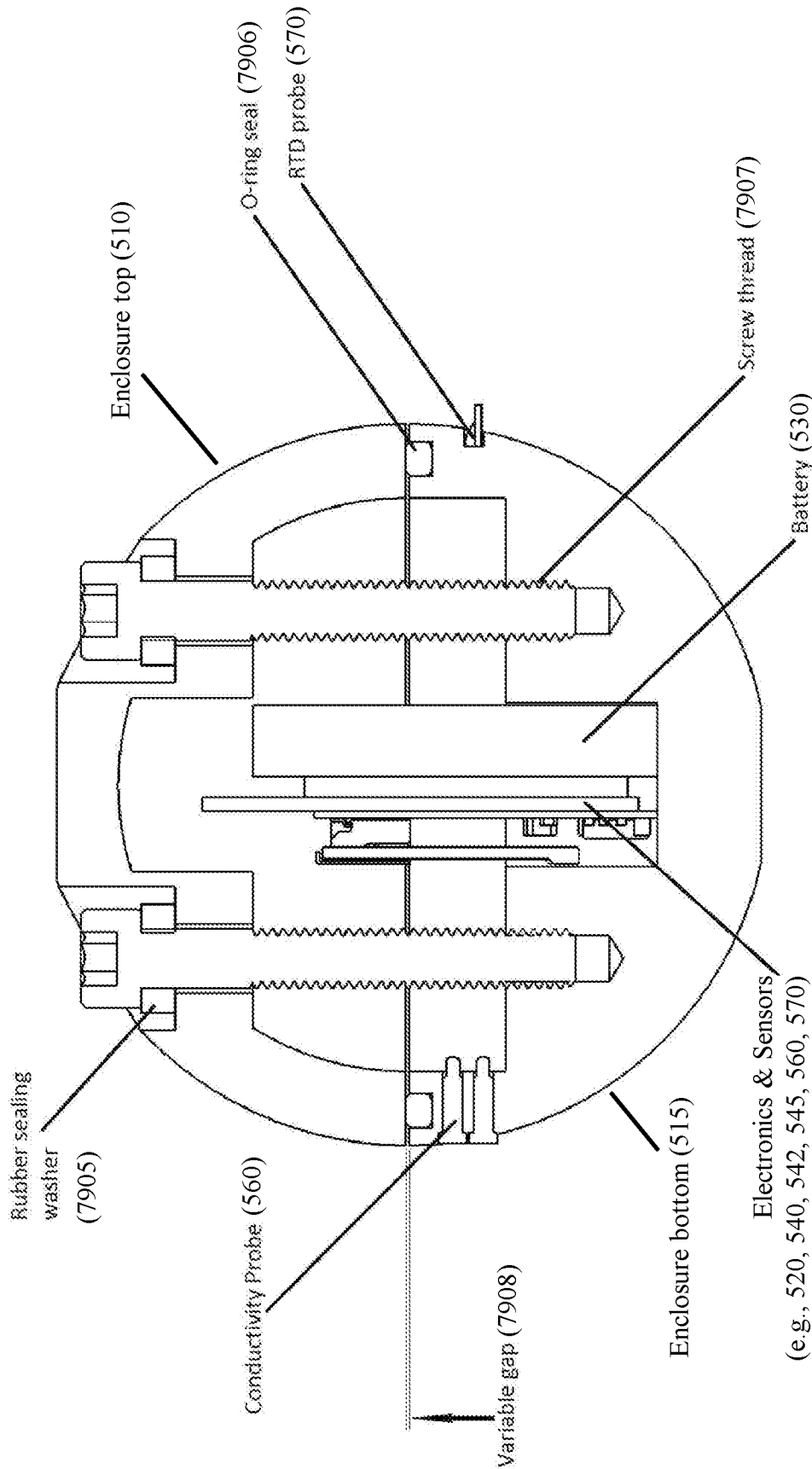


FIG. 8B

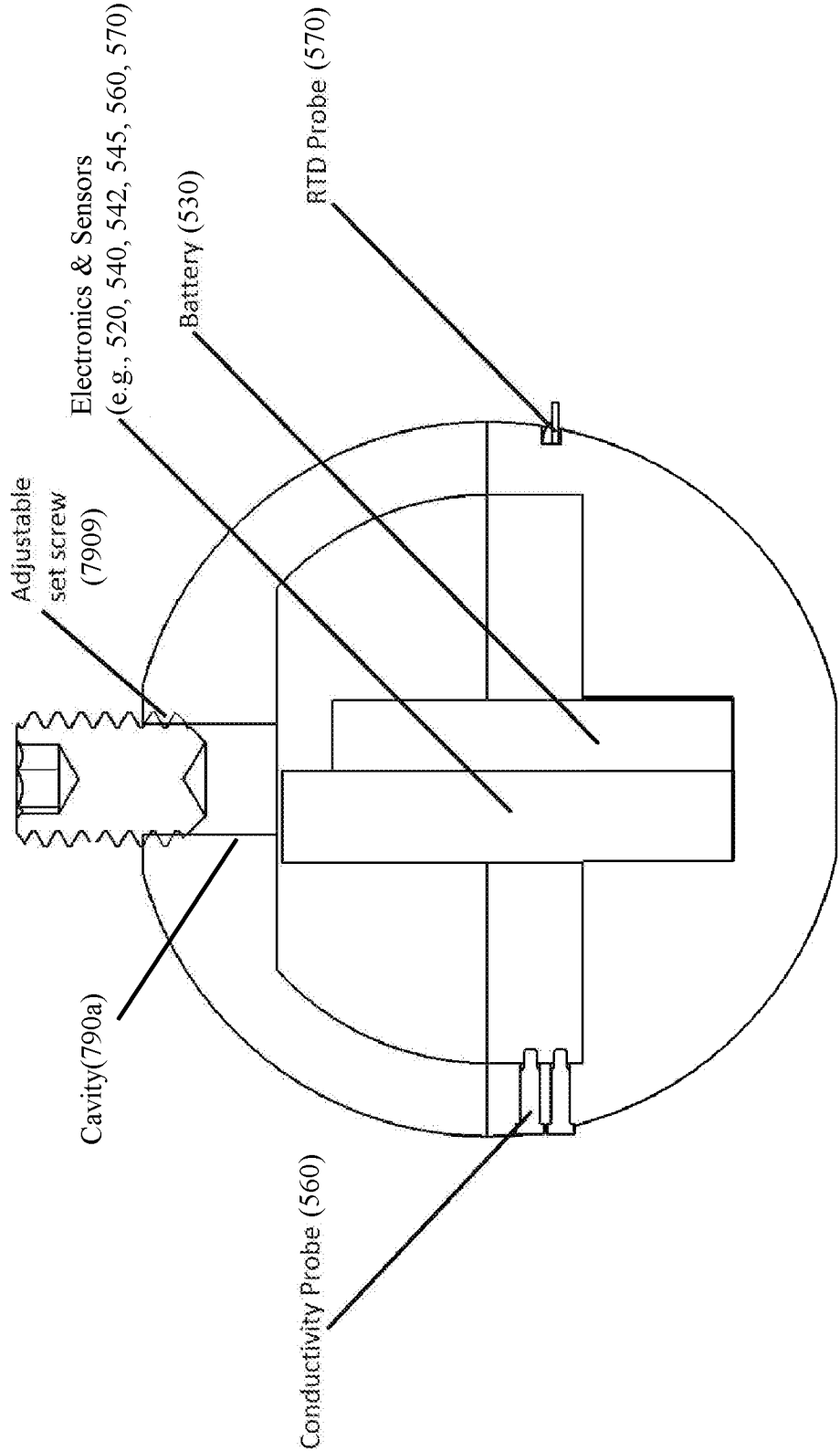


FIG. 8C

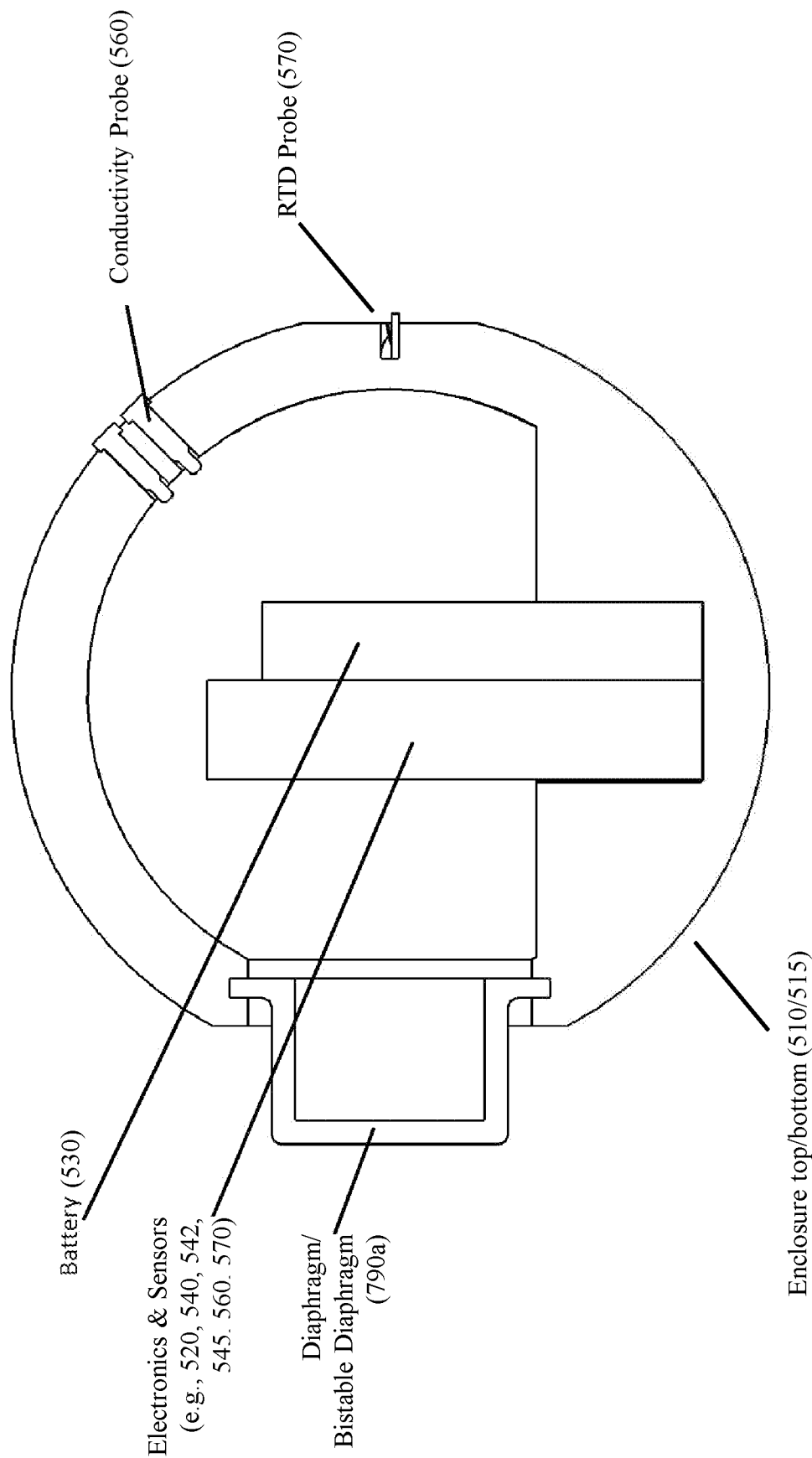


FIG. 9

1010

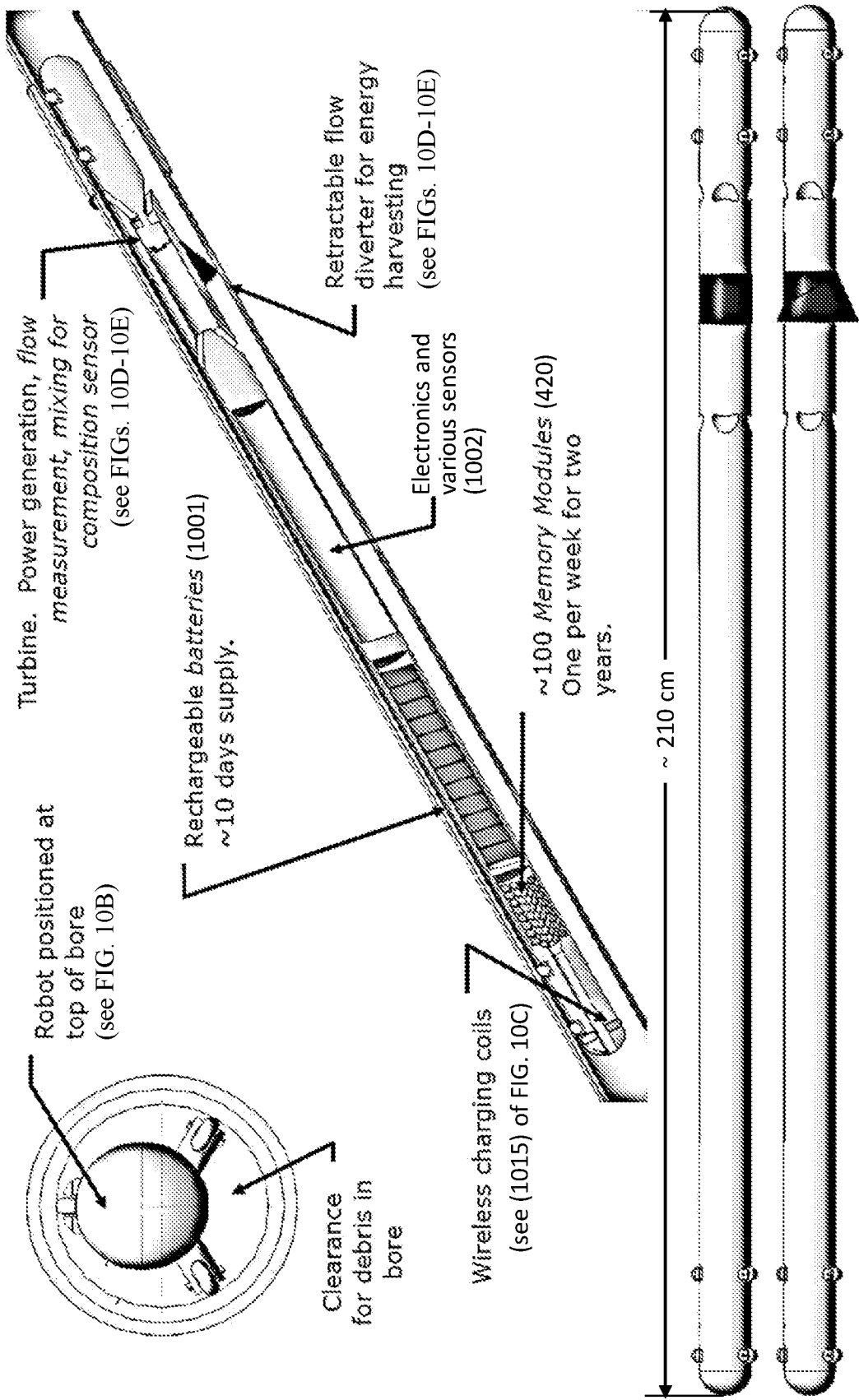


FIG. 10A

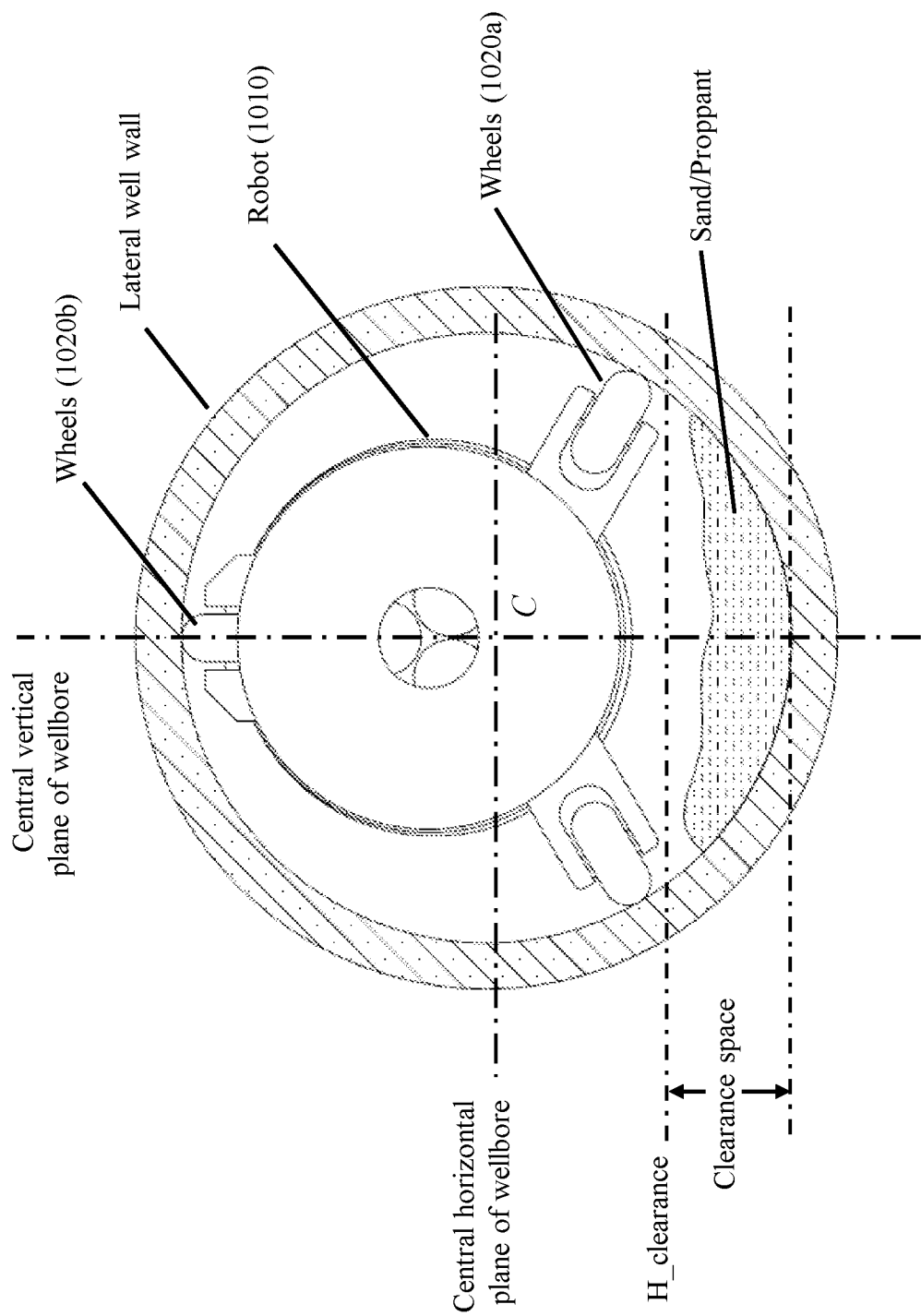


FIG. 10B

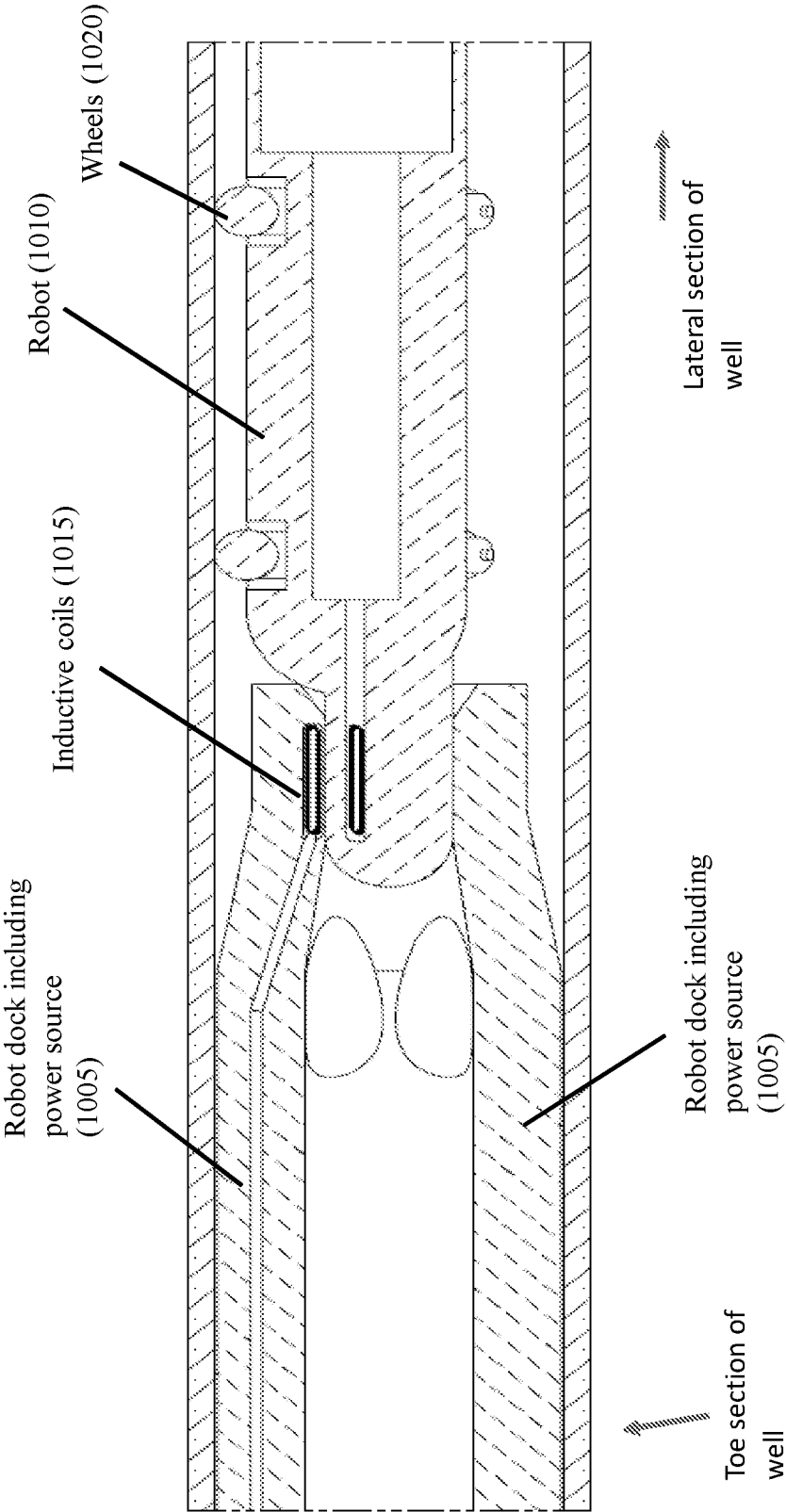


FIG. 10C

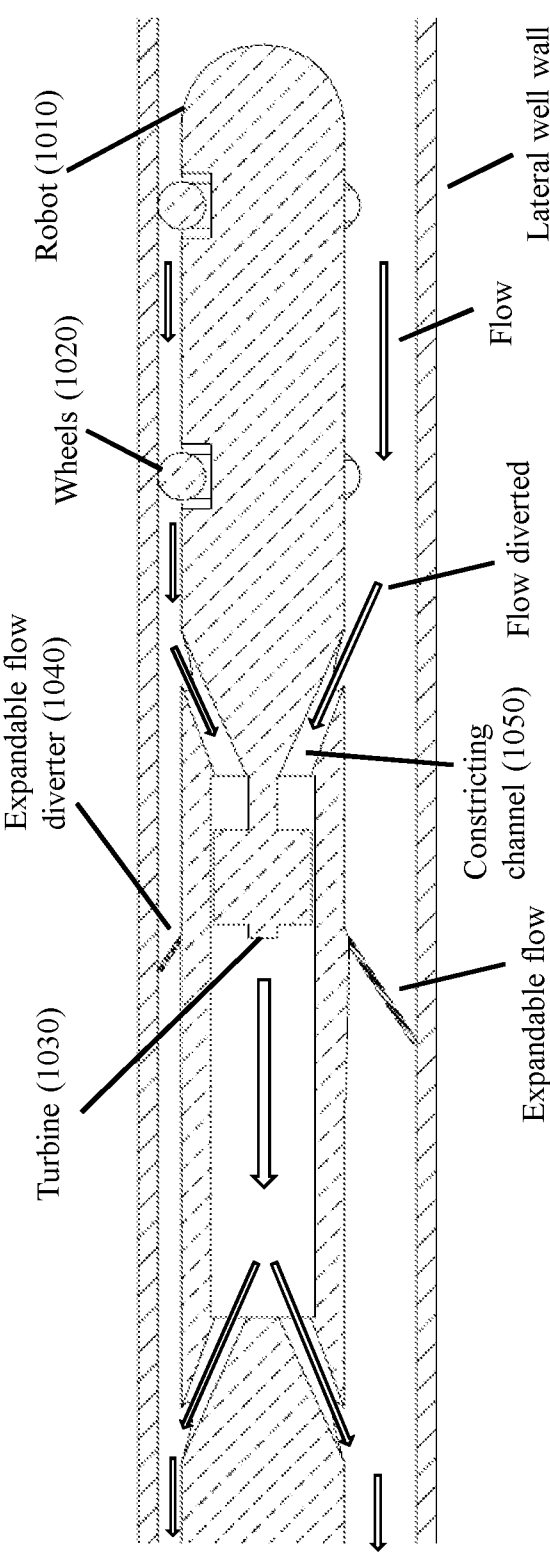


FIG. 10D

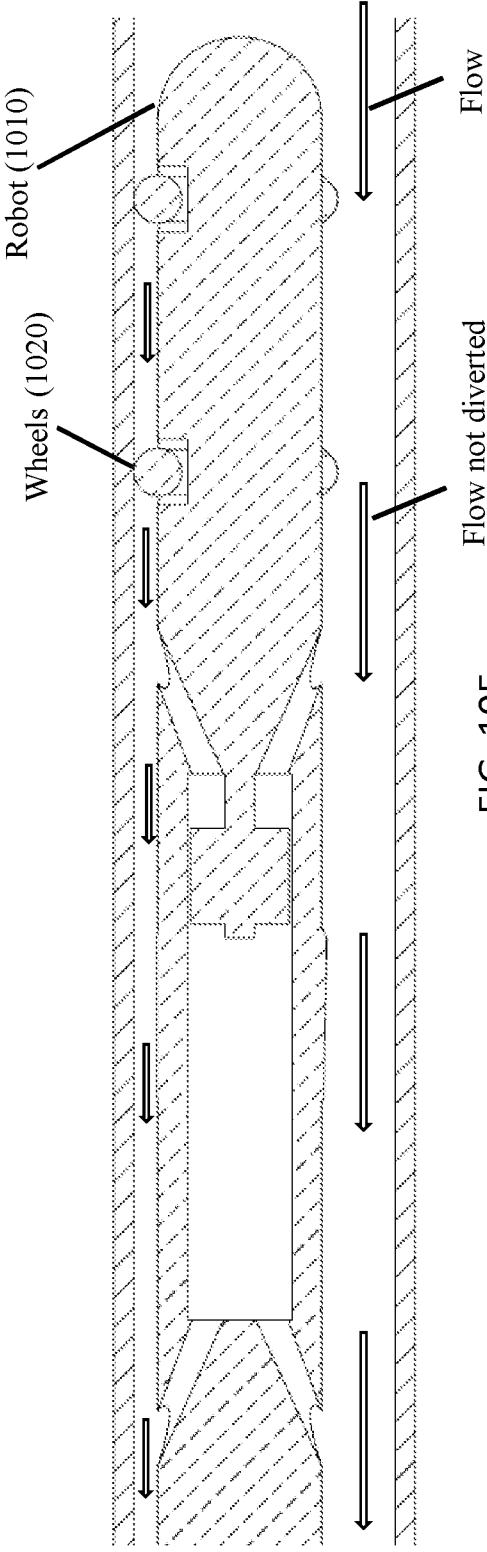


FIG. 10E

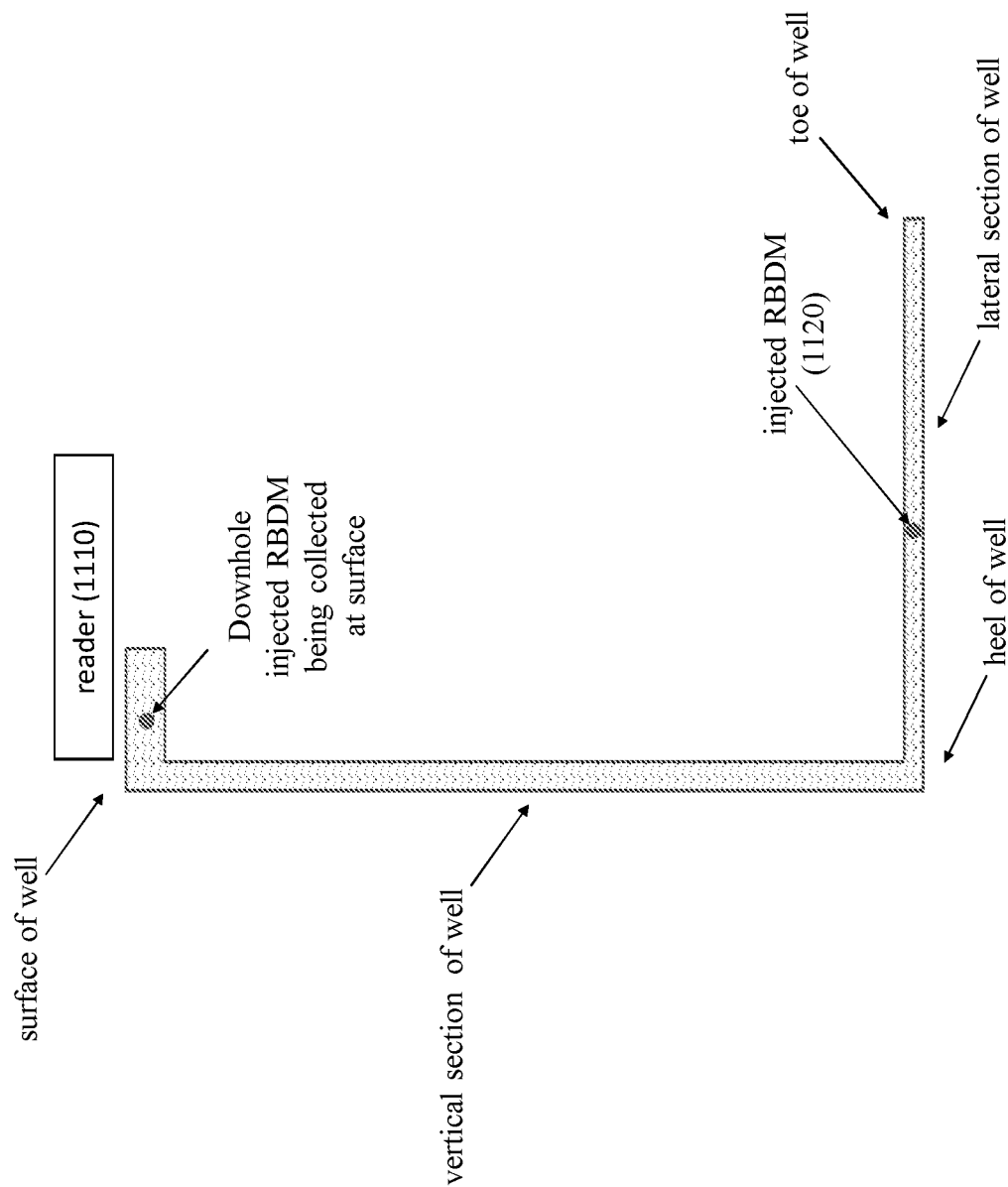


FIG. 11A

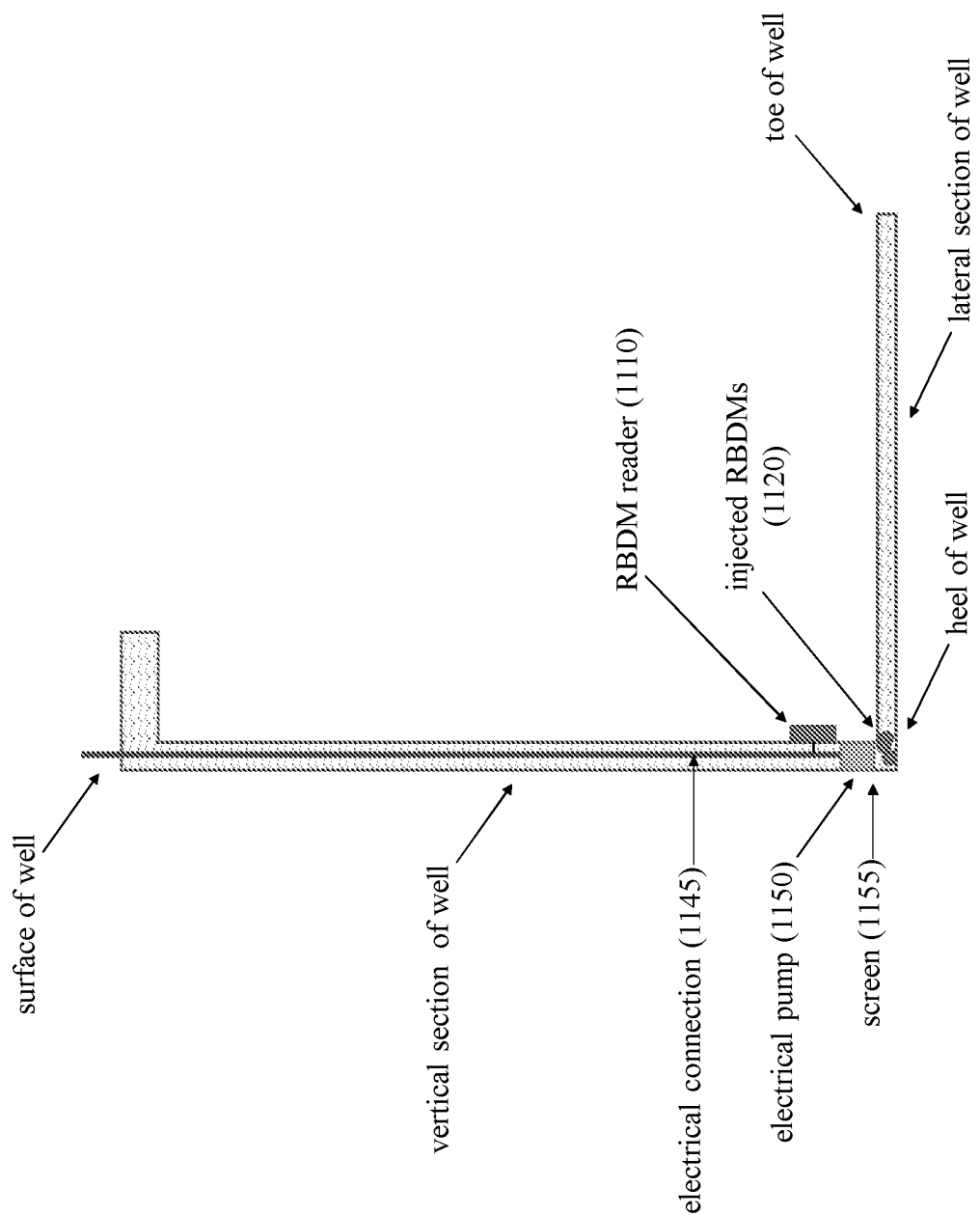


FIG. 11B

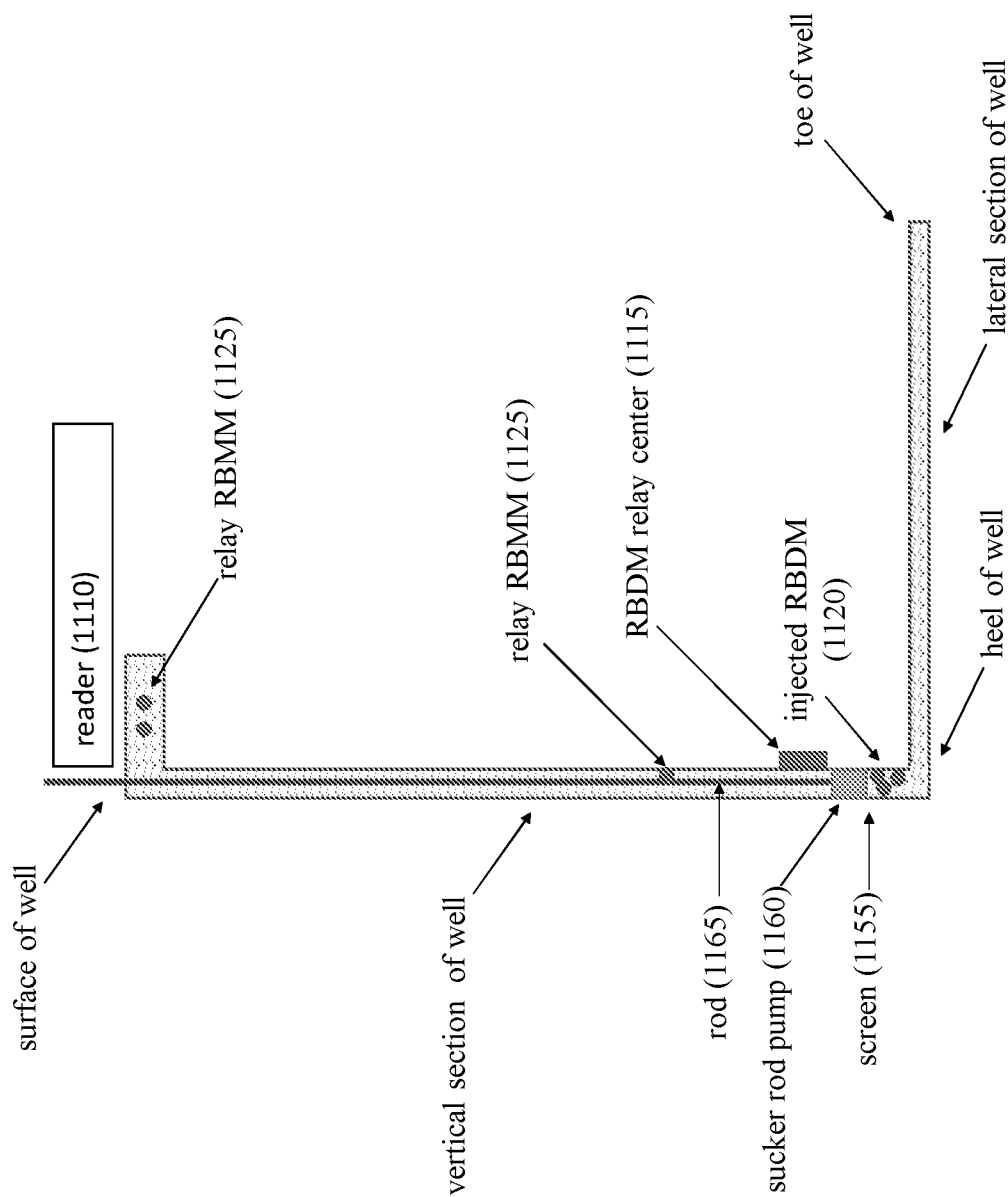


FIG. 11C

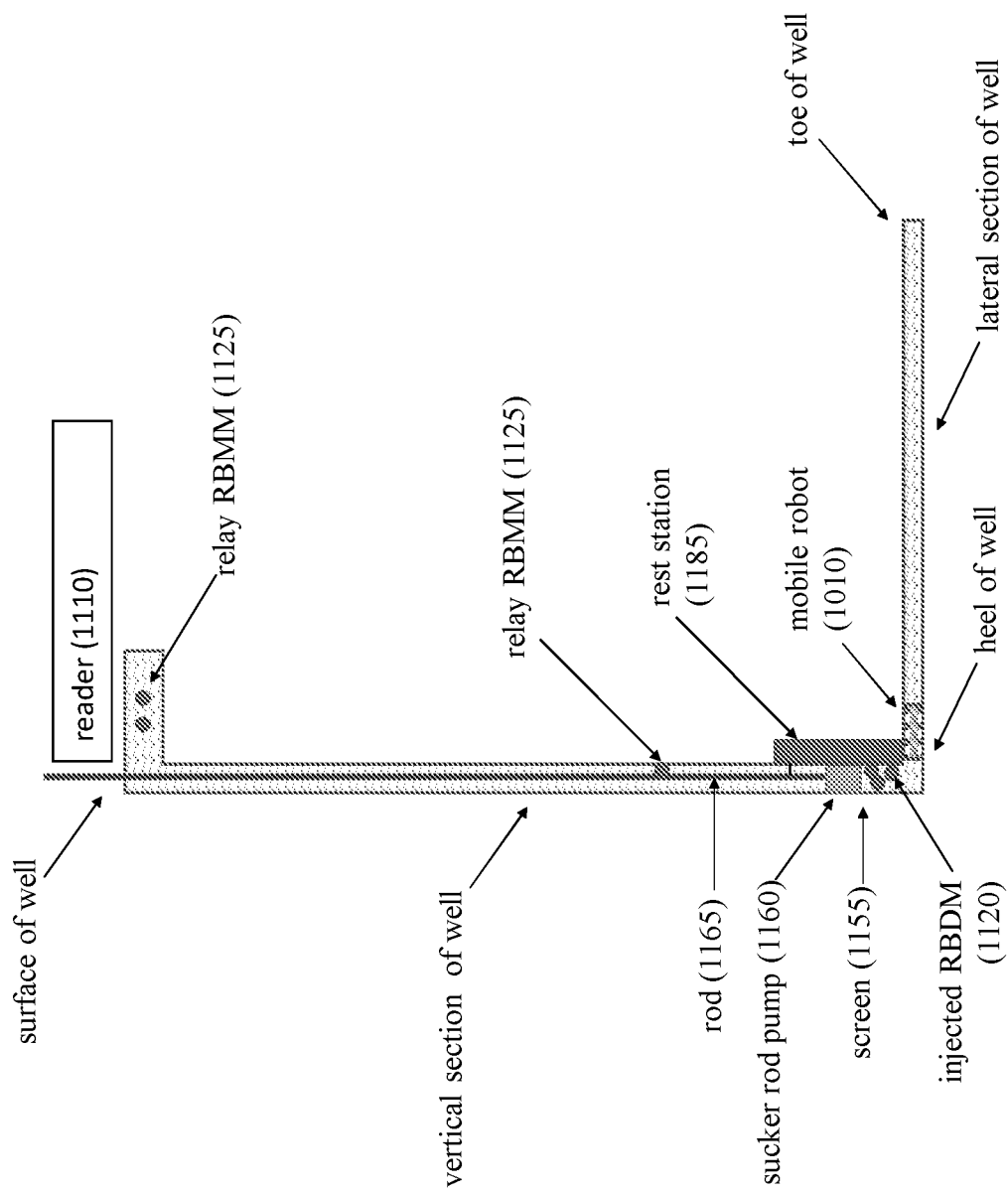


FIG. 11D

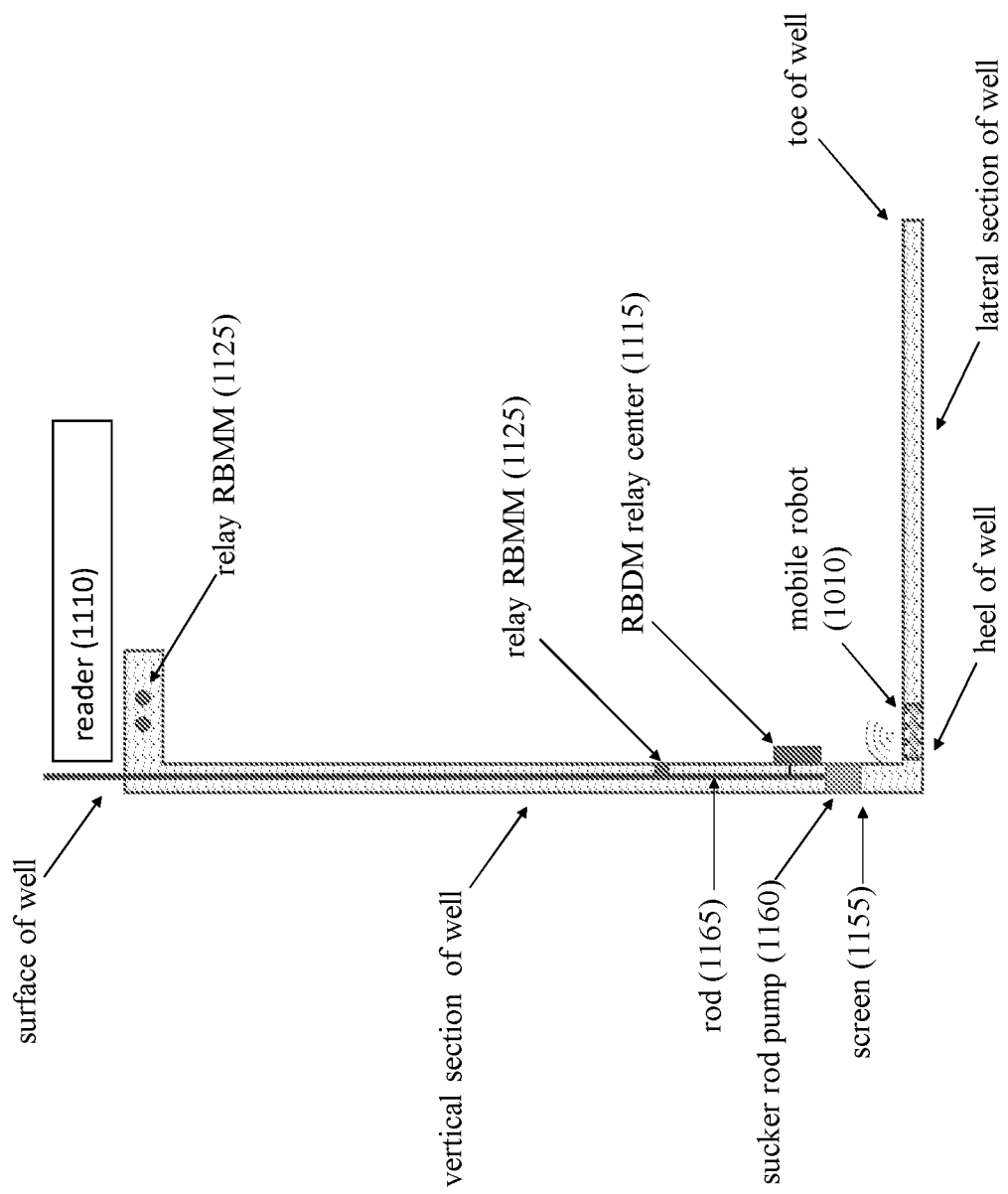


FIG. 11E

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2020/018891

A. CLASSIFICATION OF SUBJECT MATTER

INV. E21B23/00 E21B41/00 E21B43/30 E21B47/12
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)
E21B

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, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

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X	WO 2011/097063 A2 (SCHLUMBERGER CA LTD [CA]; SCHLUMBERGER SERVICES PETROL [FR] ET AL.) 11 August 2011 (2011-08-11)	24,29, 32,38
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Further documents are listed in the continuation of Box C.



See patent family annex.

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Date of the actual completion of the international search

19 June 2020

Date of mailing of the international search report

29/06/2020

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INTERNATIONAL SEARCH REPORT

International application No
PCT/US2020/018891

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

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International application No

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